A Natural Capital approach for management of a UK estuary

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Thesis submitted in partial fulfilment for the requirements for the degree of Doctor of Philosophy in the School of Biological and Environmental Sciences Liverpool John Moores University.

August 2024

Contents

Abstract

Estuaries in Northwest Europe are generally in poor condition due to continuous use, and previous conservation approaches have had limited success. Natural Capital approaches have not been widely attempted in these areas, but they could be valuable tools for restoring ecological conditions and maintaining socio-economic benefits. This study aims to explore the use of the Natural Capital approach for managing an urban estuary, using the Upper Mersey estuary as a test case. This area has a history of ecological degradation and heavy human use, making it ideal for testing Natural Capital approaches to improve a human-dominated environment.

A framework for the application of a Natural Capital approach is presented and assessments of Natural Capital for contrasting habitat and land use types under different development scenarios were undertaken using two tools: EcoservR and the Biodiversity Metric. The intensity of development directly affects the severity of the environmental impact, with green development showing the least negative effects. The location of the development also has an influence on the overall environmental impact, highlighting the importance of considering baselines in natural capital assessments. The results show that not all environmental improvements yield positive outcomes, and trade-offs will need to be considered highlighting importance of multi-metric analysis to support these considerations.

Stakeholder engagement was undertaken through a questionnaire and focus groups with residents, workers, and decision makers in the area. From this work, the varying importance of ecosystem services at different scales is evident as well as conflicting views on priorities and actions. This demonstrated both the importance of visibility in selection and promotion of priority services and a potential set of trade-offs within demands of the system which will need to be balanced. It was also shown that decision makers generally support the use of Natural Capital approaches but

emphasised the need for ongoing implementation support, guidance with monitoring and evaluation, and facilitation of co-design.

Recommendations arising from this work include assessing service supply and demand across landscapes, establishing condition indicators, fostering collaborations and codesign, promoting upskilling, and developing tools. These conclusions also provide valuable insight for future work on Natural Capital approaches in similar environments.

Declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or institute of learning.

“We have forgotten how to be good guests, how to walk lightly on the earth as its other creatures do” Barbara Ward

Acknowledgements

Thank you to Colm, Jason, Andrea and Dave for guiding me through this study and lending your expertise to me throughout this process. Thank you also to the Doctoral Academy who were always so supportive of me and my cohort. I'd also like to thank Laura, Mike and all the others who were always willing to grab a coffee with me so we could get away from our screens for a while. Finally, thank you to my friends and family for supporting me through this, particularly Kamen, Robin and my husband Keiran for being my loudest cheerleaders and learning far more about the Mersey than they ever wanted to.

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1. Introduction

Biodiversity and natural environments in the UK are declining due to the number of human induced pressures on them (Burns et al., 2023). This is particularly evident in urban-estuaries as they are under multiple pressures from increasing urbanisation (Kidd, 1995; Ruesink et al., 2006) to coastal squeeze (Borchert et al., 2018). Recognition of this damage and increasing concerns regarding the fragility of these environments led the UK government to publish the 25 Year Environment Plan. This outlined the policies and objectives to improve the UK's environments and stating that a Natural Capital approach which considers the values of natural environments to people will be taken (*25-Year-Environment-Plan*, 2018). This was followed by publication of the 'Enabling a Natural Capital Approach' (ENCA) guidance (2020) which provided an overview of the Natural Capital framework with some more detail being referred to from the HM Treasury 'Green Book' (2022) for more details on appraisals.

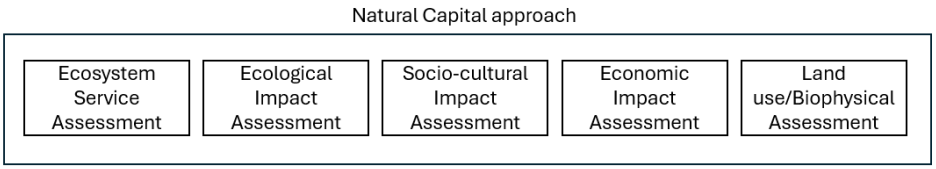


Figure 1: Diagram of the Natural Capital approach and it's relation to other assessments

Natural Capital is generally recognised as the collation of environmental goods, assets and services which provide benefits to people (Missemer, 2018; Natural Capital Committee, 2019; Voora & Venema, 2008). While the concept of Natural Capital is generally accepted the use of this concept within a Natural Capital approach is still developing, however definitions being increasingly used refer to the approach as the management of Natural Capital goods assets and services to provide the required benefits while considering ecological, economic and social concerns in decision making (DEFRA, 2020; Hooper et al., 2019; Pelenc & Ballet, 2015). Most authors agree that a Natural Capital approach needs to encompass a biophysical or ecosystem service assessment (Guerry et al., 2015a), a socio-cultural

assessment (Chiesura & De Groot, 2003; Moyzeova, 2018), and often an economic assessment (Ozdemiroglu, 2019) as summarised in Figure 1. The Natural Capital coalition went further to outline the distinctions between the features of a Natural Capital approach and other approaches as shown in the adapted table below.

Table 1: Differences between key features of a Natural Capital approach and other approaches adapted from the Natural Capital Coalition (2020).

Natural Capital Approach features	**Other approaches**
Focuses on stocks of natural capital assets and flows of benefits	Ecosystem services approach, and most economic analysis, focuses on flows of benefits – as such they are inputs to a natural capital approach
Incorporates both biotic and abiotic resources	Ecosystem services approach considers biotic resources only
Assesses how both stocks and flows are likely to change in the future and with different actions	Environment Social and Governance analysis and financial accounting mainly consider past performance
Considers both dependencies of an economic activity on natural capital and its impacts on natural capital	Most environmental regulation is about controlling the impacts of activities; the implications of the impacts are considered separately
Uses valuation of impacts and dependencies. Valuation may involve qualitative, quantitative, or monetary approaches, or a combination of these.	Different approaches use different measures, mostly of impacts
Makes the links between all of the	Research & decision making tend to be

above, to support systems-based thinking	developed separately for different sectors or issues even when they depend on the same natural capital assets

1.1 Research gaps and information needs for policy and practice

While a framework was provided there is acknowledgement that this framework is general and Natural Capital approaches and methods are still an evolving field. This lack of consistent methodology and lack of clear governance in taking a Natural Capital approach has stifled Natural Capital approaches within the UK and remains a key gap in implementation of these policies (Guerry et al., 2015b; Turner & Daily, 2008b).

Despite Natural Capital guidance being emergent there are some examples of elements of the approach being trialled in urban areas. For example, Greater Manchester's Natural Capital User Guide (Natural Course, 2019) provides some economic and non-economic values of the natural assets in Greater Manchester and the Birmingham Health Economic Assessment and Natural Capital account is a similar assessment for public parks and allotments in Birmingham (Hölzinger & Grayson, 2019). Natural Capital approaches have similarly been trialled in coastal and estuarine areas such as the Suffolk Marine Pioneer (Cosgrove, 2020) which used Natural Capital to develop a management plan and a project on the Ely-Ouse which valued the services provided by Natural Environments to the catchment (Vivid Economics, 2017). These approaches, while including elements of the Natural Capital approach, fall short of a full demonstration of Natural Capital for management and do not fully link natural capital approaches to management practises. There is no consistent framework for these

approaches, the elements which should be included and the process by which to facilitate Natural Capital approaches. This lack of holistic framework to apply Natural Capital approaches in practice is a key gap which this study will contribute to filling.

These approaches are also being trialled separately in urban and estuarine environments, there are no examples as of yet of a Natural Capital approach considering the urban-estuarine landscape as a whole. This is significant as restoration of these urban-estuarine landscapes has been described as 'not your typical restoration' (Simenstad et al., 2005) with difficulty stemming from the complexity of these landscapes (Ballinger & Stojanovic, 2010; Lonsdale et al., 2022) and these landscapes likely to grow in the future (Comber et al., 2016). Holistic Natural Capital approaches would therefore be potentially significant in these areas, further emphasised by the number of ecosystem service benefits which would be gained through this approach in urban-estuaries such as carbon sequestration, flood alleviation (Krauss et al., 2018) and a plethora of cultural services (Greenwood, 1999). The lack of consideration of urban-estuarine landscapes in Natural Capital approaches is a substantial gap within research and one this study aims to contribute to.

An additional gap is a lack of consideration of how Natural Capital approaches can be implemented in practise and the potential barriers to this(Beaudoin & Pendleton, 2012; Hooper et al., 2019). This is particularly significant in urban-estuaries as conservation and restoration of these urban-estuarine landscapes necessitates consideration of the role of development and policy and planning systems such as The National Planning and Policy Framework ("National Planning Policy Framework," 2006, NPPF herein). This document and others similar to it guide local land use planning within many urban-estuarine areas and does not make an explicit mention of Natural Capital approaches. However, they often do encourage consideration of economic, social and environmental impacts, highlighting the potential for Natural Capital approaches to be implemented into practice. Nevertheless, there has been limited discussion of the potential of this or of the barriers to this implementation, significantly limiting the impact that development of Natural Capital approaches may have and highlighting a key

gap in the development and study of Natural Capital approaches.

A barrier and a key gap which is already evident is the lack of a model which is spatial and can be used within urban-estuarine systems to assess multiple services from Natural Capital assets. While the Environment Act (2021) made the Biodiversity Metric mandatory for all but small developments, these offsetting type tools, including the Biodiversity Metric itself, have received significant criticism from ecologists regarding its efficacy (Hunter et al., 2021; Marshall et al., 2020) as well as evidence that it is not practical for use or being used by decision makers (Robertson, 2021). Tools which include spatial dynamics that are reflective of environments but are flexible enough for decision makers to implement in planning prove to be an important gap within the Natural Capital approach, particularly within urban estuarine systems with multiple ecosystem service benefits. This is a gap which this study will take steps towards addressing.

1.2 Research aims and objectives

The primary aim of this study is to design a framework for the wider application of a Natural Capital approach and to use the Upper Mersey estuary as a case study for testing. This will begin to address the gaps identified and aid in further developing a Natural Capital approach which can be implemented in practice, particularly for the conservation and restoration of urban-estuarine systems in northwestern Europe. The objectives to achieve this aim are as below.

Objective 1: Establish how Natural Capital approaches could support decision making for restoration and conservation of urban-estuarine systems (Chapter 3).

Objective 2: Demonstrate how the Natural Capital approach can be used to identify the benefits an area provides as the foundation of a Natural Capital

approach in urban-estuarine areas (Chapter 4).

Objective 3: Demonstrate how a Natural Capital approach can be used to assess impacts of changes in an urban-estuarine landscape and potential trade-offs which will need consideration (Chapter 4).

Objective 4: Establish the barriers to wider implementation of a Natural Capital approach for restoration and conservation of urban-estuarine areas (Chapter 5).

Objective 5: Explore the importance of scale in the Natural Capital approach and how this impacts benefits (Chapter 5).

Achievement of these objectives will contribute to the establishment of a methodology that can be used to adaptively manage an urban estuary using a Natural Capital approach and identify some of the key considerations required to continue to meet the needs of both people and nature.

1.3 Study area

This study focused on the Upper Mersey estuary as shown in figure 2. This is a mesotidal estuary in the Northwest of England, reaching from the Runcorn Gap to the upper tidal limit at Howley Weir. While this is an upper estuary, due to the high tides, there is still some mixing of saltwater within this part of the estuary. It has expansive mudflats as well as saltmarshes along either side, notably Astmoor saltmarsh and Widnes Warth saltmarsh. The estuary also has three urban areas surrounding it, Warrington to the East, Widnes to the North and Runcorn to the South with the Mersey Gateway bridge connecting Widnes and Runcorn. There is also agricultural land as well as Moore Nature Reserve which includes grasslands and woodland. The site comes under the administration of Halton Borough Council in the West and Warrington Borough Council in the East with a mix of public and private land ownership.

This area was selected primarily to allow for comparisons and building on previous studies that have used this study area but also allows for exclusive focus on the upper estuary without extending into the middle estuary or non-estuarine areas which have different dynamics and pressures.

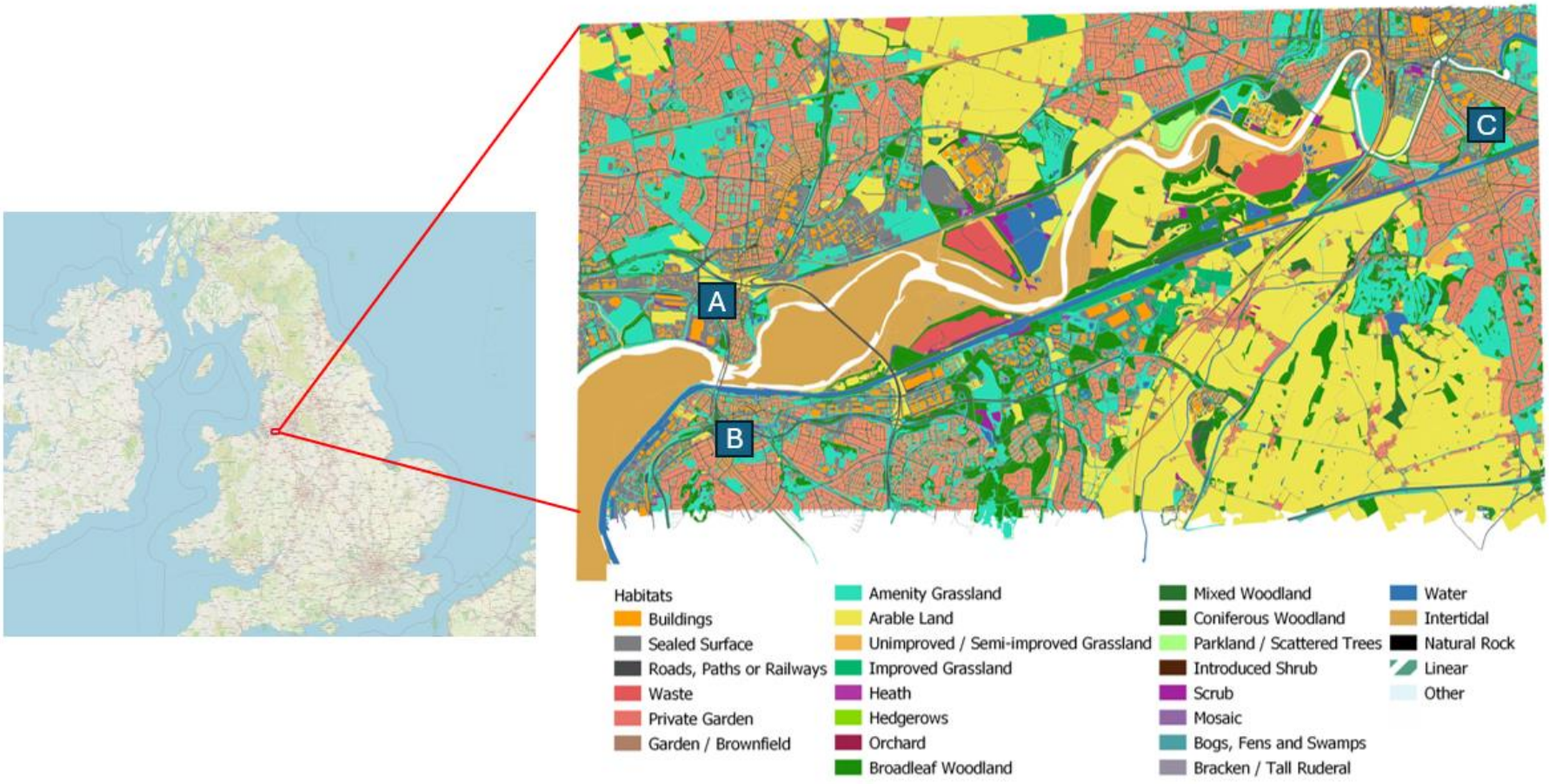


Figure 2: Habitat map of the study area in context of the UK. Widnes (A), Runcorn (B) and Warrington (C) are marked.

The Upper Mersey estuary is typical of a Northwest European estuary. It is culturally, financially, and ecologically significant to England's Northwest region (River Mersey Task Force, 2014). It also has a long history of being ecologically damaged and was considered ecologically dead by the 1970's due to sewage inputs and a lack of ecosystem management (Hawkins et al., 2020). This was substantially concerning to many both in the region and nationally, leading to a multi-billion pound remediation campaign (Jones, 2000; Kidd, 1995). This campaign significantly improved the condition of the estuary, going so far as to win the International Thiess River prize for best river system clean up. While these efforts have undoubtedly been successful, work to improve the estuary has since slowed and aims for socio-economic development of the area through policies such as 'Warrington Means Business' (Warrington Borough Council, 2020) and the Mersey Gateway Regeneration plan' (Halton Borough Council, 2017) could pose a risk of further damage to the ecosystem alongside future risks from the impacts of climate change.

Since the large-scale restoration efforts, multiple management approaches have been proposed and implemented in the area stemming from a variety of policies and programmes such as those detailed in the Mersey Estuary Blueprint. However, it is being increasingly recognised that, in order to 'future proof' the estuary and ensure it can continue to provide for those who rely on it long-term, a landscape-scale, collaborative, and holistic approach needs to be implemented. The Natural Capital approach could fill this role within urban-estuarine landscapes to effectively conserve them for the future.

1.4 Thesis structure

The diagram below shows how the described methods work alongside each other to form the overall approach and what research objectives these address.

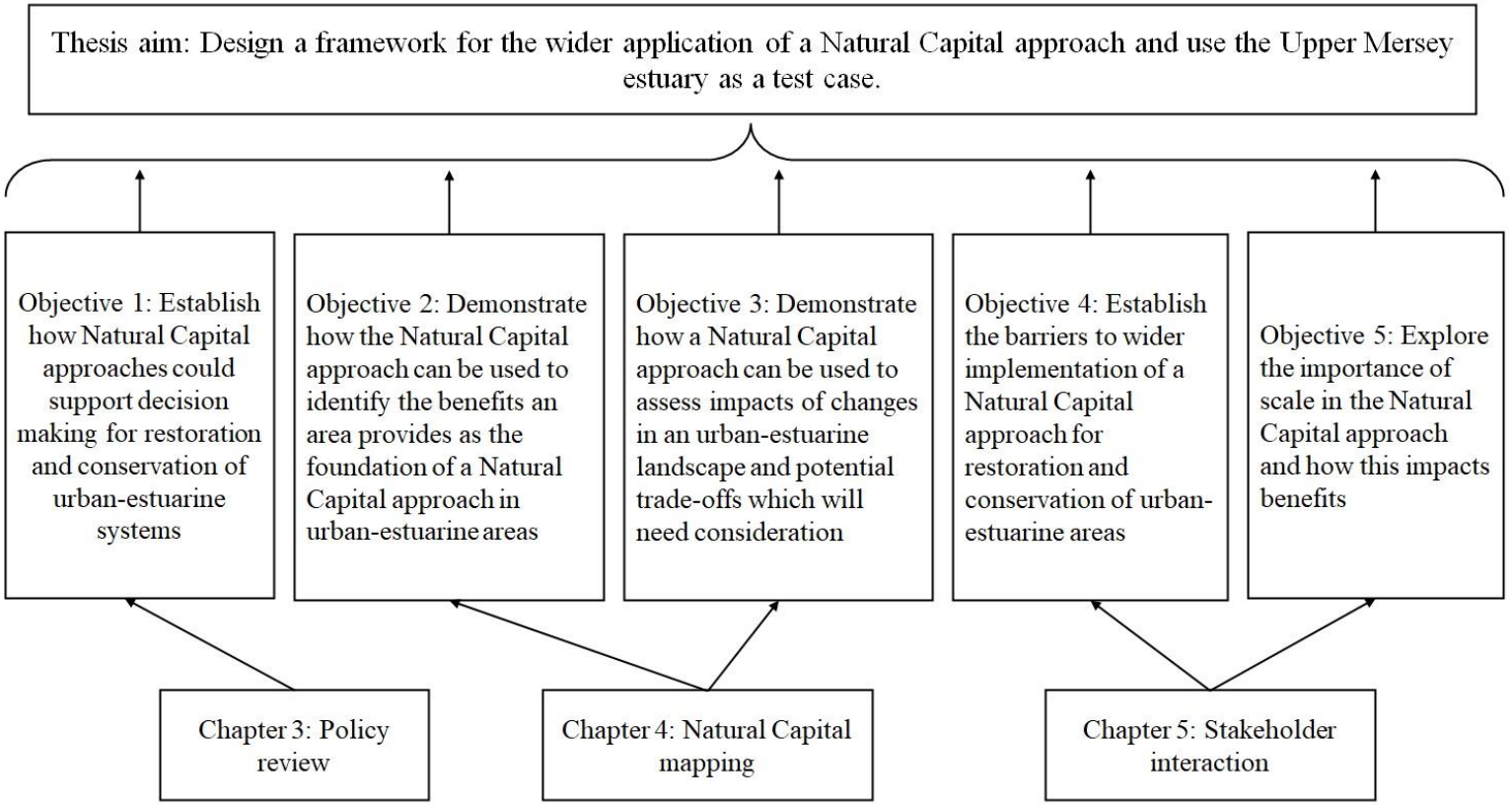


Figure 3: Summary of how each chapter in this thesis contributes to the overall aim.

1.4.1 Policy Review

To establish a Natural Capital approach within the study area, current policies must be synergistic with implementation of the approach. Thus, a grey literature review of current policies relating to environmental and developmental priorities is part of this work. This is done through collating policies from the two local authorities in the study area from local core strategies and reviewing these for facilitation of a Natural Capital approach. Following, this UK wide environmental and developmental strategy documents are collated including considerations from the Environment Act. The key areas that influence the environment and developments within the area are identified and their synergy with the Natural Capital approach discussed. This work was also used to provide a guide for designing scenarios within the Mapping chapter.

1.4.2 Mapping

A Natural Capital approach at its core requires an ecosystem service assessment in order to identify and manage services that are in supply and demand. For this reason, an ecosystem service assessment made up a significant part of this work. This was done using two different methods, EcoservR and the Biodiversity Metric. This work examined the changes in ecosystem service supply and demand under both habitat improvement scenarios and under different development scenarios, with the development scenarios further examining the impact of development intensity and location on ecosystem service provision.

1.4.3 Stakeholder Interaction

The final theme of work within this study was stakeholder interaction. Stakeholder interaction is a key part of the Natural Capital approach for multiple reasons. Firstly, it helps with identifying service supply and

demand which may not be uncovered through other means such as cultural or religious services. Secondly, it gives some ownership of the approach to those impacted by it, increasing the longevity and effectiveness of the approach as well as opening further opportunities for funding streams to aid management needed as part of the approach.

Stakeholder interaction took place in three phases in this study: an online conference group as a provisional focus group, a broad questionnaire, and a more in-depth focus group. The questionnaire aimed to determine general opinions on ecosystem services and habitats in the area with some exploration of how importance varies with scale and priorities in the study area. The focus groups explored the practical barriers to implementation of a Natural Capital approach within the study area and how these barriers could be overcome through discussions with the decision makers and land managers who would be implementing this approach.

2. Literature Review and framework for a Natural Capital approach

This chapter is an expansion of an article written by Dowdall et al., 2022, with more detail provided in all below sections, particularly surrounding Northwest European estuarine areas and details of the Mersey estuary itself. This chapter lays the foundation for the thesis through detailing estuarine importance, current condition of Northwest European estuaries and by presenting the Natural Capital approach used within this thesis.

2.1 Estuarine ecology and importance

Estuarine Ecosystems are some of Earths most unique and important habitats. While there are multiple definitions of estuaries, a generally accepted one is taken from Fairbridge, (1980).
'an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into three sectors: a) a marine or lower estuary in free connections with the open sea; b) a middle estuary subject to strong salt and freshwater mixing; and c) an upper or fluvial estuary, characterized by freshwater but subject to strong tidal action. The limits between these sectors are variable and subject to constant changes in the river discharges.'.

Estuaries can be further classified into different types dependent on the method of saltwater and freshwater mixing. Within temperate systems, such as those in Northwest Europe, they are typically positive, mixing saltwater with freshwater from the bottom up due to more fluvial input than evapotranspiration. They also vary within tidal range from microtidal, with a tidal range of less than two metres, to hypertidal, with spring tides of more than 6 metres (McLusky & Elliott, 2004).

Due to the transitional nature of estuaries, they are under both marine influences and terrestrial influences including tidal regimes, sediment influxes, mixing of saltwater and freshwater, agricultural run offs and often other urban influences (MacCready, 1999). These influences can also vary temporally and spatially, making estuaries some of the most naturally disrupted ecosystems on earth (Boesch, 1974). For more background on general estuarine geography see McLusky and Elliott (2004) or Day et al. (2012).

While being typically disrupted systems, estuaries are capable of supporting high population densities of resident species (Odum, 1956) and thus having high primary productivity values (Nixon et al., 1986). Estuaries can support these high densities in part due to some of these disruption factors such as consistent sediment input providing nutrients and organic carbon (Cloern et al., 2014; Stevenson, 1988). Estimates of primary productivity in coastal waters such as estuaries estimate that between 10-30 percent of annual global primary production takes place in these areas (Ducklow et al., 2001; Muller-Karger et al., 2005) despite them accounting for a small proportion of global cover. Supporting high population densities of producer and lower trophic level species also forms the basis of an important food web within these systems, allowing species of ecological importance to utilise the estuary in part or all of their life cycle (Day et al., 2012).

Within Northwest European estuaries these species include internationally significant species, such as Curlews (*Numenius arquata)* and Northern Lapwings (*Vanellus vanellus)* which are both red listed species as well as important migratory species such as Dunlin (*Calidris alpina)*. Some estuaries support such high densities of these species, they have been designated special protection under international and European legislation frameworks such as the Ramsar Convention. The Mersey estuary itself has been recognised as a Special Protected Area (SPA) and a Site of Special

Scientific Interest (SSSI) due to the presence and density of key bird species, further highlighting the importance of these areas to ecology. Estuarine habitats also provide ecological importance in supporting and regulating the wider ecosystem, through services such as carbon sequestration or flood alleviation (Krauss et al., 2018). It has been estimated that saltmarshes alone provided £62 million worth of flood mitigation services in England in 2019 (Watson, 2022). All of these services contribute to the significant economic, social and ecological value of the Mersey Estuary.

Estuarine areas within Northwest Europe have been sites of significant importance to people throughout history (Greenwood, 1999) due to the benefits these systems provide. Estuaries were typical sites of settlements due to the support they provide for people's daily lives such as fishing sites, transport routes and areas of cultural importance, all of which continue to be important services provided by these areas today. As a result of this they and other coastal systems have been described as having a disproportionate importance to people in comparison to their area (Agardy et al., 2001).

This study focused on the Upper Mersey estuary. The area surrounding the estuary and the estuary itself have extensively recorded histories, again in part due to the services provided by the ecosystem. The strategic transport routes it provides from the Atlantic Ocean and Irish Sea to inland Britain have been recorded as important as far back as the Domesday Book in 1086 and has helped establish the region economically and culturally during the Industrial Revolution. The estuary and the surrounding region have provided fisheries and agricultural opportunities, further supporting population growth. It is also an area which holds significant cultural and tourism values, including areas of religious significance, references in music, and recreational areas (Greenwood, 1999).

Due to the historical and continuing use of the area, the Upper Mersey

estuary has a history of being ecologically damaged. The impacts of this were particularly evident during and after the Industrial Revolution, with the Northwest of England being a hub for industry with resulting negative impacts. This is typical of Northwest European estuaries and highlights that historical and current damage is important to consider when aiming to restore and manage these areas.

2.2 Estuarine Degradation and Conservation

As estuaries have been important to people throughout history, it is unsurprising that they have experienced severe anthropogenic damage. Unfortunately, much of this damage is historical, for example from the Industrial Revolution, and records of estuarine condition predating this damage are rare, thus the actual extent and timeline of the damage is somewhat unknown, with some asserting that the damage in estuarine areas is so ubiquitous that there are no undamaged estuaries left (O'Higgins et al., 2010).

Others have demonstrated what this damage in estuaries may include, ranging from depletion of species, reductions in available habitat area and reductions in water quality (Lotze et al., 2006) all linked to anthropogenic damage. Further supporting this link, the damage appears to vary with how developed the estuarine area is with relatively undeveloped estuaries being less damaged than more urbanised ones (Kidd, 1995; Ruesink et al., 2006). The majority of Northwest European estuaries, including the Upper Mersey, fall towards the latter end of this spectrum due to long periods of urbanisation and use.

For simplicity, this damage can be organised into direct damage and indirect damage.

Direct damage to estuaries is arguably the most obvious and often common

within estuaries in Northwest Europe. In the present day this damage includes habitat destruction through land claim and coastal infrastructure (Doody, 2004; Fujii & Raffaelli, 2008) agricultural runoff (Boyes & Elliott, 2006; O'Boyle & Raine, 2007), as well as pollutants from transport routes both alongside and on the watercourse itself (Bianchi & Varney, 1998; Bravo-Linares & Mudge, 2007; Huybrechts et al., 2004). Direct damage has also taken place historically, particularly in North-western European estuaries with a substantial amount of damage taking place during the Industrial Revolution, when these areas were key locations for industry and transport as well as housing large urban populations.

The Upper Mersey estuary in particular has a long history of direct damage. Initially this was raised as a concern to Liverpool City Council by James Newlands as early as 1848 (D. Jones, 2000) and continuing to be known for its poor condition through to the 1970s (P. D. Jones, 2006). Much of this damage stems from increases in water dependant industries and the estuary becoming a key transport route for finished goods. In addition to this, Widnes and Runcorn were involved in chemical industries post World War two, with nearby Warrington being a location for soap industries and tanning. These industries led to pollution and contamination as well as supporting an increasing population and urbanisation, reducing estuarine habitat areas and leading to further agricultural and effluent run off. For more information see Jones, (2000); National Rivers Authority, (1995).

Estuarine ecosystems are also exposed to indirect damage, largely as a result of climate change. An important example of indirect damage within estuarine ecosystems stems from sea level rise. A study on the effects of sea level rise on estuaries showed that a rise of 6mm per year would lead to an inland migration of the estuary by 10 metres a year (Pethick, 2001). In estuaries without coastal infrastructure, the redistribution of sediments may lead to erosion of important habitats such as mudflats and salt marshes, leading to a decline in the populations and functioning of these systems. In estuaries with coastal infrastructure, it is unlikely that these systems would

be able to migrate inland enough to provide adequate space to support habitats, causing the estuarine ecosystem to be put under coastal squeeze (Borchert et al., 2018). Coastal squeeze would limit the area in which these habitats can exist, causing a decline in the ability of the habitats to support the species within and reducing the overall functioning of the system (Figure 4).

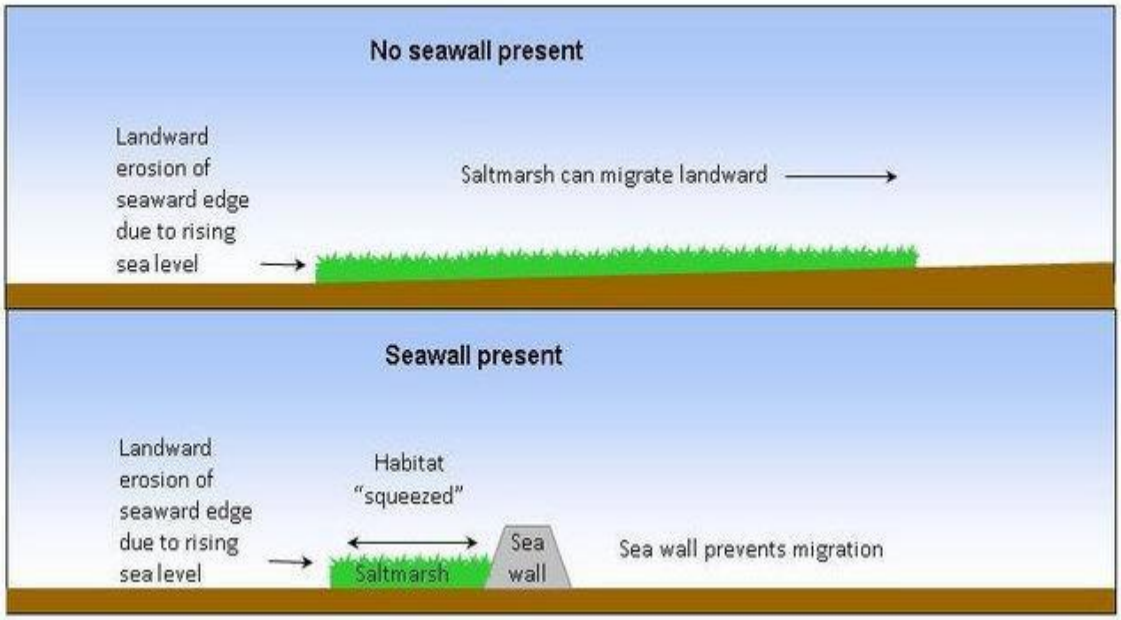


Figure 2: Diagram of coastal squeeze front Pontee, (2013)

It should be noted that damage within these systems often compounds. For example, if an estuarine area undergoes coastal squeeze due to sea level rises and habitat is lost, oyster and mussel populations within the estuary will decline. This decline tends to lead to decreases in water quality within the estuary, as filtering services offered by these species are no longer available. If the water quality decreases, the ability of the habitat to provide nursery services for commercially important fish may also decline, resulting in economic losses, or the need for costly artificial filtration (zu Ermgassen et al., 2013). This could often continue to lead to further deterioration if interventions are not sought quickly. These interventions are typically more costly if left to a later stage and may be too costly in coastal areas, particularly in England as these regions are often more deprived with less funding available for costly interventions (House of Lords Select Committee on Regenerating Seaside Towns & Communities, 2019). Therefore, for multiple reasons, conservation and recovery of estuaries is an increasingly common goal in Northwest Europe.

2.3 Conservation of Northwest European estuaries

While the condition of the Upper Mersey estuary has been improved drastically since the 1970's, the pressures on it are still present and likely to increase. The discussion on how to conserve complex and dynamic ecosystems such as estuaries is ongoing as they pose a unique challenge; they require conservation, but they are also urban centres which people depend on. Thus, they require careful management. Within Northwest Europe, most approaches to management of estuaries have been as part of the European Union's Water Framework Directive. These are typically protected area approaches or resource management approaches, such as payments for ecosystem services.

The first of these are protected area approaches, in which human use and impacts are restricted or prohibited entirely. One key example of these within estuarine ecosystems is the Ramsar wetlands programme, which includes an area adjacent to the Upper Mersey Estuary. These are typically designated due to rare or important ecological communities or species and have regulations limiting resource exploitation and habitat damage.

This restriction of human use of estuaries has often led to low compliance (Pittock, 2015) or negative impacts on those who economically rely on the estuary. This is further exacerbated by protected area approaches requiring legislation and enforcement, which can be slow moving and difficult to implement in dynamic estuarine systems. In these cases, estuarine areas continue to experience ecological degradation, often failing to reach conservation goals without additional management (Wauchope et al., 2022). In England in particular, there is evidence that protected area approaches are ineffective in estuaries due to a lack of funding and failures in monitoring-action feedback processes (Morris et al., 2014).

Thus, protected areas alone are not enough to conserve estuarine areas and there is growing support for other approaches being used in addition to them

(Edgar et al., 1999). Other typical approaches are often focused on continuing use of the system in a more sustainable way. These can be broadly categorised into resource management approaches and payments for ecosystem services.

Resource management approaches limit the use of the system, either spatially, as in the case of set aside areas, or temporally, for example closure times or seasons. They can also take the form of harvest limitation, through means such as holes in trawler nets (Grant et al., 2004). While these still allow use of the system, the limitations may still not be entirely adhered to for economic or social reasons, and this still requires enforcement. This method also does not prevent overuse of the system in many cases, particularly if the ecosystem capacity to recover from damage is low. Payments for ecosystem services (PES) can either be direct payments or indirect payments for services. Examples of direct payments include carbon credit or biodiversity credits, in which, payment is made to offset ecosystem damages. Indirect payment can come in the form of increased taxes in the area or ecotourism (Butler et al., 2020; Kangas et al., 1995). This increases funds available to restore and manage ecosystems and mitigate damage. However, these funds are not always used for these reasons and these schemes often do not specify where the offset or mitigation needs or occur. Thus, the damage within the estuarine ecosystem remains present while the offset for that damage can be elsewhere.

The continuing damage to estuarine ecosystems highlights the fact that approaches are not being taken in the most effective ways. A new approach is needed that considers the system as a whole, people and environment included, and manages the estuary based on those considerations. The Natural Capital approach could be a method to strategically use conservation approaches for more effective estuarine management. The approach takes an ecosystem-wide perspective rather than a specific habitat or species perspective. It considers key ecosystem services and functions and looks to conserve those which are in most demand, making conservation

actions more targeted. It also does not exclude people from the system which is particularly important in estuaries. Additionally, it may provide a source of funding these conservation actions through the Natural Capital approach framework.

2.4 The Natural Capital Approach

While the Natural Capital approach is relatively recent in its formalisation for conservation, it draws on the concept that people rely on nature which has been present throughout history (Mooney et al., 1997). The approach began to be discussed in ecology as a method of promoting public interest in nature in the late 1970's and was brought to more mainstream attention by Costanza & Daly, (1992) who discussed Natural Capital and sustainable development. Following this, the approach was further developed by many authors including Daily et al., (2009); Hancock, (2010); Harte, (1995); Özdemiroğlu, (2019b).

During this development, the approach was quickly moved from a scientific setting to one which also has a basis in economics and policy (Gómez-Baggethun et al., 2010). This is in no small part due to the Millennium Ecosystem assessment (MEA), initiated in 2001, to assess the impacts people have had on ecosystems and the implications this has for ecosystem services and human wellbeing. This allowed for further development of the approach, marrying it with the concept of the green economy and providing a pathway for further investment into estuarine ecosystem conservation while also improving the socio-economic status of the area, through the creation of green jobs (Loiseau et al., 2016; ten Brink, 2014).

In addition to these studies, other larger initiatives followed from the MEA such as The Economics of Ecosystems and Biodiversity (TEEB) focused on filling the gap between science and policy through valuation of nature and

ecosystem services. Similar to TEEB, the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (IPBES) also focuses on bridging the gap between science and policy through support of tools for policymakers to use and filling key knowledge gaps.
The culmination of these initiatives can be seen in policies now considering Natural Capital. A key example of this is Defra releasing the 25-year environment plan (HM Government, 2018). This outlined the UK Governments aim to use Natural Capital to improve the current state of the environment and promote sustainable use of ecosystems. This led to the Environment Bill being passed into law by the UK government, implementing some elements of a Natural Capital approach into law These include a requirement for biodiversity net gain and introduction of the Environmental Land Management Schemes.

On a smaller and specifically estuarine scale, the Medway Estuary and Swale coastal management plan (*Medway Estuary and Swale Shoreline Management Plan Medway Estuary and Swale SMP*, 2018) used Natural Capital within its development, alongside more traditional assessments. This involved assessments of pollination and carbon sequestration services to establish supply and demand to select between management options. The Suffolk Marine Pioneer (Cosgrove, 2020) also focused on taking a Natural Capital approach for management of coastal habitats which could be a replicable approach elsewhere along the UK coast. This highlighted several important stages in the approach which were needed to be effective overall such as involvement of stakeholders and multiple simultaneous conservation actions. Additionally, within the Mersey estuary itself, work has begun to renew efforts to conserve and improve the Mersey for the future. Led by Mersey Rivers, the initial concepts and pilots within this work include Natural Capital approaches as a key consideration. More information about this work can be found at the Mersey Rivers Trust website.

The approach is not without its obstacles. Notably, there is still a knowledge gap between scientists, financial bodies and policymakers (Jacobs et al.,

2013) regarding the implementation of the approach, which will need addressing. This can be overcome with more emphasis on collaborative work between these groups for greater understanding overall. In addition to collaboration between decision-makers and scientists, several authors (Cosgrove, 2020; Jacobs et al., 2013; Rounsevell et al., 2018) have indicated the need to include local stakeholders within the approach, particularly within Northwest European estuaries. This is because there is a high percentage of Northwest European populations living in these areas, increasing the demand for ecosystem services and potential trade-offs that will need consideration.

The next of these is the question of assigning a value to nature. While economic assessments have been useful for implementation into policy and facilitating funding streams, it raises the question of how to assign a value to nature. This is where it is key to point out that there is a distinction between 'value', 'cost' and 'price'. The value of an ecosystem service may not be best represented by the price paid for it. For example, an open green space is often valued highly to those who utilize it however the price of this to those who benefit is often zero and the cost would be maintenance paid through local taxes. This issue can be resolved through clearly defining terms within policies and literature. Similarly, there are criticisms regarding placing values on nature at all, with this being viewed as morally wrong as nature is worth more than its material values. While the general philosophy of natural scientists and those in conservation tends towards promotion of intrinsic values as opposed to anthropogenic ones, we must consider that those who write and implement policy may have a different view, the environment may not be a priority to them. To conserve these environments, we need to find a way to demonstrate their value, or they will be treated as having none (Tinch et al., 2019). It is also feasible that through making natures values explicit, people will feel more connected to it and be more invested in conserving the area. The aim of the approach is not to sell nature at the cost of its material values, but to conserve it and to maximise its value for the future.

It is also important to note that valuation of an ecosystem can be found via monetary or non-monetary methods. Some services or functions lend themselves to economic valuations such as fishery stock maintenance. Others however require a different and often non-economic approach for example the value of an open green space cannot be captured adequately through monetary values. Many assessments have been done, using both monetary and non-monetary focus. For example, with monetary focus (Balasubramanian, 2019; Costanza et al., 1997; Islam et al., 2019), supply and demand (Burkhard et al., 2012), delivery of the services (Daily et al., 2009a; Turner & Daily, 2008a), and comparisons of monetary and non-monetary options (Guerry et al., 2015a).

The final obstacle is creating funding opportunities for the approach within estuaries. Creation of opportunities to invest into the approach within estuaries is still under discussion. However, there is a likelihood this can be resolved through further understanding of estuarine ecosystems and engagement with stakeholders. Engagement with stakeholders across the wider ecosystem could also attract private investment into the area alongside public funding through creation of large-scale investable propositions (European Investment Bank, n.d.; Özdemiroğlu, 2019b).

These obstacles can be overcome with some effort to utilise the Natural Capital approach as one of the most powerful tools we have to conserve important estuarine ecosystems within human-dominated areas.

2.5 Methodology of a Natural Capital Approach in Estuaries

The Natural Capital framework presented below was created through evaluation of existing frameworks, as presented in table 2, and through review of the literature surrounding natural capital approaches included within this chapter. While there is no agreed framework for Natural Capital approaches, there are consistent features throughout the existing ones, such as an appraisal

or valuation and some acknowledgement that this framework needs to be cyclical. Inclusion of stakeholders throughout the process is encouraged sporadically between frameworks and the balance between being clear and being too general is also varied. Only one framework acknowledges that values can be non-monetary.

Table 2: Evaluation of different Natural Capital frameworks to develop a comprehensive framework for this study.

Framework	Advantages	Disadvantages
Natural Capital Coalition 'Natural Capital Protocol'	Acknowledges that values can be non-monetary. Follows a clear step process.	Aimed at business managers/private sector so wider applicability is limited. Stakeholder interaction is only encouraged in one stage and not throughout.
SEEA Natural Capital Accounting	Clear guidance which is widely applicable.	Monetary focus. Does not constitute a full Natural Capital approach as it only considers accounting stages.
Enabling a Natural Capital Approach	Very widely applicable. Acknowledgement that there are multiple approaches available.	Very general to the point of being vague or open to interpretation. No stakeholder interaction encourages. Monetary values are

		the focus.
HMT Greenbook	Very detailed guidance. Widely applicable.	Potentially confusing. Clear monetary focus. No stakeholder interaction included.

A Natural Capital approach in estuaries requires consideration of multiple inputs, outputs and potential impacts as shown in figure 3.

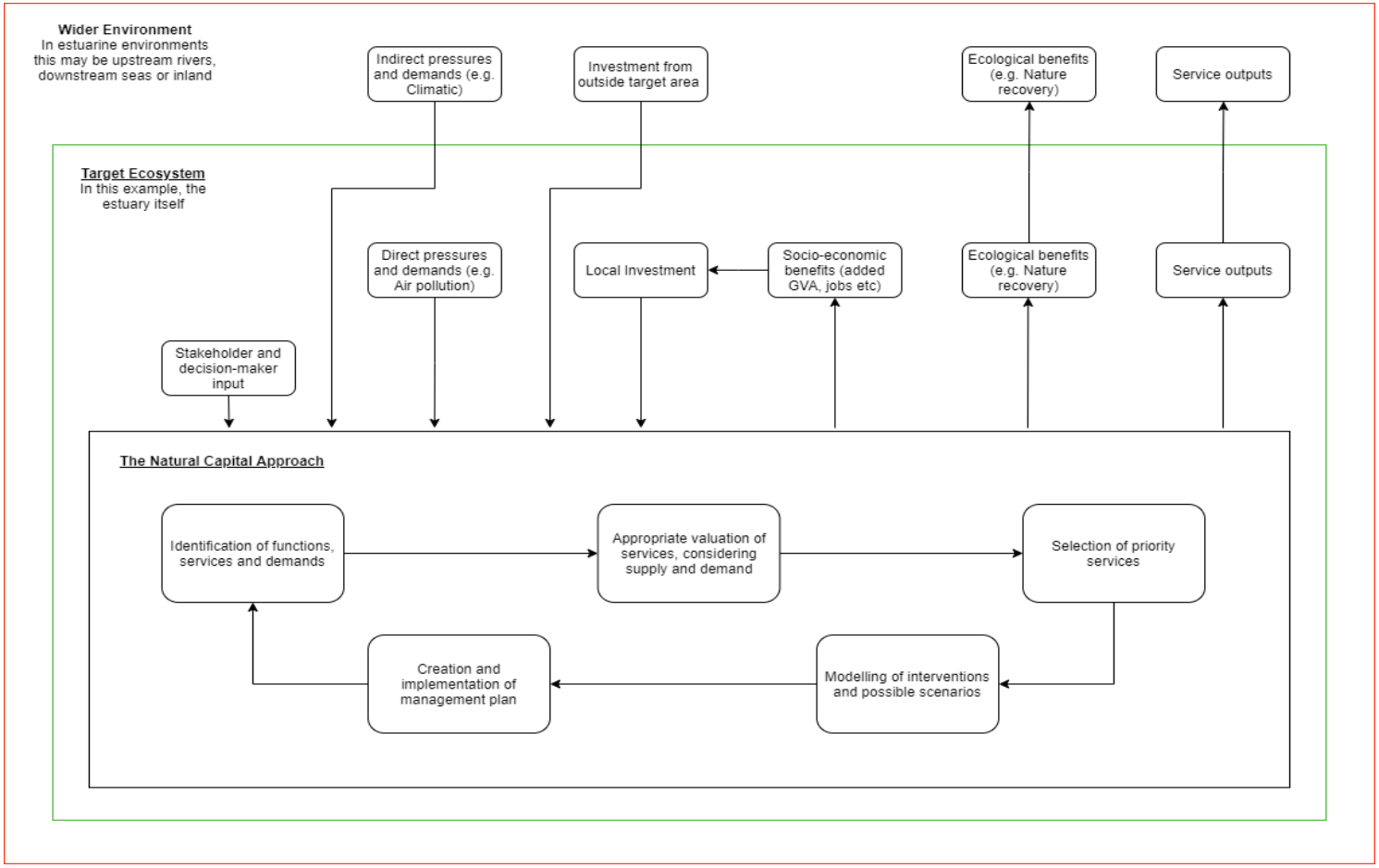


Figure 3: Diagram of the Natural Capital Approach within an estuarine ecosystems (taken from Dowdall et al., 2022). Bordered in black is the approach steps which are applicable to all systems Natural Capital is used in. Within green is the target ecosystem, in this case the estuary and surrounding land. Demands and pressures are most obvious from the surrounding land, and these must be considered. To ensure the approach is as thorough as possible stakeholder and decision-maker input should be used within the approach. The approach aims to output ecosystem service delivery to the target ecosystem and wider environment which likely will come with ecological benefits to both. There is also a socio-economic impact with creation of green jobs and added value into the area, which can lead to further investment into conservation through the approach.

2.5.1 Identification and quantification of functions, services and demands

The first stage in this approach involves identification of ecosystem function, ecosystem services and the demands on the system. This needs to be as thorough as possible, considering direct and indirect pressures on the system and stakeholder and decision-maker opinions, as well as biophysical inputs and outputs. Stakeholder interaction at this stage can be useful in identifying demands on the system as well as services that are hard to identify with other methods, such as cultural or religious services. In addition to stakeholder interaction, it is often also useful to undertake an ecosystem service assessment through ecosystem service mapping of the area, to identify services such as carbon storage and demands that may not be highlighted by stakeholder interaction. This can be done using multiple different software such as ARIES or ORVal. Examples of the services which might be identified can be found in figure 4.

Through these methods, estuaries have been shown to provide a plethora of important ecosystem services. These include food production through agriculture and fisheries, waste regulation through tidal action, increased resilience to flooding through buffering and cultural benefits (Thrush et al., 2013a). In addition to this, trade-offs between these services have been recognized which is key for management for multiple services (Needles et al., 2013) as well as pressures on estuarine ecosystems, such as urbanization and sea level rise, and beneficiaries of potential services that can stem from estuaries (Yee et al., 2019).

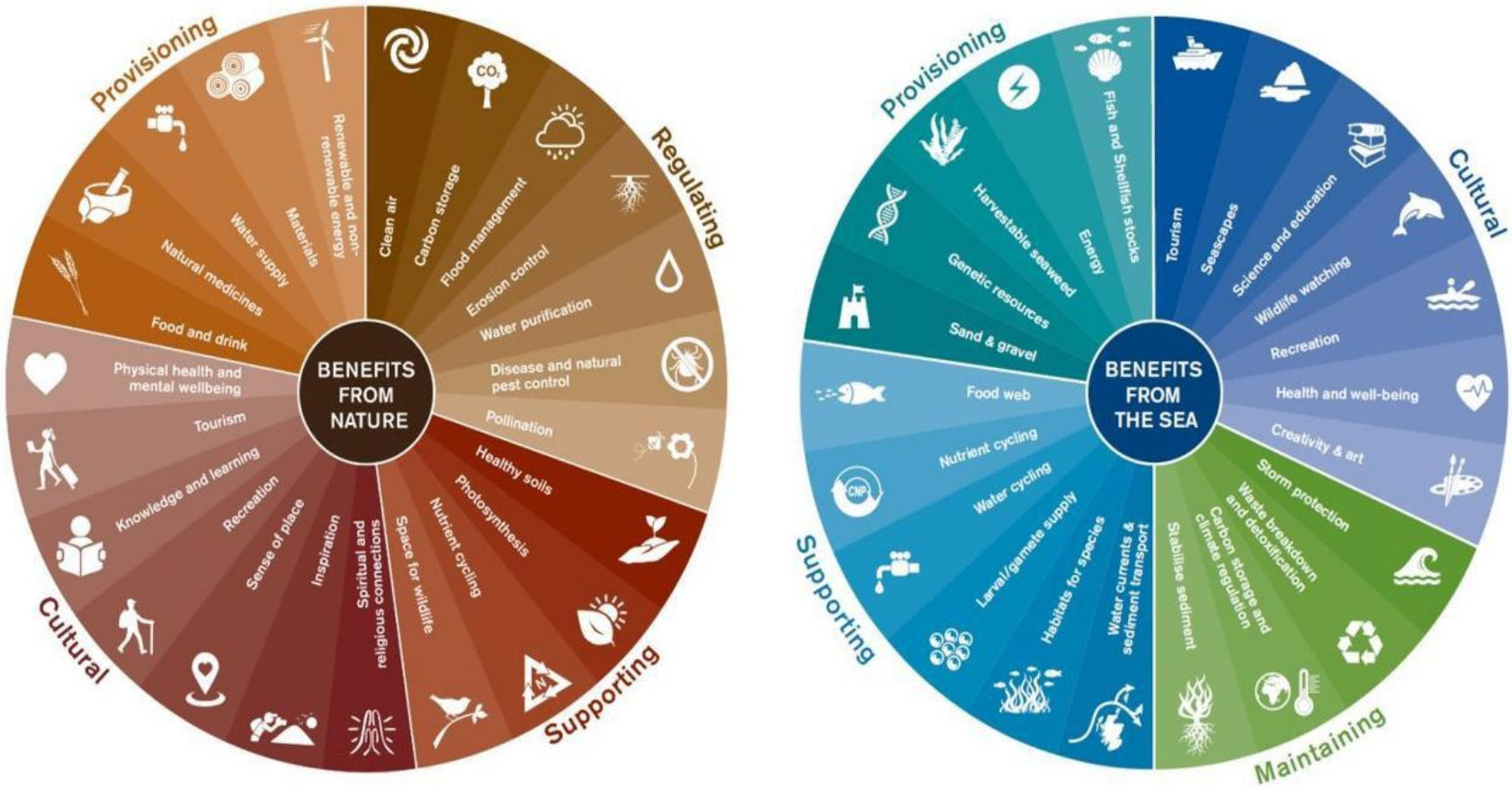


Figure 4: Different types of ecosystem services with examples, taken from the Nature Scot website

While this is relatively fast and one of the easiest ways of identifying potential ecosystem services, it does not account for the condition of the habitats present. It is likely that the condition of a habitat will have an impact on its ability to provide ecosystem services and this is not reflected in most mapping scenarios, with many assuming an average capacity and others assuming high capacity. Additionally, as Eigenbrod et al., (2010) noted some services assumed to be provided by certain habitats may not be provided at all, which would impact the validity of these assessments. To avoid these issues as much as possible, inclusion of ecological survey data or some ground truthing work is advisable during the process.

2.5.2 Appropriate valuation of services and demands

The next stage is appropriate valuation of services and demands of the system. This, again, is best performed through multiple methods and preferably, through both economic and non-economic means dependant on the service.

Economic ecosystem service valuation can be performed using different methods depending on the service being valued. It is important to apply an appropriate valuation method to the service to ensure that the value of the service and the system overall is accurate. These approaches can be broadly organised into three categories, Direct market valuation, revealed preference valuation and stated preference valuation (Pascual et al., 2017).

Direct market valuation within estuaries could represent the market value of fisheries supported by the estuary or the value of tourism in the area. For example, O'Higgins et al., (2010) demonstrated the value of fisheries in some estuarine environments through economic valuation methods. This method also includes avoided costs, such as water filtration costs avoided if Oysters are present within an estuary. An estuary can also be valued through

revealed preferences techniques such as the travel time taken to visit greenspace in the area. Stated preference values of an estuary can be found through surveying those who use it and asking directly what value they give to certain services and features within the estuary. This value could be interpreted on a scale-based system or through the choice of how much a service is worth paying for (Pascual et al., 2017).

In addition to this, economic valuation can also include the value of services that can be sold from ecosystem service improvements through schemes such as biodiversity credits or carbon credits.
Establishing the non-economic value of an ecosystem is more difficult and may require some qualitative measures as opposed to quantitative measures. As a general guide, involvement of stakeholders, the local community and ecologists who study the habitats in the area can highlight societal, cultural and environmental values that the area has that may be otherwise hard to identify. This does require time and financial investment to implement methods such as focus groups or questionnaires but provides a key element in identifying the value of the area and ensuring that the approach can be implemented with longevity.

2.5.3 Selection of priority services

After valuation, priority services should be selected taking economic value, non-economic value and services that are in demand in the area into account. This should also take into account trade-offs between services within the ecosystem system and within consultation for the approach, it is important to note that it is not possible to maximise all ecosystem services and decisions must be made as to what services to prioritise. When choosing these services, it must be kept in mind that maximising the selected ecosystem services is likely to lead to unintended trade-offs and synergies. It is important to understand what these are likely to be. These trade-offs have been well documented, with matrices being created to demonstrate the

degree of change dependant on the trade-offs (Jacobs et al., 2015; Needles et al., 2013).

The selection of priority services should be a decision between advisory scientists, local communities, and the decision-makers to ensure that the services being selected are the ones that are needed and wanted within the context of the surrounding landscape. This will make sure that the approach allows decision makers a voice but does not undermine the conservation goals of the approach.

2.5.4 Modelling interventions and possible scenarios

To predict what the effect of possible actions will be on ecosystem services, modelling can be used. This is a powerful tool when planning for conservation or mitigation actions but does require some background knowledge and skills such as the use of a GIS. There are many commonly used programmes that can map specific ecosystem services and the changes that occur when specific actions are taken. For a review of some of these tools see Bagstad et al., (2013) or the Ecosystems Knowledge Network website.

Once the intervention or action has been modelled, revaluation of the system will need to be completed to establish how ecosystem service provision has changed and the difference in value due to this change. It is important to ensure that this valuation method is the same as the previously used one.

2.5.5 Creation and implementation of a management plan

Once the changes have been modelled, the information should be used to inform and shape the management plans. The interventions modelled and

their effects on ecosystem services should be clearly presented to all stakeholders and decision makers so that they are fully understood. Once these are understood a joint plan should be made. This plan needs to be grounded in the information gathered and agreed upon by all parties to ensure its sustainability. This should also include both biophysical considerations as well as socio-economic ones. For example, if a key aim is to improve carbon storage in an area, both the ecological aspect of this and socioeconomic aspects, such as funding and job creation, should be considered. The importance of including stakeholders within Natural Capital approaches is discussed further in a review by (Hinson et al., 2022a).

Continuous monitoring and reassessment of the system should be undertaken after the management plan is implemented to ensure that ecosystem service provision is maintained and to allow any further interventions to go through the same process.

There are some obstacles which may prove challenging throughout the approach. The first of these is addressing any knowledge gap between scientists and decision-makers during the approach. While this can be resolved through collaborative work, it can take some time but will be necessary if an effective sustainable management plan is to be introduced. Additionally, it is likely there will be that conflicts arise between conservation priorities. While collaboration will resolve some of these conflicts, it is unlikely that all these conflicts will ever be resolved so compromise will be necessary (Angradi et al., 2016; Wasson et al., 2015). Finally, funding of conservation projects is typically a difficult discussion that must be had. The Natural Capital approach does need some funding; however, it also provides investment into ecosystem services and mitigation which can be used as a funding stream. It also provides some focus on improving the area and creation of green jobs, which can further fund conservation activities. Further to this, it builds on the concept of creation of investable concepts, attracting funding from public and private sources for landscape scale conservation efforts as has been done for Nature North

(https://www.naturenorth.org.uk/) the Humber Nature Partnerships Natural Capital plan (*Humber Estuary Plan 2*, n.d.).

2.6 Conclusion

Estuarine areas in Northwest Europe have long been degraded due to heavy anthropogenic uses. Recent efforts to improve their ecological condition have shown some promise despite continued heavy use. However, these efforts will not be enough to continue conserving important ecological functions and services. Increasing demands mean new decision-making tools and approaches will be needed in these complex and dynamic areas if they are to be conserved adequately while also meeting these demands. The Natural Capital approach could be the lens needed to balance humans and nature by considering ecosystem service supply and demand and the continued development of Natural Capital frameworks could significantly improve our ability to do so.

This is particularly needed in estuaries which have a long-established history of being degraded by human use such as the Mersey Estuary. These areas still have lingering effects from historical damage and an increasing urban population relying on them. This represents a ‘perfect storm’ of previous degradation due to use and increasing use likely to occur in the future, while also needing ecosystems to be restored to provide services that this increasing population relies on. The Natural Capital approach could be used to consider both ecological needs and continuing anthropogenic needs within these systems to meet both demands and continue to provide necessary ecosystem services in the future.

3. Policy Review

This chapter focuses on objective 1 ‘establish how Natural Capital approaches could support decision making for restoration and conservation of urban-estuarine systems’ which contributes to the overall aim of the thesis to deign a framework for the wider application of a Natural Capital approach and to use the Upper Mersey estuary as a case study for testing.

Following the Millenium Ecosystem Assessment, several programmes and initiatives began to take place based on Natural Capital approaches. These include the establishment of the Environment Bank in 2006, the Better Building Partnership in 2008 and the Wealth Accounting and Valuation of Ecosystem Services (WAVES) partnership in 2010. A more detailed timeline of these initiatives can be found in Faccioli and Blackstock (2017).

These programmes and approaches also began to be explored in the UK with the establishment of the Natural Capital Committee in 2011 and the beginnings of the National Ecosystem Assessment (UK National Ecosystem Assessment, 2014). This led to the publication of the 25 Year Environment Plan in 2018 (HM Government, 2018) which detailed the governments plan to use a Natural Capital approach to improve the UK’s natural environments. More recently, the Environment Act (2021) has been passed into law placing Natural Capital approaches as a key part of UK policy that decision makers will need to consider. How these approaches can be integrated into policy and decision making has been less studied, particularly at a local level, and remains a gap in the Natural Capital approach which will need addressing.

3.1 Purpose and method of review

The primary purpose of this review is to assess the local and national policies for the facilitation of Natural Capital approaches with a secondary objective to

identify policy priorities to support the Mapping chapter design process.

Firstly, a grey literature review of local policy documents was collated from Warrington Borough Council and Halton Borough Council to gain an understanding of priorities and policies in this area. Documents collected include currently active local core plans and strategies which detail the economic, social and environmental considerations of spatial planning and land use in the study area. Details of other considerations such as protected sites and neighbourhood plans would have also been included however these were not available for this study area. Following this a review of England and UK wide policies aims to establish more general development and environmental priorities and how local plans fit into this taken from documents detailing national guidance for economic, social and ecological considerations for spatial planning and land use. All these policies were assessed for facilitation of the Natural Capital approach through a close reading analysis, looking for actions that facilitate one of the stages in the framework presented in a previous chapter, such as selecting priority services or assessing impacts of actions, and any guidance for meeting socio-economic and environmental priorities, such as the mitigation hierarchy. Additionally, the documents were reviewed to help identify information which could guide the design of the developments and habitat improvements in Chapter 4.

It should be noted that this is a particularly fast-moving area of policy and, while updates have been made where possible, policies may have been changed, added to or removed from in the time taken to produce this work.

3.2 Halton Borough Council

For developments in Halton, two policy documents have been identified and used. The first of these is the ‘Halton Core Strategy and Local Plan’ from April 2013 which was written to inform development within Halton through to 2028, strategic objectives identified in these documents can be found in table 3. The second is the ‘Delivery and Allocations Local Plan Publication Document’ from January 2018 which included a partial review of the core strategy and the local plan for 2014 through to 2037.

Table 3: Halton Core Strategy and Local Plan Objectives reviewed.

Objective	Details
1	Create and support attractive, accessible and adaptable residential neighbourhoods where people want to live
2	Provide good quality, affordable accommodation and a wide mix of housing types to create balanced communities
3	Create and sustain a competitive and diverse business environment offering a variety of quality sites and premises, with a particular emphasis on the revitalisation of existing vacant and underused employment areas
5	Maintain and enhance Halton's town, district and local centres to create high quality retail and leisure areas that meet the needs of the local community, and positively contribute to the image of the Borough
6	Ensure all development is supported by the timely provision of adequate infrastructure, with sufficient capacity to accommodate additional future growth
7	Provide accessible travel options for people and freight, particularly through the realisation of the Mersey Gateway Project, ensuring a better connected, less congested and more sustainable Halton
9	Minimise Halton's contribution to climate change through reducing carbon emissions and ensure the Borough is resilient to the adverse effects of climate change
10	Support the conservation and enhancement of the historic and natural environment including designated sites and species and the Borough's green infrastructure in order to maximise social, economic and environmental benefits
11	Improve the health and well-being of Halton's residents throughout each of their life stages, through supporting the achievement of healthy lifestyles and healthy environments for all
12	Prevent harm and nuisance to people and biodiversity from potential

	sources of pollution and foreseeable risks
13	Support sustainable and effective waste and minerals management, reducing the amount of waste generated and contributing to the maintenance of appropriate mineral reserves.

3.2.1 Development priorities

Within Halton Core Strategy and Local Plan, some themes of priorities can be identified.

The first of these is economic regeneration through direct means as in strategic objective 3 or 5 or indirect means as in strategic objective 6 and 7. This is also a key objective at the regional and UK Government level and could form part of the UK governments levelling up agenda, which is discussed later in this chapter. Another key theme which can also be seen regionally is ensuring a good supply of varied housing which is reflected in strategic objectives 1 and 2. This is similarly a priority identified by the UK government within the UK development framework. Finally, a theme of improving the health and wellbeing of residents is identified in strategic objective 11 and is further identified as a principal concern within Halton Borough.

Socio-economic concerns remain a priority which is reflected in the strategic objectives which may be facilitated by Natural Capital approaches as described by the 25 Year Environment Plan, particularly those that aim to directly improve these considerations. This is particularly true for the objectives of improving the health and wellbeing of residents as air quality and access to greenspace are often priority services in Natural Capital approaches.

3.2.2 Environmental Priorities

Within the Halton Core Strategy and Local Plan, there are four objectives that directly aim to improve the natural environment in the borough, two of these are to directly improve natural environments and two are to improve environments for benefits to people.

The first two of these are strategic objectives 9 and 13, both of which aim to tackle different environmental concerns, climate change and waste management respectively, to mitigate future impacts that mismanagement of these may have in the borough. The second two are strategic objectives 10 and 12. Strategic Objective 10 aims to conserve both natural environments and historic environments to maximise benefits to both people and nature. Strategic objective 12 aims to identify risks from sources of pollution and mitigate the impact these have on people and biodiversity in the borough.

These policies clearly facilitate the use of a Natural Capital approach to achieve these objectives. Objectives aimed at mitigating impacts and reducing risks can be prioritised within Natural Capital approaches as can maximising benefits to people and nature.

3.2.3 General considerations

Within these documents there are some core strategies which cover both environmental and non-environmental policies.

The first of these is that, where possible outside of the key areas of change, development on brownfield sites should be prioritised to avoid release of the greenbelt. It is mentioned in the 2013 document that some amendments to the greenbelt boundary will be necessary and the 2018 document further clarified that inappropriate development within the greenbelt will not be allowed but did not detail or provide examples of what inappropriate development could be.

Any development which is permitted should incorporate high quality design

which includes consideration of local habitats and biodiversity according to the 2013 document. In the 2018 document there is a set of local standards for greenspace provision in residential developments to ensure greenspace is accessible and appropriately sized according to the number of residents in the area. Sites of ecological importance locally, regionally, and nationally are protected and opportunities to enhance these sites are encouraged. Any adverse reactions to these sites are considered within a mitigation hierarchy detailed in the 2018 document which states that if a development will likely affect a natural asset, it will be considered in order of avoidance of damage, minimisation of damage, mitigation of damage or compensation for damage. In addition to this development on internationally important sites will only be permitted if there are no alternatives and development on regionally and locally important sites will only receive permission under certain environmental conditions which limit damage. Sites without designation are also protected from certain environmental damage, in particular, those with protected trees or woodland.

The last environmental policy in both documents is a green infrastructure policy ensuring new development considers green space provision and linkage and protects natural habitats where possible.

These policies can further facilitate Natural Capital approaches as baselines and predicted impacts of development can be identified to better assess if a development is inappropriate or alterations should be made to designs to reduce negative impacts. These approaches can also aid in designing high quality developments and identifying high quality design for development policies.

3.3 Warrington Borough Council

For developments in Warrington, two key documents have been identified. The first of these is the Warrington Town Centre Masterplan (2020) which is an outline of planned public sector work and potential private sector

investments. The second is the Local Plan Core Strategy from 2014.

3.3.1 Development priorities

The majority of the objectives in Warrington Borough Council documents are either non-environmental or a blend of development and environmental. The first of these non-environmental objectives is from the Local Plan document and details the aim of regenerating the older areas of the town alongside objective aiming to improve the towns employment and cultural opportunities and to increase accessibility.

Cultural opportunities could be benefitted through integration of a Natural Capital approach as could objectives to regenerate the older areas of Warrington, but these policies would likely gain less benefit from the Natural Capital approach than environmental objectives as these objectives are less specific about land use.

3.3.2 Environmental priorities

There are two key environmental objectives identifiable within these documents. The first of which is in the Masterplan which includes details of a circular park. This aims to link existing parks to establish a 'full green ring' of greenspaces around the centre. While this has been identified as an environmental objective, the primary aims of this is for the services that can be provided to residents.

The second of these is in the Local plan and aims to minimise the impact any development has on the environment through high quality design and monitoring.

These policies, similar to Halton Borough Councils, also lend themselves to a Natural Capital approach to predict impacts and help define high quality design' for planning departments.

3.3.3 General considerations

Warrington Borough Council had fewer policies available for review, within the documents that were available, there are several policies and aims that blend environmental and non-environmental objectives. These include maintaining the greenbelt and protecting this from inappropriate development or development that does not align with national policy. Similar to Halton, there are also objectives to encourage high quality designs which protect the natural environment in the area. Any development that would impact a nationally or locally important environment negatively will not receive permission from the council unless the benefits of the development outweigh the losses or need to protect that environment. There is also a general policy objective to safeguard Warrington's natural environments and places of local and national importance. Again, there is little clarity on what inappropriate development is, what encompasses a high-quality design or what benefits/losses will be considered in environmentally damaging developments.

However, despite vague descriptions of high quality design, the blended approach of these policies can facilitate a Natural Capital approach and may be supported by taking a Natural Capital approach in turn.

3.4 National Policy

The UK national planning policy includes some guidance for councils with regards to environmental protections and development. For example, large-scale, non-agricultural development on high quality land requires consultation with Natural England prior to approval. In addition, biodiversity value and sensitivity of any land needs to be considered prior to allocation so any potential harm can be avoided. The National Planning

Policy Framework ("National Planning Policy Framework," 2006, NPPF herein) also outlines the local authorities' duty to consider the conservation of biodiversity and encourage the biodiversity net gain principle in development plans. It also outlines that developments which cannot meet the mitigation requirements should not be given planning permission. This principle of requiring Net Gain is a Natural Capital approach at a national policy level however there is evidence that this is not consistently adhered to at a local policy level (Robertson, 2021).

In addition to this, the 25 Year Environment plan (HM Government 2018) goes into some more detail about environmental objectives. It explicitly names the Natural Capital as the approach being taken and details several aims and policies, each with their own specific actions. The aims include clean air and water, improvements in wildlife, more sustainable resource use and engaging people with nature. The policy aims include enabling nature recovery, increasing resource efficiency, and increasing connections to the environment for increased health benefits.

The Environment Act (2021) makes biodiversity net gain a legal requirement for planning permission. This is within the existing framework of the mitigation hierarchy but allows for developers in some cases to purchase Biodiversity Credits from approved schemes for offsite mitigation.

Policymakers must also follow some principles when considering policy options. These include ensuring environmental protection is integrated into policymaking, preventative action to avoid environmental damage, the precautionary principle, rectification of environmental damage at source, and the polluter pays principle. In addition to this, the act established the Office for Environmental Protection (OEP). The OEP will act as a watchdog to ensure policymakers and developers are following the requirements of The Environment Act. Other key areas in The Environment Act include waste and resource efficiency, air quality and water quality. Following the Environment Act, the Environmental Improvement Plan (HM Government 2023) was produced by Defra in 2023 and further details aims to improve environmental quality, resource use and mitigation of climate change

alongside improving biosecurity and enhancing engagement with the natural environment. This document also detailed the funding being provided through various scheme to meet each goal.

In addition to the goals set by the UK, the UN has also set the Sustainable Development Goals (UN 2023) which were adopted by all UN member states in 2015. Of these 17 goals, three, Life on land, Life below water and climate action, are directly aimed at improving the environment and environmental considerations are included in almost all others. This further highlights the issues of sustainable development and balancing people, and nature are becoming ever more globally significant and considered at every stage in policymaking and the role Natural Capital approaches could have.

Figure 7 below summarises the policy landscape described in this chapter.

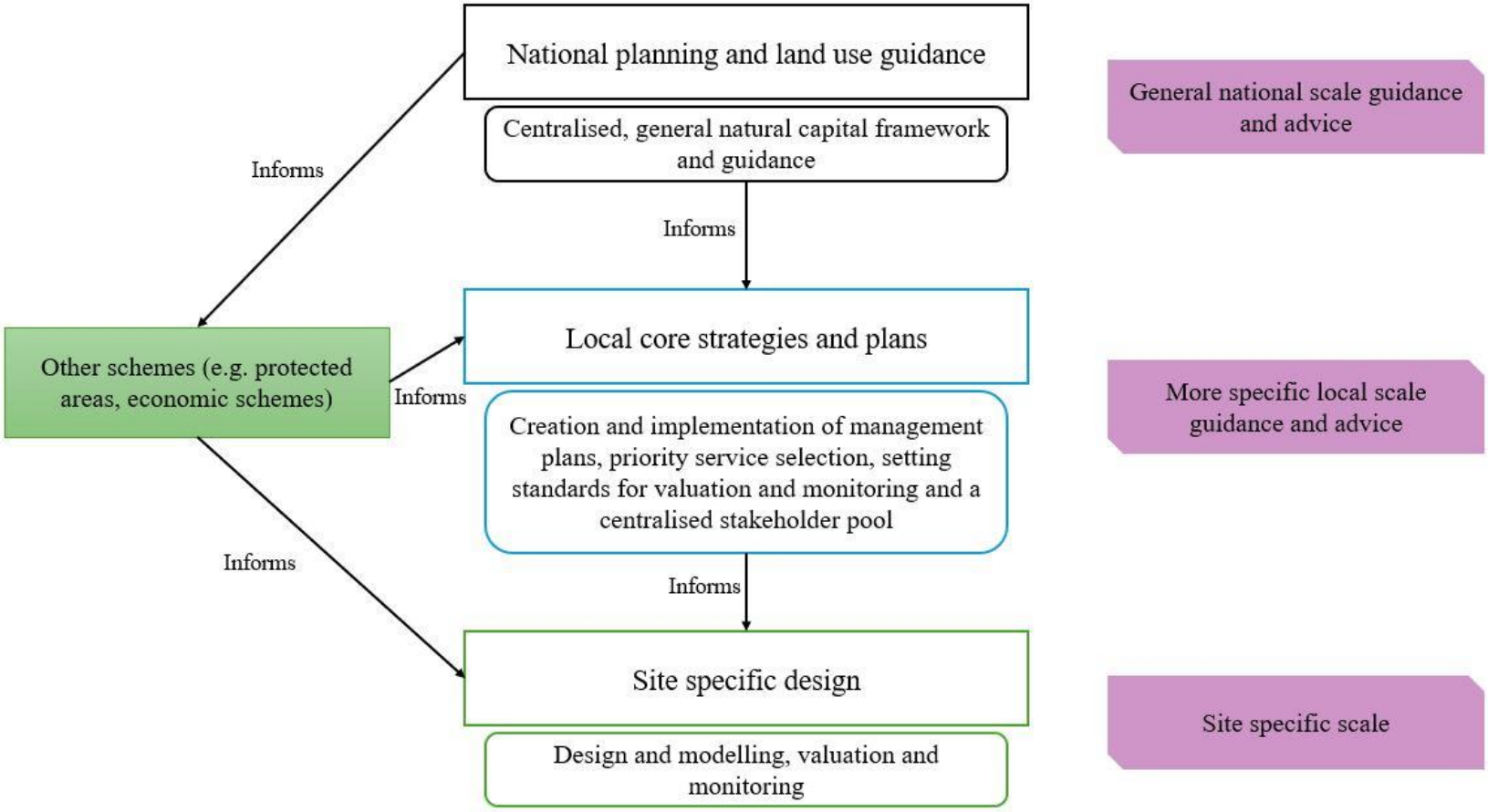


Figure 5: Diagram showing guidance information flow in the policy landscape and where Natural Capital can be supported. Square boxes are documentation/policies, rounded boxes show natural capital support/facilitation, purple boxes indicate scale and the green box indicates non-scale specific schemes. Boxes bordered in black are national, boxes bordered in blue are local and boxes bordered in green are site specific.

3.5 Policy gaps and study assumptions

3.5.1 Do local and national policies facilitate a Natural Capital approach?

Natural Capital approaches are already an explicitly stated part of national policy in the UK encompassed by the Environment Act (2021) and the 25 Year Environment Plan (HM Government 2018). This includes development and adoption of biodiversity net gain and no net loss requirements in the NPPF (2006). Local government policy approaches, however, lag behind national policy approaches in adoption and implementation of Natural Capital approaches.

Currently, local policies do have capacity to facilitate a Natural Capital approach within policy and planning, particularly when considering there are several objectives to maximise provision of benefits for both people and nature and to mitigation impacts of climate change and pollution in the boroughs. However, as Claret et al (2018) indicates, there are distinctions between conceptual inclusion and operational inclusion with significant further barriers to operational inclusion of Natural Capital approaches at local policy levels.

The first of these is a lack of resources, including data and in-house ecologists (Faccioli et al., 2023) with Robertson (2021) finding that less than 40% of Local Planning Authorities had in house ecologists for net gain or Natural Capital approach consultations. The second of these is the lack of consistent delivery framework (Faccioli et al., 2023) leaving local authorities with little direction or guidance on implementing Natural Capital approaches. The Biodiversity Metric aims to improve this however in 2019 62% of local authorities used no metrics in planning decisions (Robertson, 2021).

Establishment of a consistent Natural Capital approach framework which planning authorities can use along with the relevant toolkits and investment

in resources could resolve these issues to help Natural Capital approaches be implemented to achieve environmental and non-environmental objectives.

3.5.2 Development policy gaps

The local authority's development plans have similar gaps. The first of these is there is little information regarding the type of housing beyond 'mixed use'. To mitigate this, housing is modelled that is similar to the surrounding area outlined for the development within the study area. In addition to this, there is no information on what employment land or industrial land constitutes. Therefore, in this study, employment land consists of paved or sealed surfaces and industrial buildings.

3.5.3 Environmental policy gaps

There are several areas within environmental policies from local councils where there are gaps or interpretation is required. The first of these is what is defined as 'inappropriate development' on greenbelt land. The next of these is what constitutes 'high quality design' when planning developments.

In addition to these undefined terms, there is not much detail on how enhancement of natural sites or protection of natural sites should be done, nor how effectiveness will be measured. Further to this Warrington Council does not clarify how they determine if benefits of a development outweigh natural losses or clarification of the general safeguarding policy. It is likely that some of the gaps identified will be filled through referral to the Environment Bill (2021), such as the requirement for Biodiversity Net Gain being part of a 'high quality design'.

This study has taken the approach that open greenspace, such as parks and grassland, would be considered as an easily achievable mitigation option as well as tree planting alongside paved areas. These are two options that have previously been used in the study area and are both mentioned in core strategies as means to achieve either environmental goals or other key aims. To model different development options, 4 different intensity levels of development have been set further detailed in Chapter 4.

4.Natural Capital Mapping

4.1 Introduction

As mentioned in the Literature Review (Chapter 2), urban-estuarine systems are often severely degraded, particularly in Northwest Europe. Evidence indicates that typical restoration approaches are often unsuccessful (Edgar et al., 1999; Wauchope et al., 2022). It is key to consider measures of success that take account of both socio-economic and ecological importance of urban-estuarine systems (Hinson et al., 2022b; Özdemiroğlu, 2019a). A more holistic approach which simultaneously considers environmental and non-environmental priorities will be necessary to successfully manage actions that aim to restore urban-estuarine systems for people and nature.

While there is increasing interest in a more holistic approach to green and restore urban areas (Jones et al., 2019) and some interest in restoring estuarine environments (Ducrotoy, 2010) there is very little acknowledgement of urban estuarine environments, where urban centres are in direct proximity to estuaries, as a habitat matrix to be restored. This is despite these habitats often being in close proximity with one another, with impacts from within the urban-estuarine matrix influencing both the urban habitats and estuarine habitats.

Planning systems which have influence over these environments in the UK are often subject to reform (Shaw et al., 2017), making creating a holistic framework which can consider multiple environments and impacts simultaneously difficult. However, there has been a shift towards a focus on spatial planning aimed at shaping and designing spaces for the greatest benefit (Nadin, 2007). This may be a move towards a more holistic approach which could facilitate consideration of multiple habitats and services in a formalised Natural Capital approach.

At the core of a Natural Capital approach is ecosystem service mapping to create a baseline of ecosystem service supply and demand and to assess the impact changes may have on these services. This has been done previously in non-urban areas (Hooper et al., 2019; McVittie & Faccioli, 2020) using a

variety of tools including Defras Biodiversity Metric however little work has been done in urban-estuarine habitat matrices. This leaves the Natural Capital approach in these areas with a key gap which will need addressing for successful restoration.

Within this chapter, objectives 2 and 3 of this thesis are addressed. Objective 2 is to use demonstrate how the Natural Capital approach can be used to identify the benefits an area provides as the foundation of a Natural Capital approach in urban-estuarine areas. Objective 3 is to demonstrate how a Natural Capital approach can be used to assess impacts of changes in an urban-estuarine landscape and potential trade-offs which will need consideration. This will also identify any trade-offs that are present with planned changes. Both these objectives will help meet the overall thesis aim of designing a framework for the wider application of a Natural Capital approach and using the Upper Mersey estuary as a test case.

4.2 Methods

4.2.1 Overview

There are multiple tools and methodologies that can be used to create a Natural Capital baseline and to undertake a Natural Capital assessment. The selection of these depend on the aims and desired outputs of the assessment (i.e., biophysical, financial etc.). As this study aims to demonstrate a more comprehensive approach to urban-estuarine restoration using Natural Capital, the current standard metric for assessment, the Biodiversity Net Gain metric (5.2.2), will be used. As this is a non-spatial tool which provides a proxy for biodiversity, EcoservR (5.2.3) will also be used alongside the Biodiversity Net Gain metric to consider a wider suite of Natural Capital metrics and provide spatial context for these.

4.2.2 The Biodiversity Net Gain metric

The Biodiversity Net Gain Metric (2019) is a tool developed by Defra and Natural England. It calculates Biodiversity Units of a site through

multiplying the habitat area, distinctiveness, condition and strategic significance of habitats present. Distinctiveness, condition and strategic significance are determined through an ecological survey using the condition sheets provided in the Technical Supplement (Panks et al., 2021). Biodiversity units can be assessed before and after a habitat improvement or a development to calculate biodiversity net gain or loss on the site. Key limitations of the Biodiversity Metric include the use of habitats as a proxy for biodiversity which may lead to higher biodiversity scores than are reflected in reality and the need for expert ecological assessments to be carried out alongside the Biodiversity Metric assessment.

From January 2024, Biodiversity Net Gain will be mandatory for all but small development sites as detailed in the Environment Act (2021).

This project used the 3.0 version of the biodiversity metric released in 2021. This tool runs through an excel spread sheet which is available from Natural England's website.

4.2.3 Comparison of Ecosystem service assessment tools

There are multiple tools available for ecosystem service assessments as part of a Natural Capital approach and for each approach an appropriate tool must be used. This study requires a site scale assessment of multiple ecosystem services, using software which is free to use. Technical expertise limitations are not a concern for this study however if a tool takes a significant amount of time to run or is not flexible enough to produce alternative spatial scenarios this would make the tool inappropriate. Several tools were considered, as shown in the table below, with EcoServR being selected as the most appropriate to the needs of the study.

Table 4: Comparison of different ecosystem service assessment tools for this study. Information in this table was taken from the Ecosystem Knowledge Network tool assessor with supplement from Bagsted et al 2013.

Tool	Strengths	Weaknesses
Nevo	Easy to use.	2km resolution.

	Spatial/visual display Land cover classes can easily be edited. Values six ecosystem services.	Economic values only. Land cover classes editing is not spatial and only has broad habitat classes.
InVEST	Multiple services can be modelled. Both biophysical and economic valuation possible.	Landscape scale. Requires some technical expertise. Time intensive.
ARIES	Ecosystem service supply, demand, and flow considered. Considers natural capital accounting among other considerations.	Time intensive. Landscape scale. Requires some technical expertise. Prototypes only available for specific case studies.
ORVal	Easy to use and access. Can split results by socio-economic group.	Economic values only. Limited to recreation services. Not site scale.
EcoServR	Can be used at multiple scales including site scale. Models supply and demand of multiple ecosystem services. For the purposes of this study there was flexibility in the model.	Requires technical expertise. Does not include valuation of ecosystem services. Data intensive.

4.2.3 EcoservR

EcoservR is a tool developed by Liverpool John Moores University that is an updated version of EcoservGIS (Winn et al., 2015). It creates a habitat basemap established from multiple overlaid data sources including OS Mastermap, OS greenspace, CORINE and CroME (for a full list of data inputs please visit https://ecoservr.github.io/EcoservR/). From this basemap, models of ecosystem service flows for each habitat type are created based on literature reviews (literature reviews for each service can be found on the

NatureScot webpage for EcoServGIS) with scaled capacity scores from 0-100. Demand models are based on population data, land use and deprivation indices (IMD) included in the model with greater demand reflecting a greater number of beneficiaries. Additionally, demand models take into account spatial configuration using focal statistics. In this study, EcoservR was used to establish net gain and loss in ecosystem services at each site as demonstrated by Busdieker et al (2020). Limitations of EcoservR for this study, in addition to those in table 4, include no consideration of condition data and a limited scope to include green infrastructure. Additionally, a validation, either through ground truthing or through uncertainty analysis of EcoservR results has not been published.

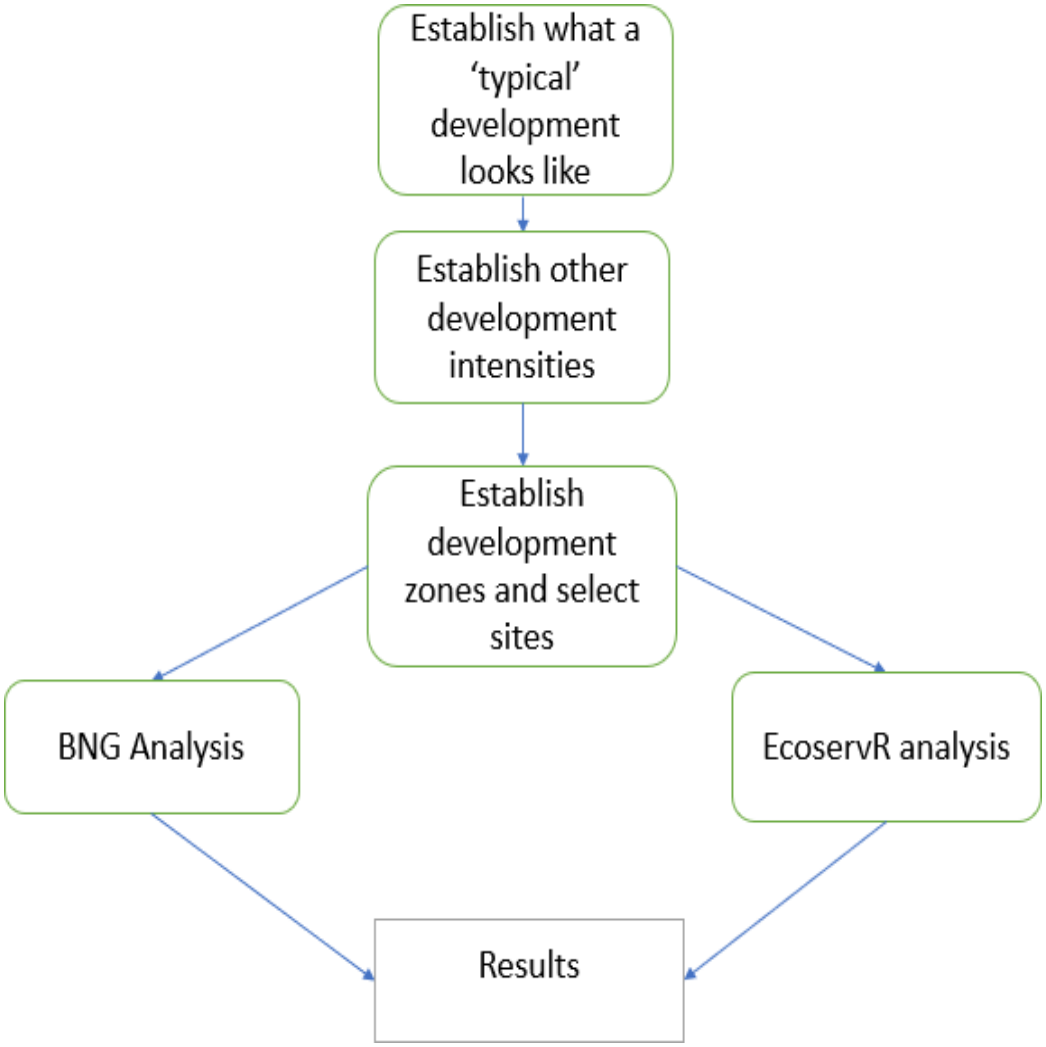


Figure 6: Overview of mapping methodology.

4.2.4 EcoservR mapping method overview

Two approaches were used to select/design study sites within this work. One for selection of habitat improvement sites and another for developments.

Habitat improvements were based on sites from the policy review using environmental priorities for improvements. This included expanding grassland and tree planting in Arpley Nature Reserve and King Georges Park and improvements to three key saltmarsh sites: Widnes Warth, Astmoor and Cuerdley. Additionally, two saltmarsh expansion sites with corresponding adjusted versions were based on maps produced by the Marine Management Organisation and the Rivers Trust (2020, accessible

via the Catchment Based Approach Website) were included in habitat improvement models.

The developments were designed in a multistep process as shown in Figure 7. Firstly, a ‘typical’ development intensity was established. This was done through identifying five recently completed mixed use developments, excluding any outlier habitats which were unique to each site and establishing what habitats were common amongst all of the sites and should be included in the ‘typical’ development. The average percentage cover of each of these common habitats was then used to approximate how much of each common habitat would appear in the ‘typical’ development. The exact percentages in the ‘typical’ development were kept as close as possible while keeping the development design realistic and including site specific elements to reflect the outlier habitats removed.

Following establishment of the typical development intensity, other developments were designed with the green/blue to grey ratio of habitats increasing or decreasing by 10% as shown in table 8, while again keeping the development design as realistic as possible.

To select where study sites for modelling these developments would be within the study area, three different development zone categories were established: high urbanisation, mid urbanisation and low urbanisation. Once these were defined, random sites were chosen across the study area and categorised into one of these zones. Inappropriate or overlapping sites were removed. Finally, each development intensity was modelled in each study site throughout all three development zones allowing for comparison of the impact of development zones and development intensities.

4.2.5 Step 1: A ‘typical’ development

To begin establishing different development intensities to compare, a ‘typical’ development was made first. This was created using a multiple step process, detailed below.

In order to develop a typical development five real mixed use development sites within the study area were identified as detailed below.

Table 5: Mixed use sample sites chosen.

Site	Description
Omega South	Part of the largest mixed-use development in Northwest England which aims to help supply over 20,000 new jobs to the area, retail spaces, affordable housing and features a 'green heart' park.
Southern Widnes	Part of a regeneration effort in Widnes focused on providing more retail options and improving residential areas.
Runcorn Town Centre	A regeneration project focused on updating the area to provide for new residents.
Ditton Corridor	Mainly focused on providing employment land as an expansion to previous developments but also included some residential space and improvements to existing greenspace.
Southern Gateway	Aimed at providing more housing, retail areas and regeneration of some brownfield land.

The average cover of different land use types within these developments was calculated. Exclusions of land use types applied as detailed below.

Exclusions:

Round 1.

Exclude any non-typical habitats included in EcoservR habitat classifications but not present in sample sites identified in table 1 (e.g. intertidal areas, railways, etc) as these are unlikely to be reflective of a 'typical' development and instead reflect individual characteristics of an area.

Round 2.

Remove any habitat types from sample sites that have a habitat with an area that is more than one standard deviation away from average. This removes any habitats that are more reflective of distinctive characteristic habitats of specific areas rather than a 'typical' or average development of an area.

Round 3.

Remove any habitats with either no representative area or just one representative area. Those with no representative area remaining or just one area remaining are unlikely to be representative of a 'typical' or 'average' development.

Typical development was then created using the policy review recommendations and considerations of the study site as well as habitat percentage cover and thus the values below also have exclusions from above.

Table 6: Final land cover percentage of the 'typical' development scenario and the average of the mixed use sample sites and the difference between these showing the similarity between the existing

mixed use sites and the modelled scenario.

Habitat	'Typical' Development scenario	Existing mixed use sample sites	Difference
Broadleaved Woodland	3.32	0.64	2.68
Broadleaved Woodland with Scrub	3.37	4.07	-0.70
Scrub	2.08	0.16	1.92
Mixed Woodland	1.45	0.18	1.28
Grassland with Rail verge	0	0.31	-0.31
Arable Land	8.74	10.69	-1.95
Amenity Grassland	10.51	14.00	-3.49
Domestic Buildings	11.42	7.62	3.80
Business or Industry	4.22	6.69	-2.46
Shed/Garage/Farm building	0.35	0.45	-0.10
Structure	0	0.02	-0.02
Sealed Surface	21.49	26.64	-5.15
Surfaced Road	12.25	13.55	-1.30
Pavement	4.30	6.10	-1.80
Sealed Path	0.04	1.69	-1.65

Private Garden	16.45	7.19	9.26

Typical Development has more private garden and less sealed surface than the sample sites. Gardens do not take into account the percentage of vegetated/unvegetated and it is assumed they are vegetated. The final basemap for typical development can be found below in Figure 9.

Overall percentages included from the sample sites can be found in Table 3. From these percentages it can be seen that the sample sites vary significantly as each site has its own characteristics and unique sense of place. To reflect this the 4.16% of habitats within the typical development that are not in the table above will reflect this variation, therefore mimicking the local character. This will be modelled based on the policy review (Chapter 4). It is important to note that because this is being designed to be as realistic as possible, a split of 95% to 5% is not possible.

Table 7: Percentage of included habitat types and excluded habitat types from the sample sites and typical development sites.

	Percentage Included	**Percentage Excluded**
Sample Sites	39.78	60.22
Typical Development	95.84	4.16

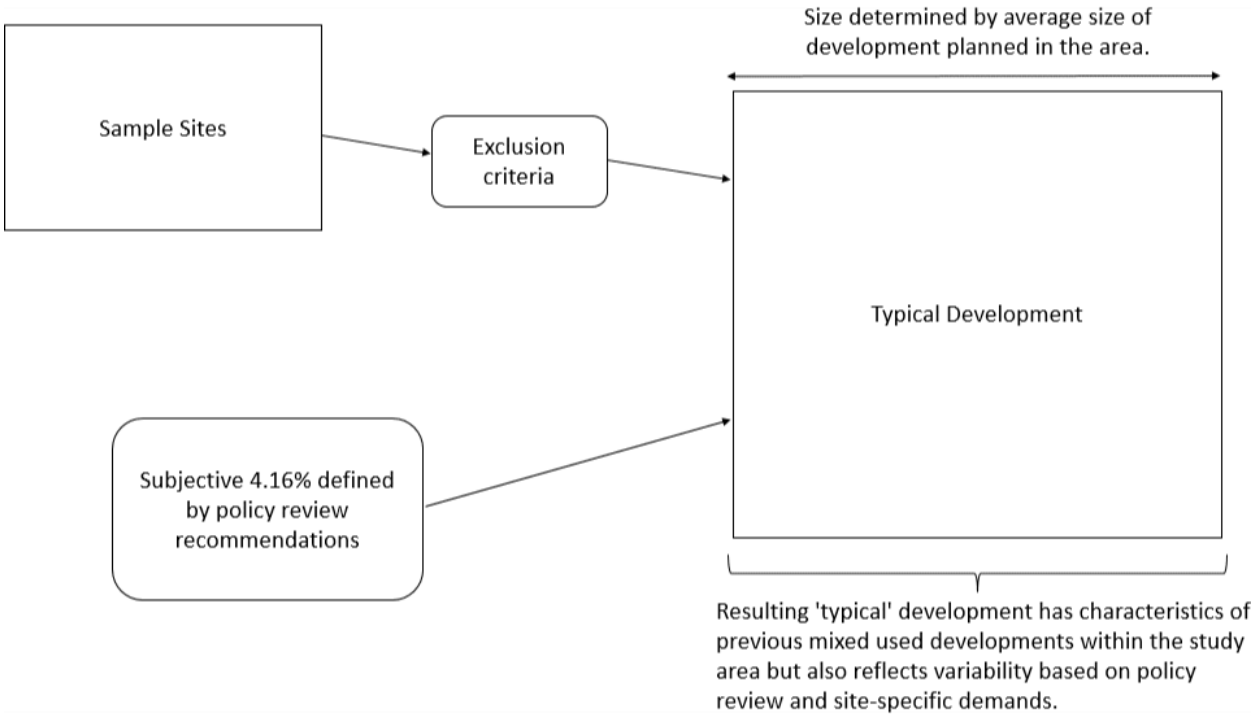


Figure 7: Overview of how typical development model was created including subjective percentage.

4.2.6 Step 2: Other development intensities

Other development intensities were set at 10% more green or grey than the typical intensity as detailed in Table 3, with an extra scenario for very green developments. These can be found in Table 4.

Table 8: Green/grey land cover ratio for different development intensities.

Scenario	Green	Grey
Intensive	30-40	60-70
Typical	40-50	50-60
Soft Green	50-60	40-50
Hard Green	60-70	30-40

This allows for modelling of different development intensity scenarios including a typical scenario. Details of these are in Table 5 with the basemaps in Figure 9.

Table 9: Development details for each of the development intensities.

Site	Residential Area	Commercial Area
Intensive	21 Blocks of flats (6 flats per block average) 1716 Houses (1340 small terraces, 87 large terraces, 89 semidetached/detached houses) Total 1842	10 commercial buildings and extensive (98,678m2) paved area (buildings could be either warehousing/retail etc and paved likely parking)
Typical	18 Blocks of flats 1219 Houses (606 Terraces, 236 large terraces, 377 semi detached/detached) Total 1327	10 commercial buildings and extensive paved area (78832m2) (buildings could be either warehousing/retail etc and paved likely parking)
Soft Green	18 Blocks of flats 1219 Houses (606 Terraces, 236 Large terraces, 377 semi detached/detached) Total 1327	10 commercial buildings but smaller paved area than Typical (74735m2)
Hard Green	18 Blocks of flats, 738 Houses (242 Terraces, 234 Large Terraces 234, 261 semi detached/detached) Total 846	9 commercial buildings, further reduction in paved area in comparison to Soft Green (59704m2)

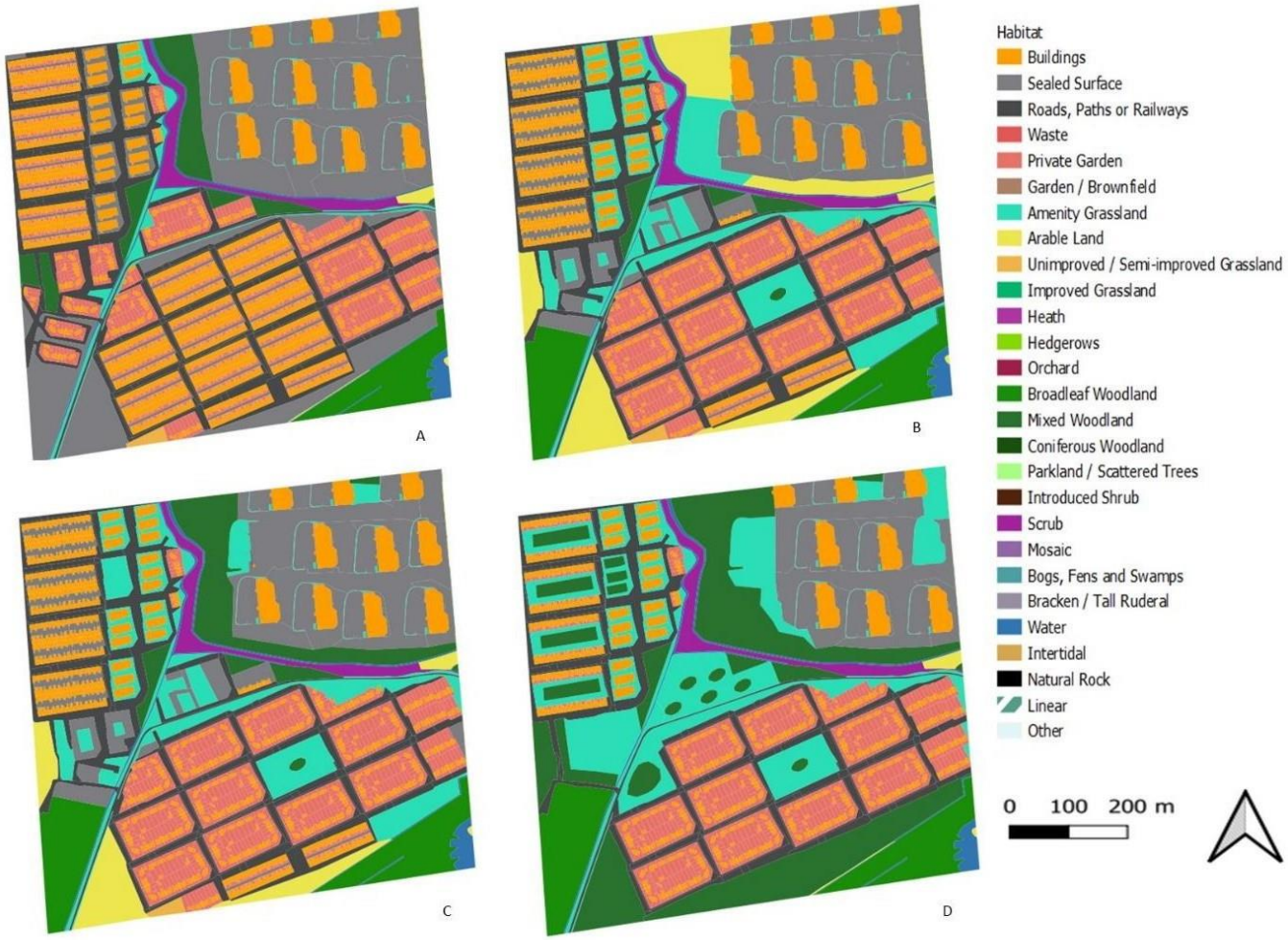


Figure 8: Basemaps for preset development intensity scenarios. A - Intensive, B - Typical, C – Soft Green, D – Hard Green.

Table 10: Land use of each of the development intensities with the area in hectares.

Habitat	Intensive	Typical	Soft Green	Hard Green
Broadleaf woodland	1.62	3.42	3.39	3.69
Mixed woodland	2.25	0.74	3.49	10.71
Scrub	1.06	1.06	1.00	1.06
Unimproved grassland	0.14	0.12	0.12	0
Water	0.87	0.86	0.86	0.86
Arable land	0.19	4.44	2.34	0.19
Amenity grassland	1.48	6.70	6.04	9.54
Buildings	7.20	8.13	8.27	5.78
Sealed surface	20.02	10.91	10.85	5.99
Roads, paths or railways	10.34	8.45	8.45	7.27
Private gardens	8.00	8.36	8.36	8.09

4.2.7 Step 3: Development zones and site selection

For this study, three different development zones were established with different levels of urbanisation. The low urbanisation zone has a land cover of at least 60% undeveloped land (land which is non-urban and has no infrastructure e.g. arable land, grassland, excluding woodland), and less than 10% built up areas. The mid-urbanisation zone has a land cover of at least 40% gardens, parks and brownfield (non-hard urban e.g. playing fields, vegetated gardens) , and between 10% and 40% built up area. The high urbanisation zone has a land cover of between 40% and 80% built up area.

These were selected using an R script which iterated sites through the study

area and selected those fitting the criteria. These sites were 53.15ha which was the average area of the existing sample sites. These were then manually checked and filtered to ensure that the selection was sensible, and any unrealistic sites were removed from the study, such as developments located in the river itself or in areas where development would not be permitted (e.g heavily wooded areas).

This resulted in seven low urbanisation zones, five mid-urbanisation zones and seven high urbanisation zones being selected for further analysis. See Figure 10 for a diagram of the selected sites.

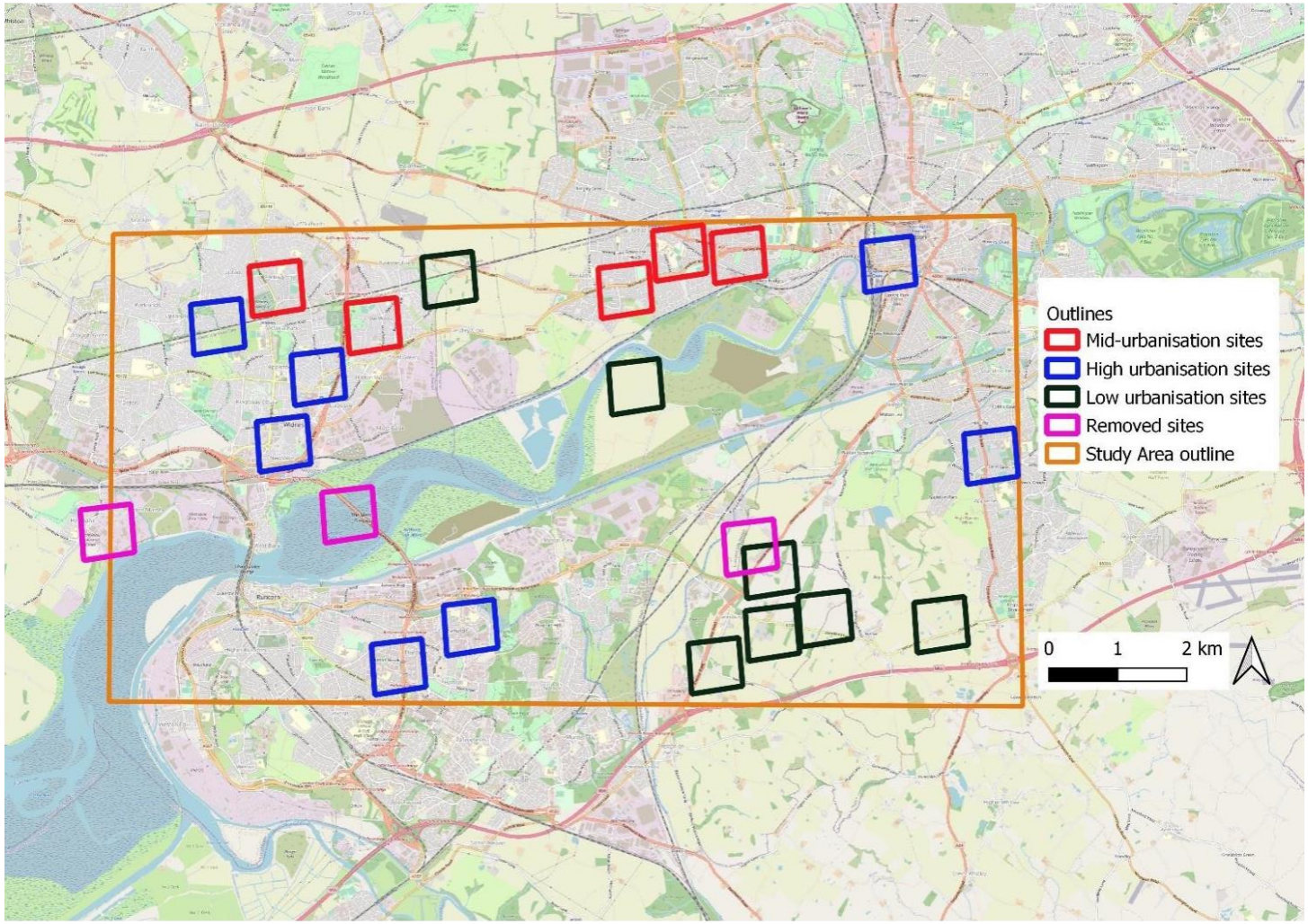


Figure 9: Diagram showing selection of random sites according to designations then exclusion of those which are not sensible, overlapping or not entirely within the study area.

Once sites were selected, each site had each scenario modelled on it with analysis run using EcoservR and the Biodiversity Net Gain metric (Figure 11).

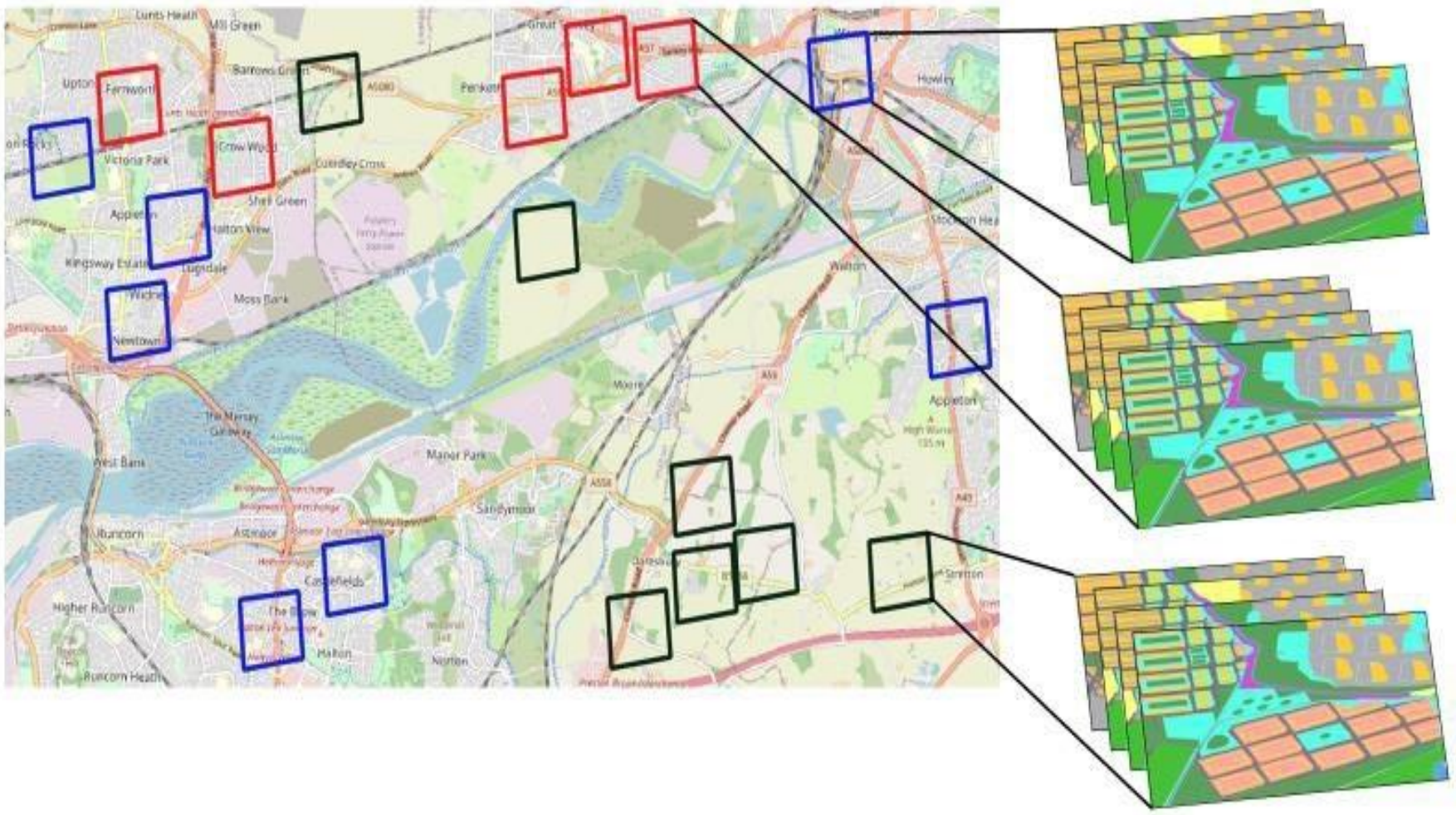


Figure 10: Illustration of method used where each development intensity was modelled on each site.

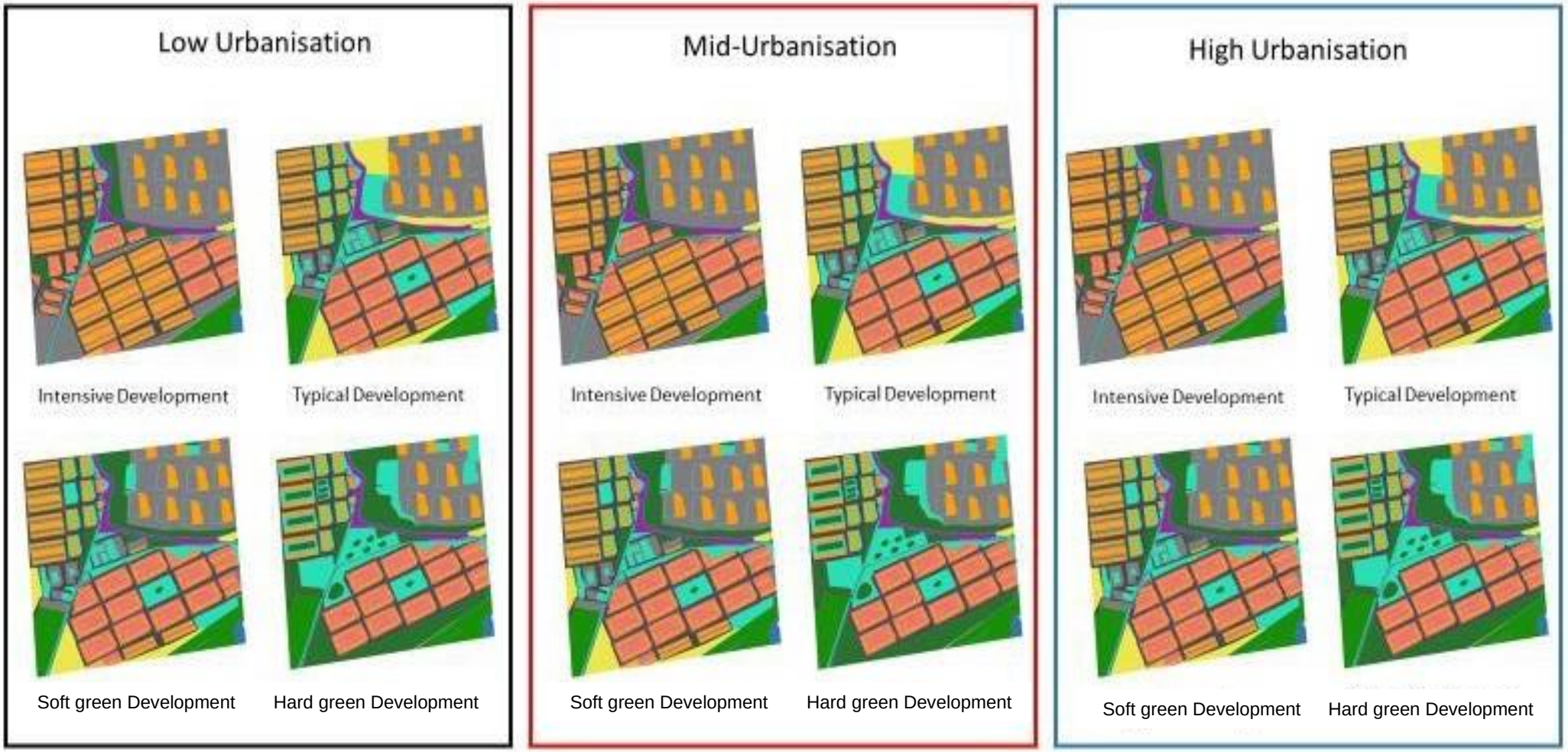


Figure 11: Comparisons can be made within urbanisation zones (e.g. Intensive vs Typical) and between urbanisation zones (e.g. mid-urbanisation Intensive vs low urbanisation Intensive)

Comparisons between development intensities and between development zones from EcoservR results were further analysed using Kruskal-Wallis tests in R Studio, R version 4.1.2. These were used due to small sample sizes, data non-normality and robustness to outliers (Ostertagová et al., 2014).

4.2.8 Habitat Improvement and Creation Sites

The habitat improvement sites modelled are shown in figure 13 below.

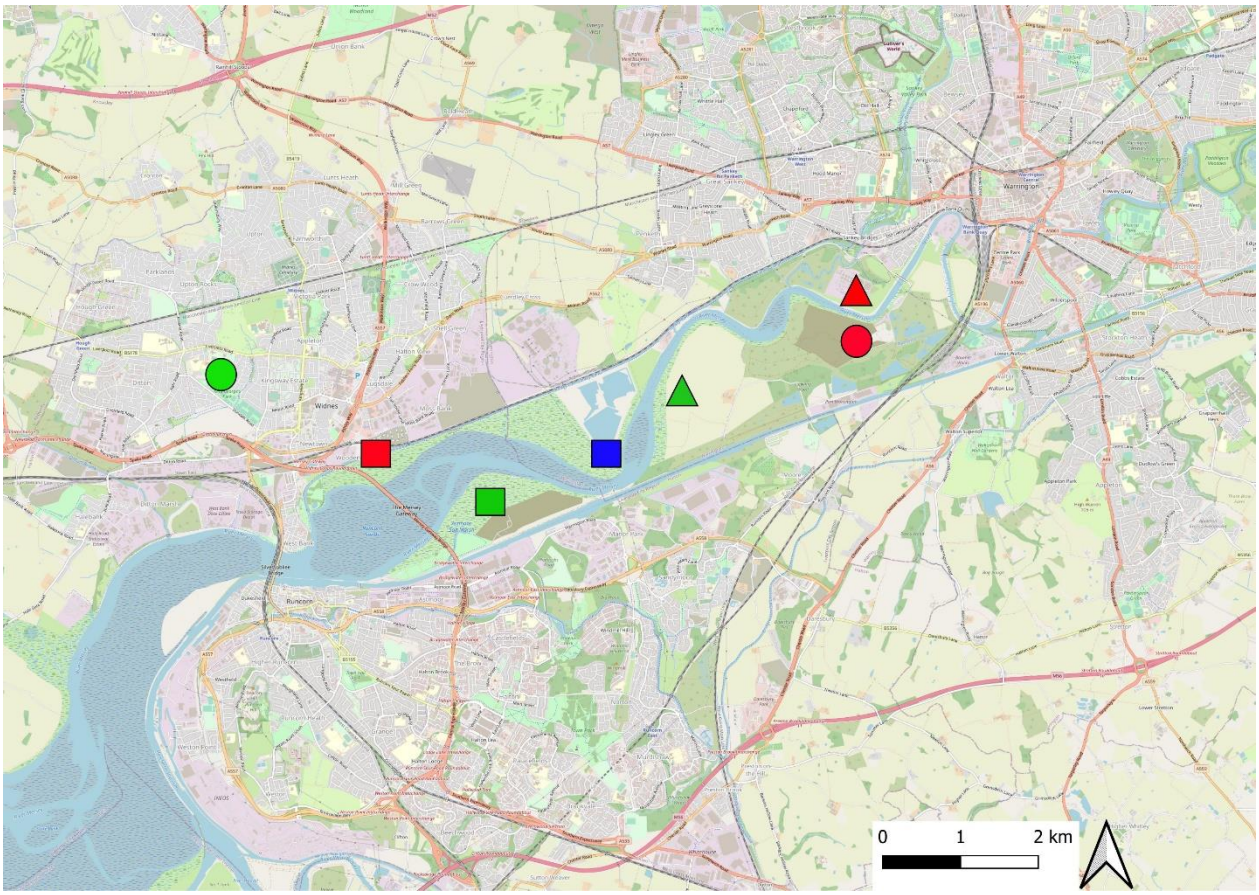


Figure 12: Habitat improvement sites within the study area. Squares represent saltmarsh improvement sites (Widnes Warth in red, Astmoor in green and Cuerdley in blue), circles show woodland and grassland expansion sites (King Georges Park in green and Arpley in red), and triangles represent saltmarsh expansion sites (Sankey Brook and Sankey Brook Adjusted in red and Moss Side Farm and Moss Side Farm adjusted in green). More detailed habitat improvement maps for each individual habitat improvement can be found in the appendix.

The habitat improvement and creation will be used to determine the impact of habitat improvements and creation in the area and to see if taking

advantage of these could offset some impact of development locally.

The land use change tables for the habitat improvement and creation areas modelled are below and the maps can be found in the appendix.

Saltmarsh creation

Saltmarsh is a distinctive habitat in many temperate estuaries, including the Upper Mersey. It also provides a series of important ecosystem services, so creation of this habitat was included in modelling.

Table 11: Sankey brook change in hectares

Habitat	Pre intervention	Post intervention	Change
Saltmarsh	0	35.21	+35.21
Woodland and Scrub	15.04	0	-15.04
Cultivated/disturbed land	8.23	0	-8.23
Standing fresh water	5.43	0	-5.43
Scrub	1.74	0	-1.74
Paths/Roads	0.33	0	-0.33
Semi-rough grassland	4.44	0	-4.44

Table 12: Sankey brook adjusted change in hectares

Habitat	Pre intervention	Post intervention	Change
Saltmarsh	0	4.44	+4.44
Semi-rough grassland	4.44	0	-4.44

Table 13: Moss side farm change in hectares

Habitat	Pre intervention	Post intervention	Change
Saltmarsh	0	223.06	+223.06

Cultivated/Arable	82.69	0	-82.69
Buildings/Paths/Roads	1.77	0	-1.77
Grassland	15.46	0	-15.46
Freshwater	17.38	0	-17.38
Woodland	105.76	0	-105.76

Table 14: Moss side farm adjusted change in hectares

Habitat	Pre intervention	Post intervention	Change
Saltmarsh	0	8.72	+8.72
Cultivated/Arable land	8.72	0	-8.72

Saltmarsh improvements

As outlined in Chapter 1, saltmarshes are a distinctive and important habitat in estuarine systems. The Upper Mersey Estuary is not an exception to this and has three major saltmarshes along its banks; Widnes Warth, Astmoor and Cuerdley. Unfortunately these saltmarshes, as is typical in estuarine systems, are degraded, largely due to historical use. Thus improving the condition of these saltmarshes could contribute to better ecosystem service provision and offset some damages in the area. In all three cases habitat classification was changed from scattered to dense saltmarsh to simulate a healthier functioning marsh and condition was improved by one category in the Biodiversity metric. This assumes that a saltmarsh improvement leads to a more densely vegetated saltmarsh which is in higher condition.

Table 15: Saltmarsh improvement area in hectares

Area name	Area of saltmarsh improved
Widnes Warth	41.47
Astmoor	35.07

Cuerdley	63.69

Grassland and woodland creation

Woodland and grassland creation is mentioned in many policy documents as an environmental target to both meet environmental goals and provide green spaces in the area for people to use. Two sites were chosen to explore the impacts of woodland and grassland creation. The first was a small expansion at King Georges Park in Widnes to represent an area where space is limited and there is already some green space present. The second is a larger site called Arpley which was previously landfill and is currently wasteland. Here space is less limited, but grassland and woodland are both being modelled to allow for public greenspace targets to be recognised.

Table 16: King Georges park change in hectares

Habitat	Pre intervention	Post intervention	Change
Amenity grassland	22.99	21.07	-1.92
Woodland	0.90	2.48	+1.58
Built up/roads/paths	1.53	1.53	0
Semi-natural grassland	0	0.34	+0.34

Table 17: Arpley change in hectares

Habitat	Pre intervention	Post intervention	Change
Artificial exposure/waste	36.86	0	-36.86

Grassland	0.08	28.58	+28.50
Built up	0.52	0.52	0
Swamp marginal	0.31	0.31	0
Mixed woodland	0	7.36	+7.36
Coniferous woodland	0	1.00	+1.00

4.3 Results

4.3.1 Biodiversity Net Gain results on preset development intensities

For each assessment one location which was most representative of the zone classifications as set in section 5.2.7 was selected for Biodiversity Metric analysis.

Table 18: Biodiversity Metric results for development models showing change in Biodiversity metric biodiversity units, a proxy for habitat quality and amount, as calculated in the method discussed in 5.2.2. Green indicates a gain in biodiversity units and red indicates a loss in biodiversity units.

Development Intensity	Urbanisation zone		
	High	Mid	Low
Intensive	-9.74	-44.59	-95.59
Typical	36.38	-17.91	-93.46
Soft green	44.54	-13.00	-93.07
Hard green	91.48	15.25	-90.82

Zone influences

Developments typically had a more positive impact/less negative impact within more urbanised zones than in less urbanised zones, potentially indicating that a ‘typical’ development from more modern perspectives is less damaging than previously typical developments. Within the low

urbanisation zone, all intensities were negative and would be difficult to mitigate on or offsite. This is also true for all but the green development intensity within the mid urbanisation zone, further demonstrating the difficulty in mitigating development in mid and low urbanisation zone areas, where developments typically take place.

Development intensity influences

As expected, development intensities have a greater negative impact the more intensive the development is. All intensive developments were negative regardless of the zone they were placed in. It is also notable that the difference between typical and soft green scenarios is consistently less than the difference between intensive and typical or soft green and hard green despite a consistent 10 percent change. This may indicate that offsetting must be a higher priority to be effective in most typical developments.

4.3.2 EcoservR results on preset development intensities

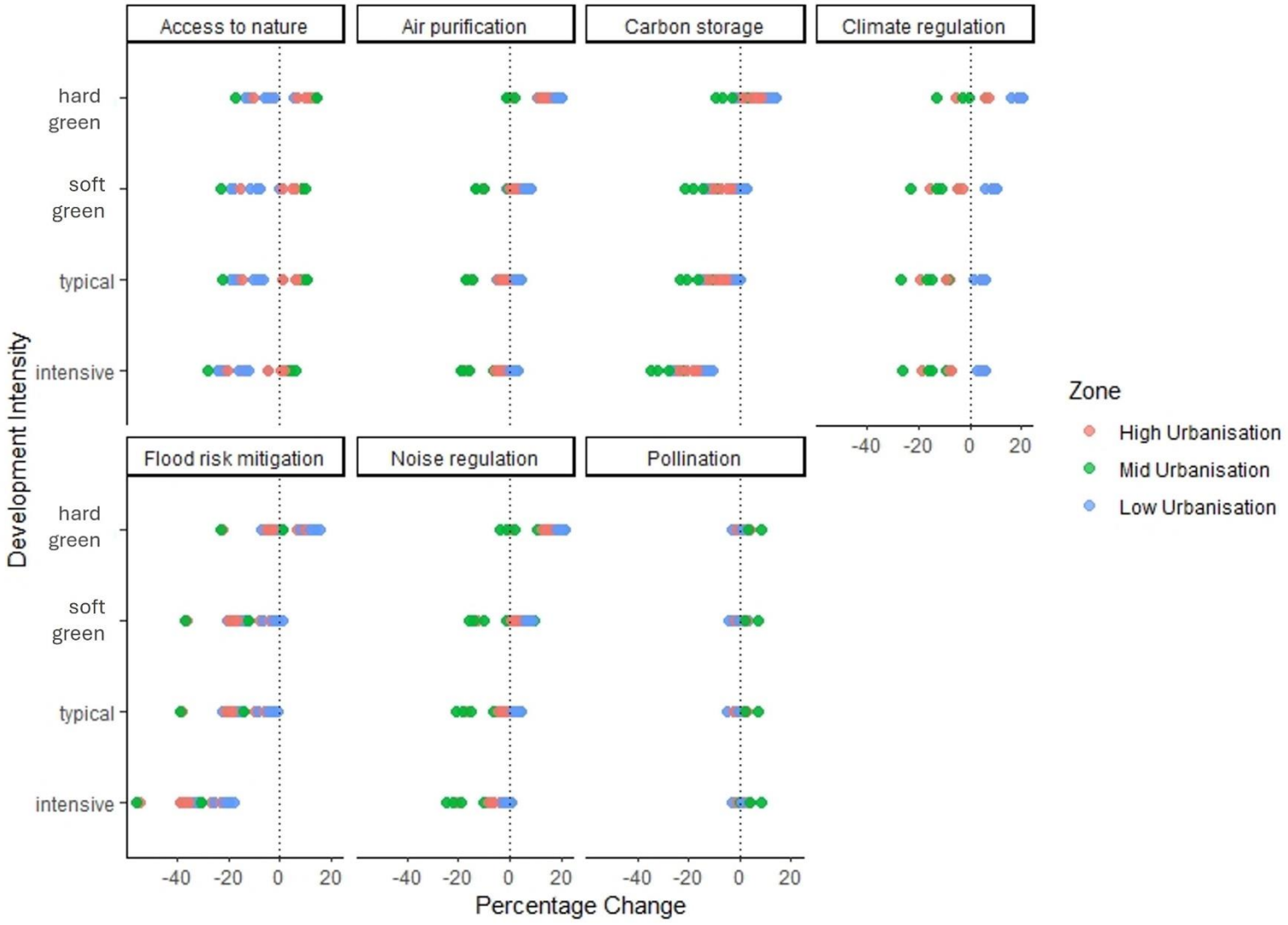


Figure 13: EcoservR results for developments

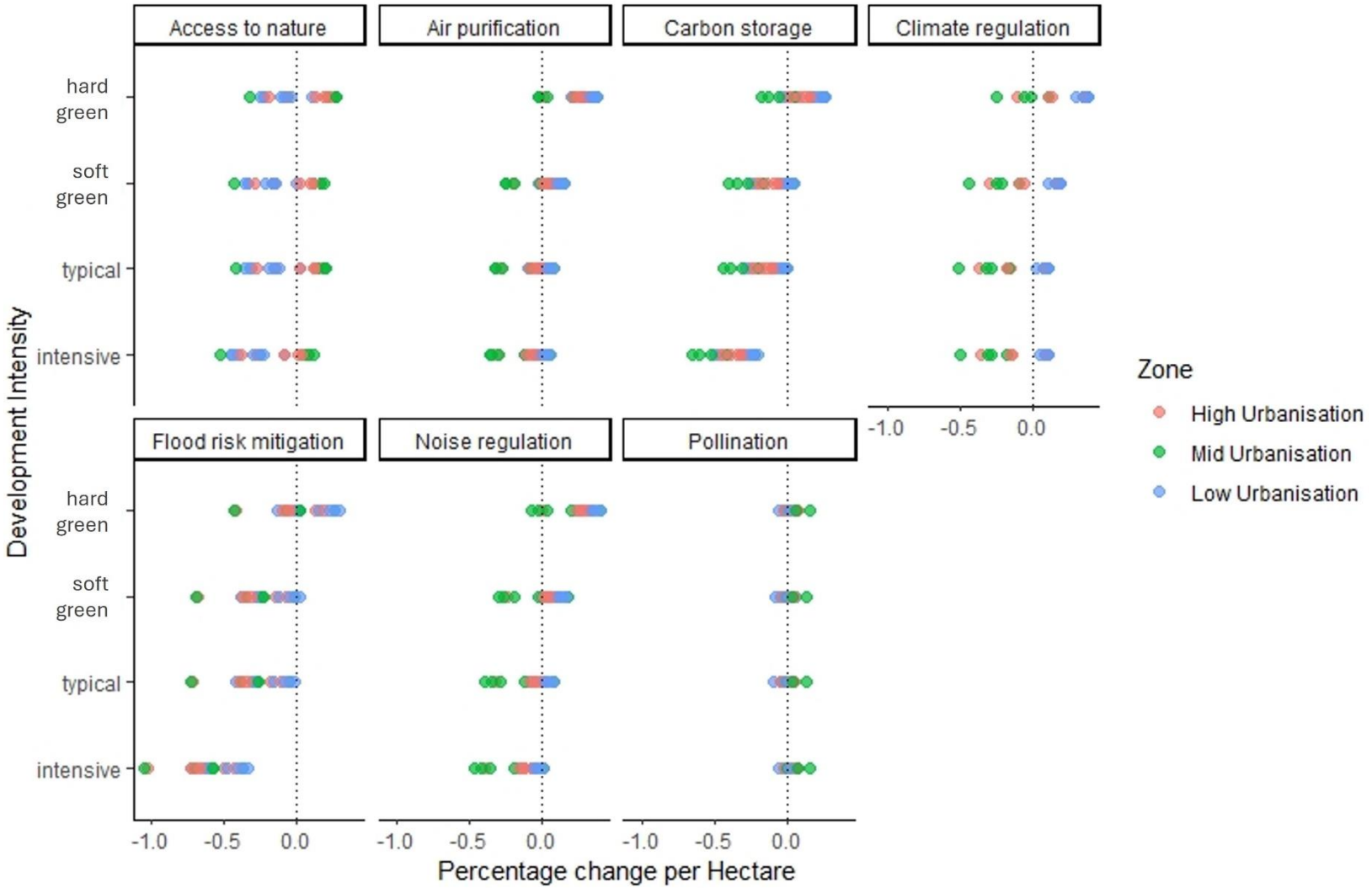


Figure 14: EcoservR results for developments in change per hectare

Statistical analysis results

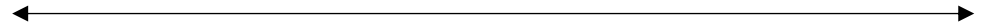
Impacts of development intensity

Table 19: Kruskal-Wallis results of impacts of development intensity on ecosystem services. Increased gain is in blue, reduced gain is in dark green, gain is in light green, loss is in orange, reduced loss is in red and increased loss is in purple. Results that are not significant are left white. This can also be found in the key below the table.

	Development intensity compared (change from intensity 1 to intensity 2)					
	Hard green – Soft green	Hard green - Typical	Hard green - Intensive	Soft green - Typical	Soft green - Intensive	Typical – Intensive
Noise regulation capacity	Reduced gain **	Loss **	Loss **	Loss **	Increased loss **	Increased loss **
Flood risk mitigation capacity	Loss **	Loss **	Loss **	Increased loss **	Increased loss **	Ns
Climate regulation capacity	Reduced gain **	Loss **	Loss **	Loss **	Increased loss **	Ns
Carbon storage capacity	Loss **	Loss **	Loss **	ns	Increased loss **	Increased loss **
Carbon sequestration capacity	Reduced gain **	Reduced gain **	ns	Reduced gain **	Increased gain **	Increased gain **
Air purification capacity	Reduced gain **	Loss **	Loss **	Loss **	ns	Ns
Access to nature to capacity	ns	ns	Increased gain *	ns	ns	ns

* p<0.05 **p<0.01

Table key



More service capacity/demand Less service capacity/demand

Differences in changes based on development zone

Table 20: Kruskal-Wallis results of impact of development zone on different ecosystem services. Increased gain is in blue, reduced gain is in dark green, gain is in light green, loss is in orange, reduced loss is in red and increased loss is in purple. Results that are not significant are left white. This can also be found in the key below the table.

Note that the first row is demand of an ecosystem service.

	Zones compared (change from Zone 1 – Zone 2)		
	Low - Mid	Low - High	Mid - High
Noise regulation demand	Gain *	ns	Ns
Noise regulation capacity	Loss **	Ns	Gain **
Climate regulation capacity	Loss **	Reduced gain **	Gain **
Carbon storage capacity	Loss **	Ns	Ns
Carbon sequestration capacity	Reduced loss **	Ns	Increased loss **
Air purification capacity	Loss **	Reduced gain **	Loss **
Access to nature to capacity	Reduced loss **	Reduced loss **	ns

* $p<0.05$ **$p<0.01$

Table key

More service capacity/demand Less service capacity/demand

Zone

Ecosystem services varied the most between low urbanisation zones and mid urbanisation zones with all changes leading to reduced capacity/increased demand other than carbon sequestration capacity and access to nature. Access to nature likely increased due to greater access to roads and paths, facilitating this service. Differences between mid and high urbanisation zones varies with noise regulation and climate regulation gaining capacity and carbon sequestration and air purification losing capacity. There were very few differences between low and high urbanisation zones, potentially indicating that despite being less urbanised, low urbanisation areas are not providing or designed to provide the ecosystem services assessed.

Development intensity

These results further reflect losses in ecosystem service capacities with more intensive development with the exception of an increased access to nature under an intensive development scenario in comparison to a green development scenario, likely due to increased paths and road networks. The other exception to this was gains in carbon sequestration capacity when comparing Soft Green and intensive development and typical and intensive development scenarios.

4.3.3 Habitat Improvement and Creation

Biodiversity Metric

Table 21: Biodiversity Metric results for habitat improvements

Site	Habitat Unit Change	Habitat change summary
Sankey brook	-21.03	Increased saltmarsh area
Sankey brook adjusted	3.19	Increased saltmarsh area
Moss side farm	54.30	Increased saltmarsh area
Moss side farm adjusted	25.98	Increased saltmarsh area
Widnes Warth	95.74	Improved saltmarsh
Astmoor	131.40	Improved saltmarsh
Cuerdley	104.76	Improved saltmarsh
King Georges park	12.90	Woodland and grassland expansion
Arpley	137.72	Woodland and grassland expansion

Saltmarsh expansion

Within the saltmarsh expansion, it is notable that Sankey Brook shows a loss in biodiversity units, likely due to the loss of some woodland as the adjusted version of this shows an increase in biodiversity units. Moss Side Farm shows an increase however, this increase is small given the size of the intervention.

Saltmarsh Improvement

Improvements of the saltmarshes lead to large increases in biodiversity units, with Astmoor increasing the most likely due to size.

Woodland and grassland

Both these improvements increased biodiversity units with Arpley gaining the most. While King Georges Park gains very little in comparison to Arpley, this is also the smallest of the habitat improvements in the area.

EcoservR

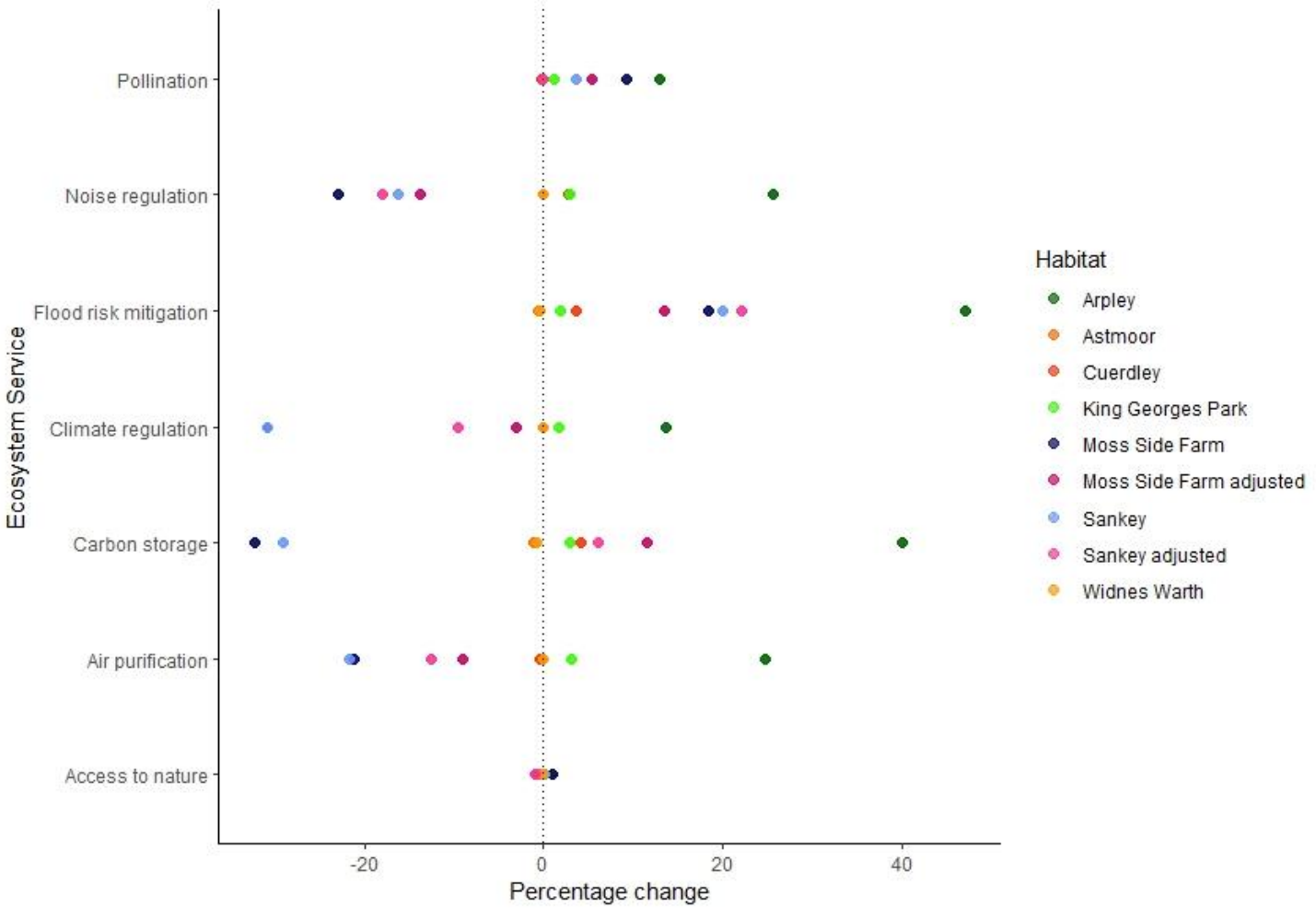


Figure 15: EcoservR results for habitat improvements

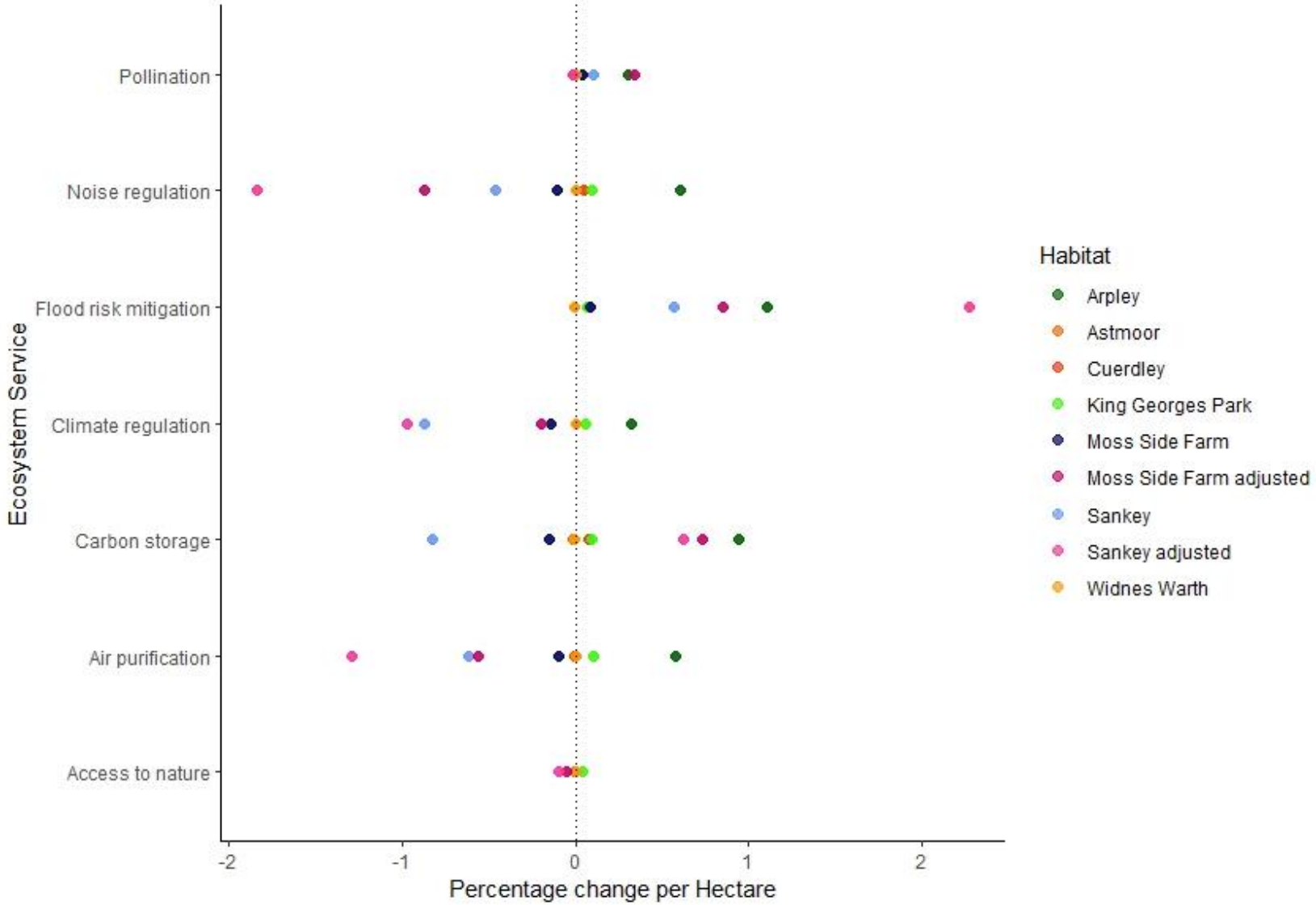


Figure 16: EcoservR results for habitat improvements in change per hectare

Saltmarsh expansions

Saltmarsh expansions show a substantial increase in flood risk mitigation as expected but result in declines in most other services, with a similar but reduced pattern in adjusted saltmarsh expansions. Moss side farm shows results consistent with this however the change per hectare values reduce the losses of other services possibly due to the size of the site and potentially demonstrating that there are inappropriate locations being included in this saltmarsh expansion.

Saltmarsh improvements

Saltmarsh improvements do not show much difference in service provision in EcoservR models but this may be due to the environments already providing these services, so improvement is not as noticeable.

Woodland and grassland

Arpley shows considerable increases in both percentage change and change per hectare for all services which is expected considering the previous land use. King Georges Park shows similar capacity gains on a smaller scale due to the size of the improvement.

4.4 Conclusions

Developments

While intensity of developments was not as impactful as location of the development, the design of these still has significant impacts on ecosystem services. Policy recommendations of ‘high quality design’ are too vague to be useful and should also be a requirement rather than a recommendation, given that these designs and the intensity of a development has been shown to have a significant impact on biodiversity and ecosystem service provision. For example, it was shown that developments in any zone other than the high urbanisation zone would typically lead to negative impacts on biodiversity, and the provision of ecosystem services was generally higher in hard green scenarios. The National Planning and Policy Framework

(2021) supports this stating that ‘development that is not well designed should be refused’ with referrals to the National Design Guide (2021) to identify good and bad design, with the Place Alliance encouraging councils to enforce these principles further (2022), as the benefits from doing so are significant for both the socio-economic landscape and the environment (Pouso et al., 2020; Weinstein, 2008).

However, while good design of these areas will help maintain ecosystem service provision at a small scale, the wider habitat restoration of urban-estuarine systems may be more challenging. While urban greening and implementation of green infrastructure is often discussed (Dorst et al., 2019; Mell et al., 2013) , inclusion of this within urban-estuarine landscapes will not be sufficient to restore these habitats. Hostetler et al (2011) noted that nearby developments and habitat improvements will impact restoration values of green infrastructure and thus must be considered as an integrated system. This study demonstrates the impacts that different development designs at development intensities can have and shows significant change in service provision, supporting Hostetler's conclusions and highlighting the need to consider green infrastructure options within the context of both the development and the habitat matrix as a whole.

Additionally, onsite mitigation is often shown to be unlikely, as most developments had some negative impacts, and given the substantial socio-economic and cultural considerations and constraints on these developments (discussed in Chapter 3: Policy Review), onsite mitigation will not be possible in most cases. Therefore, offsite mitigation will be necessary, however this should be kept as local as possible to ensure the provision of ecosystem services to the newly created area as Sonter et al (2020) also noted with suggestions that offsetting needs to be kept close to ensure like-for-like replacement and the supply and demand of ecosystem services is achieved. This may be challenging in space limited urban estuaries.

Habitat Improvements

When using the Biodiversity Metric habitat improvements generally led to increases in Biodiversity Units however each individual improvement may only be enough to offset a singular development. This will not be enough to

locally offset the amount of development required in policy for socio-economic regeneration of the area. This means that either offsetting that is not local or further exploration of greening and consideration of trade-offs will be required in this area, highlighting the need for a combination of high-quality designs and maximum local offsetting to facilitate the restoration of urban-estuarine systems.

When looking at the results for habitat improvements using EcoservR, there are more varied outcomes, with clear trade offs between services for some habitat improvements and inevitable socio-economic trade offs to consider as well, particularly in the case of Moss Side Farm in which a commercial farm would be lost for the saltmarsh expansion. These trade offs have also been noted in other studies (Needles et al., 2013) with the ultimate decision making being informed by ecosystem service mapping and thorough stakeholder input to set priorities within the area (Adams et al., 2014). Decision makers will ultimately need to use the Natural Capital framework and tools, like ecosystem service mapping, to make targeted choices and prioritise services, both ecological and socio-economic, and decide which of these trade-offs are the most appropriate to make. There is no scenario in this work in which socio-economic goals and ecological goals can be simultaneously met, unless development exclusively occurs in highly urbanised areas and is not highly intensive, which is unrealistically limiting and demonstrates that even with mitigation measures some losses will occur as the result of socio-economic development. The mapping demonstrated in this chapter can help demonstrate what losses are likely to occur to allow for more informed decision making within this complex and dynamic landscape and help acknowledge that we are unlikely to be able to meet socio-economic and ecological goals in such a limited landscape (Turkelboom et al., 2018).

Limitations of this analysis

A primary limitation of this study is in the design of the development scenarios. While effort was made to standardise these while keeping character features of the area, these are conflicting aims and may have influenced the results. It is recommended that in the future, any further

analysis similar to this uses real world examples of developments where possible or at a minimum considers the conflict between standard designs and designs which have a sense of place.

Furthermore, this analysis did not include an iterative stakeholder interaction which may have further influenced the results and demonstrated a natural capital approach better, due to time constraints. While using policies to inform designs was suitable for this study, co-designing these sites with stakeholders would have led to designs which were more realistic to the local area while also meeting policy requirements. Iterating this work after some co-design would also be recommended as a further demonstration of how natural capital approaches, particularly focused on collaboration, could be used in this area.

Finally, there were some limitations to software used. The biodiversity metric considers habitats as a proxy and requires some subjective opinion on the site which may have influenced some results. Additionally, EcoServR currently has no considerations for quality or condition of a habitat within the modelling, which will influence ecosystem service provision, and has not been subject to sensitivity testing, which is strongly recommended for future work and development of this model.

This chapter demonstrates an urban-estuarine Natural Capital assessment which considers the importance of multiple services and has begun to consider some of the socio-economic impacts of the options presented. This provides a more complete picture and may result in more targeted and beneficial actions to be identified within these complex landscapes, opposed to focusing on a simplified habitat or just one service, as recommended by Seto et al (2017) and Heymans et al (2019). This also highlights the importance of considering the spatial dynamics and planning within a Natural Capital approach for a complete understanding of options and impact. This is something which is currently lacking in the Biodiversity metric and the environmental benefits from nature tool which, while increases accessibility of these tools, limits their effectiveness as Natural Capital support tools and highlights the need to use multiple tools for an assessment.

5. Stakeholder Interaction

5.1 Introduction

Stakeholder and decision-maker involvement in a Natural Capital approach can be highly beneficial in ensuring the approach is as well-rounded and complete as possible. This is because inclusion of local stakeholders can add multiple insights and benefits to the approach such as highlighting and assessing socio-economic benefits (Chiesura & De Groot, 2003), inclusion of local knowledge and experience in the area (Moyzeova, 2018), and establishing priority services and habitats to target for improvement (Bryan et al., 2010). This can result in a Natural Capital approach which includes stakeholder participation being more effective than traditional conservation approaches (Schultz et al., 2015).

Unfortunately, this involvement is still in its infancy, particularly with local decision-making bodies which provides a substantial gap in integrating the Natural Capital approach into real world decision making. Many authors contributing to the development of Natural Capital approaches choose to focus on economic arguments (Quintas-Soriano et al., 2016), identification of benefits from a scientific perspective (Smith et al., 2017) or tool development and assessment, rather than the stakeholder perspective of these approaches. As Dick et al (2018) notes, there is little work on this in the field but that may be due to the need for interdisciplinary and multidisciplinary working and the investment of time or resources needed, however authors have called for more of this work for effective ecological restoration (Cortina-Segarra et al., 2021).

Those that have undertaken stakeholder engagement in the past have indicated that opinions differ based on knowledge (Lamarque et al., 2011), uses of ecosystem (de Juan et al., 2017) and roles in delivering ecosystem services (García-Nieto et al., 2015) and all recommend further exploration of stakeholder opinions and integration into policy (McNally et al., 2016).

As the Natural Capital approach is focused on balancing people and nature

though, it is critical that stakeholder interaction is part of the approach.

This chapter will address research objectives 4 and 5. Research objective 4 is to establish the barriers to wider implementation of a Natural Capital approach for restoration and conservation of urban-estuarine areas. Research objective 5 is to explore the importance of scale in the Natural Capital approach. These objectives will contribute to the overall thesis aim of designing a framework for the wider application of a Natural Capital approach using the Upper Mersey estuary as a case study.

5.2 Methods

Three different rounds of stakeholder interaction were undertaken as part of this study; a questionnaire, a preliminary focus group and a focus group, development of all was informed by Robson and McCartan 2016.

A questionnaire was selected because it allows for a broad generalisation of a population's opinions on a subject (as discussed by Rea and Parker 2014) while also requiring little time or cost to implement. It is acknowledged that because a subset of the population is being surveyed, the results may not be wholly representative. The questionnaire was aimed at the general public who live, work and/or travel within the study area. This was distributed physically in local community centres and digitally via Google Forms for multiple methods of accessibility to reach a wider and more varied target audience, including those who are and are not digitally adept. To reach a further audience in future study, it may be suitable to provide further in person support in completing these questionnaires. The questions aimed to determine stakeholder perceptions of natural environments, ecosystem services and developments in the area and the interactions between these. The full questionnaire can be found in the appendix. The questionnaire received ethical approval (approval number 22/BES/001) and was deemed to be minimal risk. No personally identifying information was collected. Participants were asked to identify if they were a resident or a visitor to the

area but no specific details were requested.

Focus groups were selected over interviews within this study, primarily because focus groups allow for group interactions to be studied (as discussed in Acocella and Cataldi 2021) which is an important part of co-design which requires exploration for natural capital approaches. Further, as an alternative to interviews, focus groups allow for depth in discussions without being too time intensive for the research. There may be scope for future research to conduct interviews following these focus groups to assess how participants felt the codesign process worked and to assess more in depth opinions on natural capital approaches but this is not included in this work.

A preliminary focus group was undertaken to scope out initial barriers that could be discussed and identify decision maker priorities before the main focus group. The preliminary focus group took place at an online conference hosted by the Mersey Gateway Environmental Trust and was attended by delegates from environmental and ecological backgrounds. Participants were self-selected from conference attendees so those who had opinions and wanted input into a natural capital approach were included. In the preliminary focus group, there were ten participants all of whom were from environmental or ecological conservation backgrounds. Participants were asked to identify ecosystem services and highlight their impact on decision-making.

The focus group took place on Liverpool John Moores University campus and participants included members from local councils, planners, landowners and other key decision makers. This participant selection included those who would be likely to be involved in a natural capital approach and implementation in the area following this study and thus their thoughts on the approach and any potential barriers to this would be important to capture. This session aimed to review results from mapping, discuss these and how the approach and method used could be beneficial to decision making in the future. There were six participants in this focus group, three were from local/regional scale environmental groups, one from

a local authority, one from a water company and one from a national public body. The presentation with can be found in the appendix.

Focus groups received ethical approval (approval number 23/BES/002). Personally, identifying information was collected to invite members but this data was anonymised, and participants were informed that they would remain anonymous in any publications using data from the group. Further to this, participants were informed that personally identifiable information would not be stored after the study.

Transcripts and written answers from both groups were analysed through a close reading before codes were selected to give information about appropriate codes emerging. These codes were largely regarding barriers to natural capital approaches and general comments about the approach or about the methodology used in the study data presented. Data was then coded using nVivo and further analysis of number of mentions and any emergent themes within these codes was done to explore each barrier and themes within general comments.

Themes that were being explored between the three groups were trade-offs between environmental and development priorities, importance of environmental and development priorities and any conflicts or barriers to Natural Capital approaches.

5.3 Questionnaire

While stakeholder interaction with the general public may be a significant task, within an urban estuary, the general public form the largest body of stakeholders making this interaction an important part of a Natural Capital approach. These stakeholders add clear value to the approach though identification of services and priorities that may otherwise be overlooked by decision makers and scientists (Bertram & Rehdanz, 2015; Larson et al., 2016). Furthermore, inclusion of these stakeholders views contributes to the sense of ownership of the area and actions in the area (Soste et al., 2015)

which aids the overall goal of balancing the needs of people and nature.

Interaction with this group should also be iterative and consistent, as with any stakeholders, to ensure communication and timely information is incorporated into design (Reed, 2008). This study was limited to one iteration of stakeholder engagement through a questionnaire but this could mark the start of greater engagement and involvement of the community in the future. This initial questionnaire aimed to address the research objective to engage stakeholders to identify the importance of the estuary at multiple scales, the habitats and services important to stakeholders and development and environmental priorities as well as potential conflicts in these areas.

In this study there were 17 respondents to the questionnaire. This is a very small number of respondents despite the study design allowing for in person completion in local community centres and online completion, distributed through multiple social channels, to try and reach a wider and more diverse audience. This could be due to multiple issues such as poor timing or an overly complex or overly long questionnaire. In any future methods, it is recommended that a greater number of respondents is achieved through further use and more continuous use of online distribution channels such as social media and the questionnaire is designed to be less in depth and less complex.

5.3.1 Habitat importance at different landscape scales

Questions for this section required a ranking from 1 – 5 where 1 was low importance and 5 was high importance. Questions were as follows:

- ‘In your opinion what is the international importance of the natural environments in the area?’
- ‘In your opinion what is the importance to the Northwest of the Natural environments in the area?’
- ‘In your opinion what is the local importance of the natural

environments in the area?'

- 'In your opinion what is the importance to the individual of the natural environments in the area?'

With respondents having the chance to explain each answer after ranking.

Graphs of these results can be found in figures 19-22.

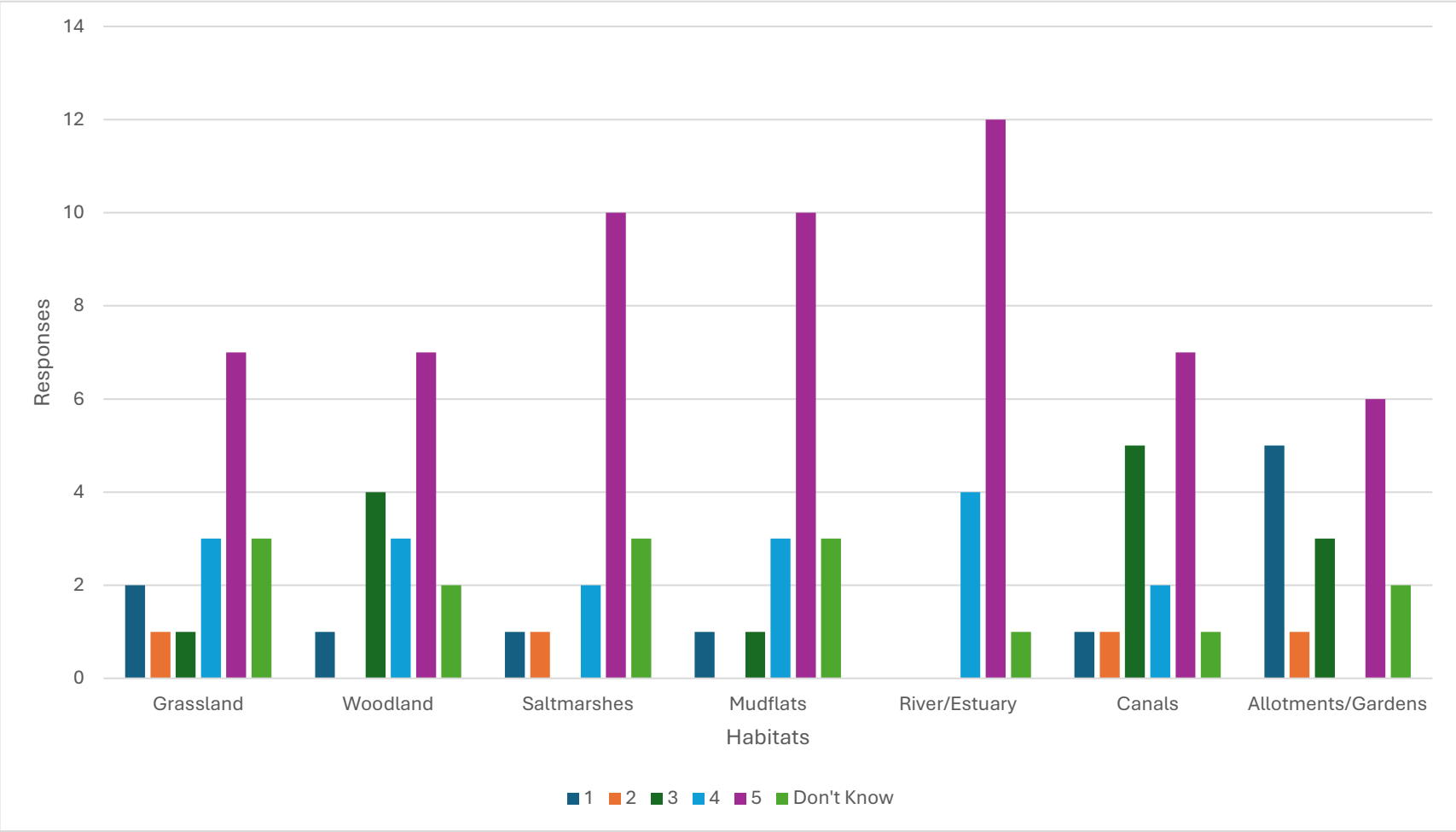


Figure 17: International importance of habitats ranked by participants where 1 was low importance and 5 was high importance.

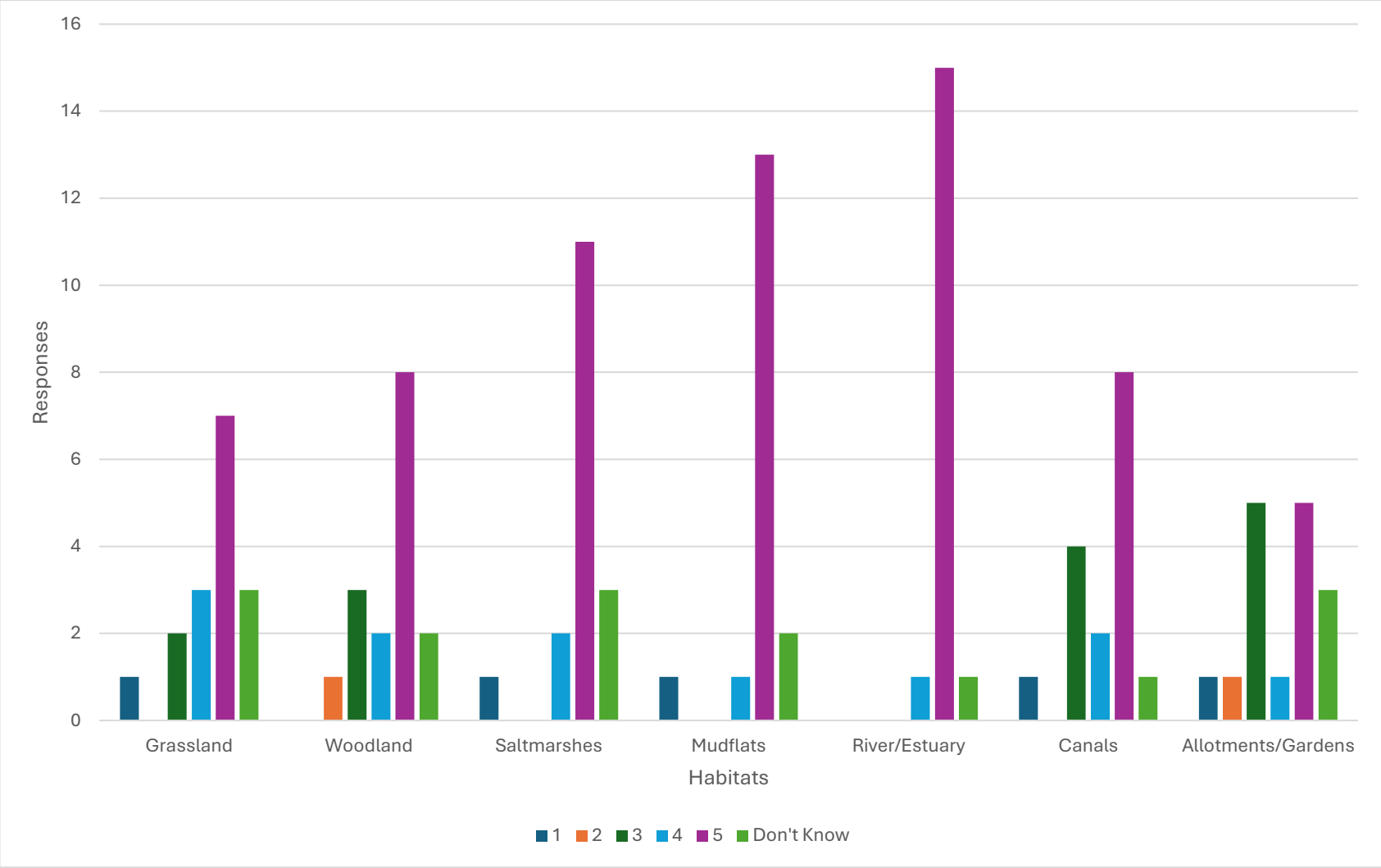


Figure 18: Regional importance of habitats ranked by participants where 1 was low importance and 5 was high importance.

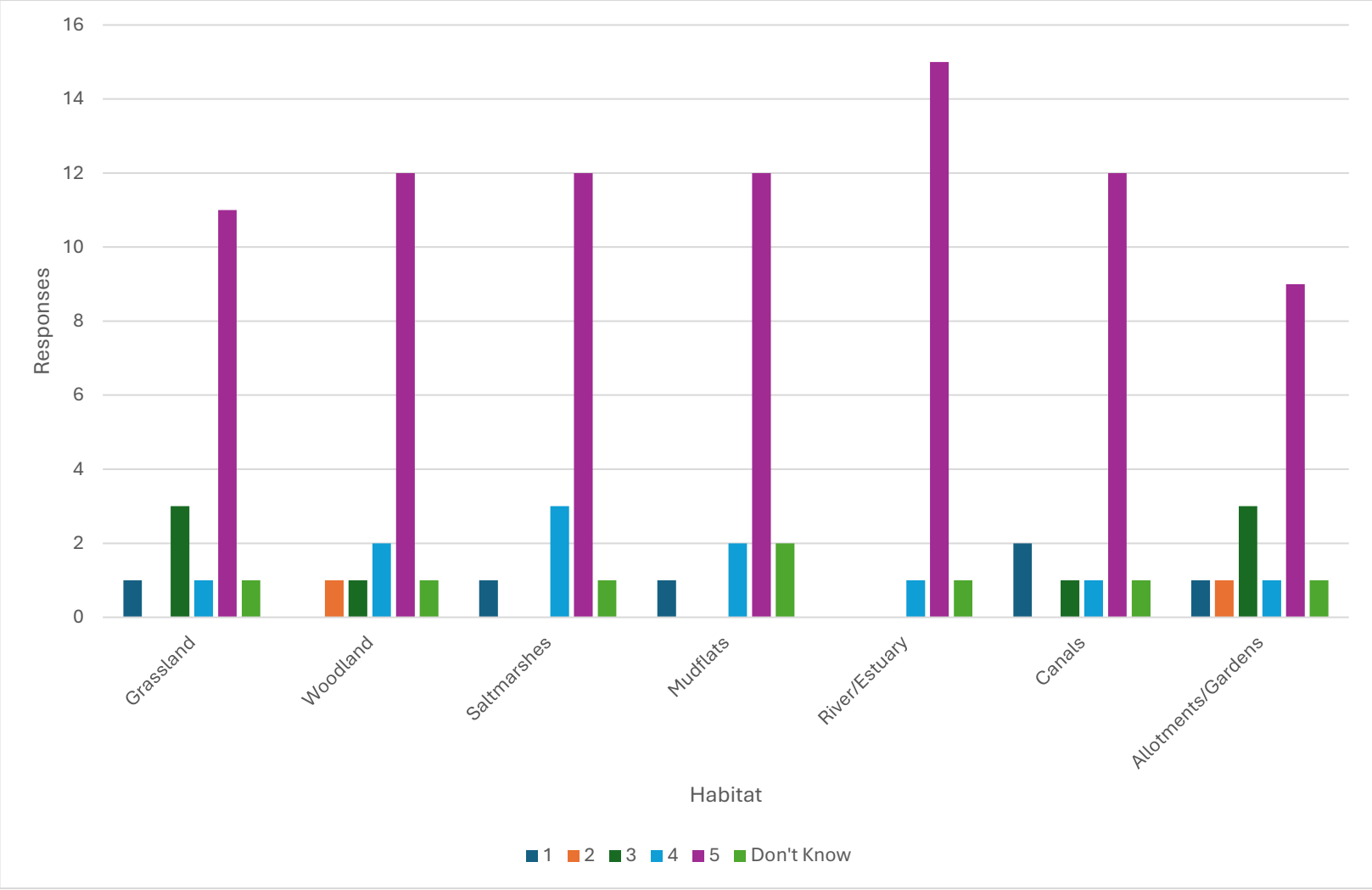


Figure 19: Local importance of habitats ranked by participants where 1 was low importance and 5 was high importance.

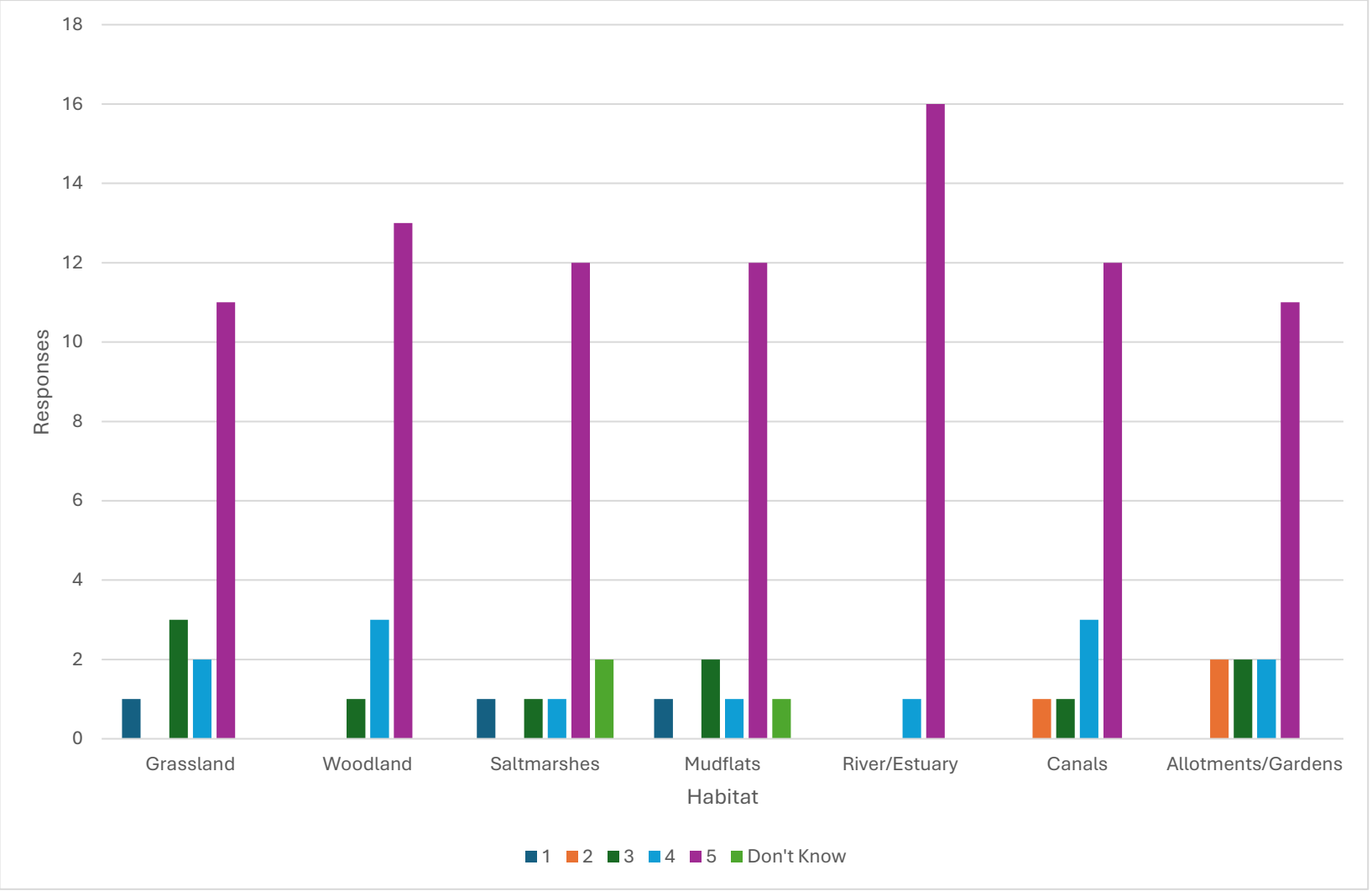


Figure 20: Individual importance of habitats ranked by participants where 1 was low importance and 5 was high importance.

As can be seen in figures 18-21, habitats were consistently ranked as having high importance.

At an international scale, the clearest consensus among participants was the importance of the Mersey estuary itself with one participant describing the river Mersey as a "dominant feature" of the landscape. All participants except one ranked this as having a high (4) or very high (5) importance, likely reflecting the cultural significance of the Mersey. Mudflats and saltmarshes were also consistently rated as having a high importance with associated comments linking this to key bird species found there. Participants comments included the importance of saltmarshes to migratory birds and one participant noted wading birds in particular. Woodlands and grasslands had more skewed results but still had a majority of participants rating them as internationally important.

Participants had differing opinions about the importance of allotments and gardens as seen in figure 18 with a relatively even split between very high importance and very low importance with one participant ranking them as low because "allotments and canals are not natural environments".

At a regional scale, trends were similar to that of international importance with canals being ranked as more important at a regional scale, likely due to the historic importance of the Manchester Ship canal with one participant stating "the Manchester Ship Canal is an important part of British and global industrial history". Allotments and gardens also increased in importance at this scale but remain the lowest ranked of all habitats.

At the local and individual scale, the trend of habitats having a high importance continues, with the only changes being allotments and gardens being ranked as more important than previous scales, reflecting the individual usage of these habitats with participants stating that "Allotments and Canals offer recreational environments" and noting that people "do not want to travel to enjoy the environment".

Comments from participants also varied based on the scale. At an

international scale, responses typically highlighted the importance of unique habitats and supporting habitats for wildlife, particularly birdlife and waders as mentioned above. Some comments also highlighted the historical and cultural importance of the canals, allotments and the river itself both regionally and globally. Some general ecosystem services were also mentioned such as carbon storage and flood risk mitigation. At a regional scale, comments highlighted the history of damage in the area, for example a participant noted that environments are important for "recovered from a heavily polluted and forgotten area". They also highlighted the use of the area as accessible nature for the region, and some noted that any international importance would also lead to regional importance. At a local scale, participants identified access to nature and access to ecosystem services as their main considerations for habitat importance. Additionally, responses highlighted the dominance of the estuary within the landscape and this lending it significant importance. At the individual scale, participants noted that what benefits habitats can give is highly dependent on the individual and their access to environments around the estuary, but mental health and wellbeing benefits were consistently identified as important.

5.3.2 Interactions between development and the natural environment

Questions for this section included

- 'In your opinion, how do developments typically interact with natural environments in the area'

Ranking from 1 through to 5 where 1 was damage heavily and 5 was improve heavily.

- 'In your opinion, how does environmental enhancement impact development and development priorities in the area'

Ranking from 1 through 5 where 1 was strongly negative and 5 was strongly positive.

Results are shown in figures 23 and 24.

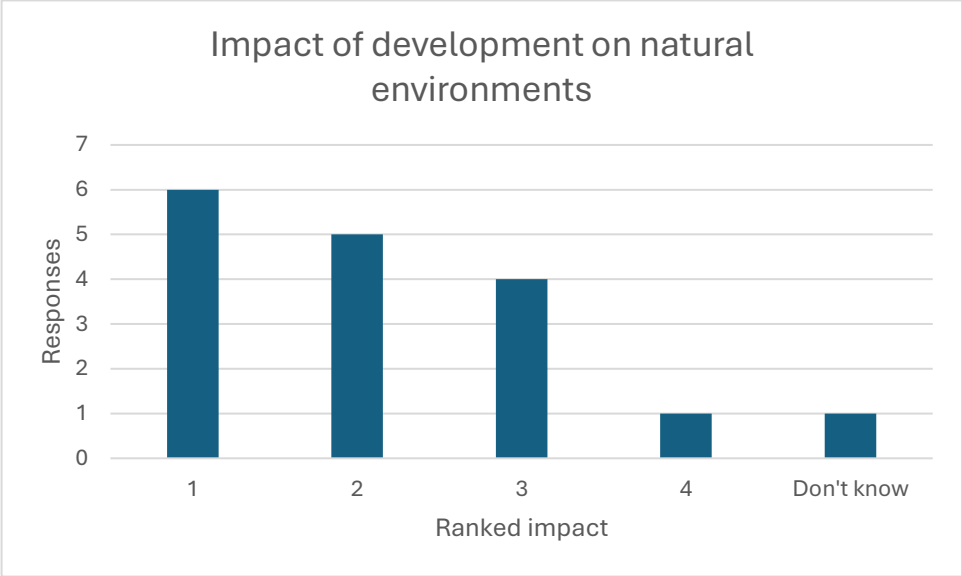


Figure 21: Interaction between developments and natural environments ranked by participants from 1 (Damage heavily) to 5 (Improve heavily)

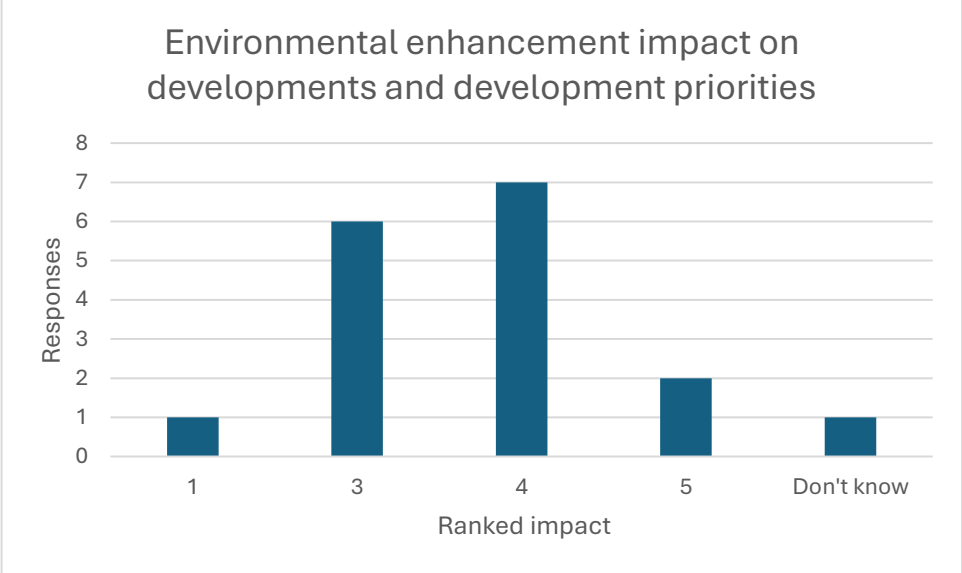


Figure 22: Impact of environmental enhancement on developments ranked by participants from 1 (strongly negative) to 5 (strongly positive)

When asked how developments typically interact with the natural environments, participants generally responded with negatively, with further comments highlighting concerns noting that there is only “short term perspective rather than long term planning”, with other participants stating that they think that towns are becoming “too dense with buildings and roads”. One participant stated that while industrial development were part of the areas identity there is “some room for more development of natural environments”. Some respondents also noted that habitat connectivity was a concern when considering development impact as well as access to nature. Some participants highlighted that the impact may depend on the businesses carbon footprint. Overall, responses generally showed some concern and identified that more consideration or long-term planning for nature is lacking within development in the area.

When asked how environmental enhancements typically interact with developments in the area responses were more mixed, skewing towards positive with participants stating they wanted more acknowledgement of environment in planning, with one participant stating there should be a “30/70 percent ratio of building to environment”. Comments following this answer typically include some acknowledgement of placemaking and improvements to quality of life through access to nature. Some participants drew attention to the need for greater consideration of natural environments and greenspace in planning and decision-making and further highlighted the cultural benefits the estuary provides.

5.3.3 Environmental and Development priorities in the area

Questions in this section asked participants to rank priorities from least important (1) to most important (6).

Questions included

- ‘In your opinion, please rank development priorities in the area’ ‘In your opinion please rank environmental priorities in the area’

With an opportunity for respondents to expand on their answers.

Results can be seen in figures 24 and 25.

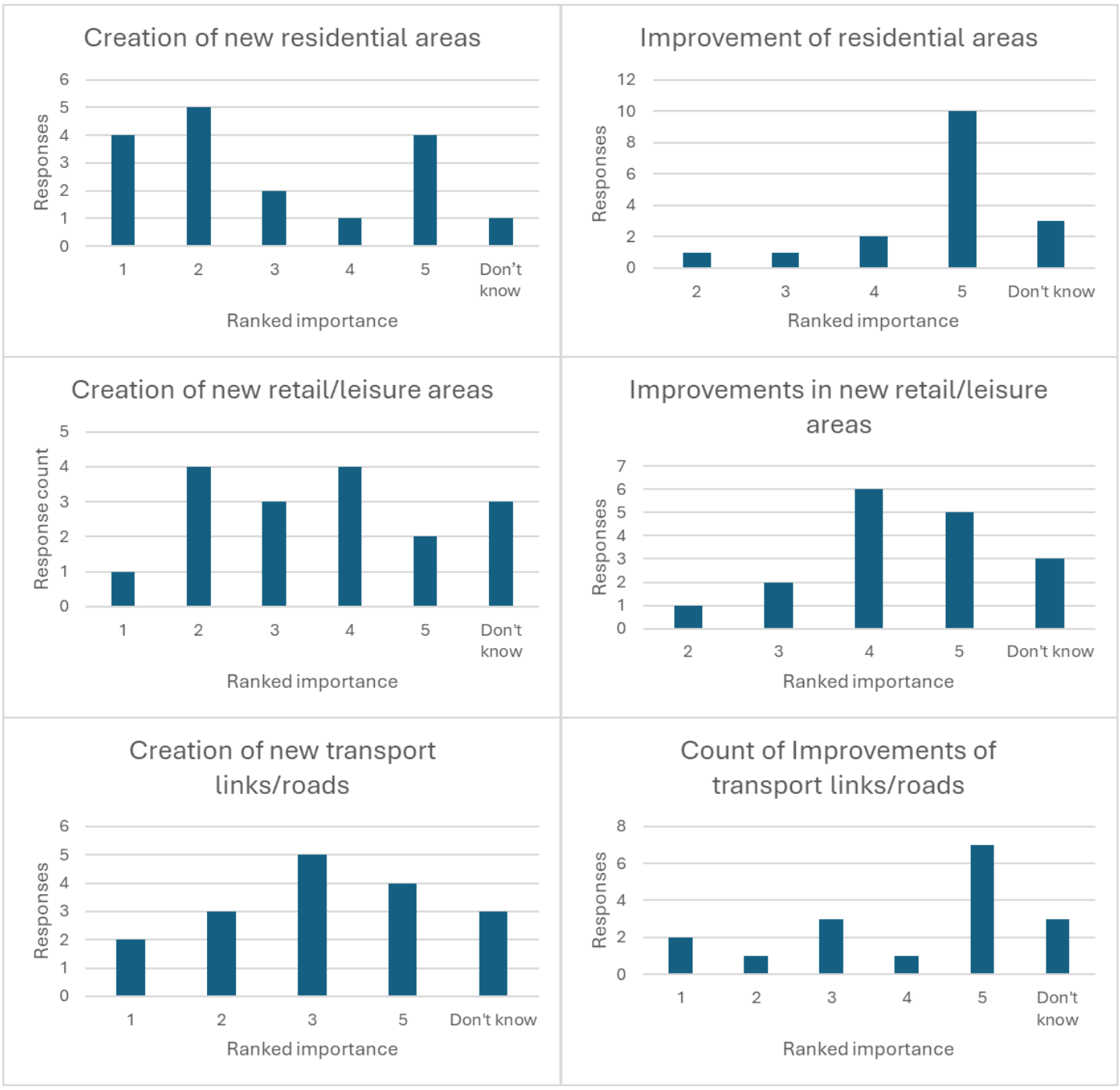


Figure 23: Importance of development priorities as ranked by participants where 1 was least important and 5 was most important.

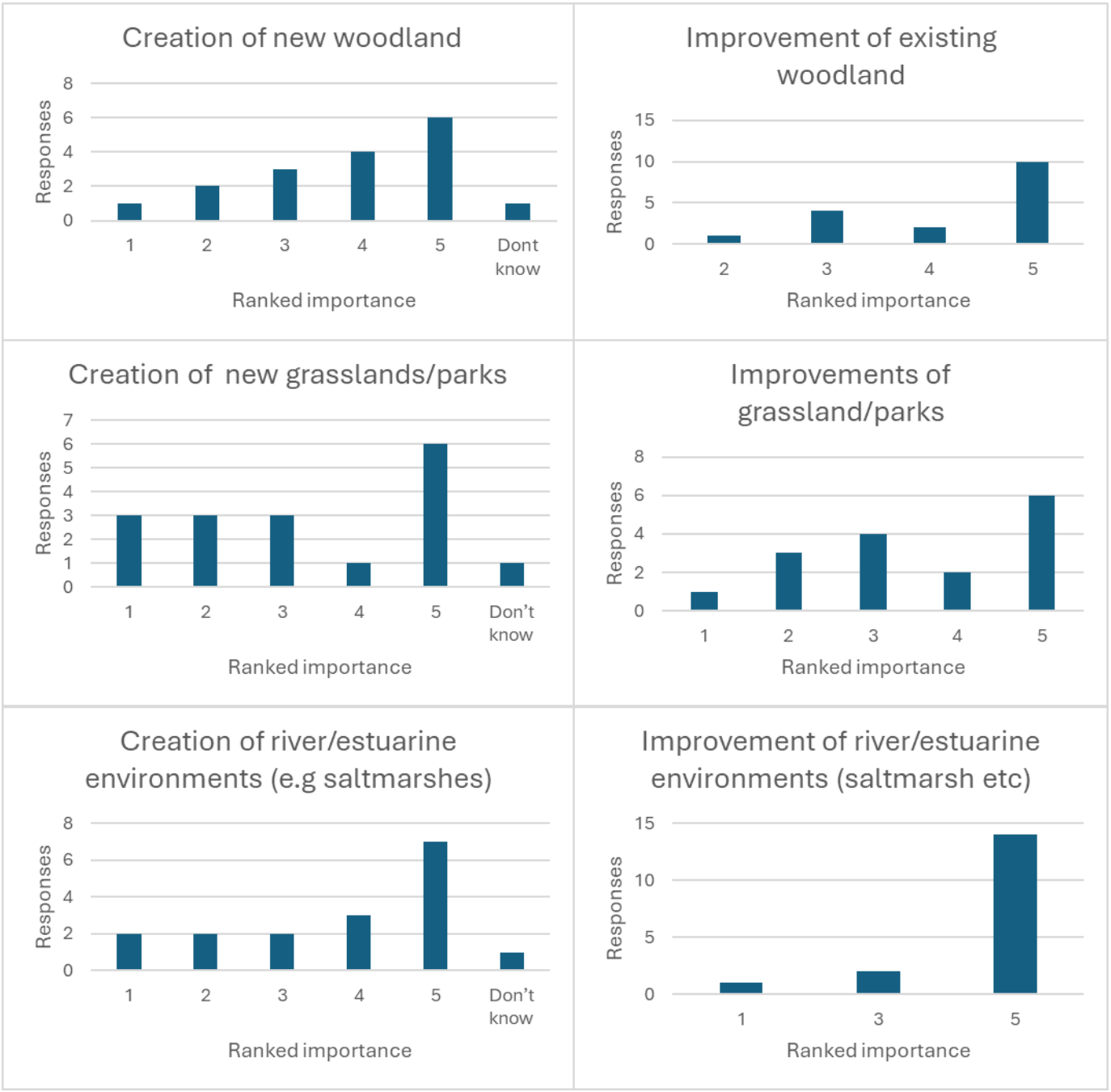


Figure 24: Importance of habitat improvements as ranked by participants where 1 was least important and 5 was most important.

When asked about developmental priorities in the area, participants strongly favoured improvements of existing areas over creation of new ones. This was particularly evident in residential areas with the majority of participants ranking the creation of new residential areas as a very low priority. This was also true for creation of leisure and retail areas and creation of new transport links although to a lesser extent.

Similar to development priorities, when asked about environmental priorities in the area, there was a bias towards improvement rather than creation, though this was less pronounced than in development priorities. Improvement of saltmarshes and other estuarine habitat was consistently ranked as the highest environmental priority in the area, possibly reflecting the importance of these habitats. Improvement of woodland and grasslands was ranked as a mid-high priority, similar to creation of woodland and creation of estuarine habitats. Creation of new grassland habitats split participant opinion with equal numbers ranking is as a high priority and as a low priority in the area.

Participants did not offer comment on these rankings.

5.3.4 Ecosystem service and other service priorities in the area

Questions in this section asked participants to rank importance from low importance (1) to high importance (5)

Questions included

- ‘In your opinion what is the importance of ecosystem services in the area?’ ‘In your opinion what is the importance of other benefits in the area?’

With an opportunity for respondents to explain their answers.

When asked about ecosystem service priorities, participants ranked four services as a high priority in the area. These were access to nature, flood risk mitigation, supporting biodiversity and water purification.

Other services were typically identified as having a high priority though this

was split between participants selecting high priority and unsure of priority. These services include carbon storage, carbon sequestration, food provisioning, noise regulation, climate regulation and timber provisioning. The only service that wasn't in either of these two categories was air purification, which was ranked mid-high priority.

For other benefits, three were ranked as a high priority by participants. These were cultural benefits, physical health benefits and mental health benefits. For the other services, there was typically a skew. For job creation this skew was mid-high priority, potentially reflecting the demographics of the area. For increased tourism, this skew was mid-low priority. Housing availability was split between participants being unsure and this being a high priority.

Participants did not offer comments on these rankings.

Figure 25: Importance of ecosystem services as ranked by participants where 1 was least important and 5 was most important.

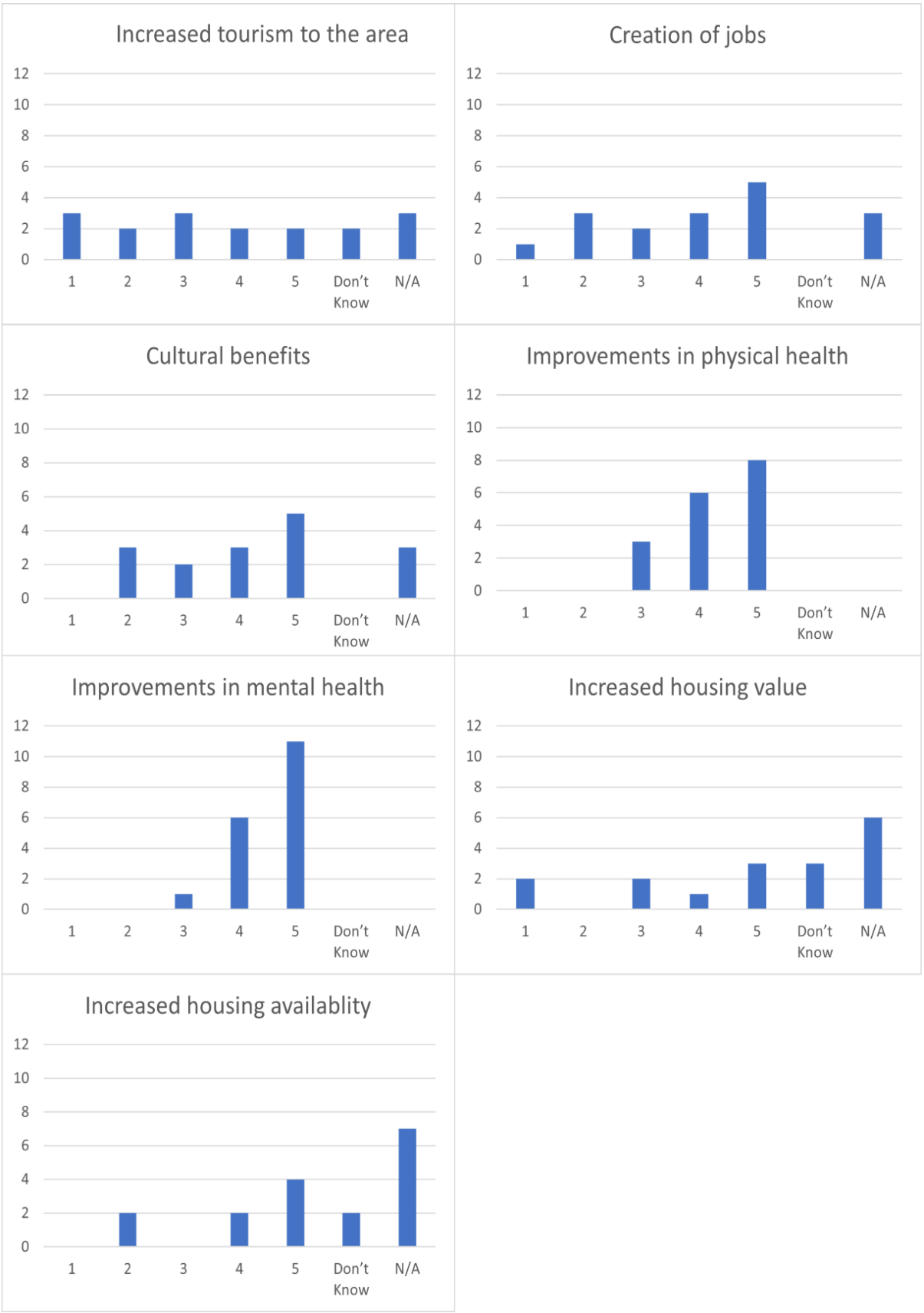


Figure 26: Importance of other services as ranked by participants where 1 was least important and 5 was most important.

5.4 Stakeholder opinions on Natural Capital approaches

Results from both focus groups have been presented here focusing on the general opinions stakeholders had regarding Natural Capital approaches and the barriers they perceived to be significant in implementation of the approach.

An important part of this focus group was the warm-up activity. The aim of this activity was to introduce participants to spatial thinking and the concepts around different development intensities. This also allowed participants to discuss priorities and concerns with each other during this activity. The warm-up activity asked participants to design their own different developments under the same scenarios used throughout this study (Intensive, Typical, Soft green, Hard green). It is recommended that this type of activity or a similar activity be repeated with other focus groups looking into natural capital approaches in practise as it allows for greater understanding and discussion throughout the session and acts as a good introduction to some key concepts.

Key quotes from the focus group linked to each of the themes can be found in table 22.

5.4.1 General opinions on the approach

Participants throughout both focus groups described their work as using elements of a Natural Capital or Ecosystem Services approach, particularly in the consideration of multiple services and acknowledgement of priorities within the area. In the preliminary focus group this often focused on regulating and cultural services with flood risk mitigation, carbon storage capacity and mental health improvements explicitly named as services being considered. Within the main focus group these considerations and those of pollution, access to nature and economic benefits were also considered.

This highlights that, although a Natural Capital approach is not formally considered within current policies and approaches, many elements are already considered and may benefit from a framework. This sentiment was shared by participants in the preliminary focus group with participants

noting that this approach would help them measure and show changes when applying for funding and communicating benefits during consultation stages.

Participants from the main focus group also commented on the benefits of being aware of changes and influences from throughout the areas as well as the advantages that clearly demonstrating trade-offs can have for decision-making. Participants from the main focus group also repeatedly noted that the process of co-design and communication between stakeholders had clear benefits to the design process including innovative thinking and inclusion of local knowledge. This process is an essential part of the Natural Capital approach proposed by this thesis so would help facilitate this co-design and communication.

These sentiments are echoed by stakeholders in other studies with a meta-analysis from Dick et al (2018) demonstrating that more than 70% of stakeholders in these case studies commenting that co-design and communication allowed for greater scientific integration within policies and McKinley et al (2019) demonstrating that stakeholders in marine management projects generally had a good opinion on ecosystem service approaches.

Further similar to Dick et al (2018), participants from both groups also noted that these approaches are likely best placed as supporting tools to the Biodiversity Metric and other policy-making tools rather than as a novel approach to policy and planning on its own. Participants also noted some further caveats to the use of a wider Natural Capital approach that will need further consideration.

This includes the accuracy of the basemaps and the spatial data used in building it. Participants within the preliminary focus group noted that some of the habitats within the basemap were inaccurate. This may be an error with the resolution of the data or errors in the spatial datasets themselves, however these will need to be addressed in order to have accurate results that can be trusted by users.

Utilisation of these tools will also need to be considered from a stakeholder

perspective, as there may be significant issues with both the skills required to use some of these tools and with the knowledge necessary to evaluate the outcomes of these tools. This is discussed further in the 'Knowledge gaps' section. Additionally, the actual use of the Natural Capital approach within policy making either as a decision-making approach or a supporting approach with the actual tools adapted to these needs.

Additionally, as the planning landscape is increasingly fluid and dynamic, Natural Capital approaches will need to be established in a framework that is similarly dynamic to avoid becoming outdated. McKinley et al (2019) further elaborates on this by identifying that stakeholders within their study demonstrated hesitancy about the potential for terms and tools to become too complex for use.

5.4.2 Barriers to implementation of a Natural Capital approach

Financial barriers and funding gaps

Funding and financial barriers to implementing approaches were discussed in both focus groups. Within the main focus group it was a consistent concern throughout discussions with acknowledgement that budgets are already stretched and environmental improvements or improvements to environmental processes may not be the highest priority for spending. This is particularly true for the Natural Capital approaches as it is still in its infancy with key questions still unanswered. Additionally, there are elements within Natural Capital approaches such as ecosystem service mapping and iterative co-design which are costly processes, both financially and in terms of time committed.

Although the approach was often seen as costly to set up, participants in both groups acknowledged that demonstration of certain ecosystem service values could facilitate further funding from different streams. Participants within the preliminary focus group identified that this style of mapping change could specifically aid in justifying further funding towards environmental priorities, particularly if co-benefits are demonstrated.

Concerns raised by participants are similar to those identified by other

authors (Dick et al., 2018; Kay et al., 2022) with approaches considered expensive to set up and maintain however there are an increasing number of markets and funding opportunities to aid with the establishment of these practices (as identified in the Literature Review (Chapter 2)). Additionally, as Kay et al (2022) indicates, the necessity to partner across disciplines can open different funding streams and further collaboration ensures that partners are working together rather than against one another for funding. Further to this, the approach as detailed in Chapter 2, once established helps identify the value of natural environments which in turn can be an avenue for funding maintenance and improvement of these environments.

One size fits all approach

A potentially substantial barrier to implementation of a Natural Capital approach participant identified is the risk of it appearing as a one size fits all approach, similar to other approaches currently encouraged in policy. Participants highlighted that there is no one solution or target which is appropriate to use across all landscapes in England or even the northwest. Though participants raised this as a concern of any approach, they also noted that the emphasis on co-design may resolve this as it may allow local knowledge and innovative solutions to be included.

Participants further noted that legislation and policy is fluid and complex so any approach taken would need to be flexible to adapt to ever-changing pressures and priorities. Participants highlighted that a rigid fixed approach which does not flex to new pressures is simply not feasible in the current policy

This is a sentiment echoed by Fleming et al (2022) in which participants noted that the values that can be captured cannot be simultaneously bespoke and standardised and that a selection of values or services must be made to focus across a landscape. Given the complexity and dynamic nature of urban estuaries, it would be sensible for these values to be identified by the stakeholders themselves, but this requires further facilitation and leadership from within the consortium.

Lack of capacity to consider multiple services and trade offs simultaneously

Legislation also requires decision-makers and land managers to consider multiple services and disservices simultaneously including non-environmental services and disservices. Participants noted that the requirement to consider and balance all outcomes for land use currently is difficult and may provide an additional barrier to implementation of a Natural Capital approach. Participants from the main focus group further noted that with other socio-economic considerations being required biodiversity and ecosystem services may not be a priority or there may be trade-offs between biodiversity net gain and ecosystem services.

While participants within this study acknowledged the considerations that must be made during decision making and how this limits the capacity to consider others, participants from other studies note that these approaches may lead to further considerations of change, though the practice is currently limited (Dick et al 2018). Additionally, Fleming et al (2022) noted that increasingly powerful technology may aid in consideration of these trade-offs but participants were wary of the degree of upskilling required.

Unexpected results and the need for iterative design

Participants within the main focus group noted that results that were unexpected, while sometimes positive, may also pose a potential barrier as it requires adaptive planning and iterative co-design and may highlight some unexpected negative impacts. This leads to further funding and time being necessary and with the potential for a planned action becoming infeasible and alternatives being required.

This can either be positive or negative and participants noted this in two scenarios in particular; King Georges Park and Sankey Brook.

Within King Georges Park participants noted that there were significant co-benefits to the habitat improvements ranging from improved social benefits to carbon storage benefits. In this scenario, it may be that this would promote the action, possibly facilitate funding and promote environmental benefits through Natural Capital approaches within the local community.

Sankey Brook however, showed significant negative outcomes from saltmarsh expansion which participants noted as unexpected. In this scenario, if habitat creation is deemed required, there would need to be further time and resources invested in new designs. This outcome also highlights the importance of local consideration within planning to ensure that outcomes are not unexpected, as understanding of the habitats being inundated in this example makes the resulting loss expected. This understanding was not taken into consideration as the maps this was based on came from a non-local perspective.

While this may be viewed as a barrier, participants further highlighted that these unexpected results allow for more informed decision making to take place and a greater consideration of actions that are implemented to be possible. This particular barrier was not found echoed in literature; however, this may be due to the more practical design of this workshop mimicking an implementation or co-design approach.

Knowledge gaps

Knowledge gaps were also a key issue raised by participants, particularly as there are very few ecologists or landscape designers in public bodies, resulting in a reliance on potentially inaccurate citizen science or expensive consultants. This means that the iterative co-design required within a Natural Capital approach must include outside organisations which further increases the resource requirement. Participants suggested that, although this is a significant gap with a high importance in the current system, this could be resolved through in-house training or apprenticeships, potentially with the support of local educational institutions to ensure that these roles are filled in the future.

There is also a knowledge gap in what assessment tools are available and appropriate, as well as a lack of suitable training to enable those who want to use them to be able to do so effectively. This can be addressed by tool developers, both by clearly highlighting what the tool is and is not suitable for and providing adequate training and support for those who wish to use them as well as the use of tool assessors such as the Ecosystem Knowledge

Networks tool assessor. A good example of this is a demonstration of EcoservR aimed at planners and decision makers within the Liverpool City Region as part of a wider training session on Natural Capital by the development team of the tool, helping participants understand the purpose and use of the tool.

It is important to note that these issues are significantly exacerbated by non-collaborative working as identified by Kay et al (2022).

Collaboration with different sectors and local communities

Throughout both focus groups collaboration and the importance of co-design were consistent themes. This includes collaboration between different organisations, professions and the local community.

Greater collaborations between different institutions and organisations would resolve some of the issues previously discussed but it does require time and resources to be invested. Additionally, as indicated in Kay et al (2022), different organisations work on asynchronous timescales with different aspects that are focused on. This may result in collaboration being difficult particularly if a facilitator role has not been established. However, as multiple authors note (Kay et al 2022, Fleming et al 2022, Dick et al 2019) these collaborations are vital to ensure the approach is as robust as possible.

An example where collaboration has been successful is the Liverpool City Region Natural Capital Working Group which includes educational public and private bodies working towards Natural Capital approaches in the region, demonstrating that while this requires time and monetary investments, these collaborations if facilitated can be successful and has produced tangible progress for Natural Capital approaches in this region (Busdieker et al., 2020).

Collaboration with the local community is also a necessary but challenging aspect to the Natural Capital approach participants described. Some of this is already a requirement within some actions however a greater emphasis on this and further inclusion of the local community would be beneficial to

local ownership of outcomes as highlighted by participants in the main focus group. Participants within this group further noted that inclusion of local communities may elicit services and values of the environment which are typically not considered leading to more thorough environmental considerations in policies which serve both people and nature.

While inclusion of land managers and decision makers are often focused on within the limited stakeholder interaction in literature, there are few considerations of general public perceptions of Natural Capital, which in an urban estuary is a key gap which will need addressing.

Table 22: Key quotes from focus groups reflecting themes

Themes	Quote
Financial Barriers, Collaborations	That's what the local nature partnerships were supposed to do but they don't have the funding
Collaborations	Co-design is the best way to do this kind of work
Financial Barriers, Collaborations	[Co-design] is very dependant on who manages the land and who foots the costs
Unexpected results, knowledge gaps, financial barriers	There are too many unknowns without that research but it's high cost to do so many things never get off the ground
Knowledge gaps, collaborations	Knowledge of the area and any previous interventions is needed
General opinions, one size fits all	It's not possible to apply anything in that geography, the scale of the intervention needs tailoring
Lack of capacity, knowledge gaps	We're all desperate to have in-house answers to some of these questions
Lack of capacity	We've got a lot of [social, economic and environmental] issues we need to consider at this scale
Knowledge gaps, lack of	I work in the field and I still don't feel I

capacity	understand it
Collaborations, general opinions	How we communicate this is fundamental
Knowledge gaps	Because [BNG] is market led the answers to questions just aren't there
Financial barriers	1.8m over 30 years over this area is nothing in this example
Lack of capacity, general opinions	There's conflicts between natural capital and biodiversity net gain I've noticed in my role
Lack of capacity, general opinions	Biodiversity in some sites is really high which blocks any potential interventions for other services
Knowledge gaps	Peoples understanding of things like biodiversity varies a lot
Lack of capacity	We're trying to balance the scale of socio-economic and environmental and there are a lot of drivers in that
Lack of capacity, financial barriers	I don't think capacity is there yet [for BNG implementation]
Lack of capacity, financial barriers	We used to have ecologists in house and it was fundamental to our work but we don't have that anymore
Lack of capacity	There isn't capacity locally to bring things forward
One size fits all	A southern county will have issues which are totally different to the ones we have in the Liverpool City Region. There is no one size fits all
Lack of capacity, financial barriers	Retaining people with the skills we need is hard as they leave for better paying roles
Knowledge gaps, lack of capacity	We have a skills shortage in the area
Financial barriers	It all comes back to a lack of finance again

5.5 Conclusions

5.5.1 Questionnaire

Ecosystem services identified by participants in the questionnaire were consistently socio-cultural services which is typically hard to quantify and often missed in Natural Capital Approaches (Dick et al 2018). Hutchison et al (2013) found a similar pattern with stakeholders often identifying and prioritising cultural services in costal zones above other ecosystem service types. In this study, the River Mersey itself was noted as having a high importance in part due to its cultural status across multiple geographic scales. This sentiment is echoed by other authors who noted the significant cultural benefits which stem from estuaries (Thrush et al., 2013b) all of which should be considered with equal importance to ecological benefits within a complete Natural Capital approach (McNally et al., 2016).

When asked about environmental and development priorities participants placed emphasis on improvement as opposed to creation, particularly for developments. This was also found by Choe & Schuett (2020) who notes that increasing development and urbanisation were key concerns of stakeholders. Participants in this study additionally noted some of the properties of placemaking, particularly when considering the degree of historical damage, similar to results from Ferreira et al (2021) who also found stakeholder emphasising the need for better management of existing greenspaces. Wild et al (2008) further discussed the principles of placemaking in an urban-riverine system in Sheffield, noting that it had led to improvements in the environment, social cohesion and economic growth. Utilising these approaches with the inclusion of stakeholders can lead to multifaced benefits and should be encouraged (McNally et al., 2016).

Stakeholders participating in this questionnaire focused on cultural and social benefits alongside high profile ecological benefits such as carbon storage. High profile services being identified is noted in other studies and linked to stakeholder knowledge and use of the estuary (de Juan et al., 2017;

Lamarque et al., 2011). Additionally, similar to results from Ferriera et al (2021), improvements in existing areas are favoured over creation of new areas with some acknowledgement of the influences these would have on multiple geographic areas.

Overall themes emerging from this questionnaire focus on cultural and social benefits alongside high profile benefits such as carbon storage. Additionally, improvements in existing areas rather than creation of new areas is favoured, noting an improvement in the local environment while also acknowledging the global influences. Multiple authors have emphasised the need for the public opinions to be explored further within Natural Capital approaches (Chiesura & De Groot, 2003; Cochrane, 2006; Thrush et al., 2013b; Weinstein, 2008) with particular importance being placed on identification and inclusion of these socio-cultural benefits. Further to this Devine-Wright (2013) also noted that further research and inclusion of the public as a stakeholder can be beneficial, particularly in light of 'think global act local' and 'NIMBY' attitudes, which may have conflicts resolved between them through greater inclusion of the public within the approach.

5.5.2 Focus group

Within both focus groups, there was acknowledgement of elements of a Natural Capital approach already being utilised however these focused on regulating services and were placed as supporting tools and techniques to legally binding policies and frameworks such as the Biodiversity metric. It needs to be acknowledged that urban-estuarine landscapes are often under multiple different policies and are the concern of multiple authorities, as shown in the policy review (Chapter 3) , which can lead to significant conflicts in opinions and actions (Ballinger & Stojanovic, 2010; Lonsdale et al., 2022), meaning the addition of a new framework or tool as a replacement instead of decision making support may be overwhelming and inefficient. However, a framework for this decision making has been strongly recommended by authors to improve natural environments while meeting policy objectives (Keenan et al., 2019).

Participants in these groups also identified other significant barriers that exist to implementing Natural Capital approaches though these can largely be overcome through collaborative efforts. There are some that will be more difficult to overcome such as institutional and financial barriers which were also identified in Keenan et al (2019) and Kronenberg (2015). Other authors such as Collier & Lofstedt (1997) have also noted that financial barriers may limit the ability of local authorities to take actions that include using newer approaches, though Kay et al (2022) noted that collaboration may open up some of these funding avenues after some initial investment and the Natural Capital approach as detailed in this thesis includes funding streams as part of the approach.

Within the approach itself, participants in this study highlighted the importance of flexibility. The approach as defined in Chapter 2 can adapt to different needs and demands of the area which stakeholders must identify, however once these are selected, there must be consensus to work towards these goals as a consortium, reviewing and adjusting course as needed as also recommended by Keenan et al (2019). This requires reassessment, and those in the facilitator role should be able to steer the group through updates to the approach regularly without confusing actions or priorities. This has been demonstrated through collaborative efforts in urban-riverine systems (Wild et al 2008) and in urban environments through the Natural Capital Working Group so is possible and potentially beneficial to urban-estuarine systems.

5.5.3 General conclusions and recommendations for further work

Participants within this study viewed different environmental and developmental priorities as important like based on roles and knowledge as has been recorded in other studies (Garcia-Nieto et al 2014).

While participants from both focus groups and the questionnaire viewed environmental priorities as important, there were differences in the specific concerns with carbon footprints being important to the questionnaire respondents, reflective of the high profile of carbon, and biodiversity being more important in the focus groups, reflective of the policy background of

participants. All groups regarded the estuary and its estuarine habitats as important to the areas, both environmentally and culturally. Similarly, there were differences in priorities, a focus on regenerating existing habitats and developments was preferred by questionnaire respondents whereas habitat creation was regarded as equally important to improvement in focus groups. These differences likely stemmed from the knowledge, roles and use cases of the participants in the area (Lemarque et al 2011, Juan et al 2017, Garcia-Nieto et al 2014).

Working alongside stakeholders is an often noted but neglected part of a Natural Capital approach. This is despite inclusion of stakeholders being vital to the approach for many reasons including identification of services, ownership of the environments and actions, opening up funding opportunities, and inclusion of local knowledge in these approaches (Quintas-Soriano et al 2016, Cortina-Segarra 2021, Soste et al 2015). Natural Capital scientists should acknowledge the calls to increase work with stakeholders as this is an area of work within the approach which needs greater acknowledgement.

This chapter demonstrates the beginnings of good stakeholder engagement but not the end goal of stakeholder engagement. Scientists, decision makers and those interested in a Natural Capital approach must acknowledge that continuous collaborative and iterative work is needed to fill this gap within the Natural Capital approach. Continuing stakeholder interaction should be a priority going forward, addressed by action and training within stakeholder interaction spheres to break down siloed working and more effectively deliver Natural Capital approaches, particularly in urban estuarine areas where there are so many stakeholders to consider.

6. Conclusions

The aim of this thesis was to design a framework for the wider application of a Natural Capital approach and use the upper Mersey as a test case to study this. This was achieved through an assessment of relevant policies, Natural Capital mapping of development and habitat improvement options and stakeholder engagement.

6.1 Policy

A gap identified within the introduction of this thesis was a lack of consideration of how natural capital approaches can be applied in practice and potential barriers to this. The policy review of this thesis takes steps towards addressing this gap through the consideration of the approach in practice alongside current policies.

Analysis of local policies shows that integration and support of Natural Capital approaches is possible within the current planning and policy frameworks. This is dependent on the approach framework being flexible and adaptive with implementation aiding decision making through greater clarity of objectives. This would potentially resolve the issues highlighted in both the policy review (Chapter 3) and stakeholder engagement (Chapter 5) of vague policies by providing some specific targets and methodologies for the broad environmental commitments made to be met (Brody, 2003).

The method of implementing the Natural Capital framework within policies needs to be well planned to adapt to the fast-moving local policy sphere (Shaw et al., 2017). This has been identified as a major challenge for policy adaptation in the UK (Dwyer, 2011; Lindley et al., 2007) as the existing policy space must be acknowledged and the potential barriers of implementing another framework need to be overcome for the framework to be effective.

Utilising a Natural Capital approach in national policy has already been made a priority by the UK government (HM Government, 2018), although an operational framework for the approach has yet to be established which is clearly needed for effective implementation (Faccioli et al., 2023). A high-level flexible framework should be established and can be held by an already existing government body such as the Natural Capital committee or the OEP. This would allow for monitoring of outcomes to be included at a high level and provide support to local councils implementing the approach.

The policy review highlighted that, although Natural Capital approaches are not yet widespread in local policies, there are policies that can facilitate inclusion of this with potentially beneficial outcomes for policy objectives, addressing this key research gap.

6.2 Mapping

Two key research gaps identified in the introduction of this thesis were a lack of consideration of urban-estuarine landscapes in natural capital approaches and the lack of a spatial model which can be used in these systems to assess multiple services. These gaps were addressed by the mapping work within this thesis through consideration of multiple urban-estuarine habitats within the approach and through a review and selection of EcoServR as a model which is spatial and flexible enough to consider both urban and estuarine habitats simultaneously. Neither urban-estuarine landscapes nor EcoServR have been widely considered or used within Natural Capital research prior to this work. This thesis demonstrates the importance of considering urban-estuarine landscapes as a whole and the utility of EcoServR in doing so.

Ecosystem service mapping is a critical part of a Natural Capital approach and formed a key part of this study. This study demonstrated the use of multiple tools, including a spatial tool, in order to identify ecosystem service trade-offs under multiple scenarios as a key part of a Natural Capital approach to spatial planning. The approach demonstrated can be used for more informed decision making to maximise ecosystem service provision while considering socio-economic development and habitat improvements

simultaneously.

Natural Capital mapping within this thesis highlighted that restoration options in urban-estuarine systems can be limited due to a lack of available space, resources and other demands on the system. However, as Simenstad et al (2005) noted, considering strategic and well-designed areas can mitigate some of these impacts if urban-estuarine areas are considered and planned holistically. While Beck et al (2023) began this process, they largely ignored any improvements that can happen in developed areas, resulting in one of the most opportunistic areas in urban-estuarine systems being left out of these assessments. This work highlights that these highly urbanised areas are the only places where onsite mitigation is possible, supporting the importance of brownfield development and urban regeneration (Mehdipour & Nia, 2013; Zaletova et al., 2021). This is coupled with the limited options for local mitigation through habitat improvements, making restoring and conserving urban-estuarine areas difficult unless well planned strategic actions are taken. This strategic approach is crucial to conserve and maintain biodiversity and Natural Capital as these cannot flow from areas of high to low supply (González-García et al., 2022) so must be supplied locally.

This work also highlights synergies and trade-offs that occur including those between ecological and socio-economic impacts. Often within urban-estuarine systems only a single service is considered with little note of others or of socio-economic impacts, for example within the Humber estuary management plan (Lonsdale et al., 2022), flood risk mitigation is the primary focus with limited interest in the socio-economic and other ecological impacts this plan will have. These limited considerations are not enough within complex urban-estuarine environments to effectively restore them as it ignores factors which may be significant (Simenstad et al., 2005). Cross-consideration of multiple ecological and socio-economic factors has been advocated for by some authors (Heymans et al., 2019; Seto et al., 2017) but this is still new to the field and lacks a consistent framework to be effective. This objective can be advanced through using the maps and outputs from Natural Capital mapping to facilitate discussions, innovation

and idea generation with key stakeholders, who may be able to identify socio-economic factors more effectively than mapping approaches can.

Overall, the results from this chapter both demonstrated the use of a spatial model which could be used for urban-estuarine systems and the consideration and importance of urban-estuarine landscapes as a whole, addressing these research gaps.

6.3 Stakeholder Interaction

A significant gap within natural capital approaches is the lack of consideration of how natural capital can be applied in practice and any barriers to implementing this. This thesis begins to explore and address this gap, particularly through the work in stakeholder interaction which discussed the approach with policy makers and decision makers to help identify potential barriers to implementation and explore how the natural capital approach could assist in decision making within practice. Stakeholder interaction within Natural Capital approaches is still emergent within the field and is an important part of ensuring natural capital can be implemented in an effective way. This thesis used stakeholder interaction to demonstrate the considerations of implementing natural capital approaches and highlighted barriers which have not yet been widely considered.

Stakeholder interaction helped to identify barriers to implementation of a Natural Capital approach, including non-economic barriers, such as knowledge gaps and complex policy landscapes. These barriers to implementation are important to identify if the Natural Capital approach is to be implemented at any scale (Claret et al., 2018) and arguably the only way to effectively identify these barriers is to discuss the approach with those who would be implementing it and tailor it to their needs. These discussions of barriers can also lead to discussions and ideas to overcome them as different views, capacities and knowledge bases become known to all parties (de Juan et al., 2017; Lamarque et al., 2011), giving more options for implementation and making the approach itself more robust.

It should be noted that identifying these barriers is only the first step in

addressing them and the importance of collaboration and co-design in overcoming significant barriers should not be understated. Collaborative efforts, while time consuming and often expensive, are the most effective method of identifying and overcoming these barriers and must be an essential part of any Natural Capital approach (Cortina-Segarra et al., 2021; Schultz et al., 2015). Researchers looking to explore these approaches and decision makers looking to implement them must be encouraged to work together in an iterative and continuous manner with good facilitation to ensure the best outcomes (Reed, 2008). In addition, those beginning to explore stakeholder interaction and facilitating stakeholder input must ensure that all relevant parties are active participants and be aware of the role they can play in moving towards a common goal. This is seldom found within academic literature, potentially due to the cycle of academic funding not allowing for continued working partnerships, however examples including academic institutions exist, including the Natural Capital Working Group (Busdieker et al., 2020), with facilitation focusing on ensuring all members are informed and active to work towards the groups goals.

Often when stakeholder views are being discussed, authors make assumptions about these views without interacting with stakeholders directly, and often link these views to economic factors (Pascual et al., 2017). This, if not paired with direct stakeholder interaction, is reductive and can be misleading. This economic focus also ignores important cultural values and those who are too economically disadvantaged to pay for services. By inclusion of a wide breadth of stakeholders not only are socio-cultural values identified but this moves towards greater equity in the acknowledgement and supply of Natural Capital benefits, a concern that must be kept in mind for the approach to have long-lasting positive impacts (Mullin et al., 2018).

Another key aspect seldom mentioned in literature is the general public's inclusion in these approaches. This is particularly important in urban-estuarine environments as those living and working in the area are the dominant stakeholder group and their opinions must be included. This is already a key part of urban planning with consultations and public forums

being common, but academic researchers, particularly those with a scientific background, seem hesitant to include the wider publics views in research with many believing that reaching out to the public is 'irrelevant' to their career despite viewing this as important for science as a whole (Pham, 2016). This is a clear institutional problem, particularly if scientists developing these tools and the Natural Capital approach wish to see it implemented and see real world impacts of their work. This study cannot propose a fix for this, short of continued promotion of interaction with the general public, training in these skills as part of scientific education (Brownell et al., 2013) and shifts in academic definitions of 'impactful work'.

Continuous and effective stakeholder interaction is a valuable part of any Natural Capital approach and should be regarded as essential to a Natural Capital framework, equivalent to Natural Capital mapping. This remains a key gap in natural capital research despite this thesis beginning to address this.

6.4 Critical reflections

While this thesis addresses some key gaps, it has not been able to demonstrate a full natural capital approach. Iteration of stakeholder co-design and setting priority services are two key parts of the approach which are missing from this study due to time constraints which may have been significant to results. Additionally, there was no validation of ecosystem service provision or modelling approaches included in this work which would have been beneficial to the overall results.

Iterative co-design is a key feature of a natural capital approach, and this is also something which is started in this thesis but is not complete. Stakeholder comments on mapping scenarios should be incorporated within designs and ecosystem service assessments re-run to present to stakeholders again in an iterative co-design process and this was not completed within the scope of this study. Additionally, it would have been beneficial to include some iterative codesign of the approach framework itself with stakeholders

to improve the framework and address some of the identified barriers to implementation.

Finally, Natural Capital approaches are mixed methods by design and thus further integration of ecosystem service mapping and stakeholder interaction would be beneficial throughout any future approaches. This thesis did include some of this but this could be integrated further to better demonstrate an effective iterative natural capital approach which can be implemented in policy.

6.5 Overall conclusions and recommendations for future work

While a framework has been shown and the beginnings of a Natural Capital approach within the Upper Mersey estuary has been completed in this work, these are first steps in a longer ongoing process. This means that there are still significant gaps this work could not address and many future recommendations for work.

The first, and possibly easiest, of these is to continue work on EcoservR. While the tool is useful as it is, there is more functionality that could be added, including some assessment of condition, potentially in a method similar to the Biodiversity Metric, and increasing ease of use for the end users through an app or clearer interface. This interface should not oversimplify the results however and should highlight where expert analysis of outputs might be necessary. Additionally, inclusion of continuous monitoring data or regular reviews of the data the models are based on would be beneficial for the robustness of the tool going forward as highlighted by stakeholders. This will require consistent feedback and continued work on the tool. Additionally, a sensitivity analysis should be performed on EcoServR models.

Additionally, future work should be done to continue to test the natural capital approach presented in this framework, particularly taking the iterative co-design of developments presented into consideration. It may be beneficial to use real world designs in this process or to adapt the designs presented here. The approach stages presented should be tested in full alongside stakeholders in future work. Furthermore, the questionnaire should be repeated and errors made in this study addressed to gain a better understanding of the ecosystem services and priorities which are highly valued by those using them within the study area.

The next is a general recommendation, and something highlighted within the focus group. While tools which are easy to use and assessments which can be carried out simply are good, some upskilling so more complex, accurate and detailed assessments can routinely be carried out will be necessary if long term sustainable conservation is going to be achieved (Fleming et al., 2022). This will require collaboration between educational institutions, public bodies and the private sector to provide training in the form of tailored apprenticeships or degree programmes. This will ensure that the specialised skills that are needed within this sector are being provided to those who will need them with positions available supporting implementation of Natural Capital approaches after this training has been completed.

These skills and this training will also need to be multidisciplinary, including numerical, modelling, ecological and social science skills. All of those involved in natural capital approaches or training to be involved in natural capital approaches must have some understanding of modelling, ecology and social science methodology for the approaches to be understood and implemented. This latter skill will be particularly important as consistent community involvement and stakeholder interaction is crucial to these approaches and it is often overlooked when undergoing ecological

study (Dick et al., 2018). Not only is this beneficial for highlighting the needs and wants of the community who are affected by any changes, but it also allows for some degree of community ownership of the environment which can lead to greater longevity of the approaches and a higher value being placed on the area by those who benefit from it (Cortina-Segarra et al., 2021; Schultz et al., 2015). Though becoming a multi-disciplinary researcher is difficult, it is one of the key methods of ensuring an effective Natural Capital approach within the future and is thus worth investing in.

Further work will also be needed from the scientific community to begin filling some key knowledge gaps within the approach. As the Natural Capital is still relatively new to ecology, there are still a plethora of unanswered questions surrounding it. However, it has been taken on by policymakers (HM Government, 2018) as it does offer some hope of helping restore delicate ecosystems, so filling these gaps and highlighting uncertainties must be a priority. These include validation of habitat cover through surveying such as through the Natural Capital Ecosystem Assessment (NCEA), validation of service provision through ground truthing or other innovative methodologies and improving confidence in projections and predictions. If uncertainties and gaps remain unresolved, there is a risk that the approach will not reach its full potential and be dismissed politically where it may have been a valuable tool.

Additionally funding options for development of and implementation of Natural Capital approaches need to be explored in greater detail. These should not be limited to public funding, and environmental markets should continue to be explored and built. This may be through explorations of existing green finance options such as the Biodiversity Metric market or through novel methodologies, particularly those which link funding to non-monetary ecosystem services. This must be done cautiously, however, as these markets must demonstrate some ecological good resulting from these trades and must be regulated to ensure that the environment is not forgotten in the environmental market. This should also include some restrictions on

geographic offsetting to ensure that, where possible offsetting is onsite or local, as ecosystem services typically do not flow from one region to another (González-García et al., 2022).

Finally, for the Upper Mersey and other urban estuaries, Natural Capital approaches should be the primary framework used to conserve the area and further exploration of the approach presented in this work should be undertaken within the Upper Mersey Estuary. There are already existing working groups focused on conservation and restoration of the area, these can be made more effective using the Natural Capital method, particularly if a wider stakeholder group is engaged and wider expertise is gained. The beginnings of this have started with the Mersey Blueprint, however this will require consistent work over many years, from all parties. This will also need a wider set of stakeholders, actions and potential funding routes to be examined to ensure there is some consistency and longevity to the approach and ultimately, the condition of the Mersey.

This thesis has demonstrated the framework and considerations of a Natural Capital approach within an urban estuary and provided the foundation for the holistic landscape scale restoration of this area using a Natural Capital approach.

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8. Appendix

8.1 Stakeholder Questionnaire

Questionnaire

This questionnaire will ask your opinions on developments and conservation in the Upper Mersey estuary and its surrounding area. No personally identifying information will be collected. Completion and submission of this questionnaire implies consent for your responses to be used in the related study. Ethics approval number: 22/BES/001 For any questions please email the lead researcher on this project l.e.dowdall@2020.ljmu.ac.uk. The closing date for this questionnaire is 31st August 2022.

All the questions relate to the area in the image below.

1. In your opinion, what is the INTERNATIONAL importance of the natural environments in the area? (1 being low importance, 5 being high importance)

Tick all that apply.

	1	2	3	4	5	Don't know
Grasslands	☐	☐	☐	☐	☐	☐
Woodlands	☐	☐	☐	☐	☐	☐
Saltmarshes	☐	☐	☐	☐	☐	☐
Mudflats	☐	☐	☐	☐	☐	☐
River/Estuary	☐	☐	☐	☐	☐	☐
Canals	☐	☐	☐	☐	☐	☐
Allotments/Gardens	☐	☐	☐	☐	☐	☐

2. Please briefly explain your answer

3. In your opinion, what is the importance to the NORTH WEST of the natural environments in the area? (1 being low importance, 5 being high importance)

Tick all that apply.

	1	2	3	4	5	Don't know
Grasslands	☐	☐	☐	☐	☐	☐
Woodlands	☐	☐	☐	☐	☐	☐
Saltmarshes	☐	☐	☐	☐	☐	☐
Mudflats	☐	☐	☐	☐	☐	☐
River/Estuary	☐	☐	☐	☐	☐	☐
Canals	☐	☐	☐	☐	☐	☐
Allotments/Gardens	☐	☐	☐	☐	☐	☐

4. Please briefly explain your answer

5. In your opinion, what is the LOCAL (Runcorn, Widnes, Warrington) importance of the natural environments in the area? (1 being low importance, 5 being high importance)

Tick all that apply.

	1	2	3	4	5	Don't know
Grasslands	☐	☐	☐	☐	☐	☐
Woodlands	☐	☐	☐	☐	☐	☐
Saltmarshes	☐	☐	☐	☐	☐	☐
Mudflats	☐	☐	☐	☐	☐	☐
River/Estuary	☐	☐	☐	☐	☐	☐
Canals	☐	☐	☐	☐	☐	☐
Allotments/Gardens	☐	☐	☐	☐	☐	☐

6. Please briefly explain your answer

7. In your opinion, what is the importance to the INDIVIDUAL of the natural environments in the area? (1 being low importance, 5 being high importance)

Tick all that apply.

	1	2	3	4	5	Don't know
Grasslands	☐	☐	☐	☐	☐	☐
Woodlands	☐	☐	☐	☐	☐	☐
Saltmarshes	☐	☐	☐	☐	☐	☐
Mudflats	☐	☐	☐	☐	☐	☐
River/Estuary	☐	☐	☐	☐	☐	☐
Canals	☐	☐	☐	☐	☐	☐
Allotments/Gardens	☐	☐	☐	☐	☐	☐

8. Please briefly explain your answer

9. In your opinion, how do developments typically interact with natural environments in the area

Mark only one oval.

	1	2	3	4	5	
Damage heavily	⬭	⬭	⬭	⬭	⬭	Improve heavily

10. Please explain your answer

11. In your opinion, please rank development priorities are in the area (1 least important 6 most important)

Mark only one oval per row.

	1	2	3	4	5	6
Creation of new residential areas	◯	◯	◯	◯	◯	◯
Improvement of residential areas	◯	◯	◯	◯	◯	◯
Creation of new retail/leisure areas	◯	◯	◯	◯	◯	◯
Improvements in retail/leisure areas	◯	◯	◯	◯	◯	◯
Creation of new transport links/roads	◯	◯	◯	◯	◯	◯
Improvements in transport links/roads	◯	◯	◯	◯	◯	◯

12. In your opinion, how does environmental enhancement impact developments and development priorities in the area

Mark only one oval.

	1	2	3	4	5	
Strongly negative	◯	◯	◯	◯	◯	Strongly positive

13. Please explain your answer

14. In your opinion, please rank environmental priorities in the area are (1 least important, 6 most important)

Mark only one oval per row.

	1	2	3	4	5	6
Creation of new woodland	◯	◯	◯	◯	◯	◯
Improvement of existing woodland	◯	◯	◯	◯	◯	◯
Creation of new grasslands/parks	◯	◯	◯	◯	◯	◯
Improvement of grasslands/parks	◯	◯	◯	◯	◯	◯
Creation of river/estuarine environments (e.g saltmarshes)	◯	◯	◯	◯	◯	◯
Improvement of river/estuarine environments (saltmarsh etc)	◯	◯	◯	◯	◯	◯

An ecosystem service is a benefit people get from nature.
For example: cleaner air or provision of food.

15. In your opinion, what is the importance of ecosystem services in the area are (1 - low importance, 5 -high importance)

Mark only one oval per row.

	1	2	3	4	5	Don't know
Access to nature for recreation (e.g walking)	◯	◯	◯	◯	◯	◯
Air Purification	◯	◯	◯	◯	◯	◯
Carbon sequestration	◯	◯	◯	◯	◯	◯
Carbon storage	◯	◯	◯	◯	◯	◯
Reduction of heat/warming (Climate regulation)	◯	◯	◯	◯	◯	◯
Noise regulation	◯	◯	◯	◯	◯	◯
Water purification	◯	◯	◯	◯	◯	◯
Food provisioning	◯	◯	◯	◯	◯	◯
Timber provisioning	◯	◯	◯	◯	◯	◯
Supporting biodiversity	◯	◯	◯	◯	◯	◯
Flood risk management	◯	◯	◯	◯	◯	◯
Other (please specify below)	◯	◯	◯	◯	◯	◯

16. Other

17. In your opinion, what is the importance of other benefits in the area (1 - low importance, 5 - high importance)

Mark only one oval per row.

	1	2	3	4	5	Don't know
Increased tourism to the area	◯	◯	◯	◯	◯	◯
Creation of jobs	◯	◯	◯	◯	◯	◯
Cultural benefits (e.g. sense of place)	◯	◯	◯	◯	◯	◯
Improvements in physical health	◯	◯	◯	◯	◯	◯
Improvements in mental health	◯	◯	◯	◯	◯	◯
Other (please specify below)	◯	◯	◯	◯	◯	◯
Increased housing value	◯	◯	◯	◯	◯	◯
Increased housing availability	◯	◯	◯	◯	◯	◯

18. Other

_____

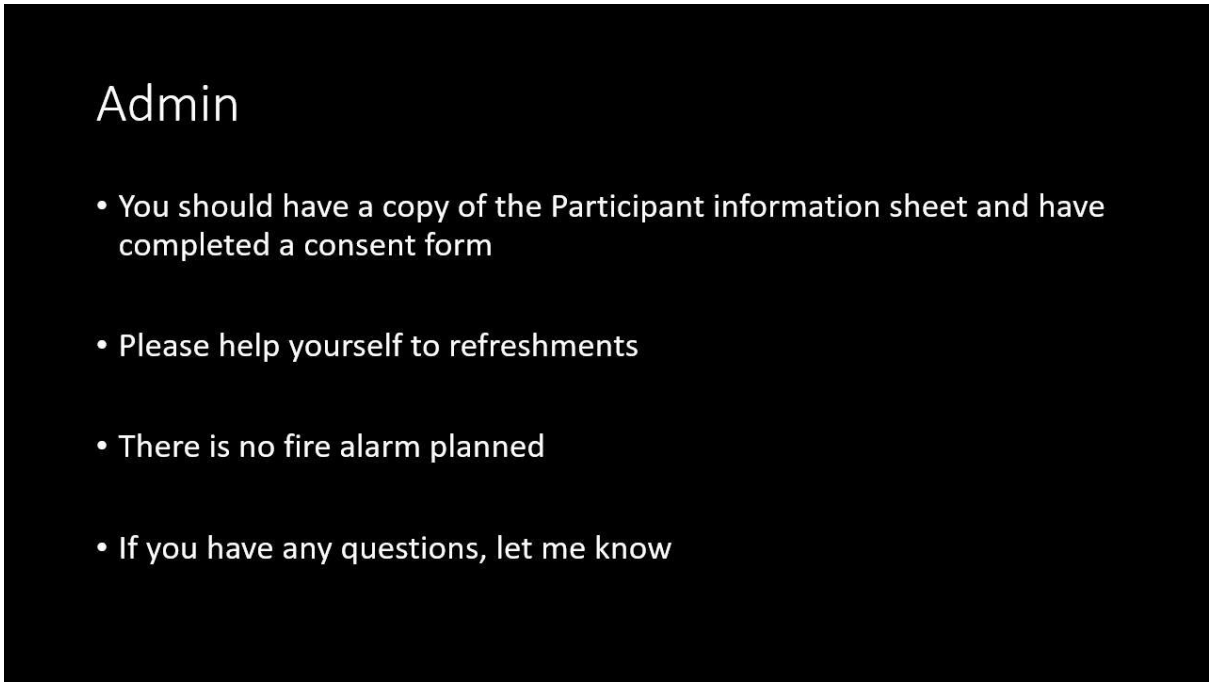
19. Which of the following groups do you identify yourself to be in?

Tick all that apply.

- [ ] Developer
- [ ] Governance/Policy maker
- [ ] Resident in the area
- [ ] Visitor to the area
- [ ] Public body
- [ ] Other: _____

20. Any other comments?

8.2 Focus Group



Session structure

- Warm up (30 Minutes)

Designing different scenarios

- Key question 1 (60 minutes)

Commenting on results of Natural Capital Scenarios

- Key Question 2 (60 Minutes)

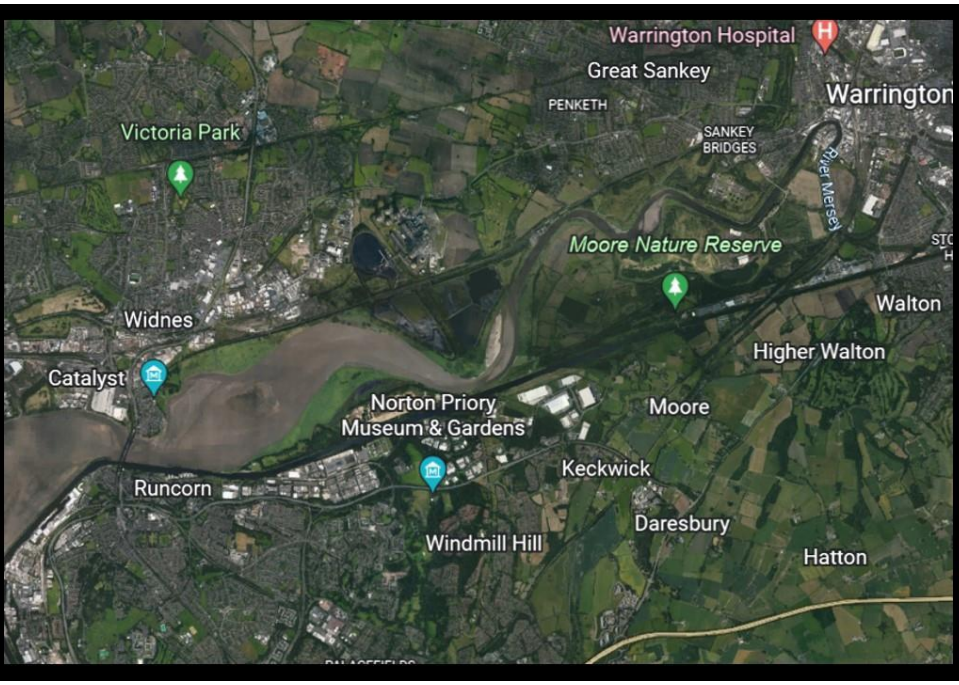
What part of Natural Capital is most important to decision making

Warm up

Using the paper and pencils provided, spend 20 minutes to design

- a high intensity development
- a typical development
- a green development
- a typical habitat improvement

All within the study area shown on the next screen. You can be as creative as you like with these and don't worry about artistry/realism. Examples are on the tables provided.

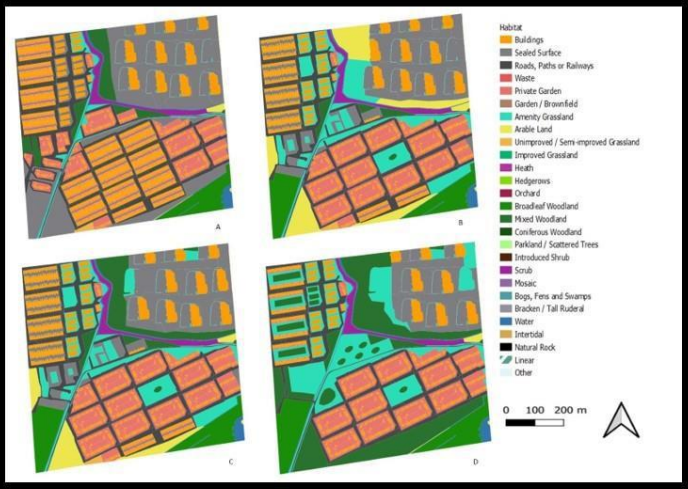


Warm up – part 2

Now that you've designed your own developments and we've discussed these, I'd like you to look at the handouts provided with my designs on to comment on.

Feel free to write/draw on these if needed!

Study Design – Development templates



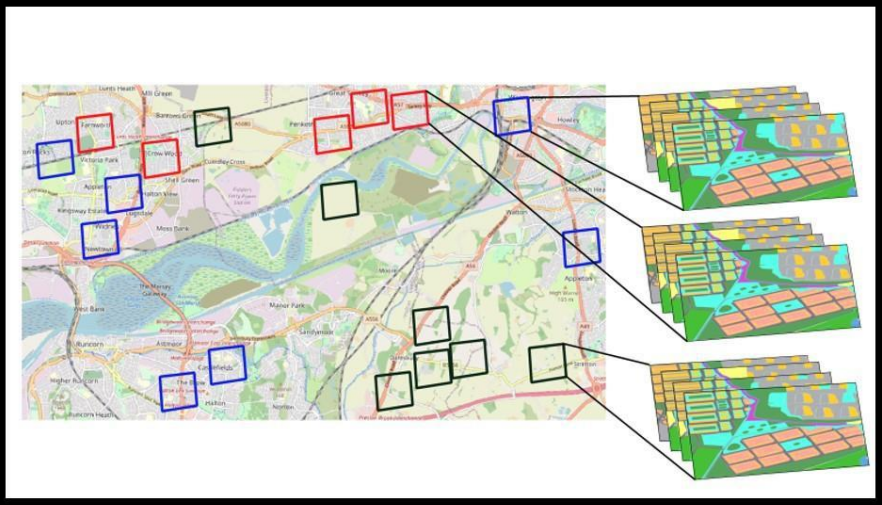
Development templates were made by taking average land use covers of other existing mixed use developments in the area and mimicking the percentage covers of these for a typical development (b) of around 53 hectares.

Intensive development (a) was set at 10% more grey area than typical.

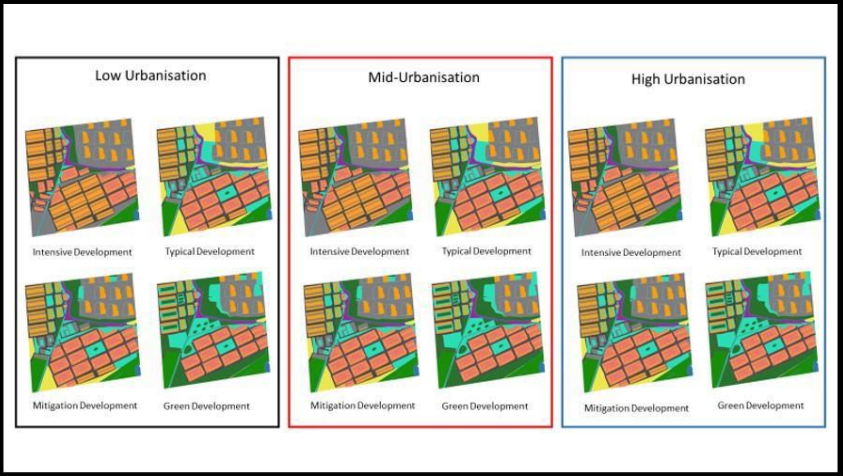
Mitigation development (c) was set at 10% less grey than typical.

Green development (d) was set at 20% less grey than typical.

Study Design - overview



Study Design - Comparisons



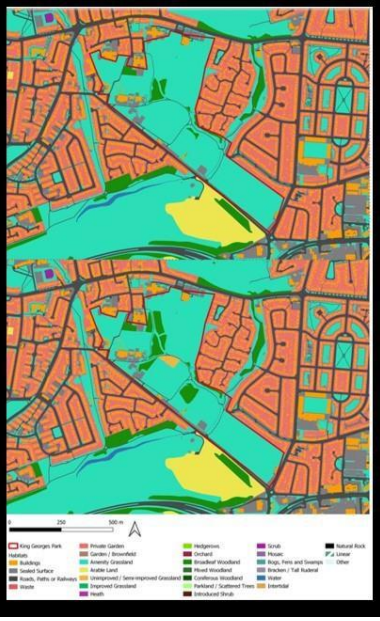
Study Design – Habitat Improvements

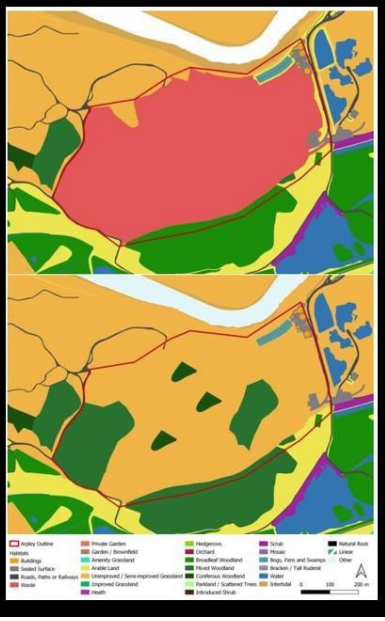
Habitat improvements were selected through a policy review for grassland/woodland expansion and saltmarsh improvements and through the Catchment Based Approach maps for saltmarsh expansion.

These were as follows:

1. King Georges Park (Grassland/woodland Expansion)
2. Arpley (Grassland/Woodland Expansion)
3. Moss Side Farm (Saltmarsh Expansion)
4. Moss Side Farm adjusted (Saltmarsh Expansion)
5. Sankey Brook (Saltmarsh Expansion)
6. Sankey Brook adjusted (Saltmarsh Expansion)
7. Widnes Warth (Saltmarsh improvement)
8. Astmoor (Saltmarsh improvement)
9. Cuerdley (Saltmarsh improvement)

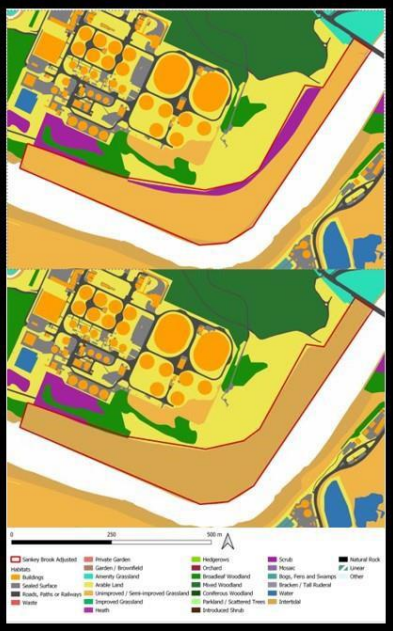
King Georges Park and Arpley



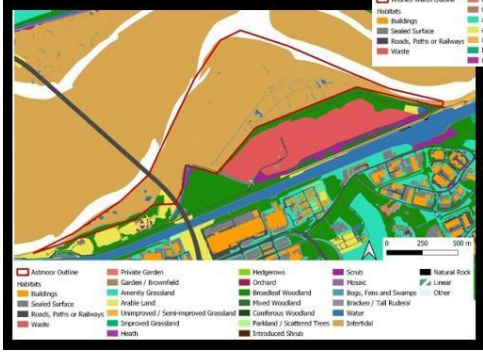


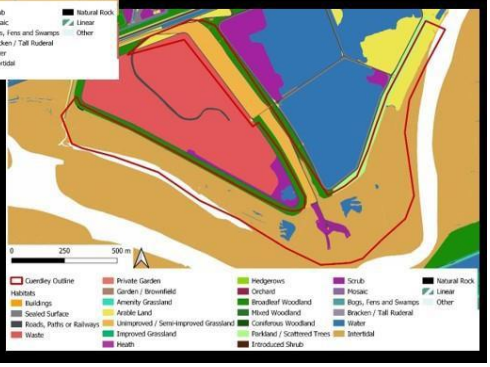
Moss Side Farm and Adjusted

Sankey Brook and Adjusted



Saltmarsh Improvements





Key Question 1 – Natural Capital assessment results

On the screen I've put a graph showing the results of the development scenarios and the habitat improvements.

I'd like you to take a minute to look over these before we discuss them.
Feel free to grab a drink while you do this.

Discussion question:
Is there anything notable/interesting about these results?

Key Question 2 – Influence of Natural Capital in decision-making

Now think about your work and the process you undergo during decision making.

Discussion question:
How could these results/this method be integrated into planning to help decision making?

Closing

Thank you so much for taking part, it's very appreciated.

If you have any questions now or later, feel free to ask me.

I hope you've also gained something from this focus group and that you get home safely.

Thank you again!

8.3 Habitat improvement maps

Figure 27: King Georges park before (top) and after (bottom) habitat improvement.

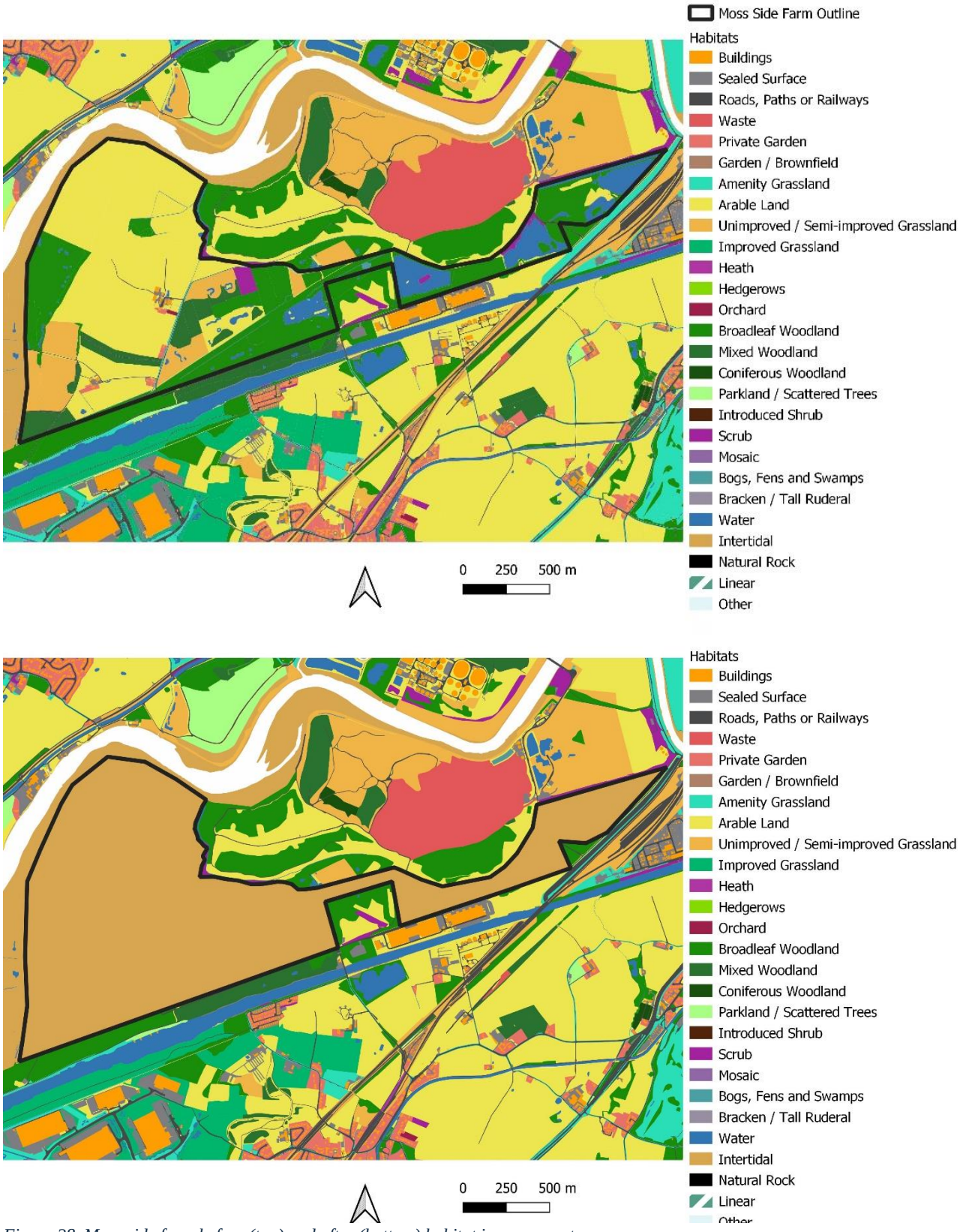


Figure 28. Moss side farm before (top) and after (bottom) habitat improvement.

Figure 29. Moss side farm adjusted before (top) and after (bottom) habitat improvement.

Figure 30. Sankey brook before (top) and after (bottom) habitat improvement.

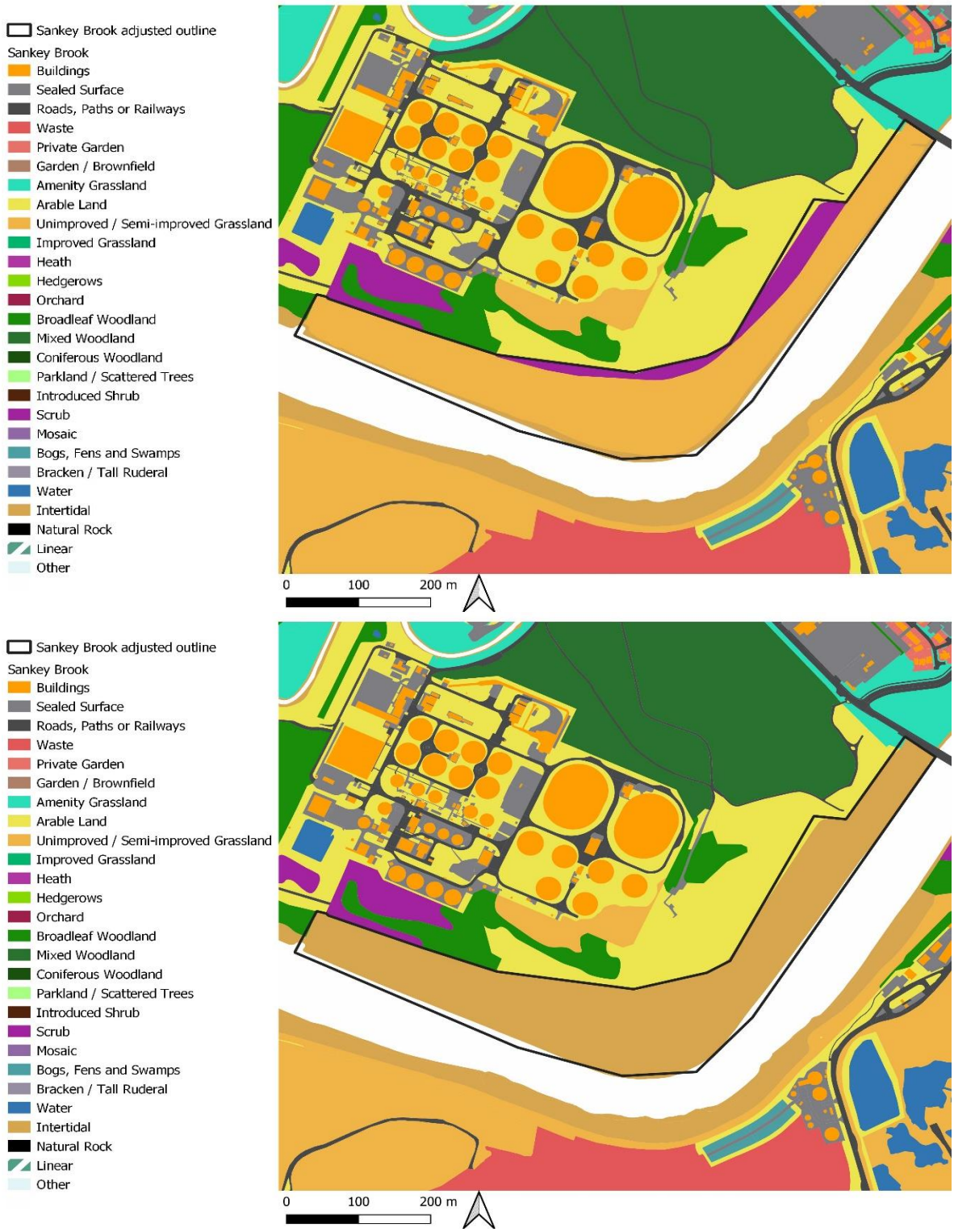


Figure 31. Sankey brook adjusted before (top) and after (bottom) habitat improvement.

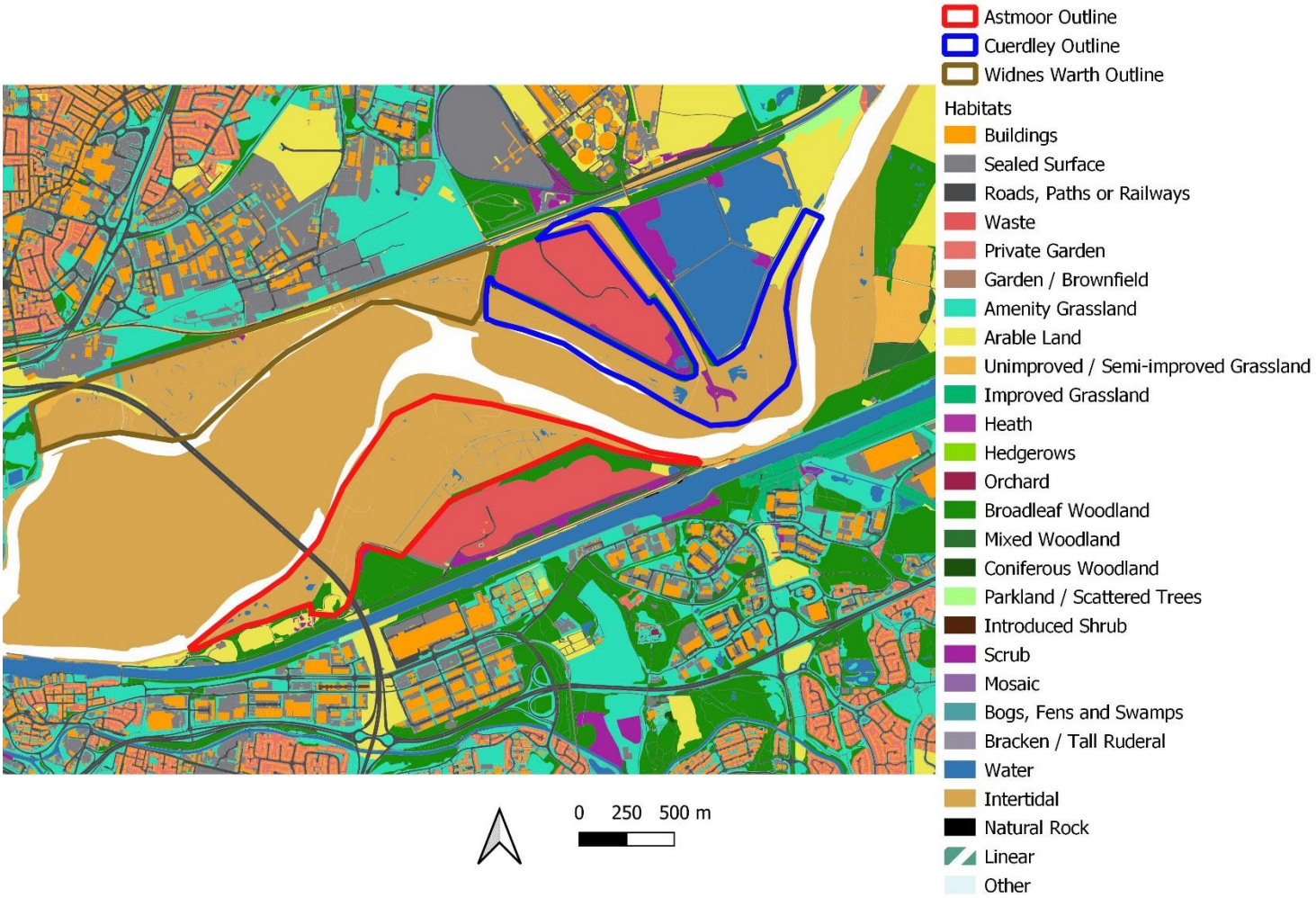


Figure 32. Saltmarsh improvement areas, Widnes Warth (brown), Astmoor (red) and Cuerdley (blue)