Release the Kvarken

A study about land uplift

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Abstract

Svedjehamn is located in the World Heritage Site of Kvarken archipelago on the Finish side of the Gulf of Bothnia. This area is where the land uplift is the fastest in the entire world and it have been going on since the last ice age when the glacial maximum was around 3000 meters pushing down the crust of the earth. The archipelago of Kvarken is generally shallow with a depth between 0-25 meters which makes the post-glacial rebound even more prominent. Every year 100 hectares of land is rising up from the sea, changing the landscape of Kvarken. The focus in this study is to see how the landscape are changing at the popular tourist destination Svedjehamn. The town is central in the World Heritage Site and have an observation tower so the visitors can look out over the archipelago. The land uplift at Svedjehamn in this study is set according to the average of the NKG2016Lu model at 7.615mm per year this is then visualized in ArcGIS pro with the help of a Digital Elevation Model. The land uplift is modeled four times with an interval of 100 years so that the visualization of how Svedjehamn may change in the future.

**Keywords:** Kvarken Archipelago, Land uplift, GIS, World Heritage Site, post-glacial rebound.
1. Introduction

Kvarken archipelago is located in the Baltic Sea which is the second largest brackish water body in Europe (Kotialinen et al. 2012). Kvarken area is the narrowest part of Bothnia and since the Kvarken Archipelago is relatively shallow 0-25 meter (Berilin et. al. 2005; Poutanen & Steffen, 2015; Tikkanen & Oksanen, 2002) it will get affected greatly by the land uplift phenomenon and it will change the landscape dramatically.

Since Finland ratified the World Heritage convention in 1987 they have obtained seven World Heritage Sites where as six of them are cultural sites, which is the most common type of World Heritage (Svels, 2011). In 2006 UNESCO decided to list Kvarken Archipelago as one of their world natural heritage sites together with the High Coast on the Swedish side. It is the only natural world heritage site in Finland and it is one of only 46 marine world heritage sites in the world (Kvarkenworldheritage, N.D.). Kvarken Archipelago is covered by more than 5,600 islands that feature unusual washboard moraines called ‘De Geer moraines’. They were formed when the ice sheet began to melt in the end of the last glacial period (UNESCO, N.D.).

Kvarken archipelago is an attractive destination for tourist and it is estimated that 338,000 visits are made each year (Meriruoho, 2011). UNESCO (N.D.) states Kvarken archipelago is an important destination to preserve since the isostatic uplift in the area is the highest uplift in the world and it offers the visitors a unique costal landscape. Isostatic uplift is when the crust of the earth are rising back up from when it was pushed down from the ice (Vuorela et al. 2009). The land uplift makes it so that the Kvarken Archipelagos landmass grows with approximately 1 km² per year, or about 100 hectares. This will create new moraine islands every year and constantly change the landscape (Kvarken, N.D.a).
The last glacial period covered Nordic countries in a thick ice sheet that had a glacial maximum of about 3000 meters (Poutanen & Steffen, 2015). The weight of the ice pushed the crust of the earth down by 500-900 meters and at Kvarken archipelago the ice started to melt around 18 000 years ago, which led to the most notable geodynamic process known as the land uplift (Berglund, 2004). When the ice melted it caused an elastic rebound in the area that is unmatched elsewhere and in the first 8000 years the land uplift was 300 meters (Poutanen & Steffen, 2015). It has since slowed down and now the apparent land uplift is calculated to be 8-8.5 mm a year around the Kvarken archipelago (Kotilainen & Kaskela, 2012). The apparent land uplift is taking the current rate of sea level rise into account which is about 3mm per year (Bindoff et al. 2007). If the land uplift were to continue at its current rate, a land bridge would be formed connecting Sweden and Finland in the next 2000-2500 years (Breilin et. al. 2005). This would turn the Bothnian bay into the largest freshwater lake in Europe.

Another reason why the land uplift phenomenon is so interesting in the Baltic Sea, is that it is almost free from astronomical tides so it easier for the visitors to see the change of the water level (Lambeck et al. 1998). Since there is almost no tide it does not matter what time of the day the visitors will be at Kvarken archipelago because it will not affect the phenomenon.

One of the most important places to visit when seeing Kvarken archipelago is the town of Svedjehamn which is located on the island of Björköby in the northern parts of the World Heritage Site. Svedjehamn have an observation tower that is called Saltkaret, which is a 20 meter tower that offers a good view of the De Geer moraines as well a view of the lake Bodvattnet. There is an also a popular nature trail that goes alongside the lake and towards the coast where the visitor can see the unique landscape. Svedjehamn offers different boat tours for the visitors in the summers as
well as a museum and café in the old fishing building Salteriet. Every second year there is a competition that attracts many visitors to the area that is called “Postrodden” which celebrates the old postal route between the Svedjehamn, Björköby in Finland and Holmön outside of Umeå in Sweden (Kvarkenworldheritage, N.D.).

2. Aim and research questions

The aim of this study is to better understand the geological phenomenon of land uplift in the area around Svedjehamn and to see how the area might get affected in the future. To do this, three question will be answered:

How does the area around Svedjehamn get affected by the land uplift over the next several hundreds of years?

How will recreation and tourism sites be affected by the geological transformation?

Will the changing sea level and other human induced factors affect the land uplift phenomenon?
3. Previous studies

Land uplift

The postglacial rebound or land uplift have been studied scientifically in Fennoscandia for almost 300 years and the first determination of the uplift was done by Celsius (1743). Celsius (1743) measured the height of abandoned seal rocks and was able to calculate that the land was rising about 1cm per year. But at the time the consensus was that the sea levels where declining. Nordenskiöld (1858) started to record more accurate calculation of the land uplift but the first map of the phenomenon was not created until the 20th century by Blomqvist and Renqvist (1914) with the help of records of the changing levels of the sea along the Baltic coasts. More recently Ekman (1996) set out to map the land uplift with the help of 56 stations around the Baltic Sea. The sea level records were measured for at least 60 years with some stations like Stockholm that had measures from as early as 200 years ago. Ekman’s (1996) study concluded that the land uplift at Vasa was 7.53 mm per year.

The phenomenon is fast enough to make it possible to see changes in the landscape during one generation so that visitors to the World Heritage Site will see a different landscape every time they visit Kvarken. The land uplift is occurring throughout Fennoscandia and at Kvarken Archipelago the rate of the uplift is around 8mm per year (Poutanen & Steffen, 2015). NGK2016LU (2016) is the official land uplift model used in the Baltic countries to calculate land uplift. The land uplift at Svedjehamn in Kvarken is according to the NGK2016LU model an average of 7.62mm per year. Poutanen & Steffen (2015) further state that the land has risen over 300 meters since the last glacial maximum and it is expected that it will continue to rise another 90-130 meters in the next 2000-3000 years.
Kvarken archipelago is covered with De Geer Moraines which have the characteristics of narrow mountain ridges that were formed when the ice sheet moved along the landscape. According to Berilin et al. (2005) the De Geer Moraines are most commonly a couple of hundred of meters long with a height of 5 meters and width of 10-50 meters and they occur at 50-300 meter intervals across the landscape. These moraines have formed thousands of island in Kvarken as the land uplift brings them up above the surface of the water.

The land uplift also creates some other distinct features in the landscape such as the flads and gloe lakes (Kvarkenworldheritage, N.D.). This happened when the descending sea level and advancing shorelines due to the land uplift create small basins that trap the water. Over time the salinity of these water basins drops and they become freshwater ponds and eventually they will dry up and disappear unless they can collect enough rain water. Other phenomena’s are scratching on rocks and mountains that shows the direction of the movements of the ice sheets (Kvarken, N.D.a).

The land uplift phenomenon has been studied by Berilin et al. (2005); Poutanen & Steffen, (2015); Tikkanen & Oksanen, (2002) before, but they all had a bigger scope looking at the whole Fennoscandia area over thousands of years or had their focus on just the geological processes. Even though the land uplift is as strong in the Swedish High Coast it is less prominent since the coast line is much steeper and the ocean is deeper than it is in Kvarken. This adds up to the uniqueness of the World Heritage Site with shallow planes at Kvarken archipelago.
Recreation and Tourism

Tourism have been stated to be the single most important industry in the world and it have been calculated that tourism could stand for 9.9 percent of the global GDP (Holloway et al. 2009, p. 86). Hall (2015) states that World Heritage Sites have a significance for tourism development and that tourism can provide a justification for conserving heritage while other economic activities could have a negative impact on the site. Tourism contributes to both positive and negative externalities. Positive ones are i.e. more income to the people in the area because of the increased number of visitors and negative ones can be pollution of the area. Physical pollution of tourist destination poses a growing threat for the global tourism industry, where heavily traveled roads and paths will be affected by erosion (Holloway et al. 2009, p. 137-151).

According to the Ministry of Economic Affairs and Employment of Finland (N.D.) tourism has become more important for the Finnish economy in the recent years. With a revenue of EUR 15 billion in 2017 and providing employment for more than 140,000 people, which is over 5 percent of all the employed people in Finland. Since Finland has a quite small population with 5.5 million inhabitant tourism plays a big part, especially in the rural areas (Statistics Finland, 2019). According to World Travel & Tourism Council (2018) the total contribution of tourism in Finland provided 230,000 jobs which would be equal to 9.1 percent of all the employed in Finland. Their estimation is that it will grow to almost 300,000 people or 11.4 percent of the population by the year 2028.

One of the main strategies in developing rural areas in Finland is to focus on the development of tourism (Svels, 2011; Pouta et al. 2006). Svels (2011) further states that rural tourism generally has a focus on the natural surroundings and experiences like forest, lakes and wilderness. About 40
percent of the population in Finland is participating in nature tourism every year and it has been found that socio-economic status and urban residence are relevant factors for the high number (Pouta et al. 2006). Second home tourism have become a bigger role in the leisure lifestyle in Finland and other parts of the developed world (Hiltunen, 2007). Hiltunen (2007) further states that the primary motive for second home tourism is the search for wellbeing and to experience nature. Nature-protected areas are according to Butler et al. (1998) an important resource for regional development and tourism. In Kvarken about 60 percent is part of national conservation programs such as the Natura 2000, which protects the animals, plants and the geological formation within the World Heritage site (Kvarkenworldheritage, N.D.). There are around 10,000 second homes within Kvarken archipelago (Svels, 2011).

World Heritage Sites often become tourist attractions which provides outdoor recreation. Visitors that come to the area will not only spend their money at the destination itself but also bring economic opportunities to the local economies outside of the destination (Selby et al. 2011). There are many different factors in life that can be stressful, it can be the fast pace of a person’s daily life, family or financial stress. Nature based recreation and activities can reduce stress and help some people who suffers from depression or anxiety to get an overall better quality of life (Kerr et al. 2012).

World Heritage Sites are considered to be special tourist destination in their own right (Becken & Job, 2014; Svels, 2015). World Heritage Sites are therefore global attractions for tourist as well as good for the local population and offers protection to the natural areas (Hall et al. 2002). According to a survey done by Svels (2015) the residents in the Kvarken area have a positive view when it comes to tourism.
The United Nations World Tourism Organization or in short UNWTO (2008) stated that the tourism industry is responsible for 5 percent of the global CO$_2$ emissions. So even if tourism can be seen as a good way to bring income to protected areas like World Heritage Sites it still contributes to the climate change that could affect the destination negatively in the future. Tourism at these destinations can be seen as a double-edged sword the money that tourism brings to the area might help to with conservation projects to preserve it for the future but on the other hand it might lead to human induced sea level rise.

**Sea level rise and human induced factors**

The coastal areas around the world are according to Kotilainen (2017) increasingly stressed by human activities. The wind conditions will change and there will be a decrease of the ice coverage in the future. This leads to costal erosion and the changing climate might create more storms that have a big impact on the shallower areas in the Baltic Sea like Kvarken (Climateguide, 2013).

According to Bindoff et al. (2007) the current global sea level rise is about 3 mm per year. When the glaciers and ice sheets are melting it causes the sea level to rise and the warming of the oceans is causing thermal expansion which also change the global sea level to rise. The global sea level rise is however uneven since the thermal expansion of the sea water can vary depending on the location. The large masses of ice have an gravitational effect and pulls the sea water towards itself but when the ice sheets and glaciers melts the gravitational effects weaken and the sea water gets pushed away from the melting ice (Mitrovica et al. 2001). Further Mitrovica et al. (2001) states that the melting of the ice sheets at Greenland will not raise the sea levels in the Baltic Sea but instead push the melt water further south. There is however chances that the Baltic Sea
will get affected more by the melting of the Antarctic ice sheet. According to Johansson et al. (2012) the Baltic Sea is estimated to get slightly less affected by the sea level compared to the global levels. With the current land uplift rates, the northern parts of the Baltic Sea and the area around Kvarken will still overcome the sea level rise. Johansson et al. (2012) states that new land will still continue to form even though it might slow down in the next century and according to their study the most probable outcome in Vasa still predicts a 30 cm sea level decline till the year 2100 (see table 1). The highest scenario is that the sea level will rise 22 cm until 2100 while the lower scenario predicts a sea level decline of 72 cm (Johansson et al. 2012).

Table 1: Sea level change in cm 2000-2100. Source: Johansson et al. (2012).

<table>
<thead>
<tr>
<th>Tide gauge</th>
<th>Low</th>
<th>Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kemi</td>
<td>-69</td>
<td>-26</td>
<td>25</td>
</tr>
<tr>
<td>Oulu</td>
<td>-69</td>
<td>-24</td>
<td>28</td>
</tr>
<tr>
<td>Raahe</td>
<td>-69</td>
<td>-27</td>
<td>25</td>
</tr>
<tr>
<td>Pietarsaari</td>
<td>-70</td>
<td>-28</td>
<td>24</td>
</tr>
<tr>
<td>Vaasa</td>
<td>-72</td>
<td>-30</td>
<td>22</td>
</tr>
</tbody>
</table>

According to Vuorela et al. (2009) the land uplift is even faster in shallow areas like the Kvarken Archipelago since there is lots of vegetation like the common reed that build up organic material. The pace of the organic material build up has increased since the amount of grazing animals has decreased and the eutrophication of the coastal areas has become higher. Rivers and streams carry organic materials from farms and plantation and it gets deposited at the shores. Another consequence of the land uplifting is that some river flows start to slow down which in turn may cause floods to the rivers inland at lower lying lands (Vuorela et al. 2009).
4. The study area

As seen in figure 1 Kvarken World Heritage Site is located on the west coast of Finland close to the city of Vasa. The Kvarken area is where the Gulf of Bothnia is the narrowest and there is ferries that goes from the city of Umeå in Sweden to the city of Vasa in Finland. The heritage site of Kvarken is part of the World Heritage Site that is shared with the High Coast in Sweden and it is often referred to as the low coast (Kvarken, N.D.b).
In figure 2 the study area of Svedjehamn is highlighted with a red square and in the top left map the area is visible in a zoomed in map. In this figure it make it clear that the World Heritage Site does not cover all of the islands in the archipelago and instead it is split up into two different areas. One bigger to the northeast, where the study area is located and one smaller to the southwest on the map.

Figure 2: Overview map of where the focus area is located within the World Heritage Site. Source: Background map from ArcGIS pro.
Kvarken Archipelago covers five municipalities in Finland and these are: Vörå, Korsholm, Vasa, Malax and Korsnäs. 94 percent of the land and 57.5 percent of the water is privately owned which could make the management of the heritage site more complex than if the whole area would be public owned (Kvarken, N.D.c). On a national level the ministry of the environment is in charge and when it comes to the regional level the Metsähallitus (Forestry Board) is in charge. They have put together a committee that has 29 local actors and people from the public that could be part of how the park should evolve in the future (Kvarken, N.D.c). The organization World Heritage Kvarken r.f. is in charge of coordinating the information and marketing of Kvarken and they have info centers in all five municipalities. Their main focus is to inform the visitors about the heritage site and what the geological phenomenon is about (Kvarken, N.D.c).

Figure 3: Overview map of the municipalities that are covered by the World Heritage Site. Source: Background map from ArcGIS pro.
As seen in figure 4 most of the area at Svedjehamn consists of forests with one bigger lake that is called Bodvattnet and eight smaller gloe and flad lakes. There is a dock that is located in the northwest corner of the map that hosts smaller boats and fishing buildings along the shores. There is one major road leading to and from the dock and on the sides of that road are some houses and second homes. The bay at Svedjehamn is covered with De Geer moraines which have created lots of smaller and some bigger islands. It is also possible to see that the way in and out from the docks have been dredged so that boats can access them easier. There is also some areas at the islands where it is possible to see that they have dredged channels so that boat traffic can get passed. The most obvious places are across the big island to the west of the docks quite close to the main land and in the northwest corner of the map.

Figure 4: Orthophoto of Svedjehamn in Kvarken archipelago. Source: Orthophoto from Maanmittauslaitos (2010).
Figure 5 shows the study area with a Coordination of Information on the Environment (CORINE) land use map where some of the features are easier to make out compared to the orthophoto in figure 4. There are for instance some summer cottages or second homes located along the lake of Bodvattnet which are more visible here. As stated before most of the study area is covered in forest and in this map it is possible to see what kind of forests. The houses are mapped as continues urban fabric and are the red colored square.
5. Methodology

The first step was to localize and download the data from the various sources. Then some features had to be digitized and some had to be clipped to fit the study area. There were some images that had to get georeferenced since they lacked spatial information. To get the outline of the World Heritage Site of Kvarken archipelago a picture from Kvarkenworldheritage (N.D.) was imported into ArcGIS Pro. Then the Georeference tool was used by adding 10 control point to the image and match them up with the base map in ArcGIS Pro. When the image was in the right place a new feature was created and a polygon was traced upon the image to create the new boundary for the World Heritage Site. This was then used to show where the World Heritage Site are located on the Finish coast.

The road network data was downloaded from Digiroads (2019) which is administered by the Finish Transport Agency. The roads got categorized in the way that all the major roads got one colored (black) and the nature paths and trails got dashed lines (black) as a symbology. This makes it easy to distinguish where the nature path around Bodvattnet is located.

Then the coordinate system that was used throughout the study was the official Finish coordinate system ETRS-TM35FIN and for the z-coordinate system the N2000 was used.

The overview map of the municipalities was done by using data from Maanmittauslaitos (2011). The data of the municipalities in Finland were modified in ArcGIS Pro by selecting only the five municipalities that were covering the World Heritage Site of Kvarken. The data had to be projected so that it had the right coordinate system. The municipalities were made into their own feature class and then they got labeled so that it would make it easier for the reader to see which municipality it was. The difficulty was
here that the municipalities in this area of Finland are not just five consistent areas. For example the municipality of Vasa is split into two major areas where the municipality of Korsholm runs through it. The municipality of Vasa does also have some smaller areas inside the borders of Korsholm municipality, most of them seems to be some sort of power plants or have something to do with the infrastructure but it made the labeling difficult. So to not make the maps cluttered the labels were converted into annotations so that they could be place manually inside the municipalities. Then it was possible to take away the labels for the smaller areas that were part of another municipality and only place labels inside the bigger areas. When this was done the map got exported into Photoshop so the area within the municipalities could be enhanced more with the help of the masking tools available in Photoshop. There after a border got added around the municipalities so they would stick out even more and the focus area world be clearer for the reader to see. Photoshop was also used in the creation of the other maps but then they only got a mask to change the brightness or saturation.

The data for the CORINE land use was downloaded from Syke (2019) and clipped to fit the study area. To create the overview maps of the study area the base map in ArcGIS Pro was used then two map frames for each map was used with an overview and a zoomed in map to highlight were the focus of the study would be. To make it even clearer a red square was added around the area that got zoomed in as well as marking out the World Heritage Site with the feature that had previously been created. Here the digitized area of the World Heritage Site was used as well to enrich the maps.

Historical maps where gathered from Maanmittauslaitos (N.D.) these maps were for the year 1970, 1988. The maps came in squares that covered 12 000 x 12 000 meters so to cover the study area one square of each year
were needed because the study area is only 2500 x 2500 meters. After the data was downloaded it was imported into ArcGIS Pro were they had to be projected into the right coordinate system but they still ended up in the wrong spatial location. To fix this the images had to be georeferenced in ArcGIS Pro and this was done by creating control points with the help on some feature that had not changed over the last 50 years which were tricky since the land uplift had change the landscape during these years so lakes and rivers could not be used as control points. The historical maps were referenced against the orthophoto from 2010 to see what features seemed to be in the same place still and then the bigger roads where picked for the control points. So by adding five to ten control points in each image it was possible to get them to the right location. The transformation that was used to do the referencing was 2nd order polynomial which uses 6 terms of correction. These are; Cartesian axes, scaling of the axes, rotation, obliquity, convexity in both axes and torsion (Mohammed et al. 2013).

There are different kinds of land uplift models empirical, geophysical and glacial isostatic adjustment. The empirical land uplift model are using observation and using mathematical methods to create the model. The geophysical and glacial isostatic adjustment models takes the historical ice melting into account when creating the model. The model used for this study is the semi-empirical land uplift model NKG2016LU (2016) which is a combination of the ones mention. First the model was a raster over the study area but then it turned into contour lines in ArcGIS Pro with the help of the tool “surface contour”. The contours got an interval of 0.1mm starting from the highest point around Umeå of 8.0mm going down to 6.6mm close to the city of Seinäjoki which is approximately 58 km south-east from Vasa. When the contour lines were done it was time to label them so it would be easier to see how much the land uplift would affect different
areas. To do this the map got imported into Photoshop and the labels got manually added alongside the contour lines to get them in the right place.

In this study the land uplift model for the Nordic countries NKG2016LU (2016) have been used along with the Finish elevation system N2000. The model is looking at the apparent land uplift, which takes the mean sea level into consideration when calculating how many millimeters per year the land rises.

The area with the highest land uplift started at a contour 8 with the highest point of the model being 8.08mm and the lowest being 5.59 (see figure 6). The study area is marked with a red square in figure 6 were the land uplift in the area is between 7.61 and 7.62 so the average value of 7.615mm per year will be used in this analysis. To create the land uplift maps for the different centuries; 100, 200, 300 and 400 years into the future the DEM from the Finnish Geospatial Research Institution (FGI, 2019) was used. This DEM were in 10x10m resolution over the Kvarken archipelago. Since the NKG2016LU (2016) model showed the average value of 7.615mm per year at Svedjehamm, it was used to calculate the land uplift for the different years. So 7.615mm got multiplied with the numbers of years that was going to be visualized so the first 100 years got the value 761.5mm or 76.15cm and the next hundred years got the value 1523mm or 152.3cm. Three hundred years was 2284.5mm or 228.45cm and lastly for the four hundred year it was 3046mm or 304.6cm.
The estimated average sea level rise by Johansson et al. (2012) to the year 2100 would still make the land rise about 3.0mm per year. So to take the estimated sea level rise into account 30 cm of land was added for the 100 year period to visualize how the landscape would change.

The orthophoto that was used for the analysis was created by downloading data from Maanmittauslaitos (2010) where it came in squares that were 6000x6000m. So to cover the study area four of these orthophotos had to be put together with the help of a raster mosaic. To create the observation tower, café, houses and docks they got digitized with the help of the orthophoto.

To create the 3D visualization maps, I had to download LiDAR data from Maanmittauslaitos (2010). The data came in a LAZ format which was not compatible with the version of ArcGIS Pro that was used (2.2.1). So Laszip was downloaded and the four LiDAR frames that were needed for the LAS

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**Figure 6: Land uplift in mm per year at Kvarken archipelago. Source: land uplift rate from NKG2016LU (2016).**
dataset were decompressed into LAS files. After this was finished it was possible to create a LAS dataset with the four LAS files. These were then calculated and the LAS dataset consisted of 31,303,809 points. The coordinate system was set to ETRS-TM35FIN and the Z coordinate was set to N2000 to display the LAS dataset. To visualize in 3D the observation tower of Saltkaret was digitized as a polygon with the help of the orthophoto and the right height of 20 meters got added to the polygon. Then the observation tower could be elevated to the custom surface of the DEM and then polygon could be extruded to the height of 20 meters by using the field as an input. The café and museum Salteriet was also digitized by using the orthophoto to help to create a new polygon of the building.

Ethics

This study was done by analyzing secondary data that was collected from FGI and Lantmäteriet so there is barely any ethic consideration for the study since it does not cover any personal data. However the bathymetric data from FGI have not been publicly published yet so it is important to not make their data accessible for the public as well as give them credit for the DEM. Bathymetric data could also be seen as sensitive data, since it could show high detailed data at areas that could be of interest for the military or national security. That is however not the case in this study.
Limitations

The limitations of this study would be due to the data that is available in the area. Since Kvarken Archipelago is a shallow area with a depth of down to -25m it is hard to measure the depth of the area and therefore a model of the average depth had to be used. In the more shallow water the vessels used to measure the depth could not enter. Detailed data of the depth and models could be sensitive information so they are usually not open to public. The model that is used in this analysis is based on a 10x10m cells, which is the best data that is available at this moment. There was some other data that was considered from Baltic Sea Bathymetry Database (N.D.) at the start of the study but they were based on 300x300m cells and other dataset that could be bought from Sjöfartsverket but they were based on a 100x100m cells. In the future there might be more detailed data using LiDAR or other more advanced measuring tools to map out the whole area including the shallower parts. This study will focus on how the land uplift will affect the landscape at Kvarken by looking at the model but there are other factors that will also change the pace of the land uplift. Like the buildup of organic material from vegetation or from sediment that is brought through rivers down to the coast. The sea level rise is also hard to calculate even though there are some estimations out there. They are mostly only to the year 2100 and it is difficult to know how the sea level will affect the Baltic Sea or the Bothnian bay. That is why the main part of the analysis was done by using the NKG2016LU (2016) model of the land rise and the estimated sea level rise was only done for the 100 year period. The CORINE land use map does only show the major roads and not the nature paths or other smaller roads that might be of interest in this study. These roads are however added later on in the process with the help of road data from Digiroads (2019).
Figure 7 shows an orthophoto over the study area with the lakes highlighted with a transparent blue color. This makes it easy to see where the lakes are located and it can be used to see the difference from the orthophoto and the Digital Elevation Model (DEM).

In figure 8 the highlighted lakes make it easy to see where the DEM is missing data. The reason for this is most likely that the model is in 10x10 meter and the lakes is smaller than that so the average depth in the cells that covers the lake is above sea level. Another reason for why they might not show up in the model is that they might be located at an higher elevation to start with and there for will not show up in the model since the height of the land is set to start at the sea level. The big lake in the DEM
is called Bodvattnet and that is the lake that is of most important in this study since it is central for the nature path and it can be seen from the outlook tower Saltkaret. The smaller lakes in the southwest corner of figure 8 is the so called flad and gloe lakes that were left there from when the sea level was higher and trapped the water creating small lakes across the landscape.

Figure 8: DEM of Svedjehamn in Kvarken archipelago with the lakes highlighted. Source: DEM from FGI (2019).
Figure 9 shows an orthophoto of the Svedjehamn with all the islands highlighted with a transparent yellow color to make them more visible. This makes it easy to compare them to the DEM in figure 10. There is mostly islands located at the bay outside of Svedjehamn, located north in the map with the De Geer moraines and some islands are located in the lake Bodvattnet.
In the DEM in figure 10 the islands at Svedjehamn is highlighted that were shown in figure 9 and it makes it clear that some of the islands are missing in the DEM. This is because the DEM is a model on a 10x10m grid where the average depth is calculated into that cell. So that islands that are smaller will not appear in the model or islands that are located at areas where the surroundings are very deep which would bring down the average depth below 0. So the bigger island located in the sea outside of Svedjehamn is in the model and most of the islands in the lake Bodvattnet is still in the model.
6. Results
The first thing that was analyzed was the historical maps that was gathered from Maanmittauslaitos (N.D.). These maps are shown in figure 11 and figure 12. The map from the 1970 (see figure 11) is the first part of the analysis since it is of interest how the area has looked historically and see if any change can be seen when compared to more recent maps. This will help to understand the land uplift phenomenon and the effect it has on the archipelago but also the effect it have on the lakes that lies inland. In this map there is a visual canal that connects the lake Bodvattnet with the Baltic Sea, the area north of Skrävelfladdan is also connected to the sea, creating a narrow bay. Other areas that are of interest are the two smaller islands that are located north of Kobådan as it seems as there is plenty of water surrounding them and the area in the northwest corner of the map at Långskat. At Långskat there is a small island outside of the mainland that almost covers the inlet to the bay inside.
Figure 12 is eighteen years later than the map in figure 11 and there is already some differences visible at the archipelago outside of Svedjehamn. The bay above Skrävelfladdan is now turned into a small lake, there is only one of the small islands north of Kobådan left the other one is now connected to the mainland. The dock area is getting bigger but narrower and the area up in the northwest corner at the map at Långskat is now only open in one area. The small island is connected to the mainland on the east side. There is still a canal connecting Bodvattnet to the Baltic Sea but some of the small islands in the lake have started to connect with the mainland.

Figure 12: Historical map from 1988 of Svedjehamn in Kvarken archipelago. Source: Maanmittauslaitos (N.D.).
Figure 13 shows an Orthophoto of the study area Svedjehamn with the digitized buildings and docks. Now the difference from figure 11 and 12 are becoming more prominent. The canal that was connecting Bodvattnet to the Baltic Sea does no longer exist and now the nature path are going along the small strip of land that has formed. The lake that was formed above Skrävelfladdan is now becoming smaller and have been divided to two separate lakes. The islands that were above Kobådan have formed one big island that is only cut off were the boat channel has been dredged out. The land around the docks has also become smaller since the land is rising even though it is possible to see that they have dredged out most part of the docks to be able to still accommodate boat traffic. Some of the lakes in the south-west part of the map looks like they have become smaller over the years and there are some areas where it is possible to make out the outlines of older lakes where only a very small part of the lake is still remaining.
In figure 14 the first one hundred years change is visible in the DEM with a lighter green. It is visible that the area around the docks will get one of the biggest effects from the land uplift phenomenon since it is quite shallow. The 100 year change is represented by a land uplift of 76.15cm, so most of the shorelines have been moved out towards the Baltic Sea. The islands have also gotten some new land added to them which connect some of the island in the archipelago outside of Svedjehamn and all of the islands inside of Bodvattnet have been connected to the mainland. Most of the houses will get affected as well since they will be further away from the sea. The nature path does not seem to be as affected by the land uplift since it was quite close to the sea and the lake to begin with.

Figure 14: DEM of Svedjehamn in Kvarken archipelago with 100 years land uplift. Source: DEM from FGI (2019).
After 200 years of land uplift the changes starting to become more visible and there are some areas that looks like they are going to get affected more than others. The land would by now have risen 152.3cm and the land uplift that was caused during both the first and second hundred years is visible in different shades of green. The area around the docks now seems like it will be join by land where Salteriet is located and the areas that are to the northeast of Salteriet also seems like they will be covered by land. By now all of the islands that are located in the archipelago outside of Svedjehamn seems to be joined up to the mainland. The lake Bodvattnet will have turned into multiple smaller lakes that are split off by the new formed land. The hoses and the nature path is starting to get even further away from the sea and lakes at this point.
After 300 years of land uplift the land would have risen 228.45cm and there would not be much left of the lake Bodvattnet and there is now just two bigger lakes and four smaller lakes left, more area would be land than water. The area around the docks would be even more landlocked and there would only be a small lake in the southern parts of where the dock was. New lakes will be formed in the sea outside of Svedjehamn as the new land cuts of the water from the Baltic Sea.

Figure 16: DEM of Svedjehamn in Kvarken archipelago with 300 years of land uplift. Source: DEM from FGI (2019).
After 400 years of land uplift the area of Svedjehamn would be almost unrecognizable, the land would have risen with 304.6cm. There will only be some lakes of water left in the archipelago outside of Svedjehamn and the Lake Bodvattnet will be completely gone. The docks would be more than 200 meters from the closest water and the small houses and the café Salteriet as well.

Figure 17: DEM of Svedjehamn in Kvarken archipelago with 400 years of land uplift. Source: DEM from FGI (2019).
The 3D visualization consist of four smaller maps from the observation tower. Where the first map in the northwest corner looks over the lake of Bodvattnet with the summer houses in the far end. The second map in the northeast corner shows the view out towards the Baltic Sea with the islands. The third map in the southwest corner shows the land bridge between the lake Bodvattnet and the Baltic Sea where the nature paths goes. Lastly the forth map in the southeast corner shows the view over the café Salteriet and the houses in Svedjehamn.
7. Concluding discussion

The aim of this study was to better understand the geological phenomenon land uplift in the area around Svedjehamn and to see how the area will get affected in the future.

The land uplift phenomenon is complex and there are many variables that can affect how it happens and how it will change into the future. It was first studied scientifically by Celsius (1743) in Fennoscandia and since then many people have tried to understand how it will affect the future. In this study a Digital Elevation Model (DEM) over the study area in Kvarken that was provided by the Finish Geospatial Research Institution (FGI, 2019) was used to visualize how the landscape would change. This was then combined with the land uplift model to see how much the land was estimated to rise in the area around Svedjehamn. The model showed that the land would rise with an average of 7.615mm per year at Svedjehamn so this was then added to the DEM to create the different outputs in the results. Figure 12 and 13 shows how the archipelago at Svedjehamn has change from 1970 to 1988 and there is already visible change in just 18 years.

So how does the area around Svedjehamn get affected by the land uplift over the next several hundreds of years?

As seen in figure 14 to 18, the area around Svedjehamn will get affected a lot in the span of 400 years and by then only some small lakes will remain out in the archipelago. The change will however change gradually and the first 100 years the change will not be as impactful out in the archipelago. The area around the docks will see the biggest effect of the land uplift since the area is generally shallower than the waters in the rest of the archipelago. This means that people will have to continue to dredge the
docks so that boats can have access to it. After 200 years of land uplift all of the island in the archipelago would have grown together which would make boat traffic hard even though they might continue to dredge ways for the boats to go. After 300 years the lake of Bodvatnet would be almost gone and there will be only smaller lakes remaining which could impact the summer houses around the lake as well as the nature path going around it. By 400 years the whole archipelago will have changed its appearance, there are only 3 lakes left visible outside of Svedjehamn.

**So how will recreation and tourism be affected by the geological transformation?**

Holloway et al. (2009) stated that tourism is one of the most important industries and that tourism contributes to 9.9 percent of the global GDP. In Finland the tourism industry provides 230 000 jobs and it is estimated that it would grow to 300 000 jobs in 2028, which would be 11.4 percent of the working population (World Travel & Tourism Council, 2018). Tourism is also one of the main strategies for rural development in Finland (Svels, 2011 & Pouta et al. 2006). So there is no doubt that tourism is important for the World Heritage Site Kvarken archipelago. One big part of tourism is also linked to recreation and it is that people spend time in nature for relaxation and to reduce stress. Pouta et al. (2006) stated that around 40 percent of the population in Finland is participating in nature related tourism every year. Hiltunen (2007) further adds that the primary motive for second homes is linked to the search for wellbeing and closeness to nature. As could be seen in the overview map of Svedjehamn (see figure 9 & 13) there are second homes located around the lake of Bodvatnet and the area around the docks. These are places that might get affected negatively from the land uplift in the long run since their closeness to water will change overtime and they might not be able to have a dock located adjacent to their house. The land uplift phenomenon is however a
reason why people find Kvarken archipelago so special and it is always changing. This will create another reason for tourist to revisit the area since it will change quite a lot during a lifetime, more islands and lakes will be created as the land rises from the sea. In the first 300 years the observation tower, café and nature path will not get affected that much. After 400 years the archipelago would be completely different and the view from the observation tower will have changed dramatically. The visitors would barely see the sea and the lake would be completely gone.

The part that will change the most over these years will be the lake Bodvattnet and the docks. The dock is an important part of both recreation and tourism since there are boat tours going from there and every second year they arrange the competition “Postrodden” (Kvarkanworldheritage, N.D.). Postrodden attracts people to come and see the historical postal journey between Svedjehamn and Holmön and to keep the tradition going the docks have to continuously have to be dredged out. It might start out to be a cheap investment but overtime the area that will have to be dredged will continue to grow to reach the open water.

**So will the changing sea level and other human induced factors affect the land uplift phenomenon?**

The current sea level rise is according to Bindoff et al. (2007) about 3 mm per year. This is caused by the warming of the oceans which contributes to the melting of the ice sheets and glaciers. The sea level rise is however not constant and it will change according to climate so since the climate is warming rapidly the sea level rise will accelerate as well. This have been studied by multiple researchers and according to Johansson et al. (2012) the Baltic Sea will get affected slightly less than other parts of the world. Johansson et al. (2012) did an estimation that the sea level rise would be from -72cm to 22cm at Vasa to the year 2100. The most likely estimate by
Johansson et al. (2012) was that that the sea level would still decline by 30 cm to year 2100 in relation to the land at this point. So even though the sea level will rise, would the land uplift is still outpace the sea level to 2100. The sea level rise is however harder to estimate than the land rise and it might change dramatically in the future. There are also factors that might speed up the land rise Vuorela et al. (2009) states that the land uplift might be faster in shallower areas since these areas will have more reeds. The reeds will build up organic material over time which will speed up the land uplift process. Historically these areas had more grazing animals that would have keep the amount of reeds lower (Vuorela et al. 2009). Modern agriculture have also contributed to more organic material being brought with rivers and streams out to the coastal areas where the material gets deposited which increases the land uplift as well. UNWTO (2008) stated that tourism stand for 5 percent of the global CO$_2$ emissions so even though tourism brings a lot of economy to the World Heritage Site it might also help to speed up the climate change and thus the sea level rise.

Final conclusions are that since Kvarken archipelago and Svedjehamn has one of the fastest land rises in the world and over the next hundreds of years it will change the landscape dramatically. This can be positive for the tourism industry since the change is so fast that the revisiting value is high. It might also affect tourism in other ways since the destination of Svedjehamn will have to keep on investing money in infrastructure in order to keep the docks operating in the future. Even in a lifetime the landscape with the De Geer moraines, flads and gloes will change. The 3D visualization of the area can be helpful to see how the area will change in the future since it shows the areas that will get affected the most of the land uplift. It is however quite hard to estimate exactly how the area will get affected since the estimated sea level change keeps changing in accordance to the climate change. Further studies on the subject are of interest and
especially the estimated sea level rise that could be done with the help of advances in technology. This could allow for even more accurate bathymetric measurements of the archipelago and would be of interest for both the people living in and the people visiting Kvarken archipelago. Since the sea level will alter how much the landscape will change in the future. The 3D visualization of the docks and the lake Bodvattnet shows how it looks at it current state and in further studies they could be compared to see how much the will differ to help understand and display the land uplift.
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