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Linking Ecosystem Health and Services of Novel Green Network for Climate Change Adaptation

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Title

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Degree: Master in Urban Climate & Sustainability

Abstract

The beneficial services of Green Network in mitigating climate change impacts for the urban area are widely acknowledged. Due to social and economic demands in Green Network implementations, it has been challenging to restore these green areas. Consequently, minimize ecosystem services from their initial naturalness condition, or create unexpected effects on city dwellers.

This dissertation aims to critically appraise the capability of the Green Network to deliver a range of climate change adaptation services through an ability to host a healthy ecosystem. And to comprehensively address the role of ecosystem integrity in climate change adaptation. By presenting that ecosystem health and ecosystem services could cause benefits as well as harms to society if they are treated separately by management, even though both are under the same scope. As such, Glasgow city has proven to be a relevant case study due to the establishment of Green Network. This study assessed Glasgow city based on qualitative and quantitative methods to detect potential sites where exist are the extent of (1) policy-focused ecosystem services (i.e., biosecurity, carbon sequestration, and flood regulation), and (2) healthy ecosystem. Indicators are used to appraise their capabilities. By using the GIS-based weighted multi-criterion decision method, practitioners from government agencies qualitatively gave weighted decisions. Potential sites are overlaid to express opportunities and threats between ecosystem services and ecosystem health. The result demonstrates that Glasgow's Green Network sufficiently has average to adequate health. While ecosystem services in the city are inadequate, the great extent coincides with good health extent; i.e., GN could adapt to climate change and provide ES to some degree despite hosting a novel ecosystem. Determining ecosystem health is helpful in terms of understanding ecosystem services supply where ecosystem services are proportionally increased if a "healthy" condition exists. This condition is highlighted by the "biosecurity," which has the greatest extent in multiple-services areas. Still, the caution of implementing ecosystem services is pronounced where ecosystem services could be identified in an "unhealthy" environment. It poses links to several ecosystem disservices, of which Glasgow city has shown mixed results. To target, the multi-functionality of ecosystem services could be the first step to eliminate adverse impact and endeavour towards ecosystem integrity. This approach could be more precise if it included data with a broader range, for instance, climatic, social cohesion, economics, and biodiversity data. However, it is suitable for learning purposes and helps capture beneficial and adaptive characteristics of Green Networks by applying open data.

Keywords

Ecosystem services, Climate change adaptation, Urban Ecology, Ecosystem novelty,

Originality statement. I hereby declare that this Master's dissertation is my own original work, does not contain other people's work without this being stated, cited and referenced, has not been submitted elsewhere in fulfilment of the requirements of this or any other award.	**Signature**

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ACRONYMS

CRC	Climate Ready Clyde Action Plan	Scottish support intiative to create adapting action plan for Glasgow and Clyde Valley region (CRC, 2020)
CXC	ClimateXChange	The Scottish Government programme to address climate change risk (CXC, 2016)
EH	Ecosystem Health	A condition displays the complexity of ecosystems that sustains continuity of ecosystem functionality and ecosystem services (Lackey 2003; Maes et al., 2016).
ES	Ecosystem Service	Range of benefits that ecosystems provide (Burkhard & Maes, 2017).
GCV	Glasgow and Clyde Valley	The Partnership brings together the regional authorities to support policies implementation like Single Outcome Agreements, Open Space Strategies, Local Biodiversity Action Plans and Access Strategies. (GCV, 2021)
GN	Green Network	A multi-functional network of open spaces, linking green spaces to combine benefits from ecosystem services
SINC	Site of Importance for Nature Conservation	A designated local wildlife sites
SSLI	Sites of Special Scientific Interest	Aeas of land and water that are considered best represent Scottish natural heritage (SSSIs, 2021)

CHAPTER 1: **INTRODUCTION**

1.1. Rationale

Climate change has increased the pressure significantly across nonadaptive ecosystems as a consequence of urbanization (Maes et al., 2018). The change amplifies ecosystem health vulnerability (Munang, 2013) and exposes the city's dwellers to climate disaster risk.

We depend on healthy ecosystems to continue delivering a range of ES (Maes et al., 2018). In a functional natural environment, Ecosystem services (ES) and Ecosystem health (EH) are synthesized in the way that EH facilitates ES provisioning (Lackey 2003, Maes et al. 2016) which are vital in a changing climate situation. Accordingly Green Network (GN) are well known to provide such services in an urban ecosystem context (Majekodunmi et al., 2020). Even so, GN is heavily delineated upon humanly-selection traits. Humans tend to spatially alter the landscape to gain ES or favor particular ES that they deem vital to the city's welfare (Evers et al., 2017). Subsequently, selected traits created novelty in the urban ecosystem could minimize ES comparing to their initial naturalness condition (Collier & Devitt, 2016). It create a compensation scenario between ES benefits (Perring et al., 2014), or emerged unexpected effects on EH and well-being (Evers et al., 2017).

Reversing urbanization to the original health baseline has proven to be challenging for contemporary GN conservation and restoration schemes (Lyytimäki & Faehnle, 2013). The pressing pressure from climate change, especially the high emission scenario, calls for the need to deepen the understanding of how to safeguarding and maximizing underpinning ecosystem health and integrity (i.e., condition to providing benefits beyond human needs) (Hatziiordanou et al., 2019). Unfortunately, knowledge of the EH and ES provided by novel ecosystems is ununiform and led to uncertainty in GN management (Evers, 2018). Due to quantitative data linking between EH and ES are not well established in the literature (Erhard et al. 2016; Maes et al. 2016, Maes et al., 2018) whereas the existing method to quantify ES is based on GN typology in the city, not GN's quality or health condition (Majekodunmi et al., 2020).

1.2. Glasgow as case study

Glasgow presents a relatable study area due to the implementation of a local GN action plan as a critical policy to tackle climate emergencies. The policy seeks to reverse the consequence of extensive land use that results in a fragmentation of key habitats and a reduction in biodiversity (Forest Research, 2020). However, the GN is found to have some degree of connectivity but has been unequally distributed (Majekodunmi et al., 2020; The Scottish Government, 2008). The pressing pressure of climate change risking the city to climatic impacts such as rising sea levels, UHI , and surface flooding (Majekodunmi et al., 2020). Glasgow’s GN require long-term management and maintenance to assess and monitoring climate change vulnerability (CXC, 2016)

1.3. Aim

To critically appraise the capability of "Novel Green Network" in delivering ranges of ecosystem services in relation to the ability to host a healthy ecosystem. In order to address the role and benefits of ecosystem health in climate change adaptation. Achieving this aim will facilitate the new insight into novel ecosystem implications in the policy.

1.4. Objectives

1. Review the literature to:
    a. Assess the link between EH, ES, and novel ecosystem
    b. Role of ES in climate change adaptation in an urban area
    c. Identify the existing method used to measure condition and ES

2. To investigate the current degree of novelty of Glasgow's GN

3. Assess the relevance attributes that determine health condition and ES of GN in the local content of Glasgow

4. To develop an approach to measure GN condition and climate change ES

5. Highlight the capability and threats from novel ecosystem to inform local policy

1.5. Questions

- How to measure the health condition of Green Network (GN) in promoting climate change adaptation in an urban area?

- How to examine a relationship between EH and climate change adaptation ES?

- Does novel ecosystems which have lower naturalness provide similar or better climate adaptivity services to the city?

1.6. Outlines

Objective	Methods
1. Review the literature to understand: a. The link between EH, ES, and novel ecosystem b. Role of ES in climate change adaptation in urban area c. Identify the existing method used to measure EH and ES	Literature review
2. To investigate the current degree of adaptivity in novel ecosystem	Conducting site analysis by review literature to capture the elements of environmental change in Glasgow city over time.
3. Assess the relevance attributes that determine capacity of GN to host healthy ecosystem in the local content of Glasgow	Develop indicators from Scottish formalized indicators and key alterations derived from Objective 2
4. To develop an approach to measure GN condition and climate change ES	Map area of EH and ES opportunities utilizing via GIS-based Multi-Criteria Decision Method
5. Highlight the capability and threats from novel ecosystem to inform local policy	Map and explain the consensuses of EH and ES maps

Table 1.1 Dissertation structure to summarize methods applied to meet the objectives (Rattanakijanant, 2021)

CHAPTER 2: **LITERATURE REVIEW**

This chapter set out to gain fundamental knowledge regarding the “ecosystem” frameworks by reviewing works of literature. Discussed are; “ecosystem services,” “ecosystem health condition,” “novel (urban) ecosystem” and available methods to quantify ecosystem. Following reviews fulfill objective one, and establishes the benefits and importance of green networks in relation to their health and integrity in the adaptation for climate change.

2.1. Ecosystem health and ecosystem services

2.1.1. Ecosystem services approach

Ecosystem services (ES) can be defined as benefits ecosystems provide (Burkhard & Maes, 2017). Initially, the development of the ES concept highlighted the “usefulness” of nature’s stock to society solely (Wrbka, 2011). Subsequently, the societal and economic “dependency” on ES was integrated into the initial concept to raise awareness for biodiversity conservation. Costanza et al. (1997) estimated the monetary value of ES as an attempt to resonance conservation among policymakers. However, Saunders & Luck (2016) states that the values of ES should be held as a communication tool across scientists and policymakers; thus, it should entirely reflect on equal distribution across society rather than economics because the intrinsic value of ES is uncountable and should not be legitimately owned on market system.

Despite the differences, ES is seen as a practical framework interfacing ecosystem and human welfare (MEA, 2005). Millennium Ecosystem Assessment (MA) recognize four main strands of services;

- “Provisioning’” or direct resources and materials from the ecosystem,
- “Regulation” or benefit obtained from the way ecosystems maintain functionality,
- “Cultural” or spiritual or experiential benefit, and
- “Supporting services,” or a fundamental functions/processes that “support” other ES (Potschin & Haines-Young, 2018). Hatziiordanou et al. (2019) explain that supporting services are difficult to quantify due to complexity of natural processes. And they could be expressed by assessment of “ecosystem condition” (Potschin & Haines-Young, 2011).

2.1.2. Ecosystem health condition to provide ES

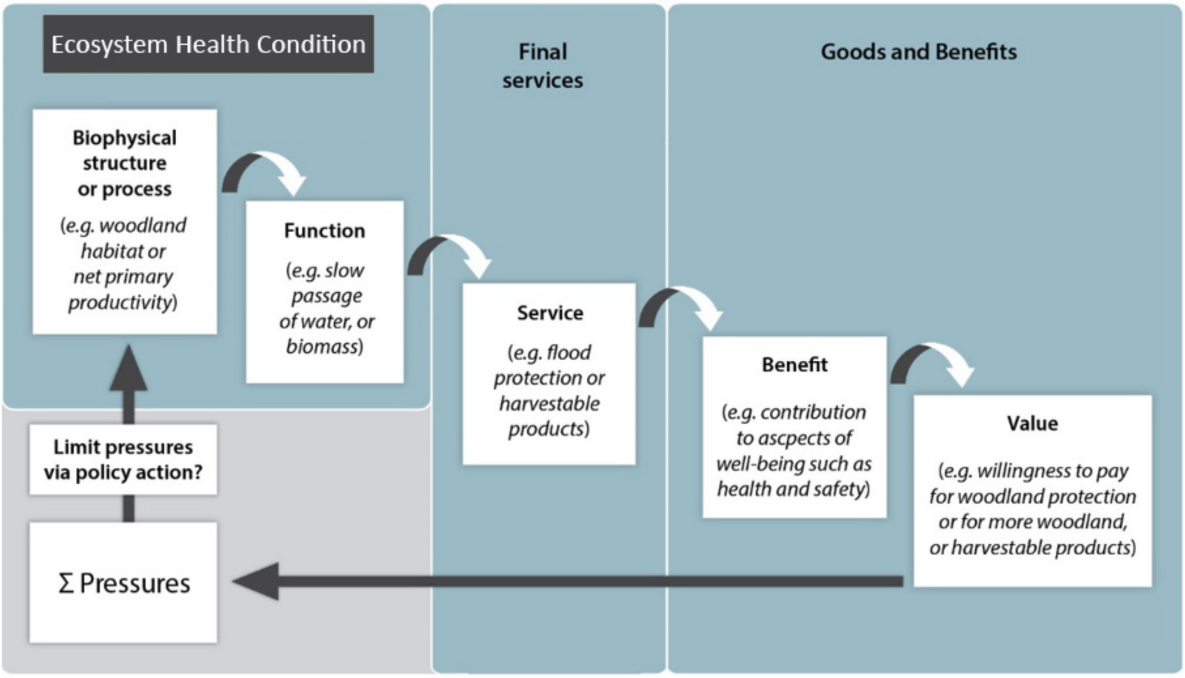


Figure 2.1 Cascade model illustrates delivery of ecosystem service
(Burkhard & Maes 2017; Haines-Young & Potschin, 2010; Maes et al., 2016; Liquete, 2010)

Ecosystem health (EH) is defined as a communication tool used to describe the condition of an ecosystem. “Health” is labeled as the baseline or benchmark condition (Lackey, 2003). Therefore, this study use the terms "health" and "condition" interchangeably.

For the concept of ecological integrity or intactness of the ecosystem, “health” refers to a condition that displays the complex interactions between living and non-living components. Healthy condition sustains the continuity of ecosystem functionality and provision of ES (Lackey 2003; Maes et al., 2016). Simultaneously, an ecosystem that constitutes high ES capability might also indicate good health conditions (Maes et al., 2016)

Figure 2.1 illustrates "the cascade model" to link EH as a constitutional factor of ES (Haines-Young & Potschin, 2010; Maes et al., 2016; Liquete, 2010) to demonstrate the link between them. ES is a consequence of “Ecological condition” that underpin the quality of “ecosystems processes” (i.e. interactions in an ecosystem to generate functions). From this interactions, humans eventually derived benefits and values.

The important idea emphasized by Haines-Young & Potschin (2010) is that “Services do not exist in isolation from people’s needs and that what people value can change over time”. Therefore, research on ecosystem healht conditions should be informed of society’s choices (i.e. demand) that could generate pressure on the ecosystem. Burkhard et al. (2018) explained that relevance pressures can be used as an indicator to identify the quality of a particular ecosystem, i.e. the absent of pressure indicates good health (Maes et al, 2016)

Many research directly related pressure to anthropogenic consequences. The literature that looks at urban ecosystems suggests parameters like pollution, nutrient enrichment, population density, or those that can be spatially examined like landscape conversion (Maes et al., 2018; Hatziiordanou et al., 2019). All literature elaborated the influence of natural pressure come from climate change and natural disasters.

2.2.Role of ES in climate change adaptation in urban area

ES Category	ES for Climate Change Adaptation	ES Role in Climate Change Adaptation
Regulating services	Carbon sequestration	Protect natural habitat from degradation due to changing climate
		Green networks sequester carbon
	Moderation of extreme events	Protect the downstream cities from flash floods
		Wind force modification
		Soil erosion control
		Coastal habitats and riparian absorb the impact of a tidal wave
	Water regulation	Urban runoff catchment
		Purifying runoff water
		Reduce the effects of drought and water scarcity
		Protect water infiltration
	Micro-climate regulation	Moderation of urban heat island
		Reduce diffuse urban pollution
		GHG regulation
		UV protection

Table 2.1 Examples of ES for climate change adaptation
(Zari 2017, Munang 2013)

"Cities are not just subjected to risk; they are also drivers of changes to climate " (Elmqvist et al., 2013). As a driver, the urbanization process impacts ecosystem processes supporting the city in the form of change in natural processes and landscape configuration (e.g., fragmented habitats) that affect ES capacity to provide services.

Simultaneously, the pressure from urbanization also increases the demand for ES. Here, the term demand included the dependency on ES for problems typical to the city – inadequate land use, urban runoff, urban heat island – risking the well-being of city dwellers.

The city, in general, benefits from ES generated by the ecosystem away from city perimeter as Bolund et al. (1999) explained that some ES are transferable within global scopes, such as food production, carbon sequestration, and large-scale water retention obtained from natural resources beyond the city. The transferable ES is where ecosystems that are physically connected carry the ES to the city. However, most urban problems are locally created and better be solved locally (Bolund et al., 1999). Whereas urbanization has deleted the nature footprint from cities. Thus, a "green network" (GN) concept is adopted to solve urban problems and create an element of “regional self-reliance” system (Wu, 2014). GN generating a nature-based solution within the city. The presence of GN increases the resiliency of social capital by “provides physical defense from climate-related disasters” (Munang, 2013). For instance, Emmanuel and Loconsole (2015) mention that a 20% increase of GN could mitigate 2°C of urban temperature.

Climate change significantly increases the pressure across the natural area by amplifying extreme events and shifting seasonal variationspp. Climate change pressure worsen ecosystem degradation, reduces natural carbon sequestration, and causes substantial changes in the current ecosystem health condition (Munang, 2013). To be climate change adapted means the city has "an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities." (IPCC, 2001). Table 2.1 give further exmaple of ES role for climate change adaptation.

2.3. Novel Ecosystem: Green Network (GN)

Glasgow City Council (GCC 2017) describes GN as a "multi-functional network" of open spaces, linking green spaces for the purpose of maximizing "combined" benefits ES from "connected" green spaces while also equally distribute ES to ensure society’s benefits from the improved urban environment.

The combined benefits occurred when multiple services were created as a consequence of maximizing another service, which is known as ecological synergies (Maes et al., 2018).

GN comprises natural (e.g., forests), semi-natural (e.g.urban parks), and man made (e.g. sports ground) landscapes that differ from the original landscape. Thus, the literature mentioned that GN has a state of "novelty" (Heger et al., 2016) because they function differently from the original ecosystem in terms of visualization, colonized species, including a different range of ES where benefits and/harm could be creates as shown in Figure 2.2 (Evers et al., 2018).

The term "novel ecosystem" not only describes a human-designed landscape or simplified landscapes, artificial weuch as tlands, ponds, roadside vegetation, and gardens. The novel ecosystem could also use to describe a landscape of *"post-anthropogenic disturbance succession (e.g., old fields with successional forest), or to currently disturbed ecosystems (e.g., an arable land)" (*Evers et al., 2018).

Novel ecosystem is used interrelated to "urban ecology" in literature (Wu, 2014). Urban ecology defined as a field that examines *"humans in cities, of nature in cities, and the coupled relationships between humans and nature." (*Indiana University, 2021*)*

Where novel ecosystem framework does not explicitly mention "urban area" but broader ecology field, but when mentioned "novelty" in an urban context, it is related to ES (Evers et al., 2018). The two approaches nevertheless aim to incorporate ES as a tool to "improve" and emphasize "the ways that human and ecological systems evolve together (Wu, 2014)" towards the sustainability of the cities. Which sustainability could be more secured "if properly designed, planned, and managed" (Wu, 2014). Perring et al. (2014) describe novel ecosystem mangement aim to promote biodiversity conservation and restoration of ecosystem functions by create a sustantial spaces and links for GN as further described below.

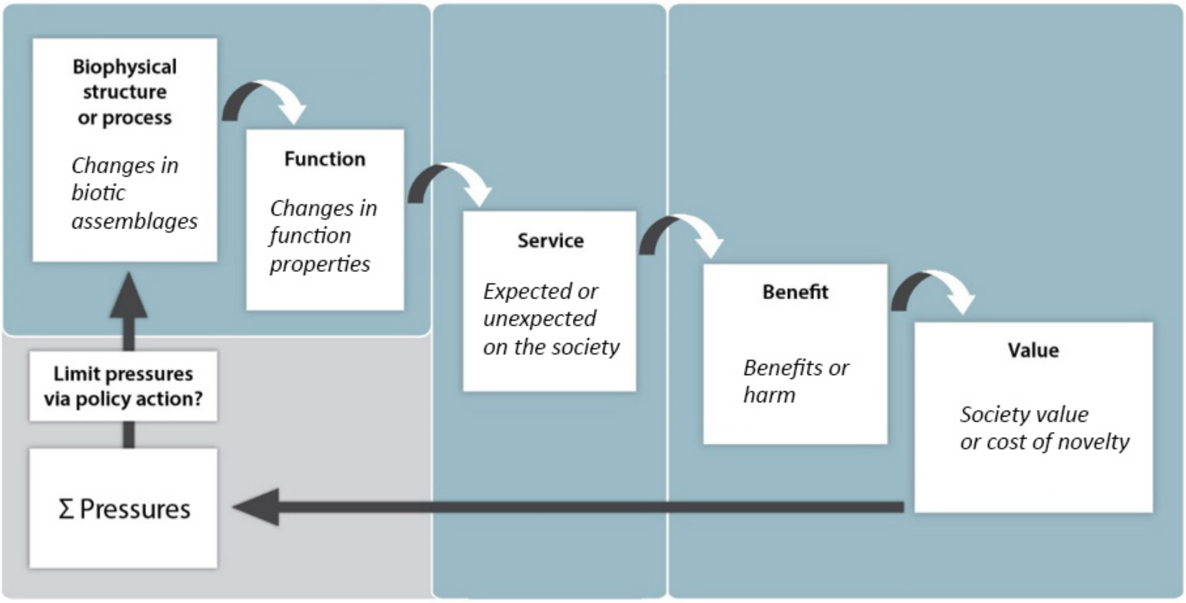


Figure 2.2 Cascade model illustrates delivery of “novel” ecosystem (Burkhard & Maes 2017, Haines-Young & Potschin 2010, Evers et al., 2018)

2.3.1. Green network to conserve and restore ecosystem

ES provided by a novel GN could confront biodiversity conservation (Evers et al. 2018.) Because targeting certain services could negatively reduce other services or imbalance underpinning biological diversity. Therefore, the areas of strictly preserving biodiversity may not always associate with high ES supply (Evers et al. 2018, Potgieter et al. 2019). Restoration however can range from small scale interventions to improve urban biodiversity such as less lawm mowing, or river cleaning, or large scale such as peatland regeneration (UNEP, 2021).

GN's physical display of biological diversity in conservation or restoration requires awareness of the interaction between species or the "ecological networks." The interactions are various but positively affect the fitness, i.e., stability, survivability, resiliency, and natural recovery of member species (Simard et al., 2015). The interactions transfer through various mediums: food web, pollination system, seed dispersal (SNH, 2020), trees mycorrhizal network (Simard et al., 2015).

Although management of conservation and restoration, is challenging because it required subsidies on top oFf scientific knowledge which could cause a short-termist in the implementation, particularly monitoring, where comprehensive conservation could not be achieved. (Hislop et al., 2019).

2.3.2. Green network for linking spatial fragmentation

Novel GN concentration on single area management has been deemed inefficient on an urban scale, particularly when focused areas are too small or isolated from other green spaces. (Fenu & Pau, 2018).

Forman (1995) described GN spatial forms as shown in Figure 2.2, in which each form performs a different function. In particular, a unit of landscape or "matrix" contains "patches" and "corridors" which link the patches. Patches represent a core living space for species to thrive. Corridors serve as stepping stones in supporting the mobility of species to distribute, migrate or disperse.

With ES, these spatial configurations form a functional network to deliver ES when comprehensively connected. For example, in water management, floodplains (matrix) providing a flood retention service; within the floodplain are rivers and streams (corridor) that store and convey water to wetlands and lakes (patch).

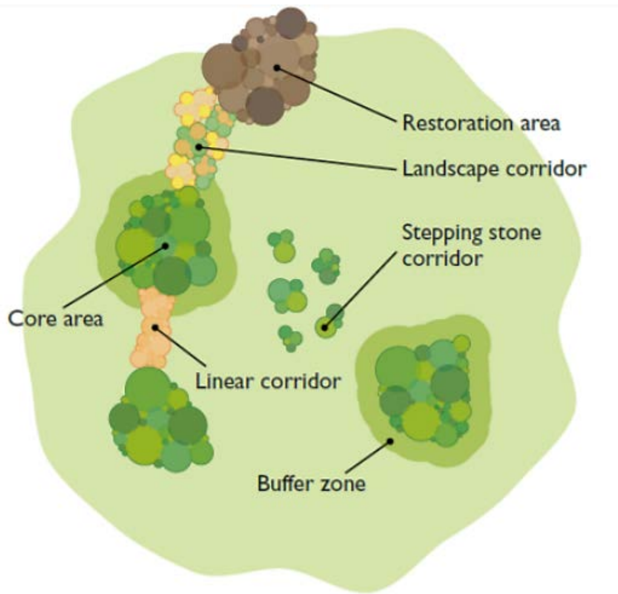


Figure 2.2 The spatial configuration of green network (HMGoverment, 2018)

2.4. Quantifying ecosystem health and services

Maes et al. (2017) reasoned the importance of EH quantification in help targeting and prioritizing ecosystem degradation area in order to be tackled by GN management (such as restoration). In an urban context, the prioritized area could infer to climate change vulnerable area or hotspot of environmental, societal, or economic issues.

2.4.1. Existing methods of quantification

Neugarten et al. (2018) explain that selecting the measurement method is informed by the aim of the assessment and expect outputs, quantitative (e.g., spatial location and monetary) or qualitative. The method must be feasible for practical purposes such as has availability of data, has enough participants in a survey, and are time feasibility. Below presents existing methods to quantify EH and ES. Table 2.2 summarize existing methods by comparing attributes of each method.

Attributes / Methods	Field / online survey	Uncertainty	Expert involve-ment	Public involve-ment	Temp-oral consider-ation	Spatial explicity	Resource & time required	Suitable ES
Field observations	x	x	x		x	x	x	Provisioning Regulation
Surveys, Interviews and questionnaires	x	x	x	x	x	x	x	Cultural Provisioning Regulation
Assess changes		x	x	x	x	x		Provisioning Regulation Cultural
Ground surface observation		x			x	x		Provisioning Regulation
Indicators	x	x	x	x	x	x		All
Accounting method		x	x	x		x		Cultural Provisioning

Table 2.2 Summary of existing methods compared by attributes
(Ruskule et al. 2018, Vihervaara et al. 2018, Ncube et al. 2018, Vallecillo et al., 2019)

2.4.2. Field observations

Field observation essentially links to data collection, which offers the observer spatial explicit data at a local scale. Field observation application is comprehensive once mixed with other methods such as mapping or modeling to assess sampling areas. Although the limitation of this method pointed out by O'neil (2013) concerns the inconsistency if multiple surveys are required. Although field observation can derive a precise measurement, it needs resources and time (Ruskule et al., 2018).

2.4.3. Surveys, interviews and questionnaires

This method qualitatively captures an overview of a focus group on their opinion. Vihervaara et al. (2018) describe the advantage of public and expert knowledge involvement, such as they could help select a relevant parameter, score them, suggest ES demand, or help eliminate the uncertainties of the assessment. Although, it should not be forgotten that the number of inclusivity can be problematic.

2.4.4. Assessing change

Ncube et al. (2018) demonstrate the application of a time series aerial maps to quantify ES supply and extent change in time. In this way, the researcher could gain information comparing lost or evolution of key ES. Ncube et al. (2018) also suggest ES research could benefit from investigating the temporal dynamic in landscape such as seasonal variation and ecosystem change.

2.4.5. Ground surface observation

Utilizing remote sensing capture by satellite Earth observation is useful to directly measure ecosystem physical state and ES supply such as land change, location of species assemblages, classify types, and size of habitats (Cord et al., 2017). ES demand and benefits calculations are more challenging to be measured by satellite Earth observation, and stimulation usually need to is usually needed to include a parameter of ecosystem attributes (Cord et al., 2017).

2.4.6. Accounting method

This method derives the numerical supply of ES from ecosystems to the community to assess whether a mismatch exists in ES demand and supply. For most ES, demand in an urban area is much higher than the supply, accounting method ensuring ES is delivered continuously (Burkhard & Maes, 2017). Accounting methods do not need additional data input like modeling (Burkhard & Maes, 2017). In fact, researchers could rely on official data such as CO2 flow. Therefore, not well-grounded data can cause high uncertainties.

ES accounting is linked with monetary values like crop yield and carbon rates. However, this approach is more suitable for ES that generates provision for a market system (Vallecillo et al., 2019).

2.4.7. Indicators

Indicators are categorized as "index," "mapping," and "model" (O'Neil, 2013). Further defined, the indicator-based framework attained for scoring to measure some given parameters and simplifies the complexity of the ecosystem to improve understanding (O'Neil, 2013).

Essentially, indicators could give an overview of EH and ES by measuring their attributes, and it is described to be a simple method of conveying and simplifying large data.

Longstaff et al. (2010) reviewed numbers of literature indicate that many indicators already exist for the urban ecosystem. It causes uncertainties in choosing the relevant indicators from the large volume of existing indicators. Longstaff et al. (2010) supported the role of literature reviews to narrow down the relevance indicator and recommended a framework that is spatially explicit to local policy.

Additionally, it is useful to choose temporal indicators, e.g., extreme events and seasonal changes indicators (Longstaff et al., 2010). Also, attention should be given to local climate as driven pressures are different such as eutrophication that is a common problem in only a temperate climate. Pressures on ecosystem conditions and the capability to deliver ES can be used as indicators as well. Furthermore, Longstaff et al. (2010) suggest that biological indicators data collection could be time-consuming and are some indicators could have received prioritization because of their role in policy (Maes et al., 2018)

Example of existing indicators

There is a number of studies that measure the same framework but using different terms and approaches. Keyword searches were undertaken using “ecosystem health indicators,” “ecosystem condition indication,” and “ecosystem services indicators, and climate change adaptation.”

The selected framework below are selected because they are accepted or involved policy-makers or experts, they are relevant to UK, Scotland or Europe, or/and informing health condition alongside ES.

a. Climate change adaptation indicators from Scotland’s CXC:

Scotland’s CXC was developed by government agencies ClimateXChange. The set contains 105 indicators to track change from climate change risks and their associated impacts for Scotland (CXC, 2016). From 6 narratives "natural environment" is the most related to this study. The others include narrative for forestry, biodiversity, agriculture, buildings & infrastructure network, and society. The indicators look at a current policies regarding climate change adaptation, progess and the effectiveness of policies to inform policymakers and the public. Experts from scientific research organizations, the Scottish Government and public agencies provided inputs for indicator development.

b. Environment Protection Agency (SEPA)'s ecosystem health indicators:

Included are 14 indicators, three narratives listed for EH assessment. SEPA'S indicators aim to quantify the benefits of ES but simultaneously prioritize action to protect or enhance EH (SEPA, 2019), which correlates to this dissertation's aim. The indicators range from "condition of ecosystem attributes," "function or capacity to deliver ES," and "resiliency," or "ability of nature to be sustained under human and environmental pressures, including climate change" (SEPA, 2019.)

c. Unformalized indicator by reseach study:

Majekodunmi et al., (2020) map ES in Glasgow city using GN performance indicator to express open space typology to assess equitability of GN distribution links typology of greenspace as an indicator for ES quantification. Hatziiordanou et al. (2019) however focus linking habitat maintenance ES to ecosystem condition to reflect EU conservation strategy framework (Maes et al., 2018), therefore the indicators are directly relate to biodiversity and pressure.

2.5. ES controversy

The known controversy of ES is termed as "Ecosystem Disservices" (EDS); it addresses the properties of ES *"that are perceived as harmful or unwanted by humans"* (Lyytimäki, 2014). The disservice ranges from natural phenomena such as extreme events to man-made causes, for instance, poisonouse species in urban area, seasonal floods in urban areas. Lyytimäki (2014) found that the area of the world with high biodiversity such as tropical area has the highest occurrence of EDS like pests and diseases, in which Gutierrez-Arellano (2018) describe that native and non-native species may jeopardize human health if ecosystem function is changed. Neverth eless Saunders & Luck (2016) explain that EDS can be eliminated by enhanced biodiversity such as pollen allergic reactions cause by urban trees.

Saunders & Luck (2016) provide an example that what is perceived as EDS could provide ES in other aspects while some ES and EDS can exist together. Thus, to enhance one ES could alos create EDS, this is known as a trade-off environment.

The literature describes EDS as highly subjective to various social groups. Therefore, a participatory approach could be useful in urban planning processes to gain insight into what people perceived as EDS (Lyytimäki, 2014). The reviewed literature all mention that rather than eliminating a single EDS, the GN planning should rather target ecosystem health despite having EDS attributes (Lyytimäki, 2014; Saunders & Luck, 2016.)

2.6. Conclusion: research gaps

Literature review studies indicate that an ecosystem framework has been developed to deal with urban issues. However, an urban ecosystem is still evolving (European Commission, 2021), which creates gaps in the existing framework. The essential knowledge gaps are highlighted below.

1) Novel GN, EH, and ES delivery links are not well established (Maes et al., 2016). Measurement often regards them separately (Evers et al., 2018) despite they both could constitute and indicate the states of one another.

2) The viewpoint of EDS in novel GN management has uncertainty due to the trade-offs environment it creates (Evers et a., 2018), which pose a challenge on to restoration and conservation of GN.

3) Existing ES measurement in Glasgow city applied GN typology for the assessment but not the underpinning EH. (Majekodunmi et al., 2020)

4) Literature mentions a gap between ecology and social aspects. Limited literature studies past ES on to the "value" society gain from ES. Understand this impact of demand quantitatively help informs the influence that antropogenic pressures has on EH (Maes et al, 2016)

CHAPTER 3: GLASGOW AREA PROFILE

The following chapter presents the Glasgow area profile to support objective two to analyze the degree of novelty in Glasgow GN for baseline setting. The knowledge derived here helps envision the case study and justify the EH and ES assessment approach.

Novelty degree can be linked to ecosystem health; it reflects pressures from anthropogenic and environmental changes that occurred to the native ecosystem. As a consequence, the role and supply of ES have changed. To understand Glasgow's urban ecological context, the GN current state must be compared to a state of naturalness or a highly adaptive ecosystem with minimal human interference, which SEPA termed "reference conditions." Reference data for Glasgow city are gathered around the pre-18th century or pre-industrial era, where naturalness conditions existed in Europe (Blackbourne, 2006.)

This chapter introduces climate change impact as a driver. Then explore natural processes and change in Glasgow to describe the issues and causes degrading Glasgow's ecosystem. The role of Glasgow's local GN policy was then identified to understand what has been done locally to resolve the environmental problems. Finally, the conclusion summarizes the degree of novelty.

3.1. Climate change impact

Climate projections by Climate Ready Clyde (2017) informs that by 2050, a 1.5°C rise in temperature and precipitation trend (12% in winter, -8% in summer) as shown in Figure 3. To be expected are change in seasonal variation and intense weather, drier summers and milder, wetter winters, and increasing extreme storm events associates with sea-level rise. While RCP 8.5 (Representative Concentration Pathways 8.5) represent high emission scenario, has projected 4.5°C rise in temperature implicates higher intensity of climatic impact. The climatic impact combines with anthropogenic change has impacted Glasgow's adaptability in regards to natural process, climate, and biodiversity security. Which are further explained in this chapter.

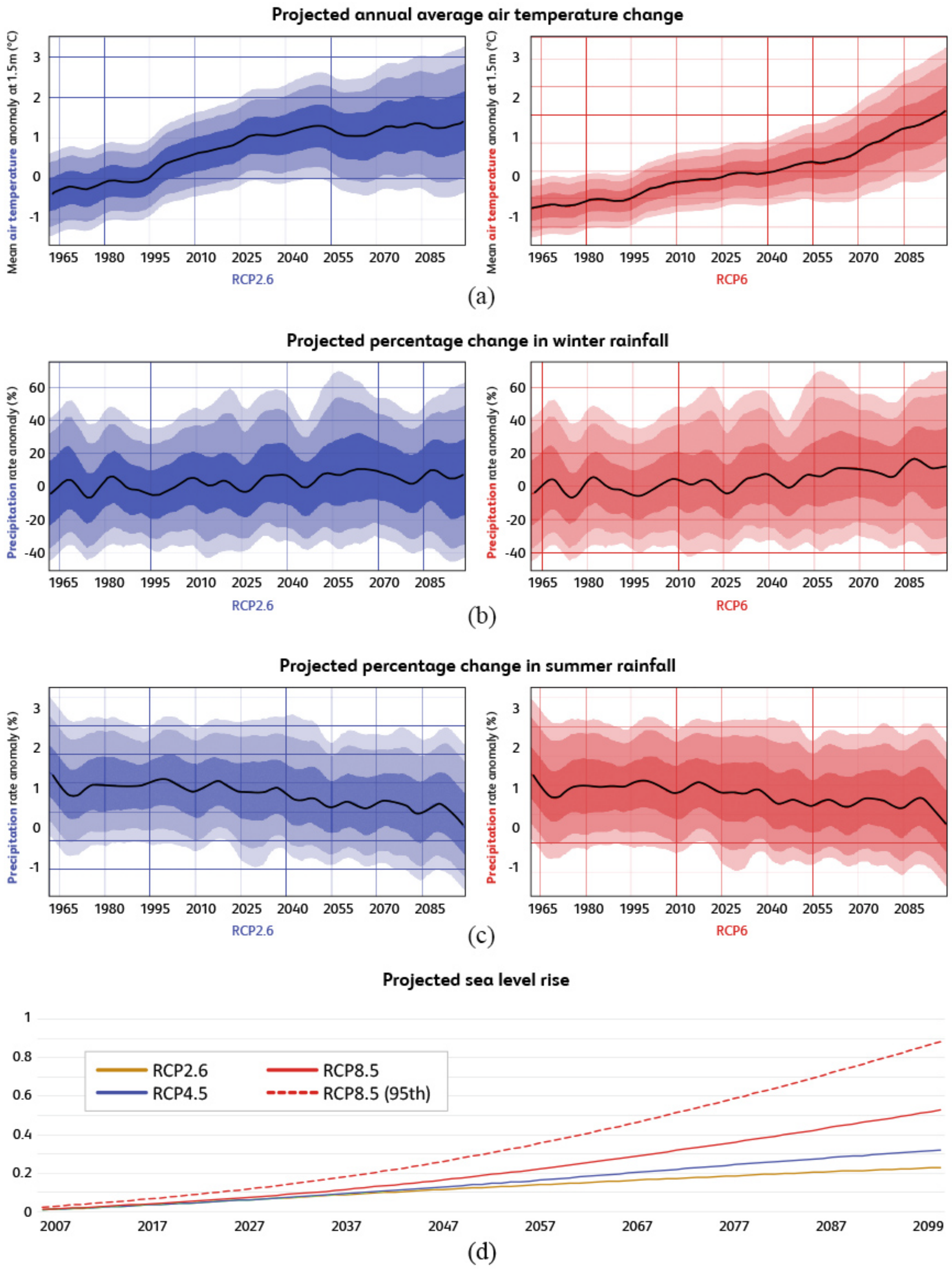


Figure 3.1 Projected climate change for Glasgow City Region
(a) Projected annual average air temperature change,
(b) Projected percentage change in winter rainfall,
(c) Projected percentage change in summer rainfall,
(d) Projected sea level rise, RCP2.6 represents very low greenhouse gas levels.
RCP6.0 is a medium emission scenario which is closer to current emission pledges.
And RCP8.5 represent high emission pathway
(CRC, 2021)

3.2. Natural process and environmental change in the Clyde Valley

Glasgow situates in the lowland of Clyde Valley enclosed by hills ranges formed by ancient glacial activities. The geography influences the meandering of River Clyde's and its tributaries; Black Cart, Gryffe, Kelvin, Leven and White Cart (Karunarathna, 2011). Glasgow's Clyde is a transitional river basin, the river flow from headwater northeastward passes Glasgow city, Clyde Estuary, and finally into the Firth of Clyde, linking land and sea.

Industrialization has had considerably modified the Clyde Valley. Through the past 250 years of land change, little remains of the native ecosystem.

3.2.1. Native habitats

Effect of saline and freshwater, Karunarathna (2011) describes existing inter-tidal marshes adjacent to Glasgow city. Historical map (Marwick, 1892) illustrates Glasgow as it existed in 1662, the river with sandbanks and islets known as inches. Jones et al. (2018) describe the clearance and drainage of "lowland forests" to make way for farmlands. These describe the floodplain environment. The remains of habitats in Glasgow city prioritized by SNH provide visualization of the past. "Woodland" survives on steep ground or inaccessible slope, of which 5% are native woodland (Forestry Commission, 2013). "Wetland" is a significant carbon sink; however, climate projection predicted inactive peatland formation, carbon sequestration and biodiversity (Scottish Government, 2015). Where "Grassland" biodiversity can decline over time diversity or graduate depends on management regimes (GCC, 2017).

3.2.2. Flooding on River Clyde

Due to its geographic location, Glasgow is tide-dominated. Hence, reoccurring inundation by tidal and river floods is sustaining the ecosystem and typical to this area. River Clyde also collects drainage from a large surface. Currently, 90% of Glasgow's rainfall depends on the urban drainage system (Bonan, 2015), limiting the storm in any given year to exceed 20% chance efficiency (WWF, 2002). Karunarathna (2011) explains that extreme climate occurrences such as water overtopping the flood wall, increased water velocity, and drainage backed up networks could cause a system failure.

The growing density increased flood-prone buildings and urban run-off. Thus, the city has lost the functional floodplain and eventually now has been under "flooding risk."

Accordingly, River Clyde, Cart, and Kelvin prioritized frontline floodplain storage and intact river corridor, safeguarding them from further land-use changes (GCC, 2019). Nature-based-solution like Water Sensitive Urban Design (SUDs) have been achieved, although they are substantially limit in extent (Edinburgh design guidance, 2020). Floodplain and water regime deliver ranges of ES such as carbon sink and biodiversity. Thus, a workable SUDs has to withstand a 0.5% probability of flooding in any year (SEPA, 2019) and holistically encourage complexity of an ecosystem to replace floodplains ability.

3.2.3. River channelization

River Clyde and tributaries underwent industrial channelization as the estuary was naturally shallowed from sediments assemblages as shown in Figure 3.3 (Jones et al., 2018). In the process, river and coastal banks were extensively managed for flood protection mechanisms such as seawalls, piers, saline intrusion weir at the Albert Bridge, and shore embankments (Karunarathna, 2011). Essentially, this novel process led to the establishment of condensing riparian, which disrupt sedimentary flows and stability.

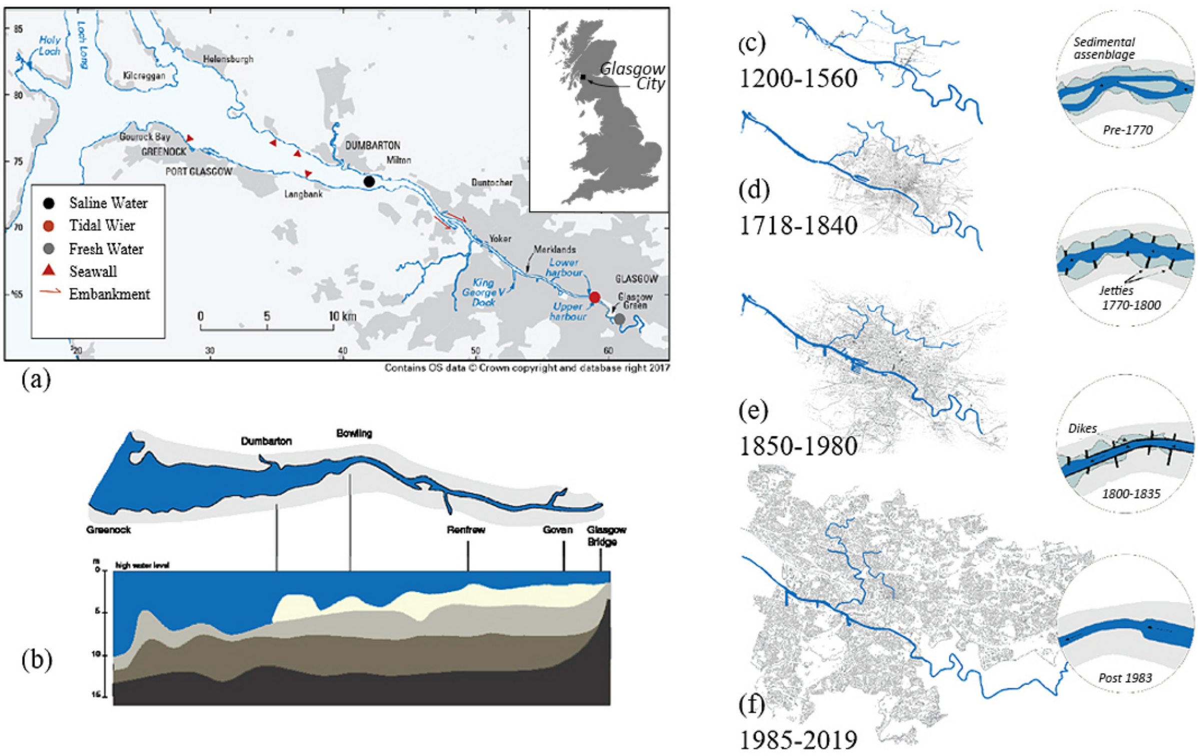
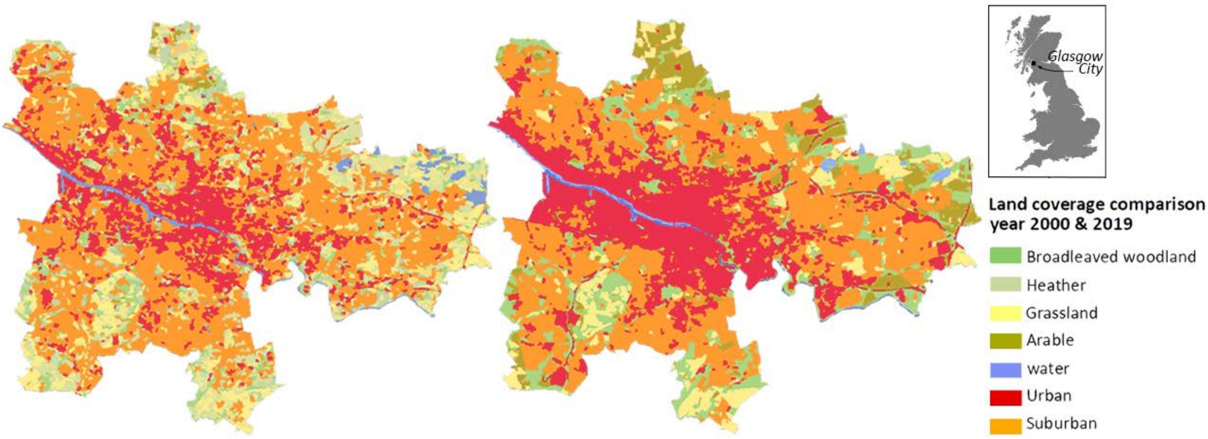


Figure 3.2 River Clyde morphological evolution
(a) Glasgow location in Clyde estuary, legends show example of channelization interventions,
(b) Effect of dredging on the bed of the Clyde,
(c) Argriculture period (1200-1560): islets channel,
(d) Trading Period (1718-1840): jetties and piers,
(e) Industry period (1850-1980): Longtitudes Dykes built on reclaimed land
(f) Urban regeneration period (1985-2019): Entirely reclaimed land and widen channel
(Adapted from Vane, 2018; WWF Scotland, 2002; Marwick, 1892; GCC, 2019)

3.2.4. Land conversion

The land coverage map of the Clyde basin of 2000 and 2019 (Figure 3.3) highlights a decreasing natural area uptook by urban area and agricultural area. The overall urban area expansion caused a 56.9% loss of permeable land. GCC reports that 35.7% of Glasgow area is open space. Moreover, 12% are natural areas within open space, which is adequate compared to other Scottish cities (GCC 2020).

The build-up densification is associated with air pollution and elevated surface temperatures. The air quality in Glasgow has been improved along with water quality since the industrial era. Although, urban areas also deleted ecological memory such as seed banks in the soil. This process still exists in wastelands that show signs of regeneration to pre-forest stages (Bonthoux et al., 2014).



(a) (b)

Figure 3.3 Glasgow land coverage comparison between year 2000 and 2019

(a) Landcoverage of 2000. Open space count is 71.09 Sq.km

(b) Land coverage of 2019. Open space count is 52.48 Sq.km

(c) This map contain modified Copernicus Service information (2015)

3.2.5. Glasgow's biodiversity

Glasgow city can support high biodiversity. Over 6,000 species are recorded (GCC, 2017) due to various non-native species encouraged by landscaping, 1,560 species categorized as naturally regenerate and more than 50% were non-native. The non-native are now under the control of the "Wildlife and Natural Environment (Scotland) Act 2011".

Climate change is expected to create vulnerability upon biodiversity security, especially for species with lesser dispersal abilities or is sensitive to a novel environment (GCC, 2017). Accordingly, GCC has adopted the "Forestry and Woodland Strategy" to expand 21% trees across urban and rural settings by 2030 (GCV, 2016). Until now, the trees population has been gain due to commercial reforestation and the state-owned forestry commission.

3.2.6. Role of Glasgow's Local GN policy

Figure 3.3 illustrates "Planning Advice Note 65 (PAN65)". PAN65 offer a GN planning system by protecting and enhancing existing types of open spaces; public parks & gardens, communal gardens, amenity space, play space, green corridors, natural/semi-natural green space, civic space, sports areas, allotments & community gardens, other functional spaces like churchyards & cemeteries (The Scottish Government, 2008). A complete novelty feature such as green roof and wall are not mentioned in this thesis scope because they are not explicitly included in PAN65 nor affected by geographical influence.

Under the authority of *"Climate Ready Clyde (CRC)"* and "*Glasgow and Clyde Green Network (GCV),"* GN framework is integrated with the "urban regeneration" process (The Scottish Government, 2008) to ensure along with nature restoration, an inward investment and attract population growth by 2035 (GCC, 2019). The road map declared community must have full access to ES benefits by 2030. Included in the derelict land regeneration is derelict land is within 500m accessibility for 60% of Glasgow's population (The Scottish Government, 2019). GCC recognized the benefits of relaxing maintenance and management regime on GN, which adding to biodiversity and avoids the future retrofitting cost (Hislop et al., 2019).

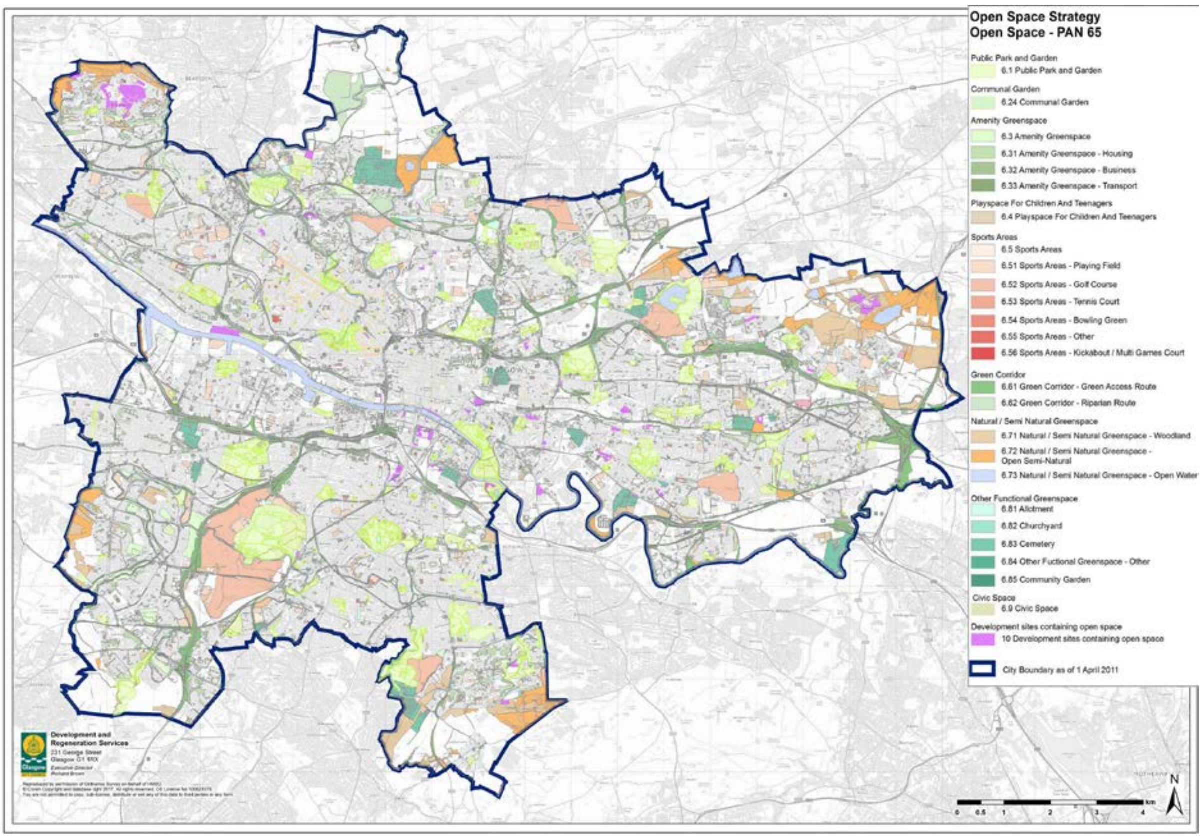


Figure 3.4 PAN65 Open Space of Glasgow City
(GCC, 2020).
This map contain Open Space PAN65 data © Crown Copyright and database right 2017

3.2.7. Conclusion: Glasgow GN's Novelty Degree

Determining a novelty degree in the ecosystem could be referenced from "naturalness baselines" (Figure 3.4b) and "anthropogenic baselines" (Figure 3.4c). "Naturalness baselines" capture ecological processes in the past (Higgs, 2014), while Evers et al. (2018) suggest "anthropogenic baselines" referencing if past or present anthropogenic pressure entirely novel/ altered the landscape. As illustrates in Figure 4.2 is a concept to define pathways of GN trajectory specifically essential for nature restoration. And Figure 3.5 gives an example of change which arrive at deliberate design.

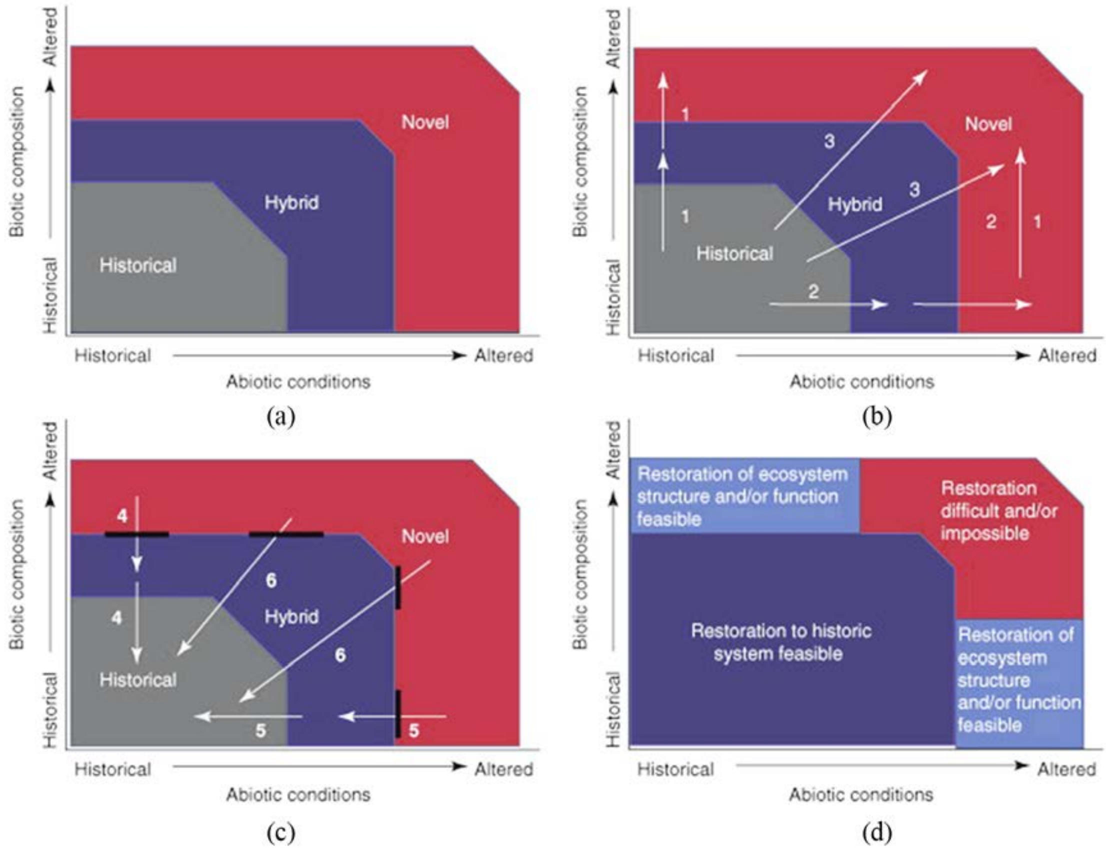


Figure 3.5 Concept of future projection for novel ecosystem
(a) Three states of changing ecosystem, (b) Pathways of ecosystems when change occurred, e.g. land use & climate, (c) Reversing the pathways of development if disturbances are removed, black lines indicate obstacle thresholds (c) For states of restoration regimes (Hobbs, 2009)

To conclude, Glasgow GN produces a hybrid condition comprised of both historical and novel elements. Glasgow area profile represents a mixture between a 5% native nature that survives industrialization, novel self-assembled on wasteland, and novel landscape design resulted of active management to elevate degraded ecosystem (Evers, 2018; Miller & Bestelmeyer, 2016). GN conservation schemes aim to reverse the ecosystem back to its historical trajectory as shown in Figure 3.4d, where most open spaces will only restore some attributes. It confronts the reality that many ecosystems cannot be restored to a natural baseline, such as altered river banks. Therefore, human-induced design requires strong intervention suitability. Nevertheless, GN signifies more benefits than the degraded ecosystem.

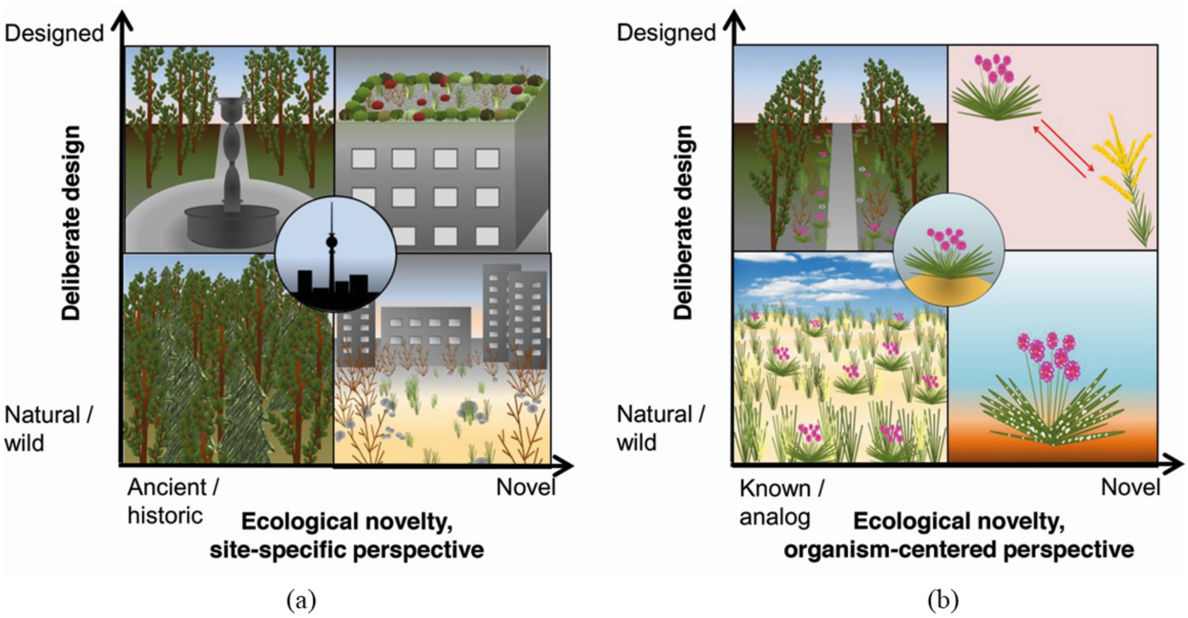


Figure 3.6 Examples for ecological novelty perspective in Berlin, Germany
(a) Example of novel lancscape, (b) example of novel species assemblages
(Heger et al., 2016)

CHAPTER 4: **METHODOLOGY**

Literature review chapters analyzed the existing methods to measure EH and ES. Accordingly, this research applied an indicator-based approach to map and assess EH and ES because of the potential to quantify and visualize the ecosystem's capacity by using selective attributes and compiling them into one single measurement. Below present the methodology framework for approaches, data collection, data proccing, and data analysis. Some content are analysed and presented in this chapter in order to explain how to quantify them.

4.1. Research approch

The research approach establishes the framework for this study following the guidance of "research onions" (Saunders et al., 2009). This study aim to appraise the capability of GN in delivering ES and EH. Thus, "deductive" approach and a partial "inductive" were combined to create framework for this study. The deductive approach flows from examining existing theories to theory testing, whereas the inductive approach helps build theory from data collection (Saunders et al., 2009).

Aware of the existing approaches, this study started by reviewing the existing ecosystem conceptual framework to test further how these concepts facilitate the ability of GN to withstand climate change impact. Combining with some inductive approaches, by gather data to develop the tool for GN assessment.

For research strategy, this study chose the case study to achieve an in-depth knowledge of a complex issue for a real-world context (Saunders et al., 2016). Accordingly, Glasgow city is a relevant case study due to robust GN policy, but impacted by climate change risk. Furthermore, the context suit the aim of this study because of its hybrid condition where some urban area restored, but some has reached a novelty point due to the industrial revolution.

4.2. Mixed-method approach

Considering research question;
- How to measure EH and ES of urban GN in support of climate change adaptation?

In order to deal with the complexity of data associates with quantifying EH and ES, a mixed-method approach including both quantitative and qualitative strategies is used to reduce the uncertainty of final results.

Qualitative methods starting from reviewing "Ecosystem framework," i.e., ES, EH, Novel ecosystem, their interrelation, current methods, and existing ES/EH indicators. While empirical data analysis from literature helps build the Glasgow area profile. Both ecosystem framework and Glasgow area profile, later on, guiding the indicator development and justify their relevancy.

For the quantitative methods, data for the indicators are collected and computed using GIS-based Multi-Criteria Decision Analysis (MCDA) for the final results. And to help validate the process, a qualitative practitioners' opinions were collected via questionnaires to prioritized the indicators; as Ponto (2015) mentioned quantitative approach could be more reliable if it includes a survey. Finally, based on the final mapping result, sites selection method was used to explain GN capability and threat. Discussion was implicated under the guidance of existing literature.

4.3. Data collection & data analysis

Data applied in this study primarily are secondary data for two purposes, qualitative and quantitative assessment. Qualitative data included concepts and empirical data. Quantitative data were used to create indicators for GIS-based assessment.

Secondary data are suitable due to the great amount of data are required for the assessment. The geospatial data were collected from different open data sources online. Although, the data collected are not customized for this study. Thus, they were processed using ArcMap 10.7.1. Further detail of the GIS analysis method was explained below in Section 4.1.2.

4.4. The Workflow

Figure 4.1 presents the workflow for this study following four steps.

Step 1: Literature reviews in Chapter 2. Included are a review for ecosystem concepts, framework and existing methods

Step 2: Based on Chapter 2, the concept help carried out site analysis in Chapter 3, it explain the degree of novelty of Glasgow's GN. Included are reviews on Glasgow's reference condition, landscape alterations, and environmental change trends.

Step 3: Chapter 4 develops indicators based on literature knowledge. Here, relevant ESs are also derived from policy content.

Step 4: This step link EH and ES by MCDA based on practitioners' opinion. Chapter 5 presents GIS mapping results. The final maps are compiled to explain GN capability and threats. Threats are investigated further at a site-specific scale.

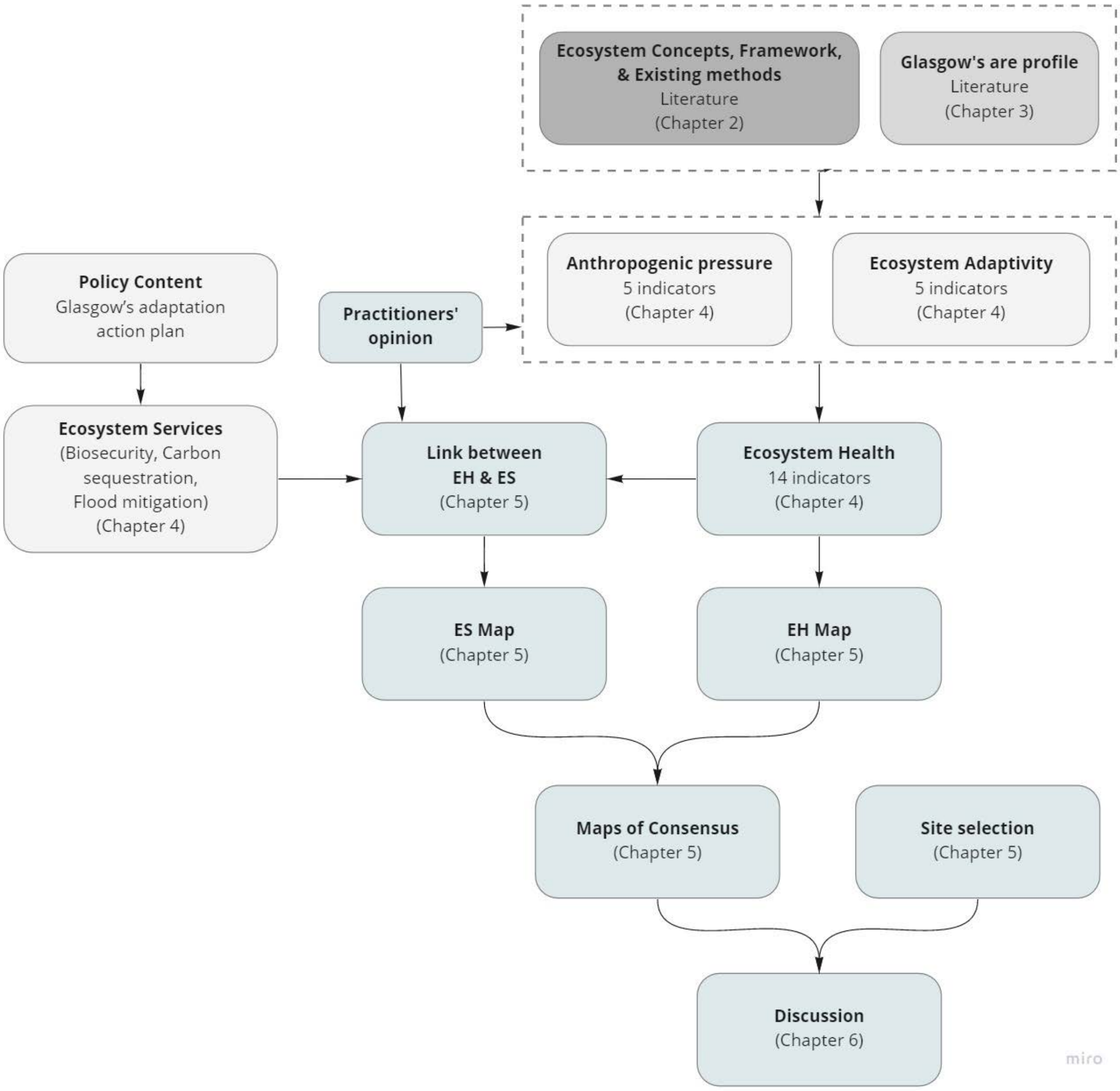


Figure 4.1 The workflow framework classified into 4 steps.
The framework adapted from Maes et al. (2016)
▭ indicate Step1, ▭ indicate Step2, ▭ indicate Step3, ▭ indicate Step4

4.5. Indicators development method

The indicator development method complies with the third objective in determining attributes to measure the GN capability to host EH and deliver ES. Following the workflow, this study adopted the method from Hatziiordanou et al. (2019), whose method maps ecosystem conditions for habitat maintenance ES. This method is adaptable, combining only two compositions; pressure indicator and biodiversity state indicator. However, this aim to develop a different ES; i.e., climate change ES. Gaining as insight from ClimateXChange 2016 (CXC, 2016), EH in this study is compose of pressure indicator and ecosystem adaptivity indicator. The indicators were adapted from the list offer by "CXC's natural environment adaptation to track the effectiveness of climate change interventions."

Section 4.5.1 presents EH indicator compositions and selection assessment. The assessment guiding by knowledge obtained from literature reviews. While Section 4.5.2 explain method to process the indicator data.

4.5.1. Ecosystem health indicator derivation

a) Pressure indicators derived from Glasgow area profile

The literature demonstrates that pressure is a consequence of anthropogenic alterations (Maes et al., 2018). This section derived "pressure indicator" from key alterations that occur to Glasgow's landscape where a large portion has been altered beyond the restoration point. Listed below in Table 4.1 are the alterations categorized into "historical" and "anthropogenic" baseline to derive relevant "pressure." The climatic change factor is a significant driver that intensifying the anthropogenic impacts on EH; the vulnerability trend in Table 4.1 represents the current situation of each alteration. Below present five "pressure" indicators from the content assessment, landscape degradation, flood risk, invasive species, deprived areas, and urban temperature

Summary of Key alterations of Glasow landscape to derived "pressure indicator"				
Driver	**Compare to historical baseline (Pre-18th century)**	**Compare to anthropogenic baseline (1950-1980)**	**Vulnerability Trend**	**Pressure derived**
Climate Change	Loss of ecological memory, e.g. seed banks		↓	Landscape degradation
	Nutrients released causing eutrophication		↓	
	Carbon released from landscape degradation		→	
	Chemical contaminants released		↓	
	Land use conversion		→	
	Reduction of key habitats		↓	Flood risk
	Condensing riparian ecotone		↓	
	Altered water flow and velocity		↓	
	Altered sediment flow and assemblages		↓	
	Channelization of water bodies		↓	
		New water management, e.g. SuDs	↑	
		Simplified landscape, e.g. landscape design	↓	Invasive species
		Nature-based recreation create cultural-ES	↑	
		New habitats created by novel structures	↓	
	Fragmented landscape		↑	Deprived areas
		Regeneration on former derelict land	↑	
	Pollutants released into the environment		→	Urban temperature
	Land take for built up areas		→	

Table 4.1 Summary of key alterations to derive "pressure indicators."
↓ = Upward trend, ↑ = Downward trend, & → = No significant trend (Rattanakijanant, 2021)

b) Ecosystem adaptability indicators derived from CXC's indicator:

The literature review chapter explains the availability of several existing indicators suitable for assessing Scotland's climate change adaptation situation. Thus, "ecosystem adaptability indicators" in this study adapted from formalized indicators collected by Scotland's environmental agencies, CXC.

Glasgow area profile provides the knowledge that many of CXC's indicators are irrelevant to Glasgow city's context, and also geospatial data are available for some of the indicators. Thus, this study does not apply the complete list of CXC's indicators but adapted and filtered out the irrelevance using the knowledge obtained by the previous chapter. Table 4.2 summarizes selected nine indicators and their descriptive justification. The total assessment is available in Appendix 1. The indicators included "Natural regeneration," "Protected area," "Habitat Connectivity," "Extent of habitats," "Vegetation health," "Pollinators and key species," "Surface water quality," "Area of a functioning floodplain," and "Soil sealing."

Summary of "ecosystem adaptability indicators" derived from CXC's indicator

Indicators	Vulnerability Trend	Descriptive justification
Natural regeneration	↓	In the city, natural habitats and vacant lots have regeneration potential. This indicator capture nature potential to recover from disturbance such as climate change and anthropogenic impact
Protected area	↑	Implementation of biodiversity conservation policies such as SINCs protects overall native habitats, ancient woodlands, and old-growth stands within the city.
Habitat Connectivity	↑	Glasgow has open spaces and greened corridors which are suitable spaces for species dispersal.
Extent of habitats	→	Extent reflects refugee for species in this changing climate. In Glasgow, a small portion of key habitats remains within the city, whereas larger patches are fragmented by urban development.
Vegetation health	↓	Healthy vegetation represents less carbon released due to vegetation decay.
Pollinators & key species	→	Glasgow has over 6,000 species. Some key species, such as birds and pollinators are good EH indicators.
Surface water quality	→	Glasgow's river qualities ranged from poor to good. Poor water quality intensifies habitat loss and plant decay to releases carbon. Water quality reflects water purification ability by the riparian, condition of water circulation, and public well-being.
Floodplain area	↑	Clyde basin is a floodplain area, although wetlands have been drained. CDP8 & SUDs system has replaced the natural floodplain system
Soil sealing	↑	Due to the lack of peat soil information as their formation may no longer occur after they have been overwritten by urban areas. Instead, soil permeability can represent the ability of soil to carry water budget, sink carbon, and mitigating UHI.

Table 4.2 Summary of "ecosystem adaptability indicators" derived from CXC

↓ = Upward trend, ↑ = Downward trend, & → = No significant trend (Rattanakijanant, 2021)

4.5.2. Data processing method

Section 4.5.1 developed indicators, then raw geospatial data of each indicator were obtained from providers such as GCC, SNH, and SEPA.=. Below is the rationale for processing each indicator item. This method customizes and normalized the raw data to be further applied in GIS-based MCDA (further explained in Section 4.7.1). Data were processed using ArcMap 10.7.1 application while the calculation approach was obtained from the literature. And finally are normalized from low to high value. The complete assessment in Appendix 2 contains detailed information on each indicator, i.e., collection date, the format available, source provider, reclassification/ calculation approach, and descriptive justification of why each indicator was selected.

Amount of natural regeneration

The natural regeneration map was derived from data of Glasgow's five key habitats digitized by SNH to visualize the location of woodlands, wetlands, heathlands, neutral grasslands, and acid grassland. The seed tree's dispersal ability from habitat cores was calculated to find the regeneration opportunities which decline with increasing distance from the core habitat (SNH, 2012). ArcMap's "Offset" tool was applied to capture are offset from key habitats, and assigned normalized values range from low to high seed dispersal ability; the cores represent the highest value, the area of 500 m. offset area has moderate value and 2,000 m. offset area has the lowest value (SNH, 2012).

Protected Area

Conservation policies support native species' survival. Geospatial data of three different conservation policies are collected, "merged" and "reclassified" using ArcMap.

Rank from low to high, "ancient woodland" preservation (raw data obtained from SNH) has high value because old-growth trees sink massive carbon quantity over a long time if not disturbed and release it slowly once decomposed (Iversen, 2018). In comparison, carbon release is much faster for the decomposition of newly regenerated or even-aged commercial forests (Luyssaert et al., 2008). Sites of Importance for Nature Conservation or SINCs (GCC, 2017) and designated "green corridors" have moderate value as they provide urban refuge for some climate-sensitive species like Lichen epiphytes. Lastly, Site of Special Landscape Importance or SSLIs (GCC, 2017) has the lowest value. As they are highly novel and prone to alterations but preserved for community use. SINCs, and SSLIs data source from PAN65.

Extent of habitats

Using ArcMap, this study "select by attribute" from PAN65 data to capture areas over 0.5 ha by using demarcation size of 0.5ha, 2ha, and 50h. Simrard (2015) demonstrated that unlike trees confiscated in small planters (4 sq.m.), the extent of habitat is critical because trees have root connections that support themselves to sink carbon and share resources. The selected area was "reclassified" by extent and typology because natural type delivers more benefits than general greenspaces (Natural England's, 2010). Natural England (2010) recommends a 2 ha size for urban parks. At the same time, Manchester Green Infrastructure Strategy (2015) suggests benefits of 0.5 ha of natural woodlands. 50 ha extent is assigned for the highest value as it capture better preservation (Beninde et al., 2015).

Habitat connectivity

The extent of Habitats map was computed by Graphab 2.6 application to generate modularity matric, normalized to low to high modularity. This method follow the suggestion of literature (Conservation corridor, 2020). Fixed distances were assigned at least 300 m. to express the foraging range of solitary bees (Natural England, 2010). Surface distance is preferable (i.e., path distance of real-world taken into account obstruction, e.g., buildings). However, this study uses graphic distance due to technical limitations.

Pollinators and key species density, and dominance of invasive species

Pollinators and key species data were retrieved from records of key species sighted in the city from the Atlas of National Biodiversity Network (NBN). Relevant species were select from the SNH's priority list (the list included in Appendix 7). This study digitized sighting locations over JPEG downloaded from the NBN website dated 2018-2021 to capture the most updated sighting, then computed in GIS using the "density" tool.

Invasive species analysis uses a similar approach. Appendix 4 included species names controlled under the Wildlife and Natural Environment (Scotland) Act 2011. Thus, the sighting after-action year (2011-2021) was digitized. Non-native species map includes data of simplified landscapes such as lawns where location available in PAN65. Limitations of this approach concerning bias from the frequency of visitors on some locations.

Surface water quality

The surface water quality map was digitized over JPEG, downloaded from SEPA's interactive map. SEPA's collected data from water stations across Clyde River and its tributaries and classified them into three values; poor, average, and good. This study follows SEPA's classification. Urban wetlands water was derived from the GCV report and assigned moderate quality.

Floodplain area

The input data for the Functioning Floodplain map was downloaded from Copernicus Land Monitoring Service. Raw data included the "Delineation of Potential Riparian Zones (DRZP)" and "Observable Riparian Zones (DRZO)." DRZP is derived from hydrological and geomorphological parameters to compute natural flood allowance space. DRZO input vegetation wetness parameter (Normalized difference water index or NDWI) to express evidence of riparian features (Copernicus, 2021). The value assigned from low to high value, DRZP and DRZO are assigned high and moderate values, respectively. The lesser value was given to the area under City Development Plan on Water Environment (CDP 8) due to areas are being monitored.

Flood risk area

Flood risk data was digitized from SEPA interactive flood map. It includes three types of inundation; coastal, riverine, and surface. The denoted area is under the worst-case scenario combined 200-year flood return. Thus, they were assigned equally low values.

Vegetation Health

Vegetation health was analyzed via Normalized Difference Vegetation Index (NDVI) to distinguish landcover surfaces by measuring vegetation's light reflection at specific frequencies (EOS, 2021). NDVI was computed based on Landsat-8 imagery dated June 28, 2019, at 11.15 am. This date and time were selected to eliminate phonological vegetation conditions. The following formula was applied (EOS, 2021);

$$NDVI = \frac{(NIR - R)}{(NIR + R)}$$

Where; NIR = reflection in the near-infrared spectrum
RED = reflection in the red range of the spectrum

NDVI index defines values from -1.0 to 1.0 (ESA, 2021) where,

-1 to 0 = Water, built up, Inanimated Object
0 to 0.2 = Bareland, dead plant
0.2 to 0.4 = Unhealthy plant
0.4 to 0.6 =Moderately healthy plant
0.6 to 1 = Very healthy plant

Urban Temperature

The urban temperature was computed from Land Surface Temperature (LST) to capture urban materials and vegetation's "skin" temperature. NDVI from the previous analysis was computed to find emissivity estimation, following the method from Jeevalakshmi et al. (2017).

Soil Sealing

The soil sealing derivation method mainly "reclassify" land cover data obtained from Urban Atlas land cover 2018. High, moderate, and low values are given to substantial green spaces with a sealing degree of less than 30%, 50%, and more than 80%, respectively. With this classification system, builtups are difficult to distinguish from bare soil. The NDVI map help locate and "erase" the builtup area.

Landscape degradation

The analysis using an "equal-weighted overlay" tool to compile “urban fabric density” from Urban Atlas Land Cover 2018 and Glasgow's population density data retrieved from GCC. Finally, using "zonal statistics" to find the extent of degradation for each data zone to capture increasing demands and consumption patterns (Hatziiordanou, 2019).

Deprived areas

Retrieved data from the Scottish Index of Multiple included seven deprivation domains: Income, Employment, Health, Education, Skills and Training, Geographic Access to Services, Crime, and Housing (SIMD, 2020). A parameter for "greenspaces accessibility" was compiled with the original SIMD data using "equal-weighted overlay." The method uses ArcMap to analyze the "zonal statistic" of open space density for each data zone to find the areas that have difficulty to benefits from ESs (European Commission, 2021). Normalization of data follow SIMD classification ranges from 5% to 80% of deprivation.

4.6. ES valued in local policy

In this section, specific ESs are introduced. Mae et al. suggest that policy objectives can be built around ES, as shown in Figure 4.2. On the contrary, this study reverses the rationale by using the local policy to extract needed ES. In this way, a policy could help justify relevancy of the ES for this study. This step is presented below; the content analysis method is undertaken. ES values were built around policy needs within Glasgow locality. Table 4.2 analyzed the content of *"Glasgow City Region's first Adaptation Strategy and Action Plan 2020–2030;*

Intervention 9: Deliver nature-based solutions for resilient, bluegreen ecosystems, landscapes, and neighborhoods." (CRC, 2021).

The action plan is applicable to this study as it seeks to "ensure the sustainability of region's social, economic, and environmental resilience to climate change, outlines the processes and interventions to manage climate risks, sets out to progress in climate resilience knowledge to improve policies and enabling citizens and organizations to play a role." (CRC, 2021).

Accordingly, Intervention 9 aims "to accelerate blue and green solutions increasing the involvement of stakeholders, exploring the potential of derelict land and the Clyde corridor." (CRC, 2021).

O'Neil (2013) describes the applicability of content analysis for deducing composer's views from existing documents by categorization. As such, this method is adopted here. Table 4.3 shows a policy content and implication of ES. Whereas extracted below are keys ES that Glasgow city valued and planned to supplement (The entire content is available in Appendix 4.) summarized into three items;

- "Biosecurity"
- "Carbon sequestration"
- "Flooding regulation"

Policy content ***Glasgow City Region's first Adaptation Strategy and Action Plan 2020–2030*** **Intervention 9;** Deliver nature-based solution for resilient, blue-green landscapes and neighbourhoods	**Ecosystem services implied**		
	Biosecurity	Flood regulation	Carbon sequestration
Identify regional priorities for nature-based solutions		x	x
Delivery of the regional Strategic Green Network	x	x	x
Increase investment in targeted habitat restoration	x	x	
Creation of the Clyde Climate Forest			x
Support for local infill and expansion of nature-based solutions			x
Roll out of large-scale blue and green infrastructure projects to demonstrate benefits to communities – either through new green infrastructure or removal of hard landscaping or public realm	x	x	x
Develop and accelerate Green and Blue Infrastructure financing			

Table 4.3 Summary of ES derived from Glasgow's adaptation action plan (Rattanakijanant, 2021)

The selection of policy ES does not signify that selected ESs have more importance than ES not mentioned here. But as per Climate Ready Clyde policy, these three ES are vital compositions for climate change adaptation of Glasgow city. So, purposefully discussed here is how "Climate change adaptation ES" amplifies social and economic ES. For instance, "Biosecurity" links to pollination that links to urban food security and safe food consumption as an opportunity for community cohesion and a reduction in cost and carbon emissions associated with food transportation (Natural England, 2010). “Carbon sequestration” regulating terrestrial climate, where the attempt at carbon removal simultaneously improves water, soil, air, and vegetation quality, sustainable land management, and cooling potential that benefits human health and urban micro-climate. “Flood regulation” has the most physical recognition influence, working together with groundwater recharge and erosion control, all directly tied to safeguarding life and building infrastructure—lastly, the integrity and health of the ecosystem where ESs are available to supply cultural and recreational potential.

4.7.Method to synthesize Ecosystem Health & Ecosystem Services

Following on the workflow to step 4. This step aims to fulfill the research question;
- How to examine a relationship between EH and climate change adaptation ES?

Finding synthesis between EH and ES would provide new insight into the role of ecosystem integrity in climate change adaptation. The qualitative framework in this section is adapted from Maes et al. (2018). Services cascade model theory (Haines-Young & Potschin, 2010) and Maes et al.'s conceptual framework convey synthesis exist between EH and ES in an urban ecosystem due to the three elements are composed of components that interact with each other. Thus, indicators for EH are strongly interconnected to ES delivery (Maes et al., 2018). This study also adopted quantitative strategy to link EH and ES via GIS-baded MCDA as explained below (Section 4.7.1).

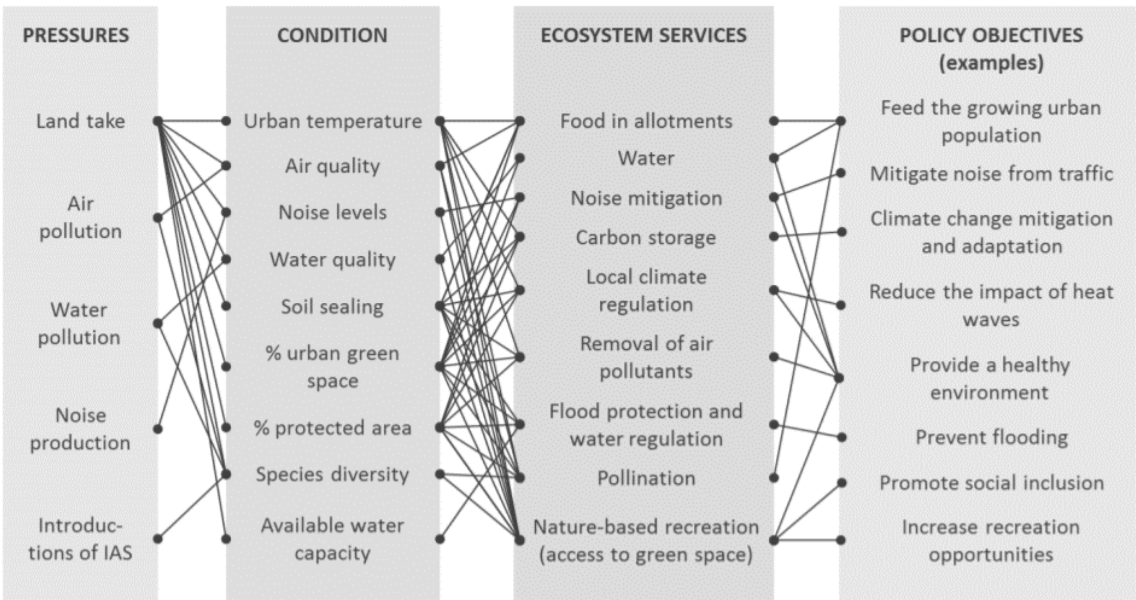


Figure 4.2 Maes et al.’s framework to link EH, ES, policy objectives, and pressure (Maes et al., 2018)

4.7.1. GIS-based Multi-Criteria Decision Analysis

This section present quantitative framework for synthesizing EH and ES. Multi-Criteria Decision Analysis (MCDA) is a general framework for supporting complex decision-making (Saarikoski et al., 2015). Thus, this study using practioners' decision and scoring system for combining the indicator into single value in acheiving the appraisal. Normalized indicator were compiled in the scoring system ranging from 1 to 5, indicating poor, inadequate,, average, adequate, and excellent value (Hatziiordanou et al., 2019). Figure 4.3 summarize the overall MCDA process from data collection until scoring adapted from Hatziiordanou et al., (2019).

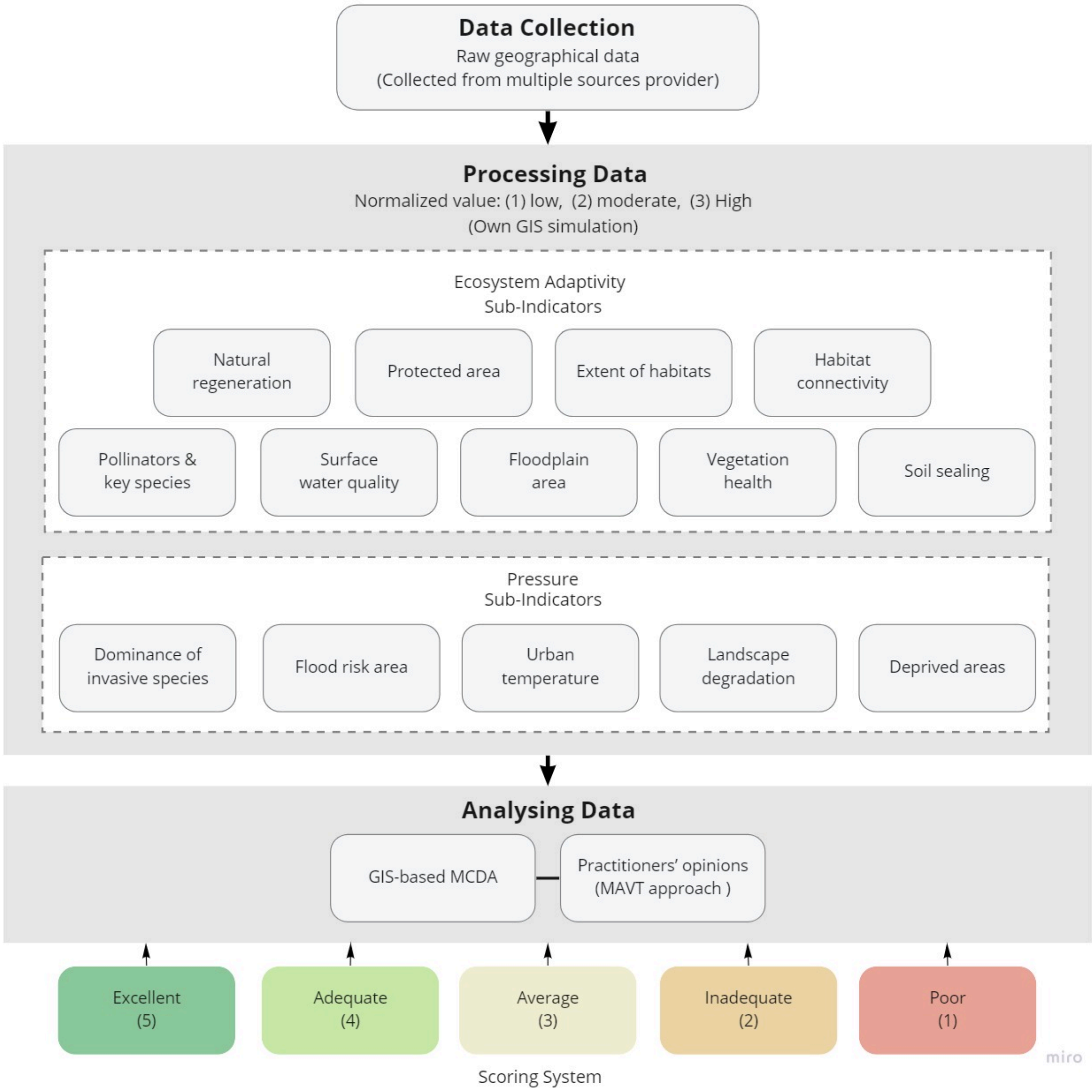


Figure 4.3 MCDA framework adapted from Hatziiordanou et al. (Rattanakijanant, 2021)

4.7.2. Practitioners' participation

Vihervaara et al. (2018) mentioned the advantage of practitioners' involvement for this method to eliminate the uncertainties of the assessment and provide in-depth knowledge on the subject. Section 4.7.3 presents practitioners' participation in this study. This study gained practitioners' participation for two purposes; (1) to selected relevant indicators to assess ES, (2) to prioritize indicators of importance. This study creates questionnaires on the "Google forms" platform. A "questionnaire" is an effective method considering the pandamic situation. Besides, both quantitative and qualitative data could be quickly gained. Thus, this questionnaire combined both questions with numerical weightings (quantitative strategies) and open-ended questions (qualitative strategies). The procedure is considered as Multi-Attribute Value Theory (MAVT) approach where participants are asked to choose the indicators and then assign numerical weightings to reflect the importance of each indicator (Saarikoski et al., 2015)

Included below are fourteen questions reflecting this method's aims (The full questionnaire is presented in Appendix 5.)

Section 1:

Q1. Name of participant's organization

Section 2: Ecological adaptivity topic;

Based on own experience and organization you represents, please;

Q2. Allocate an importance score of 100% for "Ecosystem Adaptivity" indicators.

Q3. Briefly describe your reason.

Section 3: Ecosystem services topic;

Based on own experience and organization you represents, please;

Q4. to Q6. Choose from the list the indicators that you think are important for *"Biosecurity", " Carbon Sequestration", " Flood regulation" and* in Glasgow city.

Q7 to Q9. Allocate an importance score of 100% for indicators you selected

Q10 to Q12. Briefly describe your reason.

Section 4: Anthropogenic pressure topic;

Based on own experience and organization you represents, please;

Q13. Allocate an importance score of 100% for "Anthropogenic pressure" indicators.

Q14. Briefly describe your reason.

The questionnaire was sent out to GN practitioners across public sectors, including local government bodies and government environmental agencies. The result of their questionnaire was presented in Chapter 5.

4.7.3. Calculating ecosystem health (EH)

Existing literature demonstrates that EH evaluation comprises two components, pressure and ecosystem adaptability (Hatziiordanou et al., 2019, Maes et al., 2016). Hatziiordanou et al. suggested that EH can be mapped by "equally" as they are equally influence the EH. Although, practitioners help allocate importance scores for pressure and ecosystem adaptability "sub-indicators" but on the final EH mapping will refer to Hatziiordanou et al.'s formula as written below;

"EH = 50%(Pressure) + 50% (Ecosystem Adaptivity)"

4.8. Consensus analysis

Applied MCDA, this study aims to convey following maps;

- Indicator maps
- Ecosystem health final map
- Three ecosystem services final map; biosecurity map, carbon sequestration map
- and flood regulation map

These three components are overlaid in ArcMap to arrive at final consensus evaluation. And finally include "PAN65" and "Scottish Vacant and Derelict Land Survey 2018" to capture the typology of the result area. This method supports the fifth objective of this research, which sets out to understand the capability and threats of novel GN. The consensus was made using knowledge support from the literature review.

a) Healthy ecosystem & ecosystem integrity

To analyse that healthy ecosystems (value 4 to 5) are supported by ecosystem integrety, this map finds the intersection of protected areas. "Healthy" ecosystem in this study refer to the (1) condition where ecosystem has adaptability as described in CXC policy, and (2) ecosystem has the condition remaining from industrial revolution

b) Synergy between ESs

To analyse the ability of GN to host multifunctionl-ES. This map find of high value which all ESs intersect.

c) Good health coincide with ES

To analyse the healthy ecosystem are support ES. This map find area of high value which EH and ESs intersect.

d) Poor health coincide with ES

To analyze that ES without underlying hypothetical naturalness might host ecosystem dis-service (EDS). This map find intersect area of high-value ESs but low-value EH

e) ESs exists in deprived area

To analyze Glasgow's ES distributing benefit across the city. This map finds the ES area intersection in the deprived area (5-10% most deprivation).

4.8.1. Site Analysis

To further identify probable EDS associate with the novel GN, two hotspots were selected from the Map of "Poor health coincide with ES." The following criterion was considered to select the sites.

- Area is under the GCV's development plan
- Area reflect CRC action plan aim
- Area located within Glasgow's GN

Analysis of sites is based on observation of ground truth data from Google Map and my familiarity with the sites. By comparing the intensity of pressure detected on the sites to ES supply, explanations are made in light of existing literature. This criterion would allow this research to later reflect on climate change adaptation policy.

To conclude, mixed methods set a framework for this study as it deals with ecosystem data complexity. Literature and existing policies help framed the concepts while practitioners' participation is adding to more certainty results. Finally, GIS is a powerful tool to identify and visualize the area of importance for the discussion chapter.

CHAPTER 5: **RESULTS**

This chapter address objectives 4 and 5;

- To develop an approach to measure EH and climate change ES.
- Highlight the capability and threats from a novel ecosystem to inform local policy.

In order to answer the research question of whether novel GN which has lower naturalness, could provide similar or better climate adaptivity services to the city.

Ecosystem health is mapped based on “pressure” and “ecosystem adaptivity” indicators. And by emphasize on climate change adaptation ESs, this study appraise the condition of GN and whether health condition of novel GN could increase the benefit of ESs delivery. Thus, to finally linking EH and ES to examine the synthesized benefits, area of EH, and ES supply/capacity are located by 14 indicators. However, the consensus of EH and ES could result negatively if poor health are located, or unequally distributed. Hence, EDS were investigated on site specific level. The results chapter present this framework by following order;

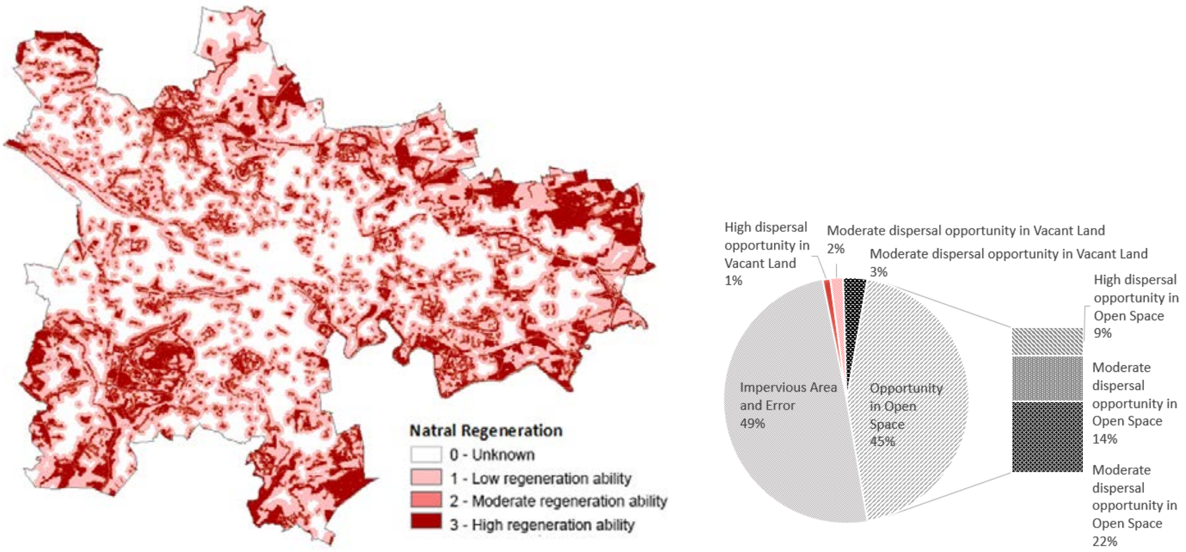
Section 1: Results of indicator mapping
Section 2: Results of EH and ES mapping, here also presented practitioner's opinion
Section 3: Final Results of EH and ES consensus area and site selection.

Section 1

5.1. Results of Indicators mapping

Indicators are processed to analayse EH and ES Glasgow’s GN supply. Each individual indicator is simulated by ArcMap application in which the result illustrate a spatial locations and configurations which these attributes are presence. The classification range from low to high (1 to 3) to capture efficiency of each indicator.

5.1.1. Natural regeneration



(a) (b)

Figure 5.1 Map of natural regeneration
(a) Map of natural regeneration, (b) Graph
(Rattanakijanant, 2021)
This map contains public sector information licensed under the Open Government Licence v3.0.

The “natural regeneration” maps illustrated in Figure 5.1a capture nature's potential to recover from climate change impact. The green belt on outer city is uptaken by key habitats which are regeneration sources provider. Figure 5.1b shows the typology of landscape that regeneration could occur. It suggests that 45% and 6% of natural regeneration opportunities fall into “open space” and “derelict”, respectively. These areas are critical for native habitats establishment. Another 49% represents error which could mean impervious areas exist within potential areas.

5.1.2. Protected Area, Extent of Habitats, and Habitat Connectivity

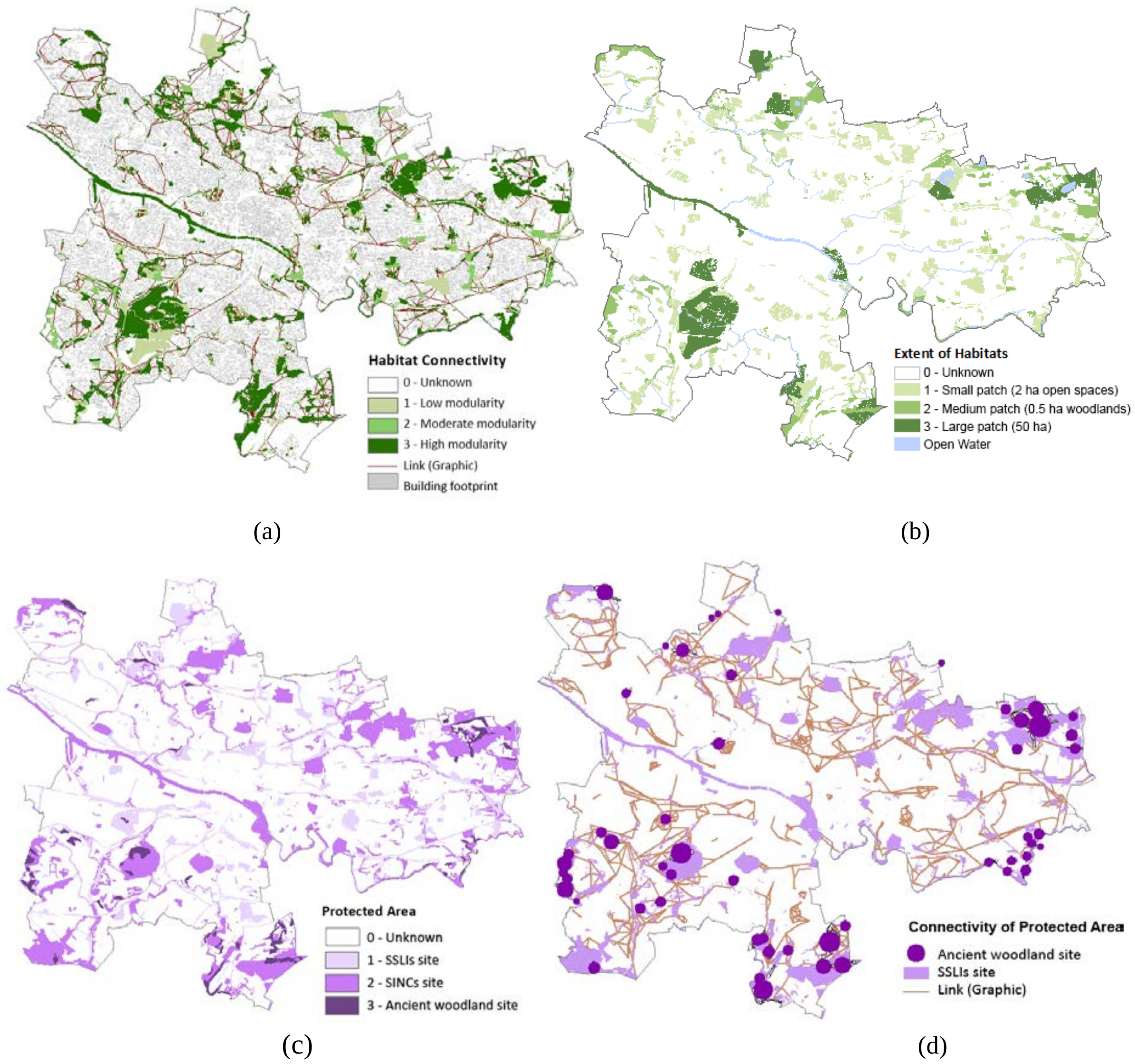


Figure 5.2 Map of Extent of Habitats, Habitat Connectivity, and Protected Area,
(a) Habitat Connectivity map, (b) Extent of Habitats map,
(c) Protected Area map, (d) Connectivity of protected area
(Rattanakijanant, 2021).
Above maps contains public sector information
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Some of the data modified from Open Space PAN65
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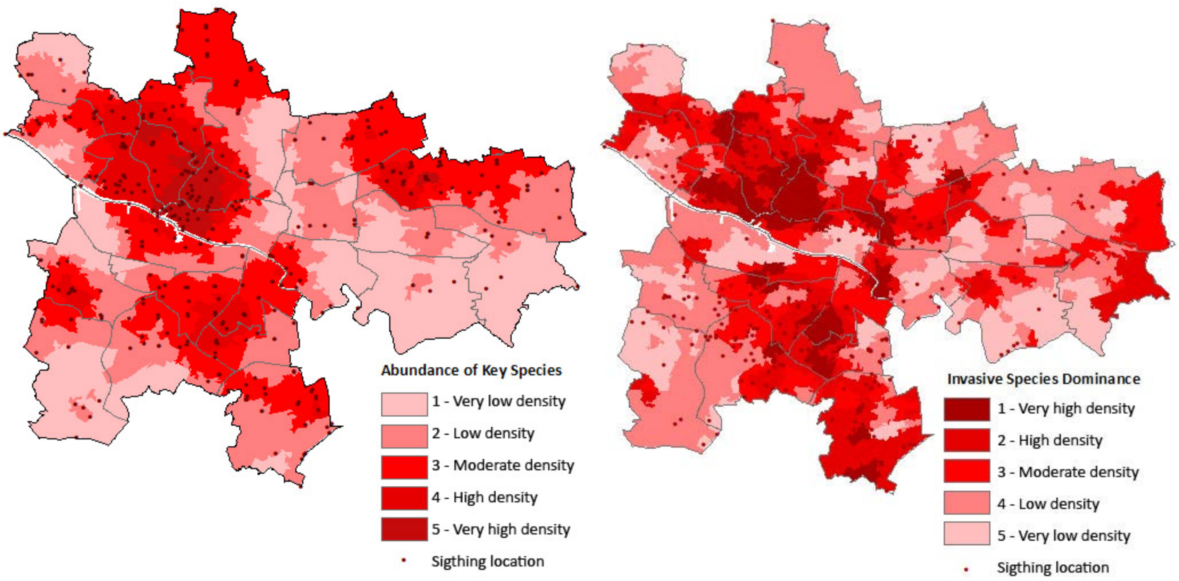
An ecosystem is likely to assist better ES, being in the vicinity of other patches to share the indirect ES, in terms of accessibility and for climate change impact absorption (Hatziiordanou, 2019). In the "Connectivity" map, two types of connectivity can be observed from the result - the linear corridor connection of the green route and the loosely connected patch (i.e., stepping stone corridor). Building footprint as overlaid represents physical obstacles for species movement and increase traveling length. "Habitat connectivity" map (Figure5.2b) and "Extent of habitat" map (Figure5.2b) shows consensus by patches with high modularity also has a large extent. Thus, less modularity creates fragmentation that decreases habitat size while a decrease in extent of habitats increases patch number.

Figure 5.2c shows "Protected area" is a proxy for biodiversity conservation policy. Glasgow city contains 5% of highly protected ancient woodland and mainly occurs in the outer city. Figure 5.2d is the analysis connectivity of the protected area. Urban ancient woodlands are mostly disconnected from one another but mostly well connected to moderately protected SINCs sites.

5.1.3. Pollinators and key species density and dominance of invasive species



(a) (b)

Figure 5.3 Map of Pollinators and key species density and invasive species
(a) Pollinators and key species map, (b) Dominance of invasive species map (Rattanakijanant, 2021).
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Species like pollinators respond quickly to variations in habitat quality and temperature change. Their population supports diversity and the number of vegetation. The result shows clustering around the area located Kelvin River, Queen's park, and Seven Loch Wetlands. These areas are correlated to the connectivity map in Figure 6.4b, increasing species' ability to disperse.

It can be observed that areas where key species maps were recorded also host invasive species. Thus, suggested three situations: firstly, both complement each other; secondly, invasive species create risk on native species population, and thirdly, pollen concentration is significant in these areas.

5.1.4. Surface water quality

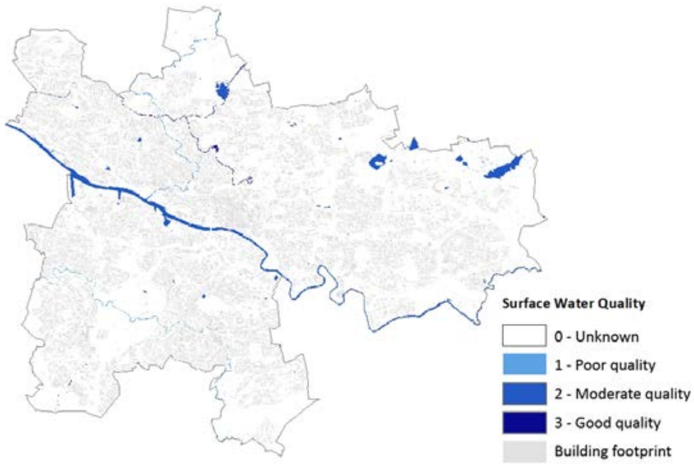
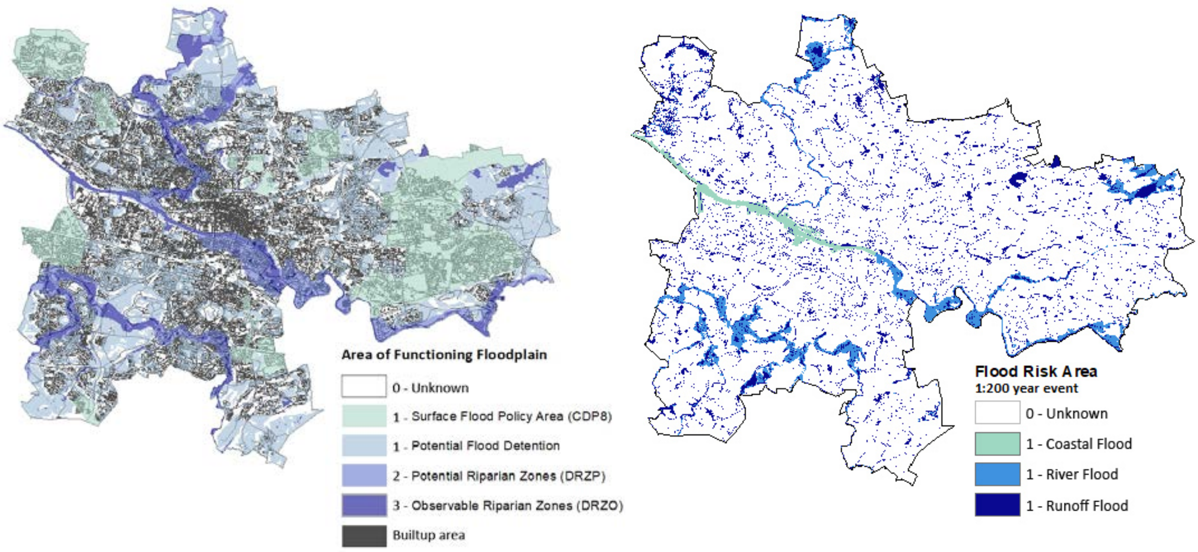


Figure 5.4 Map of surface water quality
(Rattanakijanant, 2021).
This map is Ordnance Survey data © Crown Copyright. Some features are based on digital spatial data from the Centre for Ecology and Hydrology, © NERC

Glasgow's river qualities ranged from poor to good. Urban water bodies and wetlands have a role in carbon sequestration, dissolve carbon sinking them in riverine sediments and plants. Urban wetlands have been described as generally good water quality although detected nutrients enrichment from agriculture (GCV, 2017), therefore has moderate value. Water quality in River Clyde has average quality. Good water quality can be found from Forth and Clyde Canal and Upper Block Burn. While Kelvin River, White Cart, and others have poor quality. Poor water quality and rising temperature increase eutrophication, intensify water plant decay and habitat loss which cause the release of carbon.

5.1.5. Area of functioning floodplain and Flood risk area



(a) (b)

Figure 5.5 Map of floodplain area and flood risk area
(Rattanakijanant, 2021)
Area of floodplain map.
This map contains data of SEPA data (2021) ©Crown Copyright.
Flood risk map (Rattanakijanant, 2021).
This map contain modified Copernicus Service information (2015)

“Floodplain area” hosts water regime and biodiversity in Clyde Basin. However, this map is different from the “Flood-risk” map because it conveys that specific areas are vulnerable to flood. In contrast, floodplains are where reoccurring inundations naturally occur, but both are comparable to the other. The flood-risk result shows the probability of water overtopping river banks. However, the potential riparian zone is fragmented and not entirely functional due to the built-up area, especially along River Clyde bank. The south area of River Clyde shows runoff flood risk as it lacks flood detention elements.

5.1.6. Vegetation health, Urban temperature, and Soil sealing

NDVI is applied when computed Vegetation Health, LST, and Soil Sealing value (Figure5.6). Thus these three indicators' influences on each other are.

The lowest NDVI indicates more than 50% soil sealing correlates to high temperature and UHI effect. The highest LST covers 51% of the general area; high temperature exists even in the area with less than 50% sealed surface. This high temperature possibly affects vegetation phenology patterns. Bonan (2015) mention that 50-90% of unsealed surface could infiltrate 40-83% of urban run-off. The area with a moderate value included stressed vegetation and soil sealing 30%-50% has the greatest extent. Physically, these areas mostly are transition spaces from low to high NDVI and located where open space and built-up have no clear delineation. It is worth noting that GN at the fringes of cities performs an opportunity for conveying ES benefit from the periphery into low NDVI areas such as the inner city.

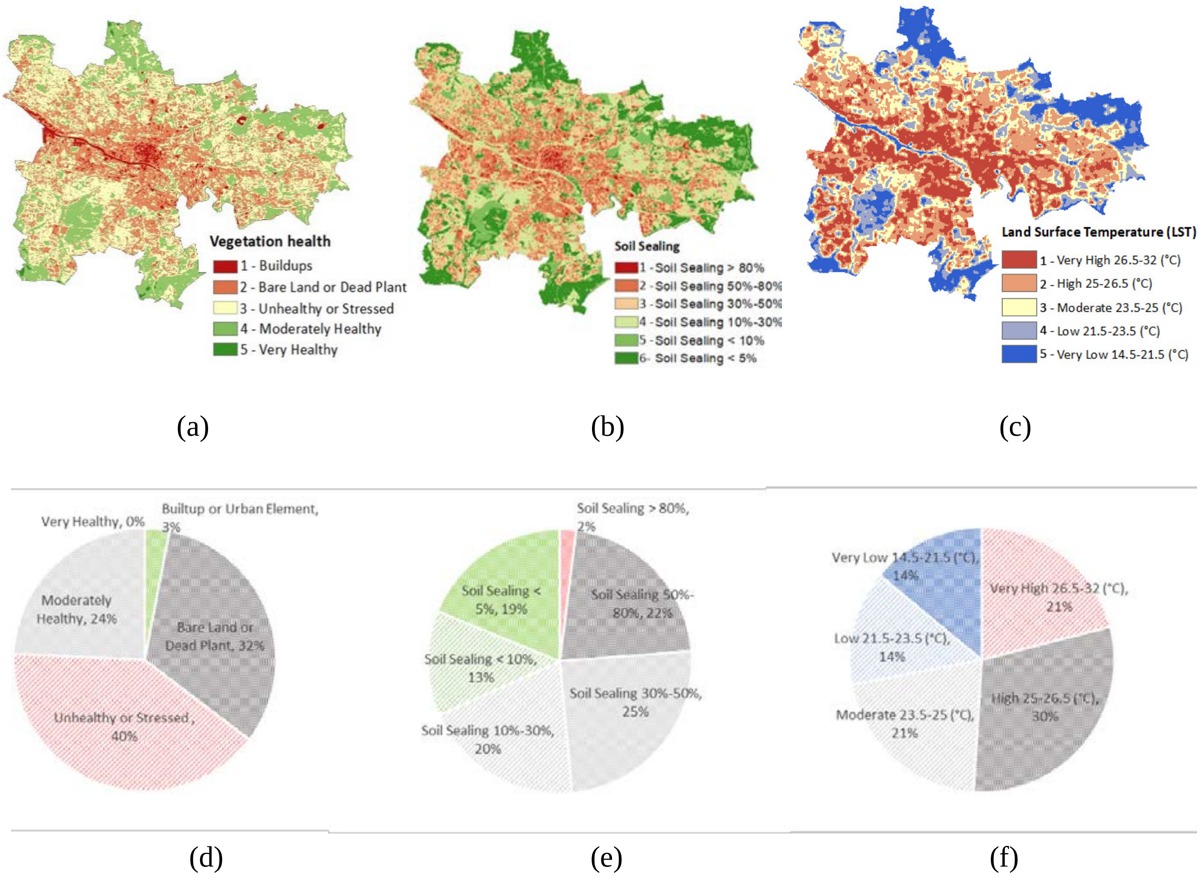
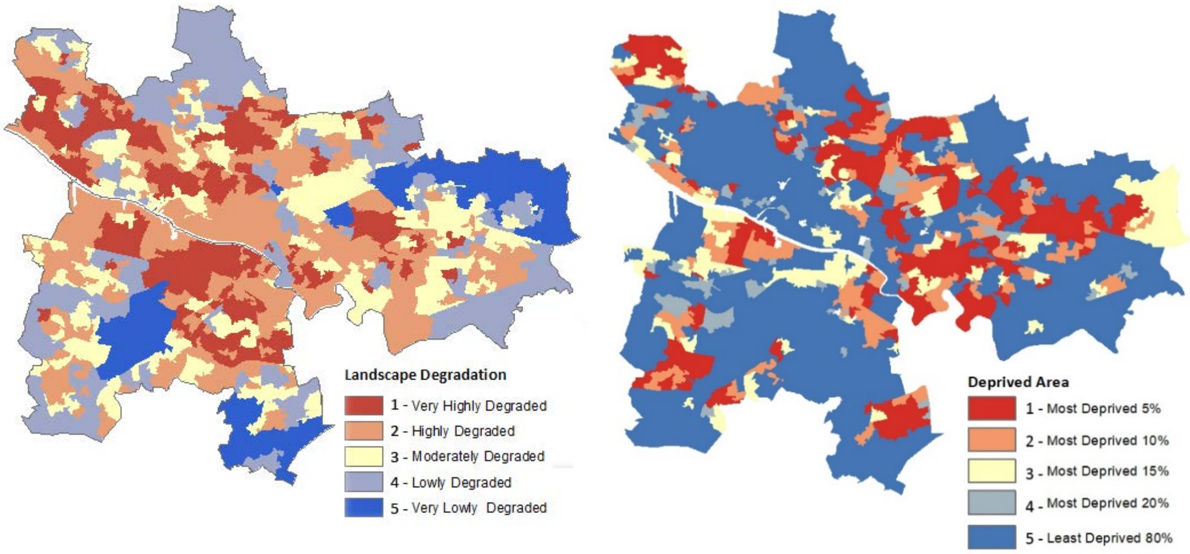


Figure 5.6 NDVI analysis
to derive: (a) Vegetation Health map,
(b) Urban Temperature map, and (c) Soil Sealing map.
(d), (e), (f) show cell count of (a), (b), (c), respectively in percentage.
(Rattanakijanant, 2021)
Above maps contain Landsat-8 image courtesy of the U.S. Geological Survey

5.1.7. Landscape degradation and Deprived areas

"Landscape degradation" map explains the degree of human dominance in the landscape. The city center and the Westend have a highly degraded landscape, although the moderately degraded portion exists.

Comparing to "Deprived area" map in Figure 5.7b, vulnerability concentrate at East End, Springburn, Drumchapel, Govan, Gorbals, and Pollock. In comparison, areas of the least deprivation are in the City center, Kelvindale, Easterhouse, and Pollockshire. Despite Easterhouse, the least deprived areas coincidentally are the area of highly degraded landscape. However, there is a consensus between deprivation and environmental problem burdens at the East Centre, Govan, and Greater Pollok.



(a) (b)

Figure 5.7 Map of Landscape degradation and deprived area
Map of Landscape degradation, (b) Map of Deprived area (Rattanakijanant, 2021).
Contains modified Scottish Government & Ordnance Survey data
© Crown copyright & database right 2012-2020.

Section 2:

5.2. Final mapping

This section presents the result of GIS and participation based-MCDA. By applying indicators dataset analysed in Section 5.1, EH and ES maps are obtained. Results provide useful spatially explicit information that can help prioritize EH and ES delivery. For each map, the result present two items (1) result of importance score from practitioners' judgement, (2) result of GIS-based MCDA mapping.

Three practitioners have responded to the questionnaire; they represent local governments and environmental agencies; Glasgow city council, South Lanarkshire, and NatureScot. Figure 5.8 summarise the resulting framework of indicators development and MCDA to guide the final mapping analysis.

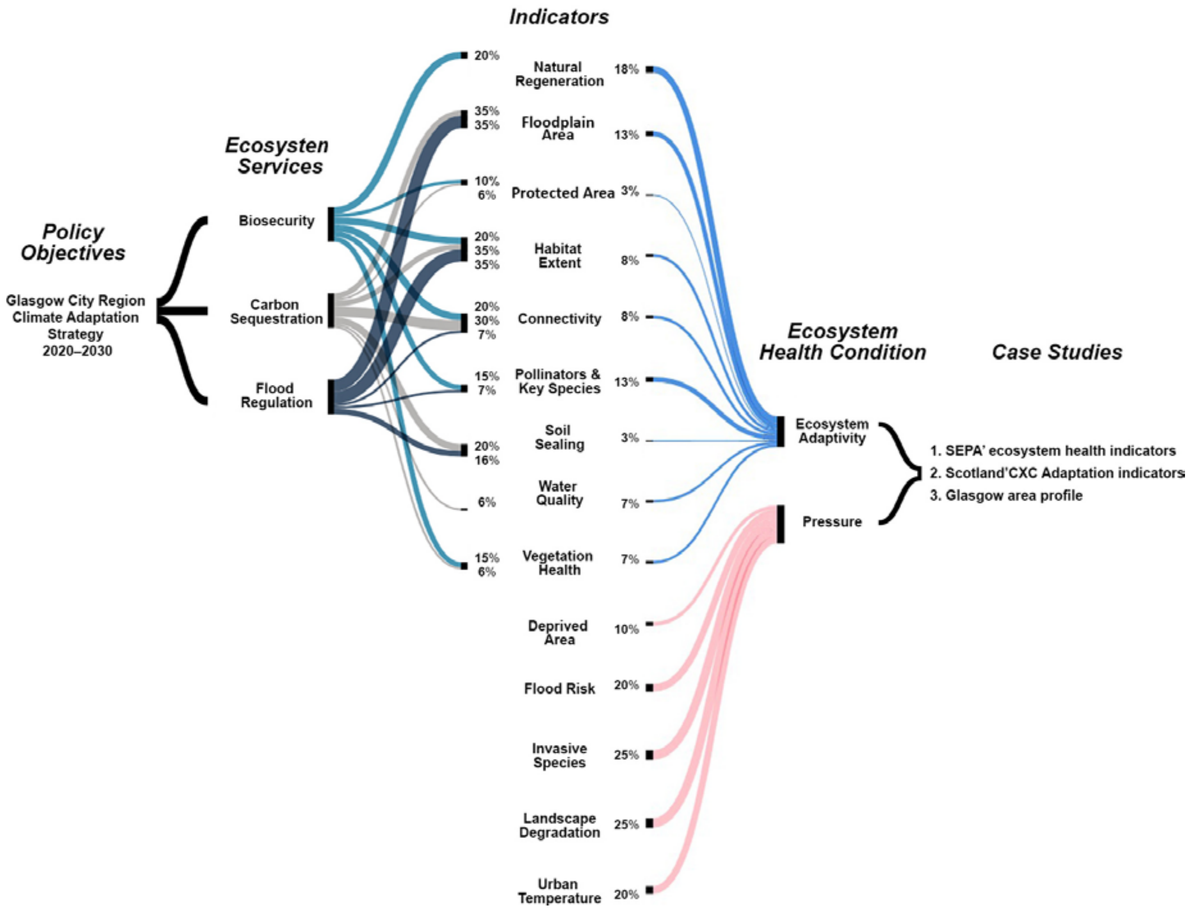


Figure 5.8 The resulting framework of indicators development and MCDA to guide the final mapping analysis (Rattanakijanant, 2021)

5.2.1. Ecosystem Services maps

This section presents the result from questionnaire survey which ask the following question;

- Based on experience and representing organization, choose the indicators that are important for "Biosecurity," "Carbon Sequestration," and "Flood regulation" in Glasgow city. Then allocate an importance score for selected indicators and describe the reasons.

All practisioners agreed that landscapes configurations are a founding attribute to ES delivery; "extent of habitat" and "connectivity." As well as they are easy to be mapped. In contrast, "water quality" and "protected area" are the least focused as they concern management aspects rather than ecology. Consensus scores are not essentially different for "natural regeneration," "vegetation health," "pollinator & key species," and "soil sealing" because they are secondary attributes that could be introduced after landscape configurations are established. Nevertheless, one opinion suggested that all indicators should take equal priority for Glasgow scale assessment.

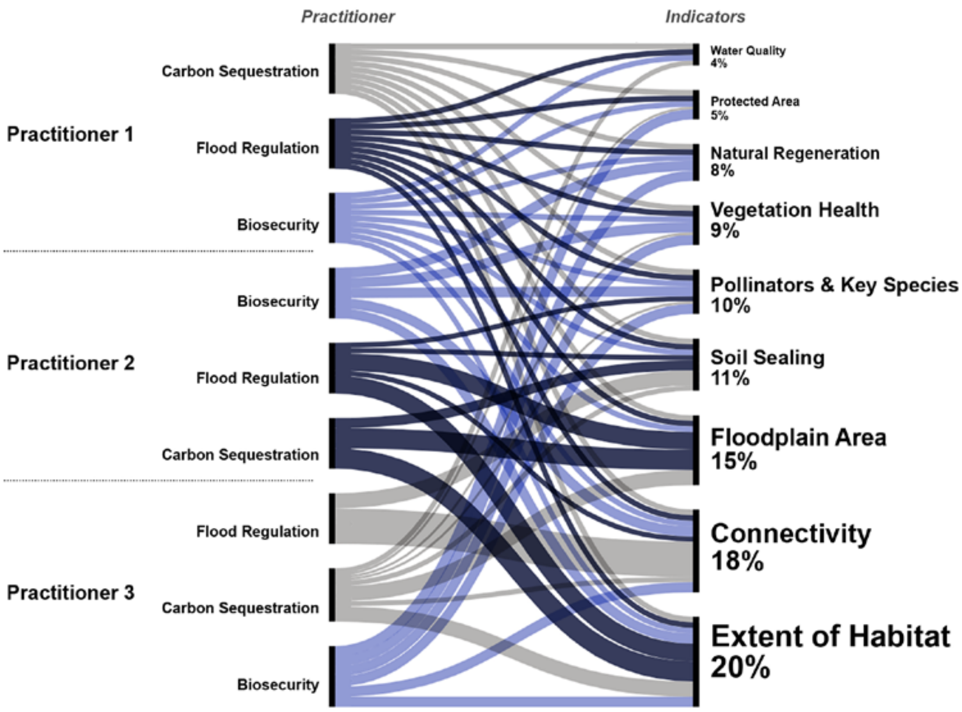


Figure 5.9 Result of ES indicator importance based on practitioner' opinion (Rattanakijanant, 2021)

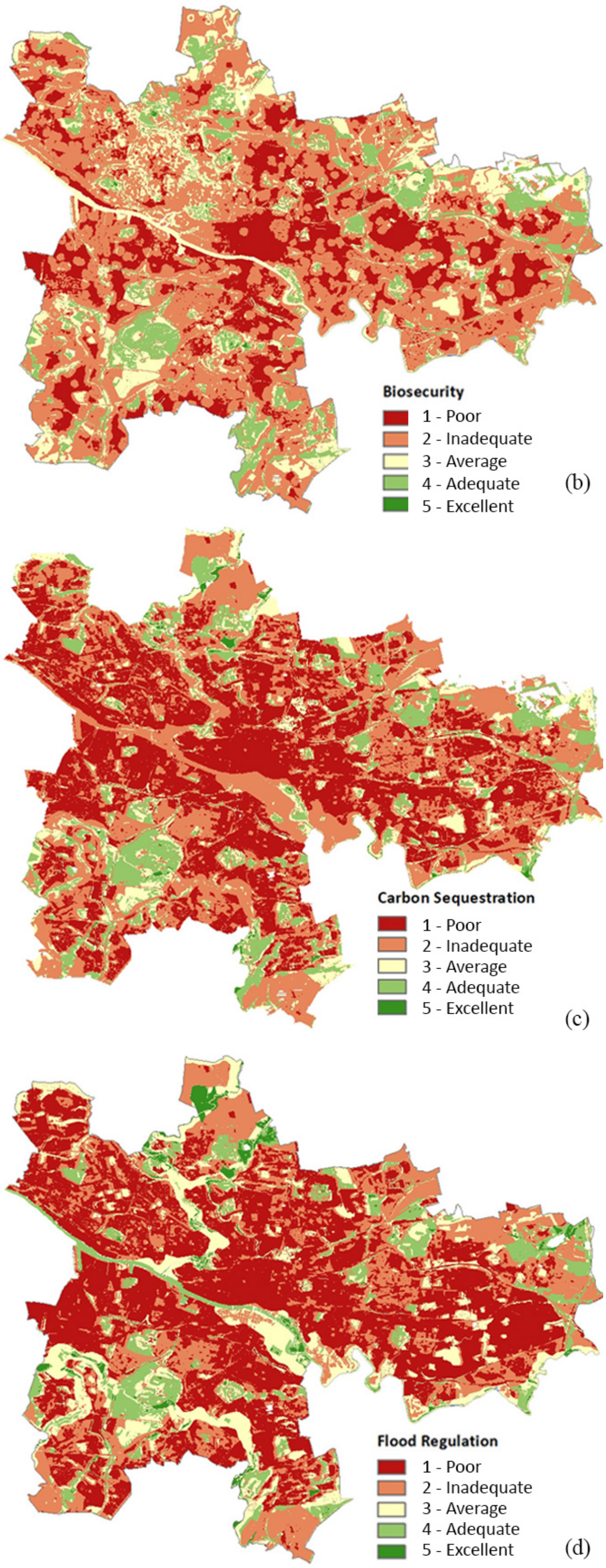
As shown in Figure 5.10a, indicators importances score were then catagorized into 3 items; Biosecurity, Carbon Sequestration, & Flood regulation.Taken an average assigned by each practitioner derived mapping result illustrates in Figure 5.10b to 5.10c

Biosecurity Sub-Indicators	Weight assigned (out of 100%)			
	Local government		Nature Scot	Avg.
	P1	P2	P3	
Natural regeneration	11%	20%	20%	17%
Protected Area	11%	0	20%	10%
Habitat Connectivity	11%	20%	20%	17%
Extent of key habitats	11%	20%	20%	17%
Vegetation health	11%	20%	20%	13%
Pollinator & key species	11%	20%	20%	13%
Surface water quality	11%	0	0	3%
Floodplain area	11%	0	0	3%
Soil sealing	11%	0	0	3%

Carbon sequestration Sub-Indicators	Weight assigned (out of 100%)			
	Local government		Nature Scot	Avg.
	P1	P2	P3	
Natural regeneration	11%	0	0	3%
Protected Area	11%	0	0	3%
Habitat Connectivity	11%	10%	0	7%
Extent of key habitats	11%	35%	40%	28%
Vegetation health	11%	0	0	3%
Pollinator & key species	11%	10%	0	7%
Surface water quality	11%	0	0	3%
Floodplain area	11%	35%	40%	28%
Soil sealing	11%	10%	20%	14%

Flood regulation Sub-Indicators	Weight assigned (out of 100%)			
	Local government		Nature Scot	Avg.
	P1	P2	P3	
Natural regeneration	11%	0	0	3%
Protected Area	11%	0	0	3%
Habitat Connectivity	11%	10%	0	7%
Extent of key habitats	11%	35%	40%	28%
Vegetation health	11%	0	0	3%
Pollinator & key species	11%	10%	0	7%
Surface water quality	11%	0	0	3%
Floodplain area	11%	35%	40%	28%
Soil sealing	11%	10%	20%	14%

(a)



(a) Result of indicator importance based on practitioners opinion. Results are categorized into three items; Biosecurity, Carbon Sequestration, & Flood regulation. Taken an average value from three set of importance score derived three ES map

(b) Map of Biosecurity

(c) Map of Carbon Sequestration

(d) Map of Flood regulation

Figure 5.10 Mapping result of ecosystem services (Rattanakijanant, 2021)

Biosecurity: Map in Figure5.10b represents "Biosecurity," or the maintenance of biodiversity. The potential area relies on substantial areas to support natural elements. Non of Glasgow area has "excellent" biosecurity. However, the city has a high proportion of open space. Due to a large extent and good connectivity, as suggested by the practitioners. The cluster of biosecurity can be observed in the proximity of Pollock county park, Seven lochs wetland, and Kelvin. Also presented here are the presence of pollinators, key species, natural regeneration, and vegetation health that practitioners suggest should be monitor to sustain long-term habitat quality or to apply appropriate interventions.

Carbon sequestration: From Figure5.9d, regardless of presence of water bodies, vegetation, and unsealed soil, "Carbon sequestration" potential in inner-city area score "inadequate" to "poor" value due to the quality of weighted attributes are inadequate.

Flooding regulation: Substantial areas for floodplains are prioritized to produced a "Flooding regulation" map. Thus, potential of rivers and riparian for flood regulation is pronounced on the map. Although, the potential is "average" given the influence of more than 30% soil sealing.

5.2.2. Ecosystem health map

In order to weight EH, practitioners following question was asked to gain practitioners' input; allocate an importance score for indicators that contributes to " Ecosystem adaptivity," and "Pressure" in Glasgow city. Figure 5.11 illustrate the overall data of importance score given by each practitioners.

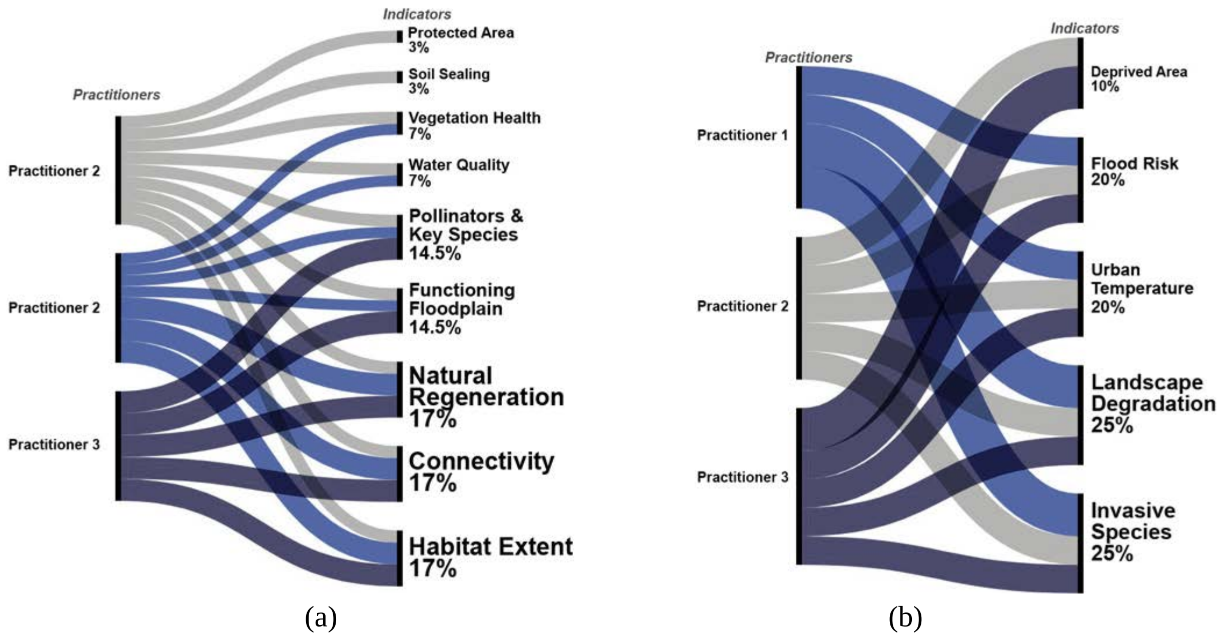
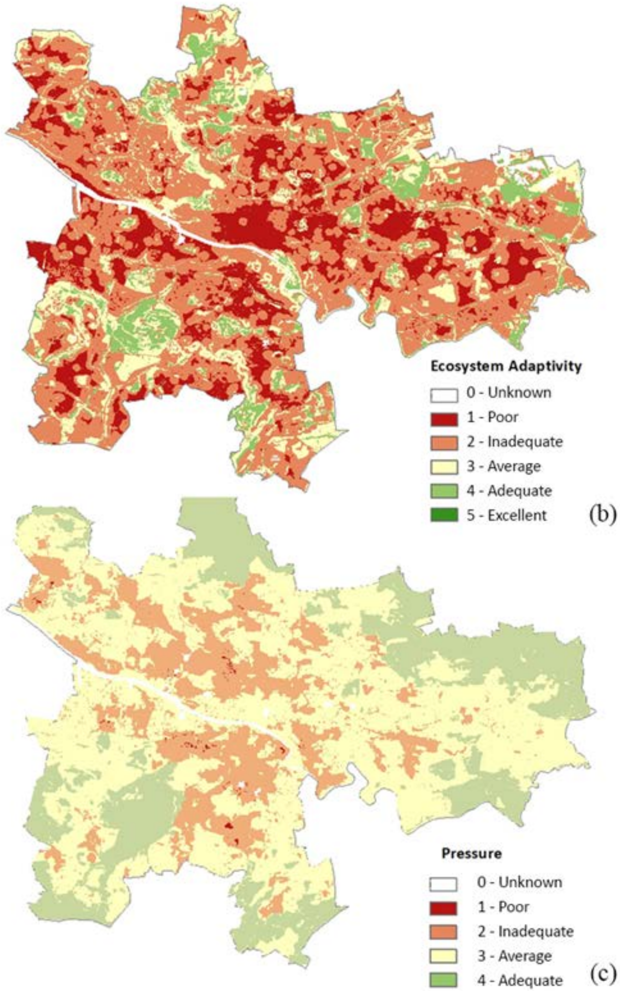


Figure 5.11 Result of EH indicator importance based on practitioner' opinion
Result of "Adaptability" indicator importance, (b) Result of "Pressure" indicator importance (Rattanakijanant, 2021)

Accordingly, the answers were quantify by finding an average of three opinions as shown in table 5.11a. The mapping assessment of ecosystem health (Figure 5.12) is resulted from composition of "pressure" and "ecosystem adaptivity". Further result are further explained in Section 5.3.

Ecosystem Adaptivity Sub-Indicators	Weight assigned (out of 100%)			
	Local government		Nature Scot	Avg.
	P1	P2	P3	
Natural regeneration	11%	20%	20%	18%
Protected Area	11%	0	0	3%
Habitat Connectivity	11%	20%	20%	18%
Extent of key habitats	11%	20%	20%	18%
Vegetation health	11%	10%	0	7%
Pollinator & key species	11%	10%	20%	13%
Surface water quality	11%	10%	0	7%
Floodplain area	11%	10%	20%	13%
Soil sealing	11%	0	0	3%
Pressure Sub-Indicators	**Weight assigned (out of 100%)**			
	Local government		Nature Scot	Avg.
	P1	P2	P3	
Landscape degradation	20%	30%	20%	25%
Flood risk	20%	20%	20%	20%
Invasive species	20%	30%	20%	25%
Deprived areas	20%	0	20%	10%
Urban temperature	20%	20%	20%	20%

(a)



(a) Result of averge value taken from three set of practitioners' importance score to map "ecosystem adaptability" and "pressure"

(b) Map of Ecosystem adaptability

(c) Map of Pressure

Figure 5.12 Mapping result of ecosystem services (Rattanakijanant, 2021)

Ecosystem adaptivity: Ecosystem adaptivity maps could be distinguished from ES maps because more "sustainable" aspects are considered. Besides "extent" and "connectivity, "natural regeneration" are deemed equally significant in practitioners' view, implying that the ecosystem is functioning and would continue doing so. The same rationale applies to pollinators and key species, which are highly scored.

Pressure Indicator: The highest weight was assigned to landscape degradation as it was considered the main cause of all other pressures (Hatziiordanou et al., 2016). Invasive species are also the primary concern in novel ecosystem environments. In comparison, the deprived area has the slightest consideration.

Section 3:

5.3. Consensus between mapping results

This section highlight the capability and threats from novel GN to fulfill the fifth objective and to answer the final research question; does novel ecosystem provide similar or better climate change adaptivity ES to the city?

Mapping results from Section 5.2 were overlaid in ArcMap to arrive at final consensus evaluation described in 5 scenarios, as follows;

- Healthy ecosystem & ecosystem integrity
- Synergy between ESs
- Good health coincides with ES
- Unhealthy ecosystem coincides with ES
- ESs exists in deprived area

5.3.1. Healthy ecosystem & ecosystem integrity

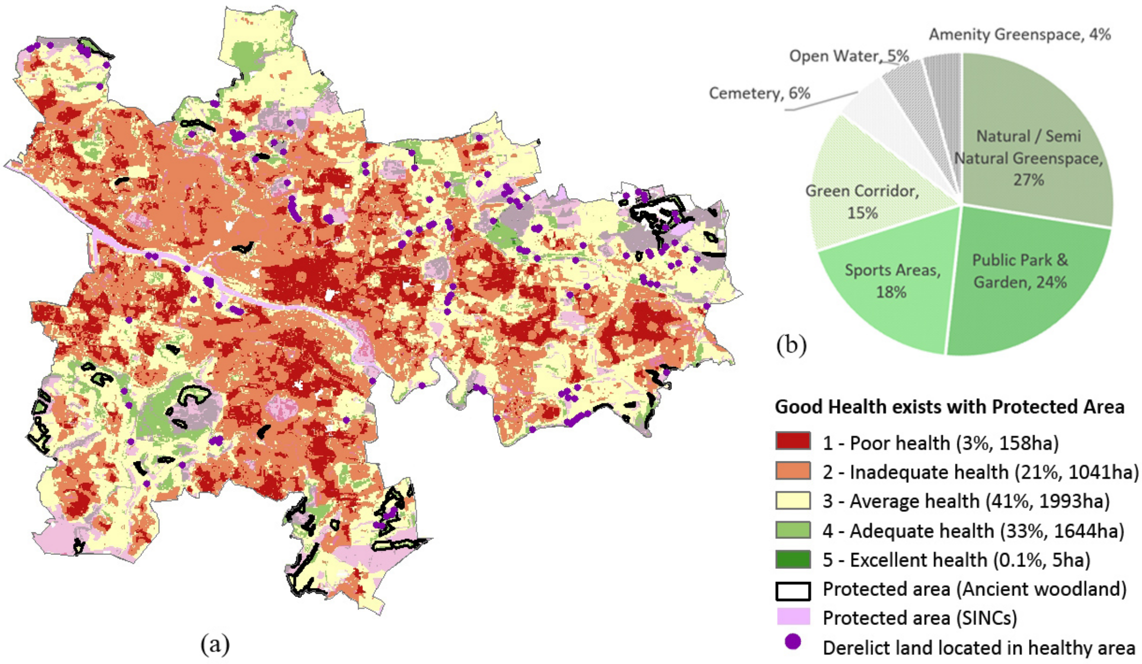


Figure 5.13 Map of ecosystem health & protected area.
Legend shows percentage of EH area in proportion to overall GN area
(a) Map of ecosystem health & protected area.
(b) Proportion of PAN65 landscape found in "healthy" area.
(Rattanakijanant,2021)

Figure 5.13 illustrates the final EH result. The 33.1% of "healthy" area (assigned "excellent" and "adequate") fall into the PAN65 area, whereas 0.5% are located in derelict land because of the influence of natural regeneration ability. A significant proportion of GN denoted "average" health (41%) and is most likely to occur in the transitional space where paved structures and landscapes are difficult to delineate.

This consensus shows the overlaid result between ecosystem health & protected area. The scenario provide insight into ecosystem integrity because protected area host the hypothethecal naturalness. An interesting finding is that 30% of healthy area does not belong in “Protected nature” (Ancient woodland and SINCs) like Sports Area (20%), cemetery (6%), and amenity transportation greenspace (4%). This is due to their high ecosystem adaptability state and low vulnerability to anthropogenic pressure. As expected, the hotspot is most pronounced in the protected area of the designated green corridor (76%), natural and semi-natural landscape (33%), and parks and gardens (24%). Also, the health score varies within these protected, even range from poor health, and adequate health. Protected site such as "Jordan Hill Ancient Woodland" and "Capeland Hill Ancient Woodland," and "Mall's Mire Community Woodland" are isolated from other nature cores

5.3.2. Synergy between ESs

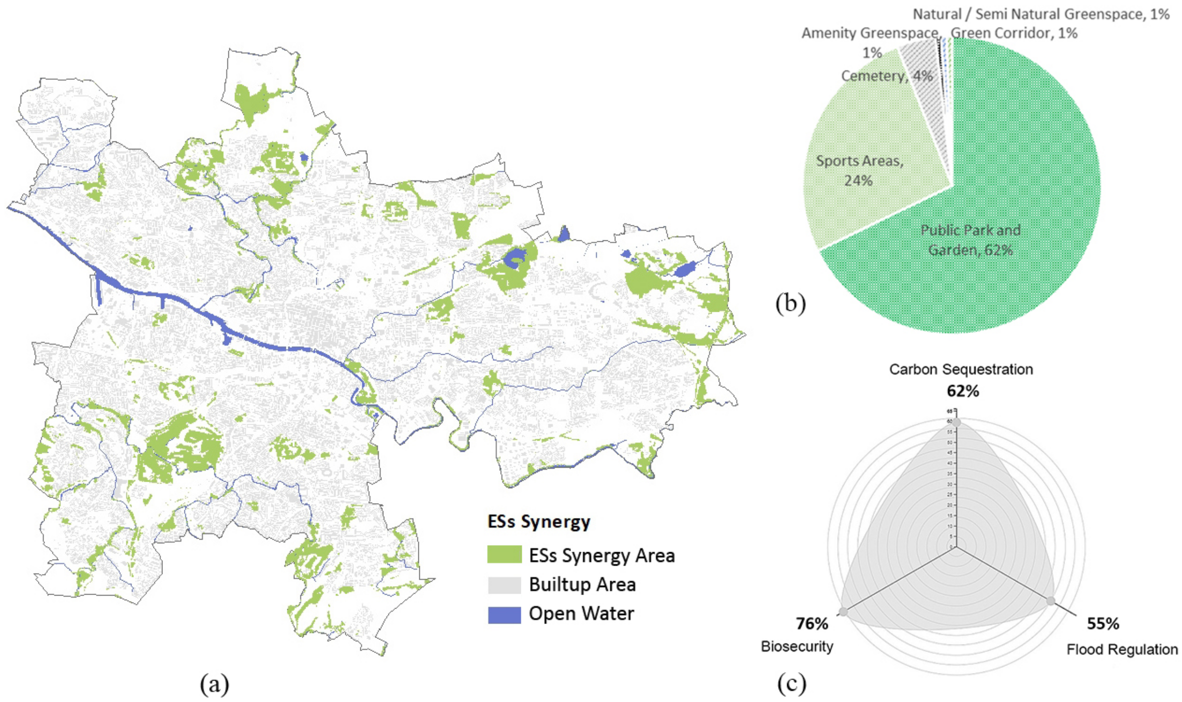


Figure 5.14 Map of Synergy between ESs
(a) Map of ecosystem health & protected area,
(b) Proportion of PAN65 landscape found in “synergy” area,
(c) Proportion of each ES detected in the synergy area
(Rattanakijanant, 2021).

ESs Supply and Synergy among ESs					
Classification ESs	Poor	Inadequate	Average	Adequate	Excellent
Carbon Sequestration	39% (6797ha)	40% (6962 ha)	10% (1775ha)	10% (1812ha)	1% (97ha)
Flood Regulation	44% (7896ha)	29% (2612ha)	15% (2612ha)	10% (1841ha)	2% (340ha)
Biosecurity	21% (3574ha)	53% (9105)	16% (2777ha)	10% (1802 ha)	0% (13ha)
ESs synergy	**40% (479ha)**	**38% (455ha)**	**11% (676ha)**	**10% (966ha)**	**1% (231ha)**

Table 5.1 Proportion of ESs Supply and ESs synergy
Synergy mapped in Figure 5.9a are combination of "adequate" & "excellent" area highlighted in blue.
Percentage of overall ES area in Glasgow city
(Rattanakijanant, 2021)

In this section, hotspots of ES synergy were spatially identified, i.e., synergy occurs between intent ESs. Figure 5.14c shows the extent of individual ES in the synergy; they share a similar proportion ranging from 55% - 76%. "Biosecurity" shown the most significant supply (76%) in the synergy, while "flood regulation" has seen the least (55%). Public parks, gardens, and sports areas are the leading provider of multiple services due to the size of their extent in the city. Regardless of the lowest synergy, table 5.1 denotes flood regulation has the largest extent. Also observed is that biosecurity has the least ES area count, especially low in the "excellent" supply area.

5.3.3. Healthy ecosystem coincides with ES

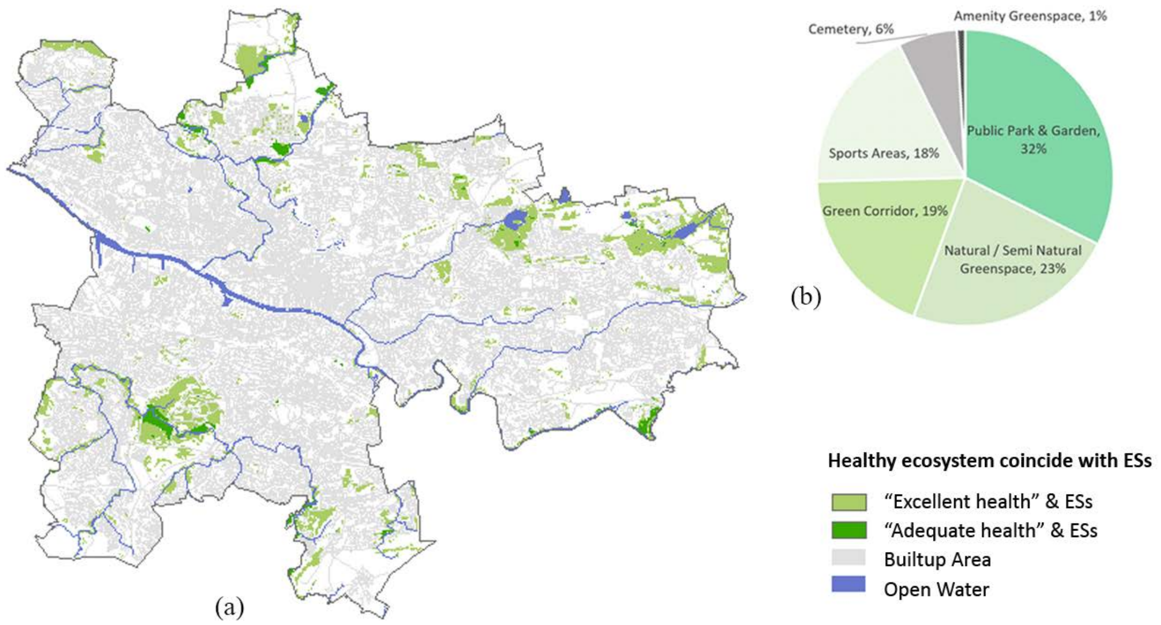


Figure 5.15 Map of Good health coincide with ES
(a) Map of healthy ecosystem & ES coinciding area,
(b) Proportion of PAN65 landscape found in "healthy ecosystem & ES coincide" area.
(Rattanakijanant, 2021)

ES coincide with "ecosystem health"				
Classification **ESs**	**ES & Poor health** (Poor + Inadequate)	**ES &** **Average**	**ES & Good health** (Adequate & Excellent)	**Error**
Carbon Sequestration	4% (88 ha)	30% (557 ha)	65% (1770ha)	-
Flood Regulation	4% (69 ha)	25% (577 ha)	54% (1244ha)	17%
Biosecurity	7% (119ha)	30% (543ha)	62% (1135ha)	-
ESs synergy	3% (917ha)	20% (237ha)	77% (31ha)	-

Table 5.2 Proportion of ESs coincide with "ecosystem health" (Rattanakijanant, 2021)

Figure 5.15 illustrates a map of "ES synergy" and "ecosystem health." in support of ESs, i.e., flooding regulation, biosecurity, and carbon sequestration. Delineation indicates 36% of PAN65 area score "excellent" and "adequate" condition (accounted for 10% of City area). As shown in Table 5.2 suggest that the majority of the "ES synergy area" (77%) falls within the "excellent" and "adequate" health areas. 19%, 23%, and 32% being green corridor, natural/ semi-natural greenspace and parks area, respectively. Similar scenarios are observed for each ES where high supply coincides with "Good health." Therefore, 65% of the PAN65 area has a natural potential to provide intent ESs.

5.3.4. ESs coincides with deprived area

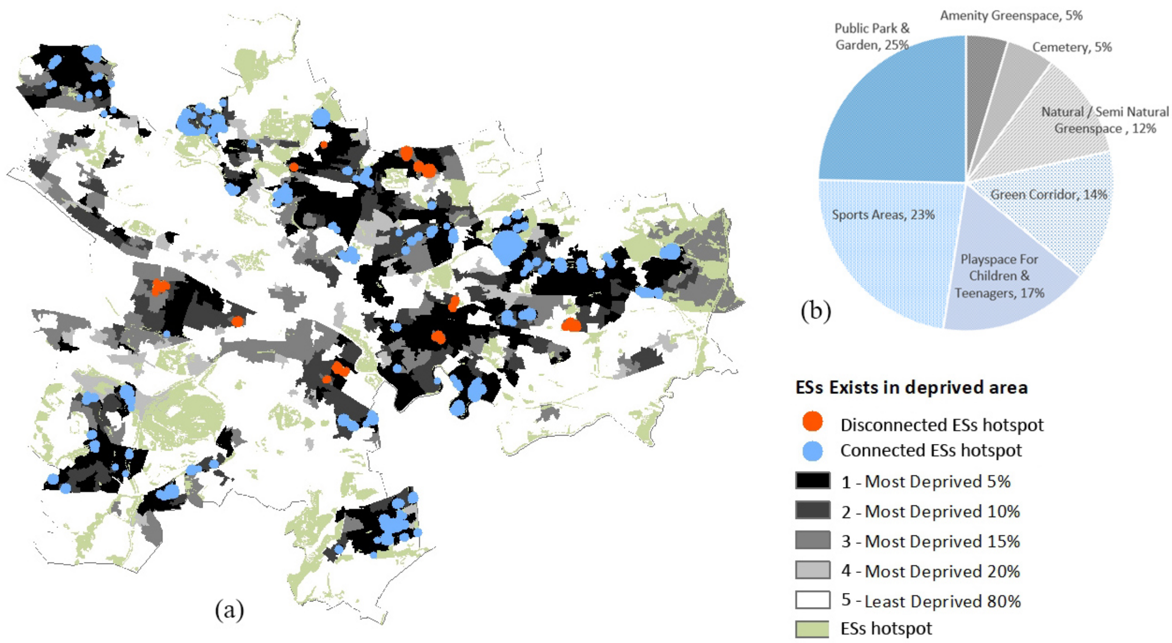


Figure 5.16 Map of ES coincide with "deprived Area".
(a) Map of ES coincide with "deprived Area," (b) Proportion of PAN65 landscape found in (Rattanakijanant, 2021)

ES coincide with "Deprived Area"				
Classification ESs	Low ES (Poor & Inadequate)	High ES (Adequate &Excellent)	Total	26% deprivation threshold
Carbon Sequestration	6% (116 ha)	13% (250 ha)	19% (367ha)	Not Met
Flood Regulation	1% (42 ha)	11% (250 ha)	12% (293 ha)	Not Met
Biosecurity	0% (4 ha)	18% (350 ha)	18% (341 ha)	Not Met
Multiple ES	4% (54 ha)	11% (142 ha)	15% (195 ha)	Not Met
Healthy Ecosystem	0.14 (0.4 ha)	0.04 % (0.1 ha)	0.18% (1 ha)	Not Met

Table 5.3 Proportion of ES coincide with "deprived Area".
(Rattanakijanant, 2021)

On the social vulnerability aspect, Figure 5.16 shows map of deprivation which is an overlaid between ES and ES synergy maps. A stepping stone pattern of ESs hotspot is observed, which distributes ES to the most deprived area of 5% - 10%. Table 5.3 denotes that 15% of ES hotspot deliver multiple ES to the deprived area, and 1 ha has a "healthy ecosystem." Similar trends are shown for individual ES, especially "flood regulation," which is least available in a most deprived area.

Table 5.3 shows the "equitable distribution" method adapted from Makanjuola et al. (2020). In particular, Glasgow city has 26% delineated as "deprived" by this study. Hypothesized that 26% of ES hotspot falls into the most deprived area would account for 'equitable distribution' (Majekodunmi et al., 2020). None of the ES met the equitable distribution threshold.

Performed together with is connectivity analysis to explain accessibility at 500 m—fixed distance to capture travel distance on foot by elderly group (Pinto et al., 2020). The result indicates that 15% of ESs are isolated from other ESs hotspots (indicated by red dot).

Figure 5.15b explains that Open space typology has seen the highest proportion in Public Park and gardens (25%), sports areas (23%), playscapes (17%), and green corridors (14%); these are excellent elements distributing ES to a deprived area. Urban woodland and parks such as "Festival Park," "Elder Park," "Hogarth Park," "Bridgeton Community Woodland," and "Bingham's Pond" are disconnected from other nature core.

5.3.5. Unhealthy ecosystem coincides with ESs

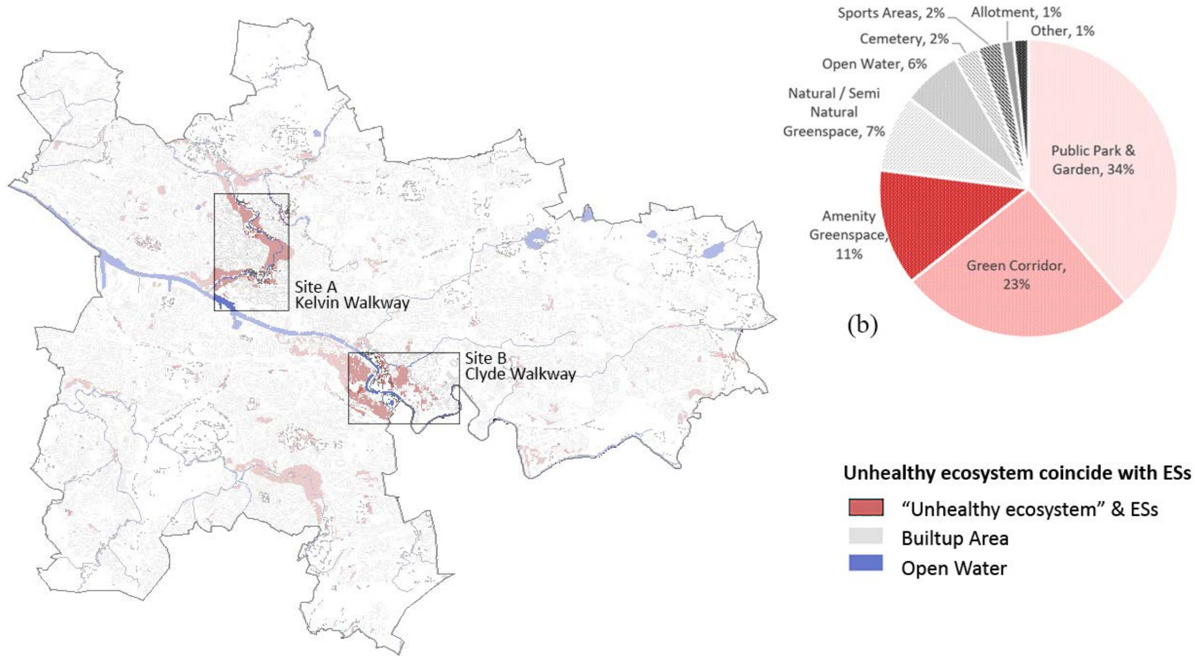


Figure 5.17 Map of unhealthy ecosystem coincides with ESs
(a) Map of unhealth area coincide with ESs, emphasized are selected site
(b) Proportion of PAN65 landscape found in "unhealthy" area.
(Rattanakijanant, 2021)

Ecosystem disservices (EDS) traits could be observed in an environment where ES is deficient or an area which undergone an ecological change (i.e., novel ecosystem), such as the reduction of ecosystem health (Potgieter et al. 2019, Dohren 2015). As the holistic aspect of ES is not included, this study selected a method of recognizing high ESs supply areas located within an "unhealthy" hotspot. In this way, this study conveys probable EDS compared to ES supply (i.e., tradeoff).

The literature explains that EDSs range from problems in accordance to an economic problem, cultural, recreation and aesthetic, health, and safe and security (Potgieter et al., 2019). The scope of the thesis will center on environmental and related well-being issues.

In particular, two GN hotspots within the range of GCV were selected and examined through Google Earth and by my familiarity with the sites. In addition, the study investigated the influence of 'pressure' on the site then compare with ESs extent to explain possible EDS under the guidance of existing literature.

Site A

Figure 5.18 illustrates Site A located in Kelvin walkway under GCC's green corridor development scheme along River Kelvin (Figure 5.18b). The area is a series of connected parks, green corridors, natural greenspace, urban farms, and amenity gardens. Situated right in between residential and commercial landuse, it is under the city's conservation scheme of Westend. The area is a sunken river walkway that separates it from the buildups by level difference.

Degraded lands being the most negative impact, where high maintenance activity on parks and gardens could create disservices such as intensive water consumption, green waste generation, and CO2 emission (Bisgrove & Hadley, 2002). Although, 17% of the site area sequester carbon. Further study is needed for accurate carbon comparison measurement.

Influence of invasive species competing and suppressing the native ones as well as affecting food web. Still, 17% of the site has flood regulation efficiency but also vulnerable due to a condense and non-native riparian may cause reduction in riverbanks' structural integrity like soil erosion. Waterlogging intolerant vegetation can be expected (Rumble et al., 2014). Simplified landscapes such as street trees and great lawns are an example of monoculture and single-gender vegetation that interact with air pollution and allergenic pollen, especially during spring and summer (MetOffice, 2021; CXC, 2016).

Site A				
Pressure Located	**Features**	**Location**	**Disservices links with pressure**	**Sources**
Landscape degradation	Farming anfd decorative landscape, e.g botanical garden, urban allotment, and lawns	1	Generates green waste	Potgieter et al. 2019
		2	Maintenance activity emits CO2	Bisgrove & Hadley, 2002
Invasive species	Non-native on riverbanks	3	Invasive plants suppress the natives species	Stinson et al. 2016
	Monoculture and single-gender vegetation , e.g. great lawn, street tree	4	Links to high atmospheric transport of allergenic pollen which could be intensified by extreme temperature	CXC 2016
	Great lawn, Undiverse street tree	Overall	The Emissions of Biogenic Volatile Organic Compounds (BVOC)	Potgieter et al. 2019
	Unspecific location	Glasgow	Waterlogging intolerant species in 200 years flood area	Rumble et al., 2014
	Decorative landscape	5	Increased water consumption for irrigation	Rumble et al., 2014
Flood risk	Condense riparian	6	Link to reduce riparian ability to prevent soil erosion	Macfarlane 2014
Urban temperature	Buildtup area	7	Reduced cooling effect efficiency	Rahman & Ennos 2016

Table 5.4 Table of probable EDS links with pressure investigated at Site A (Rattanakijanant, 2021)

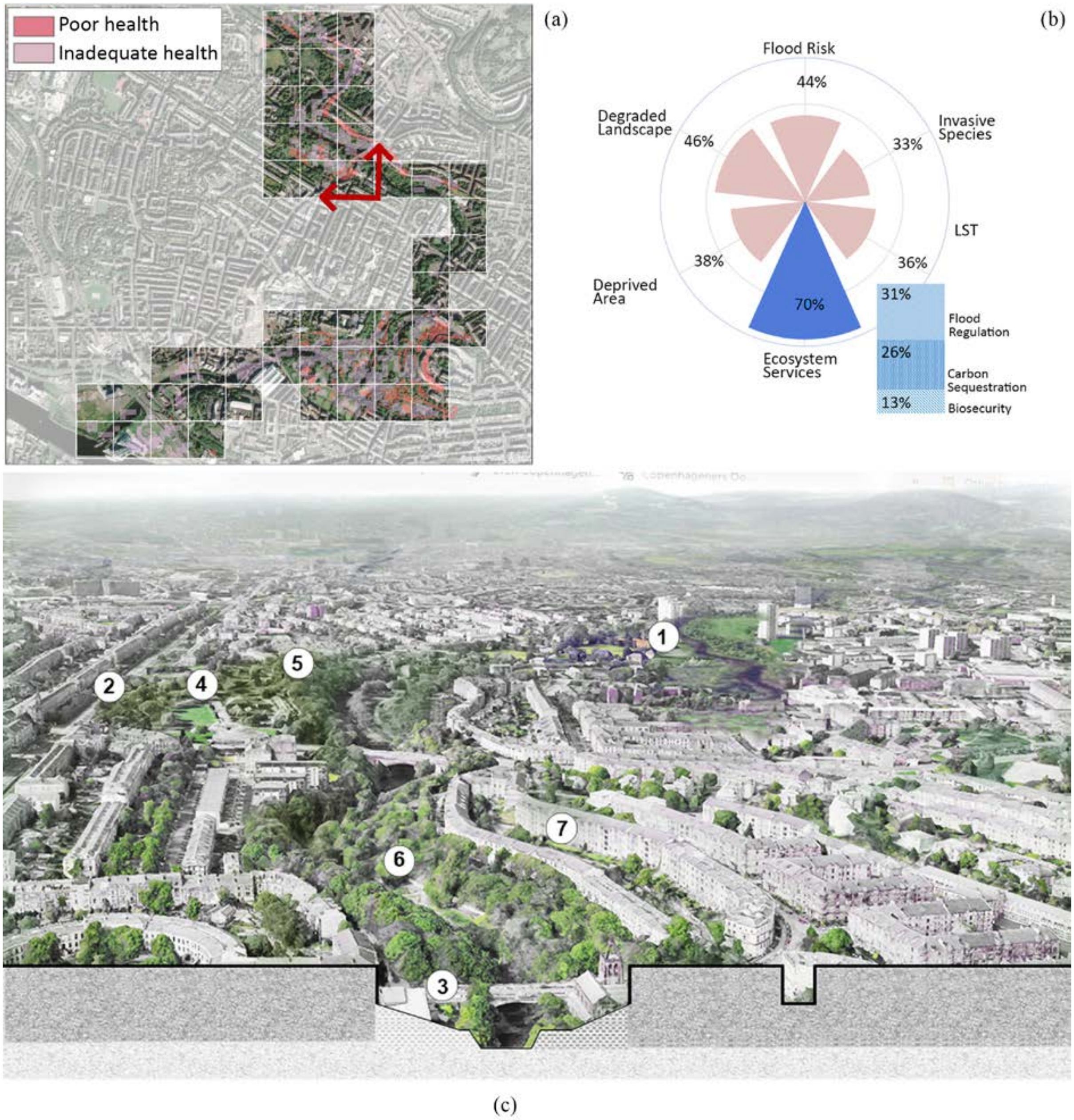


Figure 5.18 Visualization of Site A: Kelvin Walkway
(a) Chart comparing proportion of ESs & EDS identified on Site A,
(b) Location of Site A shown on Google Earth (c) 3D perspective of Site A and surroundings.
3D model of Glasgow at LOD2 belongs to Glasgow City Council (2021).
Map showing location of Looking up Kelvin River towards the West-End from Google Earth,

Site B

Site B is a part of the Clyde walkway project, comprised are Glasgow green and Clyde Gateway, which has undergone significant urban regeneration from former derelict land, connected through a green corridor. Grid cells include parklands, riparian landscape, River Clyde, residential and industrial land use. The area is in the proximity of riparian restoration forest, the Cunnigar loop.

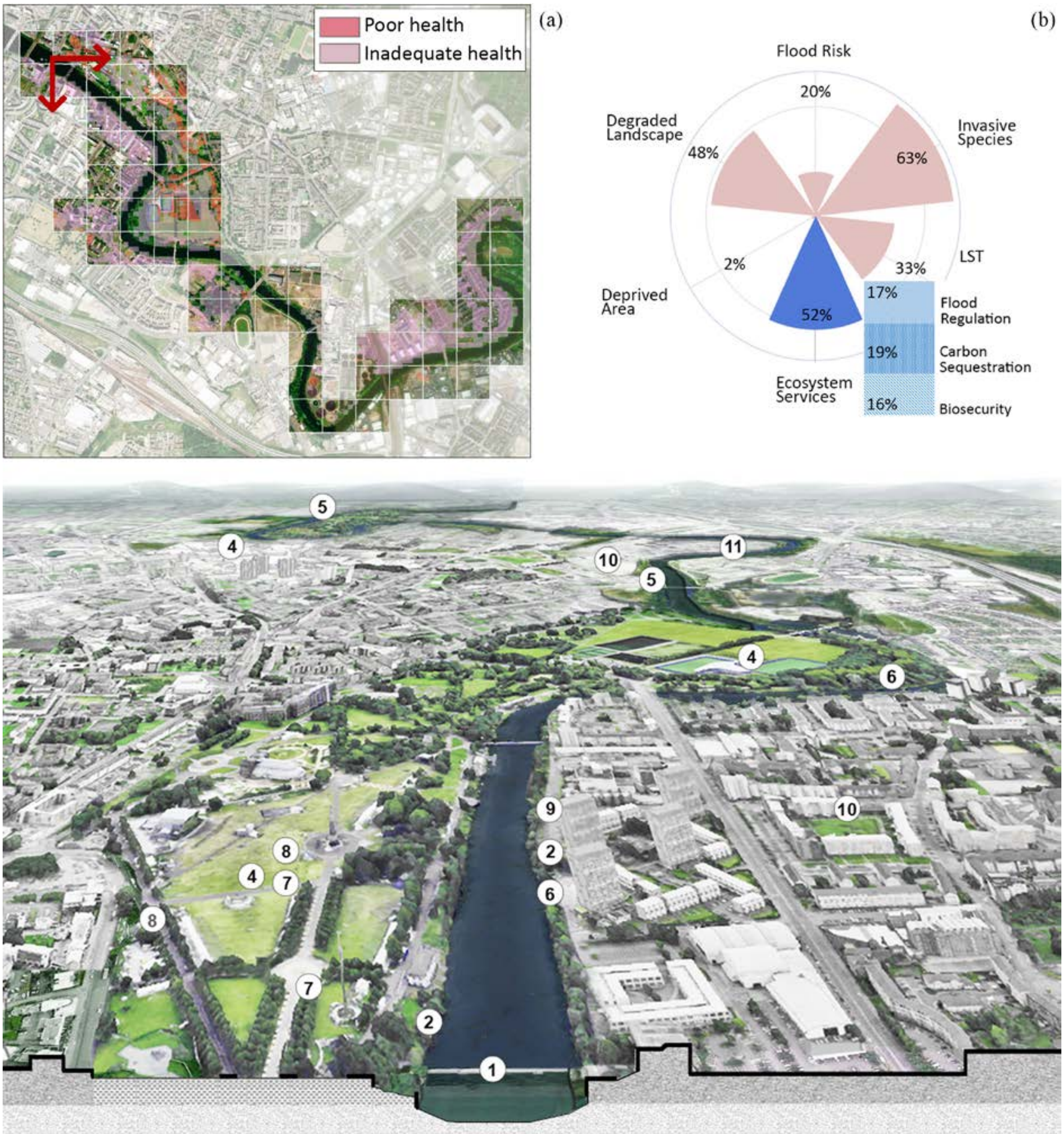
Site B has elements of an unhealthy ecosystem, as evidence in Figure 5.17b. Impact pressures and intensity are similar to site A except for an additional 7% deprivation factor. The reasoning related to the influence of 5% of most deprivation to climate adaptation exist. Flood risk, Invasive species, and landscape degradation are equal influencers. There is a link to disservices from human dominance landuse. Firstly, intensive River Clyde channelization and flood defense wall increase the risk for riparian subsidence (observable). Secondly, coastal erosion risk in the Clyde estuary and the biogeochemical release of carbon and nitrogen (Karunarathna, 2011). Finally, the lack of sediment delivery from marine and riverine sources would impact coastal habitats' ability to withstanding rising sea levels (Watkiss & Hunt, 2019).

Moving on to ES's performance, flood regulation shows a 14% likelihood because of sustainable drainage system (SuDS) features found along riparian zones and at Clyde Gateway, such as flood detention lawns and constructed wetland drainage. Although, flood regulation performance could be reduced due to invasive species dominance. Species such as poisonous *Heracleum mantegazzianum* originated in Asia, which raises flood vulnerability and erosion, especially during winter when the invasive dies back and leaves the river banks exposed (Macfarlane, 2014). Additionally, Rumble et al. (2014) demonstrate that Glasgow trees are waterlogging tolerant and drought-intolerant, which is coincides with vegetation health (NDVI map in Figure 5.6a), where 35% belong to bare land/ dead plant, and 30% are stressed vegetation category. The attempt at regeneration or recent self-colonizing of trees is to be expected at Site B considering the small size of riparian trees. As shown in Figure 5.6c, urban temperature (LST) at Site B relates to a reduced cooling effect by evapotranspiration (Rahman & Ennos, 2016).

To conclude, the concensus analysis presents an interrelation of EH and ES in Glasgow city which highlight the potential of Glasgow GN to deliver climate change adaptation benefits. Conversely, the exmaple from site selection explain negative impact that could exist together. In comparison, the proportion of ESs Site A are generally out-weights the area of EDS and has better health condition due to lower pressure detected.

Site B				
Pressure Located	**Location Description**	**Location**	**Disservices links with pressure**	**Sources**
Landscape degradation	Flood defence structure, e.g. flood wall, channelized wall	1	link to coastal erosion and biogeochemical release of carbon & nitrogen	Karunarathna 2011
		1	Link to reduce coatal ability to withstand sea-level rising	Watkiss & Hunt 2019
		2	Link to subsidence in areas with shrinkable clay shore	Rattanakijanant 2021
	Decorative landscape, e.g lawns, sport ground, and gardens	1	Generating green waste	Potgieter et al. 2019
		2	increase maintenance activity emits CO2	Bisgrove & Hadley 2002
Invasive species	*Heracleum mantegazzianum* colonization	5	Poisonous species	Rattanakijanant 2021
	Unspecific location	Glasgow	Commercial forestry (e.g. coniferous) could have a negative impact on water quality and biodiversity	Burton 2018, Price 2014
	Non-native on riverbanks	3	Invasive plants suppress the natives species	Stinson et al. 2016
	Monoculture and single-gender vegetation , e.g. great lawn, street tree	4	links to high atmospheric transport of allergenic pollen which could be intensify by extreme temperature	CXC 2016
		Overall	The Emissions of Biogenic Volatile Organic Compounds (BVOC)	Potgieter et al. 2019
	Unspecific location	Glasgow	Waterlogging intolerant species in 200 years flood area	Rumble et al. 2014
	Decorative landscape	5	Increased water consumption for irrigation	Potgieter et al. 2019
Flood risk	Condense riparian	6	Link to reduce riparian ability to prevent soil erosion	Macfarlane, 2014
Urban temperature	Buildups area	7	Reduced cooling effect efficiency	Rahman & Ennos 2016
Deprived area	Deprived rrea	11	Reduced cooling effect efficiency due to high surface temperature reduce evapotranspiration from plant canopy	Rattanakijanant 2021

Table 5.5 Table of probable EDS links with pressure investigated at Site B (Rattanakijanant, 2021)



(c)

Figure 5.19 Visualization of Site B: Clyde Walkway
(a) Chart comparing proportion of ESs & EDS identified on Site B,
(b) Location of Site B shown on Google Earth (c) 3D perspective of Site B and surroundings.
3D model of Glasgow at LOD2 belongs to Glasgow City Council (2021).
Map showing location of Looking up River Clyde towards the East-End from Google Earth

CHAPTER 6: **DISCUSSION & CONCLUSION**

This chapter is in relation to objectives five of this study by highlighting the capability and threats from a novel GN to inform local policy. Section 6.1 discusses implications of the findings and results from chapter 5, in which explanations and recommendations are made within the guidance of existing literature. Section 6.2 evaluates limitations found in this approach and Section 6.3 draws a conclusion based on the performance of this study's approach and reflecting own standing point on the urban ecosystem field.

The result implications have five sections to discuss the result of consensus analysis and evaluation of the methodology approach.

6.1. Discussion & recommendations

6.1.1. Implications for ecosystem services supply

Determining ecosystem health is helpful for an understanding of ES supply. Glasgow city has a large extent of coinciding "healthy ecosystem" and "ES." As expected, it implies that if the "healthy ecosystem" area increases, ESs proportion could also increase. However, 23% of synergized ES found on PAN65 landscapes fall out of the "healthy ecosystem & ES coinciding" area; suggest that this 23% of synergized area (i.e. 6% of overall GN area) host an environment of reduced ESs in unhealthy areas. Alternatively, unquantified ESs beyond this study scope could exist within the healthy area.

ESs focus in this study aims for climate change regulation. The mapping assessment of ecosystem health conditions delineated that Glasgow city's GN has a promising natural potential to supply flooding regulation, biosecurity, and carbon sequestration, as excellent and adequate ES areas are identified for each of every ES. Among 3 ES, Biosecurity has the largest share in "ESs synergy," i.e., biosecurity is essential to the emergence of the other two intent ES, carbon sequestration and flood regulation. Thus, Glasgow GN has an environmental risk regulating capability, especially "biosecurity," as evidence of one of the supporting services that facilitate the other services, including services beyond this thesis scope (Potschin & Haines-Young, 2018).

Glasgow's GN has "average" to "adequate" capability to generate multiple ES (two to three ESs) as intended in Climate Ready Clyde policy. Whereas ome areas only deliver single ES. Climate change projection predicted amplifying summer temperature and decreasing precipitation indicating the prevalence of drought in the same context, underscoring the need to introduce multiple ES to mitigate both conditions. The delivery of multiple ES creates synergies but conversely, focusing only individual or selected ES could compromise the other (i.e., trade-offs situation). For example, flood regulation has seen a minor synergy, implying that the landscape to retain water is unique, but some type has limited capability of attaining carbon sequestration and biosecurity. In Glasgow's case, the flood regulating landscape is entirely or partially novel. In particular, sports ground or golf course, due to large proportion of Glasgow woodland was converted into a golf course. Thus, the proximity of these extensive sports grounds is within a natural area; they have undulating terrain and an unsealed ground surface. This environment offers flood regulation probability as high as 24% among all PAN65 typologies (e.g., multi-function lawn or decorative pond such as could be adapted for water detention area).

6.1.2. Implications for ecosystem integrity and conservation

Glasgow city's GN has average health conditions as PAN65 open space is spatially made up of 36% "healthy" ecosystem, which refers to; (1) healthy as in ecosystem has the adaptive ability under anthropogenic pressure as described in CXC policy. (2) Healthy ecosystem as in hosting a naturalness remaining from the industrial revolution.

41% of PAN65 has average health, suggest a consequence of urban regeneration that facilitates integration between urban elements and nature-based solutions, or conversely, integration of urban elements into natural areas. The result reaffirms that protected areas, i.e., green corridors and natural/ semi-natural greenspace are the primary provider of good health. The study of the landscape structural composition of the above green area could inform the GN implementation scheme.

Ultimately, investigation of "protected areas" (Ancient woodland and SINCs) is suitable for understanding the complex interaction of nature to cope with novel landscapes, and most importantly, how well they withstand urban climate challenges. Conservation policy not only ensures that the city benefits from ES supply but is also crucial to the survival of existing habitats.

The consensus analysis of Glasgow's EH and the protected area has shown mixed results. The score range from "adequate" to "inadequate" health, despite the areas being under conservation policy, implies an intensity of "pressure" influence. Among all protected areas, ancient woodland isolated from other nature cores indicate that these sites are vulnerable without good management. Hence, policies could be emphasized to preserve isolated "healthy" natural areas and include them in the CRC's "Clyde Climate Forest" restoration scheme, alongside restoring protected areas with poor health. A monitoring strategy could help track a trend of climate change impact on the vulnerable sites. And finally, conservation policy could prioritize sites of immediate attention based on health score.

Rumble et al. (2014) explain that patches which are unlikely to connect with significant habitat core could obtain novel aspects—for instance, integrating low intensive cultural, educational, or recreational aspects to small ancient forests to attract conservation subsidies.

"Clyde Climate Forest" policy aims to enhance "biosecurity" by planting strategic urban trees and reforestation in Glasgow's regions (CRC, 2021). Such a concept could gain benefits from the "Rewilding framework" (SCOTLAND: The Big Picture, 2021) alongside "urban regeneration" and derelict land management (0.5% derelict land result in good health). An appropriate balance should be weighted between nurturing urban woodlands and ensuring community development in a sustainable manner. Practically, a policy to encounter loss of property to habitats restoration is crucial for the succession of the project in an urban context with multiple stakeholders, GCC strategy to utilize derelict is suitable in ths circumstance. Thus, inclusivity of neighboring community should still be recognized when enhancing conservation.

6.1.3. Implications for climate-just environment

Section 6.1.3 discusses a consensus result of ES and deprived areas. The area of most deprivation by the Scottish Government (2019) relates to people having fewer opportunities and resources. The study indicates that inequality of ESs distributions is pronounced in the most deprived area. They are indicating the challenge of social vulnerability where the most in need could access the least ES in addition to social and economic deprivation.

From the adapted method of Makanjuola et al. (2020), the result in this study does not meet the "equitable distribution" expectation. However, the quantified extent is much greater compared to Makanjuola et al. (2020)of flooding regulation results. Such contrast could cause by parameter differences, the scale of classification difference, and the extent of the analyzed area (i.e., City scale calculation).

Nevertheless, the inequity is further analyzed using ES connectivity analysis in which ES hotspots found in deprived areas attain adequate connectivity to other ES cores. When coming to ES distribution, even so, "equitable distribution" is not met, but 85% of ES in the deprived area are found to be reasonably connected to other GN to the fact that Glasgow as a whole has well distributed GN (Makanjuola et al., 2020).

Indeed, sites like parks and sports grounds are the main resources provider due to their extent and high ecological value. Thus, the 15% isolated green space in a deprived area, in the same way with "protected nature" mentioned previously, should be preserved as a site of importance, socially and environmentally. The green corridor also appears with a possible connection to a larger green patch in GN schemes. In terms of landscape planning, they represent a potential distribution of a "social" landscape, such as the integration of urban farms and playspace. But most importantly, communities' needs have to be heard to prevent shortcomings (e.g., crime risk spaces, maintenance burden, and vandalization).

Observable associations between deprivation and ES are spatially coinciding with the peri-urban context. The result has shown fair portion benefits from excellent EH from significant sites mostly located within the SINCs scheme (e.g., Seven Lochs Wetland Park). Besides, deprivation is located within an industrial declined area (e.g., along River Clyde). Alternatively, this avocates a natural regeneration on the derelict lands within the deprived community in which is a sustainable and long-term cost-effective way of GN enhancement.

Well-connected and accessible GN and basic facilities will be of greater importance in the presence of climate disasters. As explained in the literature review, the community has to benefits from both transferable ES and ES on-site to access higher efficiency ES to gain as well other ES such as health, pollution control, cooling effect, and energy conservation.

6.1.4. Implications for environmental threats

Assessment of ecosystem health facilitates EDS understanding. As identified from the result, the circumstance where an unhealthy ecosystem can host a high ES supply indicates that the Glasgow GN could function in an environment with lesser naturalness. However, results also suggest that high ESs supply has a more considerable extent in healthy ecosystems than the unhealthy.

EDS is not directly quantified in this study due to the time limit but has attempted to compare EDS and ES by investigating elements of "pressure" on selected sies. The result shows that the proportion of Ess's opportunity area generally out-weights the area of EDS.

EDS emerges in a trade-off scenario influences by various anthropogenic pressures of urban elements and novel ecosystems. Site A: Kelvin Walkway and site B: Clyde Walkway visualizes urban's riparian green corridor within the core of high-density areas. As explained in the Result chapter, novel GN provisioning "Climate change adaptation ESs" but constitute adverse results;

Flood regulation has the slightest extent in unhealthy locations because water corridors are designated in a biodiversity conservation scheme. Glasgow location in the floodplain can explain the EDS coincidence. The degraded landscape has a sealed surface (i.e., an unhealthy ecosystem). Therefore, the floodplain could physically retain inundation but would have less infiltration potential and damage the un-resilience infrastructure located within site. Thus, susceptible to flood risk EDS. The "natural floodplain" has to be gained at the extent and speed required.

Flood defense mechanisms threaten riparian subsidence and link to the disappearance of coastal habitats. Sustainable drainage systems (SuDS) are sufficiently integrated into the residential area, although they could link to simplified landscape.

The effect of Biosecurity, of all ESs, has the greatest extent in unhealthy locations. By fostering novel GN would eventually have more benefit to unhealthy than a healthy ecosystem. But biodiversity is complex and difficult to achieve. The issue of simplified landscape and non-native species spreading, particularly along the river, causes health issues and colonized vegetation prone to flood and drought that has become vulnerable under increasing temperature. The issues also persist in the maintenance of novel landscapes that any landscaping has to consider low maintenance and relax management strategy. Glasgow city is influenced by high precipitation, although climate change is predicted to increase water stress and prolong the blooming season. Extending the high maintenance landscape of non-native species could lead to increase water and energy consumption. Furthermore, causing a reduction in the cooling effect by decreasing evapotranspiration. The biosecurity links to EDS can be explained through a degraded landscape that could cause a release of carbon through degraded land water, soil, and vegetation.

Even natural/semi-natural green space is associated with an unhealthy environment. Explanation from literature links fast-growing commercial forestry to acidification discharge into soil and watercourse (Burton, 2018). Price (2014) also raised a case of commercial conifers to release carbon once timbers are harvested simultaneously. Also, peatland restoration is reported to cause methane imbalance and affect water quality short termly (Lunt et al., 2010). Even though the consequence of commercial forestry may not be relevant to site A and B at the moment; however, Climate Forest policy has to be cautiously evaluated if commercial forests are deployed in a reforestation scheme.

The prospect of trade-off leads to conflicts over whether to manage ED or EDS. There is a need to develop strategies that promote synergies and minimize negative trade-offs between ES. The mainstreaming movement informs intervention, such as removing large structures like seawalls and dams, improved flood dikes incorporating overtopping wetlands.

From an ecosystem integrity perspective in reversing the novelty trade-off, restoration of native woodland or floodplains by natural regeneration and low-intensity management to achieve natural forest structure has gained momentum in restoration science (Potgieteret al, 2018, GCC, 2017). Literature suggested that pursuing natural regeneration plantations would require site-specific evaluation. However, there is a lack of solid evidence for the detrimental effect of naturally regenerating native woodland on biodiversity. Although natural restoration has limitations, notably for highly altered landscapes might no longer support a feasible naturally restoring process.

6.2. Evaluation & limitation of methodology

This methodology has limitations: quality of data, technical inexperience, comprehensivity of indicator, scoring system, and practitioner engagement method.

Firstly, Glasgow city open data is resourceful and have wide range of coverage that fits to Glasgow’s context hence would be challenging to apply the same approach elsewhere .PAN Open Space data could be misleading because open space patches digitized are fragmented and have inaccurate landscape typology. The data resolution is applicable for urban scale but imprecise towards an analysis of site-specific scale. Besides, ensuring that data are temporally aligned is challenging when data are collected from multiple providers.

PAN65 data beyond Glasgow city's boundary are unavailable and are not feasible to recreate due to the time limit. Thus, it caused an uncomplete environment for analysis such as "habitat connectivity," "deprivation of accessibility," and isolated patch identification analysis. Furthermore, many intent abiotic data are unavailable to map soil sealing, water quality, landscape degradation, protected nature, and vegetation health. Data such as soil carbon data and GHGs counts have to be replaced with compatible data.

Fourteen indicators are suitable for learning purposes and represented a timely feasible for ecosystem quantification. A strength of the indicator method is in combining numerous abiotic and biotic contributors of the EH and ES into a single measure. However, it has a weakness because ecosystem study is still evolving, and lack of consensus on a precise definition can lead to uncertainty of results, simplifying complex systems into simplistic values (European Commission, 2021)

Further, on indicators issue, the direct urban climate parameter used in this study is LST. However, projecting the impact of climate change requires comprehensive climatic data, such as precipitation, relative humidity, wind speed. Also, comparable mapping of seasonal variation or trends over the years could generate a more precise environment of a novel ecosystem to quantify future trajectory. However, data collection is challenging, which is why this study did not include quantifiable future trends.

EDS is not directly quantified; therefore, it could create an imprecise assessment. Literature and my familiarity with the site have proven beneficial in identifying relevant EDS.

The scoring system is inconsistent throughout the analysis. There is a mismatch of the scoring range between indicator analysis and consensus analysis. Also, scoring interpretation cause misleading information due to my inexperience with the method; scoring from 1 to 3 would be more suitable for this way of interpretation. This human error also applied to some challenging analysis methods like connectivity analysis as well as data management.

Experts engaged in the MCDA process have expertise in urban planning, management and natural environment. Even so, the expert consensus has not been qualitatively analyzed because expert opinions are largely uniform except for one opinion, which suggested that prioritizing one indicator over another is not practical if ecosystem integrity is concerned. That pressures impact assessment requires a range of social cohesion beyond deprived area. Data should included health and wellbeing, economic, and broader biodiversity data to understand external drivers that might control ES provision. Lastly, the questionnaire is helpful during COVID-19, although a focus group could be an alternative method to find consensus among experts' opinions and strengthen the assessments.

6.3. Conclusion

The framework to link EH and ES aims to appraise two aspects that, despite both are mentioned in environmental aspect, a fragmented knowledge have reflected in implementation; thus, unhealthy GN emerged. Literature reviews support the connectivity between three main concepts, "Ecosystem services," "Ecosystem Health," and "Urban novel ecosystem," and their joint role in climate change adaptation. Highlighting that EH is vulnerable to climate change in an urban ecosystem context if planners solely prioritize one or selective ES. Glasgow city reflects a relevant case study as the concepts of ecosystems is applicable due to largly implemented GN. Still, Glasgow's urban ecosystems has hybrid novelty and have urbanized to the point where reference conditions are irreversible. Qualitative and quantitative data are valuable tools to understand the capability of Glasgow's GN to host EH and ES in its current state. Glasgow's GN has sufficiently average to good health, and to some extent, could adapt to climate change despite hosting a novel ecosystem. Determining EH contributing to the understanding of ES supply in several ways. Firstly, ES is proportionally increased where a large area of "healthy" conditions exists. Furthermore, synergies of multifunctional ESs are also found in healthy ecosystems safeguard by "biosecurity." Still, the caution of implementing ES is pronounced where ESs coincide in an "unhealthy" environment and link to several EDS. This study selected thress ESs as an example to quantify multifunctionality. Although in multifunctional sense, real-world project has to recognize beyond these limit number to avoid EDS emergance.

EDS reduction management is a delicate process in an urban setting. The opinion on EDS management is un-uniformed in the literature. Lyytimäki (2014) suggests the probability of removing EDSs without compromising the composition of a newly established novel ecosystem. However, planners must critically review landscape interventions to confront EDS that may arise within a less natural context. The following questions should be asked; Would it withstand the worst-case scenario?

The high emission scenario or Representative Concentration Pathway 8.5 (RCP 8.5) by 2100 express the great magnitude of climate change impacts, especially along River Clyde. Such a scenario requires a careful selection of nature-based solutions and re-evaluation of the current GN of whether they have good enough conditions to regulate the high climate impact, which this study has explored. City planners could pay extra attention to increase the extent of natural and semi-natural restoration of natural areas, which is proven in this study to have an adequate supply of climate change ES. Moreover, due to the slow-growing of natural areas, the restoration needs to be addressed immediately and substantially. Nature restoration could be challenging as it involved multidimensional planning across multiple land uses, management, monitoring, and stakeholders. In the Glasgow case, "Urban regeneration" strategies have proven to be effective simulators attracting subsidies and moving forward environment restoration along with the economy. It would also need to set baseline for conservation and restoration which needs clear delineating goal of to what extent restoration or conservation would reach.

PAN65 open space data contain various types of landscape to serve community uses. The application of PAN65 Open space has given the insight that highly communal novel ground does not always represent an "unhealthy" ecosystem. For instance, a sports ground within semi-natural area could host both a healthy ecosystem and ESs. While such ground could not replace natural areas but this notion may provides room to integrate social and environmental aspects into one comprehensive picture as natural areas which are utilized or managed could have a better chance at being conserved. Although, these social activities should not be intensive and should be managed in a sustainable way. In accordance with the Climate Ready Clyde policy that GN should be developed along with the adaptive community. This study does not include in detail the scope of "social capacity" or the ability of a community to cope together under climate risk. Still, exposure to climate change "risk" could be reduced by facilitating inclusivity through ES distribution.

As a final thought on EDS and urban novel ecosystem, this study does not intend to underscoring a novel ecosystem's negative impact or suggest eliminating them solely. Instead, to appreciate the significance of ecosystem integrity and emphasize the benefits of targetting multifunctionality of ES to achieve a more resilient ecosystem. Novel ecosystem and baseline framework aid the tracking change in an urban ecosystem which capabilities are evident in the result. Hence, a new condition does not always translate as negativity. However, it presents a lesson that any landscape planning has to fully consider the impact of a novel intervention on the adjacent ecosystem. City and landscape planner has to define clearly of where to integrate nature-based solution and how to blend them with natural environment as to link EH and ES in a cost effective. Whereas hybrid system of native and novelty could incrementally pave way for adaptive urban ecosystem.

To conclude, this approach reflects that Glasgow city's GN represents an environment that supports "Climate Ready Clyde." The method is informative in identifying characteristics of highly adaptive and beneficial GN around Glasgow city. Using fourteen indicators to capture the full range of EC and ES may lead to uncertain results. Although, it is a helpful tool compiling accessible open data on landscape characteristics, abiotic, biotic factors, and some of the social value. This method is suitable for learning purposes but there is a need to acknowledge that ecosystem integrity in the urban context is a field interconnect to a broader range of social cohesion, health and wellbeing, economic, and more comprehensive biodiversity knowledge.

REFERENCE

BAHO, D.L., ALLEN, C.A, GARMESTANI, R., FRIED-PETERSEN, H., RENES, S.E., GUNDERSON, L., & ANGELER, D.G, 2017. A quantitative framework for assessing ecological resilience. Ecology and Society [online]. 22(3). Available from: https://doi.org/10.5751/ES-09427-220317

BENINDE, J., VEITH, M., HOCHKIRCH, A., 2015. Biodiversity In Cities Needs Space: A Meta-Analysis Of Factors Determining Intra-Urban Biodiversity Variation. Ecology Letters. 18(6), pp. 581-92. Available from: 10.1111/ele.12427

BISGROVE, R., & HADLEY, P., 2002. *Gardening in the Global Greenhouse: The Impacts of Climate Change on Gardens in the UK* [online]. The UK Climate Impacts Programme, Centre for Horticulture and Landscape, School of Plant Sciences: The University of Reading. Available from: https://www.ukcip.org.uk/

BOLUND, P. AND HUNHAMMAR, S., 1999. Ecosystem Services in Urban Areas. Ecological Economics, Ecological Economics [online]. 29(2), pp.293-301. Available from: http://dx.doi.org/10.1016/S0921-8009(99)00013-0

BONTHOUX, S., BRUN, M., PIETRO, F.D., GREULICH, S., & BOUCHÉ-PILLON, S., 2014. How can wastelands promote biodiversity in cities, Landscape and Urban Planning [online], 132, pp.79-88. Available from: https://doi.org/10.1016/j.landurbplan.2014.08.010

BUIS, A., 2019. Examining the Viability of Planting Trees to Help Mitigate Climate Change [online]. NASA's Jet Propulsion Laboratory. [Viewed 14 February 2021]. Available from: https://climate.nasa.gov/news/2927/examining-the-viability-of-planting-trees-to-help-mitigate-climate-change/

BURKHARD, B. & MAES, J., 2017, Mapping Ecosystem Services [online]. Advanced Books. Available from: https://doi.org/10.3897/ab.e12837

BURKHARD, B., & MAES, J., 2017. The cascade model, Credit: Haines-Young and Potschin [online]. Mapping Ecosystem Services. Available from: https://doi.org/10.3897/ab.e12837

BURTON, V., MOSELEY, D., BROWN, C., METZGER, M. & BELLAMY, P., 2018. *Reviewing the evidence base for the effects of woodland expansion on biodiversity and ecosystem services in the United Kingdom*. Forest Ecology and Management [online]. 430, pp. 366-379. Available from: https://doi.org/10.1016/j.foreco.2018.08.003

CAMERON, R., BLANUSA, T., TAYLOR, J., SALISBURY, A., HALSTEAD, A., HENRICOT, B. & THOMPSON, K., 2012. The domestic garden: its contribution to urban green infrastructure. Central Archive at the University of Reading, 11(2). pp. 129-137. Available from: https://doi.org/10.1016/j.ufug.2012.01.002

CIHLAR, J., ST.-LAURENT, L., DYER, J.A., 1991. Relation between the normalized difference vegetation index and ecological variables. Remote Sensing of Environment [online]. 35(2–3), pp.279-298. https://doi.org/10.1016/0034-4257(91)90018-2.

CLIMATE READY CLYDE (CRC), 2017. *OUR VISION for Glasgow and the Clyde Valley* [online]. Edinburgh, Sniffer. Available from: http://climatereadyclyde.org.uk/

CLIMATE READY CLYDE (CRC), 2021. *Glasgow City Region Climate Adaptation Strategy and Action Plan* [online]. Edinburgh, Sniffer. Available from: http://climatereadyclyde.org.uk/

CLIMATEXCHANGE, 2016. *Indicators and trends* [online]. ClimateXChange. Available from: https://www.climatexchange.org.uk/research/indicators-and-trends/

Collier, M. J. and Devitt, C. 2016. Novel ecosystems: Challenges and opportunities for the Anthropocene. The Anthropocene Review [online]. 3(3). 231–242. Available from: https://doi.org/10.1177/2053019616662053

CONSERVATION CORRIDOR, 2020. *Programs and Tools* [online]. Conservation Corridor. Available from: https://conservationcorridor.org/corridor-toolbox/programs-and-tools/

CORD, A., BRAUMAN, K.A., CHAPLIN-KRAMER, R., 2017. *Priorities to advance monitoring of ecosystem services using Earth observation* [online]. Trends in Ecology and Evolution, 32(6). pp. 416-428. Available from: https://doi.org/10.1016/j.tree.2017.03.003

COSTANZA, R., D'ARGE, R., DE GROOT, R., FABER, S., GRASSO, M., HANNON, B., LIMBURG, K., NAEEM, S., O'NEILL, R.V. PARUELO, J., RASKIN, R.G., SUTTON, P., VAN DEN BELT, M., 1977. *The value of the world's ecosystem services and natural capital*. Nature [online]. 387(15), pp.253-260. Available from: https://doi.org/10.1038/387253a0

DOHREN, P., & Haase, D., 2015. *Ecosystem disservices research: A review of the state of the art with a focus on cities.* Ecological Indicators [online]. 52, pp.490-497. Available from: https://doi.org/10.1016/j.ecolind.2014.12.027

DWAIR, A' A, 2020. *Vulnerability and Glasgow Greendex: Re-valuing canals Valuation of ecosystem services provided by the Smart Canal project.* MSc thesis, Master of Urban Climate & Sustainability, Glasgow Caledonian University, UK; LAB University of Applied Sciences, Finland; University of Huelva, Spain. Available from: https://www.theseus.fi/

Emmanuel, R., & Loconsole, A., 2015. *Green infrastructure as an adaptation approach to tackling urban overheating in the Glasgow Clyde Valley Region, UK* [Online]. Landscape and Urban Planning. 138, pp71-86. Available from: https://doi.org/10.1016/j.landurbplan.2015.02.012

ENNOS, A.R., RAHMA, M.A., 2016. *What we know and don't know about the cooling benefits of urban trees.* Trees & Design Action Group [online]. Available from: 10.13140/RG.2.1.5122.2645.

EUROPEAN COMMISSION, 2021. Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners [online]. Luxembourg: Publications Office of the European Union. Available from: https://op.europa.eu/en/publication-detail/-/publication/d7d496b5-ad4e-11eb-9767-01aa75ed71a1/language-en/format-PDF/source-206665393

EUROPEAN ENVIRONMENT AGENCY (EEA), 2015. *European ecosystem assessment - concept, data, and implementation* [online]. Luxembourg: Publications Office of the European Union. Available from: https://www.eea.europa.eu

EUROPEAN ENVIRONMENT AGENCY, 2012. Streamlining European biodiversity indicators 2020: Building a future on lessons learnt from the SEBI 2010 process. Luxembourg: Publications Office of the European Union.

EVERS, C. R., WARDROPPER, C. B., BRANOFF, B., GRANEK, E. F., HIRSCH, S. L., LINK, T. E., & WILSON, C., 2018. The ecosystem services and biodiversity of novel ecosystems: A literature review. Global Ecology and Conservation [online]. 13(e00362). Available from: https://doi.org/10.1016/j.gecco.2017.e00362

FENU, G., PAU, P., 2018. *Connectivity analysis of ecological landscape networks by cut node ranking* [online]. Appl Netw Sci. 3(22). Available from: https://doi.org/10.1007/s41109-018-0085-0

FORMAN, R.T.T., 1995. Land Mosaics: the Ecology of Landscapes and Regions. New York: Cambridge University Press.

GLASGOW AND CLYDE VALLEY STRUCTURE PLAN JOINT COMMITTEE, 2006. Green Network Vacant and Derelict Land Study for Glasgow and Clyde Valley Structure Plan. Edinburgh: RPS Group.

GLASGOW CITY COUNCIL (GCC), 2015. *Flood Risk Management Strategy Clyde and Loch Lomond Local Plan District* [online]. Glasgow City Council. Available from: https://www.glasgow.gov.uk/CHttpHandler.ashx?id=44472&p=0

GLASGOW CITY COUNCIL (GCC), 2017. Local Biodiversity Action Plan [online]. Glasgow City Council. Available from: https://www.glasgow.gov.uk/biodiversity

GLASGOW CITY COUNCIL (GCC), 2020. *Glasgow's Open Space Strategy* [online]. Glasgow City Council. Available from: https://www.glasgow.gov.uk/openspacestrategy

GREENSPACE SCOTLAND, 2010. Stalled spaces – delivering community and environmental benefits through temporary greenspace. Stirling: Greenspace Scotland.

HAINES-YOUNG, R. & POTSCHIN-YOUNG, M., 2010. The links between biodiversity, ecosystem service and human well-being. In: Raffaelli, D.G. & Frid, C.L. J., ed. *Ecosystem Ecology: A New Synthesis*. Cambridge University Press, pp. 110-139.

HAINES-YOUNG, R. & POTSCHIN-YOUNG, M., 2010. *The links between biodiversity, ecosystem service and human well-being*. In: Raffaelli, D.G. & Frid, C.L. J., ed. Ecosystem Ecology: A New Synthesis. Cambridge University Press, pp. 110-139.

HAINES-YOUNG, R. & POTSCHIN-YOUNG, M., 2018. Common International Classification of Ecosystem Services (CICES) V5.1: Guidance on the Application of the Revised Structure. Available from www.cices.eu

HATZIIORDANOU, L., FITOKA, E., HADJICHARALAMPOUS, E., VOTSI, N., PALASKAS, D., & MALAK, D., 2019. Indicators for mapping and assessment of ecosystem condition and of the ecosystem service habitat maintenance in support of the EU Biodiversity Strategy to 2020. One Ecosystem [online]. 4. Available from: https://doi.org/10.3897/oneeco.4.e32704

HEGER, T., BERNARD-VERDIER, M., GESSLER, A., GREENWOOD, A.D., GROSSART, H., HILKER, M., KEINATH, S., KOWARIK, I., KUEFFER, C., MARQUARD, E., MÜLLER, J., NIEMEIER, S., ONANDIA, G., PETERMANN, J.S., RILLIG, M.C., RÖDEL, M., SAUL, W., SCHITTKO, C., TOCKNER, K., JOSHI, J. & JESCHKE, J.M., 2019. Towards an Integrative, Eco Evolutionary Understanding of Ecological Novelty: Studying and Communicating Interlinked Effects of Global Change. BioScience [online]. 69(11), pp.888–899. Available from: https://doi.org/10.1093/biosci/biz095

HIGGS, E., FALK, D., GUERRINI, A., HALL, M., HARRIS, J., HOBBS, R., JACKSON, S., RHEMTULLA, J., & THROOP, W., 2014. *The Changing Role of History in Restoration Ecology*. Frontiers in Ecology and the Environment [online]. 12(9), pp.499-506. Available from: https://doi.org/10.1890/110267

HISLOP, M., ALISTER, J.S. & CORBETT, A., 2019. What Does Good Green Infrastructure Planning Policy Look Like? Developing and Testing a Policy Assessment Tool within Central Scotland UK, Planning Theory & Practice. 20(5), pp.633-655. Available from: https://doi.org/10.1080/14649357.2019.1678667

INDIANA UNIVERSITY SOUTHEAST, 2021. What is Urban Ecology?[online]. Indiana University Southeast. Available from: https://doi.org/10.1080/14649357.2019.1678667

IVERSEN, S., 2018. Impacts and perspectives of woodland creation in upland Cumbria, UK. PhD thesis, Landscape ecology, Aarhus University. Available from: 10.13140/RG.2.2.14390.45127

JEEVALAKSHMI, D., REDDY, S.N., & MANIKIAM, B., 2017. *Land Surface Temperature Retrieval from LANDSAT data using Emissivity Estimation*. International Journal of Applied Engineering Research. 12(20), pp. 9679-9687. Available from: http://www.ripublication.com

JEROME, G., SINNETT, D., BURGESS, S., CALVERT, T., MORTLOCK, R., 2019. A framework for assessing the quality of green infrastructure in the built environment in the UK. Urban Forestry & Urban Greening [online]. 40, pp.174–182. Available from: https://doi.org/10.1016/j.ufug.2019.04.001

JONES, D.G., VANE, C.H., LASS-EVANS, S., CHENERY, S., LISTER, B., CAVE, M., GAFEIRA, J., JENKINS, G., LESLIE, A., BREWARD, N., FREEBOROUGH, K., HARRISON, I., KIM, A.W., LACINSKA, A., MILODOWSKI, T., RIDGWAY, J., RIDING, J., STRUTT, M., WAGNER, D., & WILKINSON, I., 2017. *Geochemistry and related studies of Clyde Estuary sediments*. Earth and Environmental Science [online]. 108(2-3), pp.269-288. Available from: 10.1017/S1755691018000348

KARUNARATHNA, H., 2011. *Modelling the long-term morphological evolution of the Clyde Estuary, Scotland, UK*. Journal of Coastal Conservation [online]. 15, pp.499-507. Available from: 10.1007/s11852-010-0138-8.

KAZMIERCZAK, A., CONNELLY, A., LINDLEY, S., 2015. Mapping Flood Disadvantage in Scotland 2015, 1:200. The Scottish Government.

KOHSAKA, R., PEREIRA, H.M., ELMQVIST, T. CHAN, L., MORENO-PEÑARANDA, R., MORIMOTO, Y., INOUE, T., IWATA, M., NISHI, M., MATHIAS, M.L., SOUTO CRUZ, C., CABRAL, M., BRUNFELDT, M., PARKKINEN, A., NIEMELÄ, J., KULKARNI-KAWLI, Y. & PEARSALL, G., 2013. *Indicators for Management of Urban Biodiversity and Ecosystem Services: City Biodiversity Index.* In: Elmqvist, T., et al., ed. Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities. Heidelberg: Springer Netherlands, pp.699-718. Available from: https://doi.org/10.1007/978-94-007-7088-1_32

KOPF, R.K., FINLAYSON, C.M., HUMPHRIES, P., SIMS, N.C. & HLADYZ, S., 2015. *Anthropocene Baselines: Assessing Change and Managing Biodiversity in Human-Dominated Aquatic Ecosystems*. BioScience [online]. 65(8), pp. 798–811. Available from: https://doi.org/10.1093/biosci/biv092

LACKEY, R.T., 2003. *Appropriate Use of Ecosystem Health and Normative Science in Ecological Policy*. ed. Managing for Healthy Ecosystems. Florida, pp.175-186.

LIQUETE, C., KLEESCHULTE, S., DIGE, G., MAES, J., GRIZZETTI, B., OLAH, B. & ZULIAN, G., 2015. Mapping green infrastructure based on ecosystem services and ecological networks: A Pan-European case study. Environmental Science & Policy [online], 54, pp.268-280. Available from: https://doi.org/10.1016/j.ufug.2019.04.001

LONGSTAFF, B. J., CARRUTHERS, T. J. B., DENNISON, W. C., LOOKINGBILL, T. R., HAWKEY, J. M., THOMAS, J. E., WICKS, E. C. & WOERNER, J., 2010. Chapter 5: Ecological Indicators: Assessing ecosystem health using metrics. ed. *Ecological Indicators: Assessing ecosystem health using metrics*. IAN Press, pp. 61-77.

LUYSSAERT, S., SCHULZE, E.D. & BÖRNER, A., 2008. *An Old-growth forests as global carbon sinks.* Nature [online]. 455, pp213–215. Available from: https://doi.org/10.1038/nature07276

LUYSSAERT, S., SCHULZE, ED. & BÖRNER, A., KNOHL, A., HESSENMÖLLER, D., LAW, B.E., CIAIS P., & GRACE, J., 2008. Old-growth forests as global carbon sinks. Nature [online].455, pp.213–215. Available from: https://doi.org/10.1038/nature07276

LYYTIMÄKI J., & SIPILÄ, M., 2009. Hopping on one leg - The challenge of ecosystem disservices for urban green management. Urban Forestry & Urban Greening [online]. 8, pp.309-315. Available from: https://doi.org/10.1016/j.ufug.2009.09.003

LYYTIMÄKI, J., 2014, Ecosystem disservices: Embrace the catchword. Finnish Environment Institute [online]. Ecosystem services, pp. 12. 136. Available from: https://doi.org/10.1038/nature07276

MACFARLANE, J.S., 2011. *Development of strategies for the control and eradication of Japanese Knotweed.* MPhil thesis, Earth Resources, University of Exeter. Available from: http://hdl.handle.net/10871/11862

MAES, J., ANNE, T., MARKUS, E., CAMINO, L., LEON, B., BERRY, P., BENIS, E., PHILIPPE, P., CHRISTEL, F., FERNANDO, S.M., MARIA-LUISA, P., HANS, K., HEIDI, W., JENNIFER, H., INGEBORG, E., PETER, V., SOPHIE, C., JAN-PHILIPP, S., SAN-MIGUEL-AYANZ, J., GIOVANNI, B., 2013. *Mapping and assessment of ecosystems and their services: An analytical framework for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020* [online]. Luxembourg: Publications Office of the European Union.

MAES, J., TELLER, A., ERHARD, M., GRIZZETTI, B., BARREDO, J.I., PARACCHINI, M.L., CONDÉ, S., SOMMA F., ORGIAZZI, A., JONES, A., ZULIAN, A., VALLECILO, S., PETERSEN, J.E., MARQUARDT, D., KOVACEVIC, V., ABDUL, M.D., MARIN, A.I., CZÚCZ, B., MAURI, A., LOFFLER, P., BASTRUPBIRK, A., BIALA, K., CHRISTIANSEN, T. & WERNER, B., 2018. *Mapping and Assessment of Ecosystems and their Services: An analytical framework for ecosystem condition* [online]. Luxembourg: Publications Office of the European Union.

MAES, J., TELLER, A., ERHARD, M., GRIZZETTI, B., BARREDO, J.I., PARACCHINI, M.L., CONDÉ, S., SOMMA F., ORGIAZZI, A., JONES, A., ZULIAN, A., VALLECILO, S., PETERSEN, J.E., MARQUARDT, D., KOVACEVIC, V., ABDUL, M.D., MARIN, A.I., CZÚCZ, B., MAURI, A., LOFFLER, P., BASTRUPBIRK, A., BIALA, K., CHRISTIANSEN, T. & WERNER, B., 2016, *Mapping and Assessment of Ecosystems and their Services: Mapping and assessing the condition of Europe's ecosystems: Progress and challenges* [online]. Luxembourg: Publications Office of the European Union.

MAJEKODUNMI, M., EMMANUEL, R., & JAFRY, T., 2020. A spatial exploration of deprivation and green infrastructure ecosystem services within Glasgow city. Urban Forestry and Urban Greening [online], 52, Available from: https://doi.org/10.1016/j.ufug.2020.126698

MARWICK, J.D., 1898. *The River Clyde and the Harbour of Glasgow*. British History Online [online]. Glasgow: Corporation of Glasgow, 1898 Available from: https://archive.org/details/riverclydeharbou00marw/page/n5/mode/2up

METOFFICE, 2021. Pollen forecast [Online]. Met Office, [Viewed 10 June 2021]. Available from: https://www.metoffice.gov.uk/weather/warnings-and-advice/seasonal-advice/pollen-forecast#?date=2021-07-24.

MILLER, J.R. & BESTELMEYER, B., 2016. *What's wrong with novel ecosystems, really?*. Restoration Ecology [online]. 24(5), pp.577-582. Available from: https://doi.org/10.1111/rec.12378

MUNANG, R. & THIAW, I., ALVERSON, K., LIU, J. & HAN, Z, 2013. The role of ecosystem services in climate change adaptation and disaster risk reduction. Current Opinion in Environmental Sustainability. 5, pp.47-52. 10.1016/j.cosust.2013.02.002.

NATURAL ENGLAND, 2010. *'Nature Nearby'Accessible Natural Greenspace Guidance* [online]. Darlington Borough Council. Available from: www.ukmaburbanforum.co.uk.

NCUBE, S., SPRAY, C. & A. GEDDES, 2018. *Assessment of changes in ecosystem service delivery – a historical perspective on catchment landscapes.* International Journal of Biodiversity Science, Ecosystem Services & Management [online]. 14. pp.145-163. Available from: https://doi.org/10.1080/21513732.2018.1489306

NEUGARTEN, R.A., LANGHAMMER, P.F., OSIPOVA, E., BAGSTAD, K.J., BHAGABATI, N. BUTCHART, S.H.M., DUDLEY, N., ELLIOTT, V., GERBER, L.R., ARRELLANO, C.G., IVANIC, K., KETTUNEN, M., MANDLE, L., MERRIMAN, J.C., MULLIGAN, M., PEH, K.S.H., RAUDSEPP-HEARNE, C., SEMMENS, D.J., STOLTON, S. & WILLCOCK, S., 2018. Tools for measuring, modelling, and valuing ecosystem services: guidance for Key Biodiversity Areas, natural World Heritage Sites, and protected areas (Best Practice Protected Area Guidelines Series). Switzerland, Gland: IUCN.

O'NEIL, J., 2013. *Determining the quality of an urban green network.* PhD thesis, School of Engineering and Built Environment, Glasgow Caledonian University. Available from: http://ethos.bl.uk/

PERRING, M.P., STANDISH, R.J., PRICE, J.N., CRAIG, M.D., ERICKSON, T.E., RUTHROF, K.X., WHITELEY, A.S., VALENTINE, L.E. & HOBBS, R.J. 2015, *Advances in restoration ecology: rising to the challenges of the coming decades* [online]. Ecosphere. 6(8), pp. 1-25. Available from: https://doi.org/10.1890/ES15-00121.1

PINTO, V.D., MARTINS, C., RODRIGUES, J., ROSA, M.P., 2020. *Improving access to greenspaces in the Mediterranean city of Faro*. AIMS Environmental Science [online]. 7(3), pp.226-246. Available from: 10.3934/environsci.2020014

PONTO J., 2015. *Understanding and Evaluating Survey Research*. Journal of the advanced practitioner in oncology [online], 6(2), p.168–171. Available from: 10.3934/environsci.2020014

POTGIETER, L.J., GAERTNER, M., & O'FARRELL, P.J., 2019. *A fine-scale assessment of the ecosystem service-disservice dichotomy in the context of urban ecosystems affected by alien plant invasions*. Forest Ecosystems [online]. 6(46). Available from: https://doi.org/10.1186/s40663-019-0200-4

PRICE, C., 2014. *Regulating and supporting services and disservices*. New Zealand Journal of Forestry Science [online]. 1(44), pp. 16-21. Available from: https://doi.org/10.1186/1179-5395-44-S1-S5

REID, W., MOONEY, H., CROPPER, A., CAPISTRANO, D., CARPENTER, S. & CHOPRA, K., 2005. Millennium Ecosystem Assessment. Ecosystems and human well-being: synthesis. Washington, DC: Island Press.

RICHARD, J.H., ERIC, H., JAMES, A.H., 2009. *Novel Ecosystems: Implications for Conservation and Restoration* [online]. 24(11), pp.599-605. Available from: https://doi.org/10.1016/j.tree.2009.05.012

RUMBLE, H., KENTON, R., KIERON, D. & TONY, H., 2014. *A Comparison of Urban Tree Populations in Four UK Towns and Cities* [online]. Trees, People and the Built Environment II. Birmingham, UK, April 2014. Available from: https://www.researchgate.net/publication/283079226_A_Comparison_of_Urban_Tree_Populations_in_Four_UK_Towns_and_Cities

RUSKULE, A.G., VINOGRADOVS, I., PECINA, M.V., 2018. *The guidebook on the introduction to the ecosystem service framework and its application in integrated planning*. Riga: University of Latvia, Faculty of Geography and Earth Sciences.

SAUNDERS, M., LEWIS, P., & THORNHILL, A., 2016. Research Methods for Business Students [online]. England: Pearson Education Limited

SAUNDERS, M.E. & LUCK, G. W., 2016. *Limitations of the Ecosystem Services versus Disservices Dichotomy*. Conservation Biology [online]. 30(6). Available from: https://doi.org/10.1111/cobi.12740

SCHWARTZ, M., 2021. Professor Martha Schwartz Discusses Sustainable Cities [presentation online]. Harvard Speakers Bureau, the Harvard Clubs of Southern California, 10 January.

SCOTLAND: THE BIG PICTURE, 2021. *Rewilding and people: can we have both?* [Presentation online]. Scotland: The Big Picture, 10 June.

SCOTTISH NATURAL HERITAGE, 2012. *Central Scotland Green Network - Integrated Habitat Networks Scottish Natural Heritage* [ESRI ArcGIS MXD map]. CSGNIHN_SCOTLAND [geospatial data], Updated December 2012. Scottish Natural Heritage Available from: https://gateway.snh.gov.uk/natural-spaces/dataset.jsp?dsid=CSGNIHN

SEEVERS, P.M & OTTMANN, R.W., 1994. *Evapotranspiration Estimation Using a Normalized Difference Vegetation Index Transformation of Satellite Data*. Hydrological Sciences Journal [online]. 39(4), pp.333-345. Available from: https://doi.org/10.1080/02626669409492754

SEPA, 2019. *Explore ecosystem health indicators* [online]. Nature Scot. [Viewed 14 February 2021]. Available from: https://www.environment.gov.scot/our-environment/state-of-the-environment/ecosystem-health-indicators/explore-ecosystem-health-indicators/

SEPA, 2019. *Flood Risk Management (Scotland) Act 2009: INTERIM REPORT Local Flood Risk Management Plan* [online]. SEPA. Available from: https://www2.sepa.org.uk/frmstrategies/pdf/lpd/LPD_11_Sources.pdf

SIMARD, S.W., BEILER, K.J., BINGHAM, M.A., DESLIPPE, J.R., PHILIP, L.J. & TESTE, F.P., 2012. *Mycorrhizal networks: Mechanisms, ecology and modelling.* Fungal Biology Reviews [online]. 26(1), pp.39-60. Available from: https://doi.org/10.1016/j.fbr.2012.01.001.

SIMBERLOFF, D., MURCIA, C., ARONSON, J., 2015. Opinion: “Novel Ecosystems” Are a Trojan horse for Conservation [online]. University of Minnesota’s Institute: ENSIA. Available from: https://ensia.com/voices/novel-ecosystems-are-a-trojan-horse-for-conservation/

SMITHERS, R.J., KENT, N., MILLER, K., MINNEN, J.V. & HARLEY, M., 2012. *Climate Change Adaptation Indicators for Biodiversity* [online]. Copenhagen: European Environment Agency. Available from: https://www.researchgate.net/publication/

STINSON, K.A., CAMPBELL, S.A., POWELL, J.R., WOLFE, B.E., CALLAWAY, R.M., Thelen, G.C., Hallett, S.G., Prati, D., Klironomos, J.N., 2014. *Invasive Plant Suppresses the Growth of Native Tree Seedlings by Disrupting Belowground Mutualisms*. Plos Biology [online]. 4(5). Available from: https://doi.org/10.1371/journal.pbio.1001817

THE CITY OF EDINBURGH COUNCIL, 2020. *Edinburgh Design Guidance - building our future.* Edinburgh: The City Of Edinburgh Council. Available from: https://www.edinburgh.gov.uk/downloads/download/13725/edinburgh-design-guidance

THE COPERNICUS GLOBAL LAND SERVICE (CGLS), 2015. RZ Product Specifications. European Environment Agency. Available from: https://land.copernicus.eu/global/products/

THE SCOTTISH GOVERNMENT, 2008. *Planning Advice Note: PAN 65 Planning and Open Space* [online]. The Scottish Government. Available from: https://www.gov.scot/publications/

THE SCOTTISH GOVERNMENT, 2019. *Scottish Vacant and Derelict Land Survey 2018* [online]. The Scottish Government. Available from: https://www.gov.scot/publications/

THE SCOTTISH GOVERNMENT, 2020. *Scottish Index of Multiple Deprivation 2020* [online]. The Scottish Government. Available from: https://www.gov.scot/publications/

UNEP, 2021. *A beginner's guide to ecosystem restoration* [online]. UNEP. Available from: https://www.unep.org/news-and-stories/story/beginners-guide-ecosystem-restoration

UNEP-WCMC, 2011. Developing ecosystem service indicators: Experiences and lessons learned from sub-global assessments and other initiatives [online]. Montréal: Secretariat of the Convention on Biological Dive. Available from: http://www.cbd.int

VALLECILLO, S., NOTTE, A.L., FERRINI, S & MAES, J., 2019. How ecosystem services are changing: an accounting application at the EU level. Ecosystem Services [online]. 40, pp.1-18. Available from: https://doi.org/10.1016/j.ecoser.2019.101044.

VIHERVAARA, P., VIINIKKA, A., BRANDER, L., SANTOS-MARTÍN, F., POIKOLAINEN, L., NEDKOV, S., 2019. *Methodological interlinkages for mapping ecosystem services - from data to analysis and decision-support.* One Ecosystem. 4(e26368). Available from: https://doi.org/10.3897/oneeco.4.e26368

WATKISS, P., & HUNT, A., 2019. *Economic Implications of Climate Change for Glasgow City Region – Part 2 – Adaptation Report*. Report from Paul Watkiss Associates to Climate Ready Clyde [online]. Available from: http://climatereadyclyde.org.uk/

WRBKA, T., HERMANN, A., SABINE, S., 2011. The Concept of Ecosystem Services Regarding Landscape Research: A Review. Living Reviews in Landscape Research [online]. 5(1), pp.5-14. Available from: http://lrlr.landscapeonline.de/lrlr-2011-1

WU, J., 2014. *Urban ecology and sustainability: The state-of-the-science and future directions* [online]. Landscape and Urban Planning. Landscape and Urban Planning. 125, pp. 209-221. Available from: https://doi.org/10.1016/j.landurbplan.2014.01.018.

WWF SCOTLAND, 2002. *Turning the tide on flooding* [online]. Turning the tide on flooding. Perthshire: WWF Scotland. Available from: http://assets.wwf.org.uk/downloads/turningtide.pdf

ZALA, M., 202O. *Vulnerability and Glasgow Greendex: A framework to optimise the impact of green infrastructure in improving social.* MSc thesis, Master of Urban Climate & Sustainability, Glasgow Caledonian University, UK; LAB University of Applied Sciences, Finland; University of Huelva, Spain. Available from: https://www.theseus.fi/

REFERENCE OF IMAGES

BURKHARD, B., & MAES, J., 2017. The cascade model, Credit: Haines-Young and Potschin [medium]. *Mapping Ecosystem Services*. Advanced Books. p.39.

CLARK, J. M., GALLEGO-SALA, A. V., ALLOTT, T. E. H., CHAPMAN , S. J., FAREWELL, T., FREEMAN, C., HOUSE, J. I., ORR, H. G., PRENTICE, I. C., & SMITH, 2010. Projected changes in bioclimatic space associated with the 1961–1990 baseline climate and mapped area of blanket peat using UKCIP02 high emissions scenarios. 2020s: 2011–2040; 2050s: 2041–2070; 2080s: 2071–2100 [medium]. *Assessing the vulnerability of blanket peat to climate change using an ensemble of statistical bioclimatic envelope models*. Climate Research. p.144.

CLIMATE READY CLYDE (CRC), 2017. UKCP09 Climate Projections for the Clyde River Basin [medium]. *Our Vision for Glasgow and the Clyde Valley*. Edinburgh, Sniffer. p.6-7.

CLIMATEXCHANGE, 2016. [Online photograph]. *Scotland's Native Woodlands - results from the native woodland survey of Scotland*. Available from: https://www.climatexchange.org.uk/research/indicators-and-trends/

EVERS, C. R., WARDROPPER, C. B., BRANOFF, B., GRANEK, E. F., HIRSCH, S. L., LINK, T. E., & WILSON, C., 2018. Novel ecosystems contain species assemblages that historically did not exist within a given biome, and as a result, can alter both ecosystem function and resulting services [medium]. *The ecosystem services and biodiversity of novel ecosystems: A literature review*. p.2.

HEGER, T., BERNARD-VERDIER, M., GESSLER, A., GREENWOOD, A.D., GROSSART, H., HILKER, M., KEINATH, S., KOWARIK, I., KUEFFER, C., MARQUARD, E., MÜLLER, J., NIEMEIER, S., ONANDIA, G., PETERMANN, J.S., RILLIG, M.C., RÖDEL, M., SAUL, W., SCHITTKO, C., TOCKNER, K., JOSHI, J. & JESCHKE, J.M., 2019. Degree of deliberate design and ecological novelty as two dimensions describing sites and species' environments in the Anthropocene [medium]. *Towards an Integrative, Eco Evolutionary Understanding of Ecological Novelty: Studying and Communicating Interlinked Effects of Global Change*. BioScience. p.894

HMGOVERNMENT, 2011. The components of ecological networks [medium]. *The Natural Choice: securing the value of nature*. United Kingdom, pp.18

HOBBS, R.J., HIGGS, E., HARRIS, J.A., 2009. Types of ecosystem that develop under varying levels of biotic and abiotic alteration [medium]. *Novel ecosystems: implications for conservation and restoration*. Trends Ecology Evolution. p.601

JONES, D.G., VANE, C.H., LASS-EVANS, S., CHENERY, S., LISTER, B., CAVE, M., GAFEIRA, J., JENKINS, G., LESLIE, A., BREWARD, N., FREEBOROUGH, K., HARRISON, I., KIM, A.W., LACINSKA, A., MILODOWSKI, T., RIDGWAY, J., RIDING, J., STRUTT, M., WAGNER, D., AND WILKINSON, 2017. Track plots of boomer surveys and multibeam coverage in the Clyde Estuary [medium]. *Geochemistry and related studies of Clyde Estuary sediments* pp.269–288.

MARWICK, J.D., 1895. Map of the River Clyde and Adjoining District [medium]. *The River Clyde and the Harbour of Glasgow*. Glasgow: Corporation of Glasgow, 1898. p.1

WWF SCOTLAND, 2002. Development of the lower Clyde for navigation [medium]. *Turning the tide on flooding.* Perthshire: WWF Scotland. p.8.

WWF SCOTLAND, 2002. Effect of dredging on the bed of the Clyde [medium]. *Turning the tide on flooding*. Perthshire: WWF Scotland. p.8.

APPRENDICES

Appendix 1.

Justification analysis for ClimateXChange's indicators under "Natural Environment" narrative. Indicators (CXC, 2017) are selected based on relevancy to Glasgow context. Presented in the tables are indicators name, purpose of measurement, descriptive justification, selection result, and final indicator derivation (Rattanakijanant, 2021)

CXC'S Indicators	Purpose	Justification of relevency	Selected	Adapted	Unselected	Indicator derivation for this dissertation
Extent and condition of natural landscape connections: hedgerows and ponds Risk	Tracking suitable space for species dispersal in a changing climate	Hedgerows and ponds belong to the suburbs context. In the city, open space and green corridors are more suitable dispersal mediums.		/		Habitat connectivity
Proportion of ancient woodlands with declining overall suitability for lichen epiphytes	Lichen epiphytes indicate health of local ecosystem, only found in ancient woodlands and only disperse along them to find suitable bioclimatic condition.	In urban area existing of dependent on old-growth stands in modern landscapes host disperse species		/		Protected area
Abundance and productivity of breeding sea birds	Tracking suitable space for species dispersal in a changing climate	Marine and coastal habitat although connected but are beyond Glasgow boundary			/	-
Abundance of wintering water birds Impact	Tracking suitable space for species dispersal in a changing climate	Natural water bodies exists		/		Pollinators and key species
Area of land under landscape scale conservation	Tracking LSC projects; i.e. projects for ecosystem restoration and land management to maintain ES	LSC projects does not include Glasgow area which has instead, SSLs, SINCs, etc		/		Protected area
Extent of key semi-natural habitats: terrestrial	Support a healthy and diverse natural environment with capacity to adapt	Glasgow contains extent of woodlands, grasslands, and wetlands	/			Extent of key habitats
Extent of key semi-natural habitats: coastal habitats	Tracking suitable space for species dispersal in a changing climate	Coastal habitat although connected but are beyond Glasgow boundary			/	-
Extent of key habitats: deep peat	Deep peat survey	Deep peat was replaced by urban area			/	-
Condition of key habitats: Proportion of notified habitats in unfavourable condition	Resiliencey of the natural environment (terrestrial)	Unfavourable conditions been assigned to pressure indicator			/	-

CXC'S Indicators (Continue)	**Purpose**	**Justification of relevency**	**Selected**	**Adapted**	**Unselected**	**Indicator derivation for this dissertation**
Condition of key habitats: Area of modified deep peat soils	Condition of deep peat degradation	Climate projections indicate significant areas where active peat formation may no longer occur. Urban area overwrite majority of peatland. Soil health and permeability represents urban characteristic		/		Soil sealing
Natural Capital Asset Index	Resilience of the natural environment (terrestrial)	Represents by EH mapping			/	-
Abundance and frequency of specialist and generalist species: snow-bed species	Tracking suitable space for species dispersal in a changing climate	Data unavailable			/	-
Abundance and frequency of specialist and generalist species: butterflies	Tracking suitable space for species dispersal in a changing climate	In the city smaller numbers were surveyed therefore the data is less reliable than in recent years			/	-
Annual greenhouse gas (GHG) emissions from degraded peatlands Impact	Estimated emissions released from damaged peat	Data for soil carbon stored, organic matters nor nitrates level are unavailable in city area (SNH, 2012).		/		Carbon budget
Proportion of notified habitats and species in 'positive' condition	Examine the success of the management	Good management are described in action plan, but spatial data are unavailable. Vegetation health represent result from management.		/		Vegetation health
Peatland restoration area	Extent of restored peatland	Only small portion left within city parameter. Seven loch wetland is an important site of the city		/		Protected area
Amount of natural regeneration in native woodlands	Resilience of the natural environment from native woods in regeneration stages (>1m height)	Natural regeneration influence from habitat core. Vacant lot in the city has potential. And no data available for trees height measurement method		/		Natural regeneration
Proportion of water bodies not meeting Good Overall Status	Water quality; surface, groundwater, and bathing water	Poor water quality intensify water plant decay and habitat lost	/			Surface water quality
Summer low flow events in Scottish rivers (Normalised Flow Index)	Track the condition of water scarcity	Out of thesis scope			/	-

CXC'S Indicators (Continue)	**Purpose**	**Justification of relevency**	**Selected**	**Adapted**	**Unselected**	**Indicator derivation for this dissertation**
Condition and distribution of climate sensitive species: Abundance of Arctic charr in freshwater lochs	Track the distribution of Arctic Charr	Out of Glasgow context			/	-
Freshwater monitoring stations: temperature	Tracking water temperature	Out of thesis scope			/	-
Progress towards the environmental objectives of the River Basin Management Plans	Tracking progress of conditions toward River Basin Management Plans (RBMP) baseline	Floodplain is important in Clyde basin adaptivity. SUDs and riparian are key flood regulation element		/		Floodplain area
Proportion and area of Caledonian pine woodland exposed to Dothistroma needle blight	Tracking area affect by plant disease which disperse due to warming climate	Local data unavailable			/	-
Proportion of native woodland affected by invasive non-native plant species	Non-native species can inhibit growth and suppress natural regeneration of native species, which provide ES. E.g. impedes water flow, restrict access, crowding, endanger bryophyte and lichen, divert pollinating	Measured by "Pressure" indicator		/		Invasive species dominance
Freshwater habitats with reported presence of key invasive non-native species	Number of notified freshwater habitats with invasive non-native species	Out of thesis scope			/	-
Number and area of reported wildfires in forests and key habitats Impact	Number and area of reported wildfires. Warmer drier springs and summers, will lead to an increased wildfire risk.	Local data unavailable			/	-

Appendix 2.

Summary of the overall data applied to map indicators. Included in the table are technical aspects, i.e. source of indicator, date available, format available, values examined, and calculation approach (Rattanakijanant, 2021).   .

Pressure Indicator	**Date**	**Format available**	**Data**	**Source Provider**	**Values examined**	**Calculation approach**
Landscape degradation	2018	Vector	Urban atlas landcover map	Copernicus global land service (CGLS)	Area of human dominance	ArcMap reclassification of data
Deprived area	2020	Vector	Scottish Index of Multiple Deprivation (SIMD2020)	GCC	Deprived area to climate change risk	ArcMap weigthed overlay
		Vector	PAN65	GCC	Accessibility to open space	
Flood risk	2021	Vector	Flood risk interactive map	SEPA	Coastal, surface and river flooding risk	ArcMap weigthed overlay
Urban temperature	2021	Raster	Landsat-8, dated 28/06/2021 at 11.00am, 20% cloud coverage	USGS	Land surface temperature (LST)	ArcMap computation
Invasive species dominance	2011 to 2021	Raster	Species records	NBN Atlas	Sigthing records of invasive species prioritize for strategic control, i.e., *Fallopia japonica, Mantegazzianum, Lysichiton americanus, Persicaria wallichii, Rhododendron L., Sciurus carolinensis, Neovison vison, Muntiacus reevesi*	ArcMap density analysis and zonal statistic
	2020	Vector	PAN65	GCCC	Intensity of ground maintenance	
Adaptability indicators	**Date**	**Format available**	**Source Provider**	**Source Provider**	**Values examined**	**Calculation approach**
Natural regeneration	2012	Vector	CSGN Integrated Habitat Networks	SNH	Distance of seed dispersal from key habitats	ArcMap offset tool
Protected area	2000	Vector	- Native woodland survey of Scotland (NWSS) - PAN65	SNH	Protected nature sites	ArcMap reclassification of data
Habitat connectivity	2020	Vector	PAN65	GCC	Tracking suitable space for species dispersal in a changing climate	Graphab 2.6 modularity analysis
	2012	Vector	CSGN Integrated Habitat Networks	SNH		
Extent of key semi-natural habitats	2019	Vector	PAN65	GCC	Tracking suitable space for species dispersal in a changing climate	ArcMap selected attribute and reclassification
Vegetation health	2021	Raster	Landsat-8, dated 28/06/2021 at 11.00am, 20% cloud coverage	USGS	Vegetation health	NDVI calculation via ArcMap

Adaptability indicators	Date	Format available	Source Provider	Source Provider	Values examined	Calculation approach
Pollinators and key species	2018 to 2021	Raster	Species records	NBN Atlas	Sighting records of; *Arvicola amphibius*, *Rana temporaria*, *Bufo bufo*, Bat Species, *Erinaceus europaeus*, *Apus apus*, wintering bird Pollinators included; bumblebee, dragonflies species, falcons, hawks, eagles and ospreys species, *Alauda arvensis*	ArcMap density analysis and zonal statistic
Water quality	2018	Raster	Water environment hub	SEPA	Surface water quality	ArcMap reclassification of data
Floodplain area	2015	Vector	Delineation of riparian zones	Copernicus global land service (CGLS)	Floodplain and riparian zone	AcpMap compile data and reclassified them
	2019	Vector	Potential of Policy CDP8: Water Environment	GCC	Area cover under good policy and potential SUDs	
	2018	Raster	Landsat-8	USGS	Lowlying area	
Soil sealing	2018	Vector	Urban atlas landcover map	Copernicus global land service (CGLS)	Non paved area, water infiltration allowance ares	ArcMap reclassification of data
	2021	Raster	Landsat-8	USGS	NDVI calculation	

Appendix 3.

Figure of survey in accordance to MCDA analysis. The survey was sent out to gain practitioners' opinion whose work related to GN across Glasgow City via Google Form.

Survey on Multiple Variables for Measuring Ecosystem Health (GIS-based method)

Being a thesis student at GCU's MUrCS program, I am carrying out a dissertation titled "Assessing Condition and Services of Novel Ecosystem for Climate Change Adaptation".

In brief, this thesis aims to assess the impact of landscape interventions on ecosystem health. My approach will be measuring Glasgow's Green Network of their capability to adapt and supply Ecosystem Services under climate change pressure, through a set of indicators. Later on, these indicators are to be analyzed based on GIS multiple-variables weighting analysis.

The purpose of this survey is to include your professional opinions in prioritizing the following indicators. I need your kind cooperation to fill out 13 questions, 4 questions are optional and could take some time to finish.

All information will be kept strictly confidential and you will remain completely anonymous throughout. The information you give will only be used for this dissertation. I'm grateful for your corporation and time spending here.

Q1. Name of your Organization

Your answer

ECOLOGICAL ADAPTIVITY

Ability of ecosystem to cope under climate change pressure.

Q2. Based on your experience from the organization you represent. Please Allocate an importance score of 100% for indicators listed below. If you feel that all indicators value equally, slide the screen to the left to choose "All equal"

	0	10%	20%	30%	40%	50%	60%	70%	80%
Amount of natural regeneration	○	○	○	○	○	○	○	○	○
Biosecurity by conservation	○	○	○	○	○	○	○	○	○
Habitat Connectivity	○	○	○	○	○	○	○	○	○
Extent of key semi-natural habitats	○	○	○	○	○	○	○	○	○
Vegetation health	○	○	○	○	○	○	○	○	○
Abundance of key species	○	○	○	○	○	○	○	○	○

Q3. From Q2, briefly describe your reason

Your answer

ECOSYSTEM SERVICES

Look at indicators which contribute to 3 different benefit from Green Network in Glasgow city

Q4. Based on your experience from the organization you represent. Please choose from the list below indicators that you think are important for "Biosecurity" in Glasgow city.

- ☐ Amount of natural regeneration
- ☐ Biosecurity by conservation
- ☐ Habitat Connectivity
- ☐ Extent of key habitats
- ☐ Vegetation health
- ☐ Abundance of key species
- ☐ Surface water quality
- ☐ Area of functioning floodplain
- ☐ Soil sealing

Q5. Based on your experience from the organization you represent, Allocate an importance score of 100% for indicators you selected from Q4. If you feel that all indicators value equally, slide the screen to the left to choose "All equal".

	10%	20%	30%	40%	50%	60%	70%	80%	90%
Amount of natural regeneration	○	○	○	○	○	○	○	○	○
Biosecurity by conservation	○	○	○	○	○	○	○	○	○
Habitat Connectivity	○	○	○	○	○	○	○	○	○
Extent of key semi-natural habitats	○	○	○	○	○	○	○	○	○
Vegetation health	○	○	○	○	○	○	○	○	○
Abundance of key species	○	○	○	○	○	○	○	○	○
Surface water quality	○	○	○	○	○	○	○	○	○
Area of functioning floodplain	○	○	○	○	○	○	○	○	○
Soil sealing	○	○	○	○	○	○	○	○	○

Q6. From Q5, briefly describe your reason

Your answer

Q7. Based on your experience from the organization you represent. Please choose from the list below indicators that you think are important for " Flood regulation" in Glasgow city.

- ☐ Amount of natural regeneration
- ☐ Biosecurity by conservation
- ☐ Habitat Connectivity
- ☐ Extent of key semi-natural habitats
- ☐ Vegetation health
- ☐ Abundance of key species
- ☐ Surface water quality
- ☐ Area of functioning floodplain
- ☐ Soil sealing

Q8. Based on your experience from the organization you represent, please Allocate an importance score of 100% for indicators you selected from Q7. If you feel that all indicators value equally, slide the screen to the left to choose "All equal".

	10%	20%	30%	40%	50%	60%	70%	80%	90%
Amount of natural regeneration	○	○	○	○	○	○	○	○	○
Biosecurity by conservation	○	○	○	○	○	○	○	○	○
Habitat Connectivity	○	○	○	○	○	○	○	○	○
Extent of key semi-natural habitats	○	○	○	○	○	○	○	○	○
Vegetation health	○	○	○	○	○	○	○	○	○
Abundance of key species	○	○	○	○	○	○	○	○	○
Soil sealing	○	○	○	○	○	○	○	○	○

Q9. From Q8, briefly describe your reason

Your answer

Q10. Based on your experience from the organization you represent. Please choose from the list below indicators that you think are important for " Carbon Sequestration" in Glasgow city

- ○ Amount of natural regeneration
- ○ Biosecurity by conservation
- ○ Habitat Connectivity
- ○ Extent of key semi-natural habitats
- ○ Vegetation health
- ○ Abundance of key species
- ○ Surface water quality
- ○ Area of functioning floodplain
- ○ Soil sealing

Q11. Based on your experience from the organization you represent, Allocate an importance score of 100% for indicators you selected from Q10. If you feel that all indicators value equally, slide the screen to the left to choose "All equal".

	10%	20%	30%	40%	50%	60%	70%	80%	90%
Amount of natural regeneration	○	○	○	○	○	○	○	○	○
Biosecurity by conservation	○	○	○	○	○	○	○	○	○
Habitat Connectivity	○	○	○	○	○	○	○	○	○
Extent of key semi-natural habitats	○	○	○	○	○	○	○	○	○
Vegetation health	○	○	○	○	○	○	○	○	○
Abundance of key species	○	○	○	○	○	○	○	○	○
Surface water quality	○	○	○	○	○	○	○	○	○
Area of functioning floodplain	○	○	○	○	○	○	○	○	○
Soil sealing	○	○	○	○	○	○	○	○	○

Q12. From Q11, briefly describe your reason

Your answer

ANTHROPOGENIC PRESSURE

Q13. Based on your experience from the organization you represent. Choose from the list below indicators that you think are important to "Anthropogenic pressure"

	0%	10%	20%	30%	40%	50%	60%	70%	80%
Landscape degradation	○	○	○	○	○	○	○	○	○
Flood risk	○	○	○	○	○	○	○	○	○
Urban temperature	○	○	○	○	○	○	○	○	○
Invasive species	○	○	○	○	○	○	○	○	○
Deprived areas	○	○	○	○	○	○	○	○	○

Appendix 4.

Table decribes policy content of Glasgow City Region's first Adaptation Strategy and Action Plan 2020–2030: Intervention 9. To derived ES implcates in the policy.

Policy content ***Glasgow City Region's first Adaptation Strategy and Action Plan 2020–2030*** **Intervention 9;** Deliver nature-based solution for resilient, blue-green landscapes and neighbourhoods	**Climate ES implied**		
	Biosecurity	Flood regulation	Carbon sequestration
Identify regional priorities for nature-based solutions The region's local authorities, working in partnership with the Glasgow and Clyde Valley Green Network Partnership and others should identify priority areas for blue and green infrastructure, focusing on the communities, sectors and systems most vulnerable to high temperatures or flooding and developing the region's habitat network for climate resilience.		x	
Delivery of the regional Strategic Green Network with an emphasis on maximizing the contribution of the network to adaptation.	x	x	x
Increase investment in targeted habitat restoration for natural flood management, including in peatland, wetlands and transitional habitats. Through the Forestry and Woodland Strategy, Clydeplan should continue to promote restoration of ancient and native woodland. At the same time, all partners should consider the opportunities and risks around transitional habitats such as salt marsh, and the potential need for managed retreat.	x	x	
Creation of the Clyde Climate Forest with Glasgow and Clyde Valley Green Network Partnership working with others to create the forest, creating a mechanism for carbon offsetting which will expand canopy cover in heat risk areas, connect habitats and store carbon emissions, with a focus on the most socially vulnerable neighbourhoods			x
Support for local infill and expansion of nature-based solutions with a common local delivery approach to Open Space Strategies, Local Development Plans and individual developments. These should define where blue and green infrastructure can provide climate resilience for surface water management and high temperatures. The process should engage new actors such as landlords, tenants, community groups and businesses to understand opportunities and barriers to widespread roll-out.		x	
Roll out of large-scale blue and green infrastructure projects to demonstrate benefits to communities – either through new green infrastructure or removal of hard landscaping or public realm with the Glasgow and Clyde Valley Green Network Partnership and MGSDP amongst others, continuing to develop and deliver large-scale demonstrators of green infrastructure across the region.	x	x	x
Develop and accelerate Green and Blue Infrastructure financing To accelerate the above, we will work to develop new financing methods for green infrastructure (such as landscape enterprise networks), which seek to unlock private sector investment and mobilize communities to deliver			