Master of urban climate and sustainability (MUrCS)

Re-valuing canals

Valuation of ecosystem services provided by the Smart Canal project

Ala' Al Dwairi

August 2020

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Declaration of originality

'This dissertation is my original work and has not been submitted elsewhere in fulfillment of the requirements of this or any other award.'

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ABSTRACT

The primary purpose of this work was to provide a new view of the role canals can play in cities. In Glasgow city, canals were held highly for its role in shaping the industrial image of the city during the industrial revolution (1790-1930). After the Forth & Clyde canal ('the Canal' in further text) demise due to the uprise of railway transport, it moved to hold a scheduled monument status with recreational uses in the city. This dissertation aims to highlight the different roles canals can play in cities by mapping the provision of Ecosystem Services (ES) provided by the Smart Canal project in the north of Glasgow city. Furthermore, the performed ES mapping started by adopting a Multi-Criteria Decision Analysis (MCDA) using Geographic Information System (GIS). Eight ES (one provisioning, five regulating, and two cultural) were mapped based on available spatial data for land use and landcover classes combined with other criteria. The MCDA criteria were selected based on existing research and the study area characteristics. GIS map algebra was used to analyze the ES provision maps, identify areas providing multiple ES and highlight areas of possible synergies and trade-offs between ES.

The results showed that the Smart Canal area has considerable potential for offering regulating and cultural services in comparison with provisioning services. The highest ES provision was for enhancing water quality and carbon sequestration followed by flood control and evaporative cooling. As well, the Canal showed intermediate to a high potential for the delivery of habitat areas (biodiversity).

Moreover, the north-western part of the Canal proved to be a 'hotspot' for the delivery of multiple ES, making it a highly sensitive area in need of sustainable planning to manage ES synergies and trade-offs adequately. Thus, the results of this analysis fortified the role of the Canal as an adaptation tool to face climate change threats as well as its potential for forming an ecological corridor creating a refuge for urban wildlife.

The mapping of the Canal's ES portrayed in this analysis can be used as a decision support tool for planning areas around the canals network in Glasgow and to ensure sustainable management of canal resources.

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ABBREVIATIONS

Canal Oriented Development	COD
Common International Classification of Ecosystem Services	CICES
Digital Elevation Model	DEM
Ecosystem Services	ES
Ecosystem Services Provision Unit	ESPU
Geographic Information System	GIS
Green Infrastructure	GI
King Abdallah Canal	KAC
Metropolitan Glasgow Strategic Drainage Partnership	MGSDP
Millennium Ecosystem Assessment	MA
Multi-Criteria Decision Analysis	MCDA
North Glasgow Integrated Water Management System	NGIWMS
Previously Developed Land	PDL
Red Sea-Dead Sea canal	RDC
Scottish Canals	SC
Sustainable Development Goals	SDGs
Sustainable Urban Drainage Systems	SUDS
The Canal and River Trust	The Trust
The Economics of Ecosystem Services and Biodiversity	TEEB
UK National Ecosystem Assessment	UK NEA
UK National Ecosystem Assessment Follow-on	UK NEAFO
United Kingdom	UK
United Nations	UN
United Nations Environment Programme	UNEP
Water Sensitive Urban Design	WSUD

1
INTRODUCTION

Intricate canal networks have been a part of Scotland's history for more than 200 years, initially constructed to serve purposes of navigation and goods transfer. This dissertation aims to explore the new role of canals in the built environment, specifically by defining and mapping ecosystem services offered by canals. By focusing on the Smart Canal project as a case study, this research will further additional information on the value of water bodies in the urban environment and highlight the environmental and social opportunities it offers to the broader urban development agenda.

1.1 Problem statement

Historically, civilizations thrived near water bodies. Shores, rivers, and lakes shaped the urban form and environment (Galil *et al.,* 2007). Constructing hydrological structures such as canals began as early as 2200 B.C, to be used in navigation, agriculture and flood management (Bandaragoda, 1999; Echols and Nassar, 2006; Galil *et al.,* 2007). In the city of Cairo, spanning over the banks of the Nile River, canals and lakes were used as parts of a comprehensive irrigation system that was designed to capitalize on the Nile's flooding cycle (Echols and Nassar, 2006). The canals of Cairo served its primary purpose greatly and were further used as outdoor spaces with various recreational activities taking place around it (e.g. festivals, swimming). However, In the early 19th century, most of Cairo's canals were filled and abandoned following political and social movements to modernize Egypt, driven by concerns over the hygienic status of the canals (Echols and Nassar, 2006).

Furthermore, canals were built on a larger scale to fulfill purposes of navigation and shipping; the Panama Canal was constructed to establish an artificial connection between the Atlantic Ocean and the Pacific Ocean, it was expanded in 2016 to increase its market and provide a sustainable transportation option (i.e. ships require less energy and fuel to move cargo, therefore, generating fewer emissions) compared to alternative routes (e.g. roads, rails) (Mulligan and Lombardo, 2011). The continuous growth of commerce in the eighteenth century in the United Kingdom (UK) was the primary catalyst to build canals. Traders needed reliable methods for transportation to increase profit. Canals were safe, reliable, and can convey more significant amounts of products compared with road networks at that time (London Canal Museum, 1992). By the nineteenth century, most of the canals in the UK were built. However, further technological advances in railway and road networks provided consistent routes for shipping that eventually overcame the value and purpose of the UK's canal system (Clarke, 2005). Some canals were filled and had railway networks built on top or were sold to railway companies, which had no interest in maintaining the canal status as shipping routes (London Canal Museum, 1992). Eventually, the canal system started to deteriorate, and most of the land surrounding the canals were contaminated due to the industrial works that took place in it (Clarke, 2005).

The remainder of the canal system in England (3200km) is now preserved and labeled as a historical monument managed by the Canal and River Trust ('The Trust' in further text) (The Trust, 2015). Scotland has a much smaller network; only 220km remain under the custodianship of the Scottish Canals (SC) (Transport Scotland, 2013; The Trust, 2015). Due to the smaller network in Scotland, there was not an evident relationship between people and the canals; residents did not draw reminiscence towards the culture and heritage that surrounded the history of the canals (McKean *et al.,* 2017). Therefore, government bodies managing the canals then (e.g. British Waterways) set out to reshape and identify the connection between people and canals, through engaging in major regeneration projects for the canals and its surroundings (McKean *et al.,* 2017). Canal regeneration projects commenced in Glasgow city in 2002, with the opening of the Falkirk Wheel, it connected the Forth and Clyde Canal with the Union canal. The project was a great success and managed to attract high numbers of visitors (McKean *et al.,* 2017). In 2013, the regeneration projects continued with the opening of the Helix Park and The Kelpies sculptures, built on a brownfield area of 300 hectares (Paxton *et al.,* 2000; Cooper and Prosser, 2003; McKean *et al.,* 2017). More recently, Scottish Canals are focused on drawing attention to the importance of Scotland's canal network in providing ecosystem services and forming ecological corridors within city centers (Transport Scotland, 2013; Scottish Canals, 2015). For example, the Smart Canal project commenced in 2013, focused on utilizing the Forth & Clyde canal as a sustainable solution for surface water management in the regeneration of north of the Glasgow area (Robinson, 2013; Scottish Canals, 2018).

According to Tang and Jang, (2010), Canals go through growth and decline phases and in order to reimagine a new purpose for the canal system, multiple factors need to be in balance, mainly recognizing the canal system as a resource, community involvement, and governmental leadership, this balanced mix helped the transition of the New York canal system from transportation into a tourism and leisure attraction. Similarly, in Phoenix Arizona, the ancient canal system left by Native Americans in the fifteenth century is being offered a golden opportunity for rebirth by applying Canal Oriented Development (COD) concepts to counter the effect of urban sprawl that isolated the canals from the urban environment and its inhabitants (Ellin, 2010; Buckman, 2013, 2014; Buckman et al., 2013). In modern times, canals are used and reimagined to meet basic needs, projects such as the King Abdallah Canal (KAC) in Jordan, is focused on delivering water for irrigation and drinking purposes, (Tetra Tech, 2018). The Red Sea-Dead Sea canal (RDC) aims to alleviate the shrinking water levels in the Dead Sea and partially meet the demand for Jordan's two biggest cities, Amman and Zarqa, amidst a changing climate (Al-Omari *et al.,* 2014). The New Dubai Canal, constructed to serve as a transportation route, enhance flow, reduce stagnation, and serve as a recreational destination for residents (El Amrousi *et al.*, 2019). It is essential to understand the potential of canal systems in cities and identify what ecosystem services it offers to the surrounding environment and inhabitants, which represents an essential piece towards creating a resilient urban environment (Transport Scotland, 2013).

1.2 Research questions

Scotland aspires to hold status as a hydro nation, responsible for disseminating best practices related to sustainable water management in a changing climate (Muscatelli et al., 2020). Climate change is defined as *"A change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or land use"* (IPCC, 2012). The main effects of climate change in Glasgow city include extreme weather, changes in temperature and precipitation, and flooding (ClimateXChange, 2016; Scottish Government, 2019). Following on the footsteps of the Millennium Link regeneration project *(responsible for the construction of Falkirk wheel and regeneration works of Forth & Clyde and Union canals)* (The millennium link, 2001; McKean et al., 2017); the Metropolitan Glasgow Strategic Drainage Partnership (MGSDP) initiated in 2002, between multiple governmental entities, and aiming to alleviate surface water flooding risk, which is considered one of the most significant pressures of climate change in Glasgow city (England *et al.*, 2018). Other objectives for MGSDP were to enhance river water quality, enable economic development, habitat improvement, and encourage integrated planning (Allan et al., 2016; MGSDP, 2019).

Under the MGSDP umbrella, the North Glasgow Integrated Water Management System (NGIWMS) project came to life in 2013, mainly Glasgow City Council, Scottish Waters and Scottish Canals signed into a sixty-year drainage partnership to deliver infrastructure works aiming to regenerate 260 hectares of North Glasgow area (AECOM, 2013; Allan et al., 2016; Robinson, 2013). The base of the drainage partnership is to transform a section of the Forth & Clyde canal to become a 'smart canal.' The Smart Canal scheme alters part of the Forth & Clyde canal to become an innovative drainage solution for surface water management (Brears, 2018; Scottish Canals, 2018). Basically, in case of heavy rainfall, the canal water level will be automatically lowered to take in extra volumes of water drained through Sustainable Urban Drainage Systems (SUDS) installed within future developments in the NGIWMS area, which drains naturally towards the Canal (AECOM, 2013; Robinson, 2013). The NGIWMS vision for the Smart Canal project is to create a sustainable water management solution, enhances surface water quality, and adopt Water Sensitive Urban Design (WSUD) concepts (Allan *et al.,* 2016), ensuring the Forth & Clyde canal pioneers in adopting placemaking concepts and encouraging the use of water as a resource in urban environments (Robinson, 2013).

Since reopening and regenerating the Forth & Clyde canal in 2001, the Canal has been in a rebirth phase (McKean and Lennon, 2017), where The Millennium Link project aided the restoration of the Forth & Clyde canal status as a cruising canal (Transport Scotland, 2013). Furthermore, smaller projects such as the paddle sports center at Port Dundas further enhanced the Canal's status and appeal, which aligns with the Trust's goal to create 'living waterways' (Transport Scotland, 2013; The Trust, 2015). It is evident through the Scottish Canals environment strategy (2015-2025); that SC aims to further fortify the status of the Canal as an indispensable asset to Glasgow's adaptation efforts towards climate change and environmental degradation by tapping into the Canal's value in sustainable water management, supporting biodiversity and environmental protection (Scottish Canals, 2015).

Furthermore, urban ecosystems are defined as *"those areas where the built infrastructure covers a large proportion of the land surface, or as those in which people live at high densities"* (Pickett *et al.*, 2001). Urban ecosystems include all the components of the built infrastructure and ecological infrastructure, which represents a combination of human-made structures and what natural resources lays in or at the proximity of these structures (such as parks, canals, and ponds) (EEA, 2011; Elmqvist et al., 2014). Urban ecosystems deliver ecosystem services that are of environmental, economic, and social benefit to humans (Gómez-Baggethun *et al.*, 2013). The Forth & Clyde canal is being used in flood management, environmental protection for certain species, and offers social services related to placemaking and heritage preservation (AECOM, 2013; Gómez-Baggethun *et al.*, 2013; Robinson, 2013).

Through this dissertation, I aim to answer the following research question: *what are the ecosystem services the Smart Canal project can deliver to foster adaptation to climate change threats and create environmental and social benefits within the urban environment?*

The answer will be obtained by achieving the following objectives:

- Identify key ecosystem services in the Smart Canal project.
- Map ecosystem services provision.

- Detect synergies and trade-offs between ecosystem services.
- Define the new role of the Forth & Clyde canal.
- Highlight opportunities for adaptation to climate change threats.

1.3 Methods

A progressive methodology that builds on previous work undertaken on ecosystem services classification and assessment, data collection, and mapping using Geographic Information System (GIS) was adapted for this research. Objective one will be achieved through a systematic literature review to identify key ecosystem services in the study area. Objective two will be achieved by conducting a GIS-based multicriteria decision analysis (Eastman, 1999; Fernandez-Campo et al., 2017), to map the provision of each ecosystem services (Maes et al., 2012; Rocha et al., 2015). Objective three will be achieved by creating binary bundle maps using GIS to convey different scenarios of ecosystem services management (Fernandez-Campo et al., 2017). Objectives four and five will be addressed based on contrasting the results of multicriteria decision analysis and existing literature to define a new role for the canal and highlight opportunities for climate change adaptation.

1.4 Dissertation structure

Chapter 2 explores the definitions and origins of Ecosystem Services (ES) and evaluation approaches, including previous work and studies on assessment and mapping of ES associated with water resources, urban areas, and regeneration projects. Chapter 3 provides information on the chosen methodology for conducting the research, detailing the nature of processed data, selected software, and analysis. Chapter 4 includes the final results and a discussion of the outcomes. Chapter 5 offers the conclusions and recommendations of this dissertation.

2
THE RISE OF ECOSYSTEM SERVICES

The first trial to understand the humans' effect over nature began with Marsh's book "Man and Nature," published in 1864 (Lowenthal, 2000; Marsh, 2003). Marsh argued that the decline of ancient civilizations was due to the deterioration of the surrounding environment as a result of humans' exhaustion of natural resources. Thus, earth's resources are not infinite, as it was believed at that time (Lowenthal, 2000). Furthermore, Marsh highlighted that an increasing population and industrial works are only bound to worsen environmental degradation, and now is the time to start looking into matters of environmental protection. This publication is considered the start of the study of nature's services and values (Barr, 1972; Daily, 1997; Lowenthal, 2000). This chapter is dedicated to following the birth of the concept of Ecosystem Services (ES), exploring established international and national frameworks for classifying ES, examining ES in urban environments, and within water management systems.

2.1 Ecosystem services advancement

The study of the interplay between humans and nature dates back to ancient times (Barr, 1972). However, Marsh's research is considered the start of a continuous wave of exploration in the topics of environmental degradation, natural resource depletion, and what role do humans play in it (Lowenthal, 2000). Daily's powerful book Nature's Services offers an overview of significant events in research that led to the definition and use of "ecosystem" and "ecosystem services" terms, sparked the start of the modern environmental movement and offered a deeper understanding of interactions between humans and nature (Daily, 1997; Table 1). Although Ehrlich does not provide a specific definition for ecosystem services, instead offers a series of compelling arguments calling for the prevention of species extinction and preservation of the free services ecosystems provide for humanity (Ehrlich and Ehrlich, 1981). Ecosystem services became mainstream in ecological research, and international programs (e.g., Global Biodiversity assessment by UNEP) were launched to enhance the understanding of ecosystem services, analyze changes in biodiversity and gather information to build robust knowledge in these areas (Daily, 1997; Jaakkola, 1998). Furthermore, one of the most cited definitions of ES in literature is the one given by (Daily, 1997): "*Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life.*"

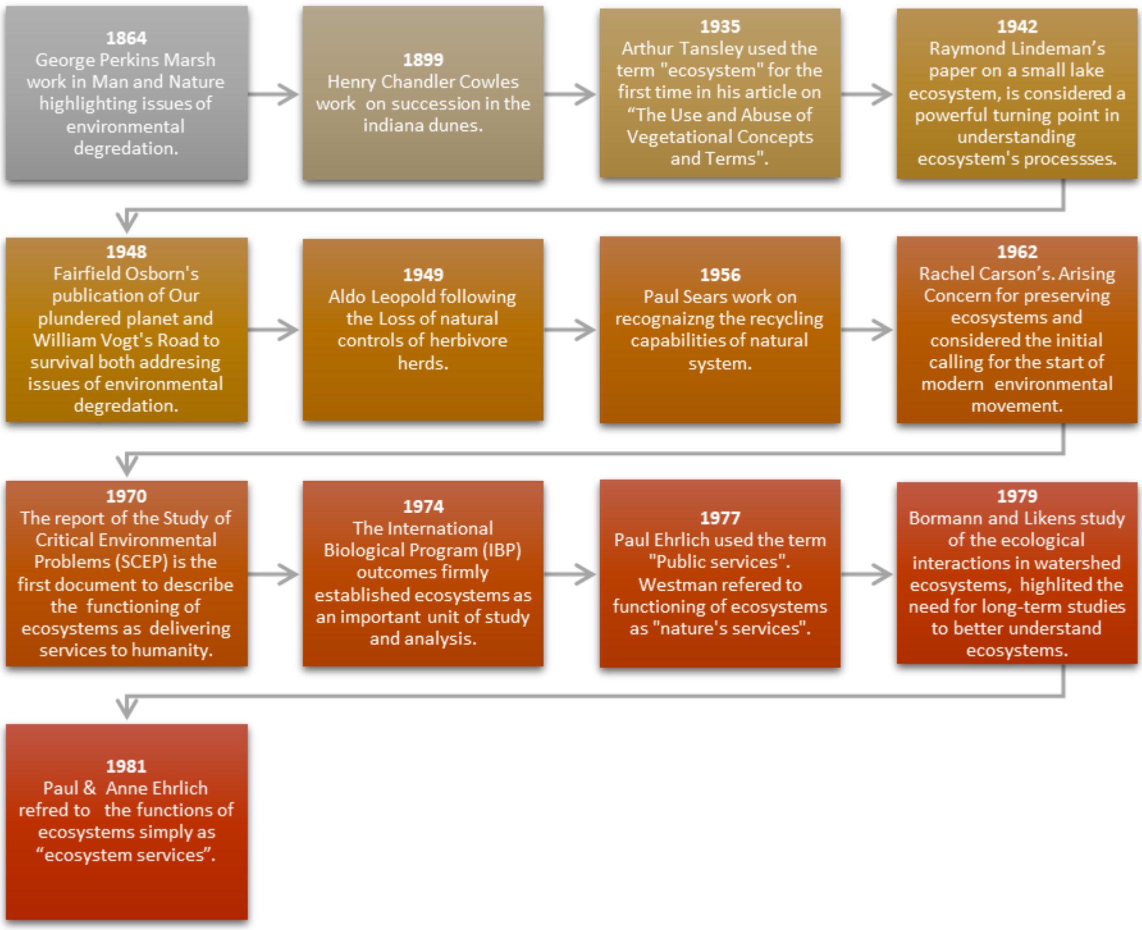


Figure 1: Major events in research leading to the definition and use of "ecosystem services" term, Adapted from (Daily, 1997)

Daily's definition could be termed as a broad classification taking into consideration all the "conditions and processes" required to arrive at tangible services, mainly aiming to value ES economically as long as these services produced benefits for human beings (Smil, 1998). Daily placed services in broad groups according to its anticipated benefits (Daily, 1997). A classification which daily reflects upon later as the cause for some services to have marginal values compared to others, resulting in some inaccuracies and double counting (Daily and Matson, 2008). Some of the main challenges in valuing ES at that time related to fluctuations of market prices, some ES cannot be evaluated using market prices (e.g., the stability of ecosystem productivity) and values assigned to ES need to be continuously revised due to ES dependency on geographical and temporal contexts. Some of these challenges still hold today (Daily, 1997). Costanza delivered equally important work on classifying ES, defining ES as*: "the benefits human populations derive, directly or indirectly, from ecosystem functions"* (Costanza *et al.*, 1997). Costanza further scrutinized ES in this definition to be "benefits" humans obtain from "ecosystem functions" in a way to emphasize the importance of valuing the benefit at the endpoint of the function or service (Costanza, 2000). Costanza estimated the annual value for seventeen ecosystem services (e.g., Climate regulation, Water supply, Food production, Raw materials, Recreation, and Cultural) to be US$16-54 trillion, with an estimated average of US$33 trillion. Arguing that the prices of goods produced from ecosystems would be much higher if the global economy were founded on the actual value of ES (Costanza *et al.*, 1997; Fisher *et al.*, 2009). From 1998 onwards, research using the term “ecosystem services” grew exponentially and further scrutiny of the definitions’ terminology sustained (De Groot et al., 2002; Daily and Matson, 2008). Boyd and Banzhaf (2007) called for consistency in the definition of ecosystem services in order to move away from the use of coarse measurement units when describing the benefits of nature to humans. Forwarding a more detailed definition of ES as: *“components of nature, directly enjoyed, consumed, or used to yield human wellbeing.”* The definition stresses two main points, firstly the importance of perceiving ES as “components,” excluding any other words such as processes or functions as was promoted by (Daily, 1997). Secondly, ES needs to be “directly” used by humans and thereof, excluding the possibility of double counting. For example, natural assets that help in preventing flooding (e.g., wetlands) and human-made infrastructure (e.g., canals) are characterized as ecosystem services delivering flood control as the component (benefit) directly used/enjoyed by people (Boyd and Banzhaf, 2007).

Moreover, the importance of having consistent and precise terminology for ES definitions stems from the desire to have comparable classification systems across different contexts (Wallace, 2007). Recommendations by (Fisher *et al.*, 2009) calls for the use of a *‘fit-for-purpose’ approach* when creating ES classifications, meaning that classification systems should be built on *“characteristics of the ecosystem under investigation”* and *“the decision-making context for the ES under consideration.”* An example of ecosystem characteristics is Spatio-temporal dynamic, which takes into consideration that ES is not uniform. Instead, services vary in space and change with time, decision-contexts pertains to the need behind classifying ES, which could be for valuation purposes or might be to promote better understating of ES. Combining these two requirements with a clear and consistent definition of ES, will result in a classification systems that takes into consideration the complex interactions that goes into delivering ES (De Groot *et al.,* 2002; Fisher *et al.*, 2009).

2.2 Ecosystem services frameworks

The first framework is the **Millennium Ecosystem Assessment (MA;** Leemans and De Groot, 2003**),** which was initiated in 2001. The main aim of the project was to evaluate the changes in ecosystems and the consequences of human activities (Leemans and De Groot, 2003). The project was founded on the joint works of more than 1360 experts worldwide (Leemans and De Groot, 2003). The primary outcomes of the assessment concluded that ecosystems have been changing rapidly in the past 50 years compared to any other period; 60% of the 24 evaluated ecosystem services were damaged

(Hassan *et al.,* 2005). Increasing demand for natural resources is causing abrupt non-linear changes in ecosystems and dryland ecosystems where human populations are still growing are the most vulnerable (Hassan *et al.,* 2005; Leemans and De Groot, 2003). MA was considered the primary catalyst for transforming the relationship humans have with the planet (Marzec, 2018). In addition to assessing and collecting existing work on ecosystems conditions, MA founded the ecosystem services approach to classify and quantify *"the benefits people obtain from ecosystems"* focusing on the interplay between natural systems protection and human wellbeing, MA branded ES as a nexus between economics and ecology (Fisher *et al.*, 2009; Dodds and Friedrich, 2015). Figure 2 clarifies the four categories of ES in MA.

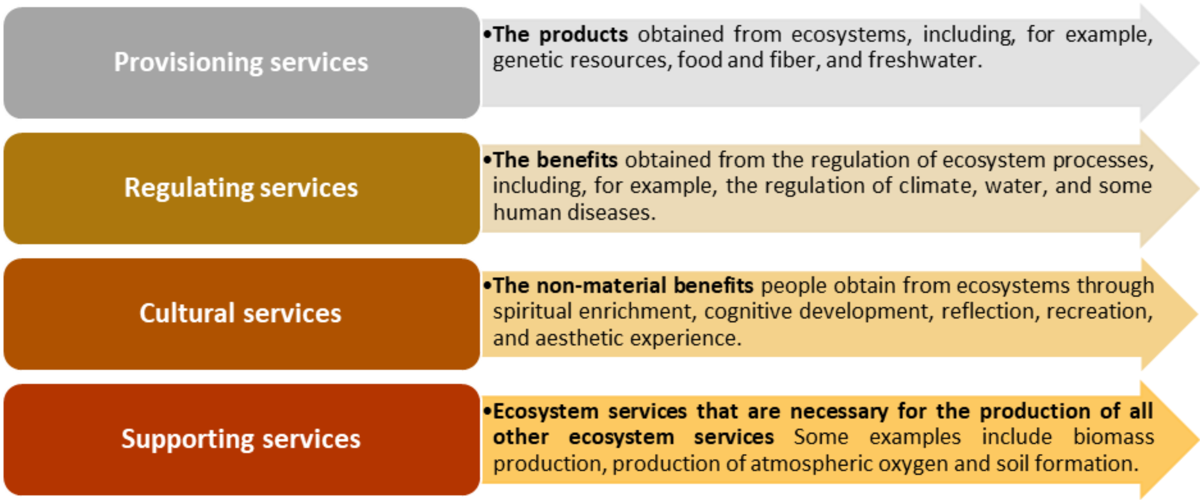


Figure 2: classification of ecosystem services according to MA, adapted from (Leemans and De Groot, 2003)

The MA classification served its purpose by creating dissemination channels for information on ecosystems' status, protection, and evaluation measures (Leemans and De Groot, 2003). Similar to the definition and classification offered by (Daily, 1997), MA classification is considered generic, fit for cultivating the awareness of the general public, but it should not be used as the sole base when quantifying and mapping ES (Carpenter *et al.*, 2009). Further scrutiny is needed to avoid double counting, define the differences, and arrive at a suitable terminology (Boyd and Banzhaf, 2007; Fisher *et al.*, 2009; Dodds and Friedrich, 2015). The MA was the first large scale pilot aiming to shift sociopolitical conceptual frameworks towards being more ecologically centered rather than being driven by economic growth, in which societies can come together to generate a new set of values and ethics allowing "the state of human and non-human existence" (Marzec, 2018). Although the MA did not have the main focus of the project on economic evaluation of ES, it paved the way for the second framework, **The Economics of Ecosystem Services and Biodiversity (TEEB),** to come to life in 2007 (TEEB, 2008). The main aim of the project revolved around estimating the cost of the loss of biodiversity and incorporating the cost of effective conservation into international policy work (Ring *et al.*, 2010). TEEB included three phases: The first phase focused on analyzing the current work on biodiversity, the second phase produced further analysis and reports targeting multiple levels (e.g., local, regional, international) and multiple users, the third phase focused on implementing TEEB approach and creating guidance material for different sectors (TEEB, 2008; Silvis, 2012). See Figure 3.

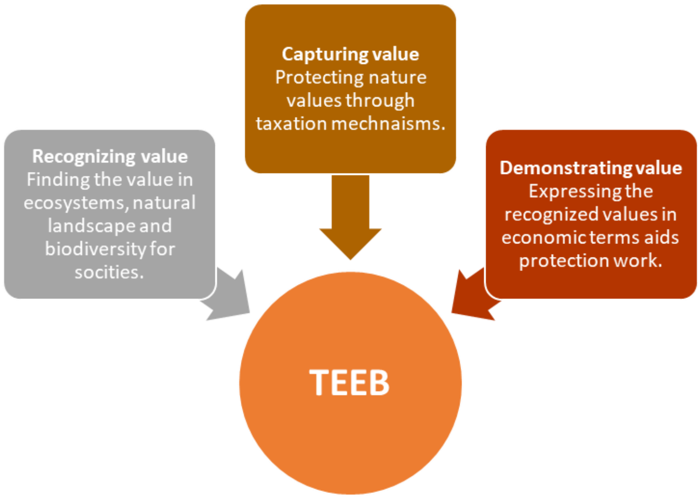


Figure 3: TEEB approach core principals, adapted from (TEEB, 2008)

TEEB outcomes emphasized that the higher the demand, the more marginalized ES values became (TEEB, 2008). Thus, the framework called for establishing an "insurance value," a threshold after which using economic evaluation on ES would be illogical (De Groot *et al.*, 2010). Moreover, TEEB recommended to cross economic valuation methods with spatially mapping ES, to identify service flows over different scales (Ashley, 2014; Dodds and Friedrich, 2015; Mongruel *et al.*, 2015). Following the work done by MA, the Environmental Audit Committee of the House of Commons found it necessary to conduct a similar assessment for the UK. The third framework is the **UK National Ecosystem Assessment (UK NEA),** which started in 2009. The aim was to track and generate data on the status of ES in the UK and to safeguard natural resources for future generations (UK NEA, 2011). The UK NEA was based on the work of more than 500 experts and is considered the first extensive assessment done for the UK. It concluded that 30% of the essential ES in the UK are declining (UK NEA, 2011; Watson *et al.*, 2011). Taking into consideration the work accomplished in MA and more recent methodologies to avoid double counting, the UK NEA framework has a similar classification as the one of MA (i.e. provisioning, regulating, cultural and supporting services) (UK NEA, 2011; Watson, 2012). However, it was customized based on eight habitat types occurring in the UK (e.g., Mountains, Moorlands and Heaths, Semi-natural Grasslands, Enclosed Farmland, Woodlands, Freshwaters—Openwaters, Wetlands and Floodplains, Urban, Coastal Margins, Marine). The UK NEA focused its hierarchy on illuminating the progression from ecosystem processes to the final value affecting human wellbeing, as shown in Figure 4 (Watson *et al.*, 2011; Waylen and Young, 2014).

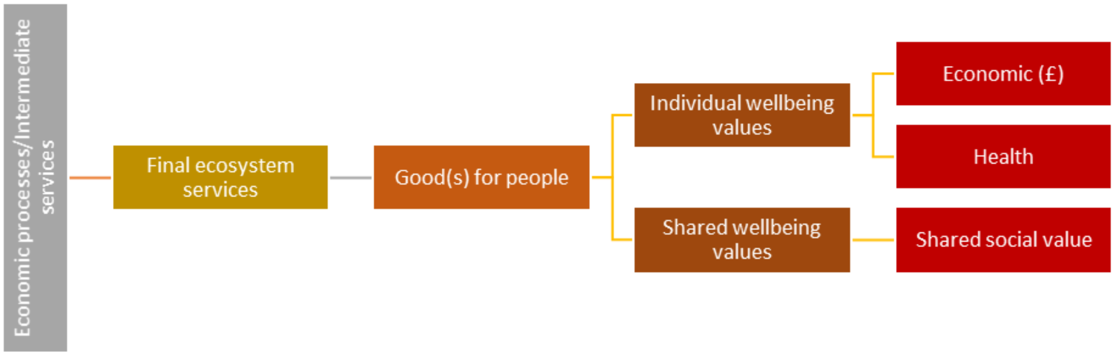


Figure 4: UK NEA framework hierarchy, adapted from (UK NEA, 2011)

UK NEA results indicate there is enough data to support the sustainable management of natural resources and that taking ES analysis and values within consideration can positively affect the decision-making process (Watson, 2012; Bateman *et al.*, 2014). The final framework is the **Common International Classification of Ecosystem Services (CICES)** founded on the works of MA in 2005; this framework focuses on identifying, assessing and accounting for ecosystem services, (CICES, 2013). CICES is ubiquitous in research focused on mapping and management of ES (Czúcz *et al.*, 2018). CICES defines ecosystem services as *"contributions that ecosystems make to human wellbeing"* (CICES, 2013). The main focus of CICES is towards classifying ES that results from living processes (biotic) and supports the supply of material and energy, regulates the environment for human benefit, and provides non-material benefits that enhance the mental health of humans, (Haines-Young *et al.,* 2014, 2017). In the latest version revised in 2018, CICES draws focus on ES produced by non-living physical and chemical processes (abiotic) and cultural services (Haines-Young *et al.,* 2018). The CICES supports a hierarchical classification of ES, in order to allow for a smooth transfer between different classifications (e.g., MA, TEEB) and to support classifying ES at different spatial scales (Turkelboom *et al.*, 2013). The framework classified ES into three main sections: provisioning, regulating & maintenance, and cultural services (Haines-Young *et al.,* 2018).

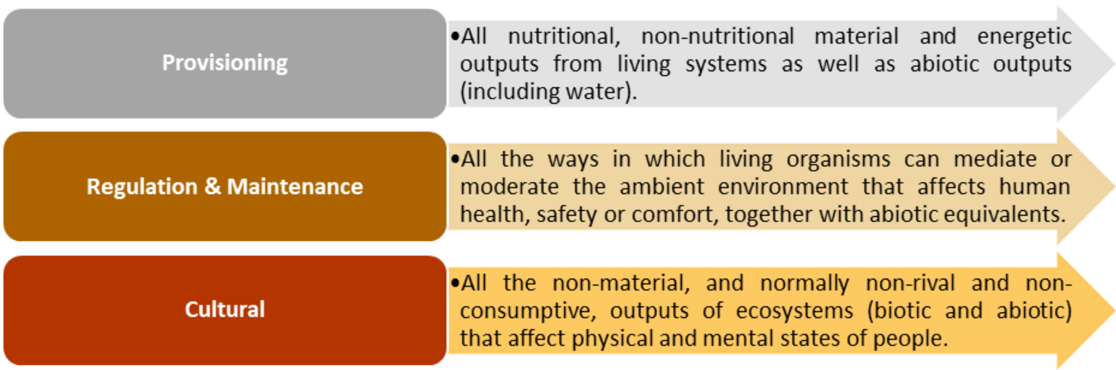


Figure 5: Main sections of ecosystem services in CICES, adapted from (Haines-Young et al., 2018)

In short, ecosystem services have multiple values that can be expressed through monetary terms or non-monetary terms (e.g., cultural significance and health) (Gómez-Baggethun *et al.*, 2010). However, most of the well-established frameworks (e.g., TEEB, UK NEA, MA), rely on attaching an economic value to ES, (TEEB, 2008; UK NEA, 2011). These methods are surrounded by criticism because the obtained values vary between different methods, have high uncertainties in some cases due to the lack of data, absence of distinct contextual elements and ethical consequences of assigning a monetary value to ecosystems and natural elements (Ashley, 2014; Dodds and Friedrich, 2015; Mongruel et al., 2015). It is vital to disseminate and adopt frameworks such as CICES, which focuses on standardizing the descriptions of ES and highlights the connections with previous ES frameworks (e.g., TEEB, UK NEA, MA) (CICES, 2013; Czúcz *et al.*, 2018). As mentioned before, ES is not uniform; services change with time and space (Fisher *et al.*, 2009). CICES brings attention to the importance of understanding the Spatio-temporal dynamic of ecosystems (CICES, 2013; Turkelboom *et al.*, 2013; Haines-Young *et al.,* 2018). Making ES spatially explicit is a step in the right direction to move away from attaching monetary values to ES into bringing focus on the relations ES has with the surrounding landscape and between each other (Fisher *et al.*, 2009; Czúcz *et al.*, 2018). Mapping the provision, synergies and trade-offs between ES and the surrounding environment can provide a solid ground for better understanding and managing natural resources, especially in highly urbanized areas, per the results of Mapping and Assessment of Ecosystems and their Services (MAES) project (Rocha *et al.*, 2015; Syrbe *et al.*, 2017). Following systemic approaches into defining and mapping ES, allows services to be attached to opportunities and new roles rather than merely a monetary term (Macdonald and Corson, 2012).

2.3 Urban ecosystem services

Urban ecosystems are defined as *"those areas where the built infrastructure covers a large proportion of the land surface, or as those in which people live at high densities"* (Pickett *et al.*, 2001). Although cities take up approximately 3% of land's surface, projections indicate that around 68% of the world's population will be living in urban areas by the year 2050 (UN DESA, 2019; United Nations, 2019). Urbanization is a dominant factor in global land-use change driven by population growth and economic development (Pickett *et al.*, 2001). As of 2018, 83.4% of the UK's population live in urban areas (ONS, 2019). Urban ecosystems are dependent on other ecosystems located outside the limits of the urban areas, to deliver essential needs (e.g. food, water, materials), and to process the waste created in urban settings (McGranahan *et al.*, 2005). Urbanization is a continuous and extensive trend, resulting in the loss of regulating and supporting functions within the urban environment (Pickett *et al.*, 2001; Spirn, 2003; McGranahan *et al.*, 2005). Urbanization is affecting the natural energy balance in cities and resulting in the Urban Heat Island (UHI) effect, where urban areas are at a higher temperature compared to rural areas, worsened by the lack of vegetation and widespread of impervious surfaces in urban centers (Kershaw *et al.*, 2010; Emmanuel and Krüger, 2012; Peng *et al.*, 2012). Furthermore, urbanization aids degradation of urban soils which leads to significant hazards such as flash floods (Wheater, 2006; Rawlins *et al.*, 2015; England *et al.*, 2018) and urban air quality has changed dramatically through the past 60 years; these effects transcend the urban boundary (Davies *et al.*, 2011). Identification of clear boundaries for urban ecosystems have proven to be difficult because services stemming from urban ecosystems are dependent on interactions taking place beyond the urban area boundaries, which are plotted through a mix of land use categories and census data, varying for each country (Gómez-Baggethun *et al.*, 2013). Therefore, it is vital to study and analyze ecosystem services potential in urban areas (Rees *et al.,* 1996). Implementing an ecosystem services approach in urban planning of dense city centers represents a critical opportunity to restore cities' connection with nature, to reduce the dependence of urban ecosystems on external ecosystem services and to create resilient cities (Pickett *et al.*, 2001; Gómez-Baggethun *et al.*, 2013; Handel *et al.,* 2013).

The UK NEA framework recognized the potential of urban areas in offering multiple ecosystem services (Davies *et al.*, 2011). UK NEA Identified urban areas as a habitat, amongst the eight broad habitat categories classified by the framework (e.g. Mountains, Moorlands and Heaths, Semi-natural Grasslands, Enclosed Farmland, Woodlands, Freshwaters—Openwaters, Wetlands and Floodplains, Urban, Coastal Margins, Marine) (UK NEA, 2011). Although there is not an absolute agreement on the characteristics of urban habitats, (OECD, 2010; Davies *et al.*, 2011), the UK NEA used the term **'green spaces'** to describe specific components of the urban environment that can offer ecosystem services, that positively affects human wellbeing, (Davies *et al.*, 2011). UK NEA Green spaces include a set of subhabitats, see Figure 6. According to the UK NEA classification, urban canals encompass multiple sub habitats, mainly green corridors (i.e., canal banks), water, and Previously Developed Land (PDL), (UK NEA, 2011). Green corridors are valued for their role as transportation links, wildlife pathways for increasing biodiversity within urban areas, and providing cultural services for residents, (Wilby and Perry, 2006; Davies *et al.*, 2011; UK NEA, 2011), (see Table 1).

Glasgow city has the highest concentration of brownfields (i.e., PDL) in Scotland, regenerating derelict and vacant land has been a significant priority for the Glasgow city council, (Glasgow City Council, 2019). Brownfields could be remediated and protected because of its role in species diversity and climate/flood regulation, or redeveloped for residential, transportation and recreation purposes (e.g., NGIWMS site) (Schadek *et al.*, 2009; Davies *et al.*, 2011; Glasgow City Council, 2019). Water sub-habitat aims to differentiate between natural and artificial water bodies in urban areas, as urban water bodies receive a higher percentage of pollutants (e.g., road runoff and wastewater sewers) which might affect the level of services it provides, (Davies *et al.*, 2011), (see Table 1). Although the UK NEA framework does not explicitly quantify services coming from the urban environment itself, instead, it sheds light on the synergies and trade-offs between its eight broad habitats (UK NEA, 2011).

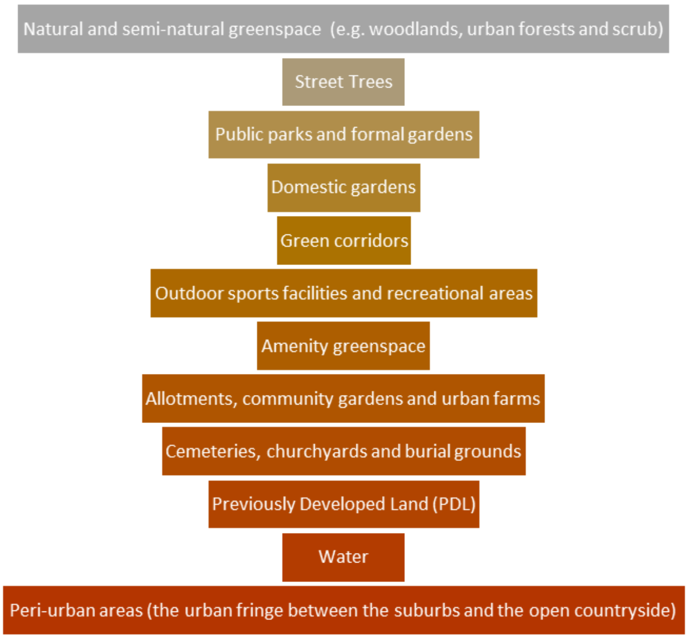


Figure 6: Subhabitats within greenspaces, adapted from (Davies et al., 2011)

Gómez-Baggethun *et al.*, (2013), highlights that urban ecosystems come to exist through a set of interactions between the '**built infrastructure'** (i.e. any human-made elements in urban areas) with the '**ecological infrastructure'** (i.e. water and vegetation in or near the built environment). These interactions take place in all green and blue spaces in urban areas (e.g., parks, cemeteries, gardens, urban allotments, urban forests, single trees, green roofs, wetlands, streams, rivers, lakes, and ponds), and are considered significant because it delivers 'direct' benefits for humans living in cities (EEA, 2011). Urban canals are a perfect example of this interaction between the built and ecological infrastructure, aiding in urban temperature regulation, promoting species biodiversity and providing recreational areas (Middleton *et al.*, 2004; Angold *et al.*, 2006; Žuvela-Aloise *et al.*, 2016; McKean *et al.,* 2017). See Table 2. Likewise, the European Environment Agency called for the integration of the built and ecological infrastructure, putting the way forward for investing and capitalizing on the services offered by '**Green Infrastructure (GI)'** in urban ecosystems (Forest Research, 2010; EEA, 2011). The most cited definitions for GI are included in Figure 7; these definitions highlight the importance of properly defining the scale and assets/components of GI, in order to accurately map and quantify ecosystem services stemming from GI in urban ecosystems (EEA, 2011).

Commission for Architecture and Built Environment (CABE)	European Commission	Natural England
• GI is the network of natural places and systems in, around and beyond urban areas. It includes trees, parks, gardens, allotments, cemeteries, woodlands, green corridors, rivers and wetlands. • **Disciplines:** Urban design. • **Key benefits:** Recreation. • **Scale:** Urban and beyond.	• GI maintains and improves ecological functions in combination with multifunctional land uses. Natural and 'man-made' structures or a territory devoid of permanent man-made structures that provide — directly or indirectly, partly or totally — through the vegetation it supports, a series of services to society. • **Disciplines:** Species conservation. • **Key benefits:** Multifunctional. • **Scale:** Landscape.	• GI is a strategically planned and delivered network of high-quality green spaces and other environmental features. It should be designed and managed as a multifunctional resource capable of delivering a wide range of environmental and quality-of-life benefits for local communities. Green infrastructure includes parks, open spaces, playing fields, woodlands, allotments and private gardens. • **Disciplines:** Land conservation • **Key benefits:** Recreation • **Scale:** Urban.

Figure 7: Most cited definitions of green infrastructure, adapted from (EEA, 2011)

Urban canals are classified to have effects on a 'city and district-scale' (EEA, 2011; Copas and Phillips, 2013), serving as a component of GI, providing direct benefits to people through local climate regulation, recreation, and improved wellbeing (Sheate *et al.*, 2008; EEA, 2011) (see Table 3). Having multiple definitions to describe the state of natural elements in the urban environment; clearly, indicates a need for systematic monitoring of greenspaces, ecological infrastructure and GI in urban areas, in order to be able to quantify its services accurately and identify synergies and trade-offs within urban ecosystems (Forest Research, 2010; EEA, 2011; Davies *et al.*, 2011). It is evident that the urban environment has a limited presence of provisioning services delivered by urban ecosystem components (e.g., GI, green spaces and ecological infrastructure), supplies of crops, livestock, drinking water and other essential services for human life, are mainly sourced from ecosystems outside the urban boundaries, (Gómez-Baggethun *et al.*, 2013). Although in recent years there has been an uprise in the production of food in urban and peri-urban areas, through the utilization of rooftops, backyards and community gardens, this only represents a small percentage of the food demand of cities (Martellozzo *et al.*, 2014; White and Bunn, 2017). Similarly, using urban water bodies to meet a percentage of cities' demand for drinking and irrigation water (Ernstson *et al.*, 2010; EEA, 2011; Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013). Conversely, regulating, and cultural services retrieved from urban ecosystem components are growing (Gómez-Baggethun *et al.*, 2013). Greenspaces, encourage social cohesion and enhancing the physical and mental health of adjacent residents (Davies *et al.*, 2011). Ecological infrastructure is tied with increasing resilience of cities and reducing its susceptibility to acute shocks (Gómez-Baggethun *et al.*, 2010, 2013), and GI has positive effects in the areas of urban ecosystems protection and maintenance (Wakenhut, 2010; EEA, 2011). See Table 1, Table 2, Table 3.

Table 1: Urban ecosystem services supplied by greenspaces, adapted from (UK NEA, 2011)

Ecosystem Service	Final Ecosystem service	Description of the primary goods and benefits from the urban environment
Provisioning	Crops, plants, livestock, fish	Food: e.g., vegetables, fruit, meat, milk, honey
		Fiber: e.g., compost
		Ornamental: e.g., flowers
		Genetic resources
	Trees, standing vegetation and peat	Trees: e.g., timber, wood chippings
		Fuel
	Water supply	Drinking water
		Industrial use of water
		Energy
Provisioning/Cultural	Wild species	Wild food: e.g., berries
		Recreation and tourism
Regulating	Climate	Avoidance of climate stress
		Carbon sequestration
	Hazard	Erosion protection
		Flood protection
	Purification	Clean air
		Clean water
		Clean soil
	Noise	Noise reduction
Cultural	Environmental Settings	Physical and mental health
		Spiritual and religious: e.g., churchyards and cemeteries
		Heritage: includes cultural heritage, aesthetic and inspirational, security and freedom, neighborhood development, social and environmental citizenship
		Recreation and tourism
		Education

Table 2: Urban ecosystem services supplied by ecological infrastructure, adapted from (Gómez-Baggethun et al., 2013)

Ecosystem Service category	Ecosystem service	Description/examples
Provisioning	Food supply	Products produced in urban and peri-urban farms, rooftops, and community gardens (e.g., agricultural products, eggs, and meat).
	Water supply	Urban water bodies provide water for agricultural, industrial, and recreational uses.
Regulating	Urban Temperature Regulation	Urban water areas and surrounding vegetation ameliorate temperature extremes.
	Noise Reduction	Urban soil and plants reduce noise pollution.
	Air Purification	Vegetation in urban systems can improve air quality by removing pollutants from the atmosphere.
	Moderation of Climate Extremes	Mangroves, deltas, and coral reefs can be used in coastal cities to reduce the impacts of flooding, storms—urban vegetation used to stabilize landslides.
	Runoff Mitigation	Green roofs, bio-swales, street trees, and other ecological infrastructure reduce stormwater runoff.
	Waste Treatment	Plant communities in urban soils, play a role in waste decomposition—nutrient retention in urban streams.
	Pollination, Pest Regulation, and Seed Dispersal	Private and community gardens, green assets of ecological infrastructure promote species biodiversity.
	Global Climate Regulation	Urban vegetation and soil play a role in carbon sequestration.
Cultural	Recreation	Parks, forests, lakes, and rivers.
	Aesthetic Benefits	Urban green areas are associated with reduced stress levels and better mental health.
	Cognitive Development	Urban green areas can be used for educational purposes.
	Place Values and Social Cohesion	Sense of place and emotional attachment to green and blue urban areas.
Habitat	Habitat for Biodiversity	Birds, bees, and butterflies seek refuge in ecological infrastructure.

Table 3: Benefits supplied by green infrastructure, adapted from (Forest Research, 2010)

Green Infrastructure Functions	Green Infrastructure Benefits
Adaptation to and mitigation of climate change	Heat amelioration
	Reducing flood risk
	Improving water quality
	Sustainable urban drainage
	Improving air quality
Health and wellbeing	Increasing life expectancy and reducing health inequality
	Improving levels of physical activity and health
	Improving psychological health and mental wellbeing
Economic growth and investment	Inward investment and job creation
	Land and property values
	Local economic regeneration
Land regeneration	Regeneration of previously developed land
	Improving the quality of place
	Increasing environmental quality and aesthetics
Wildlife and habitats	Increasing habitat area
	Increasing populations of some protected species
	Increasing species movement
Stronger communities	Social interaction, inclusion, and cohesion

Urban ecosystems are capable of offering essential services and benefits that can positively affect human wellbeing and reduce urban areas' dependence on external ecosystem services (Gómez-Baggethun *et al.*, 2013). However, ES provided by the urban environment is still prone to damage due to urbanization, changes in demographic trends, and economic development (Elmqvist and Mcdonald, 2014). These changes can negatively affect cities by increasing the percentage of impermeable surfaces and pollution, especially in highly dense city centers (Davies *et al.*, 2011). So far, there is not a single inventory directed towards understanding urban ecosystem services potential in the UK; for Scotland, urban ES inventories only exist at an aggregate national scale (Green *et al.*, 2011).

Furthermore, UK NEA, (2011) highlighted some of the critical challenges surrounding urban ecosystem services assessment, mainly: a different typology between multiple sources (i.e., multiple terms exist in literature to describe urban ecosystem components (greenspaces, ecological infrastructure, and GI), lack of a single certified platform to assemble existing information on urban ecosystem assessments, where current data is available at different spatial and temporal scales at multiple organizations and the absence of long term monitoring and follow up between organizations on the status of urban ES (Green *et al.*, 2011; Davies *et al.*, 2011). Therefore, it is essential to support urban ecosystem services with empirical evidence (e.g. the role of urban green/blue spaces in delivering ES) (Green *et al.*, 2011; Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013; Handel *et al.,* 2013).

2.4 Mapping ecosystem services

Glasgow city is the largest in Scotland and the third biggest city in the UK (MacKenzie, 2017). Established around the banks of the River Clyde and had a continuous expansion into the riverbed through the industrial revolution (Damer, 2017; Richter, 2017). The city's character is intertwined with its rivers, resulting in a significant influence on the city's development and relationship with the natural environment (Green *et al.*, 2011; Richter, 2017; Jones, 2019). The city is aiming to build a clean and resilient environment based on knowledge and service transfer (Evans and Johnston, 2019). That requires facing many future challenges affecting the city, where Glasgow is projected to have the highest population out of the 32 council areas in Scotland by 2028 (NRS, 2020), which translates into an increasing demand on housing and access to greenspaces (Glasgow City Council, 2017; England *et al.*, 2018).

In 2008, Glasgow was classified as one of the most urbanized cities in Scotland, represented by an increase in the percentage of impermeable surfaces (2-5% increase for Glasgow between 2008-2015) (ClimateXChange, 2016; England *et al.*, 2018). Thus, amplifying the number of houses at risk of flooding by surface water (SEPA, 2015). Climate change will exacerbate these challenges and result in more threats (e.g. extreme weather, changes in temperature, high risk of flooding) (England *et al.*, 2018; Scottish Government, 2019). All the more reason to focus on mapping and evaluating ES within the urban environment (e.g. canals, parks, lakes, and green roofs) (Jacobs *et al.,* 2017). Systemic mapping and assessment of urban ES facilitate a deeper understanding of future trade-offs and synergies within the urban environment and aids in creating a balance sheet for urban ES (Tratalos *et al.*, 2007). Thus, allowing for the multifunctional management of resources (Tratalos *et al.*, 2007; Green *et al.*, 2011; England *et al.*, 2018).

First publications on ES mapping were around 1996, since then mapping ES proliferated corresponding to advances in technology (e.g. GIS and modeling), which fortified the use of ES maps in establishing a connection between ES and the surrounding landscape (Jacobs *et al.,* 2017). ES maps could be used to facilitate sustainability-based decision making (Söderman *et al.*, 2012), raise public awareness (Niemelä *et al.*, 2010), serve as a base for ES accounting and assessment (Rocha *et al.*, 2015), minimize the gap between supply and demand (Ashley, 2014), illustrate ES bundles (Dittrich *et al.*, 2017), identify trade-offs and synergies (Fernandez-Campo *et al.*, 2017) and recognize ES stakeholders at different spatial scales and time intervals (Jacobs *et al.,* 2017; Syrbe *et al.*, 2017). Future urban policies for Glasgow city are focused on meeting the Sustainable Development Goals (SDGs) set by the United Nations (UN), especially "SDG11: Sustainable cities and communities", focused on creating a robust environment capable of delivering accessible urban ES (England *et al.*, 2018; United Nations, 2019).

Urban environments are relatively complicated, and mapping urban ES does not come under a general framework, as each case has its requirements (Martnez-Harms and Balvanera, 2012). Key ES in cities stems from trees, parks, private and community gardens, urban forests, and urban water bodies (Davies *et al.*, 2011). Mapping Urban ES by using GIS starts by following a tiered approach based on the primary goal of mapping to identify the most suitable level of mapping and analysis (Grêt-Regamey *et al.*, 2015), as shown in *Figure 8*. The Goals set by the EU biodiversity strategy in 2011 endorsed the importance of mapping ES, catalyzed valuing ES, and the uptake of GI within EU territories (European Commission, 2011). Mapping ES became mainstream in research, and there was an evident need to regulate the process (Dodds and Friedrich, 2015). Most popular blueprints for regulating ES mapping established that mapping ES is a data-dependent process (Rees *et al.*, 2012; Crossman *et al.*, 2013; Hooper *et al.*, 2014). The availability of data governs what ecosystem services are mapped (Maes *et al.*, 2012).

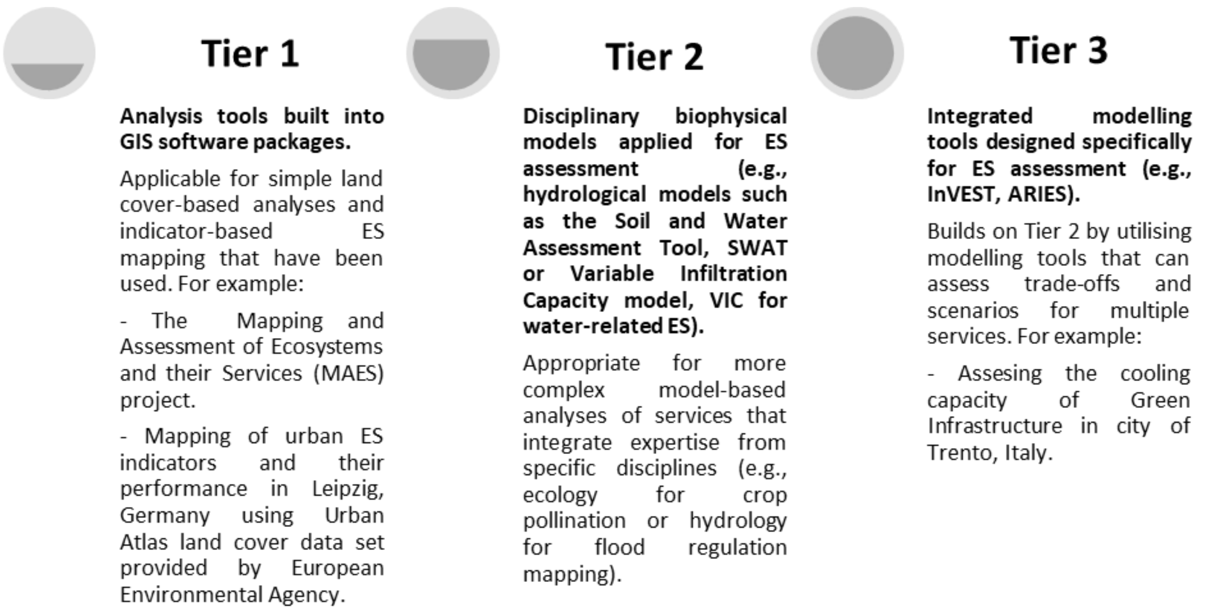


Figure 8: ES mapping tiers with increasing complexity, adapted from (Grêt-Regamey et al., 2015)

Furthermore, reviews highlighted that mapping so far has been focused on regulating services using secondary data (e.g. land use/cover, vegetation, soil) rather than tailored field data for each case study, mostly covering large areas of regional and provincial scales (Martnez-Harms and Balvanera, 2012). Currently, the most mapped ES are the ones used in decision making, namely carbon storage and sequestration, food production and Greenhouse Gases (GHGs) regulation, compared to other critical services such as pollination, disease control, and cultural value, which have an essential effect in preservation of ecosystems and human wellbeing (Maes *et al.*, 2012; Martnez-Harms and Balvanera, 2012; Rees *et al.*, 2012; Crossman *et al.*, 2013; Hooper *et al.*, 2014). It is essential to acknowledge that maps are powerful tools of expression that affect the decision-makers' perception of some issues due to the maps' ability to simplify complicated processes and cover the lack of specific data (Malinga *et al.*, 2015). Thus, ES maps should be handled attentively to avoid misguided decisions (Martnez-Harms and Balvanera, 2012). Mapping ES in the urban environments requires a precise terminology for ES potential sources and comprehensive data to produce reliable estimates of ES supply (Martnez-Harms and Balvanera, 2012; Malinga *et al.*, 2015; De Valck *et al.*, 2019).

Moreover, the ecosystem services approach was first introduced by MA to describe the benefits humans receive from ecosystems and to validate that human wellbeing, and healthy ecosystems are codependent (Dodds and Friedrich, 2015). Since then, the ES approach evolved to be used as an environmental protection tool, highlighting the connection between ecosystems degradation and the loss of benefits (Ashley, 2014). Granek *et al.* (2010), illustrated the potential of using the ES approach as a common language to promote ecosystem-based management in the case of marine and coastal environments. The EU endorsed Ecosystem-based management for its ability to incorporate environmental protection and sustainable development into marine governance (Dodds and Friedrich, 2015). Consequently, multiple policies and regulations for the EU called for the adoption of an ecosystem-based management approach towards planning and resource management (Dodds and Friedrich, 2015; Mongruel *et al.*, 2015). An essential constituent of the ES approach is a call to map environmental benefits (Maes *et al.*, 2012). Mapping benefits are centered on "*defining presence and intensity of benefits within spatially explicit units.*" Thus, mapping is considered the first step towards accurately valuing and visualizing ES (Crossman *et al.*, 2013; Dendoncker *et al.*, 2013).

However, there is an evident lack of mapping and evaluation information of ES within the urban environment in the UK (Green *et al.*, 2011; Davies *et al.*, 2011). Since 2002 the Scottish Natural Heritage launched the 'Greenspace Scotland' project aimed towards tracking and digitally mapping green spaces in Scotland for planning purposes (Greenspace Scotland, 2018). The project stressed the importance of understanding ES delivery at multiple spatial scales to achieve effective planning (Davies *et al.*, 2011; Greenspace Scotland, 2018). There is a need to invest in the expansion of mapping tools from a landscape level to the municipal level, drawing focus on mapping green infrastructure elements (e.g., rivers, canals, ponds, lakes) which aids to reinforce the role of these elements as ecological and wildlife corridors in the urban environment (EEA, 2011; Gómez-Baggethun *et al.*, 2013; Handel *et al.,* 2013).

2.5 Adapted case studies

Canal systems are considered to be vital but equally sensitive elements of urban ecosystems (McKean *et al.,* 2017). Scotland's canals are an illustration of past and present events, a timeline for the country's history (Canal and River Trust, 2015; McKean *et al.,* 2017). In Glasgow, the Forth & Clyde canal serves as a representation of the industrial past of the city, and since its revival as a cruising canal, it provided a destination for local and national recreation (e.g. Falkirk Wheel, paddle sports center, festivals) (Transport Scotland, 2013). The historical status of the canals makes its management and development a delicate matter, implementing an ecosystem-based management approach is a step in the right direction to understand the Canal's potential to deliver direct benefits for people and to enhance land planning around the canals (Ashley, 2014; Scottish Canals, 2015). Identifying and mapping ES coming from the Smart Canal project area will help in understanding the new role of the Canal as an adaptable ecological infrastructure, responsible for the delivery of a set of provisioning, regulating and cultural services (EEA, 2011; Maes *et al.*, 2012; Gómez-Baggethun *et al.*, 2013).

Buckman, (2013) defines Canal oriented development (COD) as *"a placemaking concept that aims to create mixed-use developments along canal banks using the image and utility of the waterfront as a natural attraction for social and economic activity."* COD proved to be a successful concept in canal regeneration projects, especially in highly urbanized cities (Buckman, 2013, 2014). Implementing COD allows canals to be viewed as indispensable elements of the urban environment capable of attracting people, forming communities, and generating income (Ellin, 2010; Buckman, 2013, 2014, 2016). A set of design principles governs the success of COD delivery, mainly *Preservation* of the canal infrastructure is essential; it should be frequently maintained given its status as a protected monument and an open-water public space. *Integration* where canals need to be integrated into the urban environment by connecting with other green and blue spaces, promoting multiple uses in the everyday life of city dwellers. Canals need to provide high levels of *Accessibility*, on physical, visual, and temporal scales. The Canal needs to promote a specific *identity* that relates to the residents and agrees with the city's regional image. Also, when focusing on COD, it is essential to maintain the C*ontinuity* of the Canal, making sure that any developments do not alter the natural flow of water. Equally important is the *Diversity* of the canal, ensuring that the developments offer a diverse selection of activities, uses, and landscape that serves all age groups and the final principal is S*afety*, where the canal environment needs to be secure, clean and inviting, Figure 9 (Fifield *et al.*, 1990; Buckman, 2014).

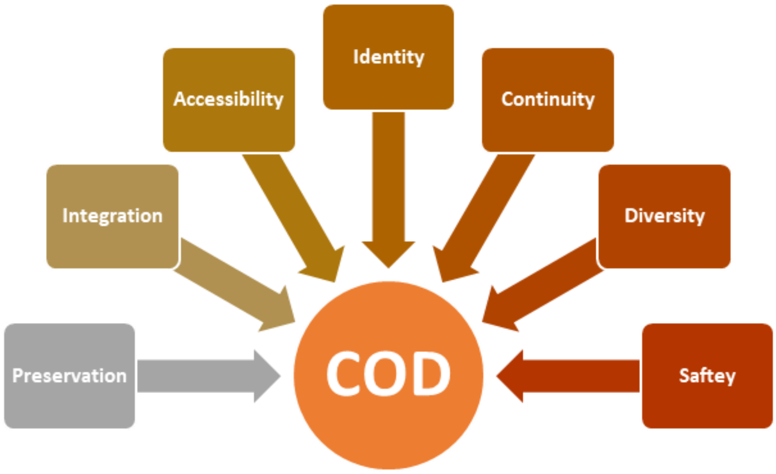


Figure 9: Design principles of COD, adapted from (Buckman, 2014)

It seems that tapping into the true potential of canal systems is not an easy task. However, having a better understanding of what ES stems from the Canal and considering all the dynamics needed for a successful COD, can result in attaching a new role for canals, rebuilding its image in the urban environment, increase economic revenues and building a sustainable public space (Buckman, 2014, 2016). The following case studies Table 4, Table 5, Table 6, Table 7 demonstrate the success of regeneration projects based on intertwining planning with an ecosystem-based approach around water bodies.

Table 4: Kent Thameside, adapted from (Sheate et al., 2008; Davies et al., 2011)

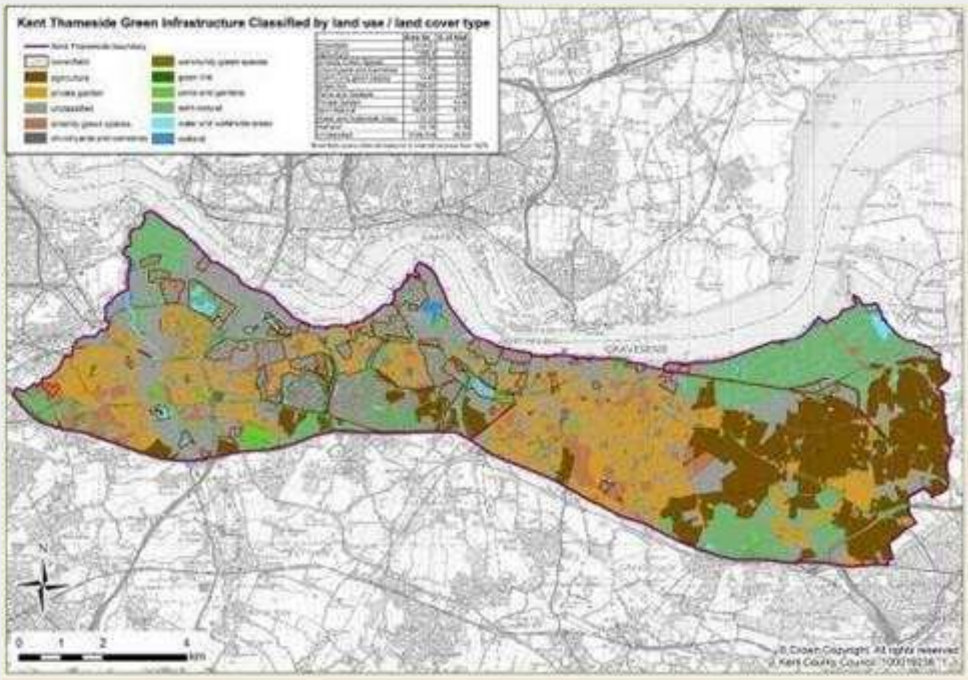
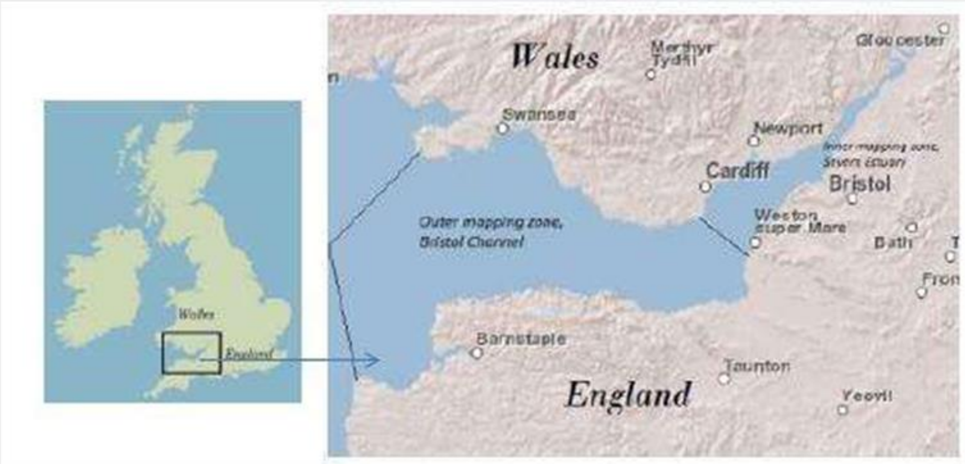
Case study 1: Developing tools and methodologies to deliver an ecosystem-based approach — Kent Thameside.	
	
Aim	The main aim was to assess the types of ecosystem services presented by green spaces in an area undergoing extensive urban regeneration and to identify the best method for evaluation.
Methodology	• **Stakeholder engagement:** to produce a typology for ES in Kent Thameside • **Network analysis:** to understand the relationships between ES typology and different open space/Green Grid land use/land cover categories (e.g., STELLA). • **Geographic Information System (GIS):** used for spatial data analysis
Outcome	• The study has shown it is possible to map potential ecosystem services using existing GIS datasets. The ability to map ecosystem services in this way offers real benefits to spatial planning, particularly in promoting multifunctionality. • Ecosystem services can be related to land use/land cover categories, rather than merely to habitats since this approach is more appropriate for spatial planning within an urban context. • There is scope for using a more extensive range of datasets than those utilized in this study, e.g., air quality, water quality, and biodiversity action plan data. The focus of this study was on testing the applicability of the tools, rather than trying to produce definitive maps. • GIS and network analysis could not do in this project were quantify the amount of an ecosystem service that was present or desirable. • Stakeholder response to ES typology linked water bodies and waterside areas, including (coasts, rivers, river frontages, canals, ponds, lakes, and lakeside areas) with improving health, wellbeing, and recreation
Relevance to the study area	• The network analysis (i.e., STELLA) results and stakeholder feedback, provided valuable information for understanding greenspaces functionality and ability to produce ES, which assisted in finalizing the list of essential ES present in/around the Forth and Clyde Canal (i.e., Smart Canal project area).

Table 5: Severn Estuary and inner Bristol Channel, adapted from (Ashley, 2014)

<table>
<tr><th colspan="2">Case study 2: Ecosystem service mapping in the Severn Estuary and inner Bristol Channel</th></tr>
<tr><td colspan="2">


</td></tr>
<tr><td>Aim</td><td>The project aimed to assess and map the delivery of crucial ecosystem services within the greater Severn Estuary and Bristol Channel, through the identification of hotspots for key ES. The research objectives were to:
• Identify and assess five key ES
• Map ES and related activities within the Geographical Information System.
• Explore potential valuation approaches to add scales to the benefits of the services and
• Communicate the findings to key stakeholders.</td></tr>
<tr><td>Methodology</td><td>• Stakeholder engagement: to determine key ES
• Geographic Information System (GIS): Mapping ES.</td></tr>
<tr><td>Outcome</td><td>• Assessment and mapping of supply of crucial ES highlighted the importance of the greater Severn and inner Bristol Channel in delivering ES that provides benefits to communities, both locally and internationally.
• The study highlighted the importance of mud bank habitats and the intertidal saltmarsh habitats for flood risk management, carbon sequestration and burial (storage), archaeological resources, and wild food and fisheries.
• Promotion of water-dependent ecosystem services.
• The stakeholders well received the mapping method in the project, and the visualization of key ES in the area facilitated productive discussions.</td></tr>
<tr><td>Relevance to the study area</td><td>• Mapping and analysis of ES in this study facilitated a better understanding of the nature of the data needed for mapping ES, criteria controlling each ES (e.g., landuse type, vegetation cover, topography) and ultimately helped in shaping the methodology for analyzing ES in the Forth and Clyde canal (i.e., Smart Canal project area).
• Provided a better understanding of the role/importance of channels as recreational destinations</td></tr>
</table>

Table 6: Mapping Urban ES in Leipzig, Germany, adapted from (Zulian et al., 2017; Kabisch, 2019)

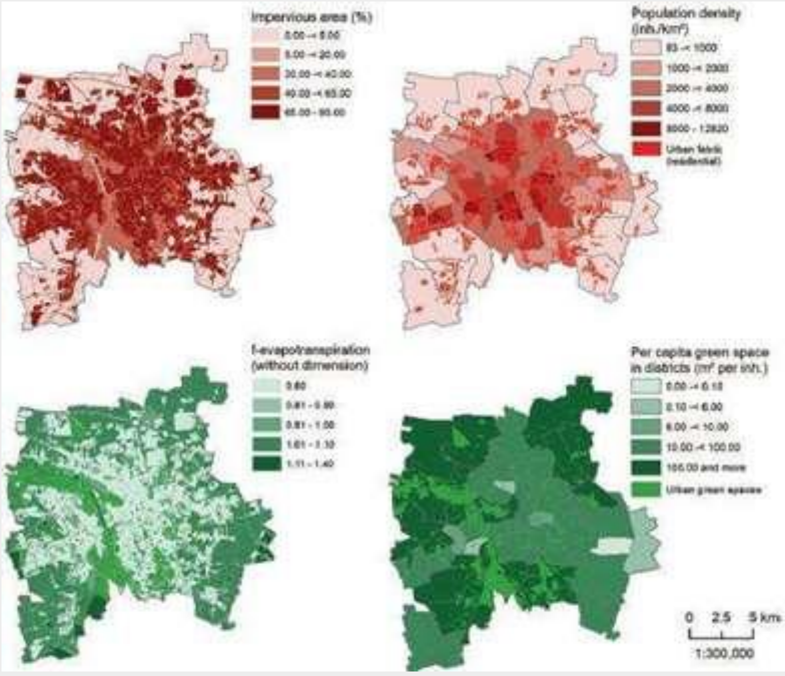
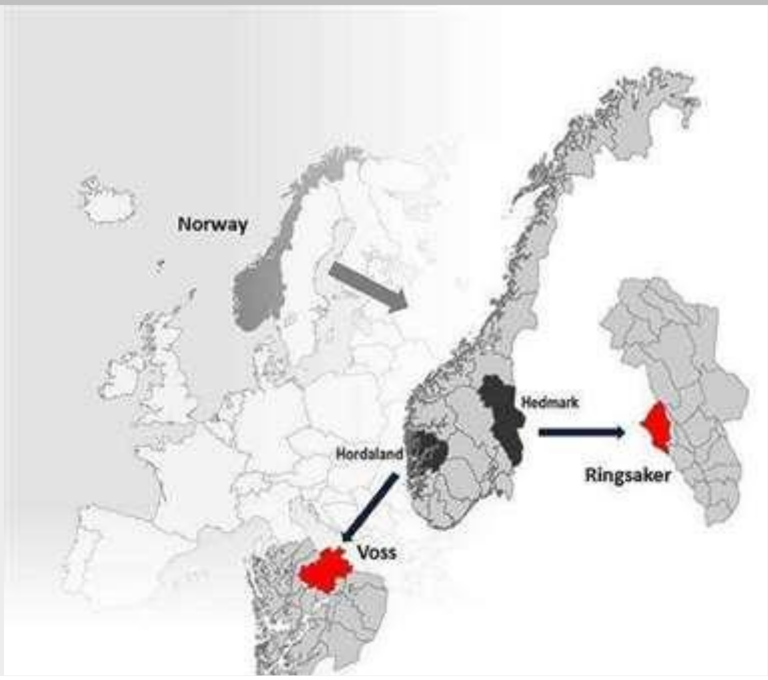
Case study 3: Urban Ecosystem Service Provision and social-environmental Justice in the City of Leipzig, Germany	
	
Aim	The main aim of the research was to address the effects of urban growth on urban green spaces. To identify the nature of pressures on green spaces and how it affects the provision (supply) of recreational and regulating ecosystem services in Leipzig city—also highlighting the role of urban growth in increasing inequality regarding access to certain urban ecosystem services.
Methodology	• GIS-analysis based on Urban Atlas land cover data set, provided by the European Environmental Agency • Use of the indicators of population density, impervious surface, f-evapotranspiration and per capita green space
Outcome	• Ecosystem service supply is highest in Leipzig's urban forest and water areas near the floodplains of the city. • Ecosystem services supply is lowest in the dense inner-city areas that are characterized by very high degrees of imperviousness. • Ecosystem services will further decrease due to continuous development pressures from ongoing population growth. • New urban development strategies should focus on integrating residential development with green space development. • Areas with a high supply of ecosystem services might experience a tendency to increase property values, which might lead to "green-gentrification."
Relevance to the study area	• The results of this study provided a deeper understanding of the potential of each greenspace and land cover to provide ES, especially in a highly urbanized area, helped to scrutinize the input data further and provided a better understanding of the value of urban water streams and its role in the urban environment.

Table 7: Ecosystem services mapping for two Norwegian municipalities, adapted from (Fernandez-Campo et al., 2017)

Case study 4: Ecosystem services mapping for detection of bundles, synergies, and trade-offs: Examples from two Norwegian municipalities	
	
Aim	The main aim of the research was to analyze how increased levels of harvesting for bioenergy production might affect other ecosystem services in the Ringsaker and Voss municipalities in Norway. This analysis initiated by identifying locations where synergies and conflicts between ES might occur. The mapping covered eight ecosystem services in total (three provisioning, three regulating, and two cultural services).
Methodology	• GIS-based multi-criteria analysis of spatially explicit data to produce ES supply maps. • Moving-window techniques. • Used map algebra to create binary maps for ES bundle and trade-offs.
Outcome	• An easily adaptable methodology presented in this research for the mapping and analysis of ES potential supply • The methodology serves as a decision support tool, providing a deeper understanding of ecosystem services allocation in an area of interest.
Relevance to the study area	• The easily adaptable method was used to analyze the Forth and Clyde canal (i.e., Smart Canal project area). • Analysis of synergies and tradeoffs provided a more in-depth understanding of the complex relationships among ES in the study area.

3
METHODOLOGY

Based on the previous literature in chapter 2, it was evident that urban ecosystems are capable of producing essential ecosystem services, positively affecting the urban environment and its inhabitants' (Gómez-Baggethun *et al.*, 2013). However, urban ecosystems are fragile and reside under increasing pressures of urbanization, population growth, and climate change (Elmqvist and Mcdonald, 2014). Therefore, there is an adamant need to increase the levels of mapping, monitoring, and valuing of ecosystem services stemming from urban ecosystem elements such as urban canals, parks, trees and ponds (EEA, 2011; Gómez-Baggethun *et al.*, 2013; Handel *et al.,* 2013). The following methodology is designed to map the ES offered by the Forth & Clyde canal, aiming to reinforce the role of the canal as a vital element of the urban environment (EEA, 2011; Gómez-Baggethun *et al.*, 2013; Handel *et al.,* 2013).

3.1 Study area

Scotland's canals are one of the most famous canals in the UK for its history and role as transportation routes (Transport Scotland, 2013). Currently, Scotland's canals are listed as scheduled monuments and are recognized as an essential part of Scotland's heritage (Paxton *et al.,* 2000; Canal and River Trust, 2015; McKean and Lennon, 2017). The Forth & Clyde canal ('the Canal' in further text), in particular, runs through the most deprived areas in the country, and this is one of the main reasons that the Canal and its surrounding areas are a part of large-scale regeneration projects (Transport Scotland, 2013; England *et al.*, 2018). Since the rebirth of the Canal through the Millennium Link project in 2001, it became evident that the Canal can play an integral role in delivering desperately needed public benefits in surrounding urban areas (Transport Scotland, 2013; McKean *et al.,* 2017).

Furthermore, Glasgow city has a wetter and colder climate compared to other parts of the UK, coupled with high levels of social inequality and deprivation (Scottish Government, 2019). Climate change impacts over Glasgow city include extreme weather, changes in temperature and precipitation, and flooding (Adaptation Sub-Committee, 2011; Kazmierczak *et al.*, 2015; ClimateXChange, 2016; England *et al.*, 2018). The most significant flooding risk in Glasgow city is associated with surface water flooding due to a high percentage of impermeability (caused by the removal of vegetation and building over greenspaces) (SEPA, 2015). Therefore, Glasgow city is one of the ten most flood disadvantaged local authorities in the UK (Sayers *et al.,* 2018). Climate change comes with a high risk towards water-based transport and infrastructure (ports, canals), increasing the levels of erosion and silting in waterways, increasing maintenance costs and jeopardizing vulnerable historical structures such as Forth & Clyde canal (Scottish Canals, 2017; England *et al.*, 2018).

In consequence, the environmental strategy of SC focuses on the following key areas: adapting and mitigating the effects of climate change, flood control, increasing environmental awareness, and, most importantly, recognizing ecosystem services delivered by the canals to the city (Scottish Canals, 2015). The Forth and Clyde canal serves as the central backbone for the NGIWMS, dedicated to the regeneration of 110 hectares in the north of Glasgow city (Scottish Government, 2019). Utilizing the canal capacity to store water as an alternative solution for surface water management, is expected to improve habitat networks potential on the site, aid the creation of open water areas and riparian habitat and save around £10million compared to a traditional onsite drainage infrastructure solution (AECOM, 2013; Robinson, 2013; Allan et al., 2016). The ES mapping is for the Smart Canal project area (666000 to 668500 N, 257500 to 260500 E), identified as "the area to the north of the Glasgow branch of the Forth & Clyde canal, which has potential to drain by gravity to the canal system" (AECOM, 2013), see Table 10.

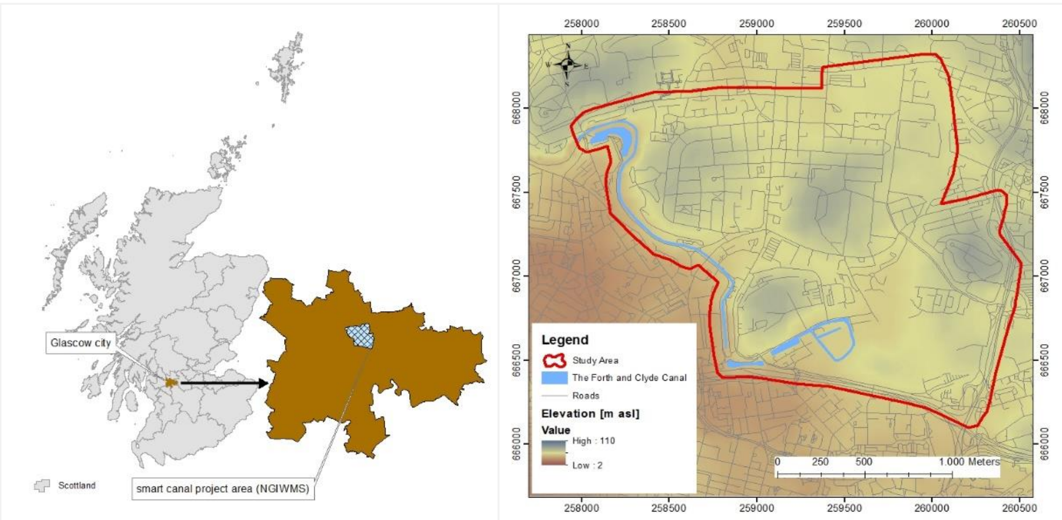


Figure 10: Smart Canal project area (NGIWMS), adapted from (AECOM, 2013)

The Smart Canal project area was chosen as an example of a complex urban environment with multiple ecosystems, undergoing extensive regeneration work (Robinson, 2013; Brears, 2018; Scottish Canals, 2018). The study area is approximately 3.60 Km^2. Altitude ranges from nearly 36 to 83m above sea level. Climate is classified as temperate oceanic according to the Köppen-Geiger system with an average annual minimum temperature of 5.5°C and an average annual maximum temperature of

12.2°C (Rubel and Kottek, 2010; UK Met Office, 2010). Precipitation rates are considered high, with an annual average of 1124mm (UK Met Office, 2010). Vegetation cover in the area mainly consists of lines of trees, highly artificial coniferous plantations, small anthropogenic forests, and some broadleaved deciduous woodland and grassland (Moss, 2014). The study area is highly urbanized, landuse mainly governed by industrial commercial and construction sites with just presence for green spaces (e.g., cemetery, nature reserve, scattered parks) (Seifert, 2009; EEA, 2017). Furthermore, the study area offers potential spaces for recreation; the banks of the Forth & Clyde canal, water-based sports attractions, Bowling Green, community gardens and some playing fields (Greenspace Scotland, 2018).

3.2 Methods

The methodology set forward by Fernandez Campo to analyze and map ES within two Norwegian municipalities represents a practical approach towards mapping and identifying ES in the Smart Canal project area (Fernandez-Campo et al., 2017), see Table 8. The approach is easily adaptable, straightforward and can be used as a decision support tool in current and future regeneration/development projects around the Forth & Clyde canal to ensure sustainable management of natural resources (Fernandez-Campo et al., 2017).Figure 11 shows a summary of the approach.

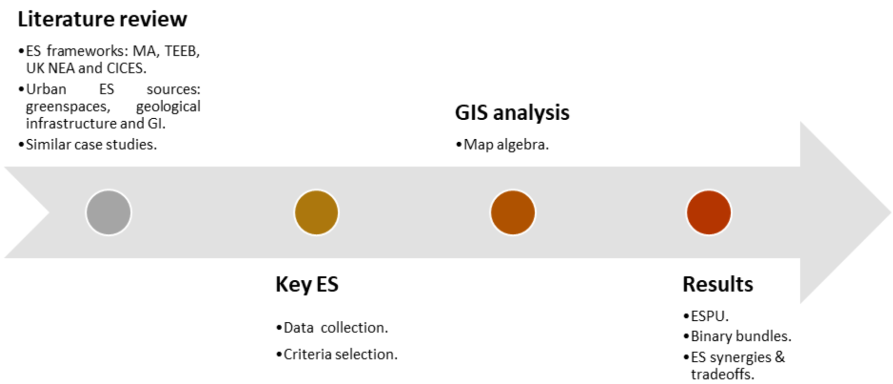


Figure 11: Methodology summary, partially adapted from (Fernandez-Campo et al., 2017)

The first part of the approach focused on producing a list of key ES present in the study area by thoroughly reviewing previous research on ES frameworks (Leemans and De Groot, 2003; UK NEA, 2011; Silvis, 2012; CICES, 2013), identifying urban components responsible for delivering ES (Forest Research, 2010; EEA, 2011; Davies et al., 2011; Gómez-Baggethun et al., 2013), contrasting the list with similar case studies (Sheate et al., 2008; Ashley, 2014; Fernandez-Campo et al., 2017; Kabisch, 2019); and associate the final list with the targets and areas of interest set by Scottish Canals environmental strategy (section 3.2.1) (Scottish Canals, 2015). After that, collected data covered landuse types, vegetative cover, topography, greenspace functions, and sustainable drainage systems, amongst others (see section 3.2.2) (Moss, 2014; EEA, 2017; Greenspace Scotland, 2018). The selected criteria for analysis of each ES had to be spatially explicit, based on previous literature different weights were assigned for each ES before being analyzed through GIS map algebra to produce Ecosystem Service Provision Units (ESPU) (section 3.2.3) (Rocha et al., 2015; Fernandez-Campo et al., 2017) and followed by further analysis with GIS to detect ES bundles in the study area (Section 3.2.4). Finally, comparison maps between ES highlighted trade-offs and synergies in the area (section 3.2.5) (Fernandez-Campo et al., 2017).

3.2.1 Key ecosystem services

Based on the several ES frameworks explored in section 2.2 (Leemans and De Groot, 2003; UK NEA, 2011; Silvis, 2012; CICES, 2013), the nature of urban ecosystems and its components in section 2.3 (Forest Research, 2010; EEA, 2011; Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013) and case studies in section 2.5 (Sheate *et al.*, 2008; Ashley, 2014; Rocha *et al.*, 2015; Fernandez-Campo *et al.*, 2017; Kabisch, 2019), a preliminary inventory of key ES in the Smart Canal project was prepared, Table 8.

3.2.2 Input data

The Urban Atlas landuse data provided by the European Environmental Agency was used as the base input to demonstrate the various urban ecosystems present in the study area; Urban Atlas maps provided reliable and detailed information for each landuse, which was suitable given the highly urbanized nature of the study area (Seifert, 2009; EEA, 2017; Zulian et al., 2017; Kabisch, 2019) see *Figure 12*. Further information on the land cover (types of vegetation) in the study area was acquired from EUNIS habitat classification, which provided a full description of the type of vegetation in the study area (e.g., forests, broadleaved woodlands, coniferous woodlands) and provided further details on the nature of the cover (e.g., natural or artificial) (Ashley, 2014; Moss, 2014; Fernandez-Campo et al., 2017). Finer details were added by considering the function of each green space in the study area; data was collected from the Greenspace Scotland project (Ordnance Survey, 2018; e.g. OS MasterMap Greenspace Layer). Understanding the function of each greenspace helps in determining its potential to offer particular ES (e.g. private gardens and public parks might share the same vegetative cover; however, parks are considered to provide higher recreational services) (Greenspace Scotland, 2018). A Digital Elevation Model (EU-DEM-v1.1) with 25 m resolution, was used to derive topographical characteristics (e.g. slope) (Copernicus Programme, 2016). Sustainable Urban Drainage Systems (SUDS) are an essential part of the Smart Canal project (AECOM, 2013). SUDS (e.g. bioretention ponds, bio-swales) will be used to collect water from the developments surrounding the Forth & Clyde canal, bio-retention ponds were georeferenced into the study area, to account for the future impact it will have in the area (AECOM, 2010, 2013; Winston *et al.*, 2013; O'Brien, 2015; Woods Ballard *et al.*, 2015; Shuttleworth *et al.*, 2017).

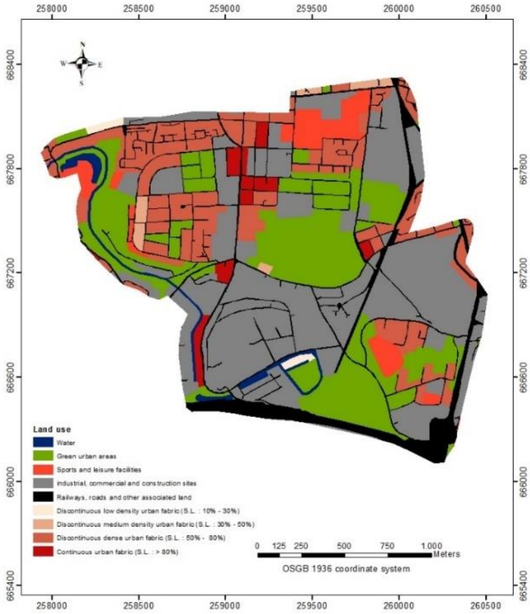


Figure 12: Landuse types, (EEA, 2017).

Finally, information on historical elements in the project area (e.g. locks, canal structure, port, and footbridges), nature reserves and core paths (e.g. cycling and pedestrian) were obtained from the Scottish Natural Heritage dataset and used to map the potential for recreational activities in the study area (Scottish Natural Heritage, 2019), see Appendix A for rest of input data. Due to the lack of access to specific data (e.g. AutoCAD drawings of the study area) I had to manually delineate the boundary of the NGIWMS area and bioretention ponds layer by georeferencing the scanned maps using Ground Control Points (GCP) in ArcGIS (AECOM, 2013; ESRI, 2020c). The input data were obtained from different sources (e.g. Urban Atlas database, EUNIS, and Edina Digimap); therefore, I transformed the multiple coordinate systems into OSGB 1936/British National Grid coordinate system to be analyzed together (Digimap Edina, 2020). In some cases, there were multiple sources for each map; therefore, I had to combine some of the maps to cover the study area (ESRI, 2020b). For instance, three shapefiles for greenspace functions were found for the study area, the shapefile from Greenspace Scotland project provided the best details, and was considered as the base input data (Greenspace Scotland, 2018). However, during the validation process with Google Earth satellite images, the greenspace functions in the southern part of the area did not fit the google earth imagery, and the further details from OS MasterMap Greenspace for Great Britain were incorporated by erasing and merging technique in GIS (Ordnance Survey, 2018; ESRI, 2020b). Furthermore, the core paths input data only represented the paths as lines in the shapefile; the Google Earth imagery indicated that the paths next to the canal are wider than the other paths; therefore, buffer zones were created for each path based on its average width (ESRI, 2020a).

Table 8: Preliminary inventory of key ES offered by the Smart Canal project

Ecosystem Service Category	Ecosystem service	Benefit description/example
Provisioning	water supply	Drinking water/the canals have private drinking water supplies on its estate (Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013; Scottish Canals, 2015)
		Water for industrial, agricultural, and recreational uses (Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013; Scottish Canals, 2015)
		Energy/ possibility of renewable energy regeneration from the canal water (Davies *et al.*, 2011; Scottish Canals, 2015; Muscatelli *et al.,* 2020)
	Material	Dredged sediments/ used to improve agricultural land, deliver ecological benefit at several locations across the canal, used in road surface material and bricks production (Davies *et al.*, 2011; Scottish Canals, 2015; Muscatelli *et al.,* 2020)
	Plants	Ornamental (e.g., flowers), rare plants (e.g., Tufted loosestrife, Bennett's pondweed) (Davies *et al.*, 2011; Scottish Canals, 2015)
Regulating	Climate regulation	Urban heat amelioration/ cooling effect of the canal, (Forest Research, 2010; EEA, 2011; Gómez-Baggethun *et al.*, 2013; Žuvela-Aloise *et al.*, 2016; Codemo *et al.*, 2018)
		Carbon sequestration/ urban vegetation, soil, and water of the canal aid in sequestering carbon (Cruickshank *et al.,* 2000; Davies *et al.*, 2011; Z. G. Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013; Chen, 2015)
	Hazard mitigation	Flood protection/runoff mitigation by storing surface runoff in the canal, (Forest Research, 2010; EEA, 2011; Davies *et al.*, 2011; AECOM, 2013; Gómez-Baggethun *et al.*, 2013; Robinson, 2013; Brears, 2018; Scottish Canals, 2018)
	Purification	Clean air/ vegetation around the canal expected to reduce PM10 concentration in air (Forest Research, 2010; EEA, 2011; Davies *et al.*, 2011; Pugh *et al.*, 2012; Gómez-Baggethun *et al.*, 2013; Scottish Canals, 2015).
	Waste treatment	Nutrient retention/use of bioretention ponds as part of sustainable drainage systems in Smart Canal projects and installation of active ecosystems (floating wetlands) in the canal, (Forest Research, 2010; EEA, 2011; Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013; Winston *et al.*, 2013; Scottish Canals, 2015)
	Pollination, pest regulation, and seed dispersal	Green assets of the canal (e.g., towpaths, grassland, hedgerows, woodland, and scrub) promote species biodiversity, (Middleton *et al.*, 2004; Forest Research, 2010; EEA, 2011; Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013; Scottish Canals, 2015)
Cultural	Recreation	Activities around/in the canal: Boating, Trim trail, wave boarding area, and Paddle Sports Centre, (Forest Research, 2010; EEA, 2011; Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013; Robinson, 2013; Scottish Canals, 2014, 2015; McKean *et al.,* 2017)
	Aesthetic value	Improved physical and mental health (Forest Research, 2010; Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013; Scottish Canals, 2015)
	Cognitive development	Educational destination/ sites of special scientific interest (SSSIs) (e.g., Dullatur Marsh site) (Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013; Scottish Canals, 2015)
	Place value and social cohesion	Canals foster a sense of place and emotional attachment (e.g., Forth & Clyde canal society charity), (Forest Research, 2010; Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013; Scottish Canals, 2015; FCCS, 2019)
Habitat	Increasing habitat area	The canals serve as a refuge for bats, otters, and badgers/ most reported wildlife are: Mute swans, mallards, frogs, damselflies, dragonflies, bumblebees, butterflies and foxes), (Middleton *et al.*, 2004; Forest Research, 2010; Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013; Scottish Canals, 2015)

3.2.3 Analysis and representation of ES provision

From the several frameworks explored in section 2.2 for classifying ES, the CICES, V5.1 was adopted, (Leemans and De Groot, 2003; Davies *et al.*, 2011; Silvis, 2012; CICES, 2013). The CICES framework offers a hierarchal approach for classifying ES, which facilitates a more natural transition between different frameworks (e.g. MA, TEEB), (Haines-Young *et al.,* 2018), see Figure 13. The CICES workbook provides equivalence tables, connecting services in TEEB and MA frameworks with similar services in CICES (Haines-Young *et al.,* 2018). CICES framework lists class types (benefits) that are most likely to be mapped based on available spatial data (Czúcz *et al.*, 2018). The selected sample of ES reflects a diverse mixture of services offered by the Smart Canal project (one provisioning, five regulating, and two cultural), following the hierarchal classification of CICES through to "class types" where possible (Haines-Young *et al.,* 2018).

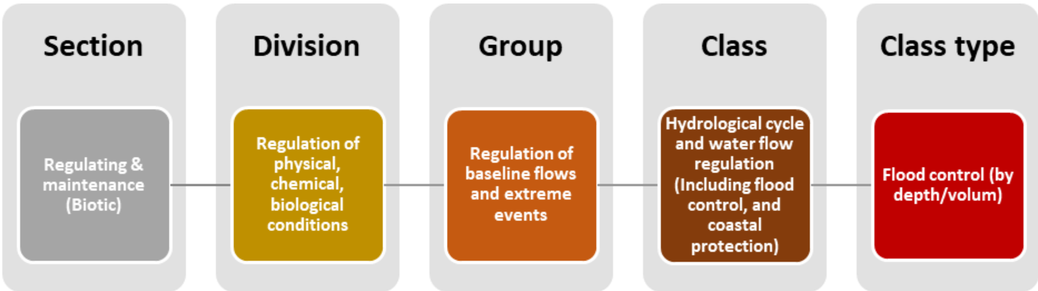


Figure 13: The hierarchical structure of CICES V5.1 for flood control, adapted from (Haines-Young et al., 2018)

GIS is one of the most used tools in mapping and analyzing ES (Malczewski, 2006). For this study, a GIS-based multicriteria decision analysis was conducted (MCDA), to generate ESPU (Eastman, 1999; Belton and Stewart, 2002; Malczewski, 2006; Koschke *et al.*, 2012; Nemec and Raudsepp-Hearne, 2013; Fernandez-Campo *et al.*, 2017). The MCDA is used to combine spatial data with values based on expert judgment and previous research, to convey information on the provision of each element (e.g., landuse, vegetation, greenspace) to deliver ES, ultimately shaping the decision-making process, (Malczewski, 2006). The analysis was based on a weighted linear combination adopted from the literature (Eastman, 1999; Fernandez-Campo *et al.*, 2017):

$$F_{ESi} = \sum_{i=1}^{n} V_i * W_i$$

Where F_{ESi} is the quantitative value of the land's ability to supply ES. V_i Is the value for each criterion (e.g., land type, vegetation, slope, greenspace) chosen for the analysis of particular ES, and classified in values ranging from 1 to 5, (Eastman, 1996). W_i Is the relative weight assigned for each criterion according to its effect on the analyzed ES ($\sum W_i = 1$), Table 9.

Table 9: Mapped ecosystem services based on the used criteria in section 3.2.3

		Provisioning (Abiotic) water	Regulation & Maintenance (Biotic)					Cultural (Biotic)	
			Regulation of physical, chemical, biological conditions					Direct, in-situ and outdoor interactions	
		Materials	Flows regulation	Habitat areas	Water conditions	Atmospheric composition & conditions		Physical & experiential	Intellectual & representative
		Surface water	flood control	Biodiversity	Water quality	Carbon sequestration	Evaporative cooling	Nature-based recreation	local identity
W_j	**Urban Atlas Land use**	**0.7**	**0.1**	**0.2**	**0.3**	**0.5**	**0.4**	**0.2**	**0.3**
V_j	Industrial, commercial and construction sites	0	0	0	0	0	0	0	0
	Railways, roads and other associated land	0	0	1	0	0	0	0	0
	Sports and leisure facilities	0	1	2	2	2	3	3	0
	Discontinuous low-density urban fabric (S.L.: 10% - 30%)	0	2	3	2	3	3	0	0
	Discontinuous medium density urban fabric (S.L.: 30% - 50%)	0	1	2	1	2	2	0	0
	Discontinuous dense urban fabric (S.L.: 50% - 80%)	0	0	0	0	0	0	0	0
	Continuous urban fabric (S.L.: > 80%)	0	0	0	0	0	0	0	0
	Green urban areas	0	5	5	4	5	4	4	0
	Water	5	5	5	5	2	5	5	5
W_j	**Vegetation**	**N/A**	**0.2**	**0.5**	**0.2**	**0.35**	**0.4**	**N/A**	**N/A**
V_j	Broadleaved deciduous woodland	-	5	5	5	5	5	-	-
	Early stage coniferous woodland	-	3	4	4	4	4	-	-
	Mixed forest	-	4	4	3	5	4	-	-
	Improved Grassland	-	2	3	2	2	2	-	-
W_j	**Greenspace function**	**N/A**	**0.1**	**0.15**	**N/A**	**0.15**	**N/A**	**0.2**	**N/A**
V_j	Community Growing Spaces	-	2	4	-	2	-	4	-
	Bowling Green	-	2	2	-	1	-	3	-
	Play space	-	1	2	-	0	-	3	-
	Playing field	-	2	2	-	1	-	3	-
	Private garden	-	2	3	-	2	-	3	-
	Public park/garden	-	3	5	-	3	-	4	-
	Cemetery	-	3	5	-	3	-	1	-
	Amenity (Transport, Business or residential)	-	0	1	-	0	-	0	-
	School ground	-	1	1	-	1	-	1	-
	Church yard	-	1	1	-	2	-	1	-
	Sport	-	1	1	-	1	-	4	-
	Canal water	-	5	5	-	2	-	5	-
	Green corridor	-	3	4	-	4	-	3	-
	Riparian Routes	-	4	5	-	5	-	3	-
W_j	**Slope (degrees)**	**N/A**	**0.4**	**N/A**	**0.3**	**N/A**	**N/A**	**N/A**	**N/A**
V_j	0-2		5	-	5	-	-	-	-
	2-4	-	4	-	4	-	-	-	-
	4-6	-	3	-	3	-	-	-	-
	6-10	-	2	-	2	-	-	-	-
	>10	-	1	-	1	-	-	-	-
W_j	**Bio-retention ponds (m^2)**	**0.3**	**0.2**	**0.15**	**0.2**	**N/A**	**0.2**	**N/A**	**N/A**
V_j	600-5000	5	4	3	3	-	3	-	-
	5000-8000	5	5	4	4	-	4	-	-
	>8000	5	5	5	5	-	5	-	-
Wj	**Core paths**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0.2**	**N/A**
V_j	Cycling routes and towpaths	-	-	-	-	-	-	5	-
	Pedestrian path	-	-	-	-	-	-	4	-
Wj	**Nature reserves**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0.2**	**0.2**
V_j	City-wide Site of importance for Nature Conservation (SINC) - Hamiltonhill Claypits	-	-	-	-	-	-	5	5
Wj	**Historical elements**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0.2**	**0.5**
V_j	Locks	-	-	-	-	-	-	5	5
	Footbridges	-	-	-	-	-	-	3	3
	Historical canal structure	-	-	-	-	-	-	4	5
	Port	-	-	-	-	-	-	4	3

Each of the above services was assigned values based on existing literature and available data:

- **Surface water for non-drinking purposes (Provisioning _ material _ surface water for non-drinking purposes):**

  Landuse was considered as the main criterion to account for the presence of surface water in the study area because the maps differentiated the Canal water from surrounding landuse (Rocha *et al.*, 2015). The Canal water represents the key source in the study area with the potential to be used in non-drinking purposes (e.g. watering of adjacent community growing spaces) (Scottish Canals, 2015; Fernandez-Campo *et al.*, 2017). Another source for surface water in the study area is the installation of sustainable drainage systems such as bioretention ponds, which are designed to provide storage areas for surface runoff before it is discharged into the canal (Fitchett, 2017; Shuttleworth *et al.*, 2017). Bioretention ponds were assigned a lower value for their potential in surface water delivery for non-drinking purposes compared with the canal water because the retention ponds are responsible for the collection of surface runoff which is usually considered highly polluted with heavy metals (e.g. lead and zinc) generated by adjacent roadway traffic (Berndtsson, 2014). Thus, requiring further treatment before being safely used in agricultural or industrial activities in the study area (Göbel *et al.,* 2007).
- **Mitigation of damage by flood control (Regulation & Maintenance _ regulation of baseline flows and extreme events _ water flow regulation):**

  Natural slope, bioretention ponds, vegetation, land use, and greenspace function were all used as criteria to locate areas with high potential for runoff mitigation (flood control). The natural slope criterion was given the highest weight, due to its direct role in affecting surface runoff movement and intensity (Gharagozlou *et al.,* 2011; Farrugia *et al.,* 2013; Rocha *et al.*, 2015). The natural slope was calculated from Digital Elevation Model (DEM) for the study area, the groups of the slope were determined based on the requirements for drainage and land use types in the area (Chen *et al.,* 2009; AECOM, 2010; Defersha *et al.,* 2011; Li *et al.*, 2011; Kassa, 2014; Mahmoud and Tang, 2015; Rocha *et al.*, 2015; Putro *et al.*, 2016). The higher the slope, the higher the probability of flooding in the same area (Li *et al.*, 2011). The vegetative cover was given half the weight of the slope criterion in runoff mitigation within the urban environment, given that soils within the urban environment suffer from high cultivation and are considered weakly aggregated (Vaezi *et al.,* 2017). Which might affect the role of vegetative covers in infiltration and flow interception. For example, an area with high slope and industrial/construction use would receive a lower value compared to a high slope area with a vegetative cover such as forests and woodlands (Dunnett *et al.*, 2008; Farrugia *et al.,* 2013; Ouma and Tateishi, 2014).

Sustainable drainage systems (bioretention ponds) were located in areas of high slope in the study area, to dilute its effects on surface runoff (AECOM, 2013). Therefore, ponds played a similar role in runoff storage, infiltration, and flow interception as the vegetative cover and were assigned an equal weight. For example, an area with high slope and a vegetative cover would provide a similar level of flood interception as an area were retention ponds are located on a high slope (Forest Research, 2010; De Macedo *et al.*, 2019; Lu *et al.,* 2019; Li *et al.*, 2020). Also, greenspace function was used as a criterion to map flood control in the study area; it was assigned a lower value because of the limited information available on the role of each function in intercepting runoff (Sheate *et al.*, 2008; Farrugia *et al.,* 2013). For example, riparian routes were given a higher weight compared with playfields, because riparian routes are proven to play a vital role in flood mitigation (Schuch *et al.*, 2017; Capon and Palmer, 2018). Playfields were given higher values compared with play spaces, which are usually landlocked areas with minimal vegetative cover, thus playing a small role in intercepting runoff (Kim, Lee and Sung, 2016). The same procedure was followed for assigning the weights for the different greenspace functions in the study area.

- **Biodiversity (Regulation & Maintenance _ lifecycle maintenance, habitat and gene pool protection _ providing habitat for wild plants and animals):**

  Land use, vegetation types, greenspace function, and sustainable drainage systems (bioretention ponds) were used as criteria to identify areas with high potential of maintaining biodiversity within the study area (providing habitat for animals and wild plants). Vegetation types were given the highest weight in this analysis to reflect the ability of different vegetative covers to form habitats. For example, broadleaved woodlands were given the highest weight because it includes old and mature trees such as old oak trees in the north-western part of the study area, old trees are usually associated with high presence of biodiversity and urban wildlife (Savard *et al.,* 2000; Fernández-Juricic and Jokimäki, 2001). Coniferous woodlands in the study area include a small percentage of natural woodland areas, high presence of artificial trees of different ages and separate lines of trees, therefore were assigned a lower value compared to broadleaved woodlands which provided a more natural setting (Middleton *et al.*, 2004; Angold *et al.*, 2006; Croci *et al.*, 2008). Grassland areas were given the lowest value between vegetative covers since it is usually mowed and replaced which might negatively affect the biodiversity potential in these areas (Stewart *et al.*, 2009; van Heezik *et al.,* 2012; Rocha *et al.*, 2015; Aronson *et al.*, 2017). Furthermore, the vulnerability of species presence is affected by landuse (Chaudhary *et al.*, 2015). The landuse criterion is taken as an indication of the level of urbanization in the area and accounting for its effects on biodiversity; where areas representing a continuous urban fabric (S.L.: > 80%) were assigned lower values compared to discontinuous medium density urban fabric (S.L.: 30% - 50%)

which offers more potential to increase biodiversity (Bateman *et al.*, 2013; Chaudhary *et al.*, 2015). The effects of greenspace functions and bioretention ponds are scale-dependent and are not fully covered in existing literature (Clarke, 2014; O'Brien, 2015). For bioretention areas, the area of the pond was the limiting criteria, the largest the retention pond, the higher the possibility it will form a refuge and resting point for urban bird species (Fernández-Juricic and Jokimäki, 2001). Similarly, greenspace functions were used to determine the effect of human activity levels on biodiversity presence. For example, Bowling Green, play spaces, playing fields were all assigned lower values compared to public parks or cemeteries because the former is associated with a higher level of human activity by using these areas for sports (Galluzzi *et al.,* 2010; van Heezik *et al.,* 2012; Speak *et al.,* 2015; Kowarik *et al.*, 2016; Cabral *et al.*, 2017; Čanády and Mošanský, 2017).

- **Water quality (Regulation & Maintenance _ water conditions _ water quality):**

  Land use, vegetation, slope, and sustainable drainage systems (bioretention ponds) were used to identify areas with the potential to enhance water quality in the study area. The natural slope criterion was given the highest weight, due to its direct role in affecting surface runoff quality, the higher the slope the more prone the area is to soil erosion and to pollutant accumulation (e.g., high slopes account for increasing nutrient levels in water due to soil erosion) (Phillips, 1989; Carroll *et al.,* 2000). Therefore, areas with a high slope in the study area were assigned lower values to indicate the lack of potential for enhancing water quality. Equally important is taking into consideration the nature of landuse in the area; where the canal water was assigned the highest values for its potential to enhance the overall water quality before being deposited into the river Kelvin, accounting for the installation of natural and artificial filters as part of the Smart Canal project (AECOM, 2013). Greenspaces were assigned higher values compared to continuous urban fabric (S.L.: > 80%), construction sites and other landuse types, to acknowledge the potential of vegetative covers over landlocked areas in enhancing water quality (e.g., industrial, commercial and construction sites increases nitrogen and phosphorus levels in the water) (Mehaffey *et al.*, 2005; Uuemaa *et al.,* 2007; Zampella *et al.*, 2007; Maes *et al.*, 2012).

  Furthermore, the vegetation criterion takes into consideration the effect of vegetative cover on water quality, where Broadleaved woodlands are associated with better water quality and responsible for high levels of phytoextraction compared with Coniferous woodlands, which consists of artificial, young and scattered trees (Wear *et al.,* 1998; McGuckin *et al.,* 1999; Mehaffey *et al.*, 2005; Layke *et al.*, 2012; Maes *et al.*, 2012; Pratt and Chang, 2012; Cabral *et al.*, 2016). Grasslands were assigned the lowest value because it is usually mowed and affected by human activities reducing its effect in traction of pollutants (McGuckin *et al.,* 1999; Seitz and Escobedo, 2008; Armson *et al.,* 2013; Rocha *et al.*, 2015).

Sustainable drainage systems play an essential role in enhancing water quality through increasing infiltration rates, bioretention areas were classified based on its area, and the number of floating wetland installed within the Smart Canal project, where increasing the number of filtration wetlands can positively affect the quality of water in retention ponds (Hsieh and Davis, 2005; Hunt *et al.*, 2006; AECOM, 2013; Winston *et al.*, 2013; Clarke, 2014; Ballard *et al.*, 2015; Muerdter *et al.,* 2018).

- **Carbon sequestration (Regulation & Maintenance _ Atmospheric composition and conditions _ carbon sequestration):**

  To map areas with high potential for carbon sequestration, land use, vegetation, and green space function were used as criteria. Landuse types were used to account for the effect of urbanization on carbon storage within cities, for example, greenspace areas and discontinuous low-density urban fabric (S.L.: 10% - 30%) were weighed higher than other landuse types such as continuous urban fabric (S.L.: > 80%) or sports areas, given that the former supports the presence of green areas and vegetative cover which offers a higher potential for carbon sequestration compared with landlocked areas and impermeable surfaces (Cruickshank *et al.,* 2000; Davies *et al.*, 2011). The existing literature indicated that urban streams could have a role as 'carbon channels' responsible for moving sedimentation sequestering organic carbon between urban water bodies (Downing, 2010). However, there was not enough information to accurately predict the role of the canal. Therefore, the canal water was assigned a low value concerning carbon sequestration (Cole *et al.*, 2007; Biddanda, 2017). The vegetative cover was used to distinguish the role of different vegetation in carbon sequestration, where broadleaved woodlands are usually associated with having older and bigger trees compared to coniferous woodlands, making broadleaved trees more capable of sequestering carbon (Liski *et al.*, 2006; Muñoz-Rojas *et al.*, 2011). Grassland was given the lowest value for carbon sequestration as it is usually subjected to continuous modifications (e.g. mowing) based on analysis done in Ireland and Britain (Cruickshank *et al.,* 2000; Davies *et al.*, 2011). Finally, greenspace function was used to indicate the level of human activity/change in green spaces; for example, parks and cemeteries were assigned higher values compared with Bowling Green area, which is subjected to mowing and used more frequently in sports activities (Chen, 2015).

- **Evaporative cooling (Regulation & Maintenance _ Atmospheric composition and conditions _ increased thermal comfort due to evaporative cooling):**

  Land use, vegetation, and sustainable drainage systems were the main criteria used to identify the potential of the Canal and surrounding areas for enhancing the thermal comfort of residents and visitors. Landuse was used to account for the effect of the urban form on heating/cooling of the surrounding environment. For example, canal water was assigned a value higher than greenspaces because existing research indicates that urban water bodies offer higher cooling rates compared to parks (House-Peters and Chang, 2011; Žuvela-Aloise *et al.*, 2016). Also, areas of discontinuous low-density urban fabric (S.L.: 10% - 30%) were weighed higher than other landuse types such as continuous urban fabric (S.L.: > 80%), because having less dense form is denoted with creating ventilation corridors resulting in enhanced thermal comfort compared with continuous urban fabric (Emmanuel and Steemers, 2018). Equally important is the nature of vegetation in the study area, where Broadleaved woodlands were assigned higher values than grassland or coniferous woodlands, as having denser older trees delivers better thermal comfort and shading (Rosenzweig *et al.*, 2006; Moss *et al.*, 2019). Included bioretention ponds depict the role urban blue infrastructure can play in improving thermal comfort, where the more significant the area of the retention pond, the higher its potential for enhancing thermal comfort (Wu *et al.*, 2019; Lin *et al.*, 2020).

- **Nature-based recreation (Cultural _ Physical and experiential interactions with natural environment _ activities promoting health, recuperation, or enjoyment through active or immersive interactions _ nature-based recreation):**

  There is a growing interest in capitalizing on the value of urban waterways as recreational destinations (Erfurt-Cooper, 2009; Olsson, 2016; Vallecillo *et al.*, 2019; Mehran *et al.*, 2020). The NGIWMS is focusing on incorporating "placemaking concepts" in the study area to convey the potential for recreation (AECOM, 2013). The chosen criteria covered the function of greenspaces in the area, the presence of core paths of pedestrians and cyclists, the presence of nature reserves, and historical elements. Landuse was used to distinguish the value of water bodies and greenspaces in the study area. The canal water was given a higher weight than greenspaces signifying the higher number of recreational activities that can be enjoyed in the canal area (e.g. water sports, boating) compared to greenspaces (Erfurt-Cooper, 2009; Robinson, 2013; Scottish Canals, 2014; Olsson, 2016; Vallecillo *et al.*, 2019; Mehran *et al.*, 2020). Other landuse types, such as continuous urban fabric (S.L.: > 80%) were not mapped, indicating the lack of recreational potential (Zhang *et al.*, 2018). Greenspace function criteria helped to scrutinize the recreational potential of greenspaces. For example, spaces such as community growing plots and water sports areas were given higher weights compared to private gardens, because the former encourages group recreation and serves multiple age groups compared to the latter where private gardens are mostly associated with individual recreation (Ghose and Pettygrove, 2014; Scottish Canals, 2014). Core paths were included to account for areas where residents/visitors can engage in physical interaction with nature through walking, cycling, and boating, the presence of a nature reserve and historical elements (e.g., canal locks) in the area is equally important in promoting recreational activities (Ricart et al., 2016). Due to the lack of data, information extracted from social media platforms, Google Maps, and websites of attractive destinations in the study area were used to track the comments, reviews, and pictures left by visitors and locals. For example, canal locks were valued the highest of all historical elements based on the number of positive reviews and pictures of vessels passages shared by visitors, similarly cycling routes were weighed higher than pedestrian paths, as most of the shared reviews found bicycle rides around the Canal to be enjoyable.

- **Local identity (Cultural _ Intellectual and representative interactions with natural environment _ Characteristics of living systems that are resonant in terms of culture or heritage _ local identity):** The Forth and Clyde canal presence intertwines both experiential and intellectual interactions (Transport Scotland, 2013; McKean *et al.,* 2017; Scottish Canals, 2017). The latter is challenging to map because it requires a more in-depth understanding of the relationships formed between culture and landscape, which constructs the value of the element in question (Ricart *et al.*, 2016). A list of historical elements in the area was georeferenced to indicate locations of attraction (e.g., canal locks, footbridges) that might create a sense of belonging within the local community. Landuse and nature reserve were included as complementary criteria at lower weights (Fernandez-Campo *et al.*, 2017). Replicating the used procedure to map nature-based recreation, social media platforms, Google Maps, and websites of attractive destinations were utilized to assign values to map local identity. For example, the Canal water and Hamiltonhill Claypits reserve were given the highest weights compared to other historical elements, because reviews and comments indicated that the Canal is a suitable area for meditation and serenity, and the Hamiltonhill reserve offers excellent views of Glasgow city. This information can be considered subjective, but it helps to understand further the connections between people and the Canal, leading to forming their local identity.

3.2.4 Detection of ecosystem service bundles

ES bundles are defined as ''sets of services that repeatedly appear together" (Raudsepp-Hearne *et al.,* 2010; Dittrich *et al.*, 2017). ES bundles concept supports the notion that a single landscape element (e.g. canal, greenspace) is capable of providing multiple ES at specific time and location (Gonzalez-Ollauri and Mickovski, 2017; Manning *et al.*, 2018). ES bundles map was created for the study area, to indicate the level of coincidence between multiple ES at a basic spatial level, without further information on synergy or trade-offs (Fernandez-Campo *et al.*, 2017). Bundles map was created by overlaying ESPU maps (section 3.2.3) and reclassifying the results using map algebra to a scale of 1 to 5, where ''1" indicates very low ES coincidence, and ''5" very high ES coincidence (Fernandez-Campo *et al.*, 2017).

3.2.5 Ecosystem services trade-offs and synergies

Mapping of ES bundles (section 3.2.4), brought awareness to the capability of individual landscape elements to deliver multiple ES at a particular place and time (Raudsepp-Hearne *et al.,* 2010). However, it did not provide any further details on the nature of the relationships and interactions between ES (Bennett *et al.,* 2009). Synergies are defined as "situations in which both services either increase or decrease," and trade-offs are defined as "situations in which one service increases and another one decreases," either due to external factors or due to interactions between the ES (Bennett *et al.,* 2009; Raudsepp-Hearne *et al.,* 2010). Identifying and understanding the causes or the nature of these synergies and trade-offs is a challenging task (de Groot *et al.*, 2010). Scottish Canals conducted a baseline assessment to identify key themes in need of future action in its environmental strategy for the years 2025. Energy and carbon management was highlighted as a red area, indicating that there is a limited activity being done, and it has a significant potential for improvement. Biodiversity, on the other hand, was marked to be an amber area indicating that Scottish Canals are already active in this area. However, there is a future need for improvement (Scottish Canals, 2015).

Given that regulating ES services are considered as indicators of ecosystem resilience (Bennett et al., 2009), using GIS map algebra comparisons between biodiversity, carbon sequestration, and another ES was performed (Fernandez-Campo *et al.*, 2017). Provision comparison was made by overlaying ESPU maps and classifying the results into three categories, where category A includes unsuitable areas (does not play a significant role) in biodiversity/carbon sequestration provision. Category B includes areas where the provision of biodiversity/carbon sequestration is higher than other ES, and category C includes areas where the provision is high for biodiversity/carbon sequestration and other ES. These three categories could be considered as indicators for areas with high or low conflict potential between ES (Fernandez-Campo *et al.*, 2017).

4

RESULTS AND DISCUSSION

The Smart Canal project area depicted a high to a very high potential for the delivery of regulating services, such as water quality enhancement, carbon sequestration, evaporative cooling, and biodiversity at 11%, 10%, 5%, and 4% of the area consecutively. The study area offered limited delivery of provisioning services, where only 3% of the area had the potential for delivery of water for non-drinking purposes. Additionally, cultural services showed limited presence and were focused in the north-western part of the canal, which means only 2% of the area is capable of delivering high to a very high provision of cultural services. Furthermore, around 38% of the Smart Canal project area indicated high to very high coincidence levels between ES, especially in the north-western part of the canal, which indicates the importance of management decisions in balancing ES. Finally, biodiversity and carbon sequestration provisions were compared with other ES, to highlight areas with possible synergies and trade-offs between services, being essential for guiding further development in the canal area. The comparison indicated that regulating services overlap the most between each other and usually have a synergistic relationship. Conversely, regulating services interaction with provisioning and cultural services usually results in a trade-off situation. Most of these interactions occurred in the north-western part of the canal.

4.1 Results

4.1.1 ESPU maps

- **Surface water for non-drinking purposes:**

In the Smart Canal project area, only 3% was covered with surface water. 2% representing a high potential for surface water delivery (e.g. the Forth & Clyde canal water), and the remaining 1% represented a low potential for surface water delivery (e.g. water existing in SUDS), Figure 14.

- **Flood control:**

Around 55% of the Smart Canal project area had a low to very low potential for flood control delivery. 39% of the area had an intermediate potential for flood control delivery, and only about 5% had the potential for high to very high flood control delivery, this is evident around riparian routs near the

Forth & Clyde canal and the southern-eastern area where some broadleaved deciduous woodlands are located, Figure 14.

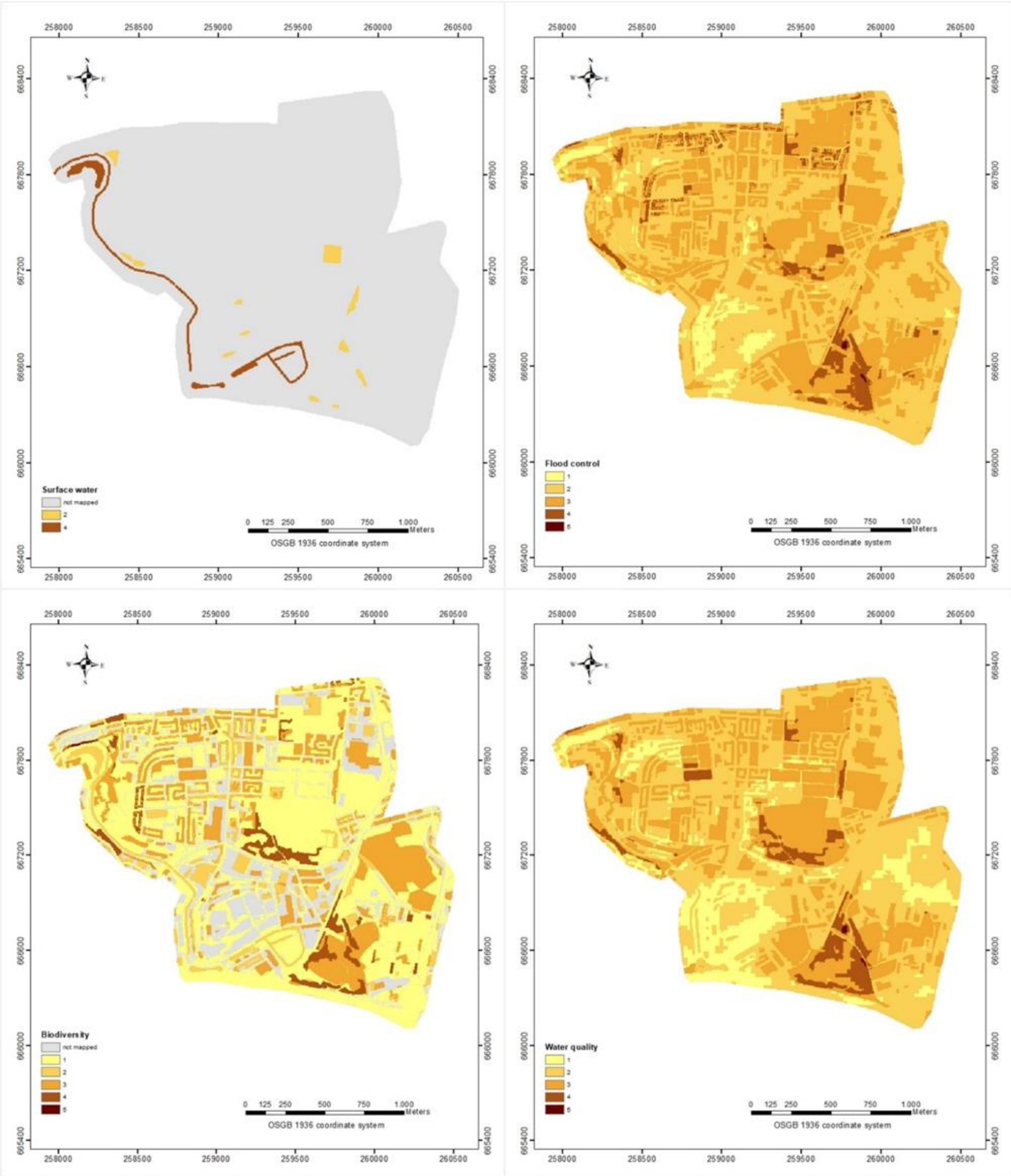


Figure 14: ESPU for surface water (upper left), flood control (upper right), biodiversity (lower left), and water quality (lower right)

- **Biodiversity:**

58% of the Smart Canal project area have low to very low potential for biodiversity service delivery. Around 20% of the area offers intermediate potential for biodiversity delivery, and only around 4% offers high to a very high potential for delivery, located in the south-eastern part of the area, Figure 14.

- **Water quality:**

Around 60% of the Smart Canal area offers low to very low potential for enhancing runoff water quality. However, 33% of the area offers intermediate potential for improving runoff water quality, and around 11% offered high to a very high potential for water quality enhancement, visible around the north-western part of the canal and in forested areas, Figure 14.

- **Carbon sequestration:**

Around 33% of the Smart Canal project area provides low to very low potential for carbon sequestration. Almost 20% of the area offers an intermediate level of carbon sequestration potential, and around 10% of the area offers high to very high levels of carbon sequestration, this is most evident in the riparian routes surrounding the Forth & Clyde canal (northwestern segment) and broadleaved woodlands, Figure 15.

- **Evaporative cooling:**

Approximately 45% of the Smart Canal project area has the potential to offer low to the very low evaporative cooling effect, present in private gardens and grassland covered areas. An intermediate potential for cooling exists within 3% of the area, represented by bioretention ponds and mixed forest areas. Another 5% of the area represents a high to a very high potential for evaporative cooling in the northwestern part of the canal, where riparian routes and old oak trees are located, Figure 15.

- **Nature-based recreation:**

In the Smart Canal project, around 46% of the area offers low to very low potential for recreational services; this is represented by the significant presence of Lawns and small private gardens. Around 2% of the area has an intermediate potential, and only 1% has high to very high potential, especially in the northwestern part of the canal, where water and old oak trees are most present in *Figure 15*.

- **Local identity:**

The Smart Canal project presented limited areas with potential for "Intellectual and representative interactions," around only 2% of the area ultimately leads to forming connections, offering high to a very high potential for local identity formation; mainly consisting of the presence of the canal structure, locks, and footbridges in the northwestern part of the area. Around 6% deliver low to very low provision representing areas in the nature reserve with old oak trees, Figure *15*.

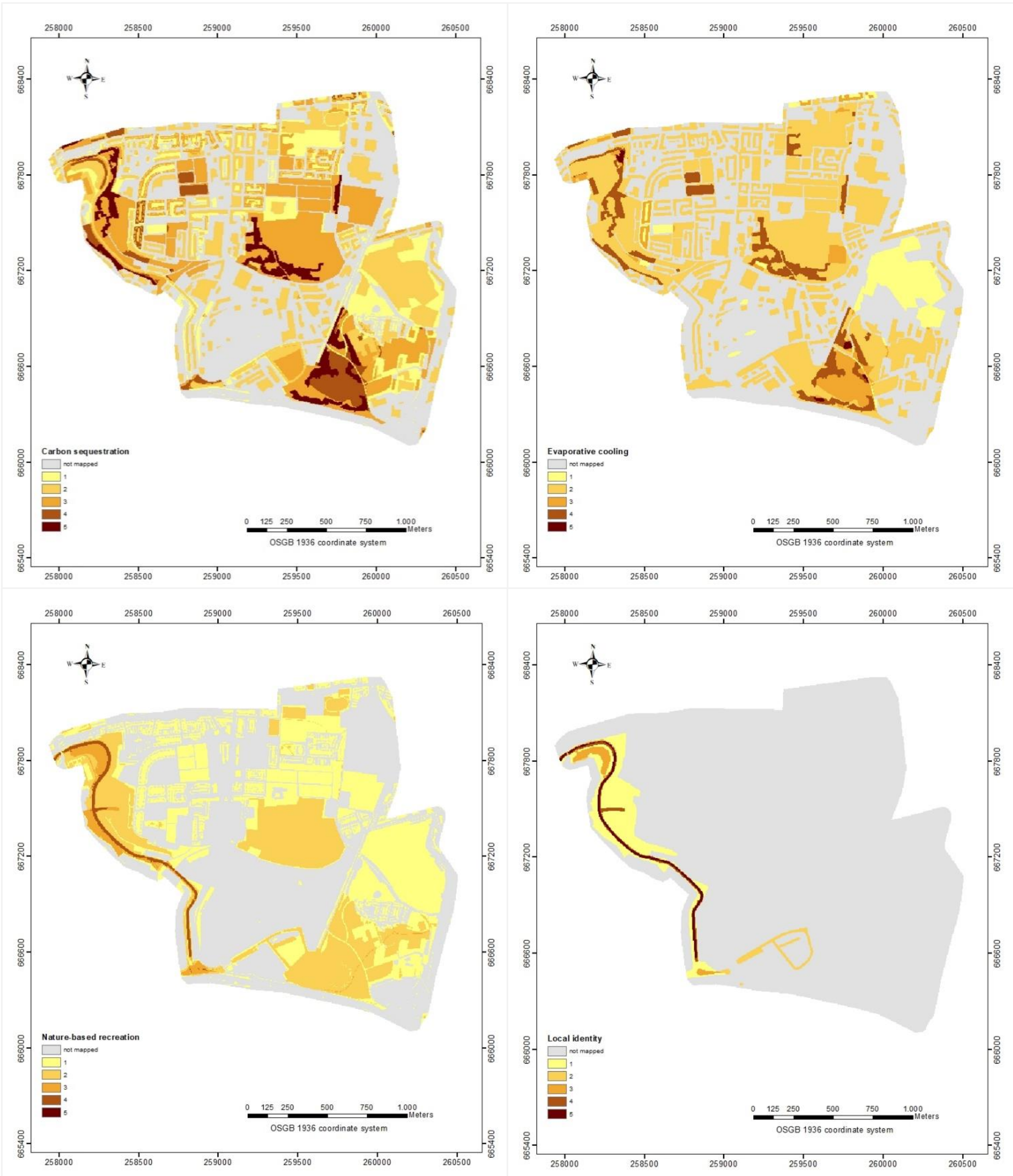


Figure 15: ESPU for carbon sequestration (upper left), evaporative cooling (upper right), nature-based recreation (lower left), and local identity (lower right)

4.1.2 Detection of bundles

A map representing the level of spatial coincidence between ES was produced by overlaying the ESPU maps for the eight mapped ecosystem services. Around 38% of the Smart Canal project area indicated high to very high coincidence levels between ES, especially in the northwestern part of the canal. Furthermore, 24% of the area represented intermediate levels of coincidence, especially in greenspace areas, in the north-eastern parts of the project area. Finally, around 38% of the area represented low to very low levels of coincidence between ES, Figure 16.

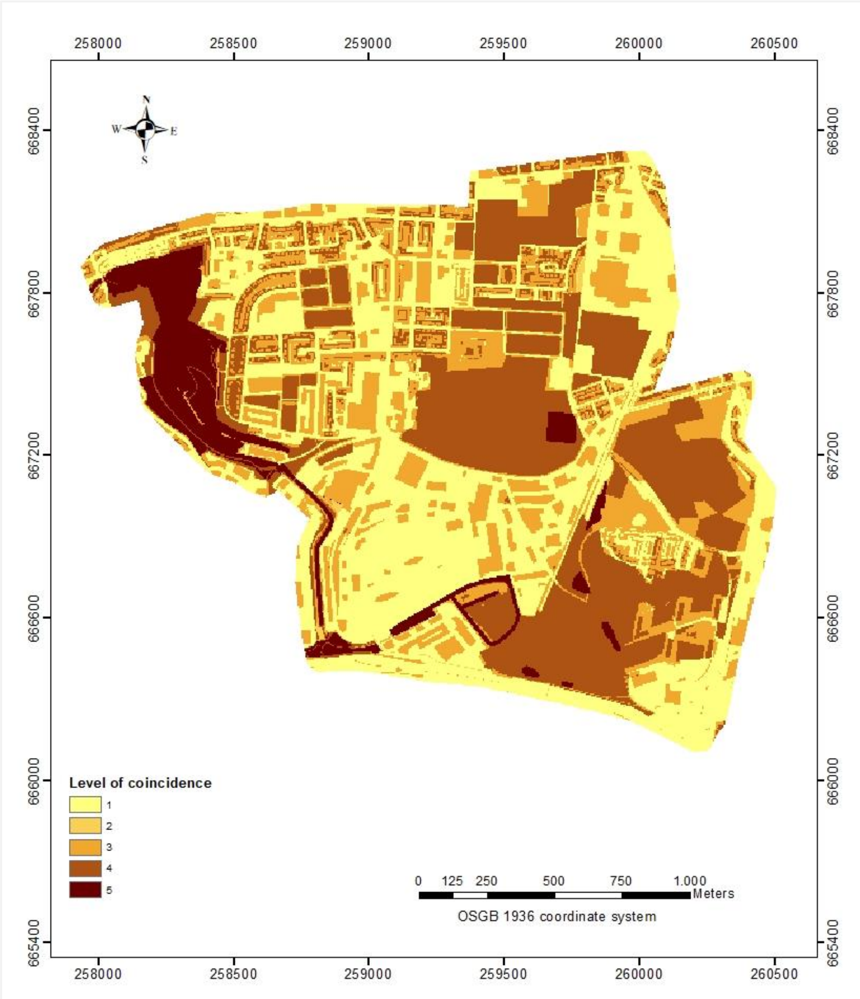


Figure 16: level of spatial coincidence between eight ESPU maps

4.1.3 ES synergies and trade-offs

The following maps provide further details on the level of interactions between biodiversity/carbon sequestration and other ES in the study area. Category A indicates areas with no provision for biodiversity or carbon sequestration, category B includes areas where the provision of biodiversity/carbon sequestration is higher than other ES, and category C represents areas where both ES have high provision, depicting high levels of vulnerability, Figure 17 , Figure 18.

- **Carbon sequestration trade-offs with other ES:**

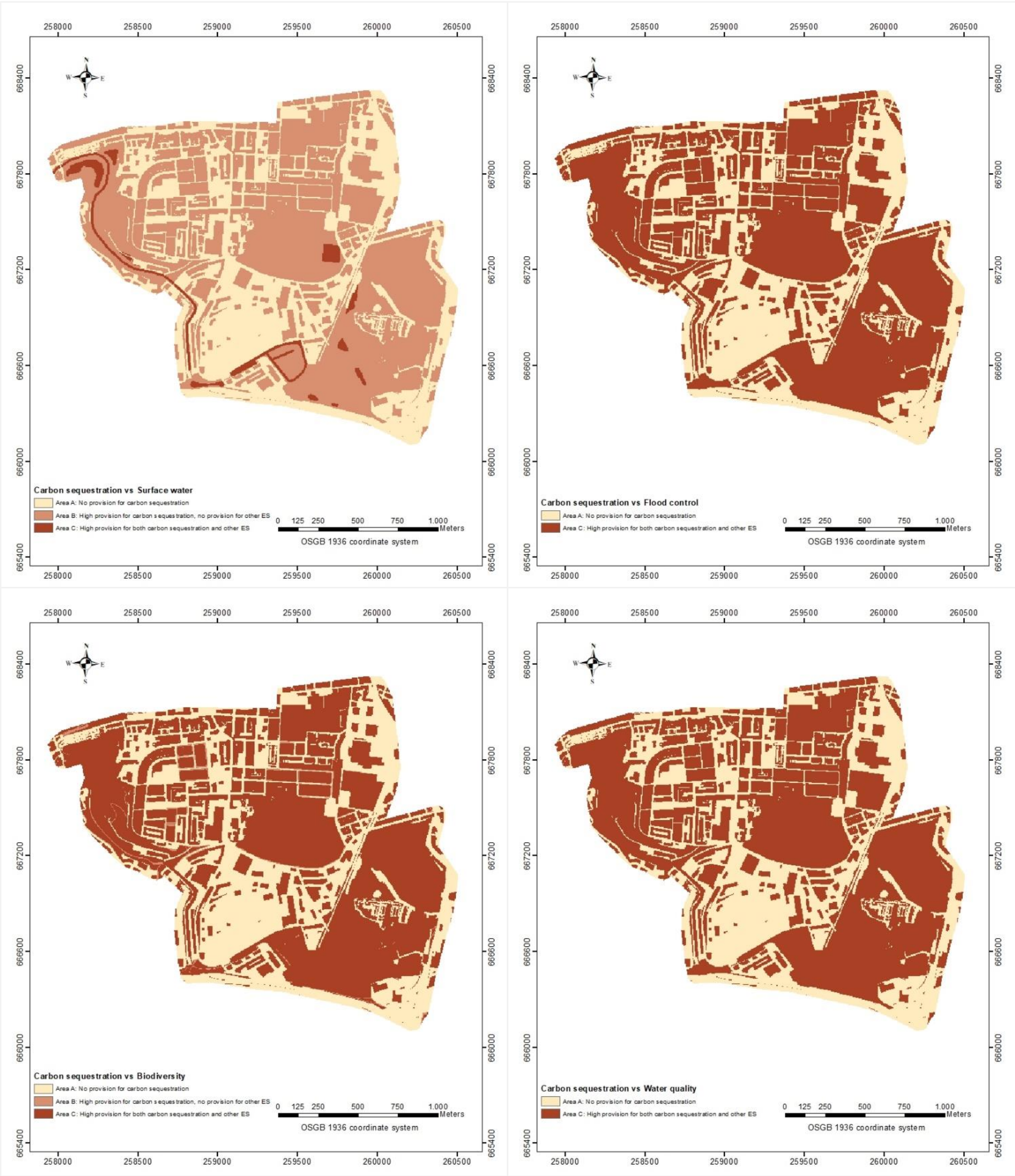


Figure 17: Carbon sequestration provision tradeoffs vs. surface water (upper left), flood control (upper right), biodiversity (lower left), and with water quality (lower right)

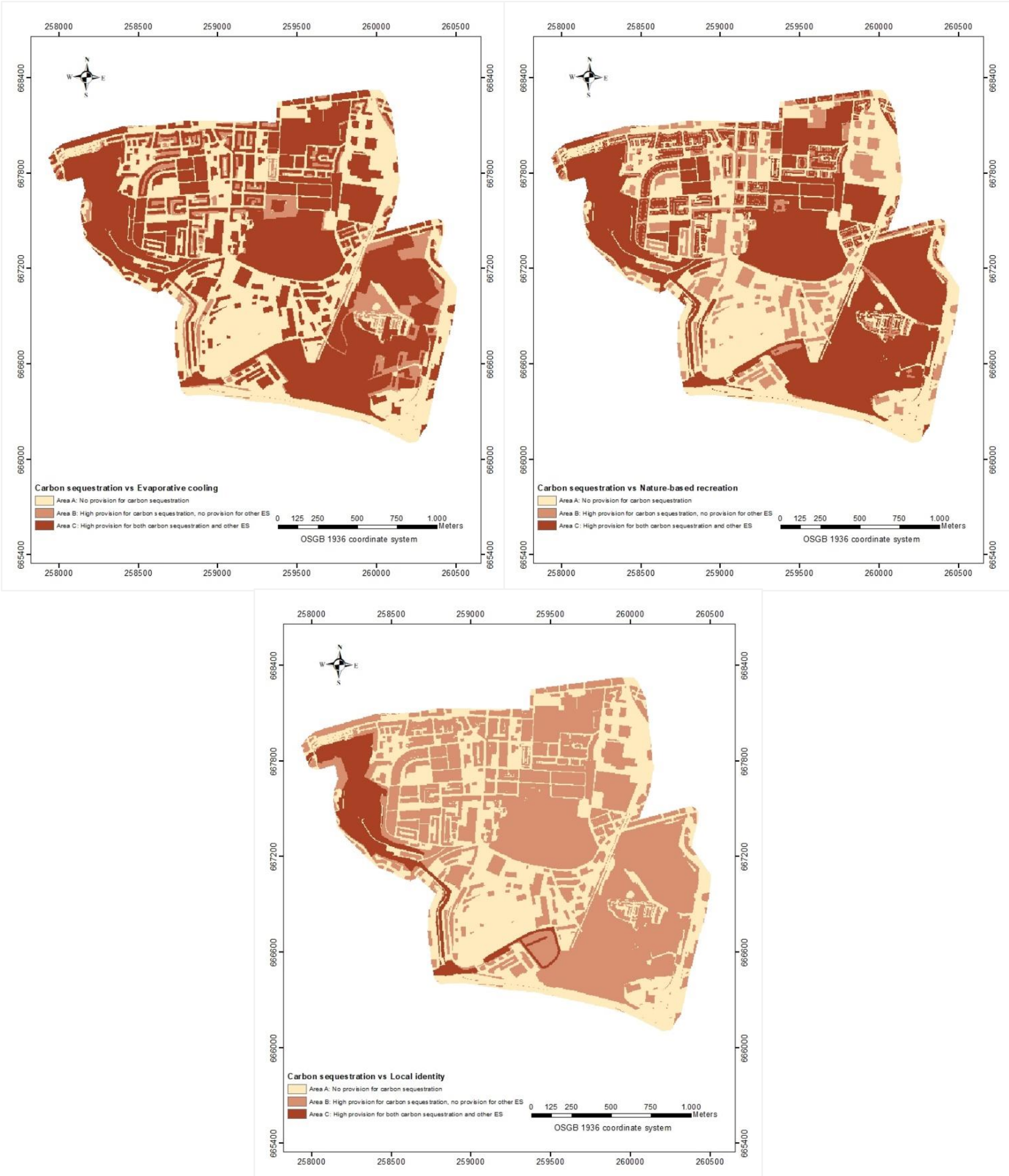


Figure 18: Carbon sequestration provision tradeoffs vs. evaporative cooling (upper left), nature-based recreation (upper right), and with local identity (lower center)

In the case of carbon sequestration, the highest levels of interaction were with other regulating ES flood control, water quality, biodiversity, and evaporative cooling consecutively, Table 10.

Table 10: Carbon sequestration vs. other ES, percentage of the study area in categories A, B, and C

	A (%)	B (%)	C (%)
Surface Water	38	59	3
Flood Control	38	0	62
Biodiversity	38	2	60
Water Quality	38	0	62
Evaporative Cooling	38	9	53
Nature Based Recreation	38	14	48
Local Identity	38	55	7

- **Biodiversity trade-offs with other ES:**

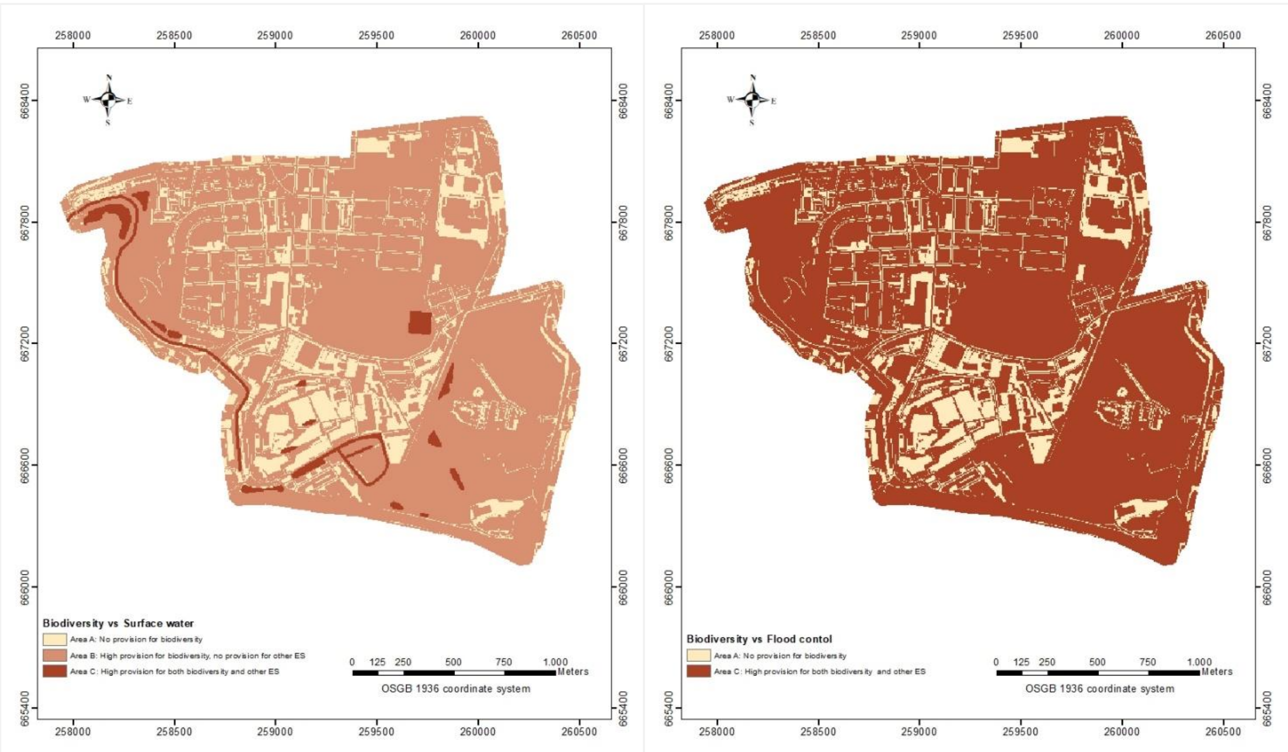


Figure 19: Biodiversity provision tradeoffs vs. surface water (left) and flood control (right)

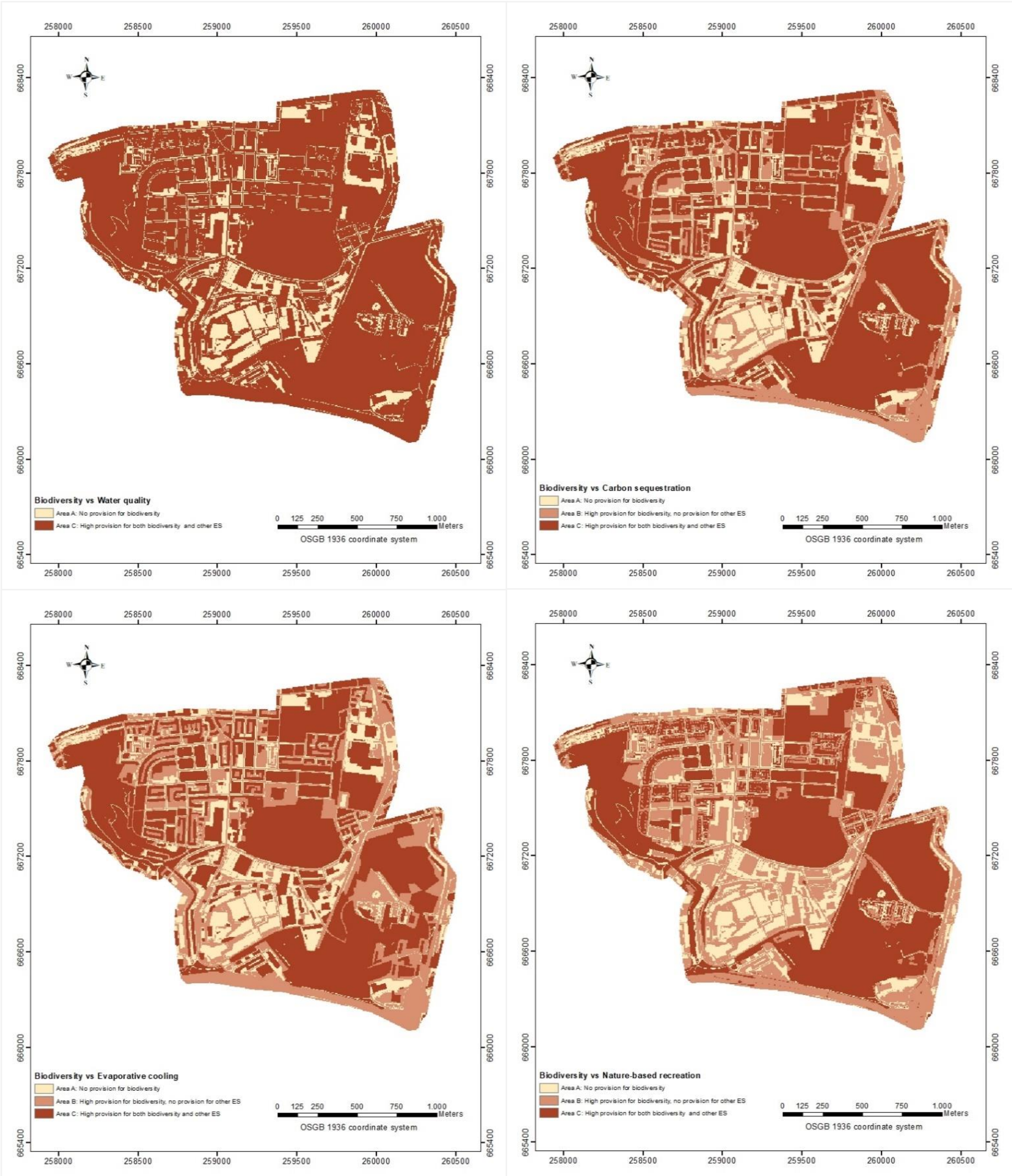


Figure 20: Biodiversity provision trade-offs vs. water quality (upper left), carbon sequestration (upper right), evaporative cooling (lower left), and with nature-based recreation (lower right)

Figure 21: Biodiversity provision tradeoffs with local identity

In the case of biodiversity, the highest levels of interaction were with other regulating ES flood control, water quality, carbon sequestration, and evaporative cooling consecutively, Table 11.

Table 11: Biodiversity vs. other ES, percentage of the study area in categories A, B, and C.

	A (%)	B (%)	C (%)
Surface Water	19	78	3
Flood Control	19	0	81
Water Quality	19	0	81
Carbon Sequestration	19	21	60
Evaporative Cooling	19	29	52
Nature Based Recreation	19	34	47
Local Identity	19	74	7

4.2 Discussion

The ecosystem services inventory (section 3.2.1) provided a comprehensive list of possible services in the smart canal project area (Table 8). The inventory aimed to provide a transferable set of ES, based on several assessment frameworks and covering multiple elements of urban ecosystems present in the study area. Although the results conveyed a higher potential for the delivery of regulating services, there was still an almost equal opportunity for the occurrence of provisioning and cultural services in the area. For instance, the north-western area of the canal can be used as a hub for starting small-scale urban agricultural projects focused on reusing the canal water to produce both ornamental and edible plants while educating residents on the rare plants in the Canal area. Thus, increasing the delivery of provisioning and cultural services (McLain *et al.*, 2012; Russo *et al.*, 2017; Hajzeri and Kwadwo, 2019).

Some of the services could be provided by the Forth & Clyde canal directly, such as using its water supply for industrial, agricultural or recreational uses (e.g., boating, paddle sports) and the possibility for renewable energy production from the canal water (Davies *et al.*, 2011; Gómez-Baggethun *et al.*, 2013; Scottish Canals, 2015; Muscatelli *et al.,* 2020). Other services might result from interactions between the canal and the surrounding ecological infrastructure elements (e.g., trees), such as in urban heat amelioration and flood protection (Forest Research, 2010; EEA, 2011; Davies *et al.*, 2011; AECOM, 2013; Gómez-Baggethun *et al.*, 2013; Robinson, 2013; Žuvela-Aloise *et al.*, 2016; Brears, 2018; Codemo *et al.*, 2018; Scottish Canals, 2018). The results of the ES inventory stemmed from previous research; finer details can be obtained through consultations with involved stakeholders and the public to understand the possible services of the Smart Canal project and draw investment opportunities towards the Forth & Clyde canal (Raymond *et al.*, 2009; Klain and Chan, 2012). Stakeholder opinion analysis and community involvement can provide essential information to better value the services of the Canal and ensure its continued success (Sheate *et al.*, 2008; Buckman, 2013, 2014).

4.2.1 Ecosystem services mapping

The selection of the eight mapped ES depended on data availability (Rocha *et al.*, 2015; Jacobs *et al.,* 2017; Syrbe *et al.*, 2017). ESPU maps (section 4.1.1) were meant as in indication of the potential of ES in the Smart Canal project area, mainly based on the ability of landuse and landcover classes to deliver ES (Cruickshank *et al.,* 2000; Maes *et al.*, 2012; Cabral *et al.*, 2016; Fernandez-Campo *et al.*, 2017). ESPU can only be considered as an indication of the presence of particular ES in the site area, without giving any further information on the actual supply of the service (Fernandez-Campo *et al.*, 2017). The ESPU maps confirmed that there is considerable potential for the delivery of regulating services in the Smart Canal project area.

In the case of enhancing water quality, the presence of riparian routes, old oak woods, and greenspaces coupled with the use of new technology (e.g. floating woodlands) in the Canal, positively affected the water quality in the Smart Canal project area. Although enhancing water quality was focused in the north-western part of the area, it can be further dispersed by increasing greenery percentage and using sustainable drainage systems such as green roofs (EEA, 2011; Ballard *et al.*, 2015). Hence, further increasing the delivery of water quality on a local scale will enhance the overall quality of water discharged into the River Kelvin on a regional scale. Also, areas of greenspaces, riparian routes, and woodlands showed high potential for sequestering carbon in the study area. Increasing the percentage of greenery in the study area and forming green corridors can result in an increase in carbon sequestration, which can offset some of the emissions resulting from future developments in the Smart Canal project area in a local context (Chen, 2015). Using the Canal as an alternative drainage solution and increasing greenery percentage can be used to promote the Smart Canal project as a low carbon development aiding Scotland's effort to reduce its carbon emissions (Scottish Government, 2019).

Furthermore, the delivery of both evaporative cooling and biodiversity was especially visible in the north-western part of the Canal, due to the presence of water, riparian routes, old oak woods, and British Ash. Thus, Increasing the percentage of greenspaces in the canal area and focusing on the interplay between green and blue spaces can increase the delivery of both services in the Smart Canal project area (Savard *et al.,* 2000; Moss *et al.*, 2019). On a city scale, the study area can increase the percentage of habitat areas available for urban wildlife and provide a critical communal space for Glasgow residents. Other regulating services such as flood control had a lower presence because of the high percentage of sealed surfaces in the study area (e.g., around 20% are classified as a dense urban fabric, and 37% are industrial, commercial, and construction sites). The Smart Canal project focused on increasing flood control delivery by using the Canal and sustainable drainage systems to drain the study area. Thus, highlighting the value of joining technological and sustainable solutions in enhancing ES delivery.

Moreover, provisioning and cultural services (especially surface water and local identity) had a restricted distribution in the Smart Canal project area due to the locality of the data used in its mapping (Figure 14, Figure 15). Most of the services were highly present in the north-western part of the project area, around the Forth & Clyde canal segment, due to the presence of the Canal water, forests, riparian routes and water-based sports areas which represents attraction points for recreation, signaling the importance of interactions between built and ecological elements for services delivery (Pickett et al., 2001; Gómez-Baggethun et al., 2013).

Provisioning and cultural ES delivery can be expanded in the area by creating new attraction points along the Canal's length, such as community growing spaces aiming to produce edible products while simultaneously educating residents on the plant's species in the Canal area. New attraction points are expected to increase recreation levels and strengthen the resident's relationship with the Canal. Thus, ESPU maps can be considered as the basis for further analysis in the study area. An invitation to quantify the supply of services surrounding the canal, such as quantifying flood control offered by calculating the 'damage cost avoided' if the canal was not utilized for drainage or if a traditional solution was used, and tracking the number of visitors or jobs created can help to quantify the value of nature-based recreation by the canal. Other services such as local identity cannot be quantified with economic values, rather surveys, and meetings with the local community can help to understand the bequest value of the Canal (Ashley, 2014). ES mapping and quantification can further guide Scottish Canal's management decisions for all future developments in the Canal area, e.g. following an ecosystem-based approach for any future developments can preserve and increase the ES supply of the canal, and highlight the Canal's potential to meet future targets of the Scottish Government (Transport Scotland, 2013).

The ESPU maps were normalized to a scale from 1 to 5, to compare the provision of different ES. Each ESPU map was created by combining different sets of criteria using GIS map algebra. Although this method was based on existing research (Fernandez-Campo *et al.*, 2017), it still offers high levels of subjectivity in choosing the relevant criteria and assigning weights for each service. In order to move away from Tier 1 approaches (that only take into consideration the role landuse and landcover classes play in ES delivery) into Tier 2 approaches, factors such as greenspace function were included to account for the human influence on the urban environment. By including all greenspaces such as lawns, small private gardens, and community growing spaces, which can be considered as critical providers for ES in the urban environment but usually are not accounted for in landcover classes, better results were obtained (Bennett *et al.,* 2009; Raudsepp-Hearne *et al.,* 2010). Other criteria were added to account for the role green infrastructure can play in ES delivery in the Smart Canal project; bioretention ponds were georeferenced and classified in GIS, based on its size and the nature of installed filtration systems. Finally, other criteria were derived from DEM, such as slope to account for the role topography can play in flood control and enhancing water quality (refer to *Figure 8* for details on tiered approaches in section 2.4) (Hunt *et al.*, 2006; AECOM, 2010; Forest Research, 2010; James and Dymond, 2012; O'Brien, 2015). Having more data on buildings types, locations of green roofs or small gardens, canal water temperature, and soil types can facilitate a transition to a Tier 3 approach, allowing the use of modeling tools to understand further interactions between ES in the Canal area (e.g., modeling the Canal's cooling capacity using ENVI-met). Having access to this data would have increased the accuracy of the results obtained in this analysis and provided a more accurate spatial distribution of ES.

Producing ESPU maps for cultural services was very challenging due to the lack of available spatial data. The only available criteria were firstly the core paths that exist in the project area, which are frequently used by pedestrians or cyclists. Secondly, the presence of Hamiltonhill Claypits natural reserve which offers excellent views of the city and is used by residents for small walks (e.g. dog walking) and the final criteria was the presence of historical elements around the canal such as locks and footbridges that can form an attraction for some locals. Due to the lack of local knowledge in this analysis, some other attractions in the area may have been missed. Therefore, the services were localized in the north-western part of the canal based on the data provided by the Scottish Natural Heritage website. Scottish canals need to draw more focus into collecting information on the number of visitors in the area, ease of accessibility, hidden attraction points which are used by the locals for physical or intellectual activities, and level of amenities can give a more accurate representation of cultural services in the area.

Consequently, the produced ESPU maps can be considered subjective and in need of further validation. GIS-MCDA should be prepared while taking into consideration expert and local community knowledge until full agreement is reached on the criteria weights before mapping ES, this can be done through organizing a series of discussion groups between Scottish Canals team, experts and the local community. Equally important is calling for community engagement to obtain information on the importance of historical elements, nature reserves, and core paths in creating an emotional connection within the Canal area. Data can be obtained through conducting interviews with locals to register their opinion and feelings about the Canal or using photo voice method to acquire levels of attachment locals have to certain locations along the Canal area (Ashley, 2014). Nonetheless, the ESPU maps remain an essential first step in introducing decision-makers to ecosystem-based management approaches.

4.2.2 Bundles and trade-offs

In order to understand the levels of interaction between the eight mapped ES, the ESPU maps were overlaid using GIS to create a map that indicates the level of spatial coincidence between ES Figure 16. The map only indicates the level of overlap between ES on a spatial level (i.e., geographical location) without adding any further details on the nature of these interactions. The map was normalized to a scale of 1 to 5, where “1” indicates very low levels of spatial coincidence, and “5” indicates very high levels of spatial coincidence, mainly to remain consistent with the classification of ESPU maps. Around 38% of the project area offers high to very high levels of spatial coincidence between ES, especially in the north-western part of the canal due to the presence of the canal water, Hamiltonhill Claypit's natural reserve, and riparian routes. Greenspace areas offered intermediate levels of ES coincidence, covering 24% of the area, mainly due to the different functions of each space, and the fact that small and scattered greenspaces dominated some areas. These results affirm that natural areas such as riparian routes, woodlands, and water are capable of delivering multiple ecosystem services in the same location compared to greenspaces affected by human activities, as changing the functions of green areas limits its ability to deliver multiple ecosystem services and results in prioritizing specific ES over others. Therefore, Scottish Canals needs to concentrate on the effects of prioritizing particular ES over others (e.g. having flood control as the primary goal of the Smart Canal project might lead to changes in the functions of some natural regions which hinders its ability to balance multiple ES delivery). The rest of the study area offered very low to low coincidence between ES, which is apparent in industrial areas and continuous urban fabric landuse classes, which already offered a limited presence of ESPU. Therefore, it is evident that areas where blue and green infrastructure intertwines (e.g., the north-western part of the study area), offers multiple ecosystem services and requires a sensitive level of management that takes into consideration the delivery level of each ES as a priority.

The environmental strategy of Scottish Canals draws attention to the importance of enhancing knowledge levels in areas of carbon and biodiversity management (Scottish Canals, 2015). Therefore, both ESPU maps for carbon sequestration and biodiversity were paired with other ES in the Smart Canal project area, in order to have a more detailed analysis of the interactions between the eight mapped ES (see section 3.2.5). By examining the overlap between carbon sequestration and surface water, it is clear that limited interactions take place between the two services due to surface water areas being spatially limited in the study area (i.e. category C is only 3%, indicating that limited areas near water are responsible for carbon sequestration in the study area such as riparian routes). The smallest water bodies (constructed or natural) are thought to play a vital role in sequestering organic carbon in its sediments (Downing, 2010), which means there is a high synergy between carbon sequestration and the presence of surface water. Nonetheless, using surface water for non-drinking purposes might cause disturbances on some levels, where the Canal is often dredged to avoid silting, control water quality, and maintain navigable status. Frequently dredging the Canal results in the removal of different levels of sedimentations, which might negatively affect the role the Canal can play in transferring sedimentations responsible for sequestering organic carbon between urban water bodies, resulting in a trade-off situation between the two services (Cole et al., 2007; Tranvik et al., 2009), see Figure 17.

Furthermore, carbon sequestration has high synergy levels with other regulating services such as flood control and water quality, mainly due to the slope criterion having a significant effect on both services (slope criterion covers the study area fully, which means ES controlled by the slope criterion will overlap with other ES). For example, having more focus on enhancing flood control in the area might result in changes to the functions of natural areas (removing specific vegetation or trees to install drainage systems), which might result in a decrease in carbon sequestration levels. Therefore, areas of overlap between regulating services require careful planning, see Table 10 and Figure 17. Given that regulating services are considered as indicators of healthy ecosystems, having improved flood control, and enhanced water quality in the Smart Canal area can result in an increase in carbon sequestration levels as well (Bennett et al., 2009). Other regulating services such as biodiversity and evaporative cooling offer high levels of overlap with carbon sequestration (see Table 10,Figure 17 and Figure 18).

However, understanding the connections between these services does not only rely on identifying the interaction between ES, but also on understanding external drivers that might control ES provision. Such as management practices focusing on enhancing microclimate in the urban environment might result in decisions controlling the type of vegetation planted in the area, consequently affecting the delivery rates of other ES that depend on vegetation types such as carbon sequestration (Bennett et al., 2009; Howe et al., 2014; Fernandez-Campo et al., 2017).

Contrasting the levels of provision for carbon sequestration with cultural services, indicated the multifunctionality of greenspaces, where areas of greenery and water were delivering regulating ecosystem services while acting as attraction points for nature-based recreation and cultural heritage (Hansen and Pauleit, 2014). This interplay was evident in the north-western part of the study area, where green areas such as towpaths surrounding the canal showed potential for sequestering carbon, while still holding a sentimental value for the locals, representing areas for recreation, physical exercise and canal enjoyment (Manton *et al.*, 2014; Ireland Waterways, 2016; Axe, 2017). Therefore, management decisions in this area can be considered critical for the preservation of cultural heritage.

A similar analysis was conducted for biodiversity vs. other ES. Like carbon sequestration, the highest levels of interactions were between biodiversity and other regulating services; intermediate and low connections took place with nature-based recreation, local identity, and surface water areas consecutively. Biodiversity can be considered to be generally synergetic with other regulating ES and more inclined to result in trade-offs when interacting with provisioning services (Bennett et al., 2009). For example, adding floating wetlands in the Canal is meant to enhance the water quality and, at the same time, can result in increasing invertebrate numbers and welcome new species into the Canal (Bi et al., 2019) increasing the overall biodiversity. However, an increase in provisioning services such as a rise in the use of canal water for non-drinking purposes might decrease/change the levels of water in the Canal, negatively affecting feeding and nesting locations for some birds and species depending on water (Kushlan, 1986; Cimon-Morin, Darveau and Poulin, 2013; Evtimova and Donohue, 2014; Howe et al., 2014; Ireland Waterways, 2016). See Figure 19, Figure 20, Figure 21 and Table 11.

In short, ESPU maps confirmed the preliminary ability of the canal and surrounding areas to deliver various ES. At the same time, mapping the level of coincidence between ES and comparing ESPU in pairs provided the necessary information for understanding the relationships between ES and identifying areas that needs sensitive management such as the north-western part of the canal. Combining the results of this research can provide decision-makers with a steppingstone towards sustainable management of the canal resources.

4.2.3 The new role of Forth & Clyde canal

The results of this research confirmed the potential of the Forth & Clyde segment involved in the Smart Canal project to deliver various ES, especially in the north-western part of the canal (where the Canal water meets with Hamiltonhill nature reserve and riparian routs occur). The Canal is responsible for delivering a higher percentage of regulating services compared with provisioning and cultural services in its current status. These results do not indicate that the canal is not capable of delivering provisioning or cultural services; instead, the inputted data into this mapping analysis provided a better representation of regulating services in the Canal area. Thus, having further information on the nature of activities around the canal, its frequency, and the number of visitors by conducting more survey work, in-depth interviews and focusing on local community engagement can provide vital information to improve the mapping of cultural and provisioning services in the area (Ashley, 2014). The mapping of ES using GIS offers a visualization of key ES that can be easily communicated to a crowd of experts, multiple stakeholders, and the general public simultaneously. ES maps provide an opportunity to contrast the provision of ES with any future development undertaken around the canal, aiding Scottish Canals in making ecosystem-based decisions.

As mentioned before, climate change effects on Glasgow city include extreme weather, acute changes in temperature/precipitation, and flooding (ClimateXChange, 2016; England *et al.*, 2018; Scottish Government, 2019). Accordingly, the results of this analysis argue that the role of the Forth & Clyde canal can go beyond its history as a transportation route or current uses in recreation into being at the forefront of facing climate change adaptation challenges. The results confirmed the role of the Forth & Clyde canal in flood control as part of the Smart Canal project (i.e., the ability of the canal to store runoff water, the presence of vegetated towpaths around the canal area and the incorporation of SUDS such as retention ponds and bioswales have a positive effect on decreasing surface water runoff). Furthermore, the canal area showed great potential for temperature regulation due to the presence of open surface water and vegetation, which provides a desirable microclimate regulation in highly urbanized centers visible in the north-western part of the canal. Further services highlight the potential of the canal to enhance water quality before being discharged to the River Kelvin, where pollutants and sediments are filtered by adjacent vegetation and by new technology installed in the canal (e.g. floating wetlands). Finally, the vegetation surrounding the canal and riparian routes offered limited but valuable potential for carbon sequestration, especially in the northwestern part of the canal. It is safe to say that the regulating services provided by the Forth & Clyde canal represent a new lens to view the canal's role in adapting to climate change. Capitalizing on the ES offered by the canal aligns closely with the climate change adaptation program of the Scottish Government, focused on creating resilient places and communities by capitalizing on the value of greenspaces and green infrastructure (Scottish Government, 2019). Equally important is the canal's role as a functioning ecological corridor responsible for enhanced species resilience, especially in the north-western part of the canal, which offers an interplay area between the green and blue spaces, allowing for an increase in biodiversity provision. Also, utilizing SUDS for surface water collection on site (e.g. the installation of floating wetlands in retention ponds enhances water quality and forms a refuge for birds and other urban wildlife) in the Smart Canal project (Winston *et al.*, 2013).

Although the representation of cultural services in the canal area was not elaborate in this analysis, it still managed to highlight areas of interest where there is a higher potential for recreation. The Forth & Clyde canal area included numerous elements with recreational value (e.g., community growing spaces, towpaths around the canal providing active paths for pedestrians and cyclists, paddling and rowing sports areas) all responsible for creating experiential interactions (Babalis, 2011). On the other hand, the presence of the old canal structure (e.g., canal locks and footbridges) is expected to contribute to creating intellectual interactions (Corbeil, 2018). In short, the results of this mapping analysis highlighted opportunities for the role the Forth & Clyde canal can play as an adaptation tool for climate change challenges, an ecological corridor, and a recreational destination within the boundaries of the Smart Canal project. The role of the canal can be taken further to account for the potential of ES delivery along the entire length of the canal, not just within the study area.

Furthermore, canals have proven its role in income generation and successful placemaking, if redeveloped by adopting a COD approach (Buckman, 2013; Buckman *et al.,* 2013). Canal networks in Phoenix, Arizona, transformed from old structures into vital elements of the urban environment, centered at the heart of waterfront developments (Buckman, 2014, 2016). The Forth & Clyde canal area holds an architectural and historical significance to Glasgow's city, recent developments such as the North Speirs Wharf proved to be successful in reviving abandoned buildings and creating a sense of community (Babalis, 2011). It is indicating the canal's great potential to be in the center of new developments, which forms an invitation to bring people closer to water and turn the Forth & Clyde canal into a much-needed public space. Hence, the long-term success of the Forth & Clyde canal closely ties with valuing its multifunctionality by harmonizing the multiple roles of the canal, Figure 22.

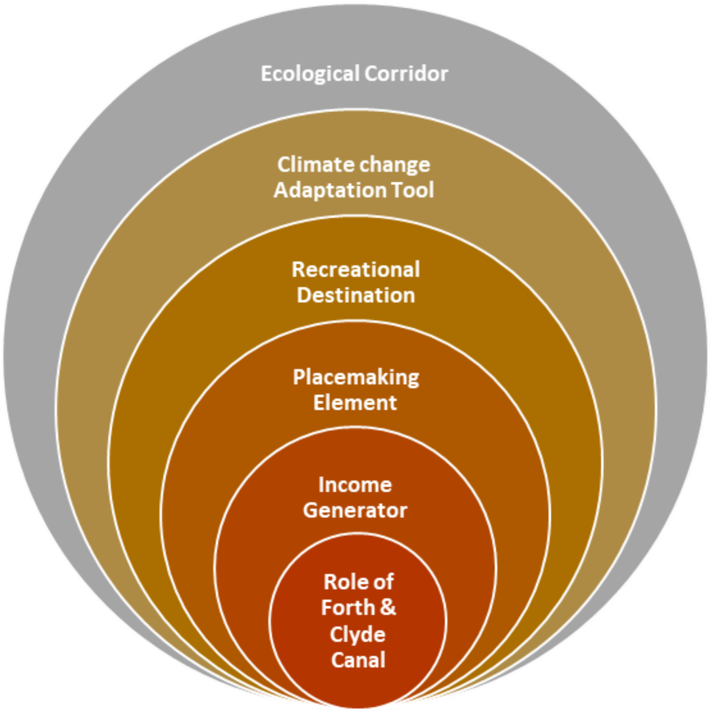


Figure 22: The new role of the Forth & Clyde canal

In short, understanding the nature, provision, and spatial allocation of ES around the canal area is essential in fostering a better understanding of the canal's potential. The mapping of ES in the Smart Canal project area confirmed the ability of urban ecosystem elements for ES delivery. This analysis accounted for the smallest elements from lawns and private gardens to churchyards, highlighting the importance of following an ecosystem-based management approach in order to capitalize on the role of each element. An ecosystem-based management approach can help planners to counter climate change threats and balance the supply/demand of ES in the project area by relying on the potential of ecological infrastructure for ES delivery. This research only provided preliminary information on the ES provision in the area based on open access spatial datasets. Refined results can be obtained by enhanced monitoring, mapping and data collection (Green *et al.*, 2011; Z. G. Davies *et al.*, 2011), building certified datasets, supporting urban ecosystem benefits with empirical evidence (e.g., the role of green spaces in reducing urban greenhouse gases emissions) and finally moving towards integrated valuation approaches, that encompasses various dimensions, perspectives and stakeholders (Gómez-Baggethun *et al.*, 2013; Handel *et al.,* 2013).

5

CONCLUSIONS AND RECOMMENDATIONS

The main aim of this research was to provide a new perspective on revaluing canals and defining its role in the urban environment. The analysis focused on mapping the provision of ecosystem services in the Smart Canal project area and highlighting the occurrence of possible synergies and trade-offs between ES. The Canal proved its ability to support the provision of multiple ecosystem services. Some of the ES were provided directly by the Canal. Such as the provisioning services (e.g. surface water for non-drinking purposes), other ES were a result of interactions between the Canal and surrounding ecological infrastructure such as the regulating and cultural services (e.g. the presence of the Canal and surrounding vegetation increased the potential for the evaporative cooling effect of the Canal and use of the Canal water for recreational activities). It was evident that natural landscape elements (e.g. canal water, riparian routes, and old oak woodland) present around the Canal and Hamiltonhill nature reserve in the north-western part of the study area, had a higher potential for ES provision delivery. Compared to other landscape elements such as greenspaces in the central part of the study area (e.g. private gardens, lawns, and parks) because the greenspace functions might change depending on the human activity in the area. Also, areas where blue and green landscape elements intertwine the most, showed the highest potential for the delivery of multiple ES (e.g. the north-western area delivered intermediate to high provision for six out of the eight mapped ES). Hence, indicating the multifunctionality of these landscape elements and its potential for ES delivery within urban ecosystems.

The delivery of multiple ES creates an environment for the occurrence of synergies and trade-offs. Taking into consideration that the primary purpose of the Smart Canal project was to enhance flood control allowing for the regeneration of north of Glasgow area. Bringing focus into a specific ecosystem service will result in a trade-off situation with other ES in the area. Having flood control as the main aim might result in changes in the functions of greenspaces, types, and allocations of vegetation in the area, which consequently affects its ability to sequester carbon or form new habitats around the Canal. Thus, areas of trade-offs and synergies require careful planning.

The Forth & Clyde canal is able to transcend beyond its role as a transportation route into delivering a set of essential ecosystem services through the Smart Canal project. Regulating ES indicate the Canal's potential to be used as a climate adaptation tool in the city (e.g. alleviating flood pressure and enhancing microclimate). Mapping biodiversity provision confirmed the importance of the Canal as an integral open water body in a highly urbanized surrounding, responsible for providing feeding and resting areas for urban wildlife, the implementation of sustainable drainage systems to collect surface water runoff in the Smart Canal project area (e.g. bioretention ponds and bioswales) serves as an extension of the Canal's role as an ecological corridor focusing on creating new habitat patches and attracting various species. Furthermore, the north-western part of the Canal holds a considerable potential for the delivery of cultural services, the presence of the old canal structure, recreational attractions (e.g. water-based sports) and proximity to Hamiltonhill reserve encourage the occurrence of physical and intellectual interactions amongst people. Hence, the role of the canal can be taken further to account for the potential of ES delivery along the entire length of the canal, not just within the study area, validating the Canal's future potential in creating environmental and social benefits within the urban environment.

5.1 Limitations

The data collection process coincided with the lockdown period due to COVID-19, limiting the research to only open-access data and literature review. Involving the stakeholders of the study area in this research was crucial to gain a local understanding of the study area as well as getting more reliable data about the Smart Canal project. However, only one introductory meeting with the head of the engineering department of Scottish Canals took place before the lockdown. The plan was to work closely with the Scottish Canals team during the implementation of this research.

Besides working with the official body of Scottish Canals, it was necessary during this research to collaborate with various stakeholders (e.g. Scottish water, Glasgow City Council, residents around the project area). To enrich the multi-criteria decision analysis process, conducting Interviews and questionnaire with the locals of Glasgow city, would have brought a vital input for the methodology, and consequently resulted in more objective values for the criteria selected. The absence of active collaborations, together with the lack of available spatial data, restricted the ability to provide detailed mapping of particular ES such as the cultural services, where only three criteria were included (a) core paths, (b) natural reserve, and (c) historical elements.

Generally, more detailed data on soil types, buildings form, locations of green roofs or small gardens, and canal water temperature would have decreased the uncertainty of the analysis and enhanced the understanding of the interactions between ES in the Canal area.

5.2 Recommendations

The analysis approach set to explore the Canal's potential by mapping the provision of eight ecosystem services in the study area by identifying the potential of each landuse/land cover category to deliver ecosystem services. As mentioned previously in the limitation section, the availability, distribution, and resolution of the data govern the mapping process significantly. To expand the scope of this research and further scrutinize the inventory of ES present in the Canal area, using a more comprehensive dataset, e.g. Water quality, air quality, species population, and soil types can produce conclusive ESPU maps (Sheate *et al.*, 2008). The complexity of ecosystem services mapping is evident in the north-western part of the canal, where multiple ecosystem services are delivered by the urban environment indicating the 'heterogeneous nature' of the present landscape elements. Therefore, there is a need for field visits, stakeholder engagement (e.g. Scottish water, Glasgow City Council), and local community knowledge to validate the provision of present ES (Ashley, 2014).

The results of the conducted research confirmed the preliminary ability of the canal and surrounding areas to deliver various ES, including provisioning, regulating, and cultural services. The mapped ecosystem services indicated the potential of the Canal for promoting environmental, social, and economic developments in the future. Thus, there is a need for an integrated management approach that takes into consideration the complex interactions between the Canal's ecosystem services and future activities and does not view it in isolation. Further understanding of the nature of these services, quantification of their provision levels, and interactions with future developments can form a steppingstone for the Scottish Canal's adoption of an ecosystem-based management approach. An ecosystem-based management approach is highly recommended to achieve sustainable land use planning around the Canal (Sheate *et al.*, 2008), harmonize the delivery of multiple ES (Sheate *et al.*, 2008; Bennett *et al.,* 2009; Ashley, 2014), guide decision-making processes (Dodds and Friedrich, 2015), and ensure the safe delivery of future management strategies (de Groot *et al.*, 2010).

Finally, the results of this research endorsed the role of the Forth & Clyde canal as a climate change adaptation tool and a vital ecological corridor. The Canal represents an urbanized waterway that is associated with the most deprived areas in Glasgow city (Transport Scotland, 2013), which makes the development of the Canal more challenging. Hence, the Canal needs a new image that holistically joins the various roles the Canal can play within the urban environment (Tang and Jang, 2010; Corbeil, 2018). It is recommended to rebrand the Canal through adopting a Canal Oriented Development (COD) approach (Buckman, 2013, 2014, 2016). COD is an invitation to tap into the Canal's potential as an attractive recreational destination locally and to ingrain the Canal into the urban fabric as an indispensable element responsible for revitalizing deprived communities regionally.

6

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7 APPENDICES

7.1 Appendix A: input data

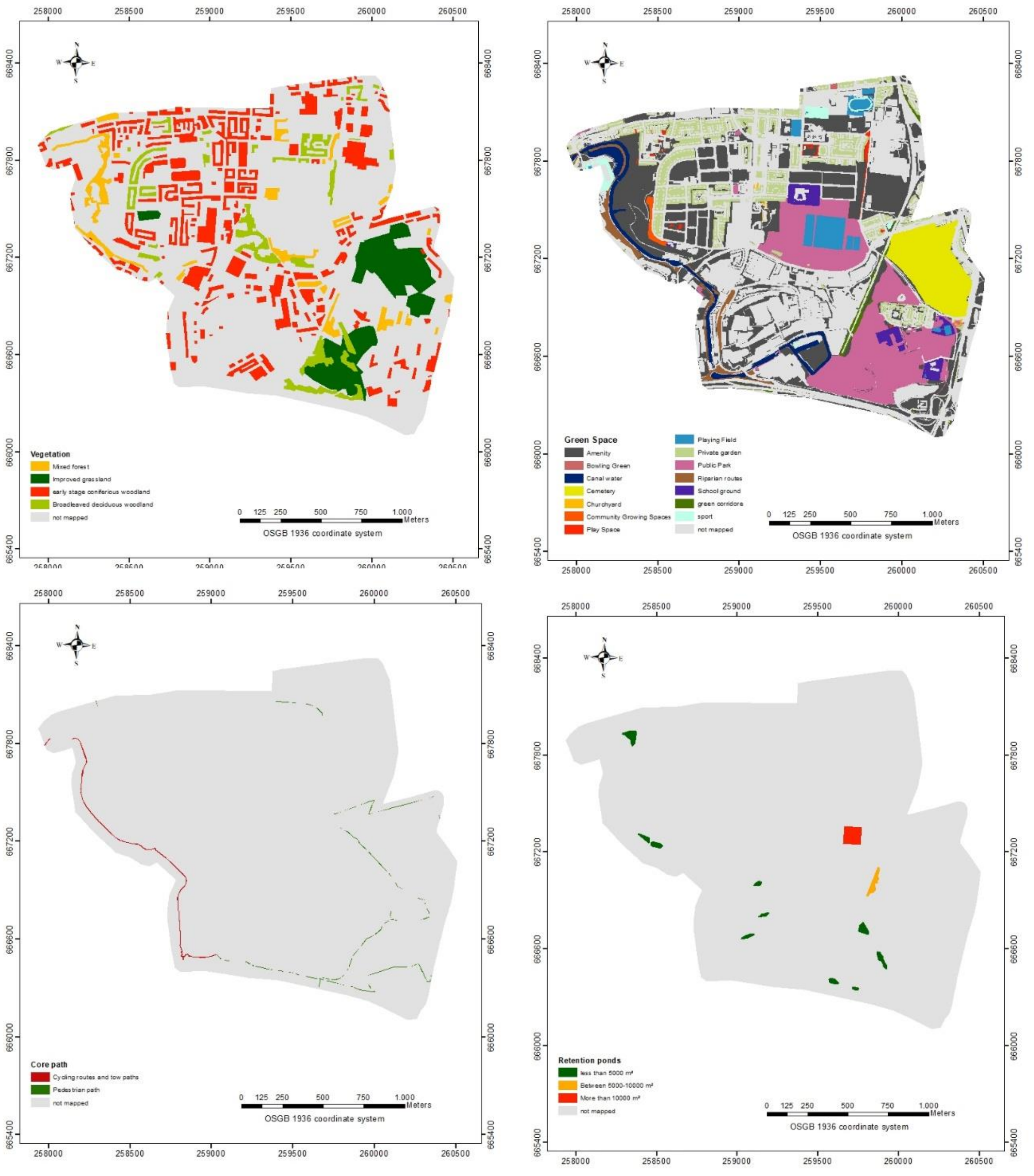

Figure 23: Input data maps for vegetation, greenspace function, core paths, and retention ponds.

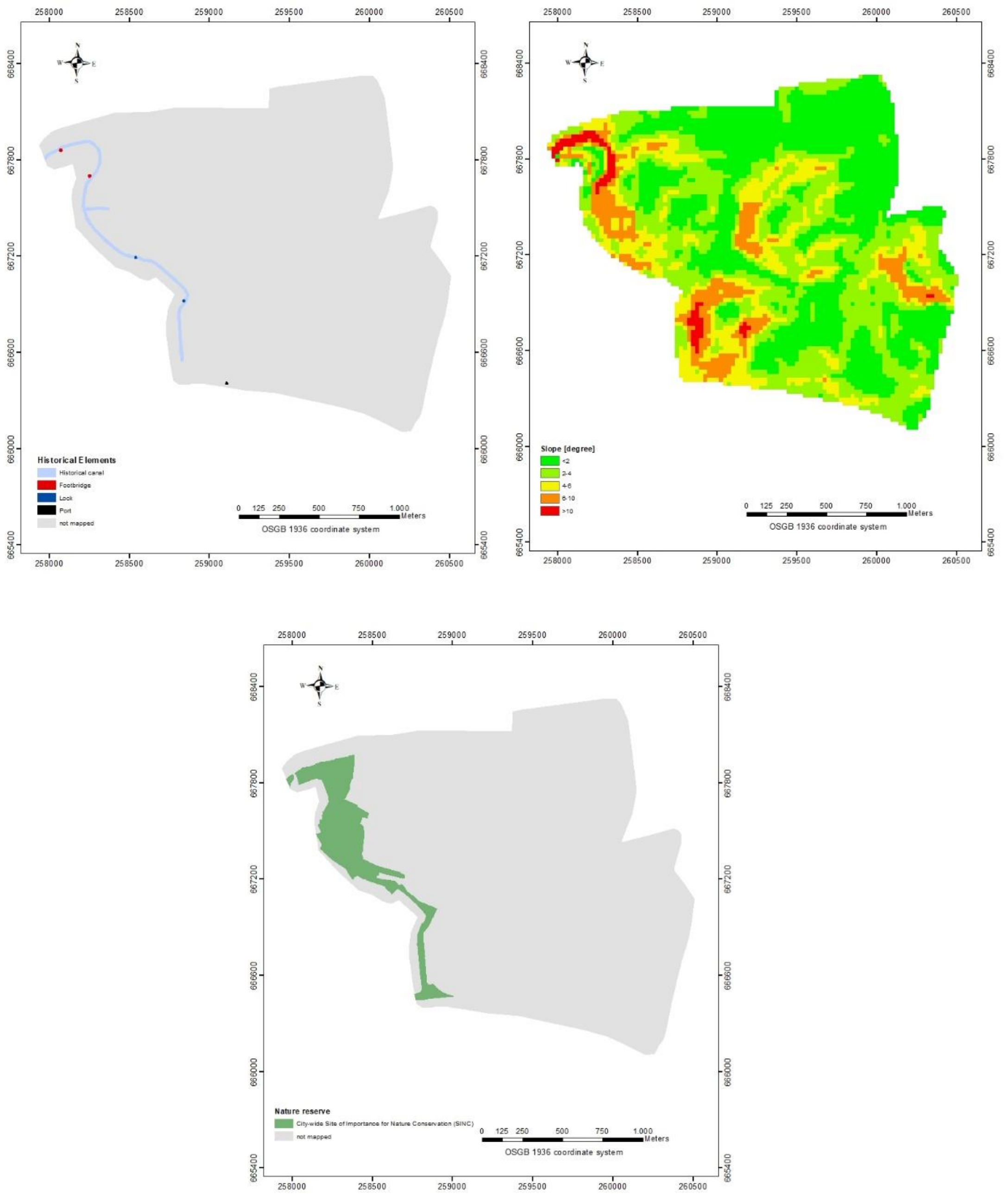

Figure 24: Input data for historical elements, slope and nature reserves