Spatiotemporal changes in Gothenburg municipality´s green space, 1986 to 2019

Photo: Månadsparken Kortedala spring 2020, credit Ruben Hallberg

Kristin Blinge

Degree of Master of Science (120 credits)
with a major in Geography
30 hec

Department of Earth Sciences
University of Gothenburg
2021 B1122

Faculty of Science

UNIVERSITY OF GOTHENBURG

UNIVERSITY OF GOTHENBURG
Department of Earth Sciences
Geovetarcentrum/Earth Science Centre

Spatiotemporal changes in Gothenburg municipality´s green space, 1986 to 2019

Kristin Blinge

ISSN 1400-3821

B1122
Master of Science (120 credits) thesis
Göteborg 2021

Mailing address	**Address**	**Telephone**	
Geovetarcentrum	Geovetarcentrum	031-786 19 56	Geovetarcentrum
S 405 30 Göteborg	Guldhedsgatan 5A		Göteborg University
			S-405 30 Göteborg
			SWEDEN

Thesis:	30 hec
Course:	GEO230
Level:	Master
Semester/year:	Spring 2020
Supervisors:	Fredrik Lindberg & Heather Reese
Examinator:	Sofia Thorsson

ABSTRACT

As the world's population is becoming increasingly more urban the infrastructure expands to accommodate the inhabitants' needs. In a dense urban environment green space has an important function since it provides vital ecosystem services, contributes to recreational and cultural values and is essential for biodiversity. Gothenburg municipality, which harbours the second largest city in Sweden, has seen an increase from about 430 000 to 580 000 inhabitants between the years 1986 and 2019 and a future prognosis shows a population increase to 700 000 by the year 2035. The municipality is currently working on a new comprehensive plan which will dictate how the city will expand in the future. This study uses Normalized Difference Vegetation Index (NDVI) from Landsat 5 TM and Landsat 8 OLI satellite data across eight dates between 1986 and 2019 to analyze historical greenness change. Together with a qualitative content analysis of the consultation material, which is the basis for the work with the new comprehensive plan, a future outlook is constructed. NDVI is highly correlated to green biomass and increase or decrease of NDVI is translated to gain or loss of amount of greenness. Gothenburg municipality has lost a considerable amount of greenness (2.8%) between the years 1986 and 2019, while there has been a 0.83% gain in green area. The areas with the largest percentage of greenness loss are large industry, harbor and logistics followed by urban middle area, urban central area and urban outer area. The areas have lost 504.7, 430.7, 36.3 and 194.9 ha respectively during the time period which translates to 10.8%, 3.7%, 2.6% and 1.8% of the areas total land area. There has been a declining cumulative net change of greenness for all areas except for nature and recreational areas which has gained in greenness with 0.1%. A visual analysis shows that areas with lost greenness in the urban middle and outer area were mostly due to commerce, industry, and housing while in the urban inner area the loss was focused to private and public institutions. The expansion of communications, roads and public transport was a common cause for greenness loss in all areas. The urban middle and outer area are those where most future development will be focused and green areas will most likely decrease due to expansion, which should be prominent around already densely built-up parts in these areas. The consultation material also shows that future development will focus on public transportation, cycling lanes, sidewalks and roads to increase accessibility. Since the development of these kind of infrastructures have been shown to affect surrounding green space a similar trend can be expected in the future.

Keywords: NDVI, multitemporal change analysis, incremental change, urbanization

Acknowledgements

This thesis is a result of a 30-credit master´s thesis course in Geography and marks the end to a five-year long commitment to the complex and unique subject that is Geography. Thanks goes out to the lecturers and those in charge of the education for sharing their enthusiasm for the subject as well as to fellow students for their relentless discussions on geographic thoughts and GIS.

Completing this thesis would not have be possible without the support of my supervisors Fredrik Lindberg and Heather Reese. I want to thank you Fredrik for piquing my interest in the metamorphic state of urban vegetation and I want to thank you Heather for sharing your great arsenal of remote sensing knowledge with me. Thanks to both of you for your guidance, encouragement, and critique along the way, it aided in times of doubt and has been essential for upholding the quality of the thesis.

Finally, thanks for all the support and strength from family and friends and a special thanks to Ruben Hallberg for the vital feedback and encouraging words during the process.

Kristin Blinge

2021-03-08

Table of content

Abbreviations

EO	Earth Observation
FK	Fastighetskartan (cadastral map)
GSD	Ground Sampling Distance
IFOV	Instantaneous Field of View
IMCD	Interannual Multitemporal Change Detection
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared band
OLI	Operational Land Imager
R	Red band
SMD	Svensk Marktäcke Data (Swedish land cover/land use data)
TIRS	Thermal Infrared Sensor
TOA	Top of Atmosphere
TM	Thematic Mapper
USGS	US Geological Survey

1 Introduction

Urban population growth presents a challenge for cities around the world. Besides having a large number of people moving from rural to urban areas, scenarios also show that existing urban areas will accommodate for a lot of the future population growth (Lin, Meyers & Barnett, 2015; Göteborgs stad, 2019). As the population increases, the urban infrastructure expands to accommodate for the inhabitants needs. In recent years city planning has focused on urban infill to locate people closer to public transportation, employment, and leisure activities, creating a denser urban environment (Thomas & Cousins, 1996; Zhou, Lin, Cui, Qiu, & Zhao, 2011). In a dense urban environment vegetated and built-up areas compete for the urban space leading to growing concerns about the prevalence of green infrastructure and loss of ecosystem services (Lin, Meyers & Barnett, 2015; Haaland & Van Den Bosch, 2015). Greenery in urban areas is essential for biodiversity and provides vital ecosystem services for people such as microclimate regulation, noise reduction and rainwater management; it also contributes to recreational and cultural values (Bolund & Hunhammar, 1999; Naturvårdsverket, 2020b). Healthy urban vegetation is dependent on the connection to other green areas through a network of habitats and vegetated passages also called a green infrastructure (Naturvårdsverket, 2020a). The main factor for loss of green areas in or close to cities has been contributed to increasing urban growth (Lin, Meyers & Barnett, 2015; Haaland, Van Den Bosch, 2015), and when a vegetated area is exploited, the ground becomes completely or partly impermeable in a process called soil sealing, an essentially irreversible process (European Commission, 2012). Focus has been drawn to a more holistic view in spatial planning when managing urban development so that the green areas and green connections are looked after. One way to measure greenness is with Normalized difference vegetation index (NDVI).

NDVI is a remote sensing metric often used to display spatial patterns of vegetation in urban areas (Furberg & Ban, 2013; Samuelsson et al., 2020; Wellmann, Schug, Haase, Pflugmacher & Van Der Linden, 2020). The index utilizes the visible red (RED) and Near Infrared (NIR) bands of optical satellite images to create an index which is highly correlated to greenness (Yengoh, Olsson, Tengberg, Tucker 2015, pp. 19-20). Combined with interannual multitemporal change detection

(IMCD) incremental change becomes visible. Change detection is a widely deployed remote sensing technique that uses satellite images to study a specific phenomenon at different points in time. It is applied when analyzing the spatiotemporal characteristics of a phenomenon's reflectance to determine change. The temporal resolution refers to the points in time in which the phenomena is studied, and the spatial resolution refers to the level of spatial detail required to detect change (Campbell, 2011, p. 445; Gamba &Dell'Acqua 2016). The US Geological Survey (USGS) Landsat program has the longest continuous program of earth observation (EO), with satellite images in medium resolution (30 × 30 m) spanning from 1984 until present day (Jones & Vaughan, 2010 pp. 120-121; NASA, 2020b). The images contain spectral information of surface materials in the visible and infrared regions (Jones & Vaughan, 2010, pp.8-10). Depending on available, cloud-free satellite images taken during peak greenness season multitemporal change detection of NDVI can show spatial vegetation patterns in high temporal scale, making it possible to decipher patterns and detect trends in areas that are subject to change. Although there have been studies of NDVI change in urban areas located in the northern temperate climate zone (Stockholm, Denmark, and Berlin) (Furberg & Ban, 2013; Samuelsson et al., 2020; Wellmann, Schug, Haase, Pflugmacher & Van Der Linden, 2020) to the author's knowledge, none has been done within this temporal scale, over three decades with five-year (±2 years) impact and , in this scale, studied land use and land cover change, by looking at the previous and present land use and land cover with high resolution orthophotos. Furthermore, none of the papers (ibid.) have considered future planning by reviewing the upcoming comprehensive plan.

The building and planning office (Stadsbyggnadskontoret) are in the process of developing a new municipal comprehensive plan for Gothenburg (Göteborgs stad, 2019b). This document will describe the alignment for creating sustainable urban development as well as how ground, water and developing areas are to be used in short and long term. It will be the foundation for future town planning, granting building permits and focus development. Highlighting the time-based aspect as an additional feature to take into consideration in spatial planning is important when looking at the amount of changes over time. Through a temporal scale other patterns should become more visible, for example the gradual loss of green areas which seen over time has a big impact on its surroundings, also known as incremental change or the "tyranny of the small decisions" (Hägerstrand, 1991).

1.2 Aim & Research Questions

The aim of this study is to examine how the spatial distribution of vegetation in Gothenburg municipality has changed between the years 1986 and 2019, as well as roughly estimate future change by examining past changes and urban development themes in the upcoming comprehensive plan.

- Can removal or expansion of green areas in Gothenburg municipality be identified over the given time period, 1986 and 2019, using NDVI from Landsat satellite data?
- What trends can be anticipated by examining the relationship of the detected spatial patterns of vegetation change and future city planning?

2 Background

As humanity becomes more urban, natural ecosystems in and near cities become more important for citizen wellbeing. Urban green environments contribute to public health by providing beneficial services such as improved air quality, noise reduction and water management (Bolund & Hunhammar, 1999). Ecosystem services such as these are reliant on green infrastructure to function. Green infrastructure is an ecologic livable network of habitats and nature areas which preserves and supports ecosystem services, these areas enable species to spread and benefit biodiversity. It is grounded in a holistic view of vegetation management and urges looking at connections beyond single green areas to see nature as a network in the urban fabric (Naturvårdsverket, 2020a; Hauck & Czechowski, 2017).

The urban fabric is the facets and infrastructure that composes an urban area, for example stone, asphalt, soil and wood that makes roads, walls, leaves which in turn are a part of a street, a house or a tree (Oke, 2017, p 473). Urban areas modify their local and regional climate in different ways by altering the atmospheric processes. These modifications impact different climatological functions such as precipitation, aerodynamics, and temperature, with the urban heat island being the most studied phenomenon (ibid., 2017, pp. 2-3; Seto, Parnell & Elmqvist, 2013). When a vegetated area is transformed into an urban block with impervious surfaces and houses the energy balance, the transferability and storage of energy, changes. Large dry, dark unshaded surfaces such as paved roads increase surface temperatures, and a compact building structure affects airflow and radiation balances, all these factors modify the urban climate (ibid., p.156, 197; ibid.). Urban ecological structures on the other hand have regulating values such as temperature buffers, runoff mitigation and air purification. These values have positive effects on citizens and affect how well the city can mitigate climate risk, for example, green areas and bodies of water can regulate local temperature mitigating heatwaves and vegetation lowers the risk of landslides by stabilizing the ground (Oke, 2017, p. 12; Gómez-Baggethun, et al., 2013).

The city and its urban fabrics are constantly undergoing a metamorphic process when new buildings are constructed or when vegetation is left to grow. This change is attributed to different actors depending on the ownership of the land, for example a farmer can leave fields to shrubification or local management can erect housing and infrastructure. The environmental impact of urbanization is almost always associated with loss or degradation of green space (Lin, Meyers & Barnett, 2015; Haaland & Van Den Bosch, 2015), which leads to habitat loss, negative effects on biodiversity and can influence the urban ecosystem processes (McDonald, Marcotullio & Güneralp, 2013). The European commission (2012) has identified urbanization as the main reason for soil sealing, the process of turning natural areas to impermeable surfaces. But urban areas do not only affect the physical land it occupies, by loss of green space and soil sealing, but also the area round it by changing the microclimates of its surroundings, by shadowing effects and radiation properties of the materials (Oke, 2017, pp. 122-123). Seen over time many small interventions in the urban fabric pile up to create major changes in space, also called the tyranny of the small decisions (Hägerstrand, 2001; 1991). The idea of the tyranny of the small decisions is that the whole picture gets lost when steps only are seen in a certain context. Since the changes are disperse and often isolated, increasing the spatial and temporal scale enables one to see how the small decisions adds up effects its surroundings. The temporal and spatial urbanization of cities today impacts the local and regional climatological systems and changes the biophysical environment.

3 Literature review of key terms

3.1 Remote sensing

Remote sensing is an Earth Observation (EO) technique defined by Lillesand, Kiefer & Chipman (2015, p. 736) as" … the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation". This study focuses on using reflected electromagnetic radiation recorded by Landsat satellites to study vegetation distribution and land use/land cover change.

The remote sensing technology is based on the knowledge of electromagnetic radiation which states that electromagnetic waves radiate through space carrying electromagnetic energy. The wavelength variations are used to measure and categorize different electromagnetic waves into regions depending on the length of the wave. The regions are organized in the electromagnetic spectrum which spans from long wave to short wave, some of the regions are y-ray, X-ray, UV, the visual region (violet, blue, green, yellow, orange, red), infrared (near-infrared, short-wave infrared), microwaves and radio waves (Singhal & Gupta, 2010; Jones & Vaughan, 2010, pp.8-10). Remote sensing uses detectors or sensors to record reflectance properties emitted from an area in different bands representing the different spectral regions. This information can then be analyzed (Jones & Vaughan, 2010, pp. 92-93) by exploiting the variation in reflectance that occurs from various surface features.

3.2 Landsat program

The USGS Landsat program is the longest continuous running EO program providing imagery over Earth's surface. The program has been running since the first satellite Landsat 1 was launched in 1972. Today a total of eight satellites have been launched within the program (NASA, 2020a). There have been different imaging instruments on the satellites but the main scanning system for spectral information on Landsat 5 is the Thematic Mapper (TM) and on Landsat 8 the Operational Land Imager (OLI, NASA, 2020b, NASA, 2020c). Landsat 5 TM is a multispectral scanning sensor with seven bands, bands 1-5 and 7 has a 30 m × 30 m Instantaneous Field Of View (IFOV) and band 6 has an IFOV of 120 m × 120 m (table 1). It uses a whiskbroom scanning technique and the approximate scene size is 170 km × 183 km with a swath width of 185 km (NASA, 2020b). Landsat 8 is the most recent earth observation system in the Landsat program, and was launched in 2013, carrying two science instruments the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The OLI collects data for nine spectral and two TIRS bands (table 1); it has a pushbroom scanning design and a scene size of 185 km × 180 km (NASA, 2020c).

Table 1 Band specific properties of Landsat 5 TM and Landsat 8 OLI (NASA, 2020c; NASA,2020d). Landsat 8 OLI TIRS has been developed to include Costal/Aerosol band, and Cirrus band.

Landsat 5 TM			**Landsat 8 OLI TIRS**			
Band	**Pixel size (m)**	**µm**	**Nominal band name**	**µm**	**Pixel size (m)**	**Band**
			Costal/Aerosol	0.435-0.451	30	1
1	30	0.45-0.52	Blue	0.452-0.512	30	2
2	30	0.52-0.60	Green	0.533-0.590	30	3
3	30	0.63-0.69	Red	0.636-0.973	30	4
4	30	0.76-0.90	NIR	0.851-0.879	30	5
5	30	1.55-1.75	SWIR	1.556-1.651	30	6
6	120	10.41-12.5	TIR	10.60-11.19	100	10
			TIR	11.50-12.51	100	11
7	30	2.08-2.35	SWIR	107-2.294	30	7
8	15	0.515-0.896	Pan	0.503-0.676	15	8
			Cirrus	1.363-1.384	30	9

Both sensors provide images of medium resolution, 30 × 30 meter (Jones & Vaughan, 2010 pp. 120-121). The satellites follow a near polar-orbit with a return cycle of 16 days (ibid.; NASA, 2020b), and it assures sun-synchronous images which minimize shadow angles and illumination variability (Jones & Vaughan, 2010 p. 98). The Landsat program has provided a wide range of easily available high-quality data that is comparable between different years and satellites.

3.3 Normalized Difference Vegetation Index

Remote sensing of vegetation has since the 1970s been a fundamental part of gaining knowledge of the amount and distribution of land use/land cover, including agricultural and semi-natural vegetation (Curran, 1980; Rouse, Haas, Schell & Deering, 1973). Normalized difference vegetation index (NDVI) utilizes the reflectance properties of the red (R) and near infrared (NIR) band to create a visual representation of the physical properties of a studied vegetation cover (Rouse, Haas, Schell & Deering, 1973). NDVI measures the reflectance ratio by dividing the difference in reflectance between NIR and R by the sum of NIR and R reflectance which creates an index spanning from -1 to 1. The index utilizes the idea that green vegetation reflects less in the visible red wavelength and reflects more in the near infrared wavelengths, while sparse or areas with no green vegetation reflects a greater amount of red wavelengths and less near infrared wavelengths. Values spanning from -1 to 0 represent surfaces with bare soil, urban structures, cloud, water or snow and the values spanning from 0 to 1 represents vegetated areas (Yengoh, Olsson, Tengberg, Tucker 2015, pp. 10-11; Jones & Vaughan, 2010, p. 166; Curran, 1980). The index is highly correlated to green biomass, where a high positive NDVI value represents a high chlorophyll content of the studied area (Yengoh, Olsson, Tengberg, Tucker 2015, p. 11 & pp. 19-20). NDVI is popular because of its good comparability, when the reflectance is divided the effect of non-uniform illumination, such as the one due to aspect, is reduced (Jones & Vaughan, 2010, p. 166).

NDVI is an important index used when studying temporal aspects of urban growth and land use change, whereas the difference in spectral response of vegetated and non-vegetated areas derived from the index is often used to define land use boundaries. This was demonstrated by a study of the fragmentation process of vegetation due to urbanization in Stockholm where Furberg & Ban (2013) analyzed SPOT 1 and 5 imagery. They concluded that fragmentation of vegetation caused by urban development was highest in the north and east part and lowest in the central parts of Stockholm. One important aspect to take into consideration when using NDVI is the time of acquisition of the EO data. NDVI can be dependent on season and extreme weather which can affect phenological characteristics such as amount of biomass. NDVI often peaks in June to August (in the northern hemisphere), and vegetation stress can affect the index (Yengoh, Olsson, Tengberg, Tucker 2015, p. 11).

3.4 Change detection

One of the most important analyses in remote sensing is change detection which is a method to calculate changes in the spectral response of a phenomena by comparing satellite images acquired in different points in time (Ban & Yousif, 2016). With the increasing availability of free, moderate to high resolution satellite images (Landsat and Sentinel), comparing images to detect changes in or changes of surface features throughout a time series sequence, also called interannual multitemporal change detection (IMCD), has become a significant way of studying spatiotemporal phenomenon (Campbell, 2011, p. 445). Using EO to detect change has some constraints, such as temporal resolution, i.e., if the time difference between the images is sufficient to detect a specific change, and spatial resolution, i.e., if the images have the level of detail required to detect change of the studied phenomena (Gamba & Dell'Acqua, 2016).

Urban expansion is a spatial process often studied using change detection, Li, Zhou, Zhu, Liang, Yu & Cao (2018) used Landsat 5, 7 and 8 time series (1985 to 2015) to map annual urban dynamics. They used a temporal segmentation approach to identify urban pixels and categorize them based on year and duration of urbanization to identify when urban expansion started and how long the process took. Furthermore, NDVI is commonly used in change detection to distinguish urban change, as when studying land use change in the Vellore district in India where Landsat TM image and NDVI differencing was used to identify the conversion of forest and shrublands to agricultural land, built-up and water areas (Gandhi, Parthiban, Thummalu & Christy, 2015). It has also been used as a greenness metric to study the relationship between population and vegetation. Studies in Berlin and Denmark have used NDVI derived from Landsat 5, 7 and 8 satellite images, showing that the urban areas are gaining in both population and vegetation-greening implying that existing urban vegetation has increased in productivity (Wellmann et al., 2020; Samuelsson et al., 2020).

Using EO to detect multitemporal change in urban areas poses a challenge because of the metamorphic spatiotemporal behavior of urbanization. The studied phenomena dictate the spatial and temporal scale of the imagery and the spatial and temporal scale of the imagery dictate what can be studied. For example, to detect spectral or geometrical changes in urban environments often requires very high (0.5-5 m) to high (5-10 m) spatial resolution EO datasets, while urban extent monitoring can be done using medium resolution (10-40 m IFOV) EO datasets (Gamba & Dell'Acqua, 2016; Belward & Skøien 2015). The temporal aspect of change detection also poses a problem since in situ observation of previous land use is impossible to obtain if it was not previously collected. Therefore, additional data is of great importance when confirming the results, for example, historical land use maps or orthophotos. Furthermore, to be able to study the multitemporal aspects of change many EO datasets from different points in time are required, since the data is not temporally correlated the data needs to be harmonized, making sure that they are as much as possible radiometrically and geometrically the same (ibid; Campbell, 2011, pp. 452-453).

4 Material and Methods

To define future municipal planning a content analysis of documents regarding the new municipal comprehensive plan was completed. To study vegetation change an interannual multitemporal change detection of NDVI derived from Landsat satellite images spanning from 1986 to 2019 was conducted. In this chapter the study area (section 4.1), content analysis (section 4.2) and the multitemporal change analysis is presented (section 4.3).

4.1 Gothenburg municipality

Gothenburg municipality is located on the west coast of Sweden where the Gulf stream creates a warm temperate climate zone with deciduous forest as the dominating vegetation (SMHI 2020a). It contains Gothenburg city which is the second largest city in Sweden. Between 1986 and 2019 the population has roughly grown with 150 000 inhabitants from about 430 000 to 580 000 (SCB, 2021) and future prognosis show a population increase of 700 000 by the year 2035 (Göteborgs stad, 2021a). The municipality has a land area of 27 980 km^2 with urban area around the mouth of the Göta river mainly surrounded by forest, open land, and cultivated fields (figure 1).

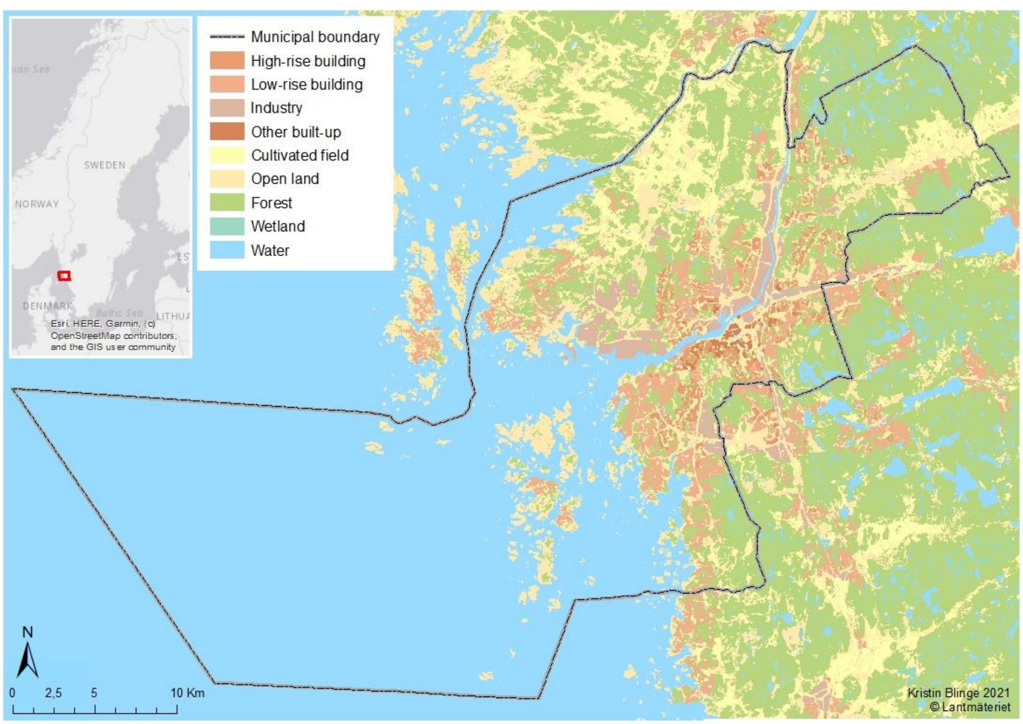


Figure 1 Map over land use in Gothenburg municipality.

4.2 Qualitative methods

4.2.1 Qualitative content analysis

Content analysis is a widely used method in qualitative research, it is a way to describe communication content by categorizing and coding several texts into themes or ideas (Bryman 2012, pp. 289-290 & 559; Drisko, 2015, p. 12). It is foremost a deductive approach meaning that the area of interest is preset based on the theoretical and empirical focus of the study. The aim and research question focuses the analysis, by determining which literature, communication or media that will be reviewed, also known as purposive or strategic sampling (Drisko, 2015, p.2; Bryman 2012 p. 418). Strategic sampling is a non-probability approach which does not allow for generalization (Drisko, 2015 pp.15-16; Bryman, 2012 p. 418), in this case future spatiotemporal aspects of green areas in Gothenburg is studied and the results from the multitemporal change detection and the content analysis is used as a base for understanding future development in the municipality and will not be used to generalize to other areas. This study uses content analysis to get an insight in to future planning by reviewing material produced by the city of Gothenburg concerning the upcoming comprehensive plan.

4.2.2 Sample

The sample process was two-fold, first the specific subject texts were selected and secondly, the text was read to identify subunits of interest as described by Drisko (2015 p. 14). Since this study focuses on the upcoming municipal comprehensive plan the literature was collected from "Stadsutveckling Göteborg, Ny översiktisplan för Göteborg" (Göteborgs stad, 2020) a webpage regarding the work of producing a new municipal plan in Gothenburg. Here five documents were found, these were the consultation report, map over land use and water management, two in-depth focuses for two areas in Gothenburg (central Gothenburg and Högsbo-Frölunda), and the current comprehensive plan. The current comprehensive plan was excluded from the analysis since the focus in this study regards the upcoming plan. The documents were produced by Göteborgs stad in December 2018 and published in 2019.

A frame for categorizing the data was set by a strategic map presented in the consultation report (Göteborgs stad, 2019b). The document has identified six areas where different development approaches are to be implemented, these are Innerstaden (urban central area), Mellanstaden (urban middle area), Ytterstaden (urban outer area), Storindustri hamn och logistik (large industry, harbor and logistics), Natur- och rekreationsområden (nature and recreational area), Kustband och skärgård (coastal area and archipelago, ibid.).

An initial categorization to detect subjects and themes regarding the different areas was done before reading the material. These themes were then revisited and revised to allow for new variables to emerge throughout the process (Bryman, 2012 p. 559). The initial categories were development strategies, current land use and future development. After reviewing the material current land use was changed to current activities and land use/land cover and future development was divided into the categories structures and mobility (figure 2).

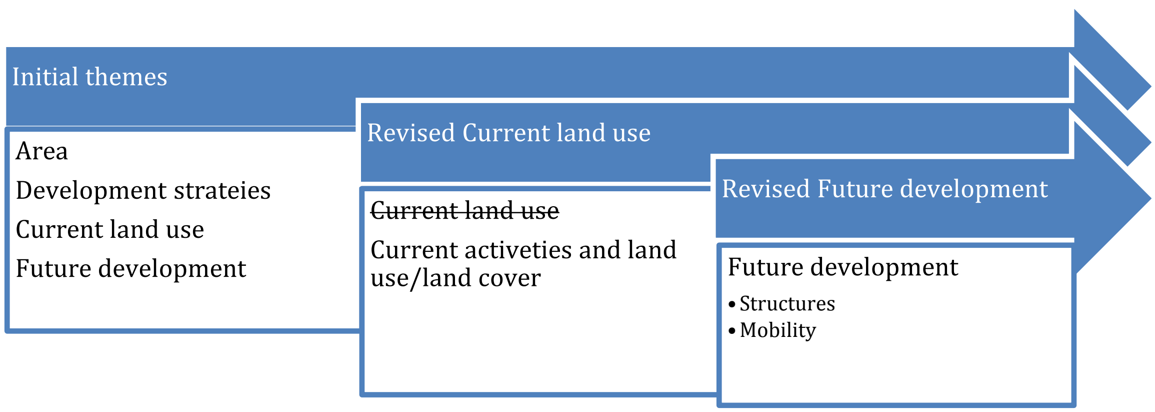


Figure 2 The analysis focused on the areas with different development plans identified in the comprehensive plan. The initial categorization was development strategies, current land use and future development. The category current land use was changed to current activities and land use/land cover and the categories structures and mobility emerged after reading the text.

4.3 Quantitative methods

4.3.1 Interannual multitemporal change detection

This study utilizes the spatial patterns of NDVI derived form from Landsat 5 TM and Landsat 8 OLI satellite images to detect interannual multitemporal change of vegetation in Gothenburg municipality. The material used in the IMCD was satellite images from the Landsat program, high resolution orthophotos from Gothenburg municipality (Göteborgs stad) and the Swedish land survey administration (Lantmäteriet) as well as Svensk Marktäcke Data (SMD), Swedish land cover/land use data (Naturvårdsverket, 2014), and fastighetskartan (FK), cadastral map (Lantmäteriet, 2020).

4.3.2 Orthophotos

High spatial resolution orthophotos for the years 1975, 2003, 2006, 2008, 2010, 2015, 2017 and 2019 were downloaded from Lantmäteriet (2021c) and Göteborgs stad (2021b) as visual reference data. The orthophoto from 1975 covers almost all of Sweden, it was compiled by aerial photographs from between 1970 and 1980 (Lantmäteriet 2021d), the data over Gothenburg municipality is compiled of images spanning from 1969 to 1980. Orthophotos from Göteborgs stad (2021b) were produced by aerial photographs (table 2, Göteborgs stad, 2021c).

Table 2 Orthophotos metadata. For the datasets 1975 and 2003, the acquisition month was not given.

Name	Acquisition date	Image size (km)	Pixel size (m)	Panchromatic/Color
1975	1969 to 1980	5 x 5	0,5 x 0,5	Panchromatic
2003	2003	1 x 1	0,25 x 0,25	Color
2006	June-July 2006	1 x 1	0,25 x 0,25	Color
2008	June 2008	1 x 1	0,25 x 0,25	Color
2010	April 2010 (south) April 2011 (north)	1 x 1	0,25 x 0,25	Color
2015	April-May 2015	1 x 1	0,25 x 0,25	Color
2017	April-May 2017	1 x 1	0,25 x 0,25	Color
2019	April 2019	1 x 1	0,25 x 0,25	Color

4.3.3 Landsat data

Satellite images from the programs Landsat 5 and Landsat 8 were chosen to be the most suitable for the study. Although Landsat 4, launched in 1982, is the first satellite providing images with a 30-meter pixel size (USGS, 2020a), Landsat 5 was launched in 1984, only two years after, and provided multispectral images for a longer period of time, until 2011 when the Thematic Mapper (TM) instrument stopped working. It was decommissioned in 2013 making it the satellite with the longest operating time, outliving Landsat 6 which when launched did not achieve orbit, as well as providing high quality images of Earth when Landsat 7 in 2003 experienced problems with the Scan Line Corrector (SLC) resulting in images with missing data (USGS, 2020b, USGS, 2020c, NASA, 2020b).

The data was retrieved from Earth Explorer (USGS, 2021). Imagery over Gothenburg municipality during the months June and July was used to ensure healthy vegetation cover or peak leaf-on season (figure 3).

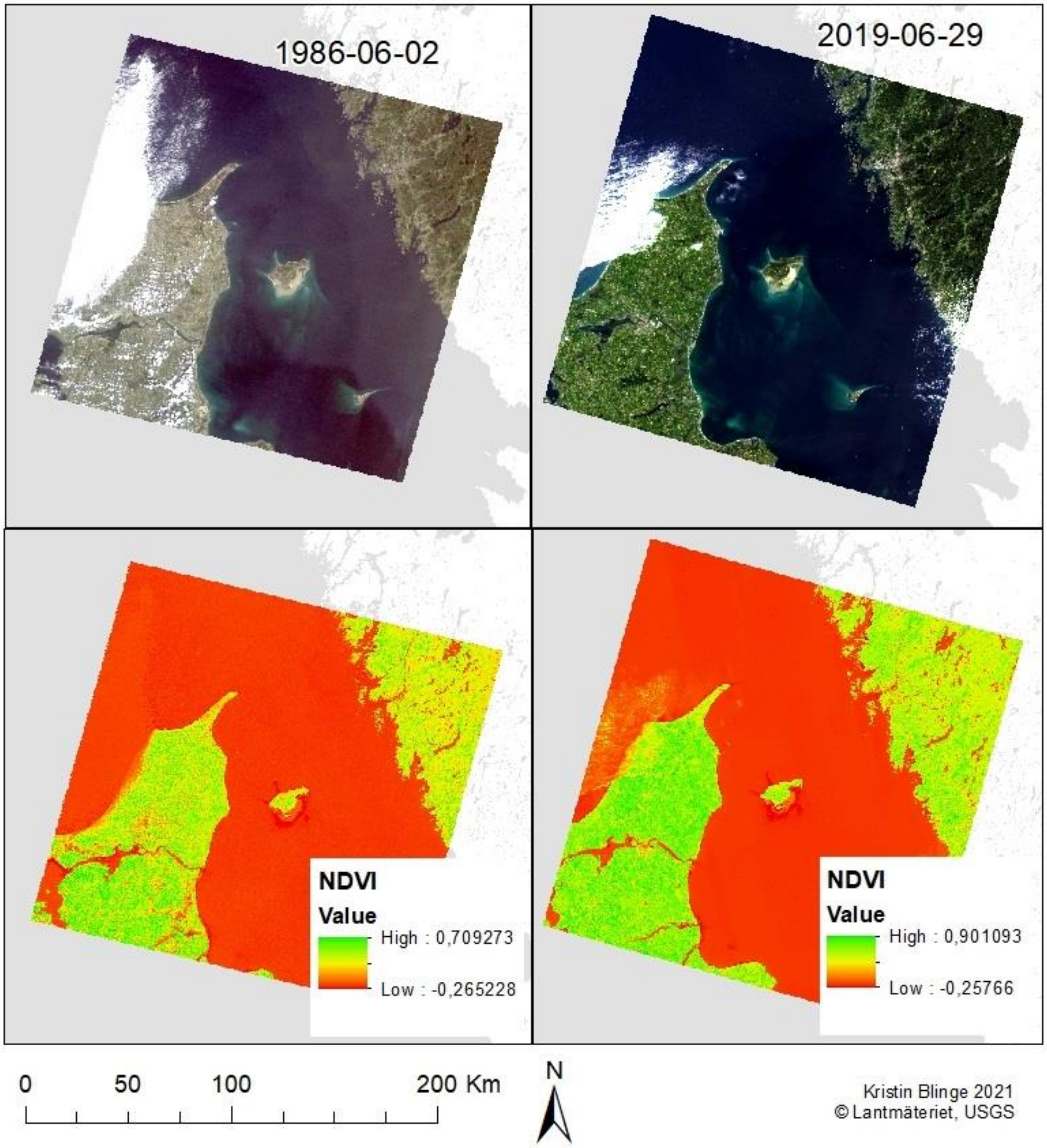


Figure 3 Landsat 5 1986-06-02 and Landsat 8 2019-06-29 natural color composite and NDVI prior to normalization.

Two selection processes were used to retrieve imagery with a low percentage of cloud cover within a suitable time interval. The first selection was done manually when retrieving data from the website where satellite pictures with low cloud cover were selected. The second selection process was done in ArcGIS where the Landsat Quality Assessment Band was used to identify images with low cloud interference over Gothenburg municipality. Two Landsat 8 OLI and six Landsat 5 TM level 2 (i.e., atmospherically corrected) products with a spatial resolution of 30 × 30 m were selected spanning over the years 1986 to 2019 with an interval of 5 years (±2 years). The images were chosen based on minimal cloud interference for optimal visibility (<1%) at the area of interest. Furthermore, two Landsat 8 OLI level 1 (i.e., geometric correction, but without atmospheric correction) images were used when correcting extreme value artifacts seen in the Level 2 images (table 3).

Table 3 Landsat 5 TM and Landsat 8 OLI satellite images used in the study. The table shows Year, date, time at nadir, processing level, clear terrain over Gothenburg municipality and path/row of the EO data.

Year	Date	UTC+1 Time zone	Satellite/Instrument	Processing Level	Clear terrain (%)	Path/row
1986	2-June	09:44:03	Landsat 5 TM	Level-2	99	196/20
1989	5-July	09:41:18	Landsat 5 TM	Level-2	99	195/20
1995	27-June	09:37:45	Landsat 5 TM	Level-2	99	196/20
2000	17-June	09:50:11	Landsat 5 TM	Level-2	99	195/20
2004	3-June	10:06:37	Landsat 5 TM	Level-2	99	196/20
2009	26-June	10:02:14	Landsat 5 TM	Level-2	99	195/20
2013	23-July	10:15:41	Landsat 8 OLI TIRS	Level-1 Level-2	99	195/20
2019	29-June	10:19:47	Landsat 8 OLI TIRS	Level-1 Level-2	99	196/20

The satellites followed along path 195 and 196 and the images were acquired at row 20. Half of the images had the coordinate system WGS 1984 UTM Zone 32N and the other WGS 1984 UTM Zone 33N which places the study area in either the north west or north east corners of the image (figure 4).

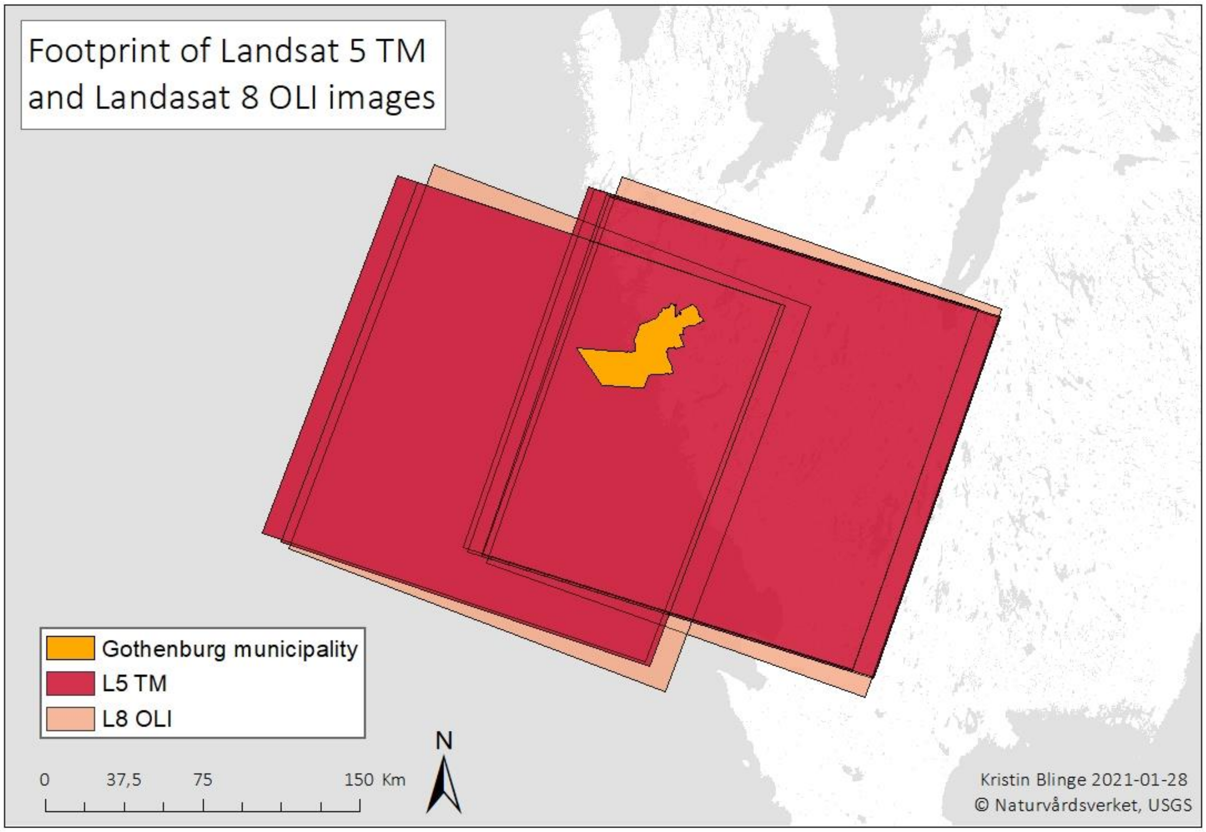


Figure 4 Footprint of Landsat 5 TM and Landsat 8 OLI images used in the study.

For the images to be comparable the NDVI values had to be in a stable state, meaning that the vegetation was in a similar phenological state during the dates when the images were taken. Precipitation and temperature have shown to be the two most important factors that impacts vegetation dynamics (Chang, Wang, Vadeboncoeur & Lin, 2014). Further, extreme weather events such as heat waves have occurred in Sweden with the most recent recorded being in 2018. Historically the years 1994,1997, 2002, 2003, 2005 and 2006 were also affected (SMHI, 2020b; SMHI 2011). To make sure that there were no extreme weather events that could have affected vegetation growth, annual average temperature and precipitation time series with meteorological data from the weather stations Göteborg, Säve and Landvetter (SMHI, 2020c; 2020d) were compiled over the years 1980 to 2019 (figure 5).

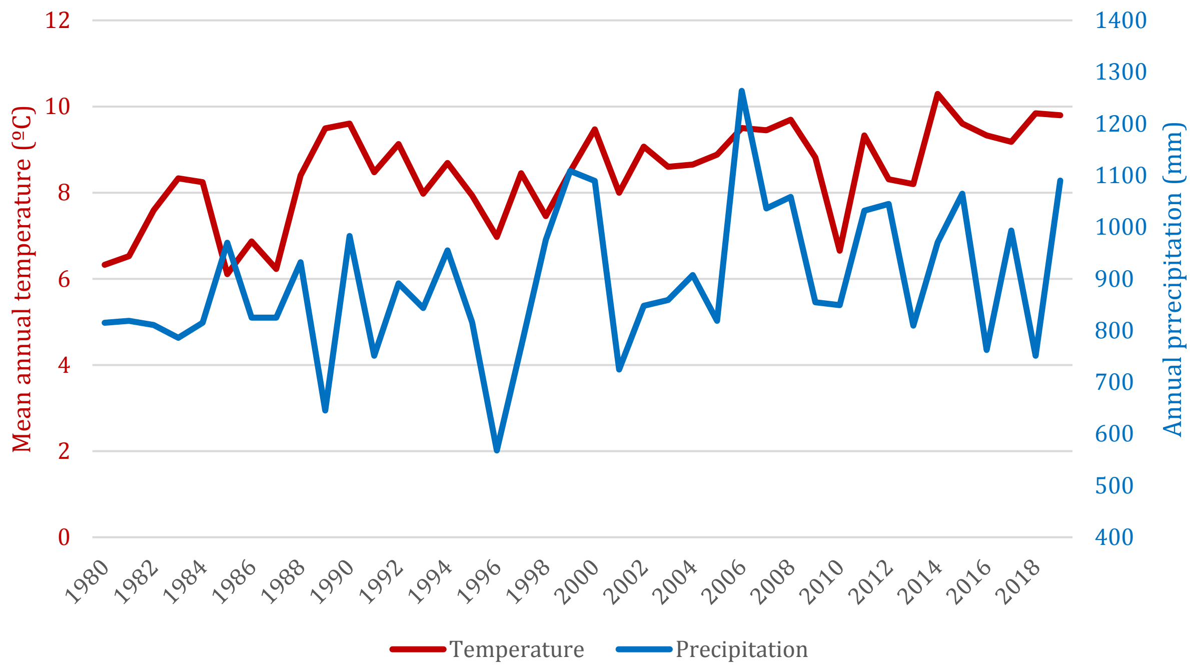
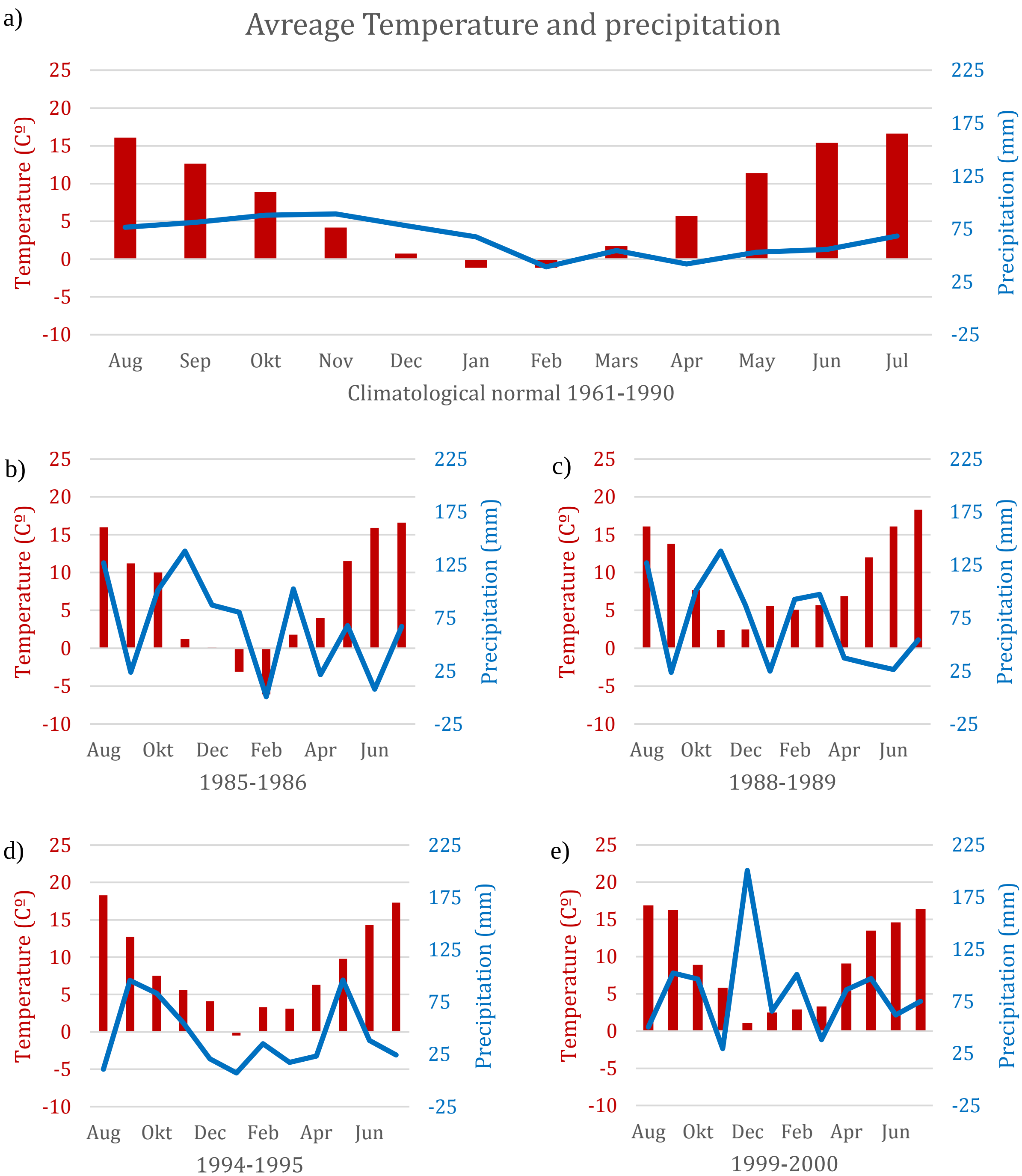


Figure 5 Annual average temperature and precipitation over Gothenburg center 1980-2019.

The years 1986, 1989, 1994, 2002, 2006, 2009, 2013 and 2019 in figure 5 correspond to the years of which there are satellite data. There is a slight increase in temperature over the years which probably can be linked to climate change. For the years used in the analysis, the year 1989 deviates with a relatively low precipitation and high annual temperature, 9.4 ° C (figure 5). Monthly average temperature and precipitation were compiled with meteorological data from the weather stations Göteborg, Säve and Landvetter (SMHI, 2020c; 2020d) for the year prior to when the images were taken (figure 6b-i). For comparison, a monthly average climatological normal (WMO, 2020) of temperature and precipitation for the area was compiled (figure 6a).


a)
Avreage Temperature and precipitation
Temperature (Cº)
Precipitation (mm)
Aug Sep Okt Nov Dec Jan Feb Mars Apr May Jun Jul
Climatological normal 1961-1990
b)
1985-1986
c)
1988-1989
d)
1994-1995
e)
1999-2000

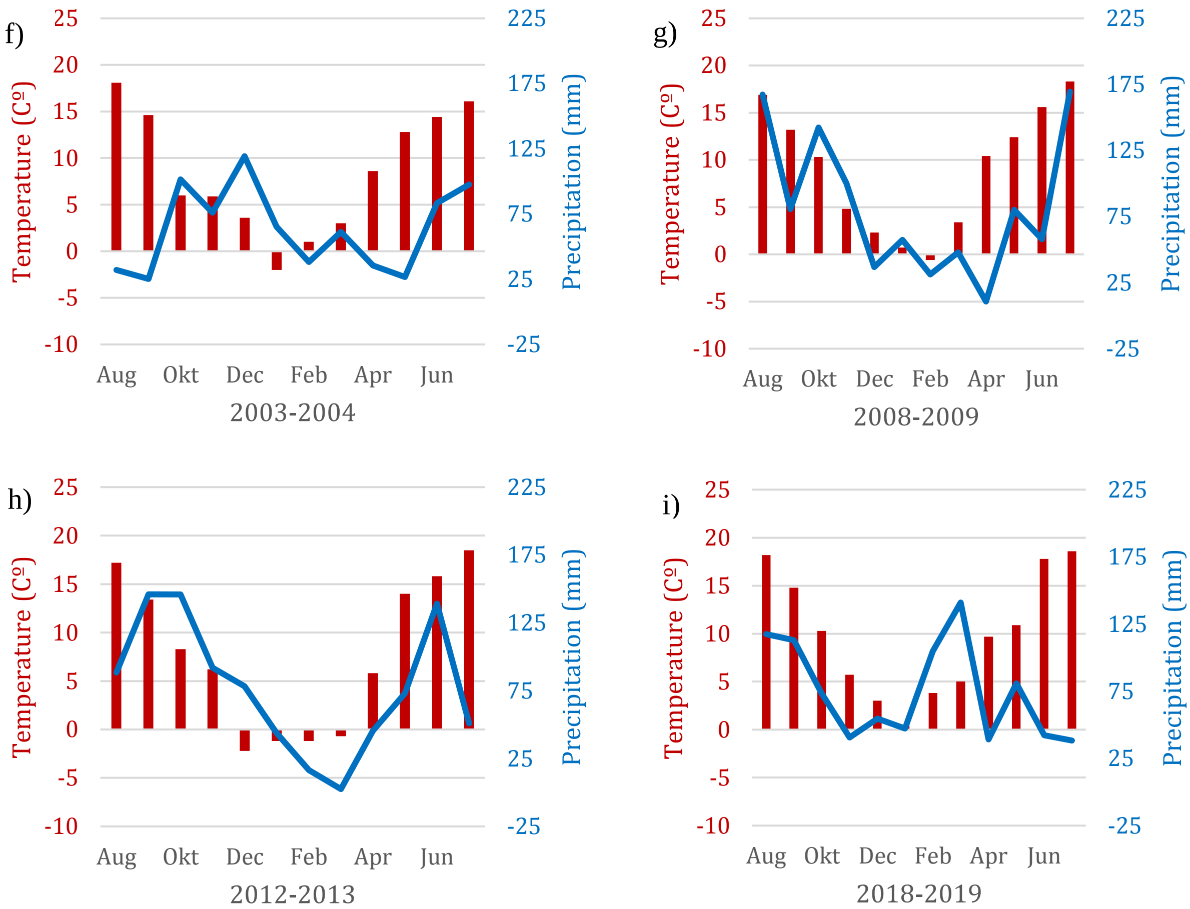


Figure 6a-i Monthly temperature and precipitation over Gothenburg a year prior to the analyzed dates and the climatological normal (SMHI, 2020c; 2020d).

For the months June and July, the climatological normal temperature was 15.4º and 16.6º C. The years deviating the most from this are the year 2019 with +2.4º C and 1995 with -1.1º C for June and 2019 with +2º C, 2013 with +1.9º C, 2009 and 1989 with +1.7º C in July (figure 6). Precipitation fluxes depending on the year, but overall, the climatological normal shows the driest months to be February and April with 39.1 mm and 41.9 mm respectively (figure 6). For 1989 the months February and March has had a relatively high amount of precipitation with 92.6 mm and 97.3 mm, with a decline in the coming months (figure 6).

4.3.4 Conversion to NDVI

The satellite images were converted to the same coordinate system, WGS 1984 UTM Zone 33N, and cropped to the study area, values over water were removed, and the reflectance values were converted to NDVI as described by Jones & Vaughan (2010, p. 166) using the following equation

$$NDVI = \frac{(\rho_{NIR} - \rho_R)}{(\rho_{NIR} + \rho_R)} \qquad \text{(eq. 1)}$$

where

NDVI is the normalized difference vegetation index

ρ_{NIR} is the near infrared IR, spectrum region (λ~0.8 µm)

ρ_R is the visible red spectrum region (λ~0.6 µm)

Two images, Landsat 8 OLI 2013 and 2019, had outliers with NDVI values over 1, 2013 had in total 43 outliers and 2019 had 6 outliers. This was due to values lower than 0 in the R band. To correct the outliers, Landsat level-1 images for the same dates as the level-2 images was used. The Level-1 images were transformed to top of atmosphere (TOA) reflectance using the radiance rescaling factors in the MTL-file as described by Mirshra et al. (2014), as well as USGS (2020d). The image data was converted to TOA reflectance using the equation

$$\grave{\rho}_\lambda = M_\rho Q_{cal} + A_\rho \qquad \text{(eq. 2)}$$

where

$\grave{\rho}_\lambda$ is the TOA planetary reflectance, without correction for solar angle

M_ρ is the band-specific multiplicative rescaling factor

A_ρ is the band specific additive rescaling factor

Q_{cal} is the quantized and calibrated standard product pixel value (DN)

The correction for solar zenith angle was calculated using the equation

$$\rho_\lambda = \frac{\grave{\rho}_\lambda}{\cos(\theta_{SZA})} \qquad \text{(eq. 3)}$$

where

ρ_λ is TOA reflectance

θ_{SZA} is the solar zenith θ

The outliers were then replaced with the level-1 TOA reflectance values.

4.3.5 Normalization of data

To be able to examine the relationship between years, a normalization of the NDVI datasets was done. This is necessary because of the variability in the spectral data, which is caused by sensor age and atmospheric disturbance amongst other things. To do this, an image-to-image matching technique was used for normalization (Campbell, 2011, p. 454). Sample points were used to provide the values for the normalization. These points were taken in urban, forest and grass areas assumed to have no to low change from 1986 to 2019 (so-called "pseudo invariant features"). They were collected in the different thematic areas identified by the municipal comprehensive plan document to assure representation of different land use in all areas. High resolution orthophotos for the years 1975, 2003, 2006, 2008, 2010 and 2019 were examined to identify suitable areas and NDVI values were collected for the different land use classes. In total 98 points were collected, 32 for urban area, 41 for forest and 25 for grass. Because of difficulties identifying 30 × 30-meter areas with static land use, no suitable urban area was identified in Ytterstaden and no suitable grass area was identified in Innerstaden or Storindustri, hamn och logistik (table 4).

Table 4 Sample points distribution

Area/Land use	**Urban area**	**Forest**	**Grass**
Innerstaden	5	4	0
Mellanstaden	4	9	14
Ytterstaden	0	3	3
Storindustri	10	2	0
Natur- och rekreationsområden	1	18	2
Kustband och skärgård	4	5	6
Total	32	41	25

NDVI values from the sample points were used in a linear regression model to examine the relationship between different years. The control sample from the Landsat 8 OLI image 2013-07-23 was chosen as the regression static values to which the other images were corrected. Landsat 8 OLI is the most recent scientific instrument with improved radiometric precision compared to Landsat 5 TM (NASA, 2020c) and the satellite had been newly launched in 2013, making the satellite image less affected to problems caused by the instrument ageing. The R^2 value was used to evaluate the model (figure 6).

To transform the images the Landsat 5 TM and Landsat 8 OLI's regression results were used to create harmonious and comparable datasets (Roy et al., 2016) with the equation

$$NDVI_{norm} = a * NDVI_x + b \qquad \text{(eq. 4)}$$

where;

$NDVI_{norm}$ is the Landsat 5 TM and Landsat 8 OLI normalized NDVI

NDVI $_x$ is the Landsat 8 OLI or Landsat 5 TM NDVI

a is the slope from the linear regression

b is the linear intercept of the y-axis

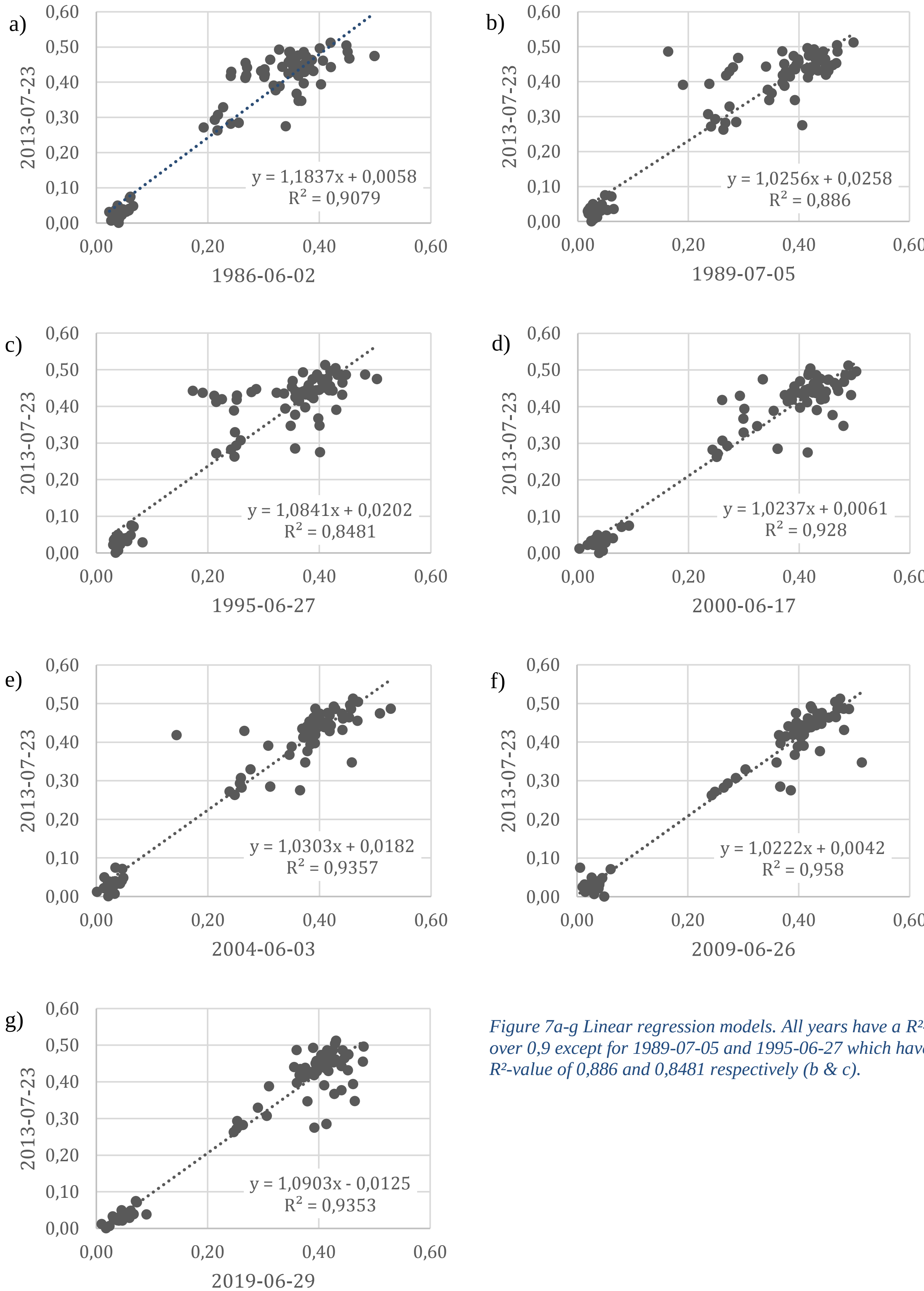


Figure 7a-g Linear regression models. All years have a R^2-value over 0,9 except for 1989-07-05 and 1995-06-27 which have a R^2-value of 0,886 and 0,8481 respectively (b & c).

4.3.6 Image differencing

The changes between the normalized NDVI images were calculated using image differencing, where one image is subtracted, pixel by pixel, from the other. This creates a third image called a "difference image" or "change image", which shows the difference in values of the pixels (Ridd & Liu, 1998). Image differencing was done in chronological order starting with 1986-06-02 and ending with 2019-07-06. To get an overall picture, the change between 1986-06-02 and 2019-07-06 was calculated. To identify NDVI loss and gain threshold values based on the standard deviation was compiled for the images. High resolution orthophotos over Gothenburg municipal from the years, 1975, 2003, 2006, 2008, 2010, 2015 and 2019 were used for a visual examination of the data. Based on the values in the change images the second standard deviation was chosen as a threshold value. This value reduced noise and showed a clear spatial distribution of areas with change. The raster was classified into two classes, *loss* and *gain* of $NDVI_{norm}$ (table 5).

Table 5 Threshold values for change image to visualize loss and gain of NDVI. The values between the two second standard deviations were excluded.

Data	**Mean**	**Standard deviation**	**Second standard deviation (loss)**	**Second standard deviation (gain)**
1986-06-02 to 1989-07-05	0,029623	0,05773	-0,085837	0,145083
1989-07-05 to 1995-06-27	-0,042233	0,054668	-0,151569	0,067103
1995-06-27 to 2000-06-17	0,039365	0,049162	-0,058959	0,137689
2000-06-17 to 2004-06-03	-0,009896	0,047753	-0,108468	0,088676
2004-06-03 to 2009-06-26	0,002372	0,049286	-0,0962	0,100944
2009-06-26 to 2013-07-23	0,019508	0,047091	-0,074674	0,11369
2013-07-23 to 2019-07-06	0,055543	-0,034689	-0,145774	0,076397
1986-06-02 to 2019-07-06	0,013833	0,065616	-0,117399	0,145065

4.3.7 Agricultural noise

Due to error in the analysis caused by areas with agricultural land the study was delimited to exclude these. Arable land is a seasonally dynamic land use, resulting in a fluctuation of both high and low NDVI values depending on what crops are grown, what stage of growth they are in, or if they have been harvested. This creates issues when comparing NDVI for different years since agricultural areas can show high and low values even though the land use is the same. The historical aspect may also cause problems since the urban expansion may have occurred at the expense of agricultural land. Therefore, the correction should be done with datasets that represents the time periods. Thus, two datasets where used, Svensk marktäckedata (SMD), which is Swedish land cover/land use data with reference year 2000 (Naturvårdsverket, 2014), and fastighetskartan (FK), the cadastral map with reference year 2018 (Lantmäteriet, 2020). Because of the high exploitation value of urban land, the chance that land which previously was classified as agricultural land would regain its classification is very low (European Commission, 2012). It can thereby be expected that the classes in these two datasets can be used to mask out agricultural land from the NDVI results for the years prior to their creation.

The SMD land cover/land use dataset used in this study was created with satellite images from the years 1999-2001 (ibid.). The FK dataset was created between the years 1992-2012 and is the most thematically detailed map produced by the Swedish land survey administration (Lantmäteriet), it has continually been revised with data from different authorities and organizations (Lantmäteriet, 2021a; 2020). The land use category Odlad åker or cultivated field is updated based on the "bildförsörjningsprogram" or National aerial photo program, where one third of Sweden is photographed in the annual aerial photo plan to acquire current image information (Lantmäteriet, 2021b).

The class Åkermark or arable land, in SMD was used to remove areas where the results and agricultural area overlapped for the datasets 1986-06-02 to 1989-07-05, 1989-07-05 to 1995-06-27 and 1995-06-27 to 2000-06-17. The category Odlad åker or cultivated field, in FK was used to remove areas where results and agricultural areas overlapped for the datasets 2000-06-17 to 2004-06-03, 2004-06-03 to 2009-06-26, 2009-06-26 to 2013-07-23, 2013-07-23 to 2019-07-06 and 1986-06-02 to 2019-07-06. Overlapping polygons of gain and loss which have their centroid in the source layer feature, SMD Åkermark or FK Odlad åker, with an additional search distance of 100 meter, to account for skewness between result polygons and target layer, were identified and removed from the results.

5 Results

The result from the qualitative content analysis is presented in section 5.1. and the IMCD is presented in section 5.2., 5.3. and 5.4. The IMCD results are presented in two ways, the change between 1986-06-02 and 2019-07-06 and the incremental change between 1986-06-02 and 2019-07-06. Instead of referring to increase or decline of NDVI, gain or loss of greenness will hereafter be used. High resolution orthophotos were used for visual evaluation of areas with change.

5.1 Future municipal planning

The Översiktsplan för Göteborg, Samrådshandling (2019b), which is the basis for the work with the new comprehensive plan, has identified six areas where different development approaches are to be implemented, these are Innerstaden, Mellanstaden, Ytterstaden, Storindustri hamn och logistik, Natur- och rekreationsområden, Kustband och skärgård (figure 8).

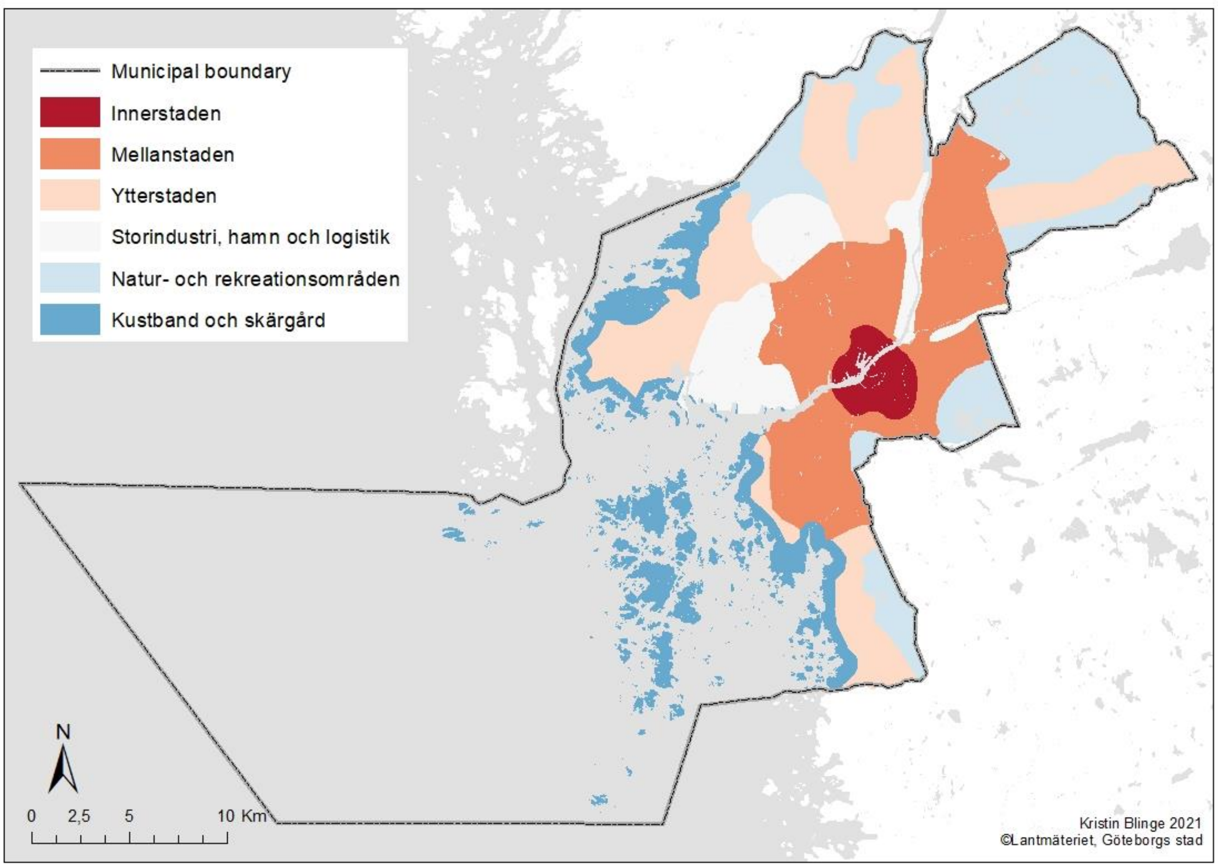


Figure 8 Map over areas from the municipal comprehensive plan with different developing approaches. The areas are Innerstaden, Mellanstaden, Ytterstaden, Storindustri, hamn och logistik, Natur- och rekreationsområden and Kustband och skärgård (Göteborgs stad 2019b). The map is based on the division of areas found in the development documents regarding the upcoming municipal comprehensive plan.

Through the consultation processes three development strategies have been identified: *a close city*, which highlights the importance of service, culture, work, communal transport, parks, green areas, and water in the immediate vicinity of the citizens. *A cohesive city*, the importance of bridging the barriers to create an easy navigated city where people meet in a natural way. *A robust city*, to build a city that is safe and can withstand climate change and other unpredicted changes now and in the future, but also, a city where the citizens have confidence in each other as well as in social structures (Göteborgs stad, 2019b). The themes identified through the qualitative content analysis is presented per thematic area in table 6.

Table 6 Themes identified in the consultation documents. Future development of Innerstaden, Mellanstaden, Ytterstaden, Storindustri, hamn och logistik, Natur- och rekreationsområden and Kustband och skärgård as described in the documents from the consultation process (Göteborgs stad, 2019b)

Area	**Current activities and land use/land cover**	**Future development focus**	
		Structures	**Mobility**
Innerstaden	Workplaces, housing, commerce, universities, parks, and public areas	Densification round old industry areas and shipyards	Public transport Sidewalks Bicycling lanes
Mellanstaden	Housing, squares and urban green area, public transport, services and technical infrastructure	Potential for high densification in already built areas Connecting dispersed built-up areas	Public transport Sidewalks Bicycling lanes
Ytterstaden	Nature areas, agriculture land and urban centers	Densification round and in already build areas Housing and workplaces	Public transport Bicycling lanes
Storindustri, hamn och logistik	Gothenburg harbor, Volvo industrial area, logistic industries, railway and fairway	Environmentally damaging activities Logistics	Railroad Fairway
Natur- och rekreationsområde	Nature and recreational areas, sports area, playgrounds, beaches, agricultural areas with high cultural values and areas with high biodiversity		Develop access points Public transport
Kustband och skärgård	Beaches, recreational areas, areas with high natural and cultural values, harbors, housing and other services	Development in already build areas	Public transport Bicycling lanes

The themes Activities and land use/land cover, Structures and Mobility were identified for all areas except for Structures in Natur- och rekreationsområden. Innerstaden contains the city's historical center, workplaces, housing, commerce, universities, parks, and public areas (Göteborgs stad, 2019b). The development in the urban central area is focused on expansion of communication such as public transports, sidewalks and bicycling lanes, as well as densification mainly areas along the river such as the old shipyard and other industrial areas as well as around the central station (Göteborgs stad, 2019a). Mellanstaden is characterized by diverse living environments with main points of built-up areas dispersed throughout its parts. It is connected to the urban central area by an extensive public transport network. In this area future focus is on densification in already built-up areas as well as connecting dispersed built-up areas with each other. Focus on public transport, bicycling lanes and sidewalks will increase mobility. (Göteborgs stad, 2019b; 2019c). It has been identified as having potential for high densification. Ytterstaden has three more densely built-up parts but is mainly constituted of nature and agriculture. Parts of the area are identified as an important reserve for future planning. Development focus in this area is on increasing population in the already built areas by constructing housing and workplaces as well as to develop public transport and bicycling lanes (ibid.). Storindustri, hamn och logistik consists mostly built-up areas, and it contains large parts of Sweden's automotive industry as well as the largest harbor in Scandinavia. Along the motorways leading to Gothenburg center are activities associated to logistics and industry. In this area environmentally damaging activities as well as activities dependent on logistics will be located (Göteborgs stad, 2019b). The Natur- och rekreationssområden has large, forested areas which extend outside the municipal borders, waterways with high biological value as well as agriculture and cultural landscapes. Future focus here will be on protecting nature and recreational values as well as make areas more available for the public. There should be no exploitation in this area, but the access points are to be developed such as entrances and more extended public transport (ibid.). Kustband och skärgård have areas with high cultural values which are also used for recreational purposes, swimming, boating, and fishing. Future focus in this area is mainly to manage nature, cultural and the marine environments. Although, there will be possibilities to develop in the already built-up areas in the archipelago as well as an expansion of public transport and bicycle lanes.

5.2 Accuracy assessment

To assess the accuracy of IMCD a simple random sample was taken where 1% of lost and gained areas were randomly selected and visually checked against the orthophotos (table 3), so that the gain or loss were either confirmed, denied or labeled as uncertain (table 7). The uncertainty is due to the variable acquisition dates between the orthophotos and EO data, which is further discussed in Section 6.3.1.

Table 7 The result of the accuracy assessment. The random selection of polygons were either confirmed, denied or labeled as uncertain.

Data	**Total number of result polygon**	**Random sample**	**Verified land use change**	**Uncertain land use change**	**Verified %**
1986-06-02 to 1989-07-05	1021	10	5	5	50
1989-07-05 to 1995-06-27	576	6	5	1	83
1995-06-27 to 2000-06-17	823	8	5	3	63
2000-06-17 to 2004-06-03	591	6	4	2	67
2004-06-03 to 2009-06-26	631	6	5	1	83
2009-06-26 to 2013-07-23	737	7	3	4	43
2013-07-23 to 2019-07-06	730	7	6	1	85
1986-06-02 to 2019-07-06	1065	10	7	3	70

5.3 Greenness change between 1986 and 2019

The spatial distribution of change in greenness varies in size and location. Larger areas of changed greenness are located to parts where the urban structure is less extensive and dense, such as in Mellanstaden and Ytterstaden. Storindustri, hamn och logistik has had the largest areas of greenness loss which are spread out throughout the different areas. In the more densely built-up areas such as Innerstaden there has mainly been smaller areas of changed greenness spread throughout. The areas with the least changed greenness are Natur- och rekreationsområden, where areas of change mainly are located along the area border, and Kustband och skärgård where areas of changed greenness are spread throughout (figure 9).

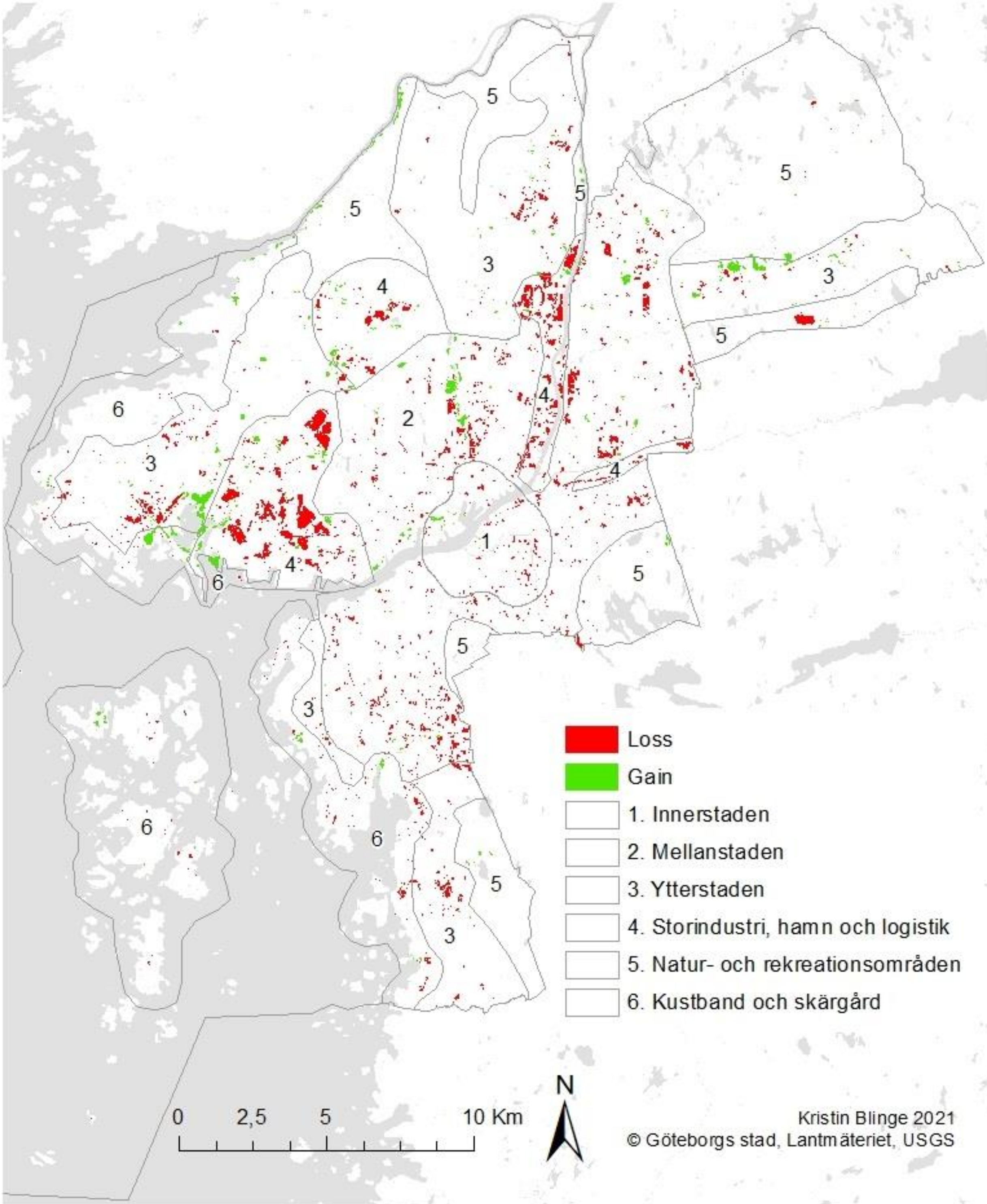


Figure 9 Change of greenness in Gothenburg municipality. The distribution of change varies between and in the different areas identified in the comprehensive plan.

Between 1986-06-02 and 2019-07-06 Gothenburg municipality (ca 45 018 ha in size) has had a greater loss of greenness than it has gained with a total of 2.79% (ca 1 256 ha) loss and 0.83% gain (ca 375 ha, table 8).

Table 8 Greenness gained and lost per area presented in hectare (ha) and percent (%) as well as Net-gain/loss.

Area	**Loss (ha)**	**Gain (ha)**	**Total land area (ha)**	**Loss (%)**	**Gain (%)**	**Net-gain/loss (%)**
Innerstaden	36.3	7.1	1 381.2	2.6	0.5	-2.1
Mellanstaden	430.7	78.8	11 512.7	3.7	0.7	-3
Ytterstaden	194.9	112.7	11 116.3	1.8	1	-0.7
Storindustri, hamn och logistik	504.6	78.4	4 663.9	10.8	1.7	-9.1
Natur- och rekreationsområden	31.9	42.5	9 858.3	0.3	0.4	0.1
Kustband och skärgård	57.7	55.6	6 485.7	0.9	0.9	0
Total for Gothenburg municipality	1 256.1	375.1	45 018	2.8	0.8	-2

All sub areas have had a higher loss than gain except for Natur- och rekreationsområden which has had 0.4% gain and 0.3% loss of greenness. Storindustri, hamn och logistik, Mellanstaden, Innerstaden and Ytterstaden had the highest precentral loss of greenness with 10.8%, 3.7%, 2.6% and 1.8%. The areas gained some greenness between 1986 and 2019 with 1.7%, 0.7%, 0.5% and 1% respectively. Kustband och skärgårdsområde have had 0.9% gain and loss of greenness (table 8 & figure 10).

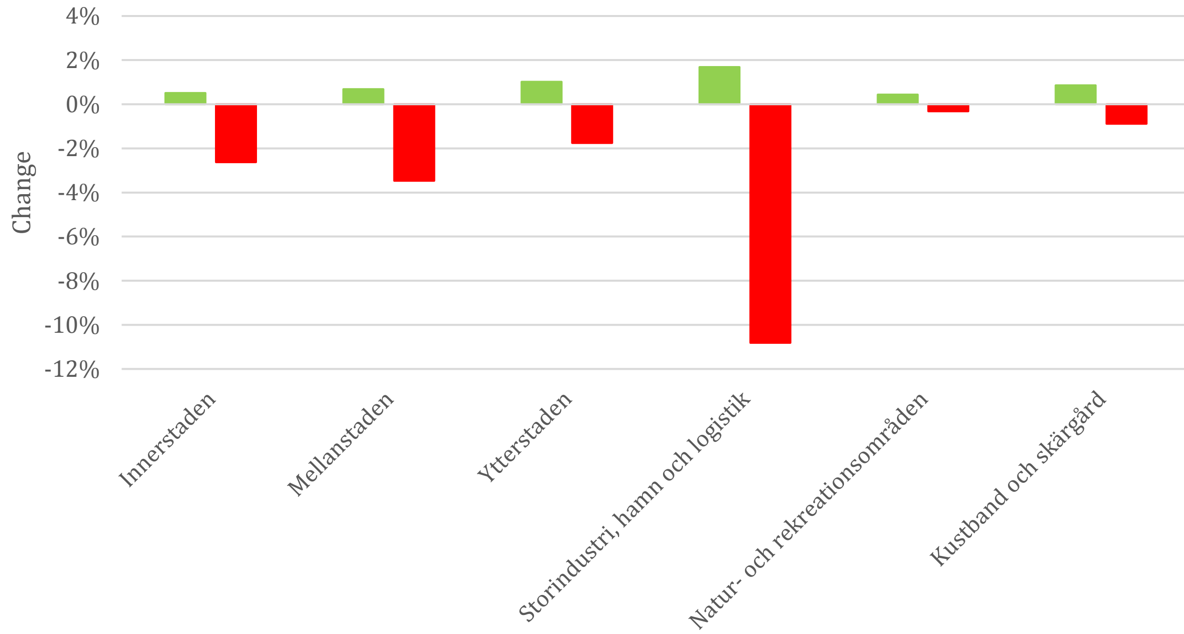


Figure 10 Lost and gained greenness per land unit between 1986-06-02 and 2019-07-06. The red bar represents loss, and the green bar represents gain.

In Innerstaden there have mainly been smaller areas of greenness loss, mostly dispersed throughout the east part on both sides of the Göta river with one exception, that is the relatively large, gained area north-west of the Göta river (figure 9). Figure 11 displays a sample of greenness change in Innerstaden.

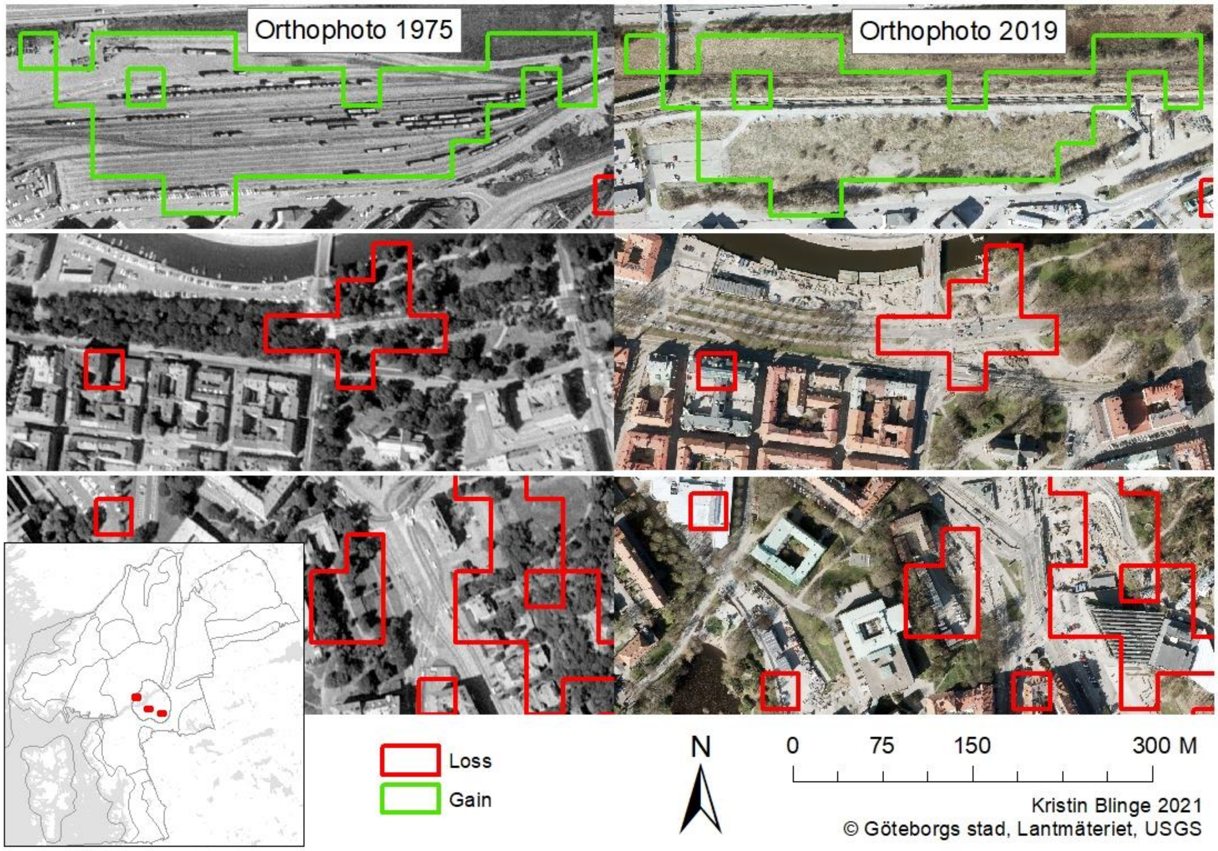


Figure 11 Three areas with greenness change in Innerstaden between 1986 and 2019.The images on the top row shows railroad tracks in Lindholmen south of Lundbyleden. The images in the middle shows the crossing Södra allén – Sprängkullsgatan and Hagakyrkan. The images on the bottom row shows a part of Korsvägen. Regard should be taken when studying the figure since there is a gap between when the orthophoto from 1975 was taken and the satellite data used in the analysis (1986).

The area of Lindholmen (in the top row of figure 11) shows an example of increased greenness, where an area previously occupied by train tracks and used by the shipyard was in 2019 grown in with shrubs (i.e., shrubification). In most of the areas with lost greenness in Innerstaden trees has been cut down and vegetation had been removed to, amongst other things, widen roads and construct buildings mainly around institutions like university areas and amusement parks.

In Mellanstaden the distribution of lost and gained areas varies in size. North of Göta älv close to the Innerstaden border there is a cluster of rather big areas with both lost and gained greenness. Otherwise, the larger areas with loss and gain are mainly spread out along the outer border of Mellanstaden (figure 9). Figure 12 displays a sample of greenness change in Mellanstaden.

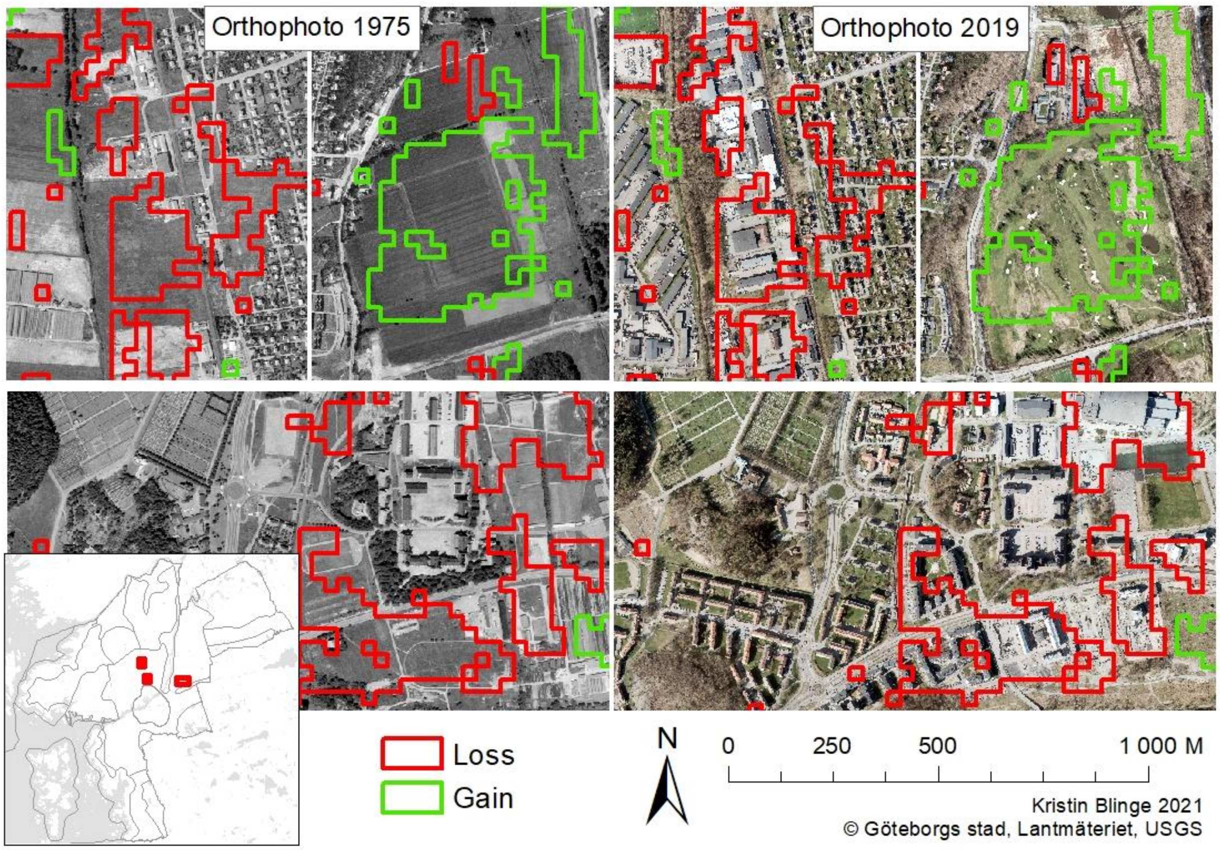


Figure 12 Three areas with greenness change in Mellanstaden between 1986 and 2019. The images on the top left shows Lillhagsvägen south of Lillhagen. The images on the top right shows a part of Tuve. The images on the bottom shows Kviberg and Kvibergs ängar. Regard should be taken when studying the figure since there is a gap between when the orthophoto from 1975 was taken and the satellite data used in the analysis (1986).

In the periphery of Mellanstaden loss of greenness is mostly due to the construction of commerce, industry, and residential areas on farmland. North of the Göta river and Innerstaden there is a large cluster of acreages with both gain and loss of greenness. Here greenness has been lost when farmland has been converted to different building complexes and greenness has been gained when a golf course was established. Closer to the center of Mellanstaden loss of greenness is mostly attributed to land use change where green areas in an already built-up district like lawns and sports areas are converted to buildings. Existing infrastructure close to forested areas has also expanded at the expense of vegetation. Like Innerstaden there has also been loss of vegetation due to widening of roads, mainly creating roundabouts as well as entrance and exit ramps.

Ytterstaden consists of five areas located in the north, north-east, north-west, and south parts of the municipality. The spatial change in these areas is relatively clustered and there are larger areas with no or low change (figure 9). Figure 13 shows a sample of land use changes in Ytterstaden.

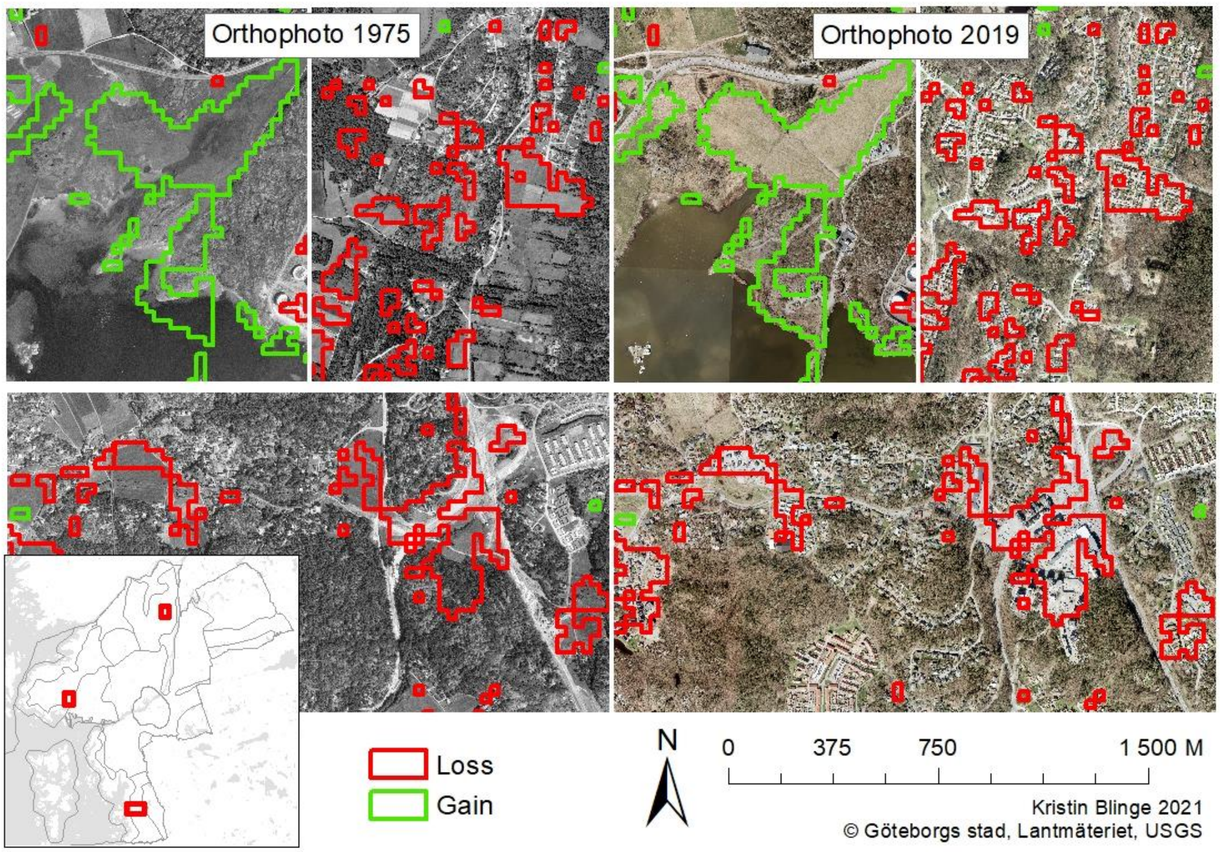


Figure 13 Three areas with greenness change in Ytterstaden between 1986 and 2019. The images on the top left shows Torslandaviken. The images on the top right shows Mysterna in the north-west part of Hisingen. The images on the bottom show road 158, Hovås Allé and Brottkärr Kinde in the south part of the municipality. Regard should be taken when studying the figure since there is a gap between when the orthophoto from 1975 was taken and the satellite data used in the analysis (1986).

Out of the five Ytterstaden areas the ones north west and north east have gained the most greenness (figure 7). In the north-west area, the gained greenness is due to a bay that has been filled with material and vegetation has started to grow. In the north-east area, the gain is attributed to two things: the construction of a golf course on farmland and areas with large open bare ground where vegetation has been left to grow. Other, smaller areas of gained greenness in Ytterstaden are mostly due to fields with a high degree of shrubification. Areas where fields and parts of forests close to existing infrastructure have been converted to housing, commerce, and industry is the main reason for greenness loss.

Storindustri, hamn och logistik consists of four areas in the north, east and west part of Gothenburg municipality. All areas have seen a high degree of greenness loss with the exception of the west part (figure 9) where cobs have been connected to the mainland and vegetation has grown on the filling material between them (figure 14).

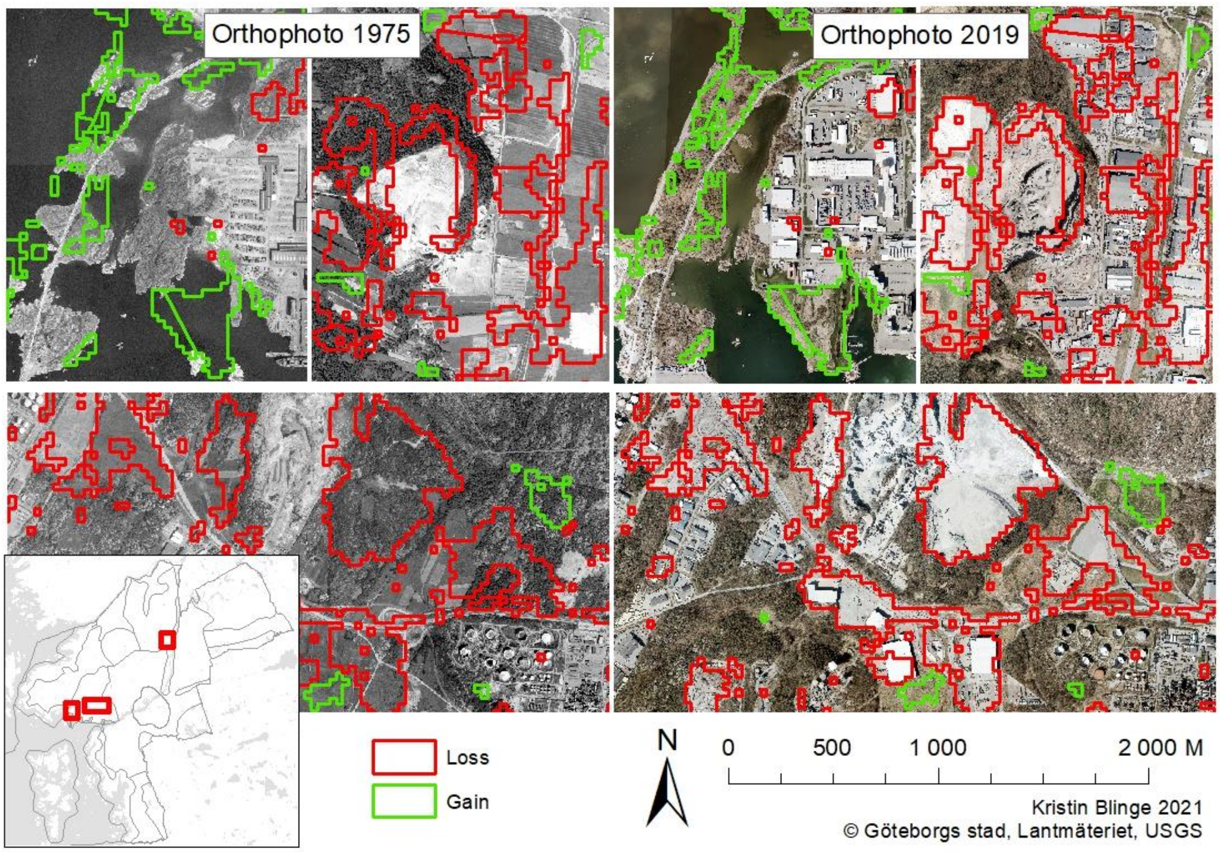


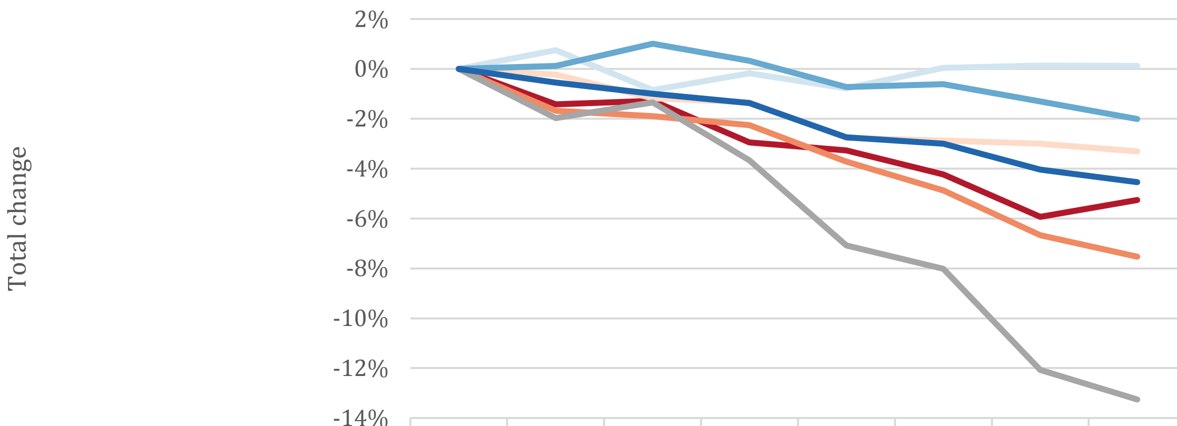
Figure 14 Three areas with greenness change in Storindustri, hamn och logistik between 1986 and 2019. The images on the top left shows a part of Torslandaviken and Arendal. The images on the top right shows the open-pit mining along road E6 west of Bönered north-west part of Hisingen. The images on the bottom shows the open-pit mining between road 55 and Hisingsleden by Halvorsäng. Regard should be taken when studying the figure since there is a gap between when the orthophoto from 1975 was taken and the satellite data used in the analysis (1986).

In the northern part along Göta älv and the western part of Storindustri, hamn och logistik two areas with open-pit mining has expanded into what was previously forests and fields. In the other areas with greenness loss, existing infrastructure has expanded in a similar way as the areas described above, with the establishment of building complexes and widening of roads, with the main difference that more large open areas with impervious surfaces such as parking lots have been erected in Storindustri, hamn och logostik. The small areas of gain are mostly located where the land use has gone from a more natural composition of vegetation such as forest in 1975 to a field with some urban elements, for example a road, in 2019 indicating that the area has been exploited and vegetation has returned.

In Natur- och rekreationsområden there has been only a little change. In the forested areas small patches of gain can be attributed to the regrowth of vegetation on clear cuts and the main areas of loss are due to an open-pit mine and clear cuts in the north east part of the municipality (figure 9). In Kustband och skärgård there has been a higher degree of change than in Natur- och rekreationsområden. The larger areas of change are a gained greenness area in the north west part of the municipality where a golf course was constructed and clusters of lost greenness areas where housing has been built in the southern part of Kustband och skärgård (figure 9). Smaller patches of loss are mainly located in close connection to already built-up areas such as housing and harbors.

5.4 Incremental change

During all the time periods the summarized change in Gothenburg municipality has been negative with the largest change for the periods 2000-06-17 to 2004-06-03, 2009-06-26 to 2013-07-23 and 1986-06-02 to 1989-07-05 with -1.3%, -1% and -0.6%. All sub-areas except Natur- och rekreationsområden have had a negative incremental change between 1986-06-02 and 2019-07-06. The area Storindustri, hamn och logistik deviates with a total incremental change of -13.3%, almost double the amount of loss seen in Mellanstaden which has the second incremental change with -7.5%. Innerstaden and Ytterstaden follows with -5.3% and -3.3% respectively and Natur- och rekreationsområden and Kustband och skärgårdsområde follows with 0.1% and -2.0%, respectively (figure 15).



	>1986	1986-1989	1989-1995	1995-2000	2000-2004	2004-2009	2009-2013	2013-2019
Innerstaden	0,0%	-1,4%	-1,3%	-3,0%	-3,3%	-4,2%	-5,9%	-5,3%
Mellanstaden	0,0%	-1,7%	-1,9%	-2,3%	-3,7%	-4,9%	-6,7%	-7,5%
Ytterstaden	0,0%	-0,2%	-1,2%	-1,3%	-2,8%	-2,9%	-3,0%	-3,3%
Storindustri, hamn och logistik	0,0%	-2,0%	-1,3%	-3,7%	-7,1%	-8,0%	-12,1%	-13,3%
Natur- och rekreationsområden	0,0%	0,7%	-0,9%	-0,2%	-0,8%	0,0%	0,1%	0,1%
Kustband och skärgård	0,0%	0,1%	1,0%	0,3%	-0,7%	-0,6%	-1,3%	-2,0%
Total for Gothenburg municipality	0,0%	-0,6%	-1,0%	-1,4%	-2,7%	-3,0%	-4,0%	-4,5%

Figure 15 Cumulative net change of NDVI per sub area between 1986-06-02 and 2019-07-06. The figure shows the joint values of gain and loss for each sub area in percent (%). The values of previous years are added together to show incremental change.

Storindustri, hamn och logistik has had the largest decline, and only between 1989-07-05 and 1995-06-27 was there a positive change with 0.7%, otherwise the decline in greenness has been steep. Between 2009-06-26 and 2013-07-23 the area had a loss of 4.1%, 2000-06-17 to 2004-06-03 a change of -3.4% and 1995-06-27 to 2000-06-03 -2.4%. Mellanstaden is the area with the second largest decline. None of the time periods have had a positive change, and the three time periods with the largest loss are 2009-06-26 to 2013-07-23, 1986-06-02 to 1989-07-05 and 2000-06-17 to 2004-06-03 with -1.8%, -1.7% and -1.4%, respectively. Innerstaden has also had a steep decline but has had two time periods with positive change, 1989-07-05 to 1995-06-27 and 2013-07-23 to 2019-07-06 with 0.1% and 0.6%. Ytterstaden has only had negative change between the periods but it is also the area which has had the lowest change of the four previously mentioned. The periods 1989-07-05 to 1995-06-27, 2000-06-17 to 2004-06-03 and 2013-07-23 to 2019-07-06 has had the largest negative change with -1%, -1.5% and 0.3% respectively (figure 14).

6 Discussion

The results show that from 1986-06-02 to 2019-07-06 Gothenburg municipality has had a greater decline than increase of green areas (figure 10), and there has also clear declining incremental change in all sub areas except for Natur- och rekreationsområden for the time period. Storindustri, hamn och logistik, Mellanstaden, Innerstaden and Ytterstaden are the areas most affected by vegetation loss (figure 15).

6.1 Spatial patterns of present and future vegetation change

There has been a decline in amount of greenness in the municipality with a cumulative net-change of -2% and a total loss of 2.8% or 1 256.1 ha between 1986 and 2019 (table 8). Drawing on figure 8 the amount and characteristics of vegetation change between 1986-06-02 and 2019-06-29 differs between the areas. The spatial pattern of change follows the urban structure: in the denser urban environment smaller surfaces are subject to change while larger areas with change are located further away from the city center. This pattern was to be expected since greenery already has been removed in dense urban environments. Most of the larger areas with increased greenness are due to the establishing of golf courses on farmland and forested areas. The vegetation on golf courses has a more static greenness than agricultural fields and they consist of specific types of grass. Grass and fields will also have a higher NDVI than coniferous forest since the rugged structure of canopies has different reflectance properties than a smoother field of grass (Jones & Vaughan, 2010, pp. 47-50). Green areas as these have shown to be able to hold high ecological value and to be important for biodiversity (Colding & Folke, 2009). A master's thesis studying three golf courses on the west coast of Sweden has shown that areas with dead wood have the potential to be key elements for biodiversity and that waterbodies are home to several protected species (Berntsson & Lindström, 2005). The green areas that are not golf courses mostly consists of fields with a high degree of shrubification.

The incremental change shown in figure 15 suggests a planning policy where vegetated areas are not dealt with as a whole, but rather get exploited bit by bit. Looking at a municipal scale the combined exploitation has a large impact on the total green area in Gothenburg municipality (table 8 & figure 15). Storindustri, hamn och logistik is where most negative incremental change has occurred; the activities in the area, such as large industries, harbor and logistics, are space consuming. The themes regarding Storindustri, hamn och logistik found in the comprehensive plan documents show that development of industries will be focused to these areas indicating that the trend of drastic vegetation loss will most likely be continued. Future development in Innerstaden will be located to old industrial areas as well as the old shipyards. It is therefore possible to say that informal green areas that have sprung up since the industry was moved, such as the shrubification of the train tracks (figure 11), will be an object for exploitation. Other areas with negative change in Innerstaden are close to institutions (figure 11) showing that vegetation near existing public buildings or functions run by private actors in this area is prone to exploitation. Between 2013 and 2019 there has been a slight increase of greenness (0.6%) in Innerstaden (figure 15). This is partly due to the establishing of greenery in a newly built housing area as well as an area where cars previously were parked and grass has started to grow. This gain in greenness could be connected to an attitude change but it is also likely that less desirable activities, such as the parking area, is moved to enable exploitation. In Mellanstaden and Ytterstaden larger building projects such as commerce, housing and industry around previously existing infrastructure are the main reason for vegetation loss (figure 12 & 13). According to the comprehensive plan these areas will also accommodate for a lot of future urban expansion by densifying existing urban areas. This will most likely influence the vegetation structure as urban green areas such as fields, shrubs and forests most likely will be exploited.

The widening of roads and expansion of streets, cycling lanes and public transport has shown to have a high impact on greenness (figure 11, 12 & 14). In Mellanstaden green areas have been removed to create roundabouts, entrance and exit ramps to accommodate for more traffic. In a similar way the widening of roads in Innerstaden and Storindustri, hamn och logistik has resulted in vegetation loss. The importance of mobility and accessibility is a recurring theme for all the areas in the upcoming comprehensive plan and will almost definitely influence nearby vegetation in the future in a similar way seen in Innerstaden, Mellanstaden and Storindustri, hamn och logistik (figure 10, 11 & 13).

The tyranny of the small decisions becomes visible when shown with a multitemporal perspective as done in this study. By reviewing urban development through the historic perspective of green area change, the impact of future planning on green areas becomes more apparent. The comprehensive planning documents as they are formulated today will most likely continue the negative trend of cumulative change (figure 15) with the most impact on Mellanstaden, Ytterstaden and Storindustri, hamn och logistik. Changing the perspective by looking at historical vegetation change and not only focusing present land use/land cover could benefit a more holistic approach regarding urban green areas and development.

6.2 Method discussion

When working with EO data to detect multitemporal vegetation change there are different factors that play an important role in what is registered in the image. One such factor, is connected to the physical properties on the ground and another is connected to the properties of the sensors. Depending on these factors the imagery will most likely have characteristics that are important to be aware of.

6.2.1 Spatial and temporal resolution

Multitemporal change detection is delimited by two factors; namely spatial resolution, and temporal resolution, which dictate what phenomenon can be studied (Gamba & Dell'Acqua, 2016; Belward & Skøien 2015). The availability of high-resolution cloud free images during peak vegetation and no extreme weather events of a specific area is limited and certain exceptions are most likely to be made. In this case Landsat imagery between 1986 and 2019 with a 30-meter pixel size within a time interval over five years ± 2 years was used.

The temporal resolution is determined by the points in time the images were acquired. Landsat is the longest continuously running EO program with the first satellite launched in 1972 and the first satellite with sensors recording 30- meter pixels launched 1984 (NASA, 2020a; USGS, 2020a). This study uses Landsat 5 and Landsat 8 imagery spanning from 1986 to 2019. The temporal resolution of the Landsat data used in this study must be considered as suitable since there is not any other EO data with this spatial and temporal resolution easily available. There is also a high comparability because of the programs near polar-orbit with a return cycle of 16 days (Jones & Vaughan, 2010 pp. 120-121; NASA, 2020b). This assures sun-synchronous images which minimize shadow angles and illumination variability (Jones & Vaughan, 2010 p. 98) which reduces the data preprocessing and minimizes alteration to the reflectance values. Furthermore, a five-year timeframe has shown to be adequate to display incremental vegetation change. Spatial patterns of urbanization such as shrubification, establishing of golf courses and vegetation loss due to urbanization, has also emerged through the analysis.

The validation of the results has however not been optimal. The verification of the method shows that all time periods had a verification percent of over 50% except for the one between 2009-06-26 and 2013-07-23. The uncertainty in verifying whether a change has occurred or not is caused by the variable characteristics and acquisition dates of the orthophoto. The orthophotos were taken in different times of the year (table 3), and the seasonality sometimes made it difficult to verify vegetated areas. Only areas where there was a clear land use change could be verified, for example if a building had been erected or if farmland grew in with shrubs. The orthophoto from 1975 was in black and white which made it hard to distinguish between different surfaces. There is also an inconsistency between the years the orthophotos and the satellite images were taken, which means that change which occurred certain years could be difficult to verify. For example, between the years 1986 and 1989 the orthophotos 1975 and 2003 were used; if an area had been clear cut in 1987, it would appear as a loss of vegetation in the analysis but in the orthophotos from 2003, the area would have had 16 years to regrow making the change hard to interpret. Most of the uncertain samples were areas with gained greenness which would be expected since vegetated areas are more dynamic than for example an asphalted parking lot.

The difference caused by the temporal resolution also becomes clear when comparing the results from the 1986 and 2019 net -gain/loss shown in table 8 and the cumulative net-gain/loss shown in figure 14. Where the cumulative net-change is greater than the net-change between 1986 and 2019. The result in table 8 shows gain and loss of greenness between 1986-06-02 and 2019-06-29 and the result shown in figure 14 is a cumulative net change of gained and lost greenness for all the years used in the study. The urban environment is in a constant metamorphic process and some phenomena that are visible in a shorter time span change and becomes filtered out when looking at it through a larger temporal scale (Gamba & Dell'Acqua, 2016). For example, trees can regrow in a previously clear-cut area and a field can be turned into bare ground and again into a field.

These kinds of changes are showing in the cumulative results ad not in the 1986 and 2019 change results.

Depending on the spatial resolution, different phenomenon can be studied; in this study the distribution of urban vegetation cover on a municipal level is in focus. Landsat is a medium resolution dataset which is considered to be a good spatial resolution for urban extent monitoring (Gamba & Dell'Acqua, 2016; Belward & Skøien 2015). With this said, there are some aspects that are important to take into consideration. The spatial resolution refers to the pixel size of the images, and a pixel can contain different features and therefore have different spectral properties also called the "mixed pixel dilemma". The mixed pixel dilemma occurs when there is more than one land cover class that affects the reflectance properties of the pixel. The ideal situation would be if the pixel only represents the reflectance properties of one kind of class. For example, that one pixel represents a forest and another agriculture, but often the boundary of different classes can pass through a pixel and mix the reflectance properties. When the pixel is mixed the spectral characteristics represents more than one surface, for example if the pixel contains both forest and water the pixel reflectance will be a mix of both those classes (Cracknell, 1998). Since Landsat imagery is a medium-resolution dataset with a pixel size of 30 m × 30 m (Jones & Vaughan 2010 pp. 120-121), there is a spatial limitation as to what changes can be detected (Gamba & Dell'Acqua, 2016; Belward & Skøien 2015). For example, if a vegetated area of 30 × 30 meter or larger is cleared the spectral response will have a clear deviation from one year to the other, but if a smaller amount of vegetation is removed the change in spectral response would be lower and the area could be filtered out as noise. In a dense urban environment such as Innerstaden with sparse cover of vegetation to begin with, the latter scenario could be the case. Another mixed pixel dilemma in urban environments is related to buildings and shadows. The city structure and its urban fabrics create a multifaceted urban canyon with an assembly of different sized buildings and surfaces. This environment creates a complex shadow pattern that effects radiance properties of vegetation as well as other materials as shown by Adeline et.al (2013) and Lindberg & Grimmond (2011). The height and type of the object that castes the shadow, affects what reflectance properties is registered by the sensor and it is therefore not possible to derive true reflectance of each pixel (Jones & Vaughan 2010, p. 167). In the scope of this study the medium spatial resolution of Landsat EO data limits what can be studied. Various urban morphology characteristics and the shadow effects from these may have an impact on the results, but the specific phenomena must be studied with higher spatial resolution EO data. To study vegetation change in a dense urban environment EO imagery from satellites such as SPOT or Sentinel with 10 m × 10 m resolution or Pléiades/WorldView with 0.5 m × 0.5 m resolution would be preferable (ibid.). However, the long-term availability of Landsat images makes it preferable in many remote sensing studies (Li, Zhou, Zhu, Liang, Yu & Cao 2018; Gandhi, Parthiban, Thummalu & Christy, 2015; Wellmann et al., 2020; Samuelsson et al. 2020).

6.2.2 NDVI and climate

Greening and senescence of vegetation in the northern hemisphere is a dynamic process that is affected by many aspects such as temperature, humidity and even climate change (Chang, Wang, Vadeboncoeur & Lin, 2014; Samuelsson, 2021). Apart from this, short-term variation of vegetation does occur for example due to light saturation and plant stress which creates variations in chlorophyll fluorescence and in turn affects the reflectance properties (Eklundh & Jönsson, 2015). The annual and monthly composition of climatological data (figure 4 & 5) shows that temperature and precipitation have not deviated too much from the climatological normal. Local effects on plant stress could have occurred, but by thresholding based on the second standard deviation high and low values were isolated and most noise was excluded. In this way only the areas with most drastic change was accounted for. With this said, short-term variation of vegetation and moisture could have influenced the results by excluding or including areas based on the second standard deviation.

The satellite's position over the study area has an important impact on the reflectance properties of the image. Depending on which time of day the imagery was taken shading effects will take place. These effects are caused by the sun angle and will alter the reflectance in the image. The near polar orbit of the Landsat program assures a systematic revisit time that minimizes these effects. For the images used in this study the maximum time difference in the scene center is 42 minutes and 2 seconds between the years 1994 and 2019 (table 4). Since the images are taken during the summer close to the solstice when the hours of sunlight are at its peak, sun angle and shading effects should be lower than during the winter.

6.3 Further research

This study has brought up aspects that should be subject for future research, the spatial resolution is one of them. Even if Landsat at the present is the best source for multi-decadal data sets it would be interesting to look at urban vegetation with a higher spatial resolution data such as SPOT or Sentinel-2 data, especially in dense urban environments. This could give a better understanding of the spatiotemporal characteristics of vegetation in a dense urban environment. Furthermore, the development of EO is ongoing with Landsat 9 launching mid-2021 (Masek et.al, 2020), which will enable future studies to examine urban vegetation patterns with a potentially higher temporal resolution.

It would also be interesting to look at how green infrastructure is affected by loss and gain of green area. Future studies can draw on inspiration from Furberg & Ban (2013) which studied the fragmentation of green areas in Stockholm but with a higher temporal scale, as well as to include previous and present comprehensive plans to create an even more detailed picture of municipal planning and its relation to greenness change.

7 Conclusion

NDVI derived from Landsat satellite data has proven to be an effective way to identify both removal and growth of green areas at a municipal level, although higher spatial resolution EO data would be preferable to detect change in a more densely built environment. The vegetation patterns derived from the analysis are diverse and the spatial distribution of change depends on the area and its development focus. In Gothenburg municipality 2.8% of the land area has lost a considerable amount of greenness and 0.8% has gained in greenness between the years 1986 and 2019 (table 8). The area with the largest percental loss of greenness is Storindustri, hamn och logistik followed by Mellanstaden, Innerstaden, Ytterstaden, Kustband och skärgård and Natur- och rekreationsområden. The area with the largest percental gain of greenness is Storindustri, hamn och logistik followed by Ytterstaden, Kustband och skärgård, Mellanstaden, Innerstaden and Natur- och rekreationsområden (table 8). Spatial patterns of gain and loss have been identified, where larger areas of loss are located to the outskirts of the urban environment except for Storindustri, hamn och logistik where there have been large areas of loss throughout (figure 9). Looking at future development plans and the cause of loss of greenness in the past, vegetation loss due to the development of road and transport infrastructure will most likely be present in all areas. In the future, densification in and around already built areas will almost certainly be a factor for vegetation loss. In Innerstaden this means mainly exploiting old industrial areas and informal greenspace such as the overgrown train tracks. In Mellanstaden and Ytterstaden this means loss of green areas close to existing structures when these are subjected to exploitation.

References

Adeline, K., Chen, M., Briottet, X., Pang, S., & Paparoditis, N. (2013). Shadow detection in very high spatial resolution aerial images: A comparative study. *ISPRS Journal of Photogrammetry and Remote Sensing, 80*, 21-38.

Ban, Y., Yousif, O. (2016). Chang detection techniques: a review. In Y. Ban (ed.). *Multitemporal Remote Sensing: Methods and Applications.* (19-43) (Vol. 20, Remote Sensing and Digital Image Processing Ser).

Belward, A., & Skøien, J. (2015). Who launched what, when and why; trends in global land-cover observation capacity from civilian earth observation satellites. *ISPRS Journal of Photogrammetry and Remote Sensing, 103*, 115-128.

Berntsson, L., & Lindström, A. (2005). *En undersökning av golfbanors potential som bärare av höga naturvärden* (Master's thesis). Göteborg: Zoologiska institutionen och Botaniska institutionen, Gothenburg University. Retrieved from https://docplayer.se/6912686-En-undersokning-av-golfbanors-potential-som-barare-av-hoga-naturvarden.html

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological Economics, 29*(2), 293-301.

Bryman, A. (2012). *Social research methods* (4th ed.). Oxford: Oxford University Press.

Campbell, J., & Wynne, R. (2011). *Introduction to remote sensing* (5th ed.). New York: Guilford Publications.

Chang, C., Wang, S., Vadeboncoeur, M., & Lin, T. (2014). Relating vegetation dynamics to temperature and precipitation at monthly and annual timescales in Taiwan using MODIS vegetation indices. *International Journal of Remote Sensing, 35*(2), 598-620.

Colding, J., & Folke, C. (2009). The Role of Golf Courses in Biodiversity Conservation and Ecosystem Management. *Ecosystems*, 12(2), 191-206.

Cracknell, A. (1998). Review article Synergy in remote sensing-what's in a pixel? *International Journal of Remote Sensing, 19*(11), 2025-2047.

Curran, P. (1980). Multispectral remote sensing of vegetation amount. *Progress in Physical Geography, 4*(3), 315-341.

Drisko, J. (2015). *Content Analysis*. (Pocket Guide to Social Work Research Methods Ser).

Eklundh, L., Jönsson P. (2015). TIMESAT: A software package for time-series processing and assessment of vegetation dynamics. In S. Dech (ed.). *Remote Sensing Time Series: Revealing Land Surface Dynamics* (141-158). (Remote Sensing and Digital Image Processing Ser).

Eliasson, I., Knez, I., Westerberg, U., Thorsson, S., & Lindberg, F. (2007). Climate and behaviour in a Nordic city. *Landscape and Urban Planning*, 82(1-2), 72-84.

European Commission (2012). *Guidelines on best practice to limit, mitigate or compensate soil sealing.* Luxembourg: Publications Office of the European Union

Furberg, D. & Ban, Y. (2013). Satellite monitoring of urban land cover change in Stockholm between 1986 and 2006 and indicator-based environmental assessment. In J. M. Krisp et al. (ed). *Earth observation of global changes (EOGC)* (205-222).

Gamba P., & Dell'Acqua F. (2016). Change detection in urban areas: spatial and temporal scales. In Y. Ban (ed.). *Multitemporal Remote Sensing: Methods and Applications.* (45-61) (Vol. 20, Remote Sensing and Digital Image Processing Ser).

Gandhi., G., M., Parthiban, S., Thummalu, N: & Christy, A. (2015). Ndvi: Vegetation change detection using remote sensing and gis – a case study of Vellore District. *Procedia Computer Science 57*(2015), 1199-1210.

Geodata - Lantmäteriet (2020). *Jordbruksblock.* Retrieved 2020-11-05 from https://www.geodata.se/geodataportalen/srv/swe/catalog.search;jsessionid=D3400C5201ABFB0449D6D101724DA908#/metadata/df439ba5-014e-44ec-86cb-ddb9e5ba306c

GIS Ag Maps.com (2011). *Simplified Landsat 8 & Sentinel-2 Conversion to Surface Reflectance Steps*. Retrieved 2020-11-20 from http://www.gisagmaps.com/l8-s2-atco-sr-steps/

Gómez-Baggethun, E., Gren, Å., Barton, D., N., Langemeyer, J., McPhearson, T., O'Farrell, P., … Kremer, P. (2013). Urban ecosystem services In T. Elmqvist (ed.). *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment* (175-251). Cham: Springer.

Göteborgs stad (2019a). *Översiktsplan för Göteborg. Fördjupad för centrala Göteborg. Samrådshandling 2018.* Kalmar: Göteborgs stad

(2019b). *Översiktsplan för Göteborg. Samrådshandling december 2018*. Kalmar: Göteborgs stad

(2019c). *Översiktsplan för Göteborg. Fördjupad för Högsbo-Frölunda med Dag Hammarsjöldsleden. Samrådshandling 2018.* Kalmar: Göteborgs stad

(2020). *Stadsutveckling Göteborg. Ny översiktsplan för Göteborg*. Retrieved 2020-02-04 from https://stadsutveckling.goteborg.se/oversiktsplan

(2021a). *Statistik och analys: Befolkningsförändringar*. Retrieved 2021-02-25 from https://goteborg.se/wps/portal/enhetssida/statistik-och-analys/demografi-och-analys/Om-befolkningen/goteborgs-befolkningsutveckling?uri=gbglnk%3A2018813103728357

(2021b). *Öppna data*. Retrieved 2021-02-26 from https://goteborg.se/wps/portal/start/kommun-o-politik/kommunfakta/stadens-digitala-service/oppna-data?uri=gbglnk%3A2015816171319546

(2021c). *Flygbilder*. Retrieved 2021-02-26 from https://goteborg.se/wps/portal/start/byggande--lantmateri-och-planarbete/kartor-matning-fastighetsfragor/kartor-och-geodata/flygbilder-info-fakta?uri=gbglnk%3Agbg.page.e0643fb4-a4a1-4b10-a65c-37a989a2f86b

Haaland, C., & Van Den Bosch, C. (2015). Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban Forestry & Urban Greening, 14*(4), 760-771.

Hauck, T., & Czechowski, D. (2017). A brief sketch of its history and ideas in the United States and Germany. In Czechowski, D., Hauck, T., & Hausladen, G. (ed). *Revising green infrastructure: Concepts between nature and design* (3-28).

Huete, A., Didan, K., Miura, T., Rodriguez, E., Gao, X., & Ferreira, L. (2002). Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment*, *83*(1-2), 195-213.

Hägerstrand, T. (2001). A look at the political geography of environmental management. In *Sustainable landscapes and lifeways: scale and appropriateness* (35-58). Cork: Cork University Press

(1991). Globalt och lokalt. In G. Carlestam & B. Sollbe (ed.) *Om tidens vidd och tingens ordning: Texter av Torsten Hägerstrand* (9-19). (T / Statens råd för byggnadsforskning, 1991:21).

Jones, H., & Vaughan, R. (2010). *Remote sensing of vegetation: Principles, techniques, and applications*.

Konarska, J., Uddling, J., Holmer, B., Lutz, M., Lindberg, F., Pleijel, H., & Thorsson, S. (2016). Transpiration of urban trees and its cooling effect in a high latitude city. *International Journal of Biometeorology*, 60(1), 159-172.

Lantmäteriet (2021a). *Fastighetskartan*. Retrieved 2021-01-27 from https://www.lantmateriet.se/sv/Kartor-och-geografisk-information/geodataprodukter/produktlista/fastighetskartan/#steg=1

(2021b). *Bildförsörjningsprogrammet*. Retrieved 2020-11-05 from https://www.lantmateriet.se/sv/Kartor-och-geografisk-information/geodataprodukter/stodsidor/Bildforsorjningsprogram

(2021c). *Hämta historiska ortofoton*. Retrived 2021-02-26 from https://www.lantmateriet.se/sv/Kartor-och-geografisk-information/oppna-data/hamta-historiska-ortofoton/

(2021d) Historiska ortofoton. Retrieved 2021-02-26 from https://www.lantmateriet.se/sv/Kartor-och-geografisk-information/geodataprodukter/produktlista/historiska-ortofoton/

(2020). *GSD-Fastighetskartan vector*. Dokumentversion 7.5.8: Lantmäteriet

Li, X., Zhou, Y., Zhu, Z., Liang, L., Yu, B., & Cao, W. (2018). Mapping annual urban dynamics (1985–2015) using time series of Landsat data. *Remote Sensing of Environment*, 216, 674-683.

Lillesand, T.M., Kiefer, R. & Chipman. J. (2015). *Remote Sensing and Image Interpretation*, 7th Edition.

Lin, B., Meyers, J., & Barnett, G. (2015). Understanding the potential loss and inequities of green space distribution with urban densification. *Urban Forestry & Urban Greening*, *14*(4), 952-958.

Lindberg, F. & Grimmond, C., S., B. (2011). Nature of vegetation and building morphology characteristics across a city: Influence on shadow patterns and mean radiant temperatures in London. *Urban ecosystems, 14*(4), 617-634

Masek, J., Wulder, M., Markham, B., Mccorkel, J., Crawford, C., Storey, J., & Jenstrom, D. (2020). Landsat 9: Empowering open science and applications through continuity. *Remote Sensing of Environment, 248*, Remote sensing of environment, October 2020, Vol.248.

McDonald, R., I., Marcotullio, P., J. & Güneralp B. (2013) Urbanization and global trends in biodiversity and ecosystem services. In T. Elmqvist (ed.). *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment* (31-52)*.* Cham: Springer.

Mishra, N., Haque, M., Leigh, L., Aaron, D., Helder, D., & Markham, B. (2014). Radiometric Cross Calibration of Landsat 8 Operational Land Imager (OLI) and Landsat 7 Enhanced Thematic Mapper Plus (ETM). *Remote Sensing, 6*(12), 12619-12638.

NASA (2020a). *About*. Retrieved 2020-02-21 from https://landsat.gsfc.nasa.gov/about/

(2020b) *Landsat 4-5*. Retrieved 2020-03-03 from https://landsat.gsfc.nasa.gov/landsat-4-5

(2020c). *Landsat 8*. Retrieved 2020-03-03 from https://landsat.gsfc.nasa.gov/landsat-8/landsat-8-overview

(2020d) *The Thematic Mapper*. Retrieved 2020-12-14 from https://landsat.gsfc.nasa.gov/landsat-4-5/tm

Naturvårdsverket (2014). *Svenska marktäckedata*. Utgåva 1.1: Naturvårdsverket

(2020a). *Grön infrastruktur för levande landskap.* Retrieved 2021-02-12 from https://www.naturvardsverket.se/gron-infrastruktur

(2020b). *Vad är ekosystemtjänster?* Retrieved 2020-10-21 from https://www.naturvardsverket.se/Miljoarbete-i-samhallet/Miljoarbete-i-Sverige/Uppdelat-efter-omrade/Ekosystemtjanster/Vad-ar-ekosystemtjanster/

Oke, T., Mills, G., Christen, A., & Voogt, J. (2017). *Urban Climates*.

Ridd, M.K., & Liu, J. (1998). A comparison of four algorithms for change detection in an urban environment. *Remote Sensing of Environment*, (2), 95-100.

Rouse, J.W., Haas, R.H., Schell, J.A., Deering, D.W., 1973. Monitoring vegetation systems in the great plains with ERTS. In*: Proceedings of the 3rd ERTS Symposium, Goddard Space Flight Center, Greenbelt, MD, Washington, DC*, pp. 48–62.

Roy, D., Kovalskyy, V., Zhang, H., Vermote, E., Yan, L., Kumar, S., & Egorov, A. (2016). Characterization of Landsat-7 to Landsat-8 reflective wavelength and normalized difference vegetation index continuity. *Remote Sensing of Environment, 185*(C), 57-70.

Samuelsson, K., Chen, K., Antonsen, S., Brandt, A., Sabel, C., Barthel, S. (2020). Residential environments across Denmark have become both denser and greener over 20 years. *Environmental Research Letters 16* (2021) 104022

SCB (2021). *Folkmängd efter region och år. Statistiska centralbyrån*, 22 February 2021

Seto, C., K., Parnell, S., Elmqvist, T. (2013) A global outlook on urbanization. In T. Elmqvist (ed.). *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment* (1-12). Cham: Springer.

Setälä, H., Francini, G., Allen, J., Jumpponen, A., Hui, N., & Kotze, D. (2017). Urban parks provide ecosystem services by retaining metals and nutrients in soils. *Environmental Pollution* (1987), 231(1), 451-461.

Singhal, B., & Gupta, R. (2010). Remote Sensing. In *Applied Hydrogeology of Fractured Rocks: Second Edition* (45-73). Dordrecht: Springer Netherlands.

Thomas, L., Cousins, W. (1996). The Compact City: A successful, Desirable and Achivable Urban Form? In Burton, E., Jenks, M & Williams, K.(ed.) (1996). *The Compact City: A Sustainable Urban Form?* Taylor and Francis.

SMHI (2020a). *Sveriges klimat*. Retrieved 2021-01-19 from https://www.smhi.se/kunskapsbanken/klimat/sveriges-klimat/sveriges-klimat-1.6867

(2020b). *Värmebölja*. Retrieved 2021-02-16 from https://www.smhi.se/kunskapsbanken/klimat/varmebolja-1.22372

(2020c). Ladda ner meteorologiska observationer: Lufttemperatur, medelvärde 1 månad. Retrieved 2020-11-19 from https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer#param=airTemperatureMeanMonth,stations=all

(2020d). Ladda ner meteorologiska observationer: Nederbörd, medelvärde 1 månad. Retrieved 2020-11-19 from https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer#param=precipitationMonthlySum,stations=all

(2011). *Faktablad nr 49. Värmeböljor I Sverige.* Norrköping: SMHI

USGS (2020a) *Landsat 4*. Retrieved 2020-12-14 from https://www.usgs.gov/core-science-systems/nli/landsat/landsat-4?qt-science_support_page_related_con=0#qt-science_support_page_related_con

(2020b) *Landsat 6.* Retrieved 2020-12-14 from https://www.usgs.gov/core-science-systems/nli/landsat/landsat-6?qt-science_support_page_related_con=4#qt-science_support_page_related_con

(2020c) *Landsat 7*. Retrieved 2020-12-14 from https://www.usgs.gov/core-science-systems/nli/landsat/landsat-7?qt-science_support_page_related_con=0#qt-science_support_page_related_con

(2020d). *Using the USGS Landsat Level-1 Data Product*. Retrieved 2020-12-10 from https://www.usgs.gov/core-science-systems/nli/landsat/using-usgs-landsat-level-1-data-product

(2021) *EarthExplorer*. Retrieved 2021-03-04 from https://earthexplorer.usgs.gov/

Wellmann, T., Schug, F., Haase, D., Pflugmacher, D., & Van Der Linden, S. (2020). Green growth? On the relation between population density, land use and vegetation cover fractions in a city using a 30-years Landsat time series. *Landscape and Urban Planning, 202*, Landscape and urban planning, October 2020, Vol.202.

WHO (2020). *WHO Climatological Norms*. Retrieved 2020-10-23 from https://www.wmo.int/pages/prog/wcp/wcdmp/GCDS_1.php

Yengoh, G., Dent, D., Olsson, L., Tengberg, A., & Tucker III, C. (2015). *Use of the Normalized Difference Vegetation Index (NDVI) to Assess Land Degradation at Multiple Scales* (SpringerBriefs in Environmental Science). Cham: Springer International Publishing.

Zhou, J., Lin, J., Cui, S., Qiu, Q., & Zhao, Q. (2013). Exploring the relationship between urban transportation energy consumption and transition of settlement morphology: A case study on Xiamen Island, China. *Habitat International*, 37, 70-79.