Student thesis series INES nr 616

Evaluating modelled natural capital values for planning processes

A case study in Stockholm, Sweden

Vania Diaz Gardell

2023
Department of
Physical Geography and Ecosystem Science
Lund University
Sölvegatan 12
S-223 62 Lund
Sweden

Vania Diaz Gardell (2023).
Evaluating modelled natural capital values for planning processes – a case study in Stockholm, Sweden
Utvärdering av modellerade naturkapitalvärden för planprocesser – en fallstudie i Stockholm, Sverige
Master degree thesis, 30 credits in *Physical Geography and Ecosystem Science*
Department of Physical Geography and Ecosystem Science, Lund University

Level: Master of Science (MSc)

Course duration: *January* 2023 until *June* 2023

Evaluating modelled natural capital values for planning processes

A case study in Stockholm, Sweden

Vania Diaz Gardell

Master thesis, 30 credits, in Physical Geography and Ecosystem Science

Anna Maria Jönsson
Lund University

Emmelie Nilsson
WSP

Exam committee:
Examiner 1, Lina Eklund
Examiner 2, Renkui Guo

Acknowledgments

This thesis would not have been where it is without those who helped me along the way.

I would like to give a big thank you to my supervisor Anna Maria Jönsson at the Department of Physical Geography and Ecosystem Science at Lund University. I came to you with an idea based on a modelling problem I encountered during my internship, and you have patiently helped me formulate it into a scientific study.

I would also like to give a big thank you to my external supervisor at WSP, Emmelie Nilsson. You have with great patience guided me through the whole process, from forming an idea until that the entire study has been completed, and beyond.

I would also like to thank Marianne Klint and Martin Rask for giving me the opportunity to test my hypotheses based on real data. Thank you for also giving me feedback during the analysis.

Finally, I would also like to thank the other contacts who helped me along the way!

Abstract

A commonly proposed principle for reducing impact on natural capital within the planning process is the mitigation hierarchy. The mitigation hierarchy means that impacts should primarily be avoided, otherwise minimized, and when this is not possible - restored or compensated according to an equivalency- and proximity principle. The outcome can be calculated in a model such as the Green Space Factor to achieve a certain goal, such as net gain.

However, it is unclear how the levels and principles work in practice. There is also an indication about transparency issues in relation to the mitigation hierarchy within Green Space Factor. At the same time, the potential of a new model called NATURE Tool has been highlighted in Sweden, which creates a need for scientific studies.

The aim of this study was therefore to evaluate modelled natural capital values based on the mitigation hierarchy in Green Space Factor and NATURE Tool. By comparing natural capital value changes of scenarios which contained poor and proper mitigation approaches, it was possible to evaluate how the models output reflected consideration to the mitigation hierarchy as well as the natural capital value changes derived from each level. A case study located in Stockholm, Sweden, was used to test the models through subjective sensitivity analysis. The mixed natural environment within the area consists of pine and deciduous forest, rock outcrop, grassland and individual trees.

The results showed that NATURE Tool did not allow poor mitigations to the same degree as Green Space Factor and that NATURE Tool presented the results more transparently. At the same time, poor mitigations in Green Space Factor would not have been possible if the recommendations in the manual were followed. Furthermore, it is debatable whether the definition of poor mitigations in the models gives actual poor mitigations in reality.

The study also showed that Green Space Factor needed less area and fewer compensatory measures given the net gain goal compared to NATURE Tool, indicating that either Green Space Factor was underestimating, or NATURE Tool was overestimating the natural capital values.

The study finally showed that the total natural capital value change due to the mitigation hierarchy levels was highest for compensation compared to the earlier levels in mitigation hierarchy (avoidance, minimization and restoration). However, the previous levels were more space efficient compared to compensation. This shows that although the previous levels are more effective, compensation can play an important role in reaching net gain.

The study's main finding is that the models could generate relatively high natural capital values also for poor mitigation approaches. Further model development should consider ensuring that such substitution does not generate similar results as proper mitigation approaches. This could be done by calibrating the models to a database of observations. Developing the communication strategies of the models may also encourage proper mitigation strategies.

Sammanfattning

Skadelindringshierarkin är en vanligt föreslagen princip för att minska påverkan på naturkapital inom planprocesser. Skadelindringshierarkin innebär att påverkan på naturliga miljöer i första hand ska undvikas, annars minimeras – och när detta inte är möjligt återställas inom området eller kompenseras enligt en ekvivalens- och närhetsprincip. Beräkningarna kan utföras i en modell som exempelvis Grönytefaktorn för att uppnå ett visst mål, som till exempel nettovinst.

Det är ännu oklart hur väl nivåerna och principerna i praktiken fungerar och vilken nytta de egentligen ger. Det finns också en indikation om transparensproblem i förhållande till skadelindringshierarkin inom Grönytefaktorn. Samtidigt har potentialen hos en ny modell med namnet NATURE Tool lyfts fram i Sverige, vilket skapar ett behov av vetenskapliga studier.

Denna studie syftar därför till att undersöka modellerade naturkapitalvärden baserat på skadelindringshierarkin i Grönytefaktorn och NATURE Tool. Genom att jämföra naturkapitalvärdesförändringar mellan scenarier som innehöll olämpliga och lämpliga skadelindringsangreppssätt var det möjligt att utvärdera hur modellernas resultat återspeglade hänsyn till skadelindringshierarkin samt de naturkapitalvärdes-förändringar som härleddes till varje nivå. Ett studieområde i Stockholm, Sverige, användes för att testa modellerna genom subjektiv känslighetsanalys. Den blandade naturmiljön inom området består av tall- och lövskog, berghäll, gräsmark och enskilda gatuträd.

Resultaten visade att NATURE Tool inte tillät olämpliga åtgärder i samma grad som Grönytefaktorn och att NATURE Tool presenterade resultaten mer transparent. Samtidigt hade olämpliga åtgärder i Grönytefaktorn inte varit möjliga om rekommendationerna i manualen följts. Dessutom är det diskutabelt om definitionen av olämpliga åtgärder i modellerna ger faktiska olämpliga åtgärder i verkligheten.

Studien visade också att Grönytefaktorn behövde mindre yta och färre kompenserande åtgärder givet nettovinstmålet jämfört med NATURE Tool, vilket indikerar att antingen Grönytefaktorn underskattade eller att NATURE Tool överskattade naturkapitalvärdena.

Studien visade slutligen att den totala förändringen av naturkapitalvärdet som följd av nivåerna i skadelindringshierarkin var högst för kompensation jämfört med de tidigare nivåerna (undvikande, minimerande och återställande). De tidigare nivåerna var dock yteffektivare jämfört med kompensation. Detta visar på att även om de tidigare nivåerna är mer effektiva, kan kompensation spela en viktig roll för att nå net gain.

Studiens slutsats är att modellerna kunde generera relativt höga naturkapitalvärden även för olämpliga skadelindringsangrepssätt. Vid vidareutveckling av modellerna bör det övervägas att säkerställa att ett sådant angreppssätt inte ger liknande resultat som en lämplig. Detta kan göras genom att kalibrera modellerna till en databas med observationer. Att utveckla modellernas kommunikationsstrategier kan också uppmuntra lämpliga skadelindringsangreppssätt.

Table of contents

1. Introduction 1
- 1.1 Aims and research questions 2
- 1.2 Limitations 2

2. Background 4
- 2.1 Models 4
  - 2.1.1 Green Space Factor 4
  - 2.1.2 ESTER 5
  - 2.1.3 InVEST 5
  - 2.1.4 NATURE Tool 5
- 2.2 Natural capital 6
  - 2.2.1 Biodiversity 7
  - 2.2.2 Ecosystem services 7
- 2.3 Planning processes 8
  - 2.3.1 Swedish planning process 8
  - 2.3.2 Mitigation hierarchy 9
  - 2.3.3 Decision theory 11

3. Methods 12
- 3.1 Case Study 12
  - 3.1.1 Södertäljevägen 12
  - 3.1.2 Sketch alternative 13
- 3.2 Data collection 13
  - 3.2.1 Available data 14
  - 3.2.2 Study visit 15
- 3.3 Data processing 15
  - 3.3.1 Habitat classification 15
  - 3.3.2 Natural capital data processing 16
- 3.4 Data analysis 18
  - 3.4.1 Sensitivity analysis 18
  - 3.4.2 Scenario definitions 19
  - 3.4.3 Mitigation measure definitions 21
  - 3.4.4 Input data formation 23
  - 3.4.5 Parameterization 23

4. Results 25
- 4.1 Receiving net gain while mitigating poorly 25

4.1.1 Poor mitigation measures 26
4.2 Compensation needed to reach net gain 27
4.2.1 Compensation measures 28
4.3 Natural capital values for each level 28
4.3.1 Avoidance 30
4.3.2 Minimization 30
4.3.3 Restoration 31
4.3.4 Compensation 31
5. Discussion 33
5.1 Need for further model calibrations 33
5.2 Assessing data uncertainty 33
5.3 Assessing knowledge gaps 33
5.4 Model simplicity and complexity 35
5.5 Future mitigation methods 35
5.6 Future decision-making 36
6. Conclusion 37
References 38

1. Introduction

Humankind is completely dependent on nature for its survival (IPBES, 2019). Nature provides people with capital in the form of, for example, food, water, energy, sensuous experiences, and healthy living environments. The need for natural capital is also expected to grow because of an increased population (IPBES, 2019). At the same time, the well-being and diversity of nature are threatened by predominantly human-influenced processes such as overfishing, climate change, erosion, invasive species, nutrient depletion, pollution, salinization, algal blooms and urbanization. These processes are today fragmenting at least 60% of all ecosystems globally (Millennium Ecosystem Assessment, 2005).

The threat to natural capital can be greatly associated with land use, especially urbanization and agriculture. Traditional agriculture and urbanist ideals have sought, in whole or from time to time, for short economic gains, leading to the development of homogeneous landscapes (Perrings et al., 2006; Rees, 1997; Millennium Ecosystem Assessment, 2005). This has led to fragmented habitats, impacting species and ecosystems. Since habitat condition is closely linked to natural capital, the degradation of ecosystems is also impacting human well-being, safety and health (IPBES, 2019; Millennium Ecosystem Assessment, 2005).

In Sweden, the trend is the same as globally, and Swedish authorities has established that greater consideration in planning is needed (The Swedish National Board of Housing, Building and Planning, 2019; EPA, 2020a). Useful methods and principles are seen as two of the most important keys to achieve this shift (Guerry et al, 2015). One approach to managing threats to natural environments in Swedish cities is through adapting a mitigation strategy in planning processes. A mitigation strategy assesses the natural capital to certain principles. The goal can be to reach a certain net value of natural capital before and after the proposed development plan, such as no net loss or net gain (Maron et al., 2018; IUCN, 2015).

One common mitigation strategy is the mitigation hierarchy, firstly proposed by Rio Tinto (2008). Mitigation hierarchy assumes that exploitation of natural environments is primarily (1) avoided, otherwise (2) minimized, (3) restored on-site or ultimately (4) compensated off-site. While level (1) and (2) mean that natural environments remain, level (3) and (4) means that the equivalent, or similar values are recreated in a nearby location. This means that two principles should be followed: an equivalence principle and a proximity principle. However, it is still unclear how the levels and principles work in practice and what natural capital change each level give (Kiesecker et al., 2010).

To be able to adapt the mitigation hierarchy in planning processes, the need for a proper model has emerged (Daily et al., 2009). One of the most common models on the Swedish built environment sector is the Green Space Factor. However, experiences from the model have proposed it to not be a proper model for compensation, as it does not distinguish biodiversity from ecosystem services (C/O City, 2022b). This means that important values for one natural capital type, such as biodiversity, could be replaced by another, such as for cultural ecosystems. This, according to the equivalence principle, could be seen as problematic (Quetier et al., 2014).

Simultaneously, in the UK, a similar model has been implemented in a tool called NATURE Tool, that manages biodiversity and ecosystem services separately (WSP & Ecosystems Knowledge Network, 2022). Thus, there is an indication it may be more transparent compared to Green Space Factor. The tool was in 2021 tested in a Swedish context a through a development project in the Royal Seaport. In a report, one of the persons involved in the pilot project states that NATURE Tool has potential to act as an alternative to Green Space Factor (WSP & City of Stockholm, 2021). The potential of NATURE Tool in Sweden, and the indication of its different handling of transparency, therefore makes it interesting to investigate in relation to Green Space Factor.

1.1 Aims and research questions

Previous reports indicate problems with transparency for Green Space Factor in relation to poor mitigation approaches (C/O City, 2022b). At the same time, the potential of NATURE Tool has been highlighted (UK GBC, 2021), but not scientifically tested in Sweden. A knowledge gap about natural capital values in in relation to the levels and principles within the mitigation hierarchy also highlights the need for evaluating studies (Kiesecker et al., 2010). This demonstrates the need for evaluating and comparative studies of these two models in relation to the mitigation hierarchy.

Based on these two needs, this study aims to compare modelled natural capital values based on consideration to the mitigation hierarchy in Green Space Factor and NATURE Tool. By examining modelled natural capital based on two different mitigation approaches, the study can evaluate how the two models reflects consideration of the mitigation hierarchy as well as the benefit derived from each level. Furthermore, the study aims to discuss what this means for the potential development of assessing natural capital transparently through models in Swedish planning processes.

The study can thus address the following research questions:

1. *What are the differences for performing a poor mitigation approach between the models and still receive a net gain of total natural capital?*
2. *What are the differences for needed compensation measures within and between both models given that a mitigation approach is either poor or proper?*
3. *How many natural capital values in the models can be derived from each level in the mitigation hierarchy given that a mitigation approach is either poor or proper?*

1.2 Limitations

In the study, two models were selected, Green Space Factor and NATURE Tool. The choice of these two models was motivated by their ability to greatly adapt to local conditions as well as the relevance of previous indications to the research questions. By using such a model, the analysis can be adapted to the local conditions that exist in a planning process. However, this also means that the study is limited these two models as well as to being applied to places with similar conditions.

The case study is based on existing data from a plan program. Therefore, the findings have been limited to the available data and the habitat types. The available data are described in chapter 3.2.1. The existing habitat types within the study area are mixed deciduous and pine forest, rock outcrop, grassland and individual trees. This means that the findings are limited to similar planning processes, unlike other planning processes such as for infrastructure or comprehensive plans.

To make both models comparative, reparameterizations were made that imply limitations in which natural capital they handle. This means that the natural capital types managed in the study are biodiversity, regulating and cultural ecosystem services. Supporting ecosystem services and non-renewable resources are not the focus of the study and is therefore not assessed in NATURE Tool.

For biodiversity, the focus is mainly on habitat diversity and to some extent species diversity. The focus is thus not on genetic- or other diversity. For regulating ecosystem services, the focus is on climate regulation, water regulation and pollination. For cultural ecosystem services, the focus is on recreation, well-being, aesthetical values and cultural-historical values.

How equivalency within the mitigation hierarchy is defined is in the time of the study uncertain. However, it is a central component since it impacts the mitigations connected to each strategy. In the study, the equivalence principle is defined, and therefore limited to, the main lost habitat type and all natural capital types. This means that the results of the study are comparable to cases where the equivalence principle is defined in a similar way.

Since there are no standardized work processes for compensation, it is also not clear when or how in the planning process it should be applied. Compensation therefore rarely occurs in practice (Quetier et al., 2014). In this study, a hypothetical compensation case was defined, not linked to an existing location or project. This creates a limitation to what it would mean in practice within the planning process.

2. Background

In this background, a current situation description and theoretical framework is given about models, natural capital and its application in Swedish planning processes.

2.1 Models

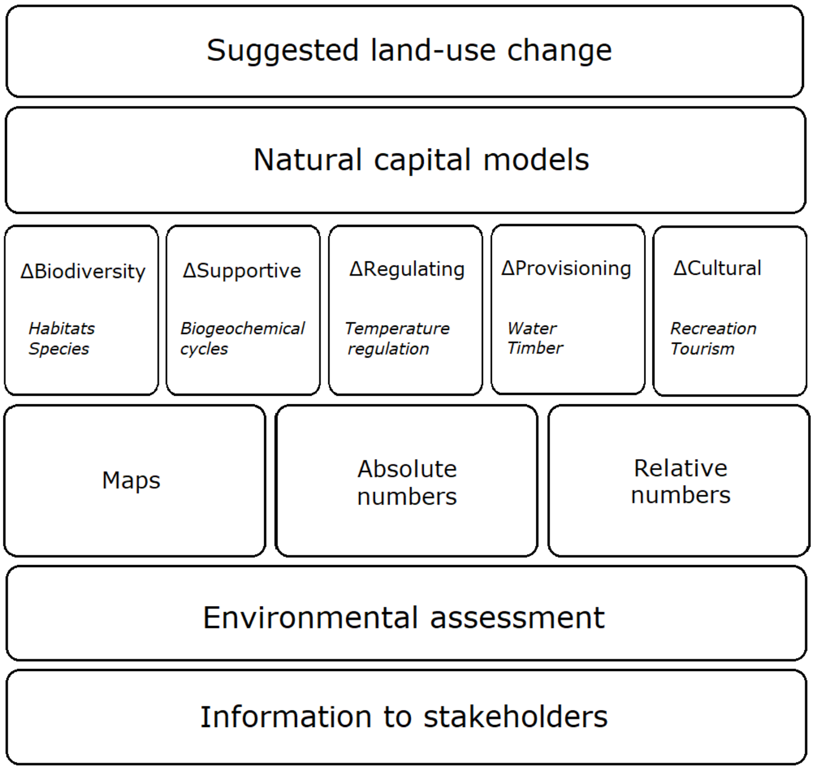

Figure 1: The task of natural capital models in the planning process. Modified from Daily et al (1997)

Natural capital models for planning processes aim to provide information to stakeholders (see Figure 1) (Daily et al., 1997). They do so by creating projections of natural capital given landscape scenarios based on metrics (Wende et al., 2018). The model output can then be presented in units or maps in an environmental assessment, such as an ecosystem service assessment or environmental impact assessment. The results can be presented along with other information, such as interpretation of results and further recommendations. The information provided can then help decision-makers make trade-offs based on various regulations, policies, and guidelines.

Generally, natural capital models are static, functional and descriptive. This means that they are relatively simple compared to other environmental models (Smith & Smith, 2007). One explanation is that there is an indication that simpler models have a greater impact on the spatial planning process. Most practitioners simply do not have the resources to handle a complicated tool (C/O City, 2022b).

2.1.1 Green Space Factor

GYF (short for *Green Space Factor*), also called Green Area Index or Urban Greening Factor, is an international model integrated in several tools. A Swedish nationally customized tool was developed in 2018 (C/O City, 2018). The common factor of Green

Space Factor models is that they calculate natural capital as an index. The higher the index, the more natural capital is supplied by the given area.

In Green Space Factor, habitat areas are firstly assigned quantitative values based on amounts of ecosystem services provided in a spatial mapping program such as GIS. Biodiversity is in this sense seen as a supportive ecosystem service. Each value has a weighting parameter that corresponds to its importance to the human wellbeing. All factors are then multiplied and divided by the total study area (C/O City, 2023):

$$GYF\ index = \frac{Y + Kx}{A}$$

Where Y equals natural space areas, K equals ecosystem service areas, x equals the weighting parameters and A equals the total plan area. The GYF index thus shows how much natural capital is provided by the area.

2.1.2 ESTER

ESTER (short for *Ekosystemtjänsteffekträkning*) is a model developed by Sweco on behalf of the National Board of Housing, Building and Planning (2022). The aim of the model is to assess simple ecosystem service analyzes. In the development, inspiration was taken from Riksbyggen's and the Swedish Agency for Marine and Water Management's model Vesta, but the model was adapted for terrestrial ecosystems instead of marine ones (Tankesmedjan Movium at SLU, 2021). In the model, biodiversity is counted as a supportive ecosystem service.

In ESTER, habitat areas are assigned qualitative and semi-quantitative values in a support program such as GIS. The values are calculated by assessing the impact of a change in yes/no/do not know format (The National Board of Housing, Building and Planning, 2022). The answers are compared with a pre-development scenario in an impact analysis and illustrate in percentages of change. However, it lacks the possibility for adjustment to site-specific conditions (Tankesmedjan Movium at SLU, 2021).

2.1.3 InVEST

InVEST (short for *Integrated Evaluation of Ecosystem Services and Tradeoffs*) is a collection of a variety of models for scenario planning. The models have been developed by an international research project lead by Stanford University. Each model calculates the value of a specific ecosystem service or biodiversity between different scenarios. This is done in a GIS software (Natural Capital Project, n.d.).

All models are based on internationally representative data, which means that they are less adapted to local conditions. In addition, the models contain relatively many variables and parameters. This indicates that the model could be somewhat complicated for planning processes (C/O City, 2022b).

2.1.4 NATURE Tool

The NATURE Tool is a natural capital assessment model that was developed in the UK in response to an increased demand to assess natural capital in their planning processes. The increase in demand was a result of an updated planning policy (Ministry of Housing, Communities & Local Government, 2021), a 25-year planning document (HM Government, 2021) and the proposal for a new law in England (Environment Act, 2021). These governing documents are expected to require a net gain of biodiversity as a result of all planning processes in England.

The NATURE Tool automatically calculates scores for the pre- and post-development scenarios of a site based on habitat data and other relevant datasets. On this basis, the tool indicates the relative change in ecosystem services provision across several ecosystem services as well as the potential for further natural capital enhancements (WSP & Ecosystems Knowledge Network, 2022). Biodiversity values are calculated separately through the model Biodiversity Metric. Biodiversity is calculated through assessing the ecosystem condition, distinctiveness and strategic location (Natural England, 2021). The results of biodiversity are presented similarly as to the natural capital, which indicates it to be more transparent. This, as well as the lack of scientific studies in a Swedish context, makes the model interesting to further investigate.

2.2 Natural capital

Natural capital are stocks and flows of natural goods that have a value for people (Millennium Ecosystem Assessment, 2005). Examples of such are timber, clean water, fossil fuels, microclimate regulation, erosion protection, minerals, recreation and cultural identity. They can be divided into natural capital types such as biodiversity and ecosystem services, or to whether they are renewable or not.

While human health and the economic development of society depends on natural capital (IBES, 2019), the renewable natural capital is difficult to notice. The reason is that the capital tends to not be noticed until it's lost (Mace et al., 2012). Another reason is that nature itself is free, and thus can be interpreted as lacking value. Consequently, it is sometimes missed in decision-making processes (Millennium Ecosystem Assessment, 2005).

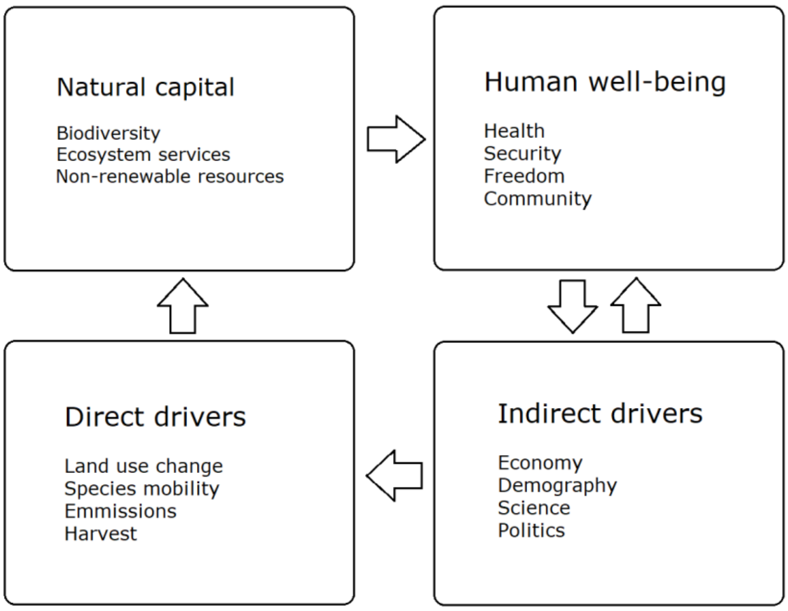

Figure 2: The relationship between natural capital and the human world. Modified from Millennium Ecosystem Assessment (2005)

In a synthesis report for ecosystems and human wellbeing (Millennium Ecosystem Assessment, 2005), it is suggested that while natural capital provides resources for human wellbeing, it is heavily influenced by human actions. The human actions are direct and indirect such as land use change or political decisions (see Figure 2). This is a part of the complex and inter-disciplinary social-ecological system. Understanding the natural capital values in this sense requires an understanding of the constituent processes and what feedback systems they provide (Millennium Ecosystem Assessment, 2005).

2.2.1 Biodiversity

Biodiversity is a term that describes the variation of biological stocks (Business and Biodiversity Offsets Programme, 2018). Biological stocks, in this sense, can consist of habitat, species or genetics. In the study, it is primarily referred to as variation in habitat, but also to some extent in species composition. Thus, there is a spatial context to the concept. Since planning processes affect the landscape, biodiversity at the habitat level is expected to be affected, given that habitats are located there (Business and Biodiversity Offsets Programme, 2018).

Biodiversity can be valued as a provider of ecosystem services, a regulator of ecosystem stability, as an ecosystem service or as an intrinsic value in itself (Mace et al., 2012). Thus, there many perspectives on how biodiversity relates to ecosystem services and therefore natural capital. In the models, this reflects in different ways. In Green Space Factor it is mentioned as a separate ecosystem service. Meanwhile, biodiversity indirectly impacts many other variables, especially those for cultural ecosystem services (C/O City, 2018). In NATURE Tool, biodiversity is managed as an intrinsic value, managed by itself (WSP & Ecosystem Knowledge Network, 2022).

2.2.2 Ecosystem services

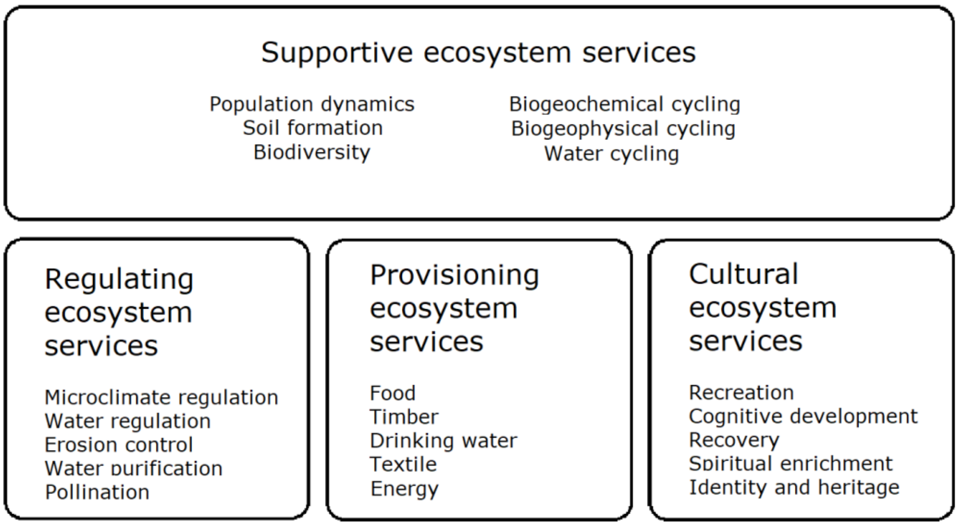

Figure 3: Various types of ecosystem services and examples of specific services. Modified from MA (2005)

Ecosystem services are defined as services that nature provides to humans (Millennium Ecosystem Assessment, 2005). These are divided into four categories; supportive, regulating, provisioning and cultural services (see Figure 3). Supportive ecosystem services are seen as the basis for the others ecosystem services. These include population dynamics, biogeochemical- and biogeophysical cycling and soil formation.

Biodiversity can also be seen as one. Among others, The Swedish National Board for Housing, Building and Planning (2019) define it as such.

Regulating ecosystem services are for example climate-, water- and erosion regulation as well as regulating processes such as pollination. Provisioning ecosystem services includes products consumed by humans such as food, drinking water, timber and energy. For cultural ecosystem services, services with wholesome, social and spiritual values such as recreation, cognitive development, perceptive and identity are included (Millennium Ecosystem Assessment, 2005).

2.3 Planning processes

It is in the planning process that environmental impacts are assessed. Through environmental assessments, natural capital changes can be valued due to a proposed change in the landscape (Bull et al, 2016). The assessments can then provide a basis for decision-making while anchored in policies and guidelines (Kelemen & Hauck, 2015).

2.3.1 Swedish planning process

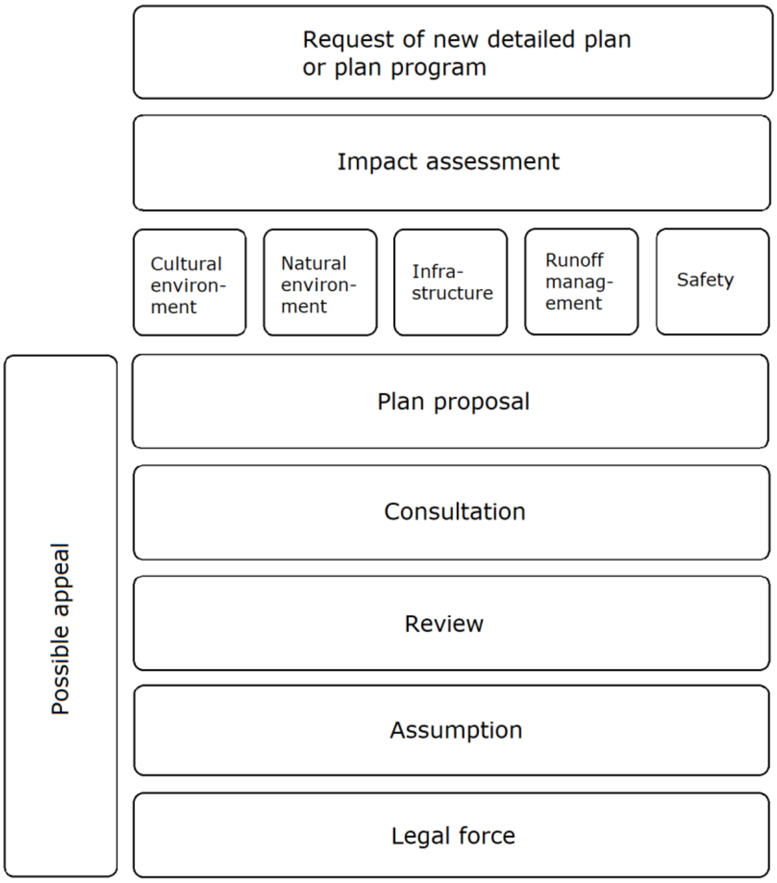

Figure 4: A simplification of the Swedish planning process. Modified from The Swedish National Board of Housing, Building and Planning (2020)

The Swedish planning process for detailed development plans or plan programs begins with a request of a suggested land-use change. Smaller areas indicate a detailed development plan to be proposed while a larger one indicates a new plan program. In a start-up meeting, the plan develops an intended development of the land that is illustrated with various location options, so-called sketch alternatives. Impact assessments are then carried out for different sketch alternative options (see Figure 4) (The Swedish National Board of Housing, Building and Planning, 2020b).

How impacts to the natural environment should be handled in planning processes is regulated in the Environmental Code (see, for example, Chapter 2, Section 7; Chapter 2, Section 8; Chapter 7, Section 7; Chapter 7, Section 29; Chapter 10, Section 5; Chapter 16, Section 9) (SFS 1998:808). In addition to the Environmental Code, there are area regulations which are legally binding documents. Depending on which values can be impacted and to what extent, different environmental assessments are applied. Examples of such are nature value inventory, ecosystem service assessment or environmental impact assessment.

In addition to the legally binding documents, there are policies and guidelines connected to each planning process. The aim of these documents is to guide and encourage desired decisions (The Swedish National Board of Housing, Building and Planning, 2021). Each municipality has a comprehensive plan, aimed at guiding the public interest. In addition to this, municipalities may have strategic documents, such as green plans. County administrative boards also have regional plans. The content of these differs depending on the environmental-, economical- and social conditions (Newman & Thornley, 1996). There are also several global streams that push towards no net loss or net gain goals (see for example Millennium Ecosystem Assessment, 2005; IPBES, 2019).

The plan proposal, and finally the assumption and legal force, is based on the weighing of different interests. How these interests are to be weighed against each other is regulated in the Planning and Building Act (SFS 2010:900). Although natural capital, biodiversity and ecosystem services are not explicitly mentioned in it, natural values are seen as a public interest (The Swedish National Board of Housing, Building and Planning, 2020a). Therefore, they are to be considered in planning processes that has an impact on natural environments (see, for example, Chapter 2, Section 3; Chapter 2, Section 6; Chapter 8, Section 9) (SFS 2010:900).

2.3.2 Mitigation hierarchy

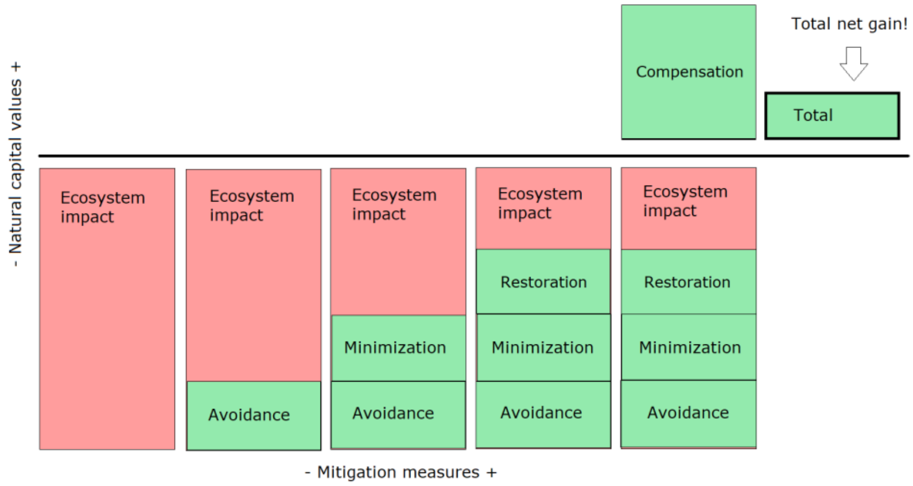

Figure 5: The relationship between natural capital values and mitigation hierarchy levels. Modified from Rio Tinto et al (2008)

The mitigation hierarchy is a commonly proposed method for applying ranked mitigation measures to proposed plans that impacts natural environments (see Figure 5). The purpose of the principle is to appropriately achieve a given goal such as no net loss, where natural values reach net zero, or net gain, where net natural values increase (Wende et al., 2018). Whether a planning process achieves the desired goal is closely linked to policies in the planning process (see section 2.3.1) and models (see section 2.1). While policies set desires guidelines to be pursued in planning processes, models measure the natural capital values to a desired outcome.

The mitigation hierarchy was first proposed by Rio Tinto (2008) and has since been disseminated in both research and practical contexts. The mitigation hierarchy was traditionally taken for biodiversity, but after criticism that other values are often lost (Millennium Ecosystem Assessment, 2005), ecosystem services have also begun to be managed through it (Jacob et al., 2016; Mace et al., 2012).

The principle, in this case adapted from Wende et al. (2018), is that impact to the natural environment should be mitigated in certain levels to reach the net goal. The levels can be interpreted in different ways. This is the interpretation this study uses (see Table 1).

Table 1: Mitigation levels, descriptions and principles in the mitigation hierarchy

Level	Mitigation	Description	Additional principle
1	Avoidance	Completely avoid certain planned constructions within plan area	
2	Minimization	Rearrange or redesign constructions within plan area	
3	Restoration	Restore natural capital values within plan area	Equivalence principle
4	Compensation	Compensate natural capital values outside plan area	Equivalence principle, proximity principle

Avoidance refers to completely avoid certain planned constructions on valuable sites within the plan area. Minimizing refers to locating, as far as possible, the planned constructions in such a way as to exploit as few natural values as possible. It is also about designing it in a way that minimizes impacts. This requires the mitigation hierarchy to be implemented early in the planning process, where the location of planned constructions could still be influenced (C/O City, 2022a)

Restoration means that lost values are restored on site, for example by restoring the condition of a habitat close to a site where the same habitat type was lost. Compensation is seen as a last resort. Both restoration and compensation are defined based on the definition of Business and Biodiversity Offsets Programme (2018) that the values of natural capital that are lost are recreated in a nearby location. This means that restoration and compensation are based on two guiding principles – an equivalency and a proximity principle.

The equivalence principle means that the recreated values should match important values that are lost, while the proximity principle means that the recreated values should be as close to the impact as possible (Business and Biodiversity Offsets Programme, 2018). How equivalent values are defined, however, is uncertain but central since it impacts the assessment (Quetier et al., 2014). It can be defined in terms of the condition or functions of habitats, ecosystems or natural capital types (Wende et al., 2018; Tarabon et al., 2019).

2.3.3 Decision theory

The decisions made within the mitigation hierarchy are subjective and carried out through expert judgements by professionals. Therefore, there is an uncertainty linked to the decision process (Polasky et al., 2011). Decision theory is about how these subjective decisions are made for different alternatives, gaining understanding to the most reasonable outcome.

Decisions for environmental assessments within the planning process are made are based on suitability where different alternatives have different likely outcomes. The most appropriate option, in this sense, is the option with the highest probability to the desired outcome, given the information available (Polasky et al., 2011). This requires a sense of which mitigation measures are reasonable. To assess uncertain decisions, it is crucial to reconcile decisions with the right skills to make sure they are reasonable. Otherwise, for example, the best scenario according to the mitigation hierarchy would have logically given 100% avoidance, which in most planning processes is unreasonable.

In the study, this means that certain mitigation measures are reconciled with professionals in the field of environmental assessments (SEA/EIA). These have practical experience in planning processes and the specific study area. The practical experience gives a certain consensus of what is reasonable and thus a greater legitimacy to the mitigation measures that are selected.

3. Methods

Since the research topic is within the physical and human geography sciences (Wende et al., 2018), selected methods were chosen that are well suited in both disciplines. Since the study examines the behavior of two models, methods related to the model evaluation were chosen based on current research literature on the assessment of models (Smith & Smith, 2007). Subjective assessments regarding certain mitigation measures were reconciled with professionals for the method to have a theoretical basis (Polasky et al., 2011). Since this method is case study focused (Wende et al, 2018), a case study was selected that was considered representative.

3.1 Case Study

A case study was chosen to test the research questions. The site selected has been considered representative of a typical Swedish planning process and of Swedish habitat types. It is located within an urban area, where planning processes often occur (Sandström, 2002). The dominating habitat types is grassland, boreal and deciduous forest, three common habitat types in Sweden (EPA, 2020b).

3.1.1 Södertäljevägen

Figur 6: The chosen study area is the Södertäljevägen, located in Stockholm, Sweden. Modified from Lantmäteriet/Metria (2023)

The chosen planning process was *Södertäljevägen* (see Figure 6) (City of Stockholm, 2023). Södertäljevägen is the name of a proposed plan program located in the Liljeholmen district in southern Stockholm, Sweden. The purpose of the project is to connect the outer district of Liljeholmen with the more central district of Södermalm.

The site today contains, among built environments, a mixed natural environment with both deciduous and boreal forest, rock outcrop, grassland and individual deciduous trees (Ekologigruppen, 2020b; City of Stockholm, 2019). Within the existing study area there is also another ongoing suggested detailed development plan that in the study is assumed to have been approved, which meant that the area was not included in the assessment carried out in the study.

3.1.2 Sketch alternative

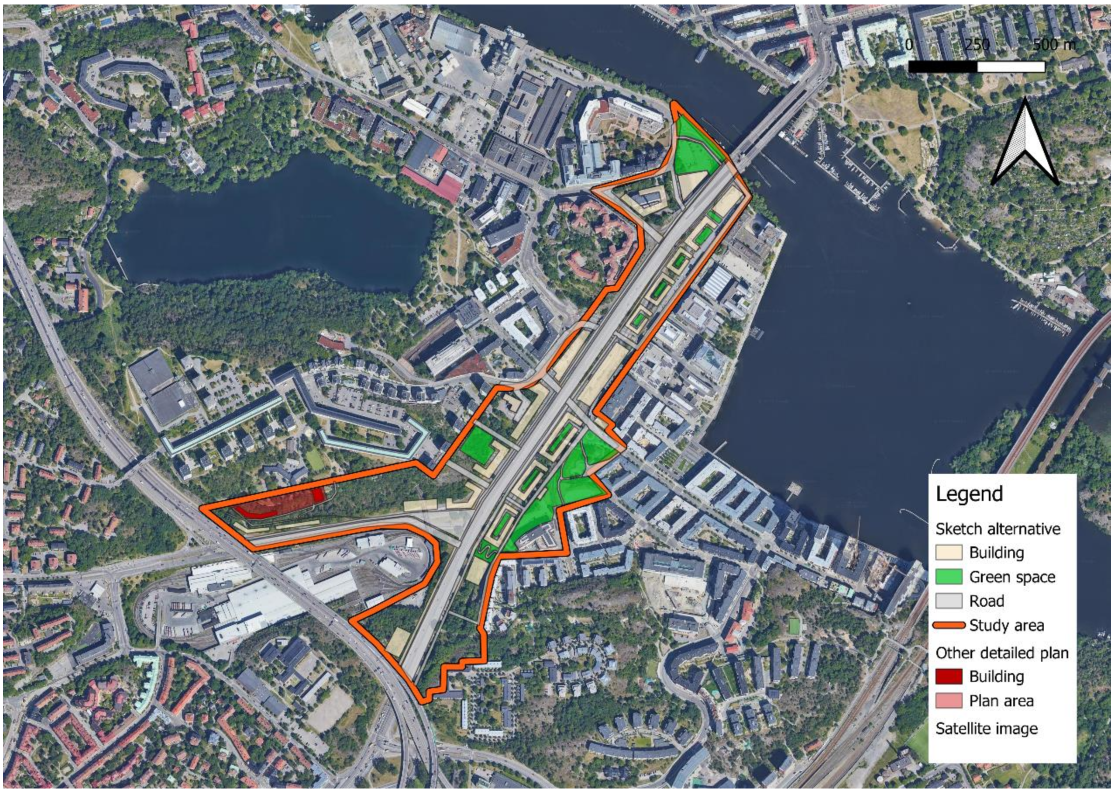

Figure 7: The sketch alternative analyzed is one of several alternatives. Modified from Lantmäteriet/Metria (2023)

The sketch alternative investigated is an interpretation of one of several alternatives that has been investigated within the framework of the program work. The sketch alternative proposes a mixed development of buildings, roads and green spaces. An interpretation of the sketch alternative was that parts of the natural environments in the southern study area are proposed to be preserved and parks are proposed to be developed in the central and northern parts of the study area (See Figure 7).

At the time of the study, the plan program was at an early stage and was expected to go out in program consultation during the fourth quarter of 2023 (City of Stockholm, 2023). At the time different land-use options in the area were under consideration. Therefore, there was no ready-made drawing for what the intended plan area would look like. One sketch alternative of the possible future land use options was randomly chosen for this case study. The sketch alternative presented does not represent the City of Stockholm's intended future land use in the area.

3.2 Data collection

Since each detailed planning process program conducts different investigations, the data availability varies greatly. The study was based on both available data linked to the specific project and from open databases. Later in the analysis process, it was supplemented with a site visit to adjust and confirm data points.

3.2.1 Available data

For the case study, a variety of data was available with relevance to the model inputs in the form of maps, text and datasets (see Table 2). Among the data retrieved from open databases was a satellite image (Lantmäteriet/Metria, 2023), dispersal investigations of amphibians (City of Stockholm, 2016), sociotope map identifying certain cultural ecosystem services (City of Stockholm, 2022), biotope map (City of Stockholm, 2019), historical map (Lantmäteriet, 1960), population density (SCB, 2023), air pollution map (City of Stockholm, n.d.), designated nature map (EPA, n.d.), runoff data (SMHI, 2023) and a topographic web map (Lantmäteriet, 2023).

Unpublished data was retrieved from the internal project database and consisted of general dispersal investigation (Ekologigruppen, 2020a), dispersal investigation about oak living insects and tassel (WSP, 2019), dispersal investigations about oak barriers (Sweco, 2019), nature value inventory (Ekologigruppen, 2020b), environmental noise assessment (Structor, 2021), runoff investigation (Ramboll, 2020), cultural environment analysis (KMV forum, 2020) and impact assessment (Ekologigruppen, 2021). A sketch alternative was also created based on an interpretation of one of several sketch alternatives investigated within the program work.

Table 2: Available data for the case study (n/a = not applicable)

Description	Source	Format
Satellite image	Lantmäteriet/Metria, 2023	Map (WMS)
Sketch alternative	n/a	Map (Vector)
General dispersal investigation	Ekologigruppen, 2020a	Text, map (PDF)
Dispersal investigation: Oak living insects, tassel	WSP, 2019	Map (PDF)
Dispersal investigation: Amphibians	City of Stockholm, 2016	Map (WMS)
Dispersal investigation: Oak barrier	Sweco, 2019	Map (PDF)
Nature Value Inventory: General	Ekologigruppen, 2020b	Text, map (PDF)
Environmental noise assessment	Structor, 2021	Text, map (PDF)
Runoff investigation	Ramboll, 2020	Text, map (PDF)
Sociotope map	City of Stockholm, 2022	Map (WMS)
Cultural environment analysis	KMV forum, 2020	Text, map (PDF)
Impact assessment	Ekologigruppen, 2021	Text, map (PDF)
Biotope map	City of Stockholm, 2019	Map (WMS)
Historical map	Lantmäteriet, 1960	Map (WMS)
Population density	SCB, 2023	Dataset (CSV)
Air pollution map	City of Stockholm, n.d.	Map (WMS)
Designated nature map	EPA, n.d.	Map (WMS)
Runoff data	SMHI, 2023	Dataset (CSV)
Topographic web map	Lantmäteriet, 2023	Map (WMS)

3.2.2 Study visit

A study visit was conducted the 19th of April to supplement or correct data. The data checked for adjustments were any water facilities, floral practices, green walls or habitat areas under bridges. It was also checked for adjustments for the data that were not developed based on site visits, such as the sociotope map. After the study visit, three input variables were adjusted by reclassifying habitats based on perceptions made by me.

A habitat in the southeastern part of the study area, which according to the sociotope map would be scored as *Serenity*, an input variable for cultural ecosystem services in Green Space Factor, was perceived noisy and polluted. Another part within the larger mixed woodland in the southwestern part of the case study area would, according to the sociotope map, be accessible and be scored for *Recreation* but was perceived as difficult to orient oneself in due to overgrowth, uneven surface and steep slope. The input data for these two variables were adjusted by reclassifying the habitat.

Another part within the same habitat was perceived to be used for school activities, which wasn't captured by the data. The input for *Education* within NATURE Tool was therefore adjusted by reclassifying the habitat.

3.3 Data processing

3.3.1 Habitat classification

To create comparable scenarios between the models, habitat areas were classified in the same way in both. The data used to classify the habitats was the biotope map (City of Stockholm, 2019) (see more information about the data in Appendix A). Since the biotope map had low spatial resolution and thus rough features, the edges were corrected with the help of satellite images (Lantmäteriet/Metria, 2023). Projected changes due to future scenarios were classified through the sketch alternative (see Table 3).

Table 3: Classifications of each habitat type in models (n/a = not applicable)

Land use information	Datasets used	Sources
Habitats	Biotope map	City of Stockholm, 2019
Projected changes	Sketch alternative	n/a
Corrections	Satellite image	Lantmäteriet/Metria, 2023

Green Space Factor and NATURE Tool calculate classify habitat areas in different ways. In Green Space Factor, they are classified more generally and based on the land-use. In NATURE Tool, they are classified based on specific biotopes. To classify these habitat types comparably, the habitat classification was converted from the biotope map (City of Stockholm, 2019) to created classifications in the study that could be linked to both models (see Table 4). This was done by firstly comparing and translating the model classifications into merged habitat names and then translating the biotope map accordingly.

Table 4: Habitat classification in study, biotope data and models (City of Stockholm, 2019; C/O City, 2023; WSP & Ecosystems Knowledge Network, 2022)

Name used in study	Biotope map	Green Space Factor	NATURE Tool
Mixed deciduous forest	Deciduous dominated forest, mixed-leaf forest, trivial leaf-forest	Larger natural area	Mixed deciduous lowland forest
Pine forest	Pine-dominated forest	Larger natural area	Native pine forest
Rock outcrop	Outcrop	Larger natural area	Rock outcrop and scree habitats
Urban grassland	Urban green structure of gray character, urban green structure of open character	Green space street	Modified grassland
Urban tree/grassland	Urban green structure of tree character, urban green structure of lush character	Green space street	Urban tree

3.3.2 Natural capital data processing

For data extraction and processing on natural capital, different datasets were used for different natural capital types and models.

For Green Space Factor, where all input variables have spatial variation within the study area, relevant data was extracted into shapefiles in QGIS (see Table 5) (see more information of data in Appendix A). For biodiversity, the input data consisted of a historical map (Lantmäteriet, 1960), the dispersal investigations (Ekologigruppen, 2020a; WSP, 2019; City of Stockholm, 2016; Sweco, 2019) and the nature value inventory (Ekologigruppen, 2020b) to detect age, quality and landscape relationships within the habitats as well as particularly valuable objects.

For noise, the input data was based on surfaces of value for noise reduction. This part of the data was retrieved from an environmental noise assessment (Structor, 2021). Here, noise reduction areas were defined based on habitats surrounding areas with a noise level of >65 dbA/day, which according to the data were identified as high noise levels.

For runoff management, the input data was based on habitat areas of value for infiltration based on the runoff investigation (Ramboll, 2020). Here, vegetation with high infiltration capacity was defined based on habitat with a river basin coefficient of <1. For microclimate regulation, the input data was based on the number of vegetation layers the biotope map (City of Stockholm, 2019). Finally, for cultural ecosystem services, the input data was based on the sociotope map (City of Stockholm, 2022). This data was later somewhat adjusted after the study visit.

Table 5: Input data for natural capital in Green Space Factor (ES = ecosystem services, n/a = not applicable) (C/O City, 2018)

Input variable	Natural capital type	Datasets used	Sources
Biodiversity	Biodiversity	Historical map, Dispersal investigations, Nature Value Inventory	Lantmäteriet, 1960; Ekologigruppen, 2020a; WSP, 2019; City of Stockholm, 2016; Sweco, 2019, Ekologigruppen, 2020b
Noise	Regulating ES	Environmental noise assessment	Structor, 2021
Runoff management	Regulating ES	Runoff investigation	Ramboll, 2020
Microclimate regulation	Regulating ES	Biotope map	City of Stockholm, 2019
Pollination	Regulating ES	Nature Value Inventory	Ekologigruppen, 2020b
Cultural ES	Cultural ES	Sociotope map, Study Visit	City of Stockholm, 2022, n/a

For NATURE Tool, only a few input variables have spatial variation within the study area (see more information of data in Appendix A). Thus, the input data was defined both by shapefiles in QGIS, by calculations in Excel and by importing information directly in the model.

For biodiversity, the input data consisted of a historical map (Lantmäteriet, 1960), the dispersal investigations (Ekologigruppen, 2020a; WSP, 2019; City of Stockholm, 2016; Sweco, 2019) and the nature value inventory (Ekologigruppen, 2020b). Through the information retrieved, age, quality and landscape relationships within the habitats could be detected. For retained habitats, the historical map was also used to approximately detect the age for habitats.

For accessibility, the study visit retrieved data for closed habitats to the public, which did appear in areas along the tramways. For Designations, a designated nature map (EPA, n.d.) was used to see if there are designated habitat areas within the study area, which there were not. For education, information about this is sought through the study visit and then supplemented after a smaller habitat area was seen to be used in school activities.

For population density, data for the City of Stockholm was calculated based on statistics on population density (SCB, 2023) and was assumed to be representative of the area. For water status, representing the environmental quality of the water body, the input variable was directly based on processed water status data from the runoff investigation (Ramboll, 2020) showing that the body of water is of moderate ecological status. Data on grazing & mowing was collected during the study visit, where it did not appear within any area.

For AQMA, representing the air quality, the area was assumed to be affected by air pollution based on a map of air pollution from City of Stockholm (n.d.) and for flood regulation, areas next to the highway were assumed to be at risk of flooding based on the runoff investigation (Ramboll, 2020). For rainfall, data that had been filtered from the weather station Observatoriekullen collected by SMHI (2023) was taken and assumed to be representative of the area. Slope steepness was finally calculated in the National Land Survey's topographic web map (Lantmäteriet, 2023) (see Table 6).

Table 6: Input data for natural capital in NATURE Tool (ES = ecosystem services, n/a = not applicable) (WSP & Ecosystems Knowledge Network, 2022)

Input variable	Natural capital type	Datasets used	Sources
Biodiversity	Biodiversity	Dispersal investigations, Nature Value Inventory	Ekologigruppen, 2020a; WSP, 2019; City of Stockholm, 2016; Sweco, 2019, Ekologigruppen, 2020b
Retained habitats	Regulating and cultural ES	Historical map	Lantmäteriet, 1960
Accessibility	Regulating and cultural ES	Study visit	n/a
Designations	Cultural ES	Designated nature map	EPA, n.d.
Education	Cultural ES	Study visit	n/a
Population density	Regulating and cultural ES	Population density	SCB, 2023
Water status	Regulating ES	Runoff investigation	Ramboll, 2020
Grazing & mowing	Regulating ES	Study visit	n/a
AQMA	Regulating ES	Air pollution map	City of Stockholm, n.d.
Flood regulation location	Regulating ES	Runoff investigation	Ramboll, 2020
Rainfall	Regulating ES	Runoff data	SMHI, 2023
Slope steepness	Regulating ES	Topographic web map	Lantmäteriet, 2023

3.4 Data analysis

3.4.1 Sensitivity analysis

A sensitivity analysis was performed in order to test and evaluate model performances. Sensitivity analysis is one of the most common methods of model evaluation (Smith & Smith, 2007). Sensitivity analysis tests the model's sensitivity to a specific component, in this case the input variables based on mitigation principles and examines how the change is reflected in the model output (Smith & Smith, 2007).

The study was based on a method of subjective sensitivity analysis proposed by Hamby (1994). Subjective sensitivity analysis aims to test a model's performance based on the change of one or more input variables by comparing them with the output variable. In the study, input variables were changed based on whether the mitigation approach was poor or proper according to the mitigation hierarchy, while still aiming to receive a given net goal, which was net gain.

Outputs for the models consisted of numerical values illustrating the difference of natural capital before and after the suggested land use according to the sketch alternative. Through the test, comparing the model input data between the two future mitigation scenarios narrates about how sensitive the models are to changes of mitigation approaches. The greater the distance is between the output data of the two mitigation approaches, the more sensitive the model (Smith & Smith, 2007).

3.4.2 Scenario definitions

To test the sensitivity of the models to the mitigation hierarchy, four scenarios were created in total. These consisted of one current natural capital description (*Pre-development*), one future scenario without mitigations (*No mitigation*) and two future scenarios with different mitigation approaches to reach a net gain goal (*Poor mitigation*; *Proper mitigation*) (see Table 7).

Table 7: Scenarios formulated to perform sensitivity analysis

Scenario name	Description	Comment
Pre-development	Natural capital today	
No mitigation	Future natural capital given sketch alternative, without mitigation measures	Only to illustrate lost values (net loss)
Poor mitigation	Future natural capital given a poor mitigation approach	Inappropriate but ambitious (+10% net gain)
Proper mitigation	Future natural capital given a proper mitigation approach	Appropriate and ambitious (+10% net gain)

While *Pre-development* and *No mitigation* consisted of fully interpreting existing data, *Poor* and *Proper mitigation* scenarios were created by interpreting data and deciding on reasonable mitigations. These were mainly based on the data retrieved from the impact assessment (Ekologigruppen, 2021) and supplemented by proposing mitigations and reconciling them with professionals in the field of SEA/EIA.

Rules were created for the two future mitigation scenarios *Poor* and *Proper mitigation*. The mitigation scenarios assume that the mitigation measures are poor or proper based on three categories; the mitigation levels (avoidance, minimization, restoration and compensation), the equivalence principle (habitat type and natural capital type) and the proximity principle (on-site restoration versus off-site compensation) (see Table 8).

Table 8: Mitigation rules used in this study to define case-study specific poor and proper mitigation scenarios

Level	Poor mitigation	Proper mitigation
1) Avoidance	No avoidance	As much as reasonable, especially for important habitat type
2) Minimization	No minimization	As much as reasonable, especially for important habitat type
3) Restoration	Low effort, restoring less important habitat type and natural capital type	As much as reasonable, especially for important habitat type and natural capital type
4) Compensation	As much as needed to reach +10% net gain for total natural capital	As much as needed to reach +10% net gain for all natural capital types and important habitat type

For the *Poor mitigation* scenario, this meant that only the later levels, i.e. restoration and compensation, were applied. The proximity principle was thus also declined since compensation is performed outside the plan area. For the scenario, important habitat types and natural capital types were also replaced with less important ones. The important habitat type was defined based on the habitat with the highest loss, while natural capital type was defined based on existing reports comparing them. At the same time, *Proper mitigation* consisted of following the mitigation hierarchy as well as possible according to the description Wende et al (2018) gave.

3.4.3 Mitigation measure definitions

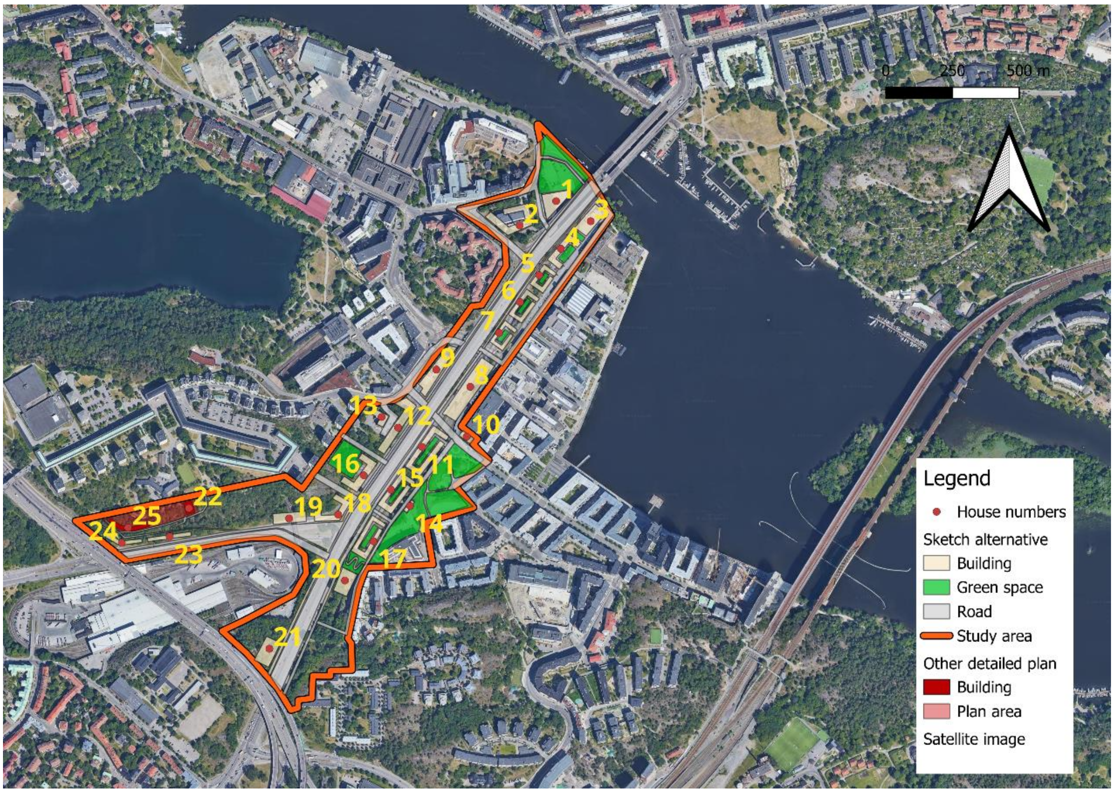

Figure 8: House numbers defined based on the sketch alternative. Modified from Lantmäteriet/Metria (2023)

Table 9 shows the mitigation measures defined for the *Poor* and *Proper mitigation* scenarios given each level in the mitigation hierarchy. Each mitigation measure consisted of an action linked to a specific location, except for the level compensation. Compensation measures were loosely defined and tested in the model to reach the desired result given the mitigation rules (see section 3.4.2). Specific locations were linked to specific locations within the study area based on house numbers (see Figure 8).

Table 9: Mitigation measures defined for both scenarios

Level	Poor mitigation	Proper mitigation
Avoidance		Houses 23 & 24 were not built
Minimization		House 5 was redesigned to avoid especially valuable trees
		House 18 was redesigned to avoid especially valuable area
		Road was designed to preserve valuable trees next to house 20
Restoration	All major natural areas were turned into parks with play areas, cultivation, paths, flowers	A multifunctional park was created next to house 1
	Green roofs were made accessible to the public	Green roofs on houses 1-2 were created
	Cultivation areas were created on all residential gardens, which are opened up for public	Tree- and grassland was created along roadsides between houses 1-21 to support and preserve valuable trees
	Tree- and grassland was created along roadsides between houses 8-18 to support new trees that enhance the experience of cityscape	All valuable trees were moved to the newly created tree-and grassland between houses 1-21
		Multifunctional gardens were created by houses 4, 5, 6, 7, 11, 15, 16, 17, 18, 19, 20 and 21
		Green ivy plants were planted along walls on houses 11-18
		A multifunctional park was created next to house 11 and 14
		An ecoduct was created between houses 17-20
		Five fauna depots and five bug boxes were created along houses 20-25
		Ten bee- and insect hotels were created along houses 19-25
		A multifunctional park was created where house 22 and 23 should've been
		Clearance of old oak trees where houses 22 and 23 should've been
		Grassland was created in unused spaces
Compensation	As much grassland interventions as needed that contributed to the greatest extent possible to cultural ecosystem services	As much mixed deciduous forest interventions as needed that contributed to all natural capital types

3.4.4 Input data formation

To facilitate understanding of the spatial context of the study area, a satellite image was firstly uploaded in WMS format (Lantmäteriet/Metria, 2023). To facilitate understanding of the future scenarios, data of proposed roads, buildings and green spaces from the sketch alternative was created in a shapefile as polygons and overlayed on top of the satellite image. Based on this understanding, input data on habitat areas and their natural capital was then processed for each scenario.

Data formation for the *Pre-development* scenario consisted of calculating the necessary input data extracted from the data files to the models. The data that did not have spatial variation within the study area was inserted directly from Excel into the models while the data with spatial variation was defined in a shapefile in QGIS. In the shapefile, polygons were defined in different layers given different data inputs. Then the expression "$area" was used through the field calculator in the attribute table to produce all the field areas. To obtain total areas for the fields that are linked to specific input variables, the SUM tool was used in Excel. It was these areas that then constituted the input data with spatial variation.

Data formation for the *No mitigation* scenario consisted of calculating changes given that some habitat surfaces disappear and are replaced by other surfaces. To do this, an overlay technique was used in QGIS where an upper layer of the shapefile containing the sketch alternative was designated a lower opacity in the symbology compared to the lower layer containing the shapefile for the natural capital values in the pre-development shapefile. In this way, a new layer was created by subtracting the surfaces that the sketch alternative covered through the Clipper tool. For the new park and garden areas contained in the sketch alternative, natural capital values were added for grassland areas to illustrate that no further mitigation measures had been taken.

For the *Poor* and *Proper mitigation* scenarios, the data was formed by overlaying the previous shapefiles in a similar way, while also testing mitigation measures while reconciling with professionals in the field of SEA/EIA to the desired result according to the defined mitigation rules (see section 3.4.2).

3.4.5 Parameterization

In order for the models to be site-specific for the case study and comparable, they were reparameterized to fit the study (see Table 10). For the Green Space Factor model, this meant that it was a change rather than a current situation that was implemented and that it is a projection. In addition to this, no further reparameterizations were carried out in Green Space Factor.

Table 10: Parameterization for Green Space Factor and NATURE Tool (ES = ecosystem service, n/a = not applicable) (WSP & Ecosystems Knowledge Network, 2022)

Parameter	Green Space Factor	NATURE Tool
Assessment type	n/a	Basic
Assessment scope	Change	Change
Assessment status	Projection	Projection
Expected completion year	n/a	2050
Duration of construction	n/a	20
Management duration	n/a	100
Assessment for the Ministry of Justice?	n/a	No
Project site location	n/a	England
Biodiversity	Assess	Assess
Supporting ES	Assess	Assess
Regulating ES	Assess	Assess
Provisioning ES	n/a	Don’t assess
Cultural ES	Assess	Assess
Photovoltaic carbon impact	n/a	Don’t assess

For NATURE Tool, a number of reparameterizations were carried out. To better match the amount of variables in the Green Space Factor model, the advanced assessment type was applied. To exclude variables developed specifically for prison environments, which the case study does not include, the parameter *Assessment for the Ministry of Justice?* was adjusted to No.

In NATURE Tool, a country within the United Kingdom was needed to be chosen for the presentation of model output in relation to current country policies. Since this part of the result was not relevant to the study, this input variable was randomized by selecting any country. The country sampled was England. Finally, the variables for provisioning ecosystem services and Photovoltaic carbon impact were removed from the model as these are not handled in Green Space Factor.

4. Results

In the study area Södertäljevägen, the results showed that the area prior to exploitation had natural environments of a total of 4,1 ha of which 2,3 ha can be defined as mixed deciduous forest, 0,2 ha pine forest, 0,2 ha rock outcrop, 0,6 ha urban grassland and 0,8 ha urban tree/grassland. The *No mitigation* scenario showed that a total of 1,8 ha of the habitat area would disappear if no additional mitigation measures were taken to those already made in the sketch alternative. Of these, it would mostly be mixed deciduous forest that would disappear (see Table 11).

Table 11: Relative change of habitat areas given no mitigations

Habitat type	Relative change (%)
Mixed deciduous forest	-55
Pine forest	-4
Rock outcrop	0
Urban grassland	-12
Urban tree/grassland	-29

The results also showed that the changes in natural capital values due to the *No mitigation* scenario compared to the *Pre-development* scenario was reflected differently in both models. While NATURE Tool showed a higher loss of total natural capital values and cultural ecosystem services, Green Space Factor showed a higher loss of biodiversity and regulating ecosystem services (see Table 12).

Table 12: Loss of natural capital values given no mitigations in each model

Natural capital type	Relative change (%) in Green Space Factor	Relative change (%) in NATURE Tool
Total	-48	-65
Biodiversity	-66	-45
Regulating ecosystem services	-60	-45
Cultural ecosystem services	-59	-82

4.1 Receiving net gain while mitigating poorly

The first question of the study concerns by how much it is possible to carry out a *Poor mitigation* approach and still receive a net gain result of +10%. The results of the study showed that it was possible, but not recommended according to the manual, in Green Space Factor.

In NATURE Tool, it was partly possible to carry out a *Poor mitigation* approach, however not for important habitat types. The reason was that the model didn't allow mixed deciduous forest to be replaced by a different habitat type due to its high biodiversity value.

Table 13 shows the natural capital value change from each natural capital and total natural capital change in the *Poor mitigation* scenario compared to the *Pre-development* scenario. The table illustrates that the total change as well as the regulating and cultural ecosystem services reached the net gain goal, while values for biodiversity did not.

In NATURE Tool, changes of total natural capital values and natural capital types were presented along each other. In Green Space Factor, however, only the total natural capital was displayed. The results thus also shows that the communication strategy for presenting results was more transparent in NATURE Tool compared to Green Space Factor.

Table 13: Natural capital value change in the Poor mitigation scenario compared to pre-development scenario (ES = ecosystem services)

Natural capital type	Relative change (%) in Green Space Factor	Relative change (%) in NATURE Tool
Total	+10	+10
Biodiversity	-16	-13
Regulating ES	+27	+25
Cultural ES	+39	+134

4.1.1 Poor mitigation measures

Table 14 describes the mitigation measures taken for each model given each level in the mitigation hierarchy. In Green Space Factor, this scenario was allowed without any obstacles. NATURE Tool, however, needed the lost biodiversity values for mixed deciduous forest and pine forest to be compensated to create at least no net loss. This meant that important habitat type (which was defined as a part of the equivalence principle) could not be declined in NATURE Tool.

Table 14: Mitigation measures needed for Poor mitigation scenario to reach net gain in the models compared to Pre-development scenario

Level	Mitigation measure in Green Space Factor	Mitigation measure in NATURE Tool
(1) Avoidance	None	None
(2) Minimization	None	None
(3) Restoration	All major natural areas were turned into parks with play areas, cultivation, paths, flowers Green roofs on houses were made accessible to the public Cultivation areas were created on all residential gardens, which made accessible to the public Tree- and grassland were created along roadsides to support new trees that enhance the experience of cityscape	All major natural areas were turned into parks with play areas, cultivation, paths, flowers Green roofs on houses were made accessible to the public Cultivation areas were created on all residential gardens, which made accessible to the public Tree- and grassland were created along roadsides to support new trees that enhance the experience of cityscape
(4) Compensation	A multifunctional park was created that provided values for recreation, cultivation, flowers and walking paths	A more accessible grassland was created with educational meetings and events that attract visitors Clearance by thinning, and laying of fauna depots in mixed deciduous forest Thinning, clearing and laying of fauna depots in pine forest

4.2 Compensation needed to reach net gain

The second question of the study concerns how many compensation measures were needed to reach net gain for the *Poor* and *Proper* scenarios. Since each model needed a certain amount of measures, different compensatory measures were implemented in the models. The results of the study showed that a compensation area of between 11-60 ha was needed to reach net gain, compared to the area that disappeared of 1,8 ha. The results also showed that Green Space Factor needed less space and fewer compensatory measures compared to NATURE Tool (see Table 15).

Table 15: Compensation area and measures needed to reach net gain in Poor and Proper scenarios compared to the Pre-development scenario

Model	Scenario	Needed area (ha)	Needed measures (no.)
Green Space Factor	Poor	12	4
	Proper	11	3
NATURE Tool	Poor	40,5	9
	Proper	60	7

4.2.1 Compensation measures

In Green Space Factor, the needed compensation area within the *Poor mitigation* scenario consisted of 12 ha grassland, while the area in the *Proper mitigation* scenario consisted of 11 ha mixed deciduous forest. In NATURE Tool, the compensation area needed within the *Poor mitigation* scenario consisted of 0,8 ha mixed deciduous forest, 0,5 ha pine forest and 32 ha grassland, while the area in the *Proper mitigation* scenario consisted of 8 ha mixed deciduous forest, 2 ha pine forest and 50 ha grassland. Within every compensation area, specific compensatory measures were taken (see Table 16).

Table 16: Mitigation measures needed for compensation in both models and both Poor and proper scenarios compared to Pre-development scenario

Scenario	Mitigation measure in Green Space Factor	Mitigation measure in NATURE Tool
Poor	Creation of multifunctional park that provides values for recreation, cultivation, flowers and walking paths	Creation of a more accessible grassland with educational meetings and events that attract visitors Clearance by thinning, and laying of fauna depots in mixed deciduous forest Thinning, clearing and laying of fauna depots in pine forest
Proper	Clearance by thinning and clearing, and laying of fauna depots in mixed deciduous forest	Clearance by thinning, and laying of fauna depots in mixed deciduous forest Thinning, clearing and laying of fauna depots in pine forest Creation of natural grazing on degraded grassland

4.3 Natural capital values for each level

The third question of the study concerns the proportion of natural capital values (NCV) that can be derived from each level of the mitigation hierarchy. The results of the study showed that the highest total change in natural capital is for restoration and compensation, given the net gain goal. However, avoidance, minimization and restoration were more space effective compared to compensation.

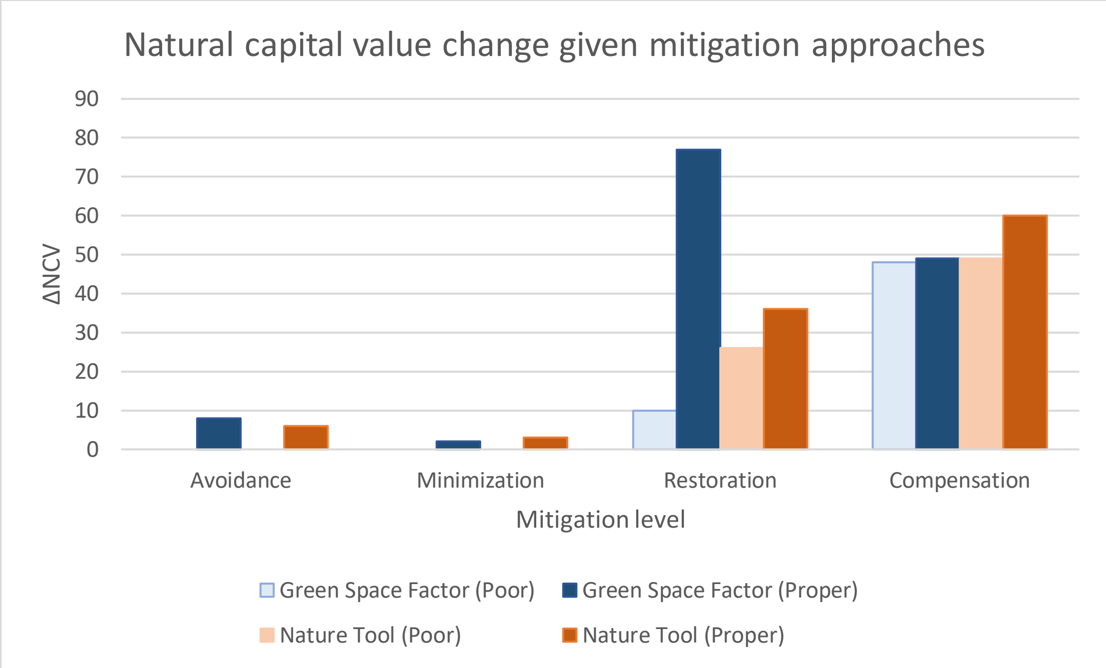

Figure 9: Natural capital value changes derived from each mitigation hierarchy level for Poor and Proper scenarios compared to the No mitigation scenario (see Table 10)

Figure 9 displays the natural capital values (NCV) change for every level in the mitigation hierarchy, showing that restoration and compensation gave a greater change. The figure also displays the difference between the *Poor* and *Proper mitigation* scenarios, showing that the restoration gave greater change in the *Proper mitigation* scenario compared to the *Poor mitigation* scenario. The natural capital value change is given for the entire study area, including the compensation area. The results can largely be explained by the fact that greater areas for restoration and compensation are mitigated, resulting in greater value changes.

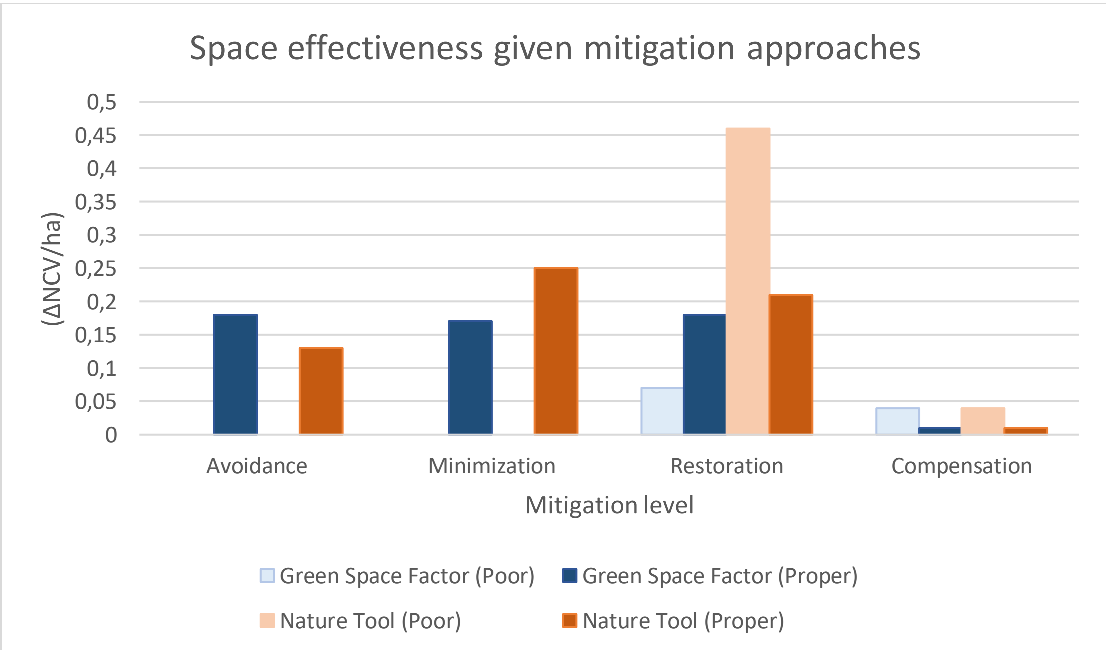

Figure 10: Space effectiveness for each mitigation hierarchy level given Poor and Proper scenarios compared to No mitigation scenario (see Table 10)

Figure 10 displays the natural capital value (NCV) change for every level, standardized to change in value per ha. This means that the natural capital value change represented the space effectiveness for the mitigation measure, regardless of the total area. For both scenarios, it is shown that the first three levels, i.e. avoidance, minimization and restoration were more surface efficient compared to compensation. The figure also displays the difference between the *Poor* and *Proper mitigation* scenarios, showing that the restoration had a greater variability in the *Poor mitigation* scenario.

4.3.1 Avoidance

For the *Poor mitigation* scenario, no mitigation measures were taken for avoidance. For the *Proper mitigation* scenario, however, an area of 0,5 ha consisted of mixed deciduous forest in the southwestern part of the plan area is avoided. The mitigation measure consisted of not building three of the proposed houses (see Table 10).

Since no mitigation action was implemented in the *Poor mitigation* scenario, there was no change in habitat area or natural capital values. In the *Proper mitigation scenario*, however, the results showed that the mitigation measures gave a greater natural capital change for cultural ecosystems in both models (see Table 17).

Table 17: Changes in natural capital values due to avoidance in both models compared to No mitigation scenario (n/a = not applicable)

Natural capital type	Change (%) in Green Space Factor	Change (%) in NATURE Tool
Poor mitigation		
Total	±0	±0
Biodiversity	±0	±0
Regulating ecosystem services	±0	±0
Cultural ecosystem services	±0	±0
Proper mitigation		
Total	+8	+6
Biodiversity	+2	+18
Regulating ecosystem services	+4	+12
Cultural ecosystem services	+9	+39

4.3.2 Minimization

For the *Poor mitigation* scenario, no mitigation measured were taken for minimization. For the *Proper mitigation* scenario, however, minimization measures of 0,1 ha were implemented in the planning area by proposing changes in the design of certain structures. The actions consisted of redesigning houses and roads to preserve especially valuable trees and areas pointed out by the data (see Table 10).

Since no mitigation action was implemented in the *Poor mitigation* scenario, there was no change in habitat area or natural capital values. In the *Proper mitigation scenario*, however, the results showed that the mitigation measures gave a greater natural capital change for total change and regulating ecosystem services within Green Space Factor and total change within NATURE Tool (see Table 18).

Table 18: Changes in natural capital values due to minimization in both models compared to No mitigation scenario (n/a = not applicable)

Natural capital type	Change (%) in Green Space Factor	Change (%) in NATURE Tool
Poor mitigation		
Total	±0	±0
Biodiversity	±0	±0
Regulating ecosystem services	±0	±0
Cultural ecosystem services	±0	±0
Proper mitigation		
Total	+2	+3
Biodiversity	+1	+2
Regulating ecosystem services	+2	+2
Cultural ecosystem services	+1	+1

4.3.3 Restoration

For the *Poor mitigation* scenario, a total habitat area of 1,4 ha within the study area was restored by creating multifunctional parks, lush roofs, cultivation areas and a lush cityscape. All surfaces were made accessible to the public. For the *Proper mitigation* scenario, a total of 1,7 ha of habitat areas within the plan area was restored by, among other things, creating multifunctional parks, plant beds along street, multifunctional gardens and an ecoduct (see Table 10).

In the *Poor mitigation scenario*, the results showed that the mitigation measures gave a greater natural capital change for cultural ecosystem services within Green Space Factor and NATURE Tool. In the *Proper mitigation scenario*, the mitigation measures gave a greater natural capital change for total change within both Green Space Factor and NATURE Tool (see Table 19).

Table 19: Changes in natural capital values due to restoration in both models compared to No mitigation scenario

Natural capital type	Change (%) in Green Space Factor	Change (%) in NATURE Tool
Poor mitigation		
Total	+10	+26
Biodiversity	+5	+5
Regulating ecosystem services	+30	+3
Cultural ecosystem services	+55	+45
Proper mitigation		
Total	+77	+36
Biodiversity	+15	+3
Regulating ecosystem services	+48	+13
Cultural ecosystem services	+52	+4

4.3.4 Compensation

For the *Poor mitigation* scenario, a total habitat area of 12 ha consisting of grassland outside the study area was compensated in Green Space Factor. Meanwhile, a total habitat area of 40,5 ha consisting of grassland, mixed deciduous forest and pine forest was compensated in NATURE Tool. For the *Proper mitigation* scenario, a total of 11 ha of habitat areas consisting of mixed deciduous forest was compensated in Green Space Factor. Meanwhile, a total habitat area of 60 ha consisting of mixed deciduous forest and pine forest was compensated in NATURE Tool (see Table 10).

In the *Poor mitigation scenario*, the results showed that the mitigation measures gave a greater natural capital change for cultural ecosystem services within both Green Space Factor and NATURE Tool. In the *Proper mitigation scenario*, the mitigation measures also gave a greater natural capital change for cultural ecosystem services within both Green Space Factor and NATURE Tool (see Table 20).

Table 20: Changes in natural capital values due to compensation in both models compared to No mitigation scenario

Natural capital type	Change (%) in Green Space Factor	Change (%) in NATURE Tool
Poor mitigation		
Total	+48	+49
Biodiversity	+48	+24
Regulating ecosystem services	+55	+15
Cultural ecosystem services	+234	+76
Proper mitigation		
Total	+49	+60
Biodiversity	+58	+87
Regulating ecosystem services	+40	+28
Cultural ecosystem services	+96	+103

5. Discussion

The study's results showed that the models could generate relatively high natural capital values also for poor mitigation approaches, and that needed compensation measures differed greatly between the models. The study also showed how the earlier levels of the mitigation hierarchy are more space efficient, however, that compensation may be a crucial role to reach net gain. An interpretation of the results, as well as what this means in a wider sense, is here discussed.

5.1 Need for further model calibrations

By comparing the results between the models, it is clear that they gave different natural capital values for the same mitigation measures. The results thus points to a gap between the models when comparing them. This also points to an uncertainty about which of the models reflects reality to the greatest extent. This indicates a need for further calibration of the models based on observational data on a large-scale.

The difficulty, however, is that there is currently no observed data on natural values derived from specific mitigation hierarchy steps that can be directly compared to the model output. Thus, it is not possible to conduct such studies. The next step needs to be to collect such data so that the models have observed values to be calibrated by.

5.2 Assessing data uncertainty

A common source of uncertainty for studies that assess natural capital spatially is linked to the input data used (Hou et al, 2013). The study uses both observed data and data based on expert judgements in investigations. The data was retrieved from a range of institutions such as government, municipalities, consultancy companies and academic institutions. The quality of the data therefore varies between different data sources, which leads to an uncertainty that is reflected through the model and to its output.

The data linked to the site-specific investigations have a higher degree of detail but are also produced to a greater degree by expert assessments that have a greater risk of uncertainty linked to subjectivity. On the other hand, input data linked to observed data from government and academic institutions generally have lower uncertainty linked to subjectivity, but higher uncertainty linked to lower level of detail. Because of these uncertainties, the results of the models should be seen as a projection rather than a prediction. This is generally in line with what has been demonstrated by similar previous studies (Carpenter et al., 2006).

5.3 Assessing knowledge gaps

Another common source of uncertanity linked to studies that assess natural capital spatially is linked to the complexity of socio-ecological systems on a landscape level (Hou et al., 2013). The changes and drivers are complex, operate at different spatial and temporal levels, which makes them difficult to assess in studies. The state of knowledge is therefore still relatively low (Mace et al., 2012). This is especially true of the later levels of the mitigation hierarchy (EPA, 2018; IUCN, 2014). There are even scientific reports suggesting compensation is impossible from a biocentric perspective (Justus et al., 2009).

In 2021, the Journal of Biological Conservation (Josefsson et al., 2021) published a paper stating that compensation as a mitigation measure so far is scientifically unproven. Since there so far are no observed natural values derived from compensation in scientific research, the measure lacks scientific support and has great uncertainty. At the same time, EPA (2018) highlights offsetting as a substantial potential for achieving environmental goals. This gives an indication that the study results about the potential benefits about compensation being crucial but ineffective may be in line with the current scientific picture. Although, since there is no observed data to compare the modelled values with, it is not certain to say. More studies assessing this are needed to create a consensus.

In NATURE Tool, the uncertainty for compensation is somewhat assessed by multiplying a risk factor into compensation that results in a larger needed compensation area compared to the previous levels in the mitigation hierarchy. This may result in lower uncertainty in the output of the model. The Green Space Factor, however, does not provide any similar assumptions. Therefore, there is an indication NATURE Tool may handle this more in line with current research.

Another uncertainty associated with low research support for mitigation hierarchy is the trade-offs made between and for the equivalency- and proximity principles (EPA 2016). The equivalence principle means that approximately the same values that are lost should be replaced. But how these values are defined differs between studies (Quetier et al., 2014). To deal with this issue in the study, assumptions are made that were expected to affect the outcome greatly. These are that equivalent values imply important habitat type and natural capital type.

NATURE Tool has an integrated an equivalence principle for the habitat type were certain important habitat types needs to be restored or compensated with a similar one. For Green Space Factor, it is not integrated in the model. Regarding natural capital type, there is no specific integration in either model. However, while NATURE Tool directly displays the results for each natural capital type more transparently, Green Space Factor displays pie charts indicating each natural capital types. It is also debatable to what extent cultural ecosystems indirectly impact biodiversity. In Green Space Factor, for example, cultural ecosystem variables give higher scores for species-rich environments (C/O City, 2018).

Finally, a net goal of +10% was chosen for both *Poor* and *Proper mitigation* scenarios. This was selected based on what was considered reasonable. A lower percentage was considered uncertain given that the uncertainty of the models had not previously been assessed in scientific studies. The risk that the models could overestimate natural capital values meant that the actual outcome may in fact not be a net gain at all. A higher percentage was considered unreasonable given the project's conditions. However, exactly which percentage is the most reasonable is still unclear from a scientific perspective (Maron et al, 2018).

5.4 Model simplicity and complexity

In the study, two out of several possible models were selected based on their ability to be site-specific and simple. The choice was based on a report on indications of what is valuable in the industry (C/O City, 2022b). The results of the study could have been different if another or more models, such as ESTER and InVEST, had been selected. Since only the Green Space Factor and NATURE Tool were analyzed, only these two can be compared.

In Green Space Factor, habitat types seem to be classified more generally. Further information about the habitats was instead supplemented manually by inserting data of habitat areas associated with specific natural capital. By a simple calculation (see section 2.1.1), the given net goal could be tested and easily reached. In NATURE Tool, on the other hand, habitat types were classified more specifically based on biotopes. Each biotope automatically got assigned values, which were then supplemented with less complementary data to give a comparison between the *Pre-development* and *No mitigation* scenarios. However, NATURE Tool included more complex calculations, including positive and negative feedback loops, meaning reaching certain net goals for specific natural capital seemed to be more difficult to manage.

This meant that it seemed to be easier in NATURE Tool to compare *Pre-development* and *No mitigation* scenarios, however, more difficult to reach specific net goals given *Poor* or *Proper mitigation* approaches. In Green Space Factor, on the other hand, it was more difficult to make the first comparison given large amounts of data, but easier to reach the net goal through the *Poor* and *Proper mitigation* scenarios.

Another aspect important to consider is the geographical scale the variables handle. In NATURE Tool, variables linked to total habitat areas are managed, while Green Space Factor provides the opportunity for variables on a much smaller scale and thus higher spatial resolution.

These arguments point to different strengths and weaknesses in terms of simplicity and complexity for both models. However, one subjective indication is that NATURE Tool may be suitable at earlier stages in the planning process and for larger areas such as detailed development plans, plan programs, infrastructure plans or even comprehensive plans. The task of NATURE Tool could then be to provide a first indication of natural capital losses given different sketch alternatives.

Green Space Factor may on the other hand be better suited at a later stage such as in the projecting stage for detailed development plans or residential courtyards, where it is possible to go into more detail in terms of design. The task of Green Space Factor could then be to reach certain goals, such as no net loss, net gain or a specific GYF quota.

5.5 Future mitigation methods

The application of the mitigation hierarchy in natural capital models is a mitigation strategy for managing natural capital quantitatively. The mitigation hierarchy as a mitigation strategy was selected based on the given the state of research today. However, which mitigation strategy is the best for reaching environmental goals has long been a topic of scientific discussion (Costanza et al., 2014; De Groot et al., 2010).

Whether the quantitative valuation is the most appropriate method is debatable since natural capital are values derived from socio-ecological systems that also have a qualitative aspect. It is not self-evident that the need for certain natural values in a place can be quantified or ruled directly in the model. Just because a place loses, for example, many recreational values does not mean that recreation is the main natural capital that the place needs. It is possible that a qualitative aspect of this is needed that is best captured in ways other than figures. One way to deal with such qualitative assessments could be through developing strategic documents at a municipal or regional level.

Another mitigation method to discuss is how compensation areas can be defined and measures delivered. Today, deliveries of compensation are made on a project-by-project basis, which makes it possible, but costly, to match the methods very well according to the equivalence- and proximity principles. At the same time, a new proposed method through so-called habitat banks has been investigated, which means that compensatory measures are delivered through a central bank (EPA, 2016). There is an indication that this creates a larger market and increased efficiency for compensatory measures, but so far there are no scientific studies on how this can impact mitigations based on the equivalence- and proximity principles.

5.6 Future decision-making

The outcome of the natural capital changes in the planning process depends on trade-offs between natural capital and other interests. It is therefore not certain that natural capital in the future will be seen as a priority.

In 2016, the previous Swedish government appointed an inquiry into measures for greater application of compensation in response to an increased need in the Swedish context. The inquiry proposed, among other things, that ecological compensation should receive greater legal support and that other delivery methods for compensation should be tested in Sweden, such as habitat banks.

However, since the report was published, the proposals have not been taken further in the Swedish government (EPA, 2023). According to the Swedish Prime Minister's Office, neither natural capital, biodiversity or ecosystem services is political priority for the current Swedish government (Stadsrådsberedningen, 2022).

While there are indications that natural capital generally is not sufficiently assessed and managed, there is a wide global consensus about the need for managing natural capital losses by applying the mitigation hierarchy with net gain as the goal (see for example Millennium Ecosystem Assessment, 2005; IPBES, 2007). Where these tendencies will lead practitioners, the future will tell.

What can be said about not valuing nature, however, is that it is a valuation in itself. To start valuing nature, even with discussable definitions and rules, may in any case be a step closer to managing natural capital losses. And managing them is a crucial component to how we can achieve the given environmental goals for a sustainable future (IPBES, 2007).

6. Conclusion

The first conclusion is that NATURE Tool did not allow poor mitigations to the same degree as Green Space Factor and that NATURE Tool presented the results more transparently. At the same time, poor mitigations would not have been possible if the recommendations in the manuals were followed. Furthermore, it is debatable whether the definition of poor mitigations in the models gives actual poor mitigations in reality.

The second conclusion is that Green Space Factor needed less area and fewer compensatory measures given the net gain goal compared to NATURE Tool, indicating that either Green Space Factor was underestimating, or NATURE Tool was overestimating the natural capital values.

The third conclusion is that the total natural capital value change due to the mitigation hierarchy levels was highest for compensation compared to the earlier levels in mitigation hierarchy (avoidance, minimization and restoration). However, the previous levels were more space efficient compared to compensation. This shows that although the previous levels are more effective, compensation can play an important role in reaching net gain.

References

Bull, J. W., Gordon, A., Watson, J. E. M., & Maron, M. (2016). Seeking Convergence on the Key Concepts in "No Net Loss' Policy. Journal of Applied Ecology, 53(6), 1686- 1693

Business and Biodiversity Offsets Programme. (2018). The BBOP Principles on Biodiversity Offsets (BBOP). URL: https://www.forest-trends.org/wp-content/uploads/2018/10/The-BBOP-Principles_20181023.pdf (Accessed 6 February 2023)

C/O City. (2022a). Ekosystemtjänster i Stadsplanering – en Vägledning 2.0. URL: https://www.cocity.se/wp-content/uploads/2023/03/ekosystemtjanster-i-stadsplanering_low.pdf (Accessed: 20 March 2023)

C/O City. (2022b). QGYF Grönytefaktor i GIS – En Erfarenhetsåterföring. URL: https://www.cocity.se/wp-content/uploads/2022/06/erfarenhetsaterforing_qgyf_slutversion-komprimerad.pdf (Accessed: 20 March 2023)

C/O City. (2018). Grönytefaktor för Allmän Platsmark 2.0. URL: https://www.cocity.se/wp-content/uploads/2018/06/gyf-ap-20-manual_lagupplost.pdf (Accessed: 10 May 2023)

Carpenter, S., Bennett, E., Peterson, G. (2006). Scenarios for Ecosystem Services: An Overview. Ecology & Society, 11(1), 29

City of Stockholm. (n.d.). Air Pollution Map [Dataset]. URL: https://www.slb.nu/slbanalys/luftfororeningskartor/

City of Stockholm. (2016). Habitatnätverk – Groddjur. [Dataset]. URL: https://dataportalen.stockholm.se/dataportalen/?SplashScreen=No

City of Stockholm. (2017). ESBO 2017 – Ekologiskt Särskilt Betydelsefulla Områden. [Dataset]. URL: https://dataportalen.stockholm.se/dataportalen/?SplashScreen=No

City of Stockholm. (2019). Biotopkartan 2019 – Biotoper. [Dataset]. URL: https://dataportalen.stockholm.se/dataportalen/?SplashScreen=No

City of Stockholm. (2022). SBK Sociotopkartan – Kvaliteter i Parker, Natur och andra Offentligt Tillgängliga Områden. Dataset. URL: https://dataportalen.stockholm.se/dataportalen/?SplashScreen=No

City of Stockholm. (2023). Södertäljevägen får nya Urbana Stadstrum. URL: https://vaxer.stockholm/projekt/sodertaljevagen-far-nya-urbana-stadsrum/ (Accessed: 2 Mars 2023)

Costanza, R., De Groot, R., Sutton, P., Van Der Ploeg, S., Anderson, S., Kubiszewski, I., Farber, S., Turner, R. (2014). Changes in the Global Value of Ecosystem Services. Global Environmental Change, 26, 152-158

Daily, G, Ehrlich, P., Kennedy, D., Matson, P., Costanza, R., Nabhan, G., Lubchenco, Postel, S., Myers, N. (1997). Nature's Services: Societal Dependence on Natural Ecosystems. Nature. Washington, DC: Island Press. 1-392

Daily, G., Polasky, S., Goldstein, J., Kareiva, P., Mooney, H., Pejchar, L., Ricketts, T., Salzman, J., Shallenberger, R. (2009). Ecosystem Services in Decision Making: Time to Deliver. Frontiers in Ecological Environment, 7(1), 21-28

De Groot, R., Alkemade, R., Braat, L., Hein, L., Willemen, L. (2010). Challenges in Integrating the Concept of Ecosystems, Services and Values in Landscape Planning, Management and Decision-making. Ecological Complex, 7, 260-272

Ekologigruppen. (2020a). Ekologisk Spridningsutredning för Centrala Liljeholmen. [Unpublished Dataset]

Ekologigruppen. (2020b). Naturvärdesinventering Liljeholmen. [Unpublished Dataset]

Ekologigruppen. (2021). Konsekvensbedömning. [Unpublished Dataset]

Environment Act 2021 (2021 Chapter 30). Office of Environmental Protection. URL: https://www.legislation.gov.uk/ukpga/2021/30/introduction/enacted (Accessed: 31 January 2023)

Environmental Code. (SFS 1998:808). Klimat- och Näringslivsdepartementet. URL: https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/miljobalk-1998808_sfs-1998-808 (Accessed: 31 January 2023)

EPA. (n.d.). Designated Nature Map. [Dataset] URL: https://www.naturvardsverket.se/verktyg-och-tjanster/kartor-och-karttjanster/kartverktyget-skyddad-natur/

EPA. (2016). Ekologisk Kompensation: En Vägledning om Kompensation vid Förlust av Naturvärden (978-91-620-0179-7). URL: https://www.naturvardsverket.se/om-oss/publikationer/0100/ekologisk-kompensation/ (Accessed: 6 February 2023)

EPA. (2018). Guide to Naluing Ecosystem Services (6854). URL: https://www.diva-portal.org/smash/get/diva2:1501652/FULLTEXT01.pdf (Accessed: 31 January 2023)

EPA. (2020a). Global Utvärdering av Biologisk Mångfald och Ekosystemtjänster (978-91-620-6917-9). URL: https://www.naturvardsverket.se/om-oss/publikationer/6900/global-utvardering-av-biologisk-mangfald-och-ekosystemtjanster/ (Accessed: 10 May 2023)

EPA. (2020b). Sveriges Arter och Naturtyper i EU:s Art- och Habitatdirektiv: Resultat från Rapportering 2019 till EU av Bevarandestatus 2013-2018 (978-91-620-

6914-8). URL: https://www.naturvardsverket.se/om-oss/publikationer/6900/sveriges-arter-och-naturtyper-i-eus-art--och-habitatdirektiv#:~:text=2019%20rapporterade%20Sverige%20statusen%20till,som%20i%20andra%20EU%2Dl%C3%A4nder. (Accessed: 15 March 2023)

EPA. (2023). Ekologisk Kompensation som Verktyg i Miljömålsarbetet (7103). URL: https://www.naturvardsverket.se/496636/globalassets/media/publikationer-pdf/7100/978-91-620-7103-5.pdf (Accessed: 10 May 2023)

Guerry, A., Polasky, S., Lubchenco, J., Chaplin-Kramer, R., Daily, G., Griffin, R., Ruckelshaus, M., Bateman, J., Duralappah, A., Elmqvist, T., Feldman, M., Folke, C., Hoekstra, J., Kareiva, P., Keeler, B., Li, S., McKenzie, E., Ouyang, Z., Reyers, B., Ricketts, T., Rockström, J., Tallis, H., Vira, B. (2015). Natural Capital and Ecosystem Services Informing Decisions: From Promise to Practice. Biological Sciences, 112(24), 7348-7355

Hamby, D. (1994). A Review of Techniques for Parameter Sensitivity Analysis of Environmental Models. Environmental Monitoring av Assessment, 32, 135-154

HM Government. (2021). A Green Future: Our 25 Year to Improve the Environment. URL: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf (Accessed: 31 January 2023)

Hou, Y., Burkhards, B., Müller, F. (2013). Uncertainties in Landscape Analysis and Ecosystem Service Assessment. Journal of Environmental Management, 127, 117-131

IPBES. (2019). Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany. URL: https://www.ipbes.net/global-assessment (Accessed: 10 May 2023)

IUCN. (2014). Biodiversity Offsets: Technical Study Paper. Gland, Switzerland: IUCN. URL: https://portals.iucn.org/library/sites/library/files/documents/2014-044.pdf (Accessed: 6 February 2023)

IUCN. (2015). Net Positive Impact for Biodiversity: The Conservation Case (IUCN). Gland, Switzerland: IUCN. URL: https://www.iucn.org/sites/default/files/import/downloads/npi__conservation__01_2016_1.pdf (Accessed: 27 February 2023)

Jacob, C., Vaissiere, A., Bas, A., Calvet, C. (2016). Investigating the Inclusion of Ecosystem Services in Biodiversity Offsetting. Ecosystem Services 21(A), 92-102

Josefsson, J., Widenfalck, L., Blicharska, M., Hedblom, M., Pärt, T., Ranius, T., Öckinger, E. (2021). Compensating for Lost Nature Values through Biodiversity Offsetting – Where is the Evidence? Biological Conservation, 257, 109-117

Justus, J., Colyvan, M., Regan, H., & Maguire, L. (2009). Buying into Conservation: Intrinsic Versus Instrumental Value. Trends in Ecology & Evolution, 24(4), 187-191

Kelemen, E., Hauck, J. (2015). Scenario Planning. In: Kelemen, E., Jacobs, S., Barton, D., Martin-Lopez, B., Saarikoski, H., Termansen, M., Bela, G., Braat, L., Demeyer, R., Garcia-Llorente, M., Gomez-Baggethun, E., Hauck, J., Keune, H., Luque, S., Palomo, I., Pataki, G., Potschin, M., Schleyer, C., Tenerilli, P., Turkelboom, F. Preliminary Guidelines for Integrated Assessment and Valuation of Ecosystem Services in Specific Policy Contexts. EU: FP7 OpenNESS Project Deliverable 4.3

Kiesecker, J., Copeland, H., Pocewicz, A., McKenney, B. (2010). Development by Design: Blending Landscape-Level Planning with the Mitigation Hierarchy. Frontiers in Ecology and Environment. 8(5). 261-266

KMV forum. (2020). Södertäljevägen, del av Liljeholmen: Kulturmiljöanalys. [Unpublished Dataset]

Lantmäteriet. (1960). Ekonomiska Kartan. View Service, Cache. [Dataset] URL: https://historiskakartor.lantmateriet.se/hk/positionsearch?e=671092&n=6578836

Lantmäteriet. (2023). Topographic Web Map View Service, Cache. [Dataset] URL: https://www.lantmateriet.se/globalassets/geodata/geodatatjanster/e_pb_twk_visn_cache_v1.1.0_1.15.pdf

Lantmäteriet/Metria. (2023). Imagery. CNES/Airbus. [Dataset] URL: https://www.google.cn/maps/vt?lyrs=s@189&gl=cn&x={x}&y={y}&z={z}

Mace, G., Norris, K., Fitter, A. (2012). Biodiversity and Ecosystem Services: A Multilayered Relationship. Trends in Ecology and Evolution, 27(1), 19-26

Maron, M., Brownlie, S., Bull, J., Evans, M., Hase, A., Quetier, F., Watson, J., Gordon, A. (2018). The Many Meanings of No Net Loss in Environmental Policy. Nature Sustainability, 1, 19-27

Millennium Ecosystem Assessment. (2005). Ecosystems and Human Well-being: Synthesis. Reid, V., Mooney, H., Cropper, A., Capistrano, D., Carpenter, S., Chopra, K., Dasgupta, P., Dietz, T., Kumar Duraiappah, A., Hassan, R., Kasperson, R., Leemans, R., May, R., McMichael, T., Pingali, P., Samper, C., Scholes, R., Watson, R., Zakri, A., Shidong, Z., Ash, N., Bennett, E., Kumar, P., Lee, M., Raudsepp-Hearne, C., Simons, H., Thonell, J., Zurek, M. Washington, DC: Island Press URL: https://www.millenniumassessment.org/documents/document.356.aspx.pdf (Accessed: 10 May 2023)

Ministry of Housing, Communities & Local Government. (2021). National Planning Policy Framework. URL:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1005759/NPPF_July_2021.pdf (Accessed: 31 January 2023)

Natural Capital Project. (n.d.) InVEST. URL: https://naturalcapitalproject.stanford.edu/software/invest (Accessed: 10 February 2023)

Natural England. (2021). The Biodiversity Metric 3.1 (JP039). URL: http://publications.naturalengland.org.uk/publication/6049804846366720 (Accessed: 13 February 2021)

Newman, P., Thornley, A. (1996). Urban Planning in Europe: International Competition, National Systems and Planning Projects. Routledge, 1-278

Perrings, C., Jackson, L., Bawa, K., Brussaard, L., Brush, S., Gavin, T., Papa, R., Pascual, U., Ruiter, P. (2006). Biodiversity in Agricultural Landscapes: Saving Natural Capital without losing Interest. Conservation Biology, 20(2), 263-26

Planing and Building Act. (SFS 2010:900). Landsbygds- och Infrastrukturdepartementet. URL: https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/plan--och-bygglag-2010900_sfs-2010-900 (Accessed: 31 January 2023)

Polasky, S., Carpenter, S., Folke, C., Keeler, B. (2011). Decision-making under Great Uncertainty: Environmental Management in an Era of Global Change. Trends in Ecology and Evolution, 26(8), 398-404

Quetier, F., Regnery, B., Levrel, H. (2014). No Net Loss of Biodiversity or Paper Offsets? A Critical Review of the French No Net Loss Policy. Environmental Science Policy. 38. 120-131

Ramboll. (2020). Dagvattenutredning för Södertäljevägen. [Unpublished Dataset]

Rees, W. (1997). Urban Ecosystems: The Human Dimension. Urban Ecosystems, 1, 63-75

Rio Tinto. (2008). Rio Tinto and Biodiversity: Achieving Results on the Ground. URL: https://bobbloomfield.files.wordpress.com/2013/03/2008riotintobi%20doversitystrategy.pdf. (Accessed: 31 January 2023)

Sandström, U. (2002). Green Infrastructure Planning in Urban Sweden. Planning Practice & Research, 17(4), 373-385

SMHI. (2023). Runoff Data. [Dataset]. URL: https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer/#param=precipitation24HourSum,stations=core,stationid=98210 (Accessed: 10 May 2023)

Smith, J., Smith, P. (2007). Environmental Modelling: An Introduction. Oxford University Press, 1-256.

Stadsrådsberedningen. (2022). Regeringens Politiska Prioriteringar. URL: https://www.regeringen.se/contentassets/d6ad6308cc984aa1903d9a542ce1421c/regeringsforklaringen-2022.pdf (Accessed: 9 May 2023)

Structor. (2021). Södertäljevägen, Stockholm Stad: Omgivningsbuller. [Unpublished Dataset]

Sweco. (2019). Eknätverket vid Nybohovsskolan – Spridningsanalys för Eklevande Insekter. [Unpublished Dataset]

Tankesmedjan Movium vid SLU. (2021). Utvärdering av ESTER. URL: https://www.movium.slu.se/system/files/news/15133/files/ESTER_Final2021-05-25_rev210614.pdf (Accessed: 10 February 2023)

Tarabon, S., Berges, L., Dutoit, T., Isselin-Nondedeu, F. (2019). Maximizing Habitat Connectivity in the Mitigation Hierarchy. A Case Study on the Terrestrial Mammals in Urban Environment. Journal of Environmental Management. 243. P. 340-349

The Swedish National Board of Housing, Building and Planning. (2019). Rumsliga Förutsättningar för Ekosystemtjänster i den Byggda Miljön – Förslag på Metod för Uppföljning, Indikatorer och Dataunderlag (Boverket, mars, 2019). URL: https://www.boverket.se/globalassets/publikationer/dokument/2019/rumsliga-forutsattningar-for-ekosystemtjanster.pdf (Accessed: 27 February 2023)

The Swedish National Board of Housing, Building and Planning. (2019). Typer av Ekosystemtjänster. URL: https://www.boverket.se/sv/PBL-kunskapsbanken/teman/ekosystemtjanster/det_har/typer/ (Accessed: 23 May 2023)

The Swedish National Board of Housing, Building and Planning. (2020a). Ekosystemtjänster och Allmänna Intressen. URL: https://www.boverket.se/sv/PBL-kunskapsbanken/teman/ekosystemtjanster/pbl/allmanna/ (Accessed: 24 May 2023)

The Swedish National Board of Housing, Building and Planning. (2020b). Guide för Detaljplaneprocessen. URL: https://www.boverket.se/sv/om-boverket/guider/hur-en-detaljplan-tas-fram/ (Accessed: 8 February 2023)

The Swedish National Board of Housing, Building and Planning. (2021). Så planeras Sverige. https://www.boverket.se/sv/samhallsplanering/sa-planeras-sverige/ (Accessed: 31 January 2023)

The Swedish National Board of Housing, Building and Planning. (2022). ESTER – Verktyg för Kartläggning av Ekosystemtjänster. https://www.boverket.se/sv/PBL-kunskapsbanken/teman/ekosystemtjanster/verktyg/ester/ (Accessed: 11 May 2023)

Wende, W., Tucker, G., Quétier, F., Rayment, M., Darbi, M. (2018). Biodiversity Offsets. 1st ed. Springer.

WSP. (2019). Stärkt Grön Infrastruktur i Mellersta Söderort – Förstärkningsåtgärder och Strategier. [Unpublished Dataset]

WSP. (2021). NATURE Tool Case Study Report for Malmi District, Helsinki, Finland. URL: https://nature-tool.com/?page_id=341 (Accessed: 13 February 2023)

WSP & Ecosystems Knowledge Network. (2022). Introduction, User Guide & Methods for NATURE Tool Version 1.1 BETA. URL: https://nature-tool.com/?page_id=214 (Accessed: 20 March 2023)

WSP & Stockholm stad. (2021). NATURE Tool Case Study Report for Royal Seaport, Stockholm, Sweden. URL: https://nature-tool.com/?page_id=326 (Accessed: 13 February 2023)

Appendix A: Geographical data

Appendix A presents the spatial data used for the analysis. It also illustrates the variation of values the data has within the study area. The data is retrieved and illustrated by me in QGIS, a geographic information software, and may therefore differ slightly from the original source.

Biotope map

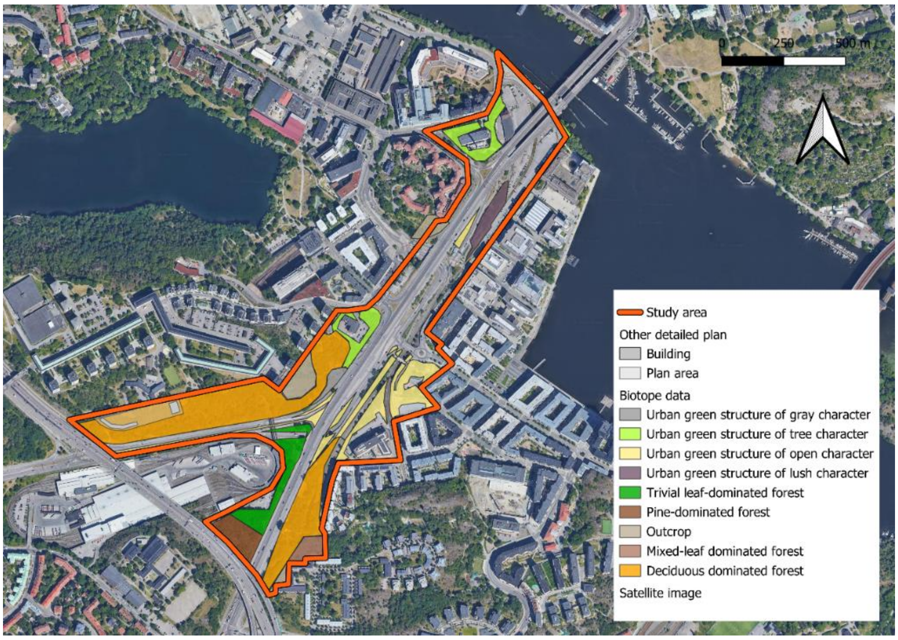

Figure 8: Biotope classification in the Biotope map. Modified from City of Stockholm (2019) and Lantmäteriet/Metria (2023)

References:

City of Stockholm. (2019). Biotopkartan 2019 – Biotoper. [Dataset]. URL: https://dataportalen.stockholm.se/dataportalen/?SplashScreen=No

Lantmäteriet/Metria. (2023). Imagery. CNES/Airbus. [Dataset] URL: https://www.google.cn/maps/vt?lyrs=s@189&gl=cn&x={x}&y={y}&z={z}

Nature Value Map

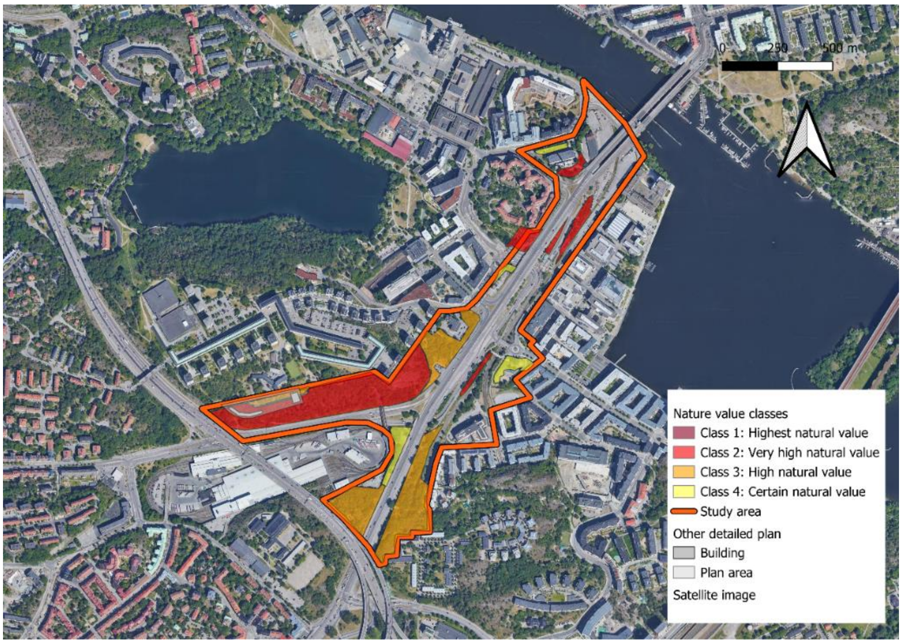

Figure 9: Nature Value classification in the Nature Value Inventory. Modified from Ekologigruppen (2020b) and Lantmäteriet/Metria (2023)

References:

Ekologigruppen. (2020b). Naturvärdesinventering Liljeholmen. [Unpublished Dataset]

Lantmäteriet/Metria. (2023). Imagery. CNES/Airbus. [Dataset] URL: https://www.google.cn/maps/vt?lyrs=s@189&gl=cn&x={x}&y={y}&z={z}

Map of valuable trees

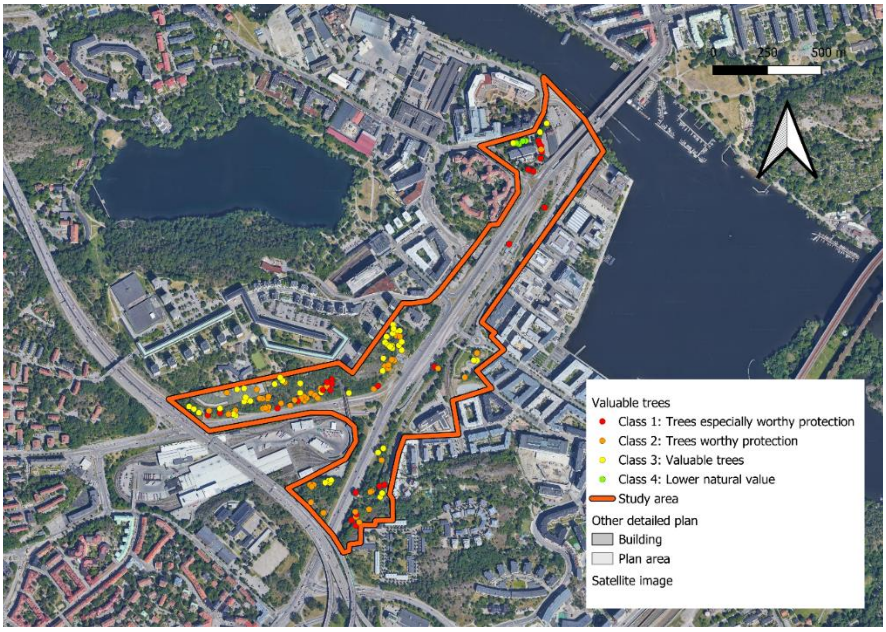

Figure 10: Classification of valuable tress in the Nature Value Inventory. Modified from Ekologigruppen (2020b) and Lantmäteriet/Metria (2023)

References:

Ekologigruppen. (2020b). Naturvärdesinventering Liljeholmen. [Unpublished Dataset]

Lantmäteriet/Metria. (2023). Imagery. CNES/Airbus. [Dataset] URL: https://www.google.cn/maps/vt?lyrs=s@189&gl=cn&x={x}&y={y}&z={z}

Map of dispersal investigations

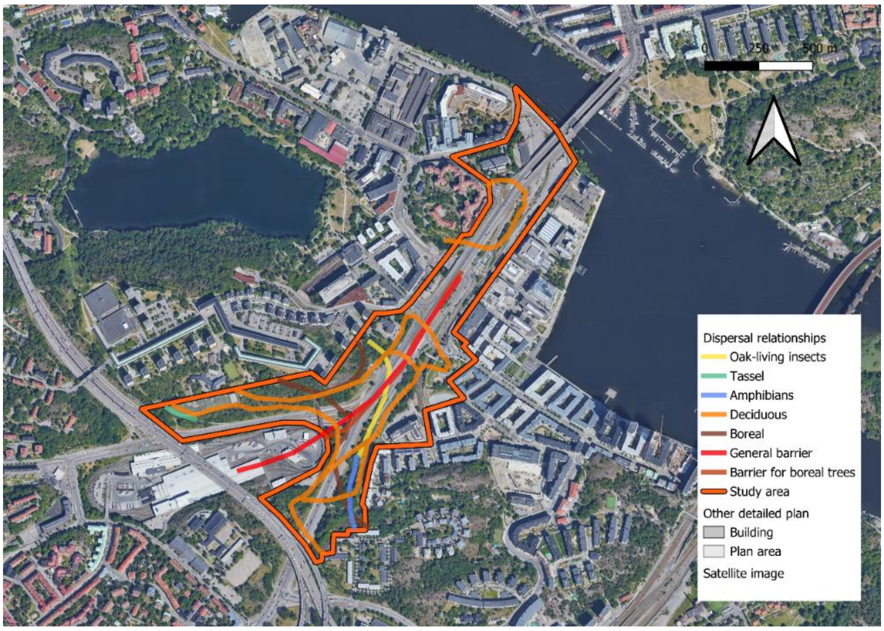

Figure 11: Dispersal classifications in the Dispersal investigations. Modified from Ekologigruppen (2020a), WSP (2019), City of Stockholm (2016), Sweco (2019) and Lantmäteriet/Metria (2023)

References:

City of Stockholm. (2016). Habitatnätverk – Groddjur. [Dataset]. URL: https://dataportalen.stockholm.se/dataportalen/?SplashScreen=No

Ekologigruppen. (2020a). Ekologisk Spridningsutredning för Centrala Liljeholmen. [Unpublished Dataset]

Lantmäteriet/Metria. (2023). Imagery. CNES/Airbus. [Dataset] URL: https://www.google.cn/maps/vt?lyrs=s@189&gl=cn&x={x}&y={y}&z={z}

Sweco. (2019). Eknätverket vid Nybohovsskolan – Spridningsanalys för Eklevande Insekter. [Unpublished Dataset]

WSP. (2019). Stärkt Grön Infrastruktur i Mellersta Söderort – Förstärkningsåtgärder och Strategier. [Unpublished Dataset]

Sociotope map

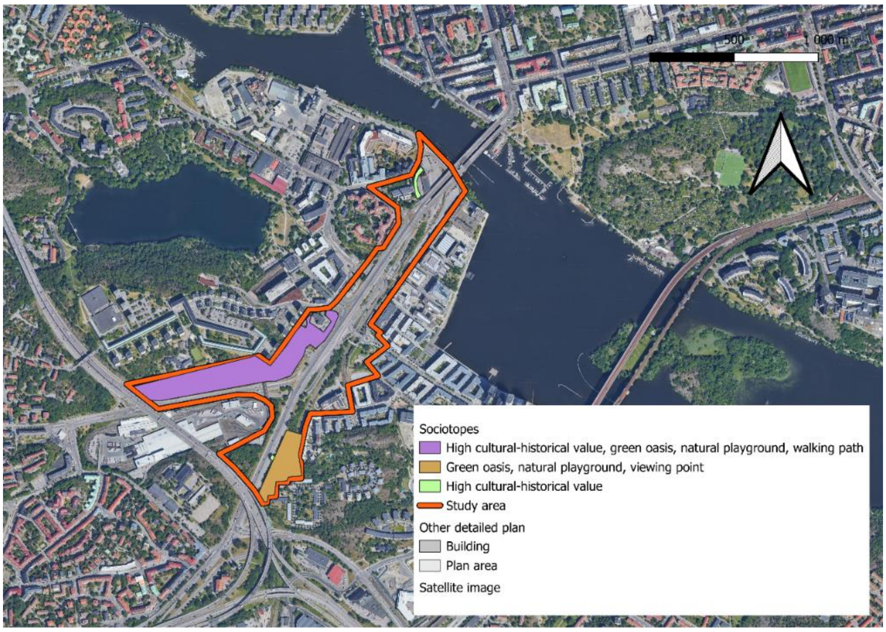

Figure 12: Sociotope classification from the Sociotope map. Modified from City of Stockholm (2022) and Lantmäteriet/Metria (2023)

References:

City of Stockholm. (2022). SBK Sociotopkartan – Kvaliteter i Parker, Natur och andra Offentligt Tillgängliga Områden. Dataset. URL: https://dataportalen.stockholm.se/dataportalen/?SplashScreen=No

Lantmäteriet/Metria. (2023). Imagery. CNES/Airbus. [Dataset] URL: https://www.google.cn/maps/vt?lyrs=s@189&gl=cn&x={x}&y={y}&z={z}

Runoff regulation map

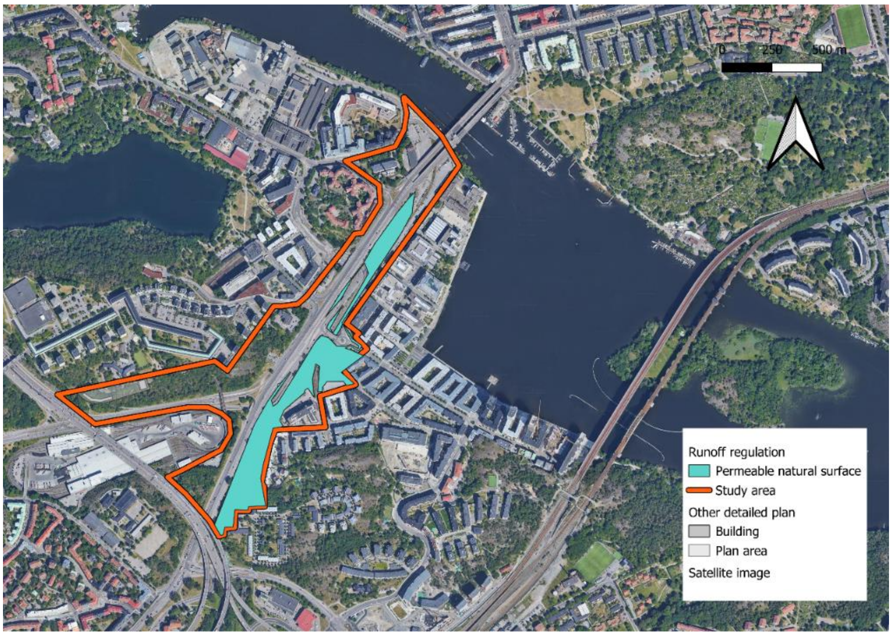

Figure 13: Runoff regulation classification in the Runoff investigation. Modified from Ramboll (2020) and Lantmäteriet/Metria (2023)

References:

Ramboll. (2020). Dagvattenutredning för Södertäljevägen. [Unpublished Dataset]

Lantmäteriet/Metria. (2023). Imagery. CNES/Airbus. [Dataset] URL: https://www.google.cn/maps/vt?lyrs=s@189&gl=cn&x={x}&y={y}&z={z}

Noise map

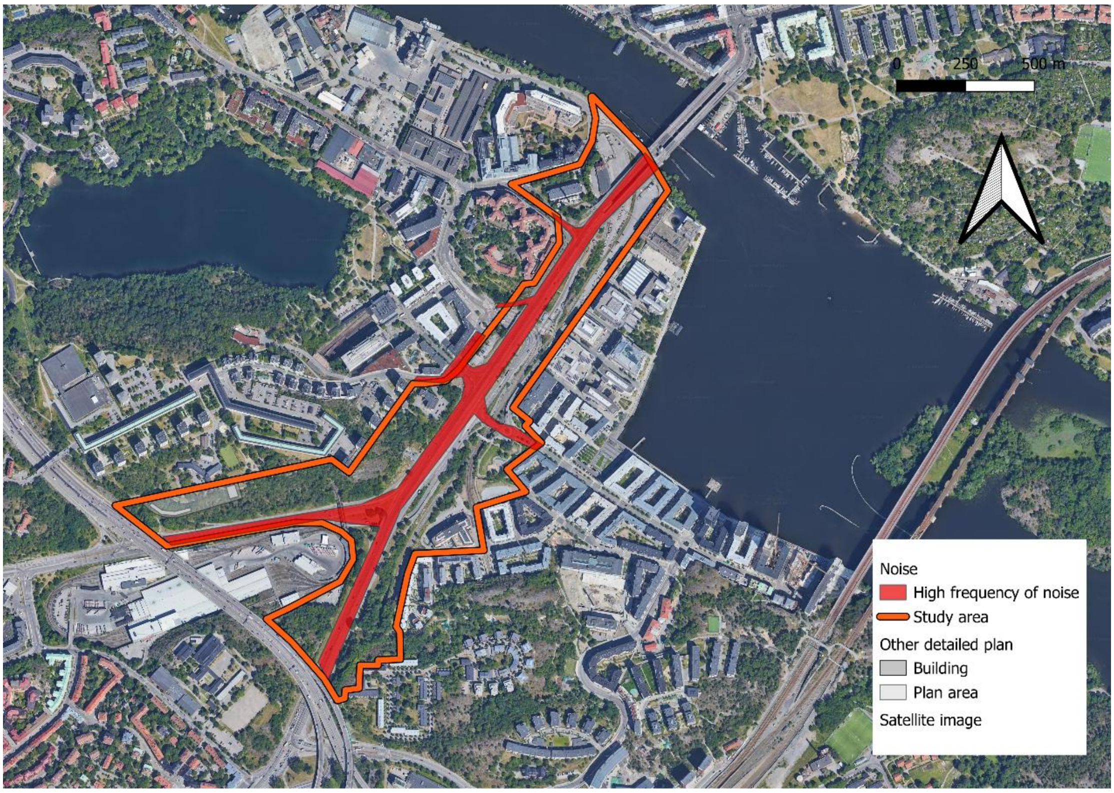

Figure 14: Noise classification in the Environmental noise assessment. Modified from Structor (2021) and Lantmäteriet/Metria (2023)

References:

Structor. (2021). Södertäljevägen, Stockholm Stad: Omgivningsbuller. [Unpublished Dataset]

Lantmäteriet/Metria. (2023). Imagery. CNES/Airbus. [Dataset] URL: https://www.google.cn/maps/vt?lyrs=s@189&gl=cn&x={x}&y={y}&z={z}