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Destructive Flooding of Cultural Heritage: Our Future and New Normal?

An Investigation of Vulnerabilities in Ekenäs Old Town

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Abstract

Higher and more common coastal flooding, due to sea level rise and changes in wind patterns, may endanger Ekenäs Old Town (SV: Gamla stan i Ekenäs; FI: Tammisaaren vanha kaupunki) by year 2100. Cultural heritage, including protected buildings and archeologically significant areas, will likely become at greater risk due to flooding.

Finnish Meteorological Institute (FMI) data and projections have been adapted to Ekenäs Old Town. Sea level rise and storm surge projections, sea level records, and minimum recommended building elevations have been modeled and analyzed using a geographic information system (GIS). Potentially affected areas of Ekenäs Old Town have been further analyzed through study of the Finnish Heritage Agency's 2002 archaeological inventory of Ekenäs Old Town and targeted field work. Data and information have also been collected from the City of Raseborg and a local resident.

Due to already existing risks to cultural heritage, the Ministry of Agriculture and Forestry of Finland should designate Ekenäs Old Town as a significant flood risk area in accordance with legislation governing flood risk management (620/2010). The Ministry should establish a flood management group to create flood maps and develop a flood risk management plan.

Further study and investigation of flood risks in Ekenäs Old Town is recommended. Wave monitoring should be conducted around Ekenäs Old Town to better understand local sea level fluctuations. Building specific investigation is needed to understand flooding risks. Absent protection measures, damage from coastal flooding will likely increase. Protection measures must be careful to respect cultural heritage and the local environment.

Language: English Key words: Ekenäs Old Town, SV: Gamla stan i Ekenäs; Barckens udde, FI: Tammisaaren vanha kaupunki; Tammisaari, climate change, global warming, cultural environment, cultural heritage, built cultural environment, archaeological heritage, sea level rise, coastal flooding, flood risk, significant flood risk area, GIS, QGIS

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On Mustikkamaa Island in Helsinki, Finland on May 23, 2019 Jack Räisänen

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1 Introduction

During my studies at Novia University of Applied Sciences in Ekenäs, I frequently went on walks in the picturesque Ekenäs Old Town, a beautiful area with rich cultural heritage. I noticed how low-lying some parts of the Old Town are, and how close the sea is. Will this beautiful and historic area be at risk of flooding one day due to rising sea levels, I wondered? I had read and heard various figures regarding sea level rise but did not know how it might end up impacting Finland. The Coast of Finland is, after all, only reachable from the open ocean via the narrow Danish Straits. Furthermore, the whole of Finland is still rising after being compressed by the immense weight of glaciers during the last ice age.

I began searching for information that would answer these questions. It was very hard, however, to find detailed sea level rise projections and fine-scale future flood maps specifically made for Ekenäs Old Town. Flood maps form the foundation for efficient flood risk management (Parjanne & Huokuna, 2014), so I wanted to find out if existing flood maps had answered my questions. The Helsinki-Uusimaa Regional Council published a general flood map for the Uusimaa Region's coast in 2007 (Uudenmaan liitto, 2007). However, as the name suggests, it was made at a general level. The Finnish Consulting Group prepared a preliminary coastal area flood risk assessment for the Uusimaa Centre for Economic Development, Transport and the Environment in 2010 (Finnish Consulting Group, 2010), but this also lacked the fine-scale maps and detailed sea level rise projections that I was looking for.

The Finnish Environment Institute has developed a very useful Flood Map Service, which includes flood maps for the entire Finnish Coast (Ympäristöhallinto, 2019a). The only map considering climate change impacts for Ekenäs, though, is a map that shows minimum recommended building elevations for the Uusimaa Region. The maps showing various flood levels for Ekenäs only consider present conditions. Furthermore, these flood maps do not contain information about possible flood risk sites; this information is only available for the significant flood risk areas designated by the Ministry of Agriculture and Forestry of Finland (Ympäristöhallinto, 2019a), and Ekenäs Old Town has not been designated as a significant flood risk area (Maa- ja metsätalousministeriö, 2018). Eventually, I realized that I would need to search for background information, perform the calculations, and make the maps myself.

Sea level rise can cause many problems for coastal areas. For example, sea level rise may cause flooding of low-lying areas, loss of wetlands, erosion, groundwater inundation, and saltwater intrusion (Cooper, Fletcher, Chen & Barbee, 2013). It can also increase how often coastal flooding occurs, as well as increase the severity and duration of flooding (Sweet, Park, Marra, Zervas & Gill, 2014). Sea level rise can cause population displacement and interruption of health services, leading to myriad health hazards (Nicholls *et al.*, 2007).

Global sea level rose by about 14 cm during the 20th century; it is extremely likely that this was faster than during any of the 27 prior centuries. Without global warming, the sea would very likely have risen by -3 to 7 cm. (Kopp *et al.*, 2016). Sea level rose in the 20th century due to thermal expansion of the oceans and melting of land ice. Due to further effects from global warming, the rate of sea level rise is expected to increase dramatically in the 21st century. (Church *et al.*, 2013).

The most recent projections by the Intergovernmental Panel on Climate Change (IPCC) for climate change predict 0.3 to 4.8 °C of global warming in the late 21st century (2081-2100) relative to the 1986-2005 average, depending on future radiative forcing values due to concentrations of greenhouse gases and other factors (Collins *et al.*, 2013, p. 1055). According to the most recent IPCC report, warming of 0.3 to 4.8 °C would result in global mean sea level (GMSL) rise of 26 to 82 cm in 2081-2100 relative to 1986-2005, depending again on future radiative forcing values. Sea level rise is expected to continue much beyond the 21st century. (Church *et al.*, 2013). In a future with “very rapid economic growth, low population growth and rapid introduction of new and more efficient technology” and where “people pursue personal wealth rather than environmental quality” (SRES A1B Emission Scenario), GMSL rise would be 42 to 80 cm in 2100 (Church *et al.*, 2013, p. 1182; IPCC, w.y.). IPCC projections have been noted for their conservatism, though (Garner *et al.*, 2018). IPCC 2013 projections for GMSL rise focus only on likely (67% probability) outcomes. These projections leave out the highest 17% of GMSL outcomes, which might be very important for risk management and coastal planning. (Kopp *et al.*, 2014). This topic is discussed further in Chapter 7.

Regional sea level change may be much different than the global average, due to the effects of dynamic ocean processes, sea floor movement, and gravity changes as water mass redistributes, for example (Church *et al.*, 2013, p. 1191). Thus, it is essential to consider and understand regional conditions for GMSL change projections to be useful in local risk assessment and planning. In Finland, mean sea level is affected by many factors, such as global mean sea level, post-glacial land uplift, and wind patterns. In the past, mean sea level has decreased as land uplift has been greater than GMSL rise. This trend is reversing on the South Coast of Finland, though, and mean sea level is expected to increase on the south coast throughout the 21st century. (Pellikka, Leijala, Johansson, Leinonen & Kahma, 2018).

In addition to mean sea level change, it is very important to consider changes in likelihood of extreme sea level, commonly known as coastal flooding, storm surge, or a high water event. Sea level extremes are usually caused by large storms; this is especially the case when the timing of large storms coincides with high tide. Depending on how long winds last and their direction, low-pressure systems above the ocean and high winds can cause coastal flooding. (Rhein *et al.,* 2013). Future changes in the strength, frequency, length, and path of extratropical and tropical storms will subsequently affect sea level extremes and ocean waves. Even excluding changes in storms, sea level rise increases the starting point for extreme sea level events. (Church *et al.,* 2013).

IPCC 2013 found that the height of sea level extremes has already increased, mainly due to sea level rise (Church *et al.*, 2013). Vitousek *et al.* (2017) found that “[t]he 10 to 20 cm of sea-level rise expected no later than 2050 will more than double the frequency of extreme water-level events in the Tropics”. This will make low-lying Pacific island nations less habitable and cause difficulty for equatorial coastal cities (Vitousek *et al.,* 2017). Clearly, there is a need for attention to growing possible impacts from sea level rise and coastal flooding.

As with mean sea level change, coastal flooding risks and projections must be studied regionally. In Finland, annual sea level maxima are increasing. High sea levels were more likely in the late 20th century than the early 20th century. (Johansson, Boman, Kahma & Launiainen, 2001). Part of the increase in sea level maxima in Finland is due to changes in wind conditions; this change is not yet fully understood, though (Johansson, 2014; Havu Pellikka, personal communication, May 6, 2019). Rapid changes in sea level in Finland are mainly caused by strong winds, changes in air pressure, and internal oscillation (seiche) (Kahma, Pellikka, Leinonen, Leijala & Johansson, 2014). Significant flooding can occur when many factors causing high sea level come together. On the South Coast of Finland, probabilities of coastal flooding are expected to significantly increase during the 21st century. By 2100, the extreme sea level during the January 2005 storm that caused €12 million in damage will on average occur once in two years. In 2018, that magnitude of sea level had a likelihood of occurring only once in around 33 years. (Pellikka *et al.,* 2018).

Ekenäs Old Town is an interesting area to me due to its history, cultural heritage, and beauty. In this thesis, I wanted to answer these questions: What will the impact of global mean sea level rise be on the Coast of Finland? How might sea level rise and coastal flooding in the Gulf of Finland affect Ekenäs Old Town in the future? How might these changes affect the built cultural environment and archaeological heritage in the Old Town? How has flooding already affected the Old Town?

To help answer some of the aforementioned questions, I have adapted calculations for mean sea level change and future storm surge on the Coast of Finland to Ekenäs Old Town. I have made flood maps depicting changes in mean sea level and storm surge. I have analyzed and investigated some of the implications of these changes on aspects of the built cultural environment and archaeological heritage in Ekenäs Old Town. I have also adapted and mapped minimum recommended building elevations to Ekenäs Old Town. I have conducted targeted and small-scale field work to better understand flooding risks to some buildings in the Old Town. I have calculated and mapped a theoretical high sea level for Ekenäs Old Town during the January 9, 2005 flooding event which set sea level records in some parts of Southern Finland. I also obtained information about the height and impact of this flooding event on Ekenäs Old Town from a local resident and the City of Raseborg. I met with an insurance specialist to better understand flood insurance coverage, pricing, and risk. I have reviewed the criteria for designation of significant flood risk areas, investigated current vulnerabilities to cultural heritage in Ekenäs Old Town based on these criteria, and concluded that Ekenäs Old Town should be designated as a significant flood risk area according to Finnish legislation governing flood risk management (620/2010).

2 Background

2.1 Cultural Heritage

Cultural heritage is the spiritual and material heritage that results from the impact of human activity. Material cultural heritage can be either moveable or immoveable; books and tools are examples of moveable material cultural heritage, while the built cultural heritage is an example of immoveable cultural heritage. (Kulttuuriymparistomme.fi, 2015). Ekenäs Old Town is a good representation of immoveable cultural heritage. However, it would be physically possible to move parts of Ekenäs Old Town, and this has been done to protect other cultural heritage sites (Kaslegard, 2011). I think that doing so would be inappropriate, though, as the Old Town seems very connected to place, specifically to Barckens udde Peninsula and the surrounding bay. It is also a place of living cultural heritage and moving it would disrupt the lives of the people living there.

2.2 Cultural Environment

Berghäll and Pesu, in their 2008 report on Climate Change and the Cultural Environment, explain that:

> "'Cultural environment' is a general term for an environment with traits manifesting the various stages of culture and the interaction between [hu]man and nature. The cultural environment also encompasses [hu]man's relationship with [her or] his environment in the past and present, involving its varied meanings, interpretations and naming. The cultural environment comprises cultural landscapes, the built cultural environment, traditional rural biotopes and the archaeological heritage (Ministry of the Environment & the National Board of Antiquities 2006)." (Berghäll & Pesu, 2008).

While cultural landscapes and traditional rural biotopes are also very interesting and important, in this thesis work the built cultural environment and archaeological heritage are of primary interest with Ekenäs Old Town as the focus. Berghäll and Pesu (2008) define the built cultural environment, or the architectural heritage, as:

> "[A]n entity consisting of the urban structure, buildings with their exteriors and interiors, yard areas and parks, infrastructure (e.g. streets, roads, bridges, canals), and other manmade works in the environment (Ministry of the Environment & the National Board of Antiquities 2006). The concept refers to the environment built in concrete terms, the history of land use and building, and how it has come about." (Berghäll & Pesu, 2008).

The built cultural environment is often very visible. In the case of Ekenäs Old Town, this built cultural environment is still in active use and it features extensive history regarding the land use and buildings there. Ekenäs Old Town also features extensive archaeological heritage (Mökkönen, 2002). Regarding archaeological heritage, Berghäll and Pesu (2008) explain that:

> "The archaeological heritage consists of structures and layers preserved in the landscape or the soil deriving from the activities of people who have lived at the site. They include burial cairns, offering stones, ancient hillforts, stone labyrinths and fortifications (Ministry of the Environment & the National Board of Antiquities 2006). In addition, immovable archaeological heritage under the surface of the ground, such as inhumation graves, and the underwater archaeological heritage are antiquities as defined in the Antiquities Act (295/63). The underwater archaeological heritage consists of the wrecks, or parts thereof, of ships or other vessels that can be assumed to have sunk over a hundred years ago, and man-made underwater structures related to past settlement and history." (Berghäll & Pesu, 2008).

In addition to archaeological heritage in Ekenäs Old Town buried under the surface of the ground (Mökkönen, 2002), there could also be underwater archaeological heritage in the surrounding area. For example, in Södra viken Bay, where there have been piers for boats even hundreds of years ago (Mökkönen, 2002), there could be items underwater dropped by fishers and other people.

Legislation on building and land use direct preservation and maintenance of the cultural environment. For example, the Finnish Act on the Protection of the Built Heritage protects the built cultural environment, defined in the law as built heritage (498/2010). Finland has ratified international conventions in which it has committed to protect and maintain the cultural environment. In ratification of the United Nations Educational, Scientific and Cultural Organization (UNESCO) Convention Concerning the Protection of the World Cultural and Natural Heritage, "Finland has agreed to attend to the preservation of its nationally significant cultural and natural heritage for future generations." Other commitments to the preservation and maintenance of the cultural environment have been made through agreements by the Council of Europe which Finland has ratified. (Berghäll & Pesu, 2008).

2.3 Climate Change and the Cultural Environment

Climate change is expected to have many impacts on the cultural environment, including impacts on cultural landscapes, the built cultural environment, and archaeological heritage. Some of the impacts will come directly from global warming. For example, as Finland warms, the habitat range of other species may expand, introducing new species into cultural landscapes in Finland. Other impacts may come from changes in the water cycle and humidity. There may also be indirect impacts on the cultural environment due to climate change; mitigation and adaptation measures might create impacts. Wind parks, constructed to reduce the share of fossil fuels in the energy sector, could have an impact on cultural landscapes. (Berghäll & Pesu, 2008).

In this thesis I am primarily interested in the effects of climate change on the built cultural environment and archaeological heritage. The climate in Finland is expected to become warmer and more humid. Winters will be warmer and rainier. More rainfall and higher groundwater levels make the soil moister. This can make the ground less stable, potentially causing disturbance for building foundations. Conversely, the longer and drier summers expected will lower groundwater levels, potentially causing further disturbance for building foundations. Increased rainfall and humidity can add to problems of mold and decay in wooden and other buildings. Old wooden buildings have some features that make them more adaptable to climate change. Traditional timber buildings featuring ventilated bottom floors are rather resistant to movements of the foundation. This building style also helps prevent damage from ground humidity and is less susceptible to damage from flooding. (Berghäll & Pesu, 2008).

Underground archaeological heritage is typically "in balance with the hydrological, chemical and biological processes of the soil," which helps preserve this heritage. Climate change may disturb this balance, as temperatures and humidity increase, changes occur in the water table, and emission deposition causes changes in pH. This could cause destruction of underground archaeological heritage. Winds and storms could also increase the strain on underwater archaeological heritage, though shorter winters and less pack ice may reduce mechanical strain on underwater archaeological heritage in shallow areas. (Berghäll & Pesu, 2008).

Clearly, climate change poses many threats to the cultural environment. Many of these threats are relevant to Ekenäs Old Town. Attention should be paid to the buildings there, above and underground archaeological heritage, and possible negative impacts from changes in humidity, increased rainfall, flooding, and more.

2.4 Climate Change, Coastal Flooding, and the Cultural Environment

Flooding can be very damaging for the cultural environment. High movements of water can cause stress and wear on buildings; structural collapse can even occur. Flooding can cause coastal erosion. The shorter winters expected due to climate change may make the coastal erosion from flooding worse. With less ice cover and more coastal winter storms, coastal areas may be at risk. (Berghäll & Pesu, 2008). Higher sea levels and higher coastal flooding poses a risk to the cultural environment near the sea, due to the potential for coastal erosion and damage to buildings (Kaslegard, 2011). Erosion can damage building foundations, causing building failure. In addition to the power of water movement itself, debris in floodwaters may cause damage to buildings. (Federal Emergency Management Agency, w,y.).

Problems from flooding can also occur after the flood has passed. After flooding is over, buildings may need to be dried out. If buildings are not dried properly, hazardous micro-organisms such as mold and fungi can develop, causing myriad problems. (Berghäll & Pesu, 2008). Many of the materials needed for the construction of old buildings have become rare. The skills needed are also disappearing. Repair of cultural heritage buildings usually results in a loss of original materials and components. Damage to old buildings and subsequent repairs can result in loss of authenticity and cultural-historical traits. (Berghäll & Pesu, 2008).

In Finland, coastal flooding has caused damage to the built cultural environment. A strong storm and high sea levels in January 2005 caused damage to the Suomenlinna Fortress, an UNESCO World Heritage Site. Sea level rose by 151 cm (Ilmatieteen laitos, w.y.a.) and caused, for example, erosion and the collapse of a supporting wall and sand earthworks of a gun battery at the Fortress. Sea level rise of only 150-160 cm can cause damage to Suomenlinna Fortress' shoreline structures. (Berghäll & Pesu, 2008). By 2100, such sea level will be very common (Pellikka *et al.*, 2018).

2.5 Ekenäs Old Town

Ekenäs Old Town is a picturesque and historic part of the former City of Ekenäs, between Helsinki and Turku on the South Coast of Finland. Ekenäs was legally established as a place of trade in 1528. Before this, it had already been known as a trade place and harbor. (Mökkönen, 2002). Ekenäs was then established as a city by Gustav I Vasa, King of Sweden, in 1546. As such, it was the first city established in Finland after the Middle Ages.

(Museovirasto, 2009). Since 2009, Ekenäs has been a part of the City of Raseborg, together with the City of Karis and Municipality of Pojo (1075/2007).

Figure 1: Ekenäs Old Town viewed from across Södra viken Bay. Photo by © Anna Björklund.

Figure 2: View of Linvävaregatan Street in Ekenäs Old Town. Photo by © Jack Räisänen.

For me, Ekenäs Old Town stands out as a place rich in history, cultural heritage, and beauty. The narrow streets bring out feelings of nostalgia, and the street and place names quietly whisper of past times. The old wooden homes breathe a sense of timelessness, and in the summer the wind plays a beautiful melody in the trees nestled behind garden fences. Pleasant smells of coffee and cake float down the peaceful lanes, drawing visitors and locals alike to the quaint and cozy Café Gamla Stan, where delicious apple cider is served from the local bounty.

Figure 3: Café visitors enjoying the ambience and spring weather at Café Gamla Stan in Ekenäs Old Town. Photo by © Jack Räisänen.

Ekenäs Old Town is a place where many people enjoy living, even though some of the amenities are modest and old-fashioned. Residents find it very cozy, and appreciate the history, beauty, vegetation, and colors there. Residents of the Old Town respect the place and want to be there. The mainly Finland-Swedes living in the Old Town experience the area as a support network. This creates a feeling of safety where neighbors watch out for each other. Old wooden areas have been more appreciated in Finland-Swede areas than in Finnish speaking areas, where some such areas have been completely demolished. The local Finland-Swede culture in Ekenäs Old Town has helped preserve Ekenäs Old Town. Local identity is strong and connected to the place; this has helped a voluntary preservation of the area that has had an important role in maintaining the Old Town. Strong consensus exists regarding the future of the Old Town and a development that respects the past. (Sociologist Kalle Reinikainen, personal communication, March 7, 2019; Reinikainen, 2005; Suikkari & Reinikainen, 2005).

The Old Town features many wooden buildings from the 1700s and 1800s built on natural stone and brick foundations. Many of the buildings in the Old Town are protected. (Mökkönen, 2002). The entire Ekenäs Old Town and Harbor is designated as a Nationally Significant Built Cultural Environment (RKY 2009). Ekenäs Old Town contains what is likely the oldest still existing planned urban area in Finland (see Figure 4) (Lilius, 1987 as cited by Mökkönen, 2002). There are many areas in the Old Town that are of archeological and protection interest. Some of these areas contain deposits from the 1600s that have likely been well preserved. For example, the Fisktorget Market Square area might contain remnants of piers, harbor storage buildings, and shore constructions from before the Great Northern War (1713-1721). (Mökkönen, 2002). Clearly, Ekenäs Old Town is significant as a cultural environment, with an extensive store of the built cultural environment and archaeological heritage.

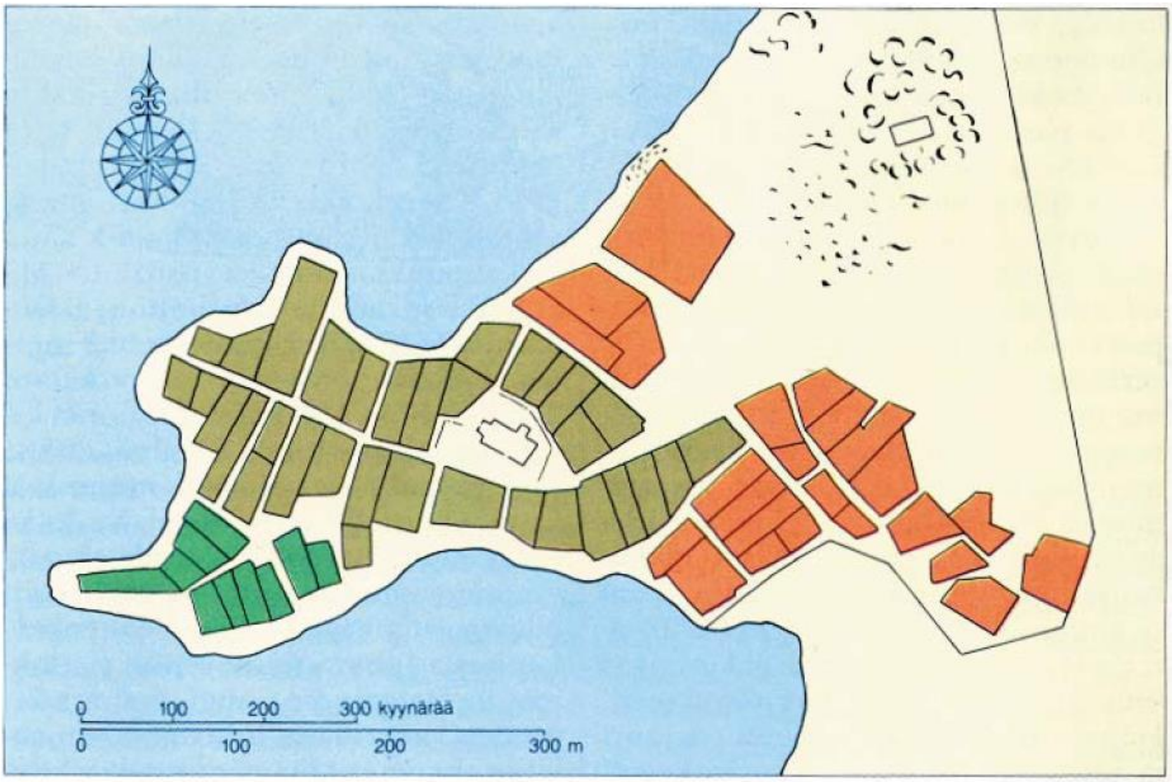

Figure 4: The area in olive green is of city blocks along Stora Kyrkogatan Street in Ekenäs Old Town. These city blocks are believed to have been established in 1556-1557. The area represents what is likely the oldest still existing planned urban area in Finland. (Lilius, 1987 as cited by Mökkönen, 2002). The photo comes from Mökkönen (2002), the map is apparently an adaptation of Samuel Brotherus' 1696 map of Ekenäs, possibly by Lilius (1987). Included with the written permission of Teemu Mökkönen, Finnish Heritage Agency.

Figure 5: A wooden storage building at Fisktorget Market Square. The same building may be seen flooded by high sea levels on January 9, 2005 in Figure 16. Photo by © Anna Björklund.

Figure 6: The Adolfsson House on Linvävaregatan Street 1, protected under the Act on the Protection of the Built Heritage (498/2010) (Museovirasto, w.y.). Photo by © Jack Räisänen.

Figure 7: Storage building protected under the Act on the Protection of the Built Heritage (498/2010). The same building can be seen with the water level much higher in Figure 15. Photo by © Anna Björklund.

2.6 Linvävaregatan Street 1

Based on research done in the early 2000s, Linvävaregatan Street (see Figure 2) was found to be considered the most beautiful street in Ekenäs Old Town by the residents there (Suikkari, 2005). On this street there is also a plot with two buildings protected by the Finnish Act on the Protection of the Built Heritage (498/2010); the Adolfsson House and an outside storage building (see Figures 6 and 7) (Museovirasto, w.y.). This plot is on the end of the street, very close to the sea. I chose to investigate the vulnerability of these two buildings further due to their protection status, proximity to the sea, age, and my own personal interest.

2.7 Study Area Borders

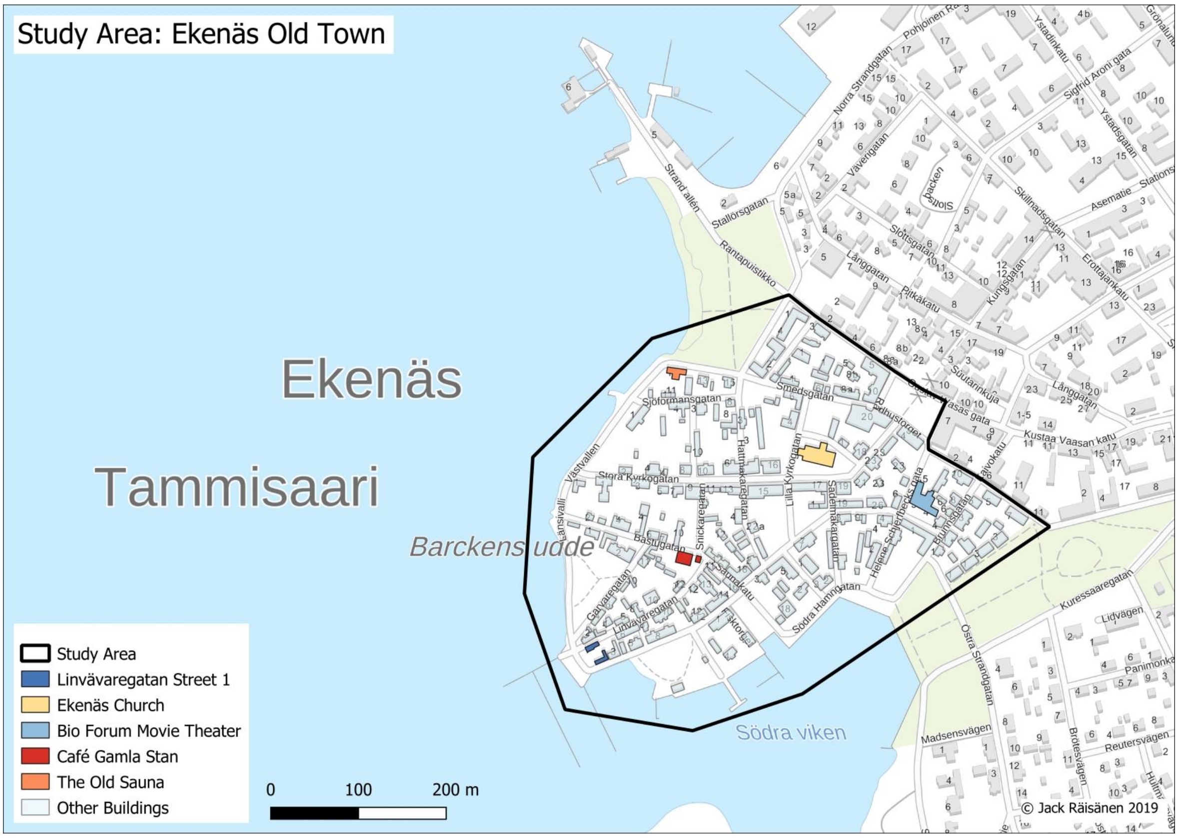

Figure 8: A map depicting borders of the study area and some selected sites of interest.

The specific area chosen for this study is shown in Figure 8. This area is partially based on the borders of an archeological inventory of Ekenäs, which was based on Samuel Brotherus' 1696 map of Ekenäs (Mökkönen, 2002). For simplicity and coherence, though, I chose to include all the shore area on Barckens udde Peninsula and also included the housing area to the southeast of Brunnsgatan Street up to the park with The Finnish Untuned Bell. I chose not to include the area between Gustav Wasa Street and Långgatan Street, considering that it is relatively far from the sea and quite secure from flooding.

3 Materials and Methods

Using data from the Finnish Meteorological Institute for mean sea level change at tide gauges in Hanko and Helsinki, I calculated mean sea level change scenarios for Ekenäs Old Town from year 2000 to 2050 and 2000 to 2100. I mapped the average and high mean sea level change scenarios for year 2100 in a geographic information system to show which areas of the Old Town might be at risk of flooding in the future. Using the geographic information system, I also analyzed which buildings, if any, might be reached by overall higher sea levels by year 2100.

Based on other data from the Finnish Meteorological Institute for the Hanko and Helsinki tide gauges, I calculated storm surge levels at various recurrence intervals for Ekenäs Old Town in years 2011, 2050, and 2100. I mapped the storm surge levels at the 20-, 50-, 100-, 250-, and 1000-year recurrence intervals for years 2011 and 2100. I also mapped the storm surge increase from 2011 to 2100 at each respective recurrence interval. For each storm surge scenario, I used the geographic information system to analyze which buildings might be reached by high waters in years 2011 and 2100. This reveals the climate change induced increase in the flooding vulnerabilities of buildings from 2011 to 2100.

3.1 Linear Interpolation

The Finnish Meteorological Institute has 13 tide gauges along the Coast of Finland. These tide gauges monitor and record the sea level. There is not an official tide gauge in Ekenäs; the closest tide gauges are at Hanko and Helsinki. To obtain sea levels for a location between tide gauges, a linear interpolation method may be used, which involves a calculation based on two (or more) points of reference. Calculations for sea levels at Ekenäs Old Town were made according to a linear interpolation method described by Kahma *et al.* (2014):

Ekenäs Old Town = ((Hanko × distance to Helsinki) + (Helsinki × distance to Hanko)) /

(distance to Helsinki + distance to Hanko)

This adjusts the sea levels at Hanko and Helsinki to Ekenäs, based on the distance from Ekenäs to Hanko and Helsinki. As Ekenäs is closer to Hanko than to Helsinki, the Hanko sea levels have more weight in the calculation.

The specific locations used for the calculations are listed in Table 1. The Hanko location is the site of a tide gauge at Lilla Kolaviken Bay. The Helsinki location is the site of a tide gauge at Kaivopuisto Park. The locations of the Hanko and Helsinki tide gauges were recorded with a GPS in 2011 in the WGS84 coordinate system. (Kahma *et al.*, 2014). The Ekenäs location is at the end of Barckens udde Peninsula on Linvävaregatan Street. The coordinates were retrieved from the National Land Survey of Finland's GeoData Portal Paikkatietoikkuna and are shown in the ETRS89 geographic (~WGS84) coordinate system (National Land Survey of Finland, w.y.a.).

Table 1: Ekenäs Old Town and tide gauges coordinates used for data interpolation.

Location	Latitude	Longitude
Hanko	59° 49.372'	22° 58.595'
Helsinki	60° 09.218'	24° 57.373'
Ekenäs Old Town	**59° 58' 17.930"**	**23° 25' 42.992"**

The Hanko and Helsinki tide gauge locations come from Kahma *et al.* (2014).

Distances from the Ekenäs Old Town point of reference to the Helsinki and Hanko points of reference were measured using the GeoData Portal Paikkatietoikkuna (National Land Survey of Finland, w.y.a.) with the Finnish Background Map overlay. Measurements were made in the WGS84 geodetic system, as that is the system that the tide gauge coordinates in Kahma *et al.* (2014) are given in.

Distance from Ekenäs Old Town to Hanko: 30.248 km

Distance from Ekenäs Old Town to Helsinki: 87.460 km

3.2 Source Data: Mean Sea Level Change, Baseline, and Storm Surge

Mean sea level change data from 2000 to 2100 for Hanko and Helsinki comes from Pellikka *et al.* (2018). The year 2000 baseline is based upon Research Scientist Milla Johansson's improved mean sea level estimates for Hanko and Helsinki, shown in Table 4. These estimates consider the speeding up of global sea level rise since the 1990s. These estimates are also more accurate as they are determined afterwards, as opposed to the theoretical mean sea level, which is calculated beforehand. (Milla Johansson, personal communication, March 15, 2019; Johansson, Kahma & Boman, 2003). Storm surge levels for Hanko and Helsinki in 2011, 2050, and 2100 come from Kahma *et al.* (2014). Storm surge levels by Pellikka *et al.* (2018) are also provided for Hanko and Helsinki in 2010, 2050, and 2100 (Table 15, Appendix 23). As the storm surge levels did not change much from Kahma *et al.* (2014) to

Pellikka *et al.* (2018), and Kahma *et al.* provided sea levels at a wider range of recurrence intervals than Pellikka *et al.*, the maps are based only on data from Kahma *et al.* (2014).

3.3 Maps

Most material for making the maps came from the National Land Survey of Finland's open data file download service (National Land Survey of Finland, w.y.b.). The 2 m elevation model (National Land Survey of Finland Elevation Model 2 m), 1:5000 background map (National Land Survey of Finland Background Map Series), and data from the topographic database (National Land Survey of Finland Topographic Database) were used to make the maps. The guaranteed accuracy of the part of the elevation model for Ekenäs Old Town is on average 0.3 m (Maanmittauslaitos, 2012; Maanmittauslaitos, w.y.). Information about protected buildings and archeologically valuable areas in Ekenäs Old Town came from an archeological inventory of the area conducted by T. Mökkönen (2002) as part of a Finnish Heritage Agency project.

Maps were made with QGIS, an open-source geographic information system. The ETRS89 / TM35FIN (E, N) coordinate reference system was used. The project was started with QGIS Version 2.18.13 and finished with QGIS Version 3.4.6, as the software was updated during completion of the project. The raster calculator, polygonise conversion tool, and select by location research tool were the main QGIS features used to make the maps. Colors for the maps were chosen using the ColorBrewer 2.0 color advice tool by Brewer, Harrower, and The Pennsylvania State University (2013). Colors were chosen that are colorblind safe, print friendly, and hopefully helpful for understanding the data presented in the maps.

I checked sea level map layers for hydrological connectivity and cleaned them up accordingly. As the map layers for sea level are based solely on elevation data, areas that were not connected to the sea sometimes appeared as flooded. I manually removed these areas from the maps. Without such manual clean up, buildings in areas hydrologically unconnected to the sea would have appeared flooded. I considered map layer cells that were touching in the corner hydrologically connected.

3.4 Field Work

I conducted small-scale field work to further investigate storm surge vulnerability of some buildings in Ekenäs Old Town. I chose to investigate vulnerability of the buildings to storm surge in 2100 at the 250-year recurrence interval. I chose the 250-year recurrence interval because that is the recurrence interval used for the minimum building elevation recommendations by Kahma *et al.* (2014). I selected several buildings in the Old Town, checked the elevation of corners accessible from the street using the elevation model in QGIS, then measured how high the sea would reach. I made observations about the building construction and materials and possible points of entry for sea water. All the buildings I checked are protected (Mökkönen, 2002). Selections were made based on my own interest. One of the buildings (Södra Strandgatan Street 12) was chosen as it is in an area that is archaeologically well preserved, of great archaeological research interest, and has high protection value (Mökkönen, 2002).

3.5 Interview with Local Resident

I met with long-time resident of Ekenäs Old Town Leif Stenwall who has tracked and documented the sea level in the area. We discussed the observations he has made, and I obtained copy of video documentation he made of a high sea level event in the Old Town on January 9, 2005. I presented some of the maps I have made, including mapping of the January 9, 2005 high sea level. We discussed his recollection and documentation of the event compared to the theoretical sea level I calculated and mapped based on linear interpolation of maximum sea levels measured at the Hanko and Helsinki tide gauges. I gained more information about previous impacts of flooding in the Old Town.

3.6 "Potentially Affected Buildings" and "Unaffected Buildings"

In my maps and calculations, I have used the phrases "potentially affected buildings" and "unaffected buildings". This is inconclusive, though. Whether a specific building will be affected in a given sea level rise or storm surge situation must be individually determined. In using these phrases, I simply refer to whether a given water level will reach or exceed the building's foundation, according to elevation and building location data. A building might be affected by storm surge even before the water level has reached the foundation, or it might only be affected by storm surge greatly exceeding the foundation level. If a building has a cellar and high water levels exist for long enough for the water to seep through the ground, flooding and damage might occur even before the water level has reached the foundation. On the other hand, a building which rests upon a high and solid foundation might be safe from flooding and damage even after the water level has reached the foundation. (Ympäristöhallinto, 2019a). Thus, my definition of potentially affected and unaffected buildings is an arbitrary one.

To gain a better idea of whether a specific building may be in danger in a given storm surge situation, I recommend looking at the maps which include water depths in addition to the maps comparing the change in storm surge from year 2011 to 2100, then also considering the specifics of the building, such as: Is there a cellar? How high off the ground is the first floor? What is the foundation made of? What materials might be soaked by flooding? Such assessment, however, will require expert knowledge. It may also be important to investigate the vulnerability of buildings close to the border of the illustrated flood zones.

4 Post-Glacial Land Uplift

The land is rising in Finland and other parts of Fennoscandia. During the last ice age more than 10,000 years ago, a 2 km thick ice mass caused a half a kilometer depression in the Earth's crust. The ongoing rebound from this depression results in annual land uplift in Finland of less than 3 mm per year in the southeast corner to nearly 1 cm per year in the Quark area. (Poutanen, w.y.). Land uplift rates at Hanko, Helsinki, and Ekenäs are presented in Table 2.

The effects of post-glacial land uplift on the development of Barckens udde Peninsula, where Ekenäs Old Town is located, may be seen in Figure 9. The red line depicts a projected shoreline in 1400 CE based on land uplift of 4.2 mm a^{-1}. The blue line depicts the shoreline in a map of Ekenäs Old Town from 1696. The violet line depicts the shoreline in a map from 1798. (Mökkönen, 2002). However, shorelines drawn in maps made in the 17th and 18th centuries were based simply on the shoreline at the time of mapping (Teemu Mökkönen, personal communication, April 24, 2019). The actual mean sea level at the time may have differed at least slightly from the shoreline drawn in the maps from 1696 and 1798.

Table 2: Annual land uplift rates at Hanko, Helsinki, and Ekenäs.

Location	Land uplift rate (mm a^{-1})
Hanko	5.00 ± 0.50
Helsinki	4.37 ± 0.51
Ekenäs	**4.84 ± 0.50**

Hanko and Helsinki rates come from Pellikka *et al.* (2018). Ekenäs rate is based on linear interpolation.

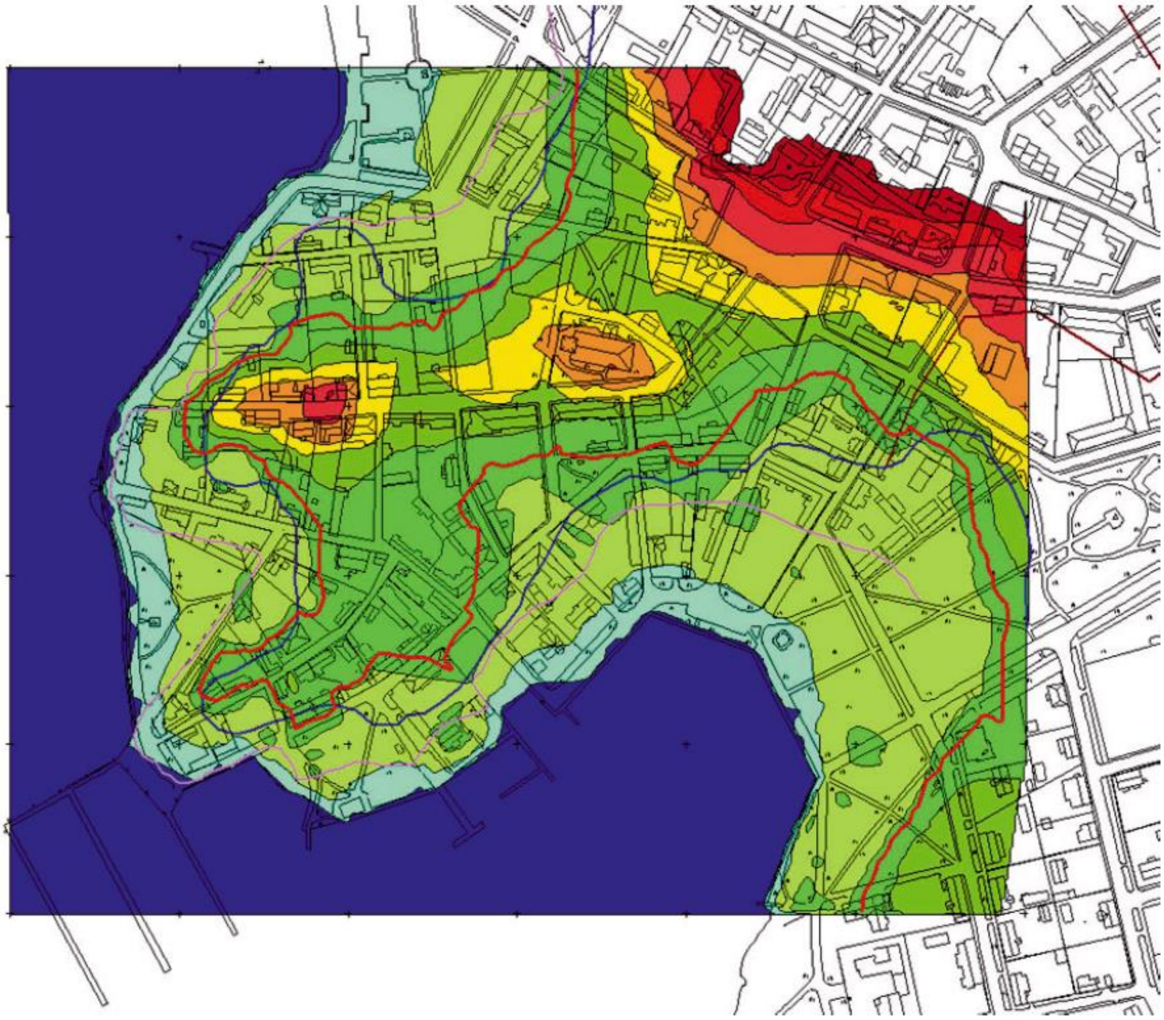

Figure 9: Map depicting the effects of post-glacial land uplift on the development of Barckens udde Peninsula, where Ekenäs Old Town is located. The map is from Mökkönen (2002), used with the written permission of Teemu Mökkönen, Finnish Heritage Agency.

5 Representative Concentration Pathways (RCPs)

The IPCC presents climate change projections for four different representative concentration pathways (RCPs); RCP2.6, RCP4.5, RCP6, and RCP8.5. These pathways correspond to varying amounts of radiative forcing in Watts per square meter (W/m^2), or how much heat enters the earth's atmosphere compared to the amount that leaves, compared to pre-industrial times. (Collins *et al.*, 2013). Levels of radiative forcing depend, for example, on emissions and concentrations of greenhouse gases, aerosols, and chemically active gases, land-use, and land cover (van Vuuren *et al.*, 2011a).

RCP2.6 is a mitigation scenario in which radiative forcing would peak at about 3 W/m^2 (the equivalent of about 490 ppm CO_2) before 2100. Radiative forcing would then decline to 2.6 W/m^2 by 2100. This is considered a "peak-and-decline" scenario. (van Vuuren *et al.*, 2011a).

RCP2.6 is a pathway representing ambitious mitigation efforts that would lead to very low concentrations of greenhouse gases and aim to limit the increase in global mean temperature to 2 °C (van Vuuren *et al.*, 2011b). van Vuuren *et al.* (2011a) explain that "RCP2.6 represents the range of lowest scenarios, which requires stringent climate policies to limit emissions."

RCP4.5 is a medium stabilization scenario in which radiative forcing stabilizes at – and never exceeds – 4.5 W/m^2 (the equivalent of about 650 ppm CO_2) shortly after 2100 (van Vuuren *et al.*, 2011a). This is considered a stabilization and cost-minimizing scenario. In this scenario, policies are put in place to limit emissions and radiative forcing. Simultaneous and effective mitigation measures by the entire world are assumed, with for example, a price on emissions. (Thomson *et al.*, 2011).

RCP6 is also a medium stabilization scenario. In RCP6, radiative forcing stabilizes at 6 W/m^2 (the equivalent of about 850 ppm CO_2) after 2100. (van Vuuren *et al.*, 2011a). Stabilization is achieved through different technologies and reducing greenhouse gas emissions (Fujino, Nair, Kainuma, Masui & Matsuoka, 2006; Hijioka, Matsuoka, Nishimoto, Masui & Kainuma, 2008).

RCP8.5 is a very high baseline emission scenario in which radiative forcing rises continuously and is at 8.5 W/m^2 (the equivalent of about 1370 ppm CO_2) by 2100. This is a very energy-intensive scenario due to high population growth and less technological development than in other scenarios. van Vuuren *et al.* (2011a) explain that "RCP8.5 is representative of the high range of non-climate policy scenarios." A scenario like this could occur in case of high population and no climate policy (van Vuuren *et al.*, 2011a).

6 Global Warming

The most recent IPCC projections for climate change predict 0.3 to 4.8 °C of global warming in the late 21st century (2081-2100) compared to the 1986-2005 average, depending on future radiative forcing values due to concentrations of greenhouse gases and other factors. RCP2.6 would mean 0.3 to 1.7 °C of global warming in 2081-2100 compared to the 1986-2005 average. RCP4.5 would result in 1.1 to 2.6 °C of warming. Under RCP6, there would be 1.4 to 3.1 °C of warming. Finally, under RCP8.5 there would be 2.6 to 4.8 °C of global warming. (Collins *et al.*, 2013, p. 1055).

7 Mean Sea Level Change

7.1 Global Mean Sea Level Rise

According to the most recent IPCC report, warming of 0.3 to 4.8 °C would result in global mean sea level (GMSL) rise of 26 to 82 cm in 2081-2100 relative to 1986-2005, depending again on future radiative forcing values. By 2100, GMSL is expected to have risen by 28 to 98 cm. RCP2.6 would result in 28 to 61 cm of GMSL rise in 2100. RCP4.5 would result in 36 to 71 cm of GMSL rise in 2100. RCP6 would result in 38 to 73 cm of GMSL rise. Finally, RCP8.5 would result in 52 to 98 cm of GMSL rise. (Church *et al.*, 2013, p. 1182). In a future with "very rapid economic growth, low population growth and rapid introduction of new and more efficient technology" and where "people pursue personal wealth rather than environmental quality" (SRES A1B Emission Scenario), GMSL rise would be 42 to 80 cm in 2100 (Church *et al.*, 2013, p. 1182; IPCC, w.y.).

Many other studies have projected a higher maximum range of GMSL rise by 2100 than IPCC 2013 projections. Part of the reason for this is that IPCC projections focus on likely ranges of GMSL rise while many other studies also include less likely outcomes. (Garner *et al.,* 2018). However, Brysse, Oreskes, O'Reilly, and Oppenheimer (2013) suggest that work contributing to IPCC 2013 projections by Working Group I was biased toward cautious estimates, a tendency they called "erring on the side of least drama (ESLD)". Garner *et al.* (2018) note the conservativeness of IPCC projections and provide several reasons for this.

One area of uncertainty in IPCC and other GMSL rise projections is melting in Antarctica (Church *et al.,* 2013), and especially melting of the West Antarctic ice sheet (Bakker, Wong, Ruckert & Keller, 2017). The IPCC 2013 report notes the difficulty of quantifying the potential impact of melting of the Antarctic marine ice sheet during the 21st century but reports with medium confidence that melting "would not exceed several tenths of a meter of sea level rise" (Church *et al.*, 2013). Deconto and Pollard (2016) found that melting in Antarctica alone could cause over one meter of sea level rise by 2100. Other researchers have observed changes in glaciers in West Antarctica and marine ice sheet instability there that "will significantly contribute to sea level rise in decades to centuries to come" (Rignot, Mouginot, Morlighem, Seroussi & Scheuchl, 2014).

Given myriad uncertainties and the need to prepare for future flooding risks, it is important to consider a wide range of projections in risk assessment and coastal planning in response to sea level rise, not only those by the IPCC. Projections by researchers at the Finnish

Meteorological Institute for GMSL rise during the 21st century combine a total of 14 studies' projections. Predictions by Church *et al.* (2013) for IPCC AR5 were given the most weight in their work. This combination and expert weighting of projections yielded an estimate of 31-155 cm of GMSL rise from 2000-2100 (5-95% range of probabilities). (Pellikka *et al.*, 2018).

7.2 Mean Sea Level Change on the Coast of Finland

Regional sea level change may be much different than the global average. This is due to factors such as the effects of dynamic ocean processes, sea floor movement, gravity changes as water mass redistributes, and land uplift. (Church *et al.*, 2013). Therefore, it is essential to consider and understand regional conditions for GMSL change projections to be useful in local risk assessment and planning. On the Coast of Finland, mean sea level on the long-term is affected by factors such as global mean sea level change, post-glacial land uplift, and changes in wind patterns (Pellikka *et al.*, 2018). Overall sea level in the Baltic Sea is affected by wind conditions that can enable additional water to flow into the Baltic Sea through the Danish Straits (Johansson, 2014).

Pellikka *et al.* (2018) adapted projections for GMSL rise to the Coast of Finland. The regionally adapted calculations estimate 24-124 cm (5-95% range of probabilities) of sea level rise in the Gulf of Finland from 2000-2100. The regionally adapted scenarios account for factors such as global mean sea level rise and the uneven geographic distribution of sea level rise due to the fingerprint effect. After accounting for post-glacial land uplift in Finland (see Table 2) and long-term meteorological changes, Pellikka *et al.* (2018) arrived at projections for local mean sea level change in 2000-2100 for tide gauges on the Coast of Finland. (Pellikka *et al.*, 2018). Results for the Hanko and Helsinki tide gauges are shown in Table 3.

Table 3 presents projections for mean sea level change from year 2000 to 2100 and resulting mean sea levels in 2100 at Hanko, Helsinki, and Ekenäs. Pellikka *et al.* (2018) explain that "[t]he average scenario is the weighted average of the probability distribution, high and low scenarios correspond to the 5% and 95% cumulative probabilities." The improved mean sea level is used as the year 2000 baseline for calculating mean sea level in 2100 (see Table 4).

Table 3: Mean sea level change from year 2000 to 2100 and year 2100 mean sea levels at Hanko, Helsinki, and Ekenäs. The year 2000 baseline is based on the improved mean sea level estimates in Table 4.

Location	Mean sea level change 2000-2100 (cm)			Mean sea level in 2100 (cm, N2000)		
	Low	Average	High	Low	Average	High
Hanko	– 22	24	80	– 2	44	100
Helsinki	– 15	30	87	6	51	108
Ekenäs	**– 20**	**26**	**82**	**0**	**46**	**102**

Mean sea level change data for Hanko and Helsinki comes from Pellikka *et al*. (2018). Mean sea level change at Ekenäs is linearly interpolated from the Hanko and Helsinki data.

Table 4: Year 2000 improved mean sea level estimates at Hanko and Helsinki, year 2000 theoretical mean sea level at Hanko and Helsinki, and linearly interpolated year 2000 mean sea levels at Ekenäs. Rounded to the nearest whole.

Location	Theoretical mean sea level (cm, N2000)	Improved mean sea level (cm, N2000)
Hanko	17	20
Helsinki	19	21
Ekenäs	**17**	**20**

Year 2000 improved mean sea level estimates at Hanko and Helsinki were provided by Research Scientist Milla Johansson (personal communication, March 15, 2019). Year 2000 theoretical mean sea levels at Hanko and Helsinki are according to the Finnish Meteorological Institute (Ilmatieteen laitos, w.y.b.).

As seen in Table 3, the low sea level change scenario would result in a decrease in mean sea level at Ekenäs Old Town of 20 cm from 2000-2100. The rate of land uplift would be higher than the rate of sea level rise, resulting in a net decrease in mean local sea level. As this scenario results in a net decrease in vulnerability to flooding, I chose not to map it.

The average sea level change scenario would result in an increase in mean sea level at Ekenäs Old Town of 26 cm from 2000-2100. I mapped this scenario (Appendix 2) and found no significant increase in flooding vulnerability from the mean sea level rise alone by 2100. The 26 cm increase covers only an insignificant amount of additional land area. However, an overall higher mean sea level contributes to flooding risks when combined with other affecting factors (Chapter 8).

The high sea level change scenario would result in an increase in mean sea level at Ekenäs Old Town of 82 cm from 2000-2100. This scenario is shown in Figure 10 (and Appendix 3).

The 82 cm increase would flood part of Fisktorget Market Square and under normal circumstances the sea would reach four buildings in the Old Town. The high mean sea level rise scenario could be devastating for the Old Town when combined with storm surge.

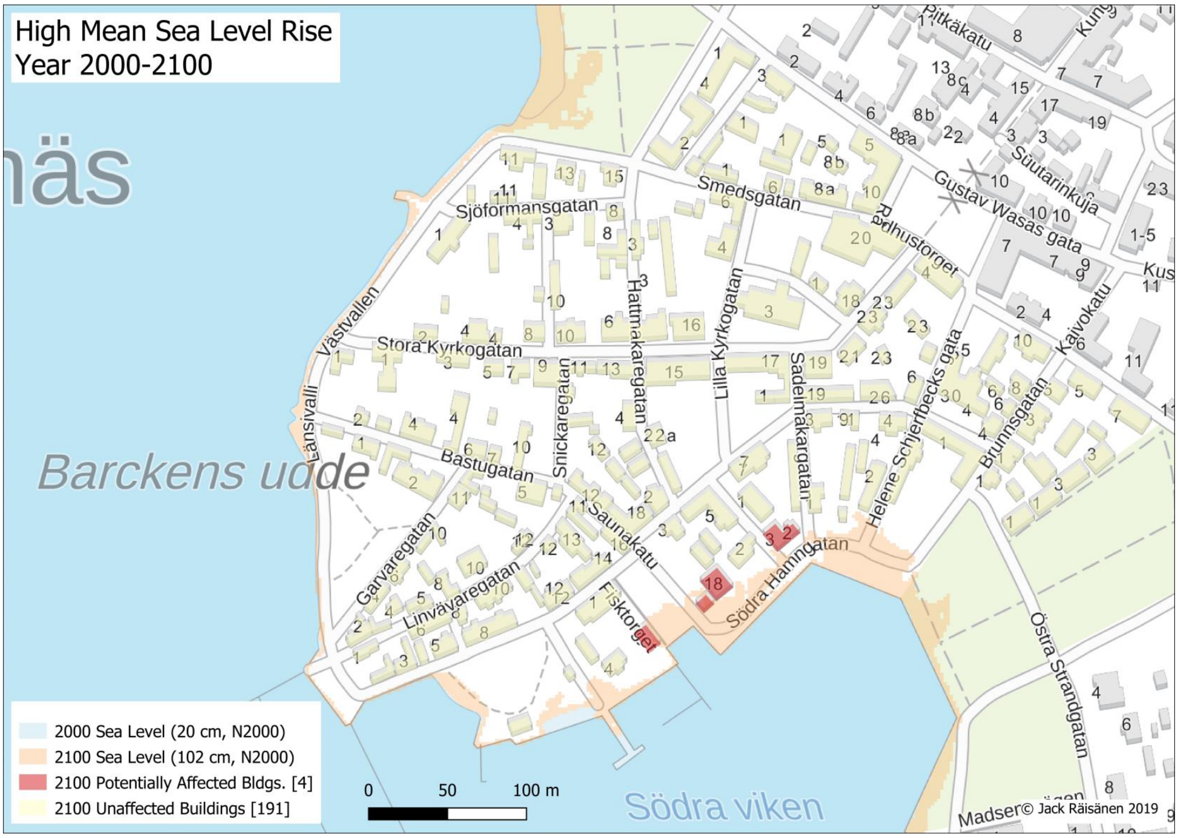

Figure 10: A map depicting 82 cm of mean sea level rise from 2000-2100 at Ekenäs Old Town.

7.3 Global Mean Sea Level Rise and the Paris Agreement

Even if the goal of the Paris Agreement to limit global warming from pre-industrial times to 1.5 or 2 °C by 2100 is reached (United Nations, 2015), GMSL may still rise significantly from 2000-2100. Based on calculation of the impact of ice-sheet melting using a process-based approach, median GMSL rise by 2100 could be 44 cm (20-67 cm, 5-95% range) if warming is limited to 1.5 °C and 50 cm (24-74 cm, 5-95% range) if warming is limited to 2.0 °C. According to a semi-empirical approach, median GMSL rise by 2100 would be 57 cm (28-93 cm, 5-95% range) if warming is limited to 1.5 °C and 68 cm (32-117 cm, 5-95% range) if warming is limited to 2.0 °C. (Jackson, Grinsted & Jevrejeva, 2018). However, research published in 2017 found it unlikely that global warming will be less than 2 °C by 2100 (Raftery, Zimmer, Frierson, Startz & Liu, 2017).

8 Coastal Flooding

Extreme sea level is often known as coastal flooding, storm surge, or a high water event. Sea level extremes are usually caused by large storms; this is especially the case when the timing of large storms coincides with high tide. Depending on how long winds last and their direction, low-pressure systems above the ocean and high winds can cause coastal flooding. (Rhein *et al.*, 2013). Future changes in the strength, frequency, length, and path of extratropical and tropical storms will subsequently affect sea level extremes and ocean waves. Even excluding changes in storms, sea level rise can increase the starting point for extreme sea levels. (Church *et al.*, 2013).

IPCC 2013 found that the height of sea level extremes has already increased mainly due to sea level rise (Church *et al.*, 2013). Vitousek *et al.* (2017) found that "[t]he 10 to 20 cm of sea-level rise expected no later than 2050 will more than double the frequency of extreme water-level events in the Tropics". This will make low-lying Pacific island nations less habitable and cause difficulty for equatorial coastal cities (Vitousek *et al.*, 2017). Clearly, there is cause for attention to the growing impacts from sea level rise and coastal flooding.

9 Flood Recurrence Intervals and Probabilities

The rarity of a flood can be described by recurrence interval and annual probability. Recurrence interval describes on average how often a given water level is reached or exceeded. For example, sea level at the 20-year recurrence interval is reached or exceeded *on average* once in 20 years. Sea level at the 20-year recurrence interval has a 5% probability of being reached or exceeded in any given year. Such a high water event can be described in words as a *fairly common flood.* (Ympäristöhallinto, 2019b). Descriptions, recurrence intervals, and probabilities of this and other floods are described in Table 5.

Table 5: Verbal description, recurrence interval, and annual probability descriptions of various floods.

Verbal Description	Recurrence Interval	Annual Probability
Common flood	< 10-year	> 10 %
Fairly common flood	20-year	5 %
Fairly rare flood	50-year	2 %
Rare flood	100-year	1 %
Very rare flood	≥ 250-year	< 0.4 %

Adaptation and English translation of work by the Finnish Environment Institute (SYKE) on the Environmental Administration website (Ympäristöhallinto, 2019b).

10 Coastal Flooding on January 9, 2005

On January 7, 2005, the Finnish Institute of Marine Research (now Finnish Meteorological Institute) delivered its first ever flood warning to the Finnish Ministry of the Interior's Emergency Department. The flood warning raised alarm about a serious flood predicted to threaten the Gulf of Finland in the morning of January 9. The high sea level was predicted to last for hours. The warnings were justified, and Winter Storm Gudrun ended up causing coastal flooding and record-setting sea levels on parts of the South Coast of Finland in January 2005. (Finnish Consulting Group, 2010).

This is an important storm to investigate and write about due to the record-setting sea levels, damage caused, and the increased likelihood of such extreme sea level in the future. The impacts of the flood are helpful to better understand future flooding vulnerabilities. Through studying this flood, I was also able to test the applicability of the linear interpolation method for calculating storm surge levels and the accuracy of my maps based on interpolated data.

10.1 Flood Height

High sea level records were set on January 9, 2005 at the two tide gauges closest to Ekenäs, Hanko and Helsinki. Sea levels reached 150 cm at Hanko and 170 cm at Helsinki in the N2000 height system. (Ilmatieteen laitos, w.y.a.). Based on linear interpolation of sea levels at Hanko and Helsinki, I theorize that the sea level reached a high of 155 cm (N2000 height system) at Ekenäs Old Town on January 9, 2005 (Table 6). I mapped this sea level in QGIS to understand what areas might have been affected by the flooding (Figure 11; Appendix 20).

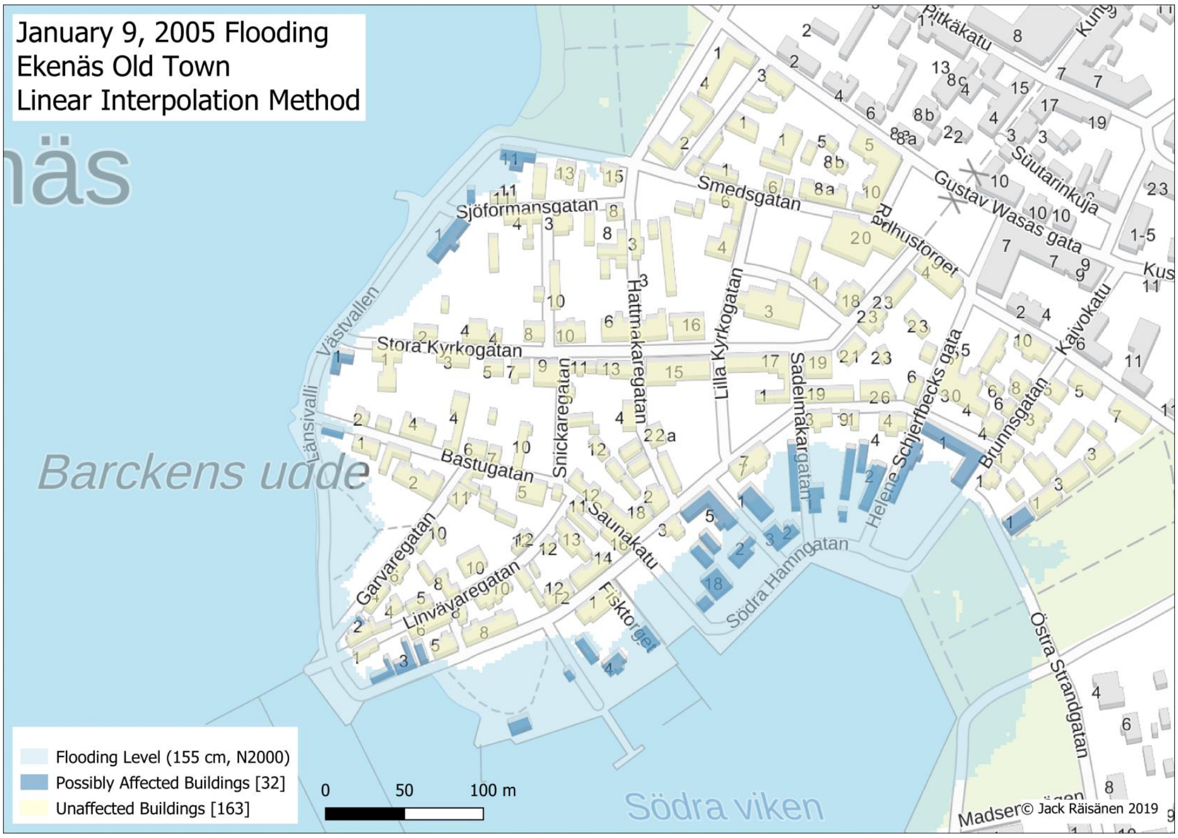

Figure 11: Map depicting theoretical maximum sea level of 155 cm during January 9, 2005 flooding in Ekenäs Old Town.

I discussed the January 2005 high sea level with long-time resident of Ekenäs Old Town Leif Stenwall who witnessed and documented the flooding. Stenwall has followed the sea level for many years. During the January 2005 storm, he observed and documented that the sea level reached 145 cm according to a water level gauge on Skeppsbron Pier in Södra viken Bay at about 3:00 am. (Leif Stenwall, personal communication, April 25, 2019). City of Raseborg Technical Services measured the water level gauge on Skeppsbron Pier and found that it is quite close to the N60 height (Roger Nyberg, personal communication, April 29, 2019). Roger Nyberg, Head of Measurement in the City of Raseborg, recalled that during the January 2005 storm surge the sea level in Ekenäs Old Town reached a height of 137 cm in the N60 height system (personal communication, April 26, 2019).

For comparison purposes, I converted the data from the N60 height system to the N2000 height system, as my other data is in the N2000 height system. I used the GeoData Portal Paikkatietoikkuna (National Land Survey of Finland, w.y.a.) to mark and find the coordinates of the water level gauge on Skeppsbron Pier. The coordinates in the ETRS-TM35FIN coordinate system are: N: 6653584; E: 300897.

I recorded the coordinates in the ETRS-TM35FIN coordinate system, not in the ETRS89 geographic (~WGS84) coordinate system previously used, as the ETRS89 geographic system does not work in the National Land Survey of Finland's GeoData Portal Paikkatietoikkuna Coordinate Transformation Tool. I used the Coordinate Transformation Tool to convert the measure of 145 cm in the N60 height system to the N2000 height system. (National Land Survey of Finland, w.y.a.). I also used the coordinates for Skeppsbron Pier to convert the measure of 137 cm in the N60 height system from the City of Raseborg to the N2000 height system, as I did not receive the coordinates at which that measure was taken.

Table 6: High sea levels at Hanko, Helsinki and Ekenäs on January 9, 2005.

Location	January 9, 2005 (cm, N2000)
Hanko	150[1]
Helsinki	170[1]
Ekenäs	**155[2] / 162[3] / 170[4]**

[1] The sea level increased by 133 cm at Hanko and 151 cm at Helsinki compared to the theoretical mean sea level (Ilmatieteen laitos, w.y.a.). The theoretical mean sea level in 2005 in the N2000 height system was 17 cm at Hanko and 19 cm at Helsinki (Ilmatieteen laitos, w.y.b.).

[2] Sea level at Ekenäs based on linear interpolation of the max sea levels at Hanko and Helsinki.

[3] Sea level of 137 cm in the N60 height system (Roger Nyberg, personal communication, April 26, 2019) converted to the N2000 height system (National Land Survey of Finland, w.y.a.).

[4] Sea level of 145 cm recorded at Skeppsbron Pier (Leif Stenwall, personal communication, April 25, 2019) converted to the N2000 height system (National Land Survey of Finland, w.y.a.).

The converted January 2005 storm surge sea level measurements from Nyberg and Stenwall are 7 cm and 15 cm higher, respectively, than the sea level I linearly interpolated from the maximum sea levels at Hanko and Helsinki. This surprised me. I did not know if it would be higher or lower, but I predicted that it would have been lower due to the narrowness of Pojoviken Bay and possible storm surge protection from the archipelago between Ekenäs Old Town and the Baltic Sea. On the other hand, the swelling of water in long and shallow bays can result in higher local sea levels; this phenomenon should be considered when determining safe building elevations near the sea (Kahma *et al.*, 2014). Shallow bays in this case are those which are 1-2 m in depth (Ulpu Leijala, personal communication, April 4, 2019). Compared to the interpolated sea level, the higher sea level heights reported by the City of Raseborg and Stenwall suggest that there may be a swelling effect around Ekenäs Old Town during extreme sea level events. Further investigation of local bathymetry and conditions would need to be made to determine if swelling occurs around Ekenäs Old Town.

10.2 Flood Likelihood

Based on storm surge recurrence interval data for up to year 2010 from the Finnish Institute of Marine Research (now Finnish Meteorological Institute), the Finnish Consulting Group (2010) calculated that the January 9 sea level in Helsinki (170 cm, N2000) was at about the 110-year recurrence interval. In their 2018 publication, Pellikka *et al.* (2018) refer to the same flood and explain that "[a]ccording to our results, such a flood has an exceedance probability of 3 events per century at present". I do not know why the recurrence interval/ exceedance probability of the January 2005 sea level changed so much from 2010 to 2018. What is more important, though, is how the likelihood of this sea level develops in the future. Pellikka *et al.* (2018) continue and explain that "by the end of the century the conditions have changed so that such a flood would occur on average every second year". So, the very unusual and record-breaking sea level experienced in January 2005 will be quite common by 2100.

10.3 Flood Impacts

High sea levels due to Storm Gudrun caused a variety of damage. For example, the Helsinki Market Square flooded, building cellars filled with water in cities along the coast, various roads became impassable, ferry traffic to Suomenlinna Fortress was disrupted, and numerous imported automobiles were flooded in the Sörnäinen Harbor. (Finnish Consulting Group, 2010). According to the Helsingin Sanomat newspaper, as cited by the Finnish Consulting Group (2010), some residents in Porvoo had to be evacuated from their homes by boat. The preparedness level of the Loviisa Nuclear Power Plant was raised when water rose 171 cm above normal (Helsingin Sanomat, 10.1.2005 as cited by Finnish Consulting Group, 2010).

In Ekenäs Old Town, Stenwall explained that during the January 2005 storm a power distribution box near Västvallen Road between Stora Kyrkogatan Street and Sjöformansgatan Street stopped working (Figure 12). This disrupted power distribution to many homes in the area. Homes in the Old Town have water pumps to remove water from cellars in case of flooding. Water pumps relying on electricity stopped working due to the electricity failure and cellars flooded. Stenwall explained that the power distribution box that failed has been raised since the January 2005 flooding. Stenwall did not know of any mold problems in the Old Town that may have resulted from the high water. (Leif Stenwall, personal communication, April 25, 2019). I have not checked the elevation of the box but based on observation of the power distribution box on May 15, 2019, it appears to still be at rather low elevation (see Appendix 25).

In total, flooding caused €12 million in damage on the Finnish Coast (Kaatra *et al.,* 2009; Pellikka *et al.,* 2018). According to Pellikka *et al.* (2018), the damage would have been much greater without the flood warning issued 30 hours beforehand. Prior to 2005, damage from sea flooding had been very rare in Finland (Kaatra *et al.,* 2009). It is clear that many places were unprepared for this magnitude of flooding; both in Ekenäs Old Town and other parts of the South Coast of Finland. It is good that flood risk assessment and preparation work has been done and is ongoing in many flood prone areas on the coast. Throughout the completion of this project, though, I have observed that awareness of and preparation for flood risks in Ekenäs Old Town is too low. Detailed flood risk assessment and preparation should be conducted for Ekenäs Old Town, as the likelihood of high water levels will be even greater in the future.

Figure 12: January 9, 2005 flooding in Ekenäs Old Town. Workers are attending to the power distribution box near Västvallen Road that failed. Photo by Sebastian Lindberg.

Figure 13: The tranquil and idyllic Ekenäs Old Town was disturbed by flooding on January 9, 2005. The Ekenäs Church is visible in the background. Photo by Sebastian Lindberg.

Figure 14: January 2005 flooding brought water over Västvallen Road. In this photo by Sebastian Lindberg, taken on January 9, 2005 at 9:12 am, water is seen reaching the steps of the Old Sauna.

Figure 15: Water covered Södra Strandgatan Street and reached some surrounding buildings during the January 9, 2005 flood. The dark red building in the center is protected under the Finnish Act on the Protection of the Built Heritage (498/2010), part of the property at Linvävaregatan Street 1 (Museovirasto, w.y.). Photo by Sebastian Lindberg.

Figure 16: Water covered the Fisktorget Market Square in Ekenäs Old Town on January 9, 2005 and reached this building and fence. Photo by Sebastian Lindberg.

11 Future Coastal Flooding in Finland

Flooding from extreme high sea levels on January 9, 2005 highlights the need to prepare for storm surge in addition to changes in global mean sea level. In fact, I find preparation for risks from short-term variations in sea level of even greater importance than responding to long-term mean sea level changes alone. Sea level extremes can cause devastating flooding on the coast. Thus, in coastal management applications it is very important to consider changes in sea level extremes (Pellikka *et al.*, 2018).

Coastal flooding risks and projections must be studied regionally. In Finland, annual sea level maxima are increasing. High sea levels were more likely in the late 20th century than the early 20th century. (Johansson, Boman, Kahma & Launiainen, 2001). Part of the increase in sea level maxima in Finland is due to changes in wind conditions; this change is not yet fully understood, though (Johansson, 2014; Havu Pellikka, personal communication, May 6, 2019). Rapid changes in sea level in Finland are mainly caused by strong winds, changes in air pressure, and internal oscillation (seiche) (Kahma *et al.*, 2014).

When many factors causing high sea level come together, significant flooding can occur. On the South Coast of Finland, probabilities of coastal flooding are expected to significantly increase during the 21st century. A variety of direct impacts from coastal and stormwater flooding are expected in the future. The greatest of these are flooding of buildings and equipment and disruptions to services, traffic, data transfer, and energy supply. (Parjanne, Silander, Tiitu & Viinikka, 2018).

By 2100, the sea level during the January 2005 coastal flood that caused €12 million in damage will on average occur once in two years. In 2018, extreme sea level of that height had a likelihood of occurring only once in around 33 years. (Pellikka *et al.*, 2018). Such a change highlights the need for serious consideration of future coastal flooding risks. Sea levels in Hanko and Helsinki at various recurrence intervals in 2011 compared to 2100 are shown in Table 7.

Table 7: Sea level (cm, N2000) in Hanko and Helsinki at various recurrence intervals in 2011 vs. 2100.

Recurrence Interval	Hanko		Helsinki	
	2011	2100	2011	2100
20-year	142	201	166	228
50-year	156	217	181	245
100-year	168	228	193	257
250-year	182	244	208	273
1000-year	205	266	231	297

Data on sea level at various recurrence intervals comes from Kahma *et al.* (2014).

12 Future Coastal Flooding in Ekenäs Old Town

Based on linear interpolation of the increase in coastal flooding probabilities for Hanko and Helsinki, coastal flooding probabilities in Ekenäs Old Town will also increase dramatically during the 21st century. As with the change for Hanko and Helsinki (Kahma *et al.*, 2014; Pellikka *et al.*, 2018), coastal flooding probabilities for Ekenäs Old Town will increase moderately by 2050 and then much more dramatically between 2050 and 2100. Extreme sea level expected in 2011 on average only once in 1,000 years will occur on average nearly once in 20 years by 2100.

Higher coastal flooding in the future will endanger more of Ekenäs Old Town than at present. Future coastal flooding will also reach older and more archeologically valuable parts of the Old Town.

12.1 2011 vs 2050

Extreme sea levels are expected to increase only moderately on the South Coast of Finland before 2050. Sea levels in Hanko, Helsinki, and Ekenäs at various recurrence intervals in 2011 compared to 2050 are shown in Table 8. I chose not to map extreme sea levels in 2050 due to the only minor change from 2011.

Table 8: Sea level at various recurrence intervals in 2011 compared to 2050 in Hanko, Helsinki, and Ekenäs.

Recur. Interval	Hanko (cm, N2000)			Helsinki (cm, N2000)			**Ekenäs (cm, N2000)**		
	2011	2050	Change	2011	2050	Change	2011	2050	Change
20-year	142	147	+ 5	166	173	+ 7	148	154	+ 6
50-year	156	162	+ 6	181	188	+ 7	162	169	+ 7
100-year	168	173	+ 5	193	200	+ 7	174	180	+ 6

Year 2011 and 2050 sea levels for Hanko and Helsinki were calculated by Kahma *et al.* (2014). Projections for Ekenäs are based on linear interpolation of the Hanko and Helsinki sea levels.

12.2 2011 vs 2100

The probability of extreme sea levels will increase dramatically by 2100. Sea levels that occurred on average once in 1,000 years in 2011 will occur nearly once in only 20 years by 2100. Extreme sea levels at given recurrence intervals in Ekenäs Old Town will increase on average by about 61 cm from 2011 to 2100. This change will put many more buildings and areas in Ekenäs Old Town at risk, including many more protected buildings and archeologically valuable areas.

Sea levels at the 20-, 50-, 100-, 250-, and 1000-year recurrence intervals in Ekenäs Old Town in 2011 compared to 2100 are shown in Table 9. I mapped all these sea levels; these maps are shown in the appendix section; see Appendices 4-18. Maps of sea level at the 1000-year recurrence interval in 2011 and 20-year recurrence interval in 2100 are shown for comparison purposes (Figures 17 and 18). Results of analysis of the amount and increase in potentially affected buildings by these extreme sea levels is also shown in the appendix section for each respective recurrence interval; see Appendix 19, Tables 10-14. Buildings that might be reached by the extreme sea levels are shown in the comparison maps. The comparison maps indicate the additional amount of potentially affected buildings in 2100 compared to 2011; the value for potentially affected buildings for flooding in 2100 is not the total, only the increase from 2011. Potentially affected buildings are not shown in the maps that show different water depths; I made this choice to keep the maps easy to understand.

Even fairly common flooding (20-year recurrence interval) may affect significantly more buildings in Ekenäs Old Town in 2100 compared to 2011. Based on my map analysis, I found that fairly common flooding in 2011 (1.48 m, N2000) would have potentially affected 28 buildings. By 2100, fairly common flooding (2.08 m, N2000) might reach 74 buildings, 46 more buildings than in 2011. Table 10 (Appendix 19) also shows that by 2100, there could be 32 buildings reached by 0.5 to 1 m of water, while in 2011 only 2 buildings were reached by water of this depth. By 2100, 6 buildings may be reached by 1-2 m of water during fairly common flooding.

Future coastal flooding will also reach older and more archeologically valuable parts of Ekenäs Old Town. By 2100, even fairly common flooding (20-year recurrence interval) may reach areas designated Class 1 for their archaeological value (see Appendix 24). By 2100, extreme sea level at the 20-year recurrence interval will cover nearly all of Fisktorget Market Square. Fisktorget Market Square is an area which may contain remnants of piers, harbor storage buildings, and shore constructions from before the Great Northern War (1713-1721), as explained in Chapter 2 (Mökkönen, 2002).

Table 9: Sea level (cm, N2000) in Ekenäs Old Town at various recurrence intervals in 2011 compared to 2100.

Recur. Interval	2011	2100	Change 2011-2100
20-year	148	208	60
50-year	162	224	62
100-year	174	235	61
250-year	189	251	62
1000-year	212	274	62

Projections are based on linear interpolation of the Hanko and Helsinki projections by Kahma *et al.* (2014).

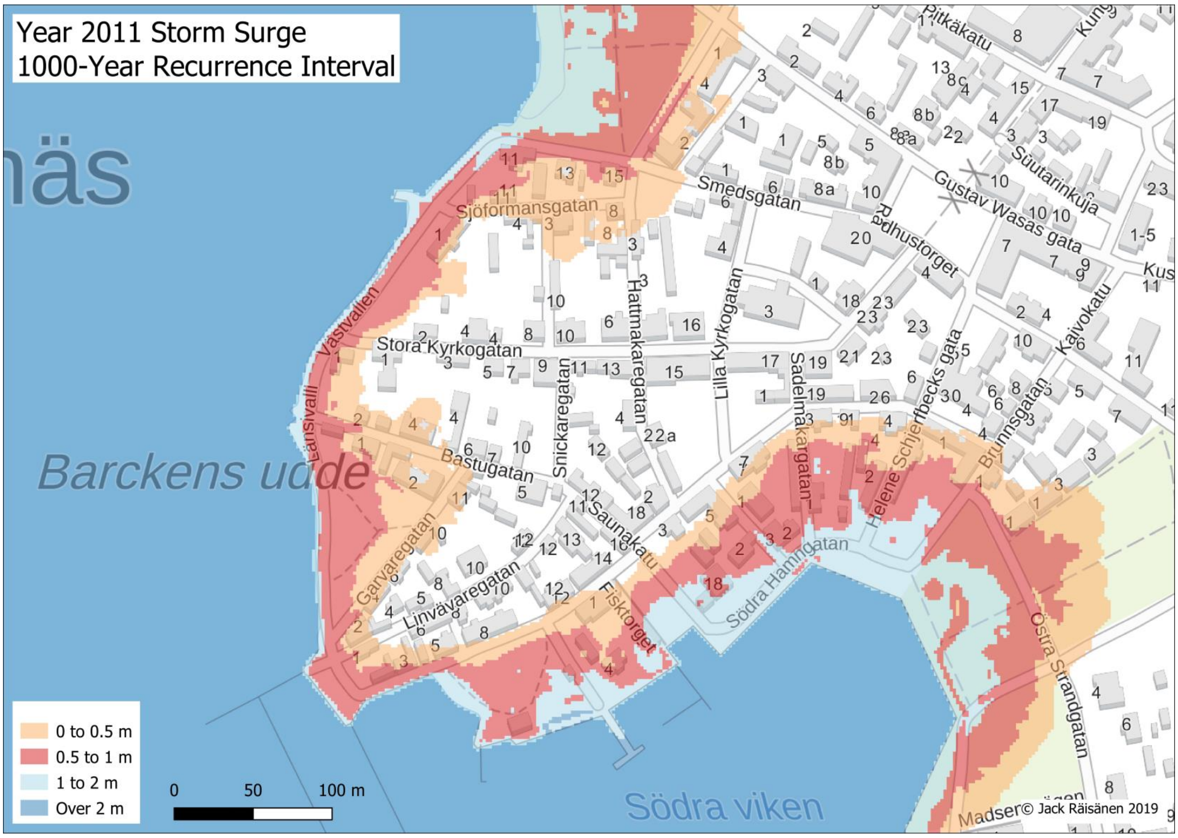

Figure 17: Flood map showing sea level at the 1000-year recurrence interval in 2011 in Ekenäs Old Town.

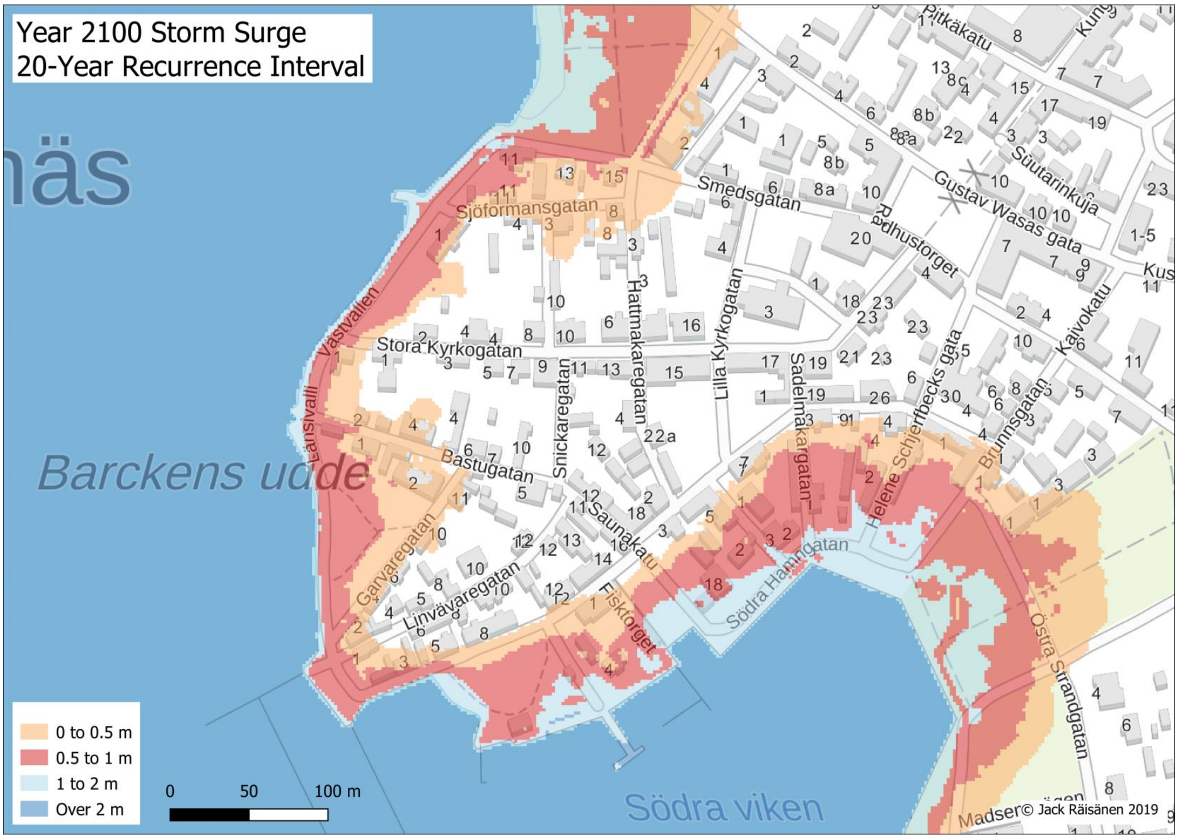

Figure 18: Flood map showing sea level at the 20-year recurrence interval in 2100 in Ekenäs Old Town.

13 Field Work Findings

To investigate flooding vulnerabilities in Ekenäs Old Town further, I conducted small-scale, targeted field work in the area on November 23, 2017. Investigation was based on vulnerability of the buildings to high sea level in 2100 at the 250-year recurrence interval (2.51 m, N2000). I chose the 250-year recurrence interval because that is the recurrence interval used for the minimum recommended building elevations by Kahma *et al.* (2014).

Based on my observations of the protected Adolfsson House, sea level at the 250-year recurrence interval in 2100 would have the potential to cause significant damage. I found that sea level would exceed the foundation by more than 50 cm and nearly reach the window. It seems that such a flood would be very devastating for this building. Regarding the outside storage building on the same property, I observed that sea level would exceed the wall along Södra Strandgatan Street by more than 1 m (this building is visible in Figures 7 and 15).

Figure 19: The Adolfsson House at Linvävaregatan 1. The house has a very low foundation which may be exceeded by coastal flooding in the future. Photo by © Jack Räisänen.

Södra Strandgatan Street 12 is a house protected in plan and on the site of an area of archeological interest (“Class 1”; see Appendix 24). According to an archeological inventory of Ekenäs Old Town, the house has a cellar. (Mökkönen, 2002). As it is protected, on a site of high archeological interest, and close to the sea, I was interested in checking the vulnerability of the building to storm surge in the future. I found that the house has a rather high stone foundation, about 84 cm. The area of lowest elevation, the southwest corner, is at an elevation of 2 m. Sea level at the 250-year recurrence interval in 2100 would only reach the foundation. If the house does indeed have a cellar, and if there are parts of the structure at or below the foundation level, there could be vulnerability to flooding at the 250-year recurrence interval by 2100.

Based on my field work, I can conclude that some buildings, including those important from a cultural heritage perspective, could be at risk due to flooding of the 250-year recurrence interval and more common flooding by 2100. An in-depth analysis of building foundations, ground stability, structural characteristics, and similar aspects would need to be conducted to more fully understand the vulnerabilities of the buildings to flooding. This field work did not consider or investigate potential risks to the archeological heritage, only to the built cultural environment.

14 Minimum Recommended Building Elevation

The Finnish Meteorological Institute has published recommendations for minimum building elevations for the Coast of Finland. The recommendations are based on sea level at the 250-year recurrence interval by 2100. Recommendations have been given for the two tide gauges closest to Ekenäs, Hanko and Helsinki, of 250 cm and 280 cm, respectively (N2000 height system). Possible swelling impacts and a wave reserve must be calculated locally for local conditions. (Kahma *et al.* 2014). Due to a lack of time and resources, I have not adjusted minimum recommended building elevations for possible swelling impacts and local wave action. Based solely on linear interpolation of elevation recommendations for Hanko and Helsinki, I calculated and mapped an elevation recommendation for Ekenäs Old Town of 258 cm (N2000). I then mapped this elevation, showing which buildings are currently above and below the linearly interpolated recommendation. Based on my mapping (Figure 20; Appendix 21), I can see that many buildings in the Old Town are located completely or partially below the minimum recommended building elevation.

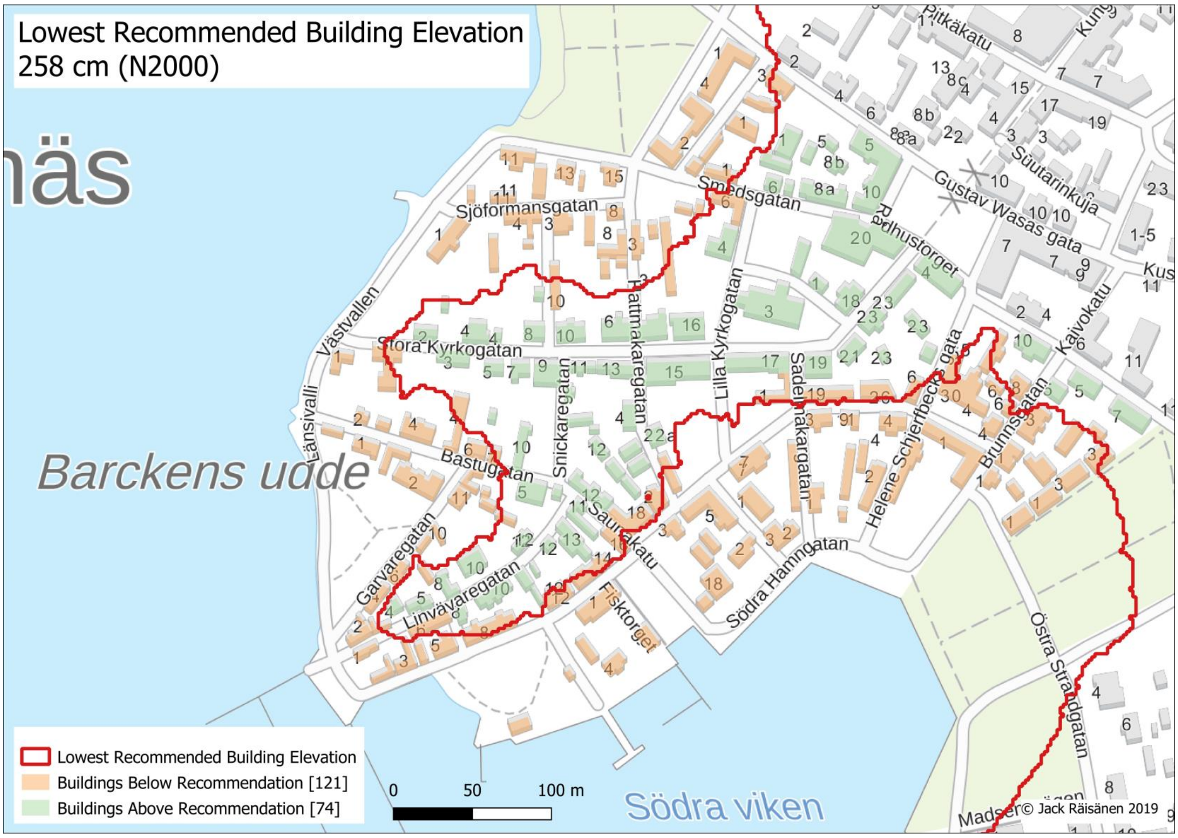

Figure 20: Map depicting a minimum recommended building elevation of 258 cm for Ekenäs Old Town.

15 Significant Flood Risk Areas

In accordance with the Flood Risk Management Act (620/2010), flood maps and flood risk management plans have been created for the 22 areas designated as significant flood risk areas (Parjanne *et al.*, 2018). The significant flood risk areas have been designated at the national level by the Ministry of Agriculture and Forestry of Finland, based on recommendations from the Centres for Economic Development, Transport and the Environment. The significant flood risk areas are determined based on the probability of flooding and possible impacts from flooding. Factors such as population and potential impacts to essential services like water and energy supply affect determination of the significance of flood risk areas. (Maa- ja metsätalousministeriö, 2018).

Regarding the cultural environment, the Flood Risk Management Act (620/2010) explains that the risk for “irreparable adverse consequence to cultural heritage” can be cause for an area to be designated as a significant flood risk area (8 §, 620/2010). The Ministry of Agriculture and Forestry of Finland’s Flood Risk Management Coordinating Group explains that flooding at the 1000-year recurrence interval is used as the flood risk level. In the criteria for determining the significance of flood risks, the Coordinating Group explains that a flood risk is significant if there are several protected buildings in the flood zone of a very rare flood (1000-year recurrence interval) which could experience irreparable damage from the flood. (Tulvariskien hallinnan koordinointiryhmä, 2010).

To check whether this might apply to Ekenäs Old Town, I picked out and mapped the protected buildings (Mökkönen, 2002) that could be reached by the 1000-year flood zone for 2011 (sea level of 2.12 m, see Figure 21 and Appendix 22). Based on this, I can see that there are 40 protected buildings in the flood zone of extreme sea level at the 1000-year recurrence interval in Ekenäs Old Town. The buildings with the “sk” designation (2 buildings) are protected by the Act on the Protection of the Built Heritage (489/2010). The buildings with the “sr” designation (31 buildings) are protected in plan (Teemu Mökkönen, personal communication, April 24, 2019). The buildings with the “sh” designation (7 buildings) are marked in the plan as buildings that are significant due to their history or architectural appearance (Teemu Mökkönen, personal communication, April 24, 2019).

High sea level at the 1000-year recurrence interval for 2011 would also cover areas of the Old Town that are of archeological interest. These are areas that are of interest for research and protection (see Appendix 24). There may be a risk that flooding at the 1000-year recurrence interval could damage archeological heritage in Ekenäs Old Town, due to possible impacts of erosion and water saturation, for example.

Based on my mapping, analysis, and understanding gathered from my field work, I have concluded that flooding of Ekenäs Old Town at the 1000-year recurrence interval (2.12 m) could damage protected buildings representing the built cultural environment. I have also concluded that extreme sea level at this height could pose a risk to valuable archeological heritage in the Old Town. Thus, I think that the Ministry of Agriculture and Forestry of Finland should designate Ekenäs Old Town as a significant flood risk area. In accordance with the Flood Risk Management Act (620/2010), the Ministry should establish a flood management group to create flood maps and develop a flood risk management plan for the area.

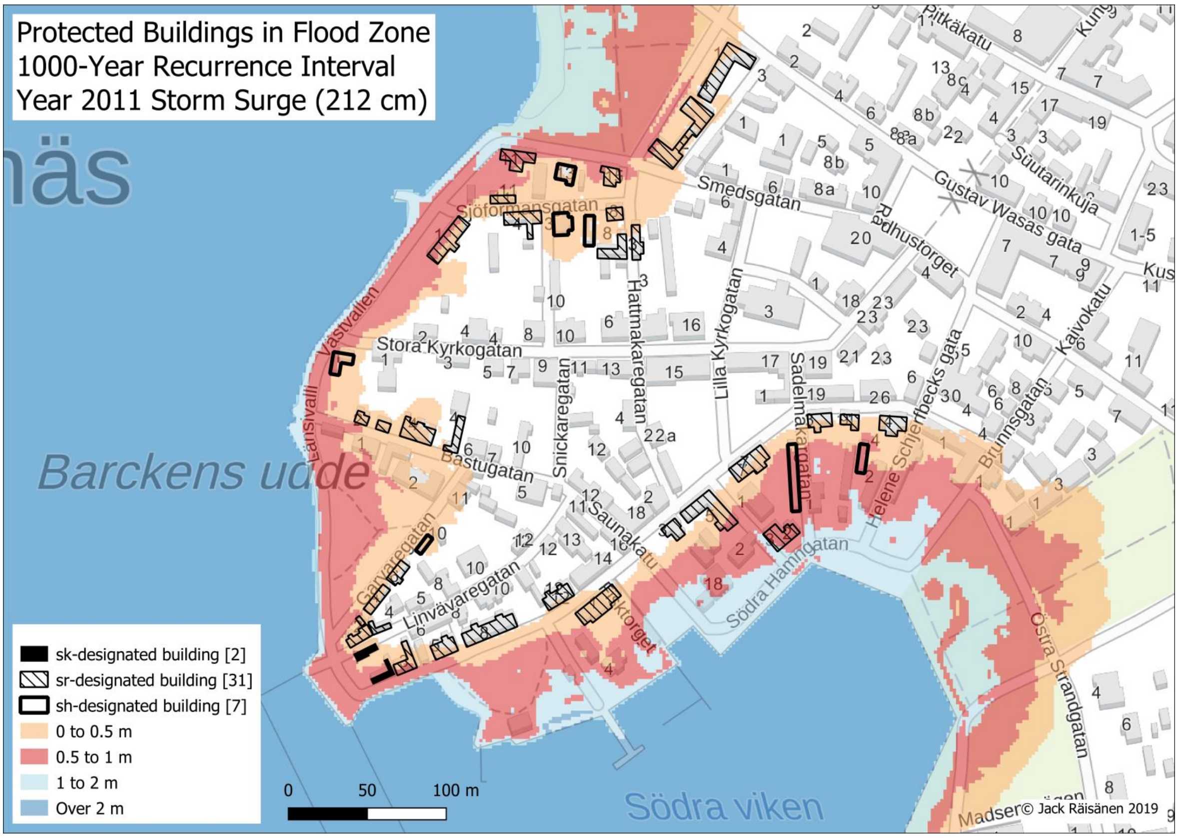

Figure 21: Protected buildings in Ekenäs Old Town reached by the sea at the 1000-year recurrence interval.

16 Paying for Flood Damage

Prior to 2014, compensation of damage from waterway flooding up to the 20-year recurrence interval was paid by the State of Finland. Damage from floods more common than the 20-year recurrence interval was not compensated. In the beginning of 2014, responsibility for compensation of flood damage was shifted to homeowners and private insurance companies offering flood insurance. The insurance companies that offer flood insurance in Finland typically reimburse flood damage from flooding up to the 50-year recurrence interval. The insurance companies might not reimburse flood damage from flooding more common than the 50-year recurrence interval. The reason for this change was the idea and principle that responsibility for and preparation against the potential effects of exceptional natural disasters should be primarily borne by property owners. This means that homeowners must consider which insurance protections they need, understanding that the state and municipality are not responsible for compensation of flood damage. (Parjanne & Huokuna, 2014).

OP Financial Group is one financial company in Finland which offers insurance coverage for natural phenomena. Sea flooding is one of the natural phenomena which is included. With sea flooding, OP Financial Group refers “to an exceptionally high rise of the sea level caused by gale-force winds, change in air pressure or flow in the Danish straits." (OP Insurance Ltd, 2019). They also cover damage from flooding only up to the 50-year recurrence interval, as they state:

> "By an exceptionally high rise of freshwater or saltwater levels we mean such a rise caused by gale-force winds or water level that is likely to occur only once every 50 years or less frequently. A flood caused by a permanent rise in mean water line, normal variation of water level or waves is not considered exceptional." (OP Insurance Ltd, 2019).

The Terms and Conditions for the insurance, however, include an exclusion for loss or damage caused by "moulding, rotting, the spread of fungus, smell, material fatigue or other equivalent gradual phenomenon." (OP Insurance Ltd, 2019). When buildings are flooded, they can develop mold if not dried out properly. This is a problem that can affect the built cultural environment. (Berghäll & Pesu, 2008). It would be good to know if mold caused by exceptional flooding would be covered by the natural phenomenon coverage.

To better understand flood insurance for old buildings, I met with Susanne Lindén, an insurance specialist in the Ekenäs Branch of OP Financial Group. Lindén explained that currently, building age and its plumbing are the primary factors affecting the cost of this insurance. Buildings representing cultural heritage cannot be insured with ordinary home insurance. When insuring a cultural heritage building, an insurance specialist must inspect the building and approve a maximum amount that can be paid in the event of an insurance claim. Insurance for typical homes without cultural heritage features do not include this maximum. The reason for this inspection and claims limit is that the repair or replacement of a building representing cultural heritage requires more work than other buildings; in case of fire or other damage, it is not possible to simply order another factory built home. For this reason, the insurance is also more expensive. Insurance coverage may also be denied if the insurer deems the risk too high. Lindén did not know if considerations are currently being made to consider changing flood and other risks due to climate change. (Susanne Lindén, personal communication, May 17, 2019).

It is important to be aware that extreme sea level at the 50-year recurrence interval will increase noticeably during the 21st century. In the case of Ekenäs Old Town, flooding at the 50-year recurrence interval in 2100 (2.24 m, N2000) may reach 53 more buildings (94 total buildings) than would have been reached by flooding at the 50-year recurrence interval in 2011 (1.62 m, N2000; 41 buildings). Also, the increase in extreme sea level height from 2011 to 2100 will likely mean worse damage for those buildings already in the flood zone of extreme sea level at the 50-year recurrence interval in the event of extreme sea level. These changes may be seen in maps for the 50-year recurrence interval in Appendices 7-9 and Table 11 in Appendix 19, which shows the change in potentially affected buildings from extreme sea level from 2011 to 2100. If insurance companies maintain compensation for flood damage from coastal flooding at the 50-year recurrence interval, the amount of compensation payments can be expected to increase dramatically. This could lead to an increase in the price of insurance premiums or increased denial of coverage due to excessive risk. There must be awareness of and preparation for such changes.

It is important to consider whether it is wise to leave responsibility for protection of the built cultural environment to private owners and insurance companies. If protected buildings in Ekenäs Old Town experience significant damage in the future due to coastal flooding, will homeowners have sufficient resources to pay for proper repair of the damage? Will flood insurance coverage for buildings representing cultural heritage become more expensive and difficult to obtain? How much will insurance companies offering flood insurance be willing to pay for the expertise needed for proper repair and restoration of old wooden buildings? Much of the expertise and materials used in historic buildings has become rare and the skills are disappearing (Berghäll & Pesu, 2008). Even if the expertise and materials could be found and repair were possible, how expensive would repair be that maintains as much originality as possible? In an area like Ekenäs Old Town, which represents our cultural heritage, it may be unwise to rely solely on the financial resources of homeowners and the willingness of insurance companies to compensate for potentially costly and lengthy flood damage repair. The state and local governments and homeowners will need to take action to reduce flood risk.

17 Adaptation

Bryggen is the old harbor area of Bergen, Norway, featuring many wooden buildings near the sea. Bergen, Norway is a World Heritage Site and is at risk due to rising sea level. The buildings have sunk over time as the wooden foundations have rotted; drainage of the water table has caused even further sinking. Bryggen has flooded several times. With Bergen expecting 53-108 cm of sea level rise, the area could be at even greater risk in the future. A restoration project was started in 2000, during which all the buildings are being raised about 60 cm above sea level. This will place them higher than any sea level recorded in Bergen, but it is uncertain if this will be enough in the future. (Kaslegard, 2011). As another wooden town at risk of coastal flooding, Ekenäs Old Town may be able to learn something from the work that has been done in Bryggen and from their future protection plans.

To protect cultural heritage in Canada, some buildings have been moved away from the coast to keep them dry (Berghäll & Pesu, 2008). I do not think this is a very suitable option for Ekenäs Old Town, though, as the homes and yards seem very connected to local place and geography. The sea, while it will bring risks for flooding in the future, is also an integral part of the Old Town. The underground and underwater archaeological heritage would also be extremely difficult to simply move. Other solutions will need to be applied.

Denmark's oldest city, Ribe, is another cultural heritage area. It is protected by an extensive network of dikes, which rise about 7 m above sea level. (Kaslegard, 2011). Protection measures like this may be needed in the future in Finland, too. However, such structures could also have impacts on local ecology and other aspects.

During flooding on January 9, 2005, some parts of Helsinki were protected by bales of cardboard. The Helsinki Old Market Hall was protected in this way. The cardboard bales were a temporary measure, removed after sea level decreased. (Finnish Consulting Group, 2010). Such protection measures could be needed and of use in Ekenäs Old Town in the future. One advantage of this method is that it does not cause permanent changes to the area. I think that more permanent protection measures are likely needed, though, as the risk of flooding increases in the future.

Adaptation measures should be careful to respect the cultural heritage of Ekenäs Old Town. Adaptation measures should also be developed in a way that respects the surrounding environment. Rather than implement hard and engineered structures that reduce coastal habitat, protection measures should be explored that support coastal ecosystems. Research from North Carolina, USA found that living shorelines offered more effective protection against landward erosion and were more resilient than hardened shorelines during Hurricane Matthew (2016). Living shorelines incorporate natural habitat elements and can support coastal ecosystems while improving coastal resilience. (Smith, Puckett, Gittman & Peterson, 2018). Following hurricane damage, Smith *et al.* (2017) found that bulkheads experience more damage and are more costly to repair than living coastlines. At the same time, a higher proportion of homeowners with bulkhead protection experience property damage (Smith *et al.*, 2017). While the conditions in Finland are different than on the East Coast of the United States, it is worth exploring whether living shorelines could also offer more effective protection than hardened shorelines in Finland while also supporting coastal ecosystems.

18 Discussion

Global mean sea level rise and changes in wind patterns will likely cause an increase in sea level in the Gulf of Finland during the 21st century (Pellikka *et al.*, 2018). This will likely cause an increase in local sea level in Ekenäs Old Town despite the impact of post-glacial land uplift. Based on current projections, local sea level rise itself is unlikely to endanger Ekenäs Old Town by 2100 under normal conditions. However, there may be significant risks of flooding during storm surge conditions by 2100. For example, when sea level in the Baltic Sea is higher than normal, southwesterly winds push water into the South Coast of Finland of Finland, air pressure is low, and there is internal oscillation in the Baltic Sea, Ekenäs Old Town may be at significant risk of flooding. Extreme sea level heights are expected to increase; coastal flooding is expected to become more common. More common and greater coastal flooding may endanger the built cultural environment and the archaeological heritage of Ekenäs Old Town by 2100. Future flooding is likely to endanger older and more archaeologically valuable parts of Ekenäs Old Town. Higher and more common coastal flooding may put more buildings at risk and create greater risks for already vulnerable buildings. Attention should be brought to these risks. Based on existing tolerances for flood risk, I have also concluded that Ekenäs Old Town should be designated as a significant flood risk area. This is due to the damage that flooding at the 1000-year recurrence interval could cause to the cultural heritage there.

I question the standard used to determine significant flood risk areas. Based on current projections, the current 1000-year recurrence interval standard will be outdated by 2100. In my study of Ekenäs Old Town, I found that sea level at the 1000-year recurrence interval for 2011 will occur nearly once in 20 years by 2100. This means that flooding which is currently very rare will become rather common by the end of the 21st century. The 1000-year recurrence interval standard is likely enough for now, but between 2050 and 2100 a new standard will likely be needed. This should be considered when making long-term plans to protect cultural heritage and the coastal area in general.

Projections for global and local sea level change are varied. The amount of global and local sea level change by 2100 and beyond depends on climate change mitigation efforts (Church *et al.*, 2013). Mitigation efforts in Finland and around the world should be increased to reduce the risk of significant GMSL rise and other climate change impacts. Projections for regional sea level rise should continue to be updated as new information becomes available.

Regional sea level rise projections should be monitored and updates to these projections should be incorporated into local flood risk planning.

The projections for global warming and sea level rise in this thesis are limited to the year 2100. 2100 is not a backstop for global warming and sea level rise, though, and sea level rise is expected to continue far beyond the year 2100 (Church *et al.,* 2013). Projections are limited to 2100 as the most recent regional sea level rise projections from the Finnish Meteorological Institute (Pellikka *et al.*, 2018) extend only to year 2100.

All the flood and sea level rise calculations and maps that I have made for Ekenäs Old Town are based solely on a method called linear interpolation. The linearly interpolated storm surge levels, mean sea level rise calculations, and minimum recommended building elevation are based on data from the Finnish Meteorological Institute for Hanko and Helsinki, the two nearest tide gauges to Ekenäs. The Finnish Meteorological Institute (FMI) has published projections for mean sea level change, flooding risks, and minimum recommended building elevations at 13 tide gauges on the Finnish coastline. FMI has also published sea level maxima for tide gauges along the Finnish Coast; the sea level maximum in Ekenäs on January 9, 2005 is based on the maxima recorded in Hanko and Helsinki (see Chapter 10). The calculations and maps for Ekenäs Old Town herein have not been adjusted for various potentially influencing factors, which may include but may not be limited to local wind conditions, extent of open sea area, local bathymetry, possible protection from the surrounding archipelago, etc. As such, the calculations and maps do not include a "wave reserve" or other similar adjustment.

Some of my maps show topographical change in the relatively flat park bordered by Brunnsgatan Street and Östra Strandgatan Street. This is likely due to disruption of the laser measurements by the Finnish Untuned Bell during the production of the elevation models. (Romi Rancken, personal communication, May 15, 2019). I chose to leave this inconsistency, as it seemed to affect only that park area and did not affect the count of potentially affected buildings during storm surge. This inconsistency demonstrates that the elevation model is not completely accurate. Local knowledge is valuable when developing maps based on spatial data, and it is good to visit the areas being mapped to check for consistency. Also, there is one protected building outside of my study area (see Figure 8 or Appendix 1) that would barely be reached by sea level at the 1000-year recurrence interval in 2100. This is the building at Gustav Wasa Street 2.

There is uncertainty in all the data used for the calculations and map making described herein. Pellikka *et al.* (2018) explain that “the increase in the flood probabilities from 2010 to 2100 is partly due to increasing uncertainty, not just the change in the physical process itself.” It would be good to know the impact of this uncertainty on the extreme sea level heights. It would also be good to know the extent of uncertainty in the flood probabilities in Kahma *et al.* (2014), which were primarily used in this thesis work.

My findings show a need for further research, investigation, and possible implementation of flood protection measures. These findings should not be used in the assessment of property values, insurance premiums, or other similar applications. I recommend wave monitoring to understand local fluctuations in sea level in response to wind conditions, air pressure, and other factors. Some evidence suggests that there may be a swelling effect around Ekenäs Old Town during extreme sea level (see Chapter 10). More research of the buildings, building foundations, foundation heights, base floor heights, soil conditions, and building materials should be conducted to better understand flood risks. It would be good to develop a more accurate elevation model for Ekenäs Old Town than the 2 m elevation model available and used in this project; the elevation model used has an average accuracy of 0.3 m (Maanmittauslaitos, 2012; Maanmittauslaitos, w.y.). Possible flood protection measures should be made in respect and celebration of the rich cultural heritage in Ekenäs Old Town and of the beautiful surrounding environment.

This thesis work has primarily investigated future flooding risks to the built cultural environment and archaeological heritage in Ekenäs Old Town. Climate change poses many other risks to the cultural heritage that should also be considered (Berghäll & Pesu, 2008; Kaslegard, 2010). Climate change and coastal flooding do not only pose a risk to cultural heritage. For example, coastal flooding can also disrupt and endanger lives, mobility, health, traffic, and infrastructure. Consideration should also be made of these risks. Future flooding impacts on, for example, stormwater drainage infrastructure have not been considered and are beyond the scope of this thesis. Future impacts of a rise in local sea level and higher and more common coastal flooding on local ecosystems are also beyond the scope of this thesis.

Recent research in the US has brought attention to the possibly devastating impacts of compound flooding. When storm surge and heavy rainfall occur simultaneously, the potential for flooding can increase dramatically. (Wahl, Jain, Bender, Meyers & Luther, 2015). As rainfall is expected to increase in Finland in the future due to climate change, it may be important to consider risks of compound flooding in Finland, too. From my review of the literature thus far it seems that this possibility has not been considered in Finland.

Planning to prepare for climate change impacts and efforts to mitigate climate change should be increased. A rapid reduction in greenhouse gas emissions and a transition to a zero carbon or carbon negative world would reduce climate change risks. Future climate change impacts, including the rate and amount of sea level rise, depend on future emission pathways. (IPCC, 2018). In order to reach the goal of the Paris Agreement to limit global warming to 1.5 °C (United Nations, 2015), dramatic societal changes are needed. Significant changes are needed in consumption patterns and lifestyle choices. Individual change, new business models, and a renewal of sustainability governance are all needed. (Institute for Global Environmental Strategies, Aalto University, and D-mat ltd, 2019). So, is devastating flooding of cultural heritage our future and new normal? This is still up to all of us. Without significant climate mitigation action, increased coastal flooding and other climate change impacts will likely become our new normal.

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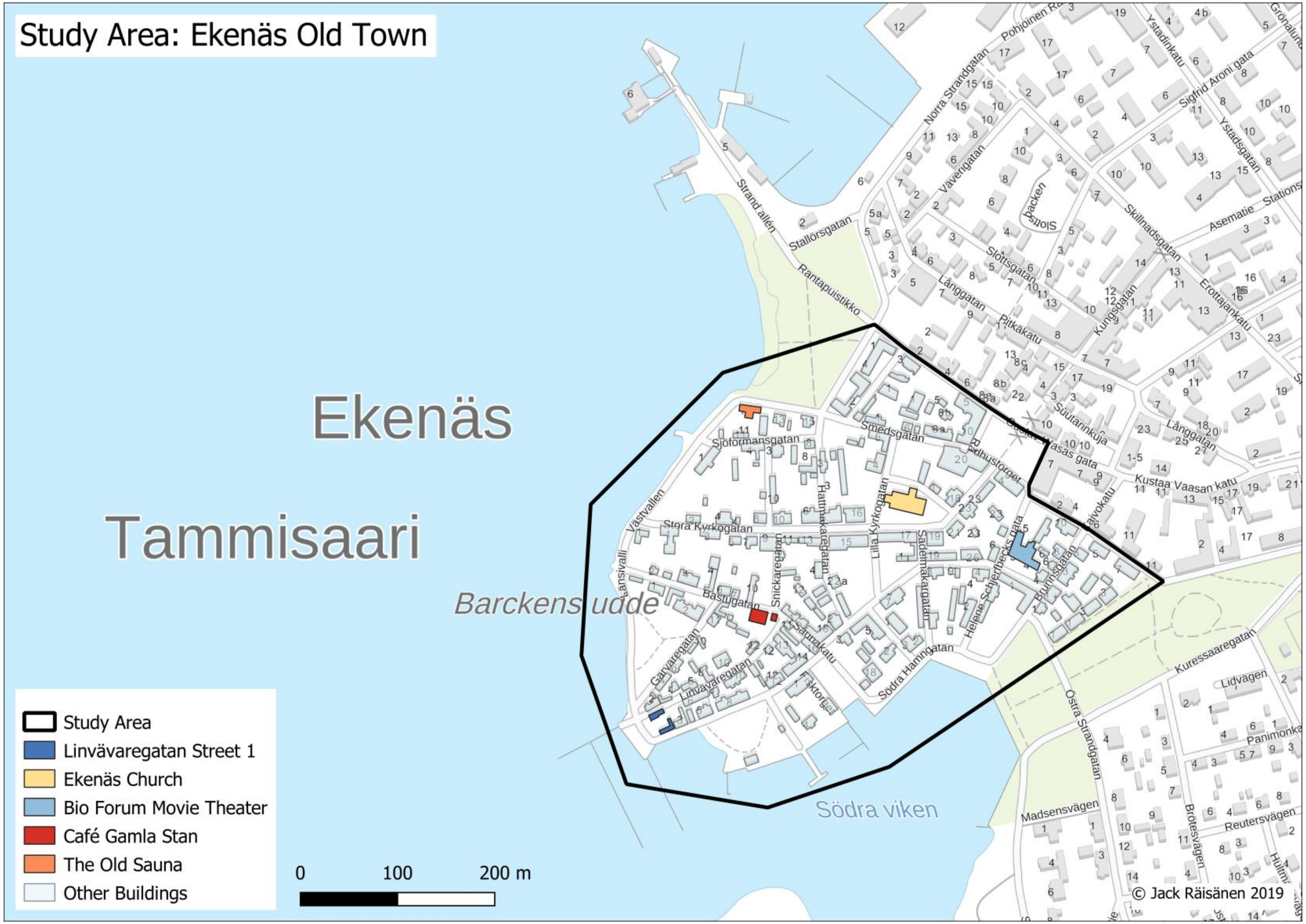
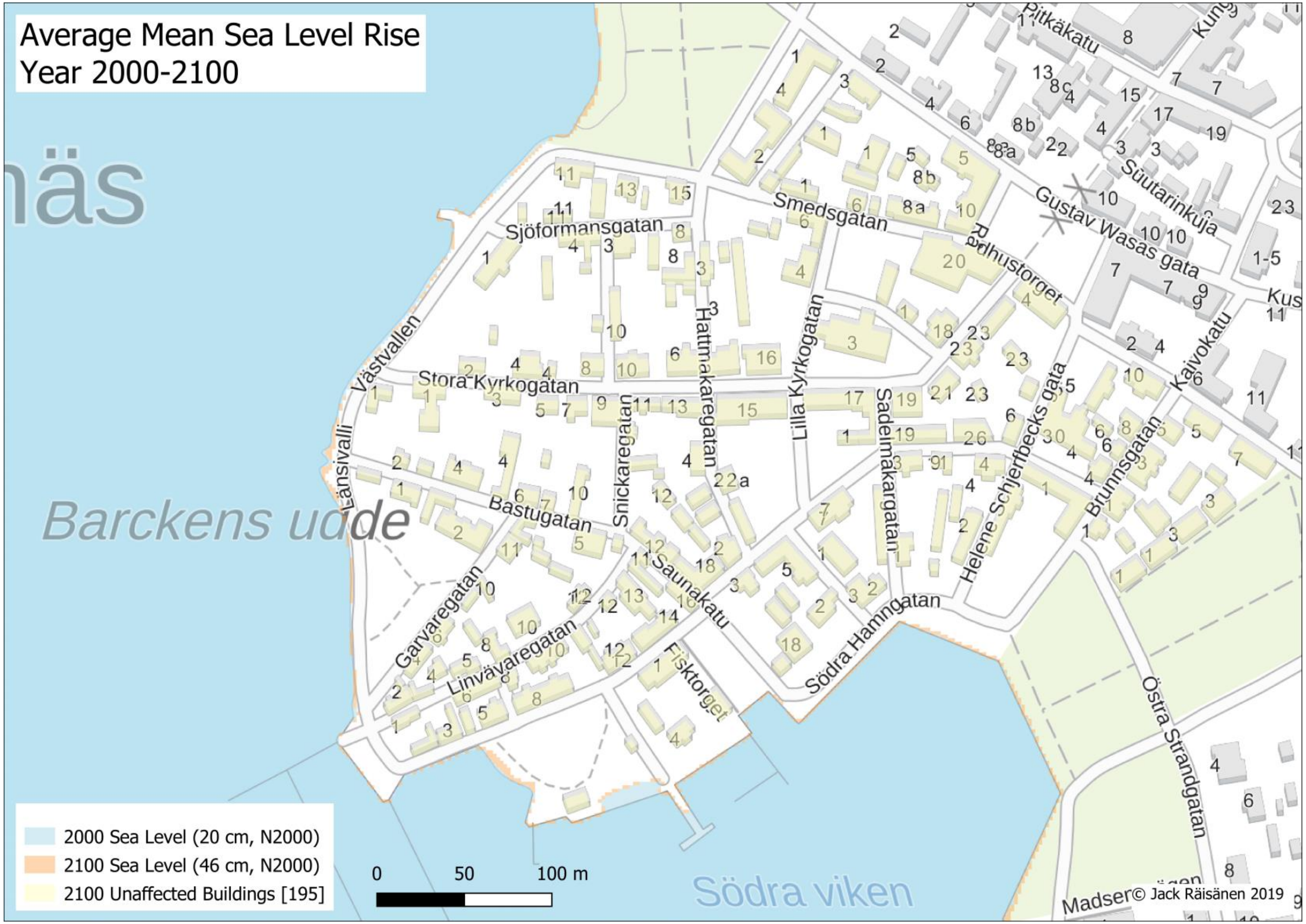
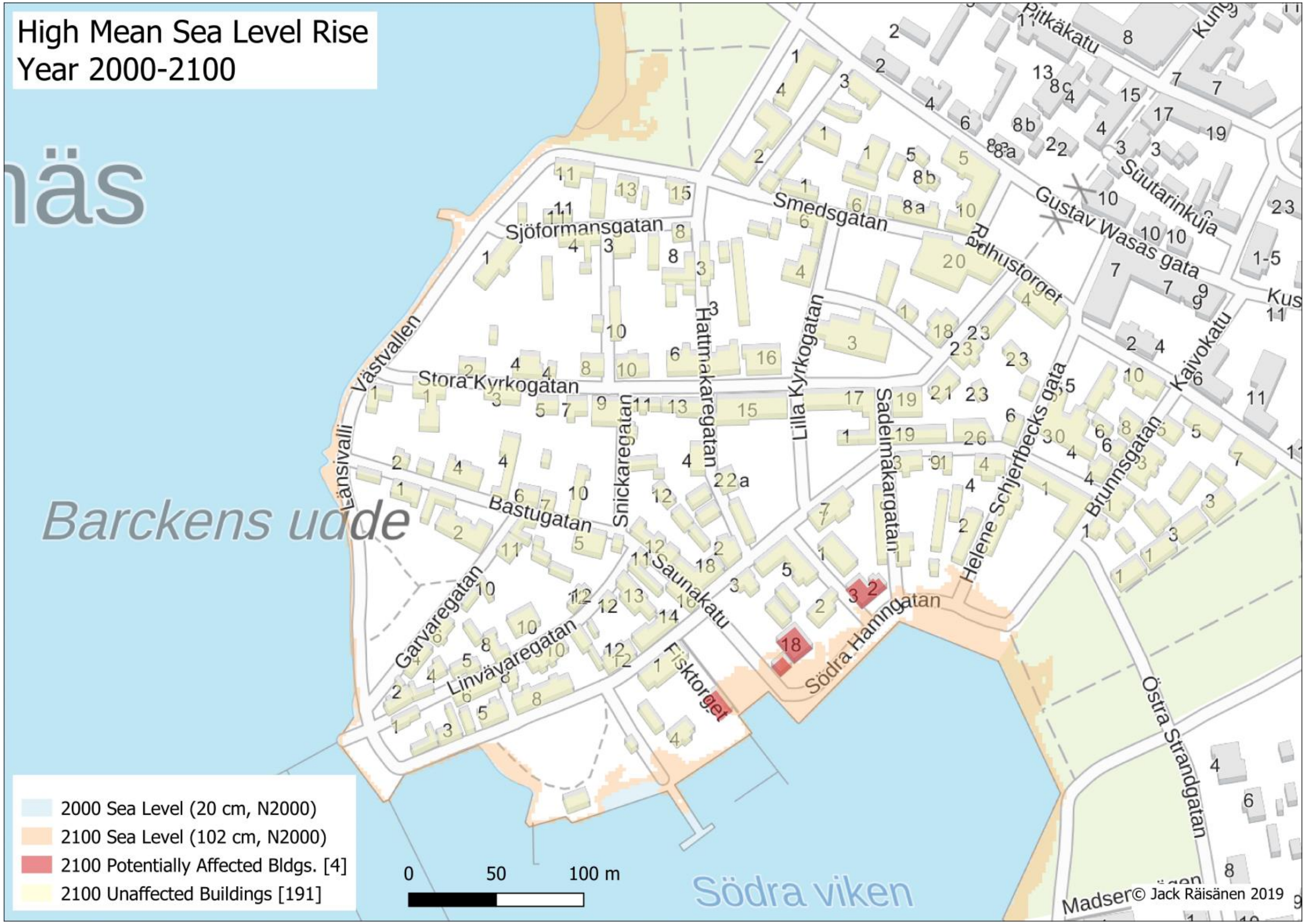
Appendix 1: Study Area Boundaries.



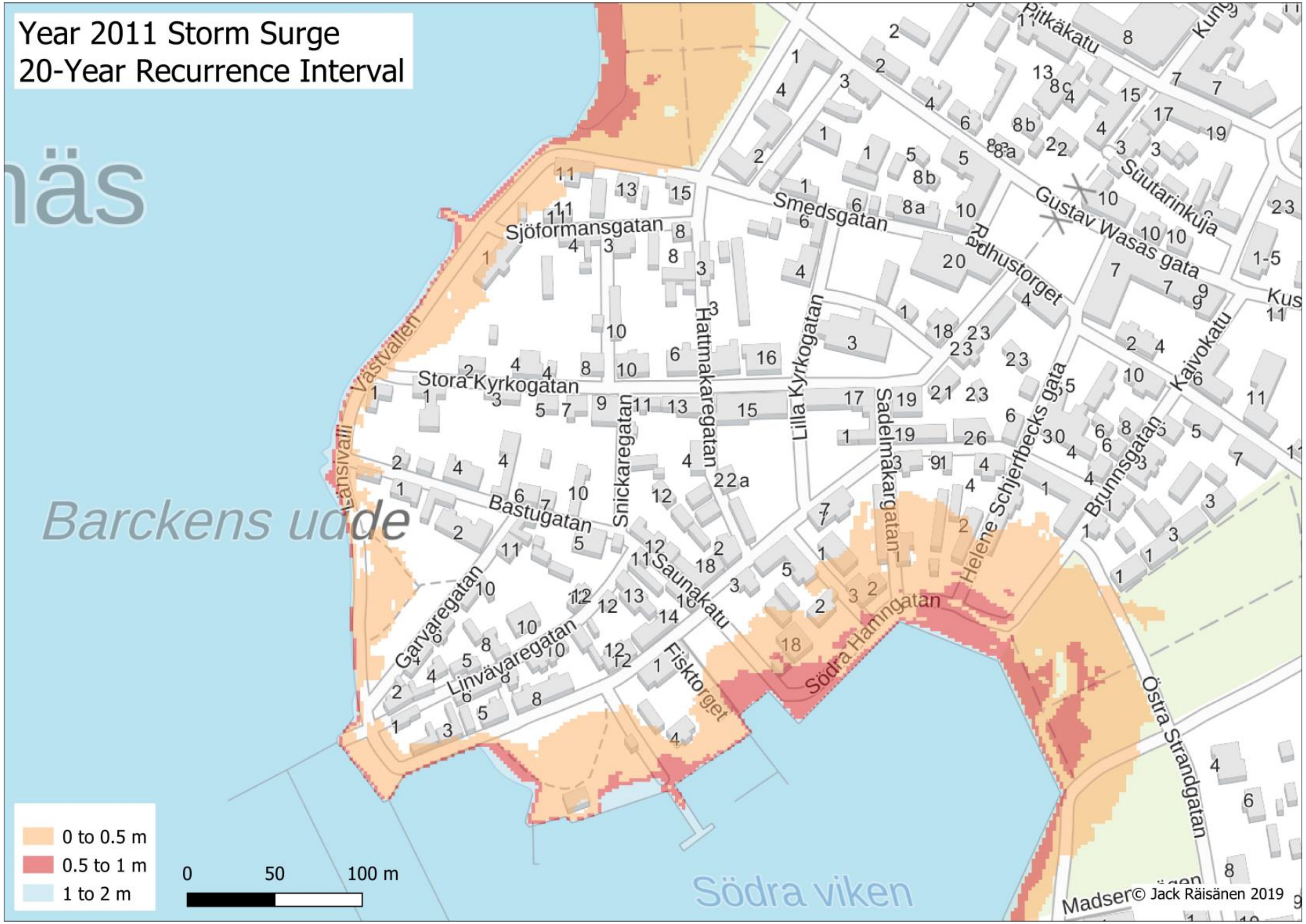
Appendix 2: Average Mean Sea Level Rise, 2000-2100.



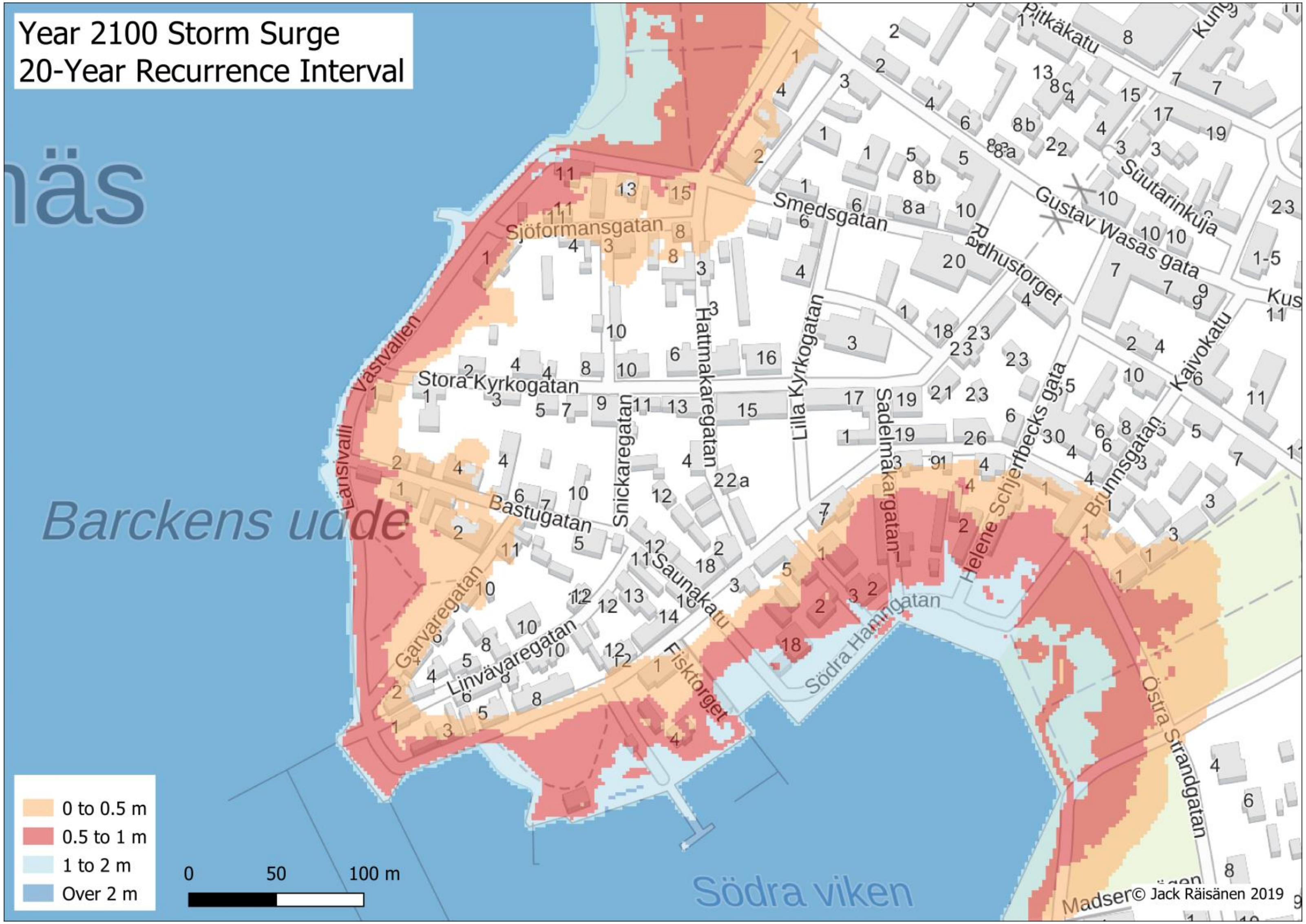
Appendix 3: High Mean Sea Level Rise, 2000-2100.



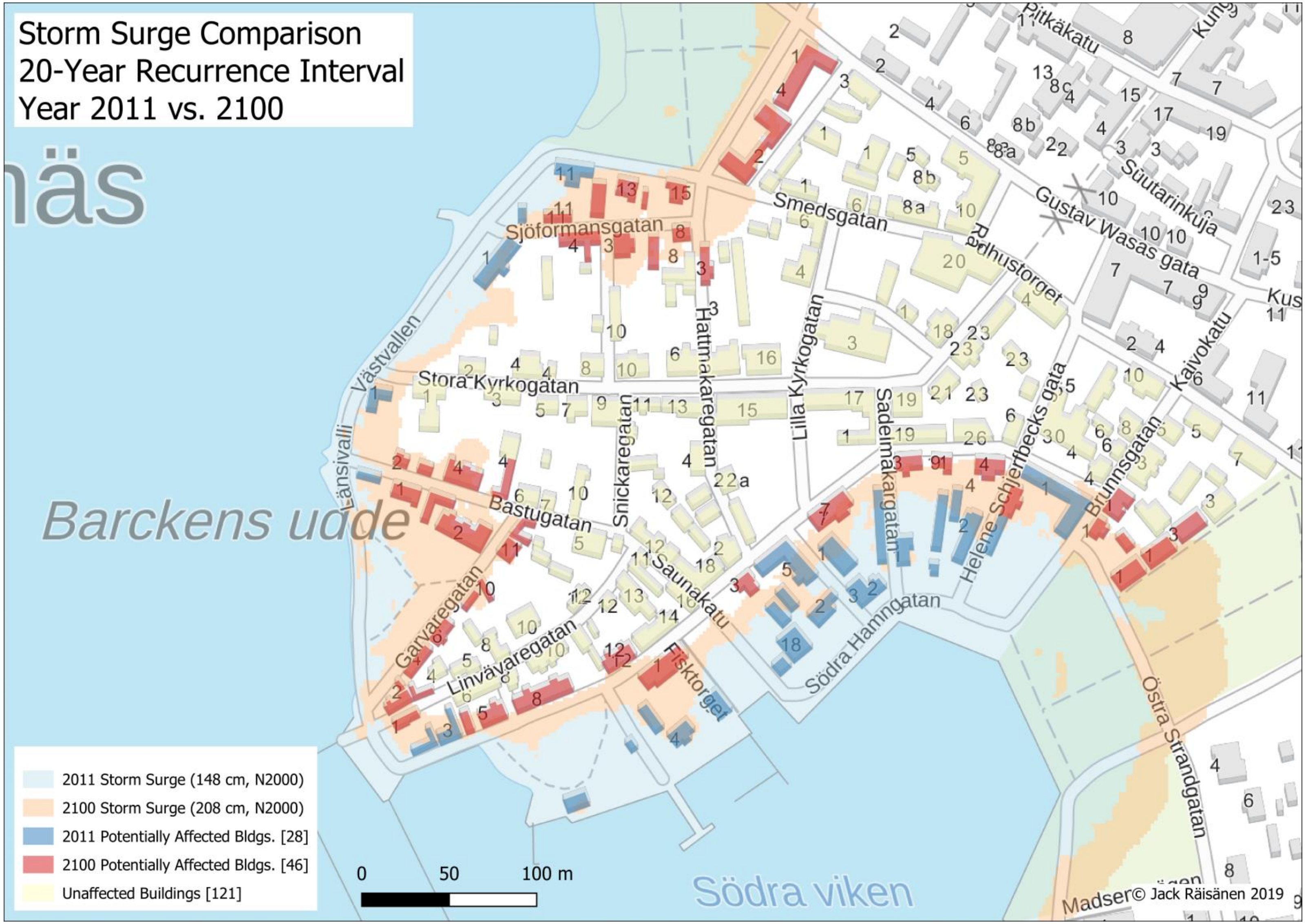
Appendix 4: Year 2011, Extreme Sea Level at the 20-Year Recurrence Interval.



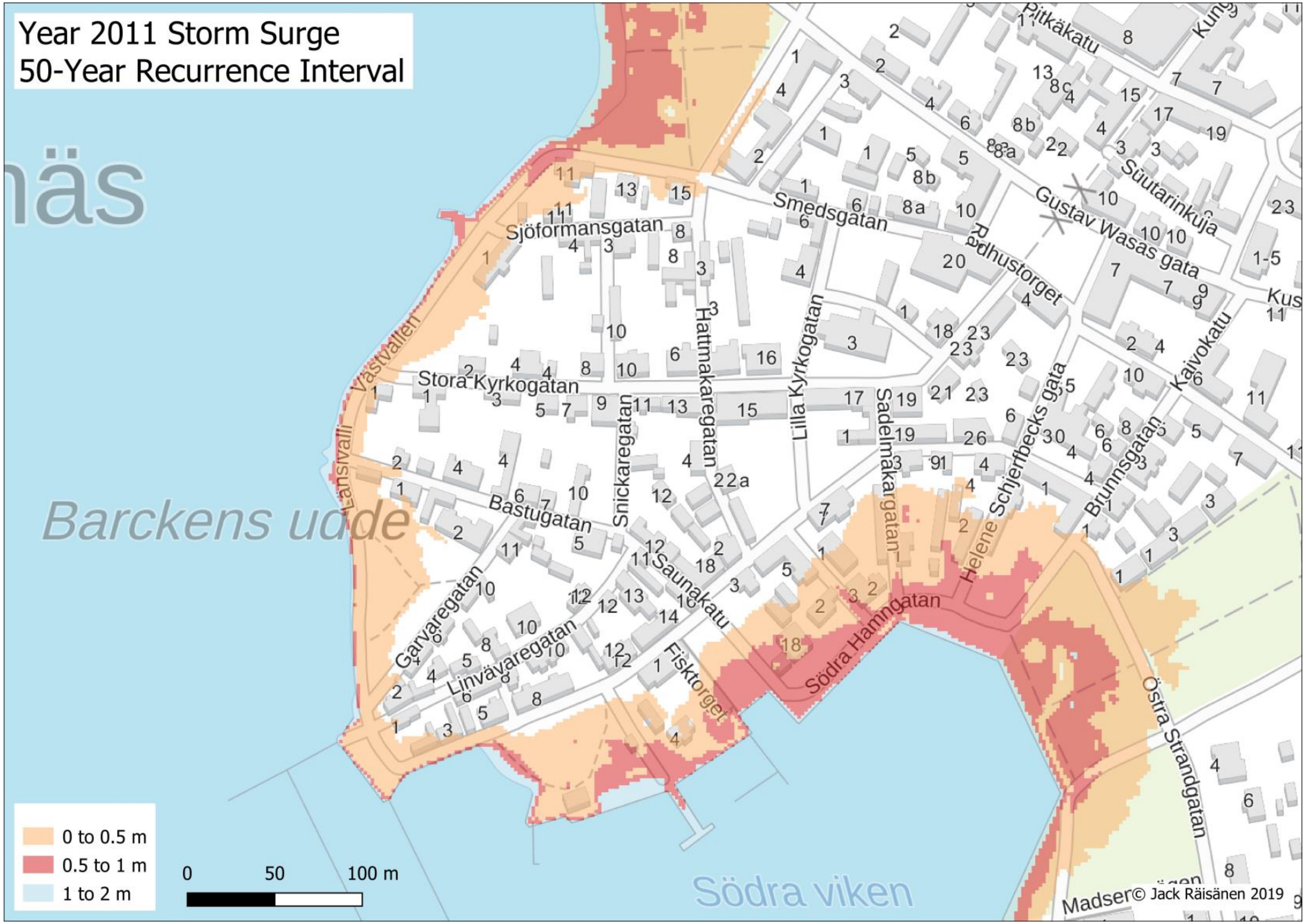
Appendix 5: Year 2100, Extreme Sea Level at the 20-Year Recurrence Interval.



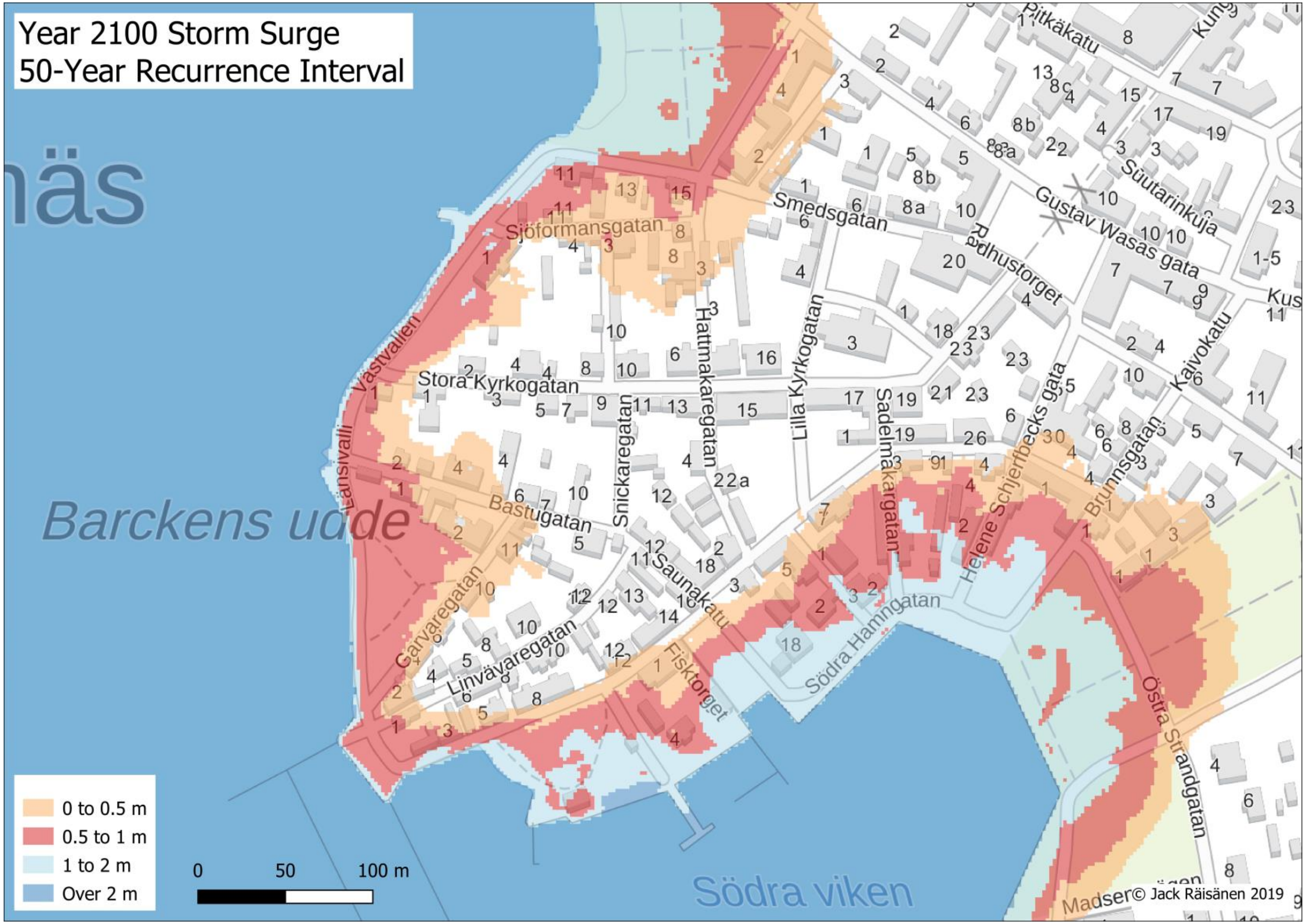
Appendix 6: Extreme Sea Level at the 20-Year Recurrence Interval, 2011 vs. 2100.



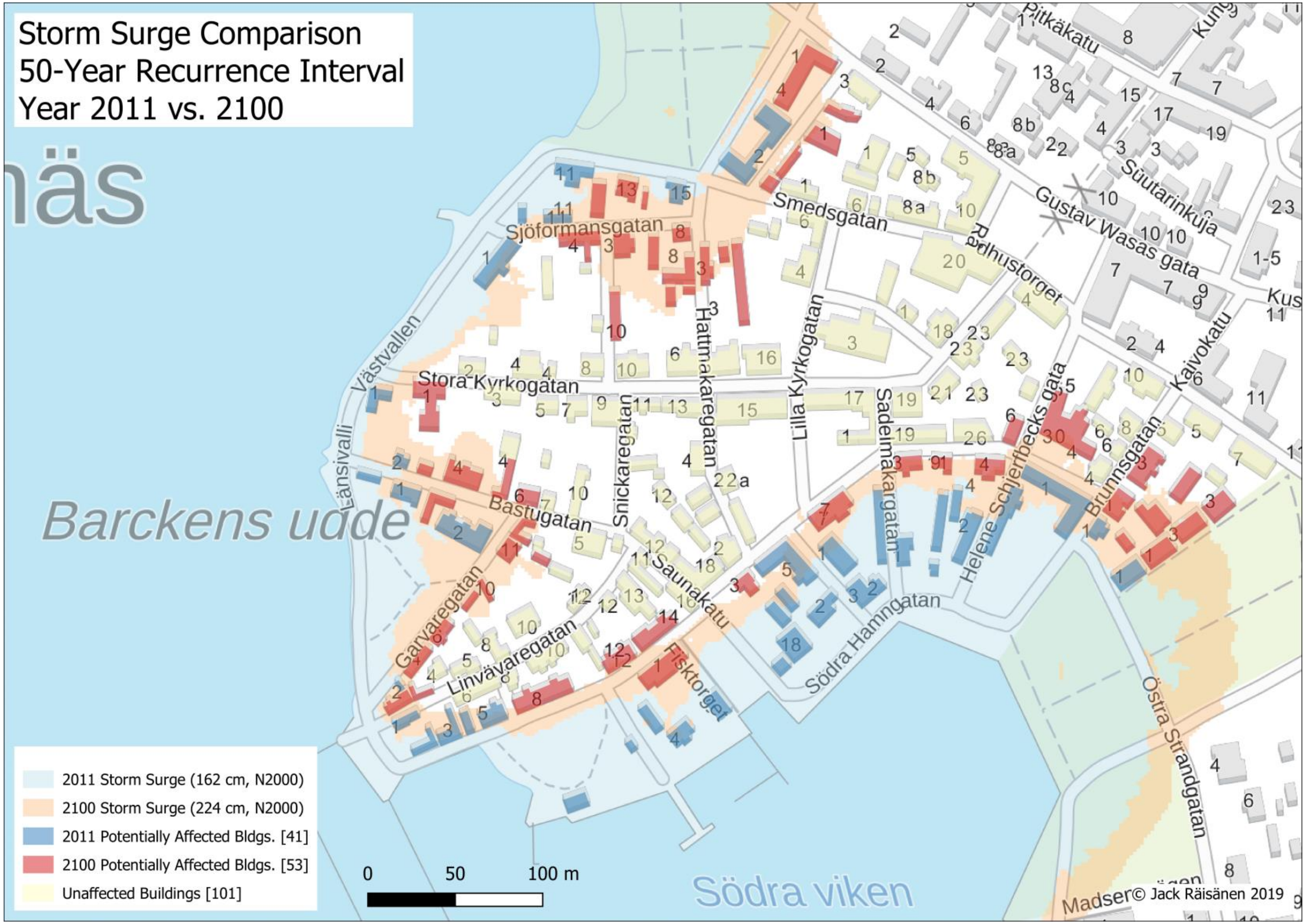
Appendix 7: Year 2011, Extreme Sea Level at the 50-Year Recurrence Interval.



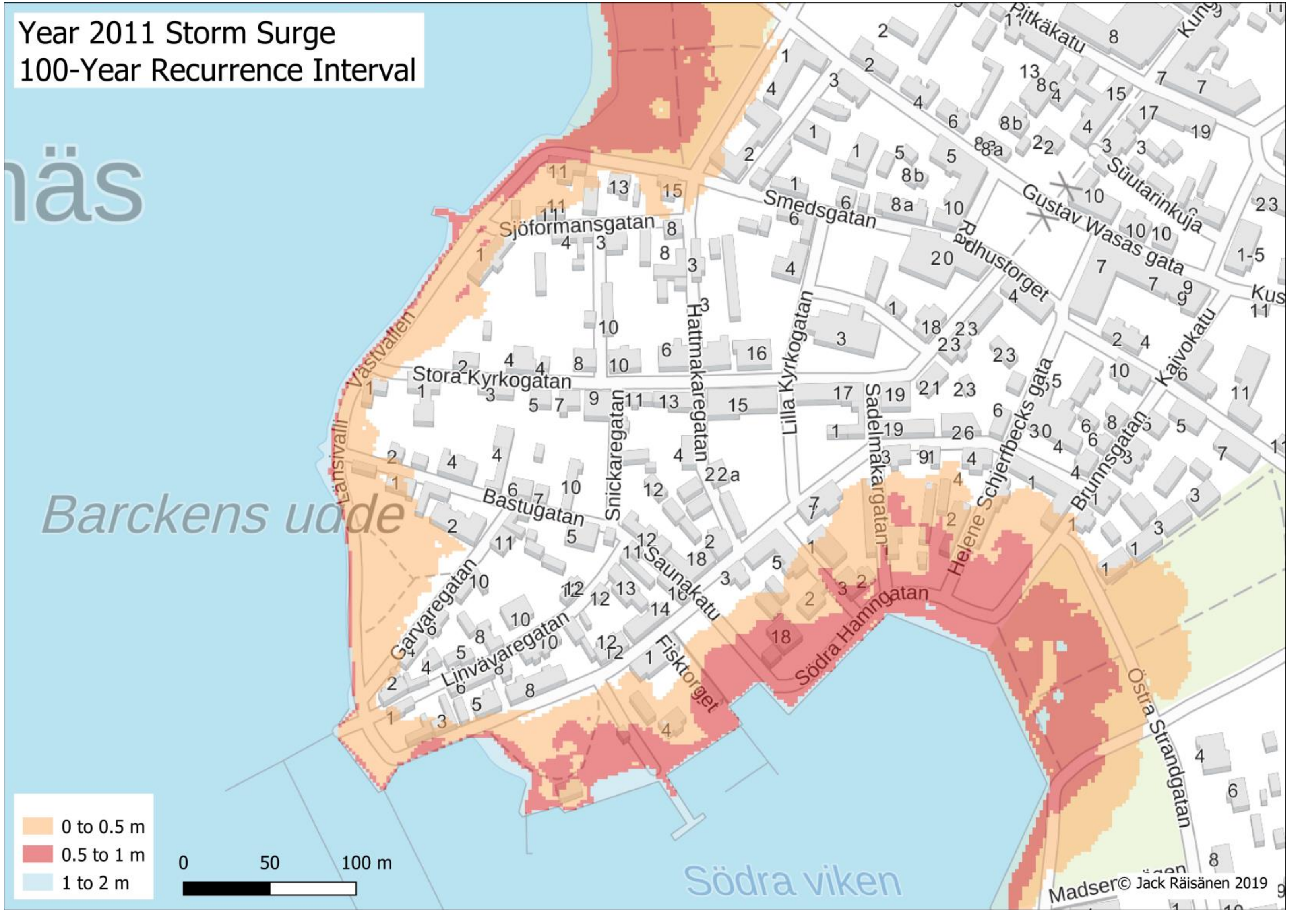
Appendix 8: Year 2100, Extreme Sea Level at the 50-Year Recurrence Interval.



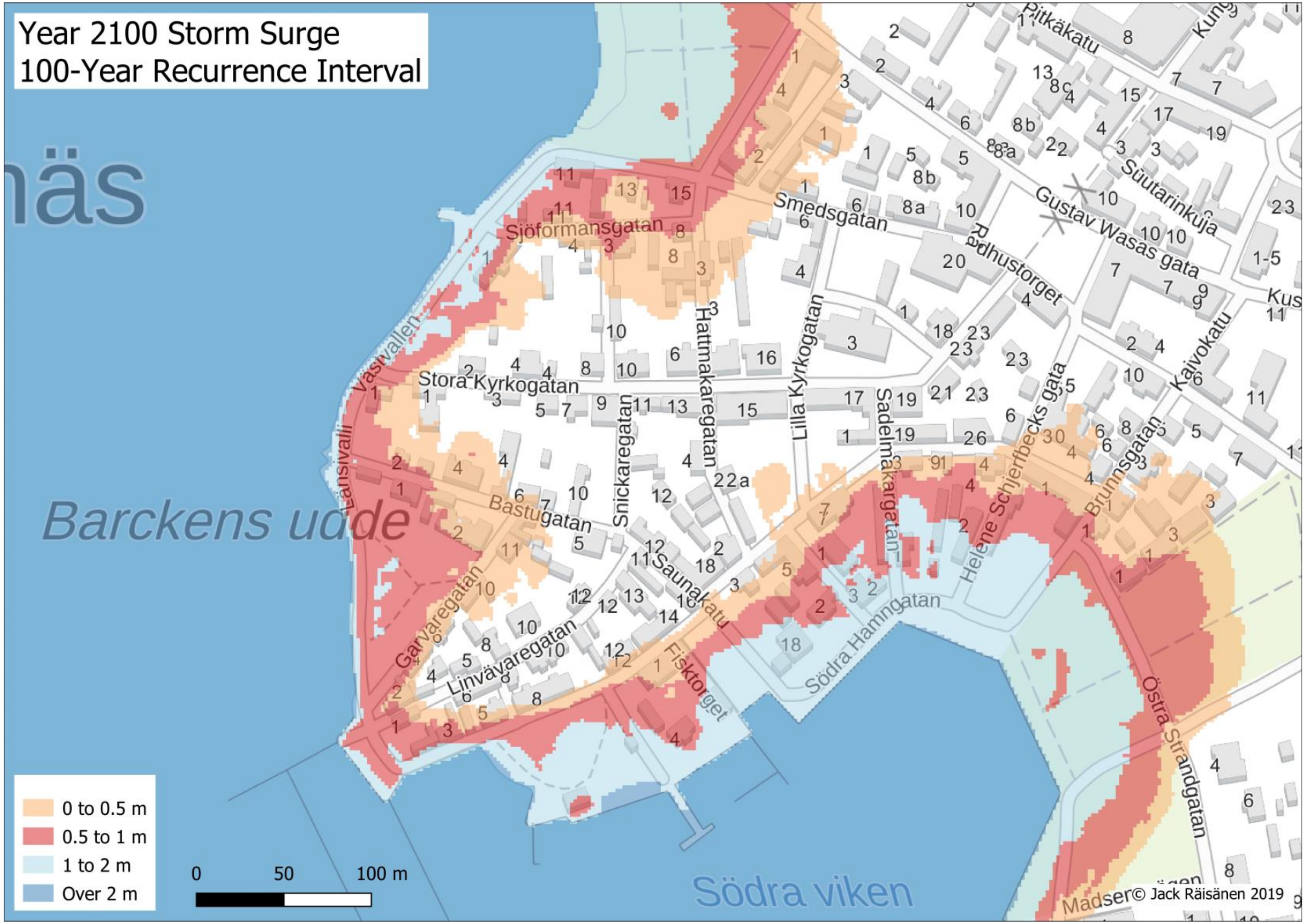
Appendix 9: Extreme Sea Level at the 50-Year Recurrence Interval, 2011 vs. 2100.



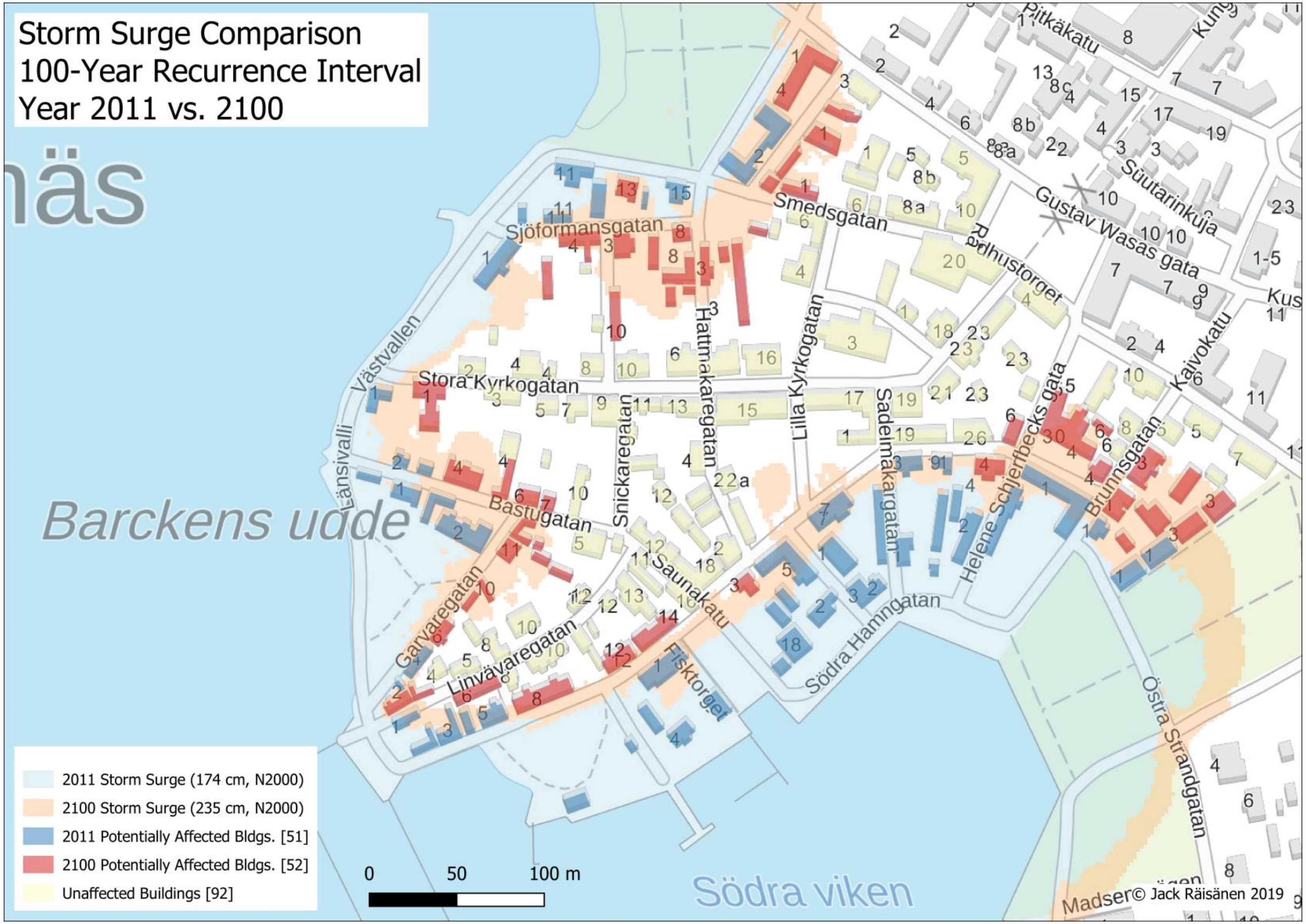
Appendix 10: Year 2011, Extreme Sea Level at the 100-Year Recurrence Interval.



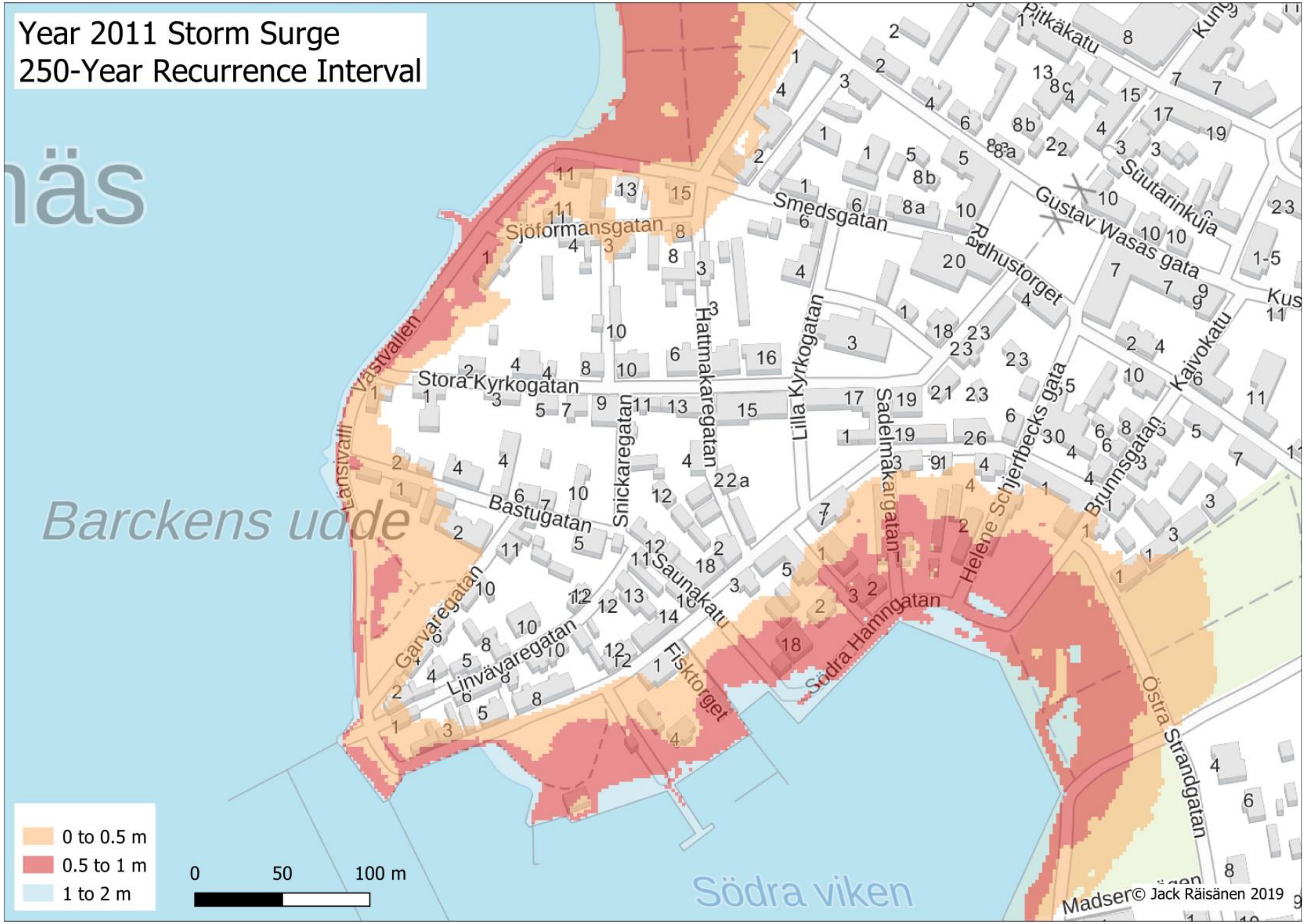
Appendix 11: Year 2100, Extreme Sea Level at the 100-Year Recurrence Interval.



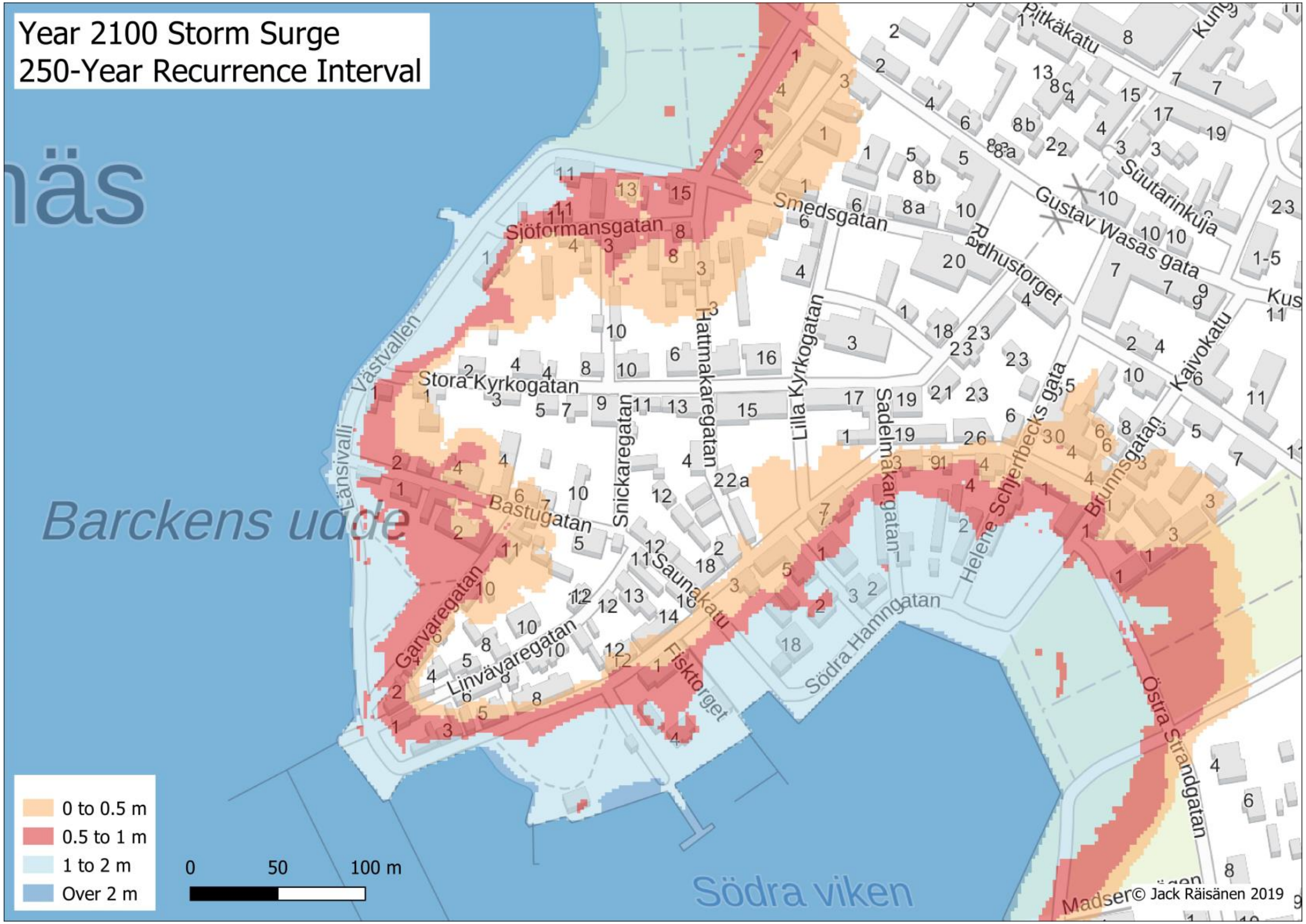
Appendix 12: Extreme Sea Level at the 100-Year Recurrence Interval, 2011 vs. 2100.



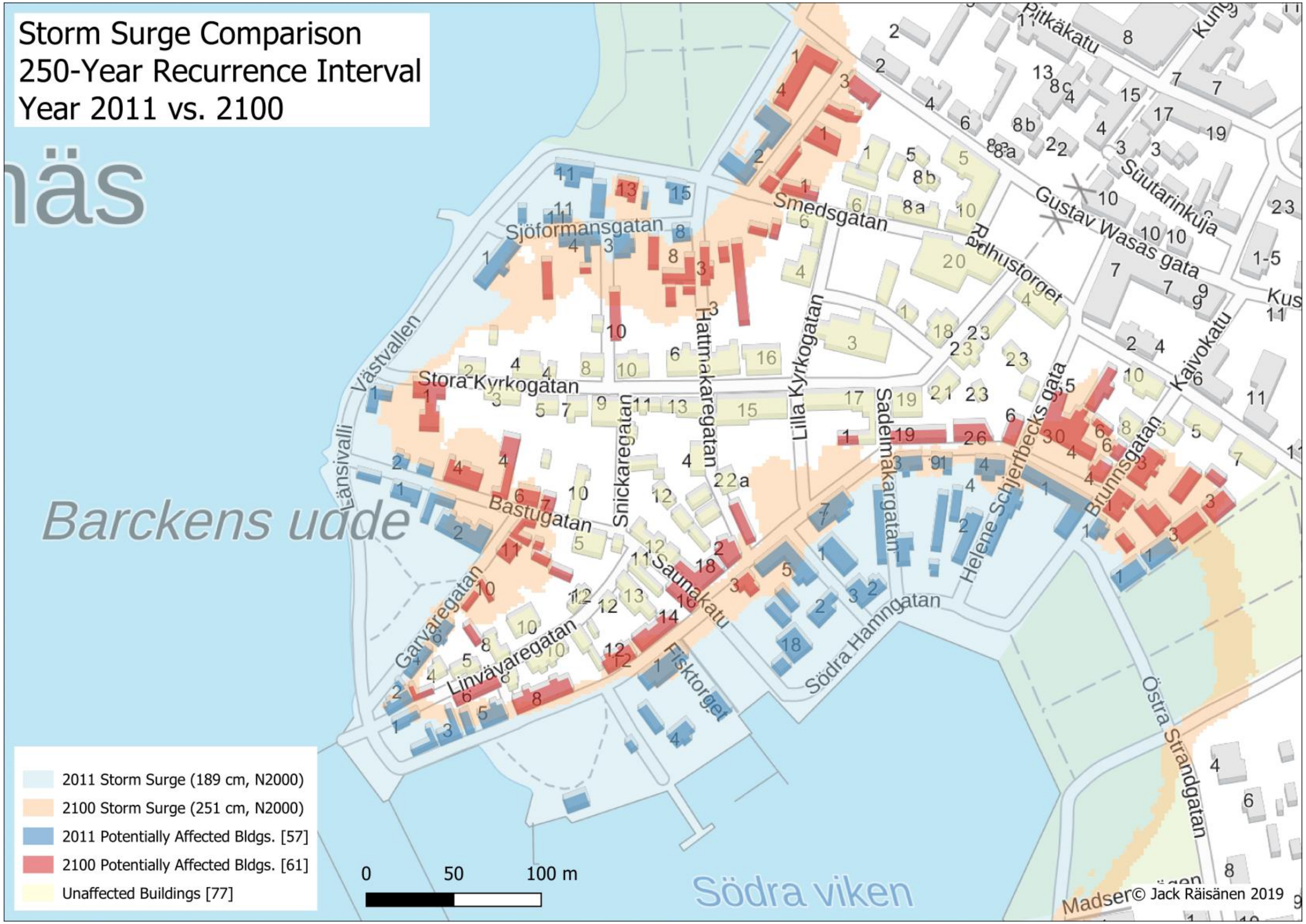
Appendix 13: Year 2011, Extreme Sea Level at the 250-Year Recurrence Interval.



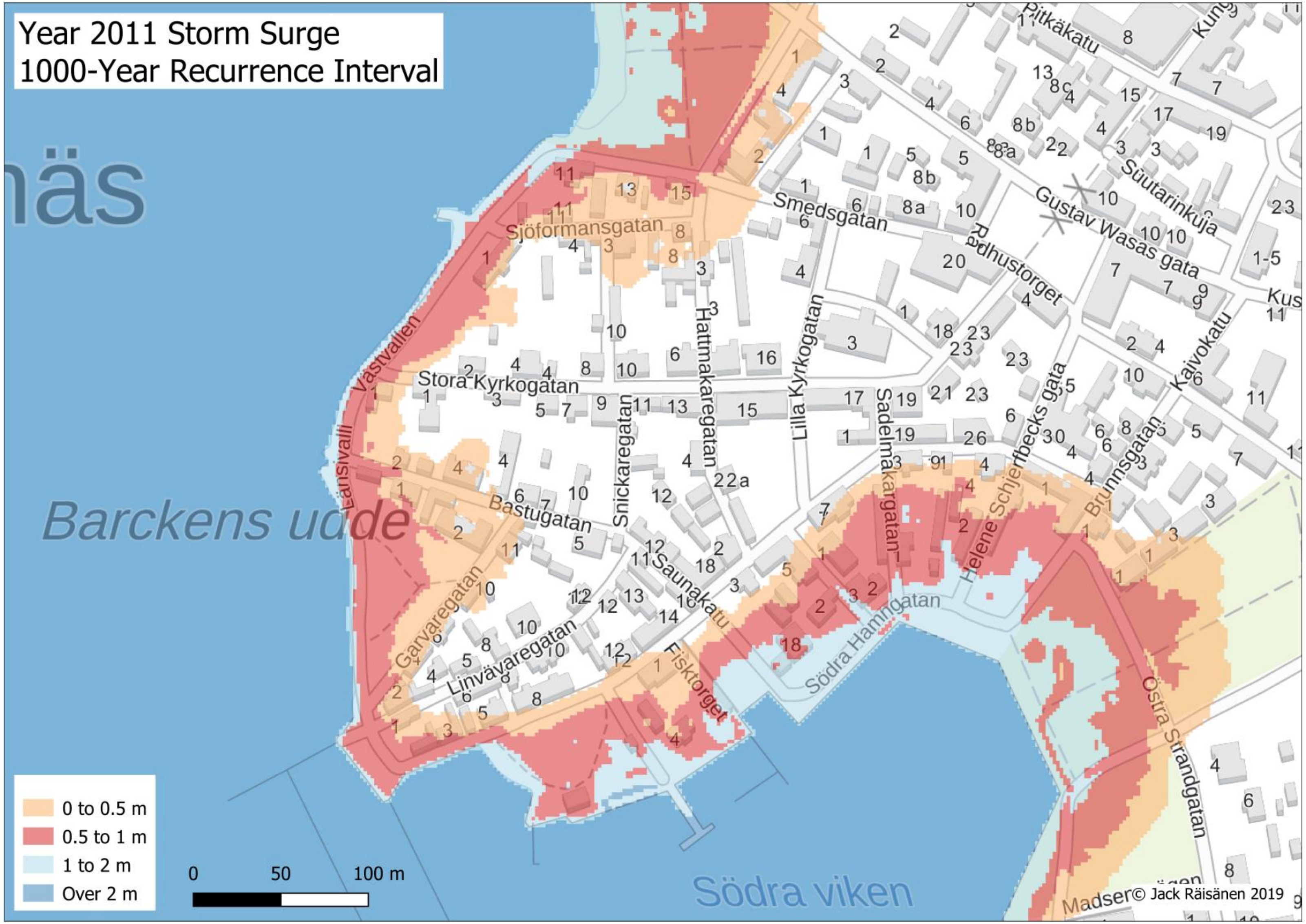
Appendix 14: Year 2100, Extreme Sea Level at the 250-Year Recurrence Interval.



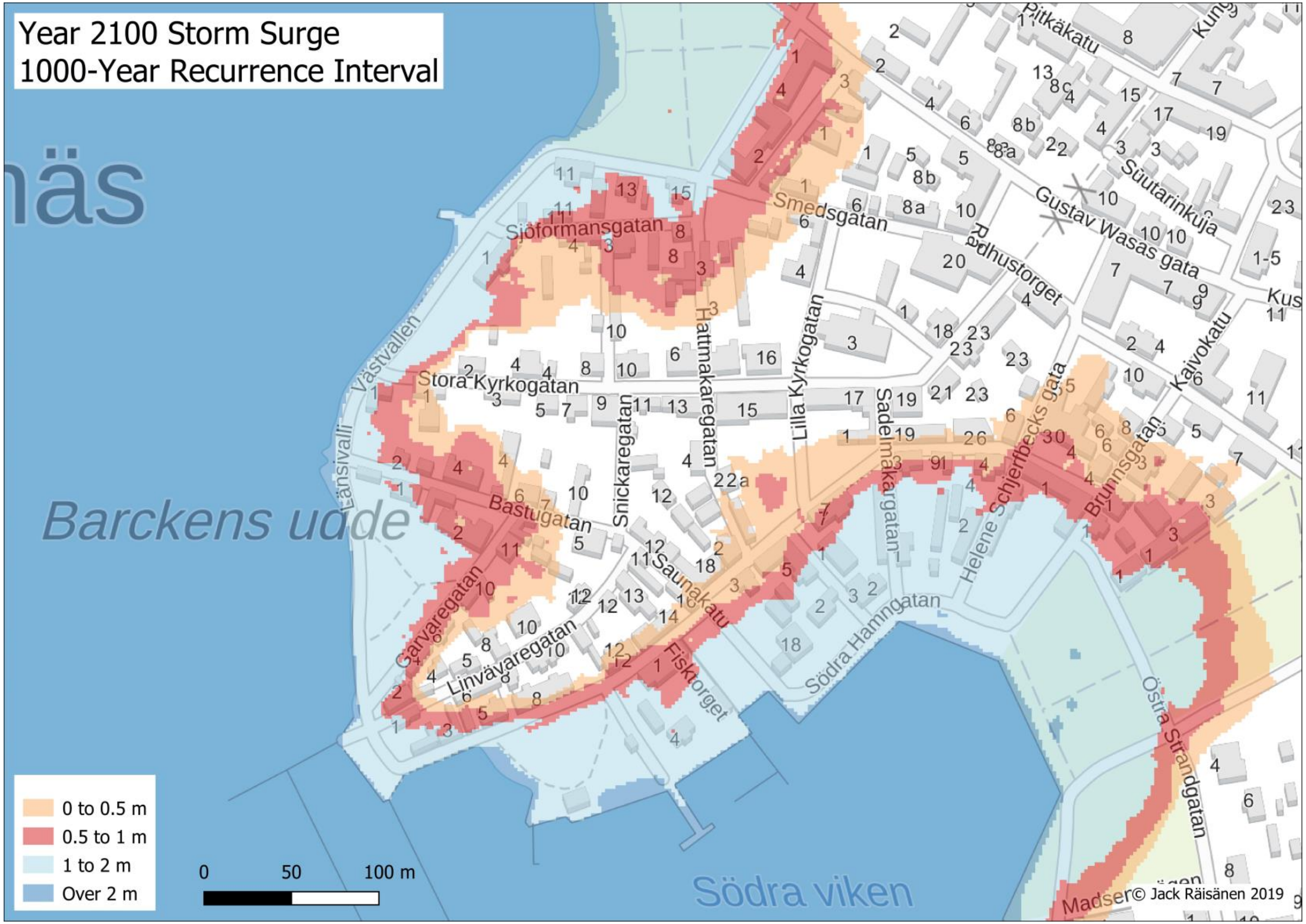
Appendix 15: Extreme Sea Level at the 250-Year Recurrence Interval, 2011 vs. 2100.



Appendix 16: Year 2011, Extreme Sea Level at the 1000-Year Recurrence Interval.



Appendix 17: Year 2100, Extreme Sea Level at the 1000-Year Recurrence Interval.



Appendix 18: Extreme Sea Level at the 1000-Year Recurrence Interval, 2011 vs. 2100.

Appendix 19: Potentially affected buildings by extreme sea level in 2011 compared to 2100.

Table 10: Potentially affected structures, 20-year recurrence interval

Water depth	2011	2100	Change
0 – 0.5 m	26	36	+ 10
0.5 – 1 m	2	32	+ 30
1 – 2 m	0	6	+ 6
over 2 m	-	0	-
Total	28	74	+ 46

Table 11: Potentially affected structures, 50-year recurrence interval

Water depth	2011	2100	Change
0 – 0.5 m	34	43	+ 9
0.5 – 1 m	7	37	+ 30
1 – 2 m	0	14	+ 14
over 2 m	-	0	-
Total	41	94	+ 53

Table 12: Potentially affected structures, 100-year storm surge

Water depth	2011	2100	Change
0 – 0.5 m	37	47	+ 10
0.5 – 1 m	14	34	+ 30
1 – 2 m	0	22	+ 22
over 2 m	-	0	-
Total	51	103	+ 52

Table 13: Potentially affected structures, 250-year storm surge

Water depth	2011	2100	Change
0 – 0.5 m	34	47	+ 13
0.5 – 1 m	23	42	+ 19
1 – 2 m	0	29	+ 29
over 2 m	-	0	-
Total	57	118	+ 61

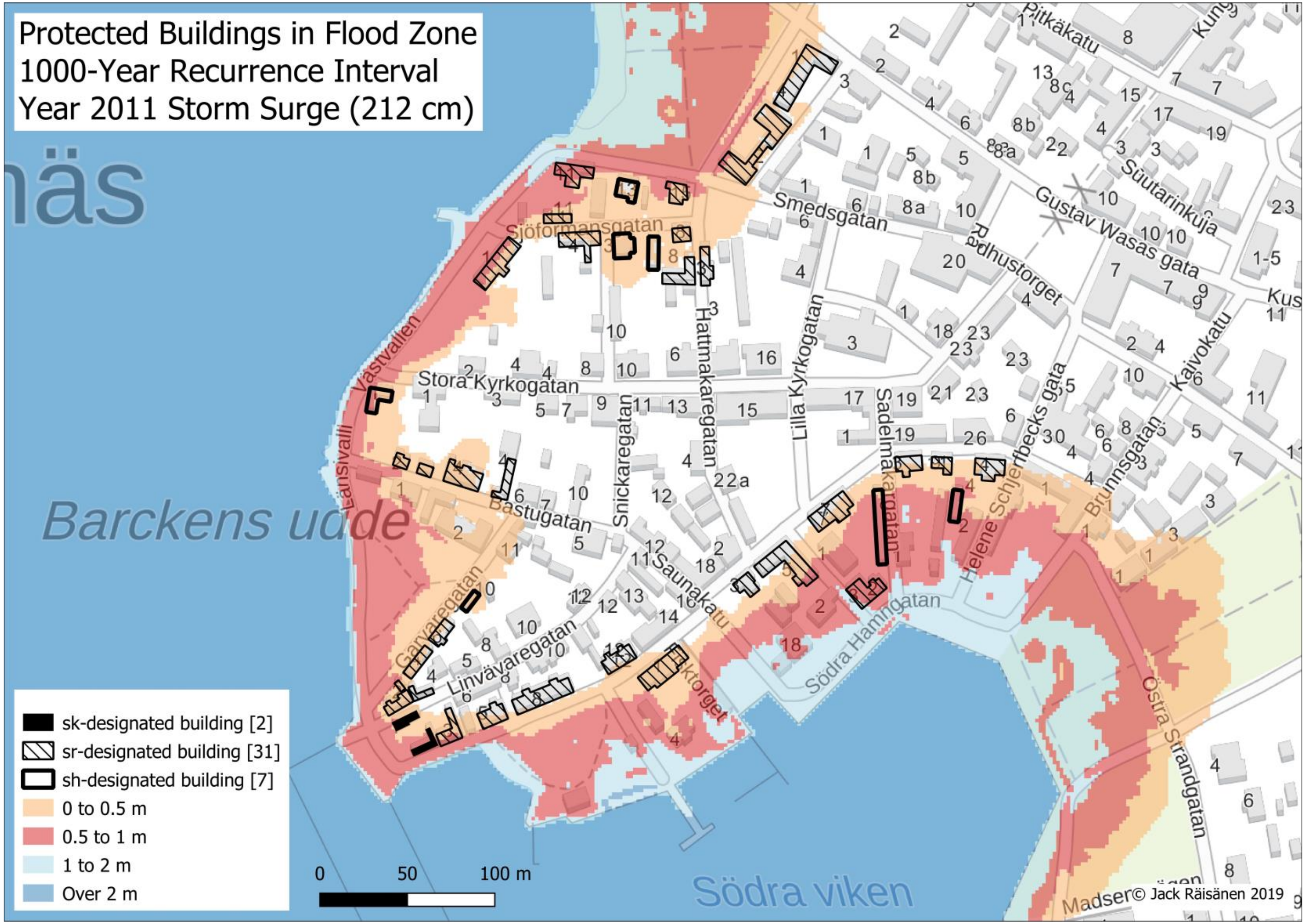
Table 14: Potentially affected structures, 1000-year storm surge

Water depth	2011	2100	Change
0 – 0.5 m	35	36	+ 1
0.5 – 1 m	34	43	+ 9
1 – 2 m	7	51	+ 44
over 2 m	0	0	-
Total	76	130	+ 54

Appendix 20: Flood map of a theoretical high water level of 155 cm (N2000) in Ekenäs Old Town on January 9, 2005.

Appendix 21: Map of the minimum recommended building elevation in Ekenäs Old Town, without a wave reserve.

Appendix 22: Flood map showing protected buildings reached by sea level at the 1000-year recurrence interval in 2011. See Chapter 15.



Appendix 23

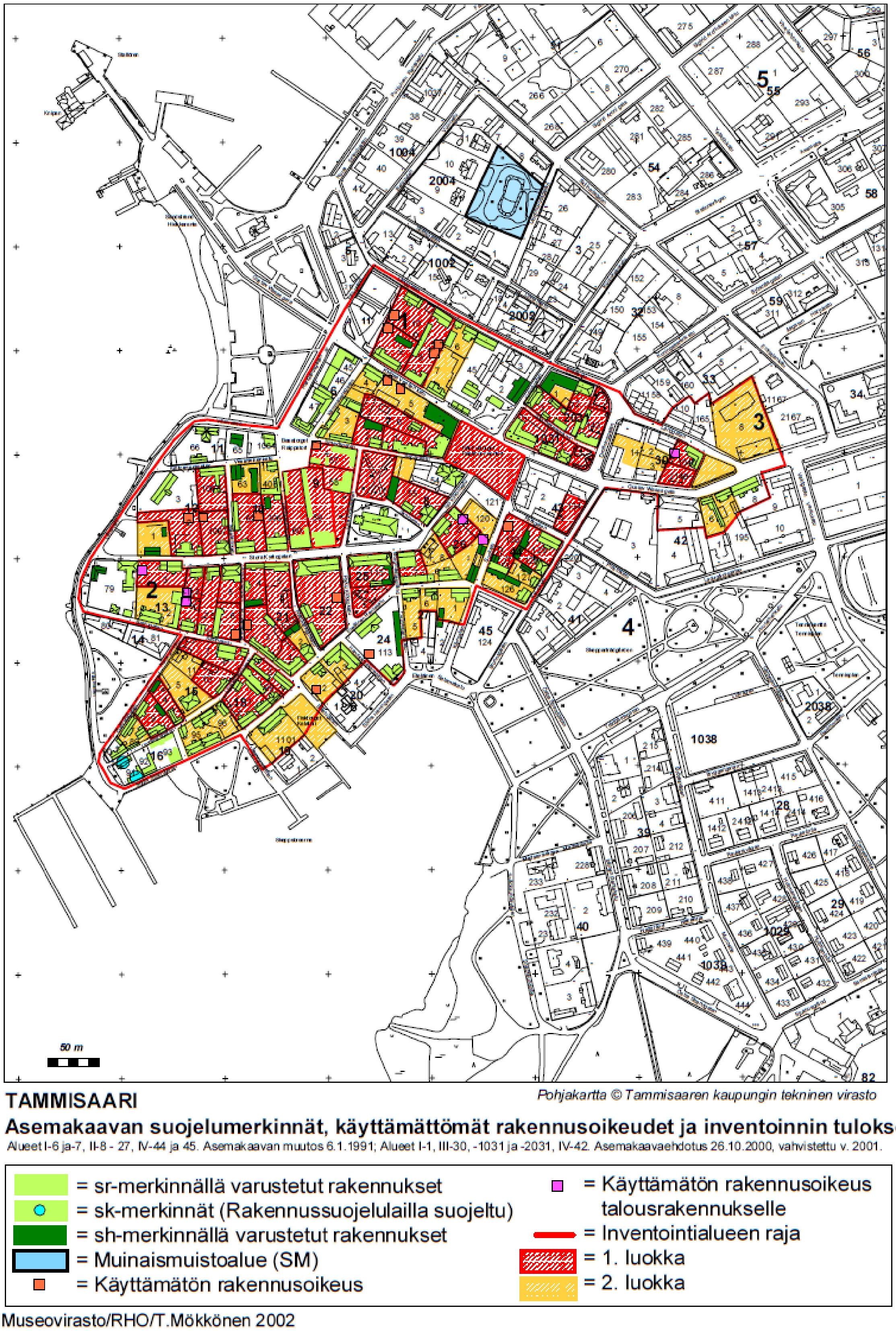
Table 15: Sea level at various recurrence intervals in Hanko, Helsinki, and Ekenäs in 2010, 2050, and 2100.

Recur. Interval	Hanko (cm, N2000)			Helsinki (cm, N2000)			**Ekenäs (cm, N2000)**		
	2010	2050	2100	2010	2050	2100	2010	2050	2100
20-year	134	142	200	159	168	225	140	149	206
50-year	146	154	217	174	183	243	153	161	224
100-year	155	163	229	185	194	256	163	171	236

Data for sea levels in Hanko and Helsinki comes from Pellikka *et al.* (2018). Sea levels in Ekenäs are a linear interpolation of the Hanko and Helsinki sea levels.

Appendix 24: Mökkönen's (2002) map of protection designations in plan and archeological inventory results from Ekenäs Old Town. Areas in red are categorized "Class 1": Preserved areas. Of great interest for research and valuable areas for protection. Areas in orange are categorized "Class 2": likely preserved or only partially destroyed areas. Of interest for research and valuable areas for protection. (Mökkönen, 2002).

Map used with the written permission of Teemu Mökkönen.



Appendix 25: Power distribution box near Västvallen Road. Photo by: © Jack Räisänen. Photo taken on May 15, 2019.

Appendix 26: A view from the southwest of the protected buildings at Linvävaregatan Street 1. Photo by: © Anna Björklund.

Appendix 27: Ekenäs Old Town is home to many old and well-cared for wooden homes. Photo by: © Anna Björklund.

Appendix 28: A view of Linvävaregatan Street from Café Gamla Stan.
Photo by: © Anna Björklund.

Appendix 29: Bio Forum, located on Helene Schjerfbeck Street in Ekenäs Old Town, is one of Finland’s oldest movie theaters. Old combines with new in some parts of the Old Town.

Photo by: © Anna Björklund.

Appendix 30: Beautiful nature is close to Ekenäs Old Town. Respect and protection of the environment will be needed when considering flood protection measures.

Photo by: © Anna Björklund.