MONITORING COASTAL EROSION

in DENMARK, Hirtshals – Løkken, using REMOTE SENSING data

School of Architecture, Design and Planning
Master's Programme (Cand.Geom.) in Surveying, Planning and Land Management, with specialization in Surveying and Mapping

Master Thesis

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Abstract:

The purpose of this project is to monitor and evaluate the coastal erosion process occurring on a segment in north of Denmark, Hirtshals - Løkken, using remote sensing data collected from different years.
First, the project describes the area of interest used for the study and the main reasons it was chosen for. Afterward, the data used in the project is presented, along with three different software (eCognition, ArcMap and MatLab).
In order to understand better the differences between these software solutions, tests and comparisons are held, and where this part is closed with a few conclusions stated. Counting on the workload and the time available for the project, the effectiveness criterion of the process was important, where obtaining as close as possible to an automatic process was desired.
After the erosion lines for each data set are extracted, different analysis and statistics referring the erosion situation and the consolidation offered by the protective constructions found along this segment is presented.

Aknowledgements

We would like to thank our supervisor, Associate Professor *Karsten Jensen*, who gave us guidance and support in order to finish this project. We would also like to thank him for taking his time to discuss our questions.

Besides our supervisor, we would also like to thank *Henrik Ussing Lynge*, for giving us the opportunity to join their professional team in the "Mapping and surveying" COWI division and for allowing the access to the company equipment and data. Without this help it would have not be possible to conduct this project.

Foreword

This report is written by Edin Ahmetspahić and Daniel Dobra, Master students at Aalborg University in the 10^{th} semester of Surveying, Planning and Land management with the specialization of Surveying and Mapping.

The project work was accomplished in the period 1^{st} of February 2016 and 15^{th} of June 2016 as a collaboration with COWI company, located in Aalborg.

All the chapters are identified by a name and a corresponding number. In contrast with this, the appendices are identified with a letter and name. The appendices that are considered to be most important, are given at the end of the report. The rest are stored in the CD attached, which has a description in A on page 83.

In order to identify the pictures, the tables and the equations, they will be marked with two digits. The first digit describes the number of the chapter and the second digit refers to the position given in the specific chapter.

Citations are expressed as following: [1]. A list of all used sources in this report, are written in Bibliography, which is numbered by the order of appearance in the text.

NOMENCLATURE

Acronyms

AAU	Aalborg University
NN	Nearest Neighbor
GPS	Global Positioning System
RGB	Red Green Blue
DMI	Danish Meteorological Institute
DCA	Danish Coastal Authority
DTM	Digital Terrain Model
DEM	Digital Elevation Model
GST	Geodatastyrelsen
LIDAR	Light Detection And Ranging
STD	Standard Deviation
ISODATA	Iterative Self Organizing Data Analysis Technique
GPS	Global Positioning System
GSD	Ground Sampling Distance
ECW	Enhanced Compression Wavelet
LAB	Lab Color Space
RAM	Random Access Memory
WMS	Web Map Service
TIFF	Tagged Image File Format
TFW	World File
LZW	Lempel Ziv Welch (lossless data compression)
POI	Point Of Interest

CONTENTS

1. Introduction

Our planet is alive and constantly in motion. If we take a look in a bigger picture, it can be obviously noticed that is divided in two big worlds, the land and the sea, and there is a big fight going on there. The worlds coastal lines are living landscapes that are constantly changing, since millions of years.

The coastal erosion is a process which occurs thanks to many factors: waves, tidal and wave currents, drainage and high winds, and not the least, extreme weather. Since this factors can be independent and unpredictable, plus the land texture is different around the world, from sand to hard rocks, the coastal erosion is a continuous process with different output for different locations around the worlds coasts.

In the picture 1.1, the coastal erosion patterns are presented across Europe. As it can be noticed, most of the shoreline is between a state of aggradation and erosion, in a continuous change. The coast line which is mapped as stable, is either made of a very rough matter , either the sea activity is not that intense in that area.

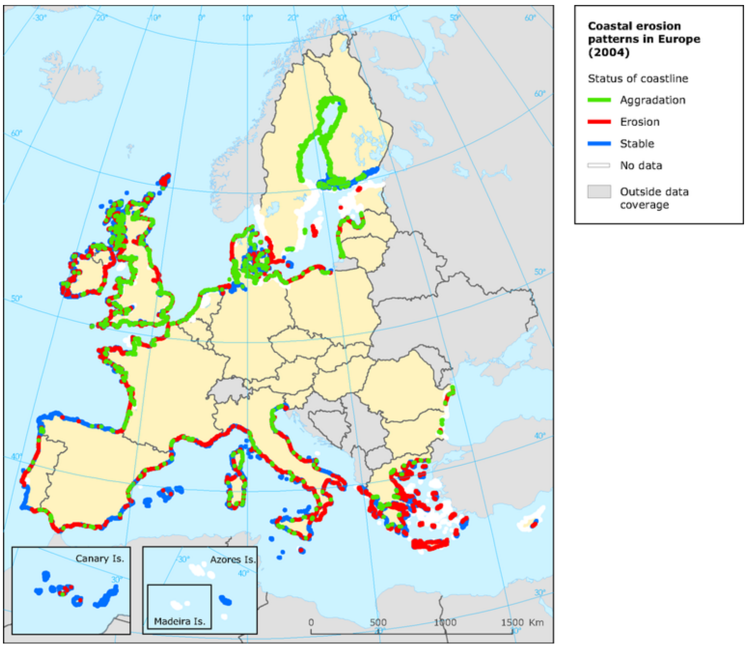

Figure 1.1: *Coastal erosion patterns in Europe [2]*

The coastal erosion around the world is not just resulted by natural drivers, it is also affected by human project activities such as oil-drilling, gas-mining, dredging etc. On the global perspective, in the last years the humans have accelerated the erosion, both on offshore and onshore areas. The societies near shorelines with human influence and activities on urbanization has defined coastal erosion, from a natural phenomenon into a growing problem.

This means that coastal erosion is a major problem for many countries, where political and local actions are needed, in order to find solutions for securing shorelines. [3][4]

1.1 Coastal erosion in Denmark

Denmark has a long and diverse coastline which summarize about 7,300 kilometers. The East coast is facing *Kattegat*, *the Belts* are separating by the sea Jutland, Funen and Sealand, while the *LimFjord* is covering the inner Danish coasts. From the geographical perspective, Denmark offers a great variety of the coastal landscape. However, the characteristics of today's coastal line it has its origins from the last glaciers period called Saale and Weichsel. [5]

The West Coast is the most affected and in interest, by neighboring the North Sea, where it is highly exposed and many human activities and protective constructions can be found, in order to minimize the coastal erosion. This constructions which are built with the purpose of protecting the shore in bigger picture, can affect the coastline, counting on the law that "for every action, there is a reaction", and can produce secondary effects, as so called lee-side erosion.

The coast landscape mainly consists of sandy beaches and dunes, which are stretching from north of Skagen to south of Skallingen, for approximately 360km. The erosion along the western Danish coast is mainly wave-induced, with an average of 3 to 4 meters per year, while in some locations can reach a maximum value of 11 meters.

Figure 1.2: *Western Danish coast. Løkken*

Sea level rise and climate change is of major interest in Denmark. About 80% of the Danish population lives around coastlines areas, where half of these within 3 km of the coast. That says a lot about the societies view and interest in dealing with the consequences of climate changes. These activity relations, are considered within physical planning infrastructures from the national level to the coastal municipalities. [5]

In general, the land owners are responsible for protecting their lands against the sea, therefore the owner of the property must request permission and pay for the construction, operation and maintenance of the established protection. However, for a few places in Denmark, where the coast is considered to be of a national importance, the government will participate in the costs of the construction. [6]

Figure 1.3: *Protection works along the West coast. Groynes construction and sand nourishment [6]*

1.1.1 The Danish Coastal Authority

The Danish Coastal Authority (DCA) was established in 1868, being the official coastal and port government agency and is a division of the *Danish Ministry of Transport*, covering all the coastline in Denmark and having 110 employees. The regular tasks are concerning coastal protection, ports and the socio-economical interests of coasts, by the means of analysis, project planning, construction, operation and warning.

In the figure 1.4 on the following page, the main activities of the DCA across Denmark are presented. The map offers an overview about the areas of interest and where the problems occur along the Danish coast.

The history of coastal protection in Denmark starts by chance, around 1000 A.D., when farmers started to built dikes in order to protect the farmland against sea flooding. Later on, groynes were constructed along the Danish West coast since 1874, before building this protections the erosion being very large. First nourishment with sand was introduced in 1974.

Until today, along the Danish coasts the following had been constructed:

- 900 km of dikes
- 700 km of revetment
- 13000 groynes and breakwaters
- 5600 jetties and other constructions

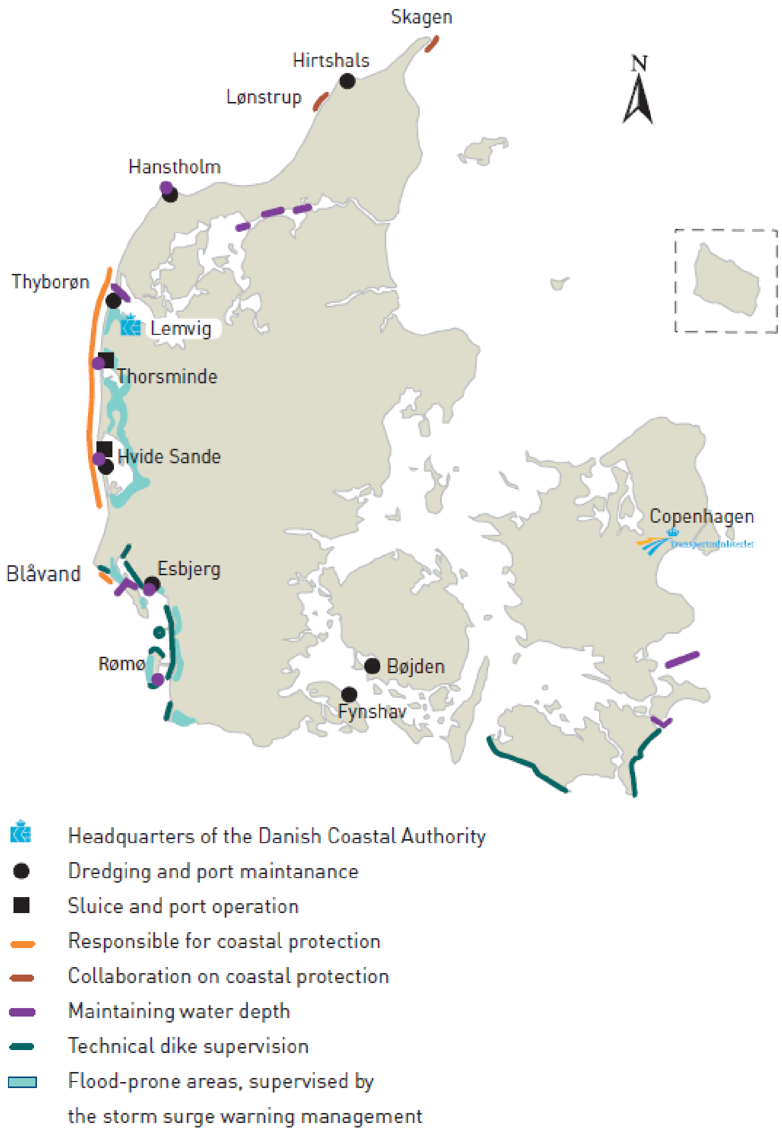

Figure 1.4: *The Danish Coastal Authority tasks on map [6]*

The National Coastal Protection Strategy was launched in 2011, to raise awareness about the coastal management and to increase the quality of the Danish coasts, for the benefit of everyone.

While in the future years, the climate change will increase the erosive effect by the means of higher waters and more powerful storms, the demand of using near-shore land will be higher. The objective is to ensure that the coastal protection works are carried out in an optimal and on a long-term way.

Not the last, the strategy also promotes the importance of removing the inefficient existing protection along the coasts and improving the cooperation between the privates and the public authorities.

1.1.2 Storms in Denmark

The Danish Meteorological Institute (DMI) is responsible for monitoring the weather, the climate and the seas with the purpose of safety in human life and property. The institute collects and processes meteorological, climatological and oceanographic measurements and observations in order to predict future natural disasters.

Extreme weather phenomenons such as storms, create bigger waves which accelerate the coastal erosion. Since 1891, DMI is recording all important storms, including storm type and remarks, date and period of storm, wind direction and a classification of the storms occurred (in 4 different classifications, **stormy, storm, strong storm and hurricane**).

Having available this data sets, the impact of the most important storms which occurred in Denmark can be investigated and taken into account in the future research.

In the table 1.1, the main storms since 1999 are recorded and described by intensity (*on a scale from 1 - 4*) and time of occurrence. In further research, these data sets can provide a relation and extend the analysis of the impact of these powerful natural events on the coastal landscape. As it can be observed in the table, in the most of the storms, the wind comes from the west part of Denmark, from the North Sea.

In the figure 1.5 on the following page, the occurrence and the intensity of these storms are presented in a graphic, in a relation with a time scale, where it can be observed that in the last years (2011 - 2015) important storms occurred more often in Denmark.

Day / Year	Type of storm	Wind direction / Intensity
3/12/1999	**Hurricane**	**West / 4**
29-30/1/2000	Strong storm	West / 2
6/12/2003	Storm	North / 1
8/1/2005	**Hurricane**	**West / 3**
8-9/12/2011	Storm	West / 1
3-4/1/2012	Storm	West / 2
28/10/2013	**Hurricane Allan**	**S-West / 4**
5-6/12/2013	**Hurricane Bodil**	**N-West / 4**
29/11/2015	Strong storm	West / 3

Table 1.1: *Storms recorded by DMI since 1999 [7]*

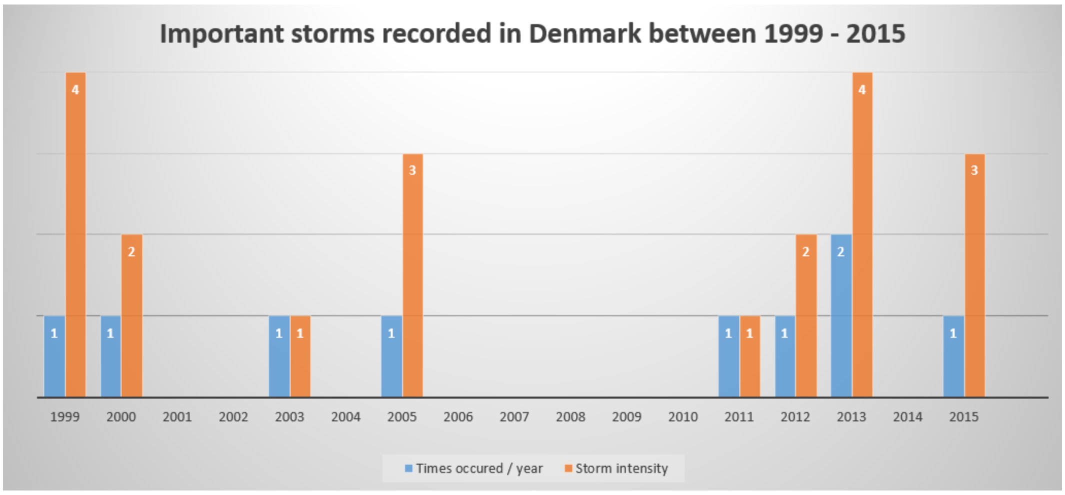

Figure 1.5: *The important storms in Denmark on a time scale*

2. Area of interest. Hirtshals - Løkken

Initially the project group considered monitoring the whole western coast of Denmark, but after a few tests, counting on the time available for the project and the huge size of the areas involved in the discussion, it was decided to choose a smaller segment along the coast which gather as many interesting subjects, and the allows a more detailed analysis counting on the time available for the project.

Another important criteria is the distance between the location of the project work and the area of interest, taking into account future measurements needed for the project. Since this is a research project, what matters is the quality and diversity of the subjects not quantity of the data processed.

The coastal area between Hirtshals and Løkken is located in Hjørring Kommune, which is part of Nordjylland region in Denmark, and is facing a harsh neighbor, the North Sea, which eats away the shore systematically and brings strong winds blowing the sand around in a constantly changing landscape.

Where the Atlantic, Baltic and North Sea waters are merging having different temperature and salt concentration, strong currents can form, brushing repeatably the fragile soil of western Denmark. At the same time offers to the people living there for the last centuries, a great source of food and prosperity, where fishing and tourism are the two main industries. Three main coastal towns are situated along this 30 kilometers segment, see figure 2.1.

Figure 2.1: *Area of interest*

Media institutions often present the situation occurring on this segment as a hot topic, as a reflection to the reaction of the public. The erosion process present in this segment proved to be devastating from many points of view for the people living there, in some cases ending up with house loses.

The wave energy in this area, as it can be seen in figure 2.2, is one of the highest in Denmark.

Figure 2.2: *Wave energy in Denmark, calculated for each 5 km [5]*

The sediments transport directions alongshore in Nordjylland are presented in figure 2.3. The results are divided in three categories and are referenced by facing the sea: significant transport towards right, left or no significant transport.

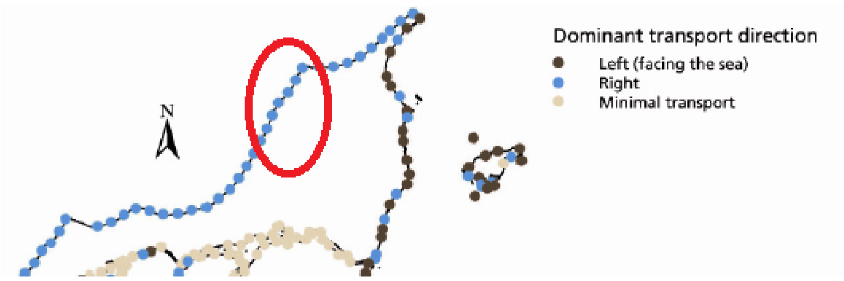

Figure 2.3: *Dominant transport direction [5]*

Not the least, a classification of the coast is illustrated in figure 2.4. Here it can be observed that the area in interest is classified as *sandy dune* (loosely to unconsolidated sediments) and *soft cliff coast* (consolidated sediments, glacial tills, meltwater deposits).

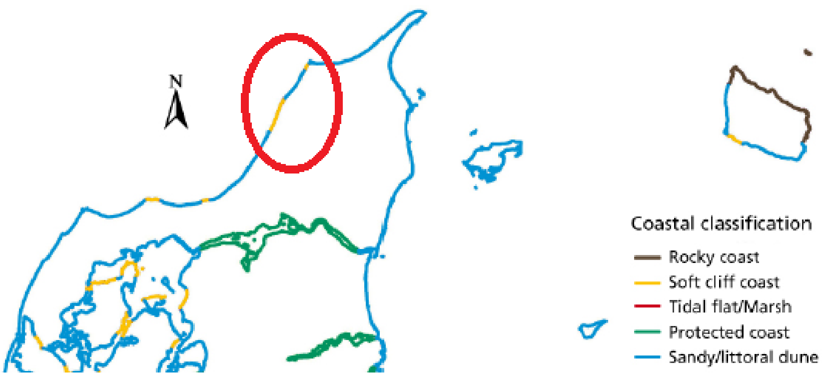

Figure 2.4: *Coastal classification [5]*

2.1 Hirtshals

In the northern part of the segment, Hirtshals is located, a city known by its fishing harbor and international ferry port, which developed the city since was built at the beginning of 20th century. In figure 2.5, the city overview is presented.

Figure 2.5: *Ortophoto image representing the town of Hirtshals with the harbor*

Its geographical position offers an interesting study, where the coast in the west of the city and harbor is facing the North Sea powerful currents. Counting on the dominant sediment transport direction along this segment, see figure 2.3 on the facing page and the sea currents direction map according to the Danish Meteorological Institute, see figure 2.6, the type of the sediments present in the south of the harbor, see figure 2.4 on the facing page (sandy/littoral dune and soft cliff coast), it is likely that in this area **aggradation** might occur.

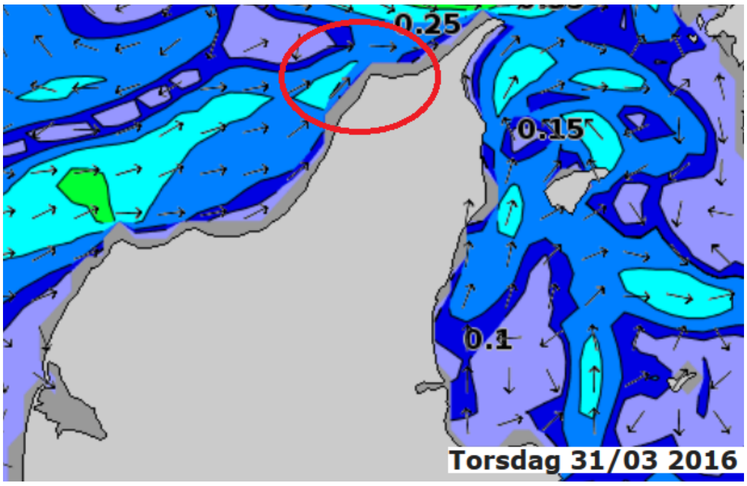

Figure 2.6: *The Sea currents directions in Hirtshals area [8]*

2.2 Lønstrup

Lønstrup is a small town considered a pearl of the Danish western coast, where many tourist attractions can be found. It started as an old fishing village, and thru history it has been witness to a few violent storms, first recorded in 1877 which formed a small canyon visible even today. A year later after the second violent storm, in 1981, Lønstrup became part of the Danish Coastal Authority projects, where a group of *waterbreakers* were constructed in order to protect the city shore, and a stone-made *dam*, is constructed along the shore in the northern part of the town. Not the least, two kilometers north of Lønstrup, close to Skallerup Klit, four groynes are constructed into the sea, as it can be seen in figure 2.7.

Figure 2.7: *Aerial imagery of Lønstrup town, the waterbreakers constructed starting from 1982 (left) and the groynes close to Skallerup Kilt (right)*

Patrimony buildings

In the south part of the town, the site of *Maarup Church* can be found, which was built in the 13th century. At the present time the church has been dismantled and moved in the National Museum custody because of the progressive erosion happening in the area, and the fears of the authorities that the church would fall into the sea from the high cliff where was situated, see figure 2.8 on the facing page.

Three kilometers south to Lønstrup, drama provoked by erosion is continued by another building with historical importance. *Rubjerg Knude lighthouse* it is 23 meters high and was built in 1899 on the highest point, approximately 60 meters above the sea level. During the last decades, a unique scene for that area was created by the nature, a gigantic migrating dune has interfered and buried the lower part of the building. During the 1920s, works removing large quantities of sand started and in the early 1950s the dune reached a height where the ships could no longer see the fog warning signal. On 1 August 1968, the lighthouse was switched off for good and the fight against nature was abandoned.

At the time it was built, there were only modest signs of sand migration and it was situated at more than 200 meters from the coastal cliff. Today only 20-30 meters lie between the sea and the lighthouse making it easy to predict that in the next years the building will be swollen by the sea. [10]

Figure 2.8: *Maarup church. [9]*

Figure 2.9: *Rubjerg Knude lighthouse [10]*

2.3 Løkken

Løkken is the southern town in the section in interest, about 14 kilometers south to Lønstrup. It was founded in 17th century as a fishing village and today is a flourishing resort town hosting up to 1 million tourists per year.

The city has a particular construction on the coast, a pier, which was built between 1927 - 1931 and it has over 220 meters in length. At the time, the primary function of the pier was to help fisherman to anchor the boats and transport the goods easier to the land, but in time its function became more and more recreational than economical. [11]

The pier construction in the sea for more than 80 years it could offer an interesting study or some differences in relation with the rest of the coast, see figure 2.10 on the next page.

Figure 2.10: *Aerial imagery of Løkken town*

Housing and property risk

Along the segment in interest, many properties are located within a few meters from the coastline. Counting on the erosion happening in the area and the elevation of the coast, this properties can be considered in danger, see figure 2.11 on the facing page.

Having a situation plan of the erosion in the last years would help to obtain an estimation or prediction of the erosion for individual areas, which would help to protect the properties or to build a proper plan regarding the construction of future protections.

Starting from this plan, would be easier for the people in this situation to group and analyze the existing solutions. Therefore the case would be more valuable and effective, with a more realistic overview about the situation and costs, and easier to forward the plan to **The Danish Coastal Authority**, which would have to approve or maybe even contribute with funds and consultancy to the project.

Not the least, an inspection of how the groynes or other protection constructions have influenced the erosion in this area would clear up some of the questions people have in this situation. In order to highlight even more the erosion process that occur in the area, in figure 2.11 on the next page it can be seen some of the *bunkers* which were built during the **Second World War** in land, today are already laying on the beach close to the sea water.

Figure 2.11: *Cadastral plan. Aerial imagery from the northern part of Løkken, Tranevej street (left) and example of properties already affected by erosion (right)*

2.4 Area of interest. Conclusion

As presented above, along these 31 kilometers of coast many interesting study cases can be found. Old patrimony buildings collapsing into the sea or covered by a moving sand dune, makes erosion culpable for history lost. By obstructing the use of the Rubjerg Knude lighthouse along the years, a negative economical impact affected the area.

Another economical effect is the housing and property risk along the coast, where in some cases the inevitable already happened. The price of the properties is affected by this natural events, which makes any investments in the area insecure. Counting that the government and the Danish laws are not covering any loses, or helping the citizens constructing protections in the area, getting an insurance covering the property is not easy.

Four different kinds of man-made constructions are located within this segment, which probably have influenced the coastline in one way or other:

- Hirtshals geographic position on the coast and its harbor (1921)
- 4 groynes constructed close to Skallerup Klit
- Breakwaters, Lønstrup town (1982)
- Pier, Løkken town (1927)

Some of the constructions mentioned above are built with the purpose of protection, where their efficiency can be observed, and some are built with other purposes but might have been act as protection constructions or at least affected the coast around them in some way or other.

Lee side erosion occurs as an adverse effect on shore stability which appears on the down-drift side of a beach drift barrier, see figure 2.12 on the following page. This refers to man-made constructions and which have a directly proportional impact effect according to the area covered by them. As an example, a group of groynes is expected to create a larger **lee side** erosion than a one-groyne construction. [12]

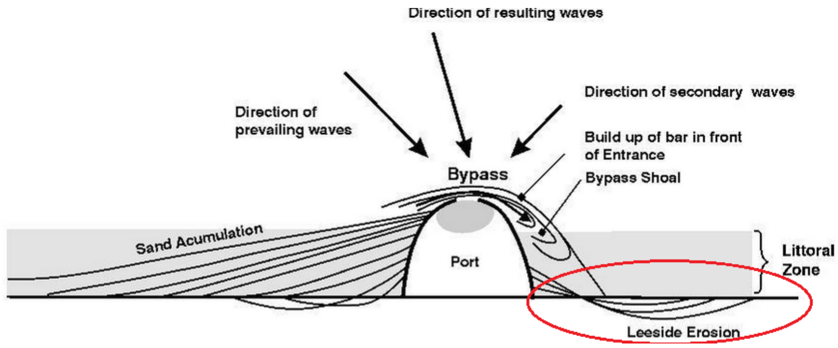

Figure 2.12: *Lee side erosion. [12]*

Not the last, the area in interest is presented by the experts and the relevant literature as a high erosion area, because of many factors, such as the coast fragile geology and neighboring the harsh North Sea. However, counting on the protection constructions built in the last 80 years, it might be possible to find areas where **aggradation** occurred.

3. Initial problem statement

The previous chapter presented how erosion influenced the social activities, modeled the landscape and affected the coastline along these 31 kilometers between Hirtshals and Løkken, and what are the main concerns.

The purpose of this project is to observe, evaluate and map the coastal erosion in the presented area of interest. Having an analysis of the erosion in the specific area, makes it easier to understand what impact has this process to the landscape, and not the last to the society living along shore.

Mapping accurately the erosion on a long term run, involving more than 130 years, different statistical factors can be extracted in order to understand better this phenomenon. Along this segment and during all this time, the coastline was first totally unprotected, while gradually got different kinds of constructions along the shore, in different locations.

The initial problem statement question is:

- **How to map and evaluate the coastal erosion between Hirtshals and Løkken?**

3.1 Flowchart

The flowchart presented in figure 3.1, represents the project content overview and the steps the project is following. Earlier, the first two steps of the flowchart were presented, in order to introduce the project direction and to present the location which is going to be studied. Further on, the project is following the steps presented in the chart.

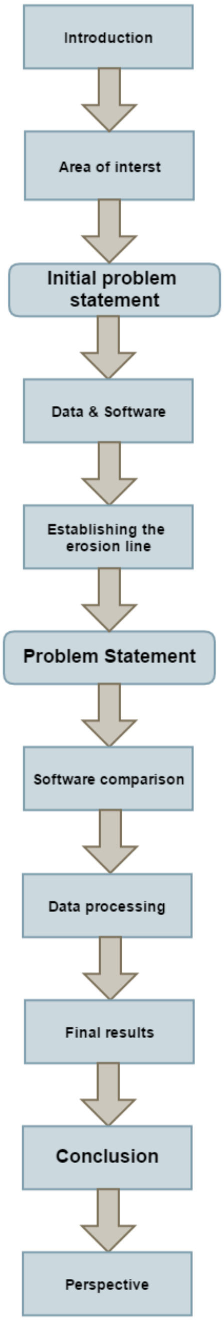

Figure 3.1: *The project flowchart*

4. Data and software

The purpose of this chapter is to explain the data availability from licensed COWI-WMS and Geodatastyrelsen (GST) servers and how the data was obtained. In addition to this, the downloaded data is also described and followed later by quality test. The quality test is performed, in order to ensure that the given data for the different years of the same place is matching, by using the GPS measurement as a reference-point.

4.1 The data availability

Before the coastal erosion could be mapped in the desired area using the remote sensing approach, it has been decided to use several types of data from Geodatastyrelsen and COWI. However, since the coastlines are changing constantly, it is then important to find the suited data, where it can be observed these dynamic changes over the time.

For this purpose, it was decided to use the orthophotos from the following years: 2015, 2012, 2010, 2008, 2006, 2004, 2002, 1999 and 1995, which are covering 20 years of detailed coastal erosion changes. The oldest orthophoto is from 1954 and have 41 years of gap from the 1995 orthophoto, which makes it interesting to investigate the coastal erosion process occurring in that period of time. The mentioned orthophotos will be used for accurate mapping of the coastal erosion between Hirtshals and Løkken. In addition to this, there are available two historical maps from the years 1862-1899 and 1928-1945 with 1:20000 scale. These historical maps are also used, to extend the research of coastal erosion changes.

The orthophotos from the year 2015, 2012 and the historical maps, are obtained from the GST server, as free data. The GST orthophotos are usually taken between March and May, due to the good ground visibility from the camera.

The licensed COWI-WMS service only provides orthophotos from the year 2010 to 1995, with intervals of two years in between, in average, except the orthophoto from 1954, which is taken in May period. The last mentioned orthophoto is taken by US Air Force, with the scale 1:10000. The given orthophoto is originally taken from an older camera, where COWI has scanned these images and converted them into the digital orthophotos with georeference and projection.

The image quality varies for the mentioned data, where the quality is expressed as “Ground Sampling Distance (GSD) and is only available for the mentioned orthophotos, which are listed in the figure 4.1 on the following page. The GSD value of the old historical maps is not available, since the maps are scanned, georeferenced and projected by GST. Later in section 4.2.1 on page 23, the old historical maps are going to be compared to a GPS reference-point and orthophotos, in order to check the difference in translation.

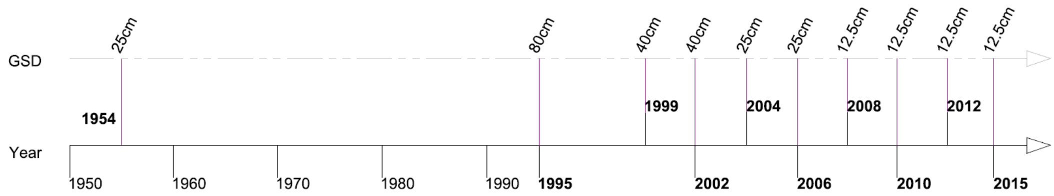

Figure 4.1: *The timeline of avaible orthophotos*

4.1.1 The data download and quality

The data availability from GST was in general easy to obtain, because it could be accessed directly via GST-FTP server and downloaded in "Enhanced Compression Wavelet" (ECW)[1] format, keeping the original GSD value. while the historical maps are available just in GeoTIFF format, with 254dpi resolution in a grid of 10000x10000 pixels.

On the other hand, the data from licensed COWI-WMS service was a challenge to be solved. Having WMS service, means that the data is generated via GIS-database. In general, the maps from a WMS service could be exported in a desired pixel resolution, if the GIS-database server allows it.

In order to get the data for the project from COWI-WMS, the idea was to download the orthophotos for the respective years, and export the one orthophoto via ArcGIS software in a highest possible resolution. The desired image resolution from COWI-WMS service could not be accessed, because it was limited to 10000x10000 pixels resolution.

In order to see if this resolution meet the requirements for the coastline extraction, one orthophoto was exported withe the mentioned resolution along the area between Hirtshals and Løkken with the scale of 1:125000. The GSD on the exported orthophoto resulted to be 3.3m (the GSD quality can be seen in the "tfw" file, which comes along with the given raster file), and it can be seen in the figure 4.2. The result from the image with 3.3m GSD is concluded to have a very poor resolution quality, counting on the project purpose and the errors which this high value can bring to the final results, the coastline extraction.

Figure 4.2: *The GSD quality from the image with 10000x10000 pixel (left) compared to the original orthophoto (right) with GSD quality 12.5cm*

[1]The ECW format is used for compressing the high resolution imagery, while the pixel quality is retained.

However, the 10000x10000 pixels resolution could have been used for extracting the images in ArcMap, if the given software had a direct download export of orthophotos from a WMS service within a defined grid system. This method can be applied only if the image is stored on the computer.

The table 4.1 is illustrating the properties of the available imagery:

Maker	Year	GSD	Resolution	Size	Color depth	File type
Geodatastyrelsen	2015	12.5 cm	X[2]	5 GB	24 bit	ECW
Geodatastyrelsen	2012	10 cm	X	22 GB	24 bit	ECW
COWI-WMS	2010	12.5 cm	X	X	24 bit	X
COWI-WMS	2008	12.5 cm	X	X	24 bit	X
COWI-WMS	2006	25 cm	X	X	24 bit	X
COWI-WMS	2004	25 cm	X	X	24 bit	X
COWI-WMS	2002	40 cm	X	X	24 bit	X
COWI-WMS	1999	40 cm	X	X	24 bit	X
COWI-WMS	1995	80 cm	X	X	24 bit	X
COWI-WMS	1954	25 cm	X	X	24 bit	X
Geodatastyrelsen	1928-1945	N/A	10000x10000	0.1 GB	8-bit	GeoTIFF
Geodatastyrelsen	1862-1899	N/A	10000x10000	0.1 GB	8-bit	GeoTIFF

Table 4.1: *The overview of the available data.*

4.1.2 The orthophoto export

The problem for getting orthophotos directly from COWI-WMS service, has been solved by using **Global Mapper** software. The given software is especially designed for downloading the orthophotos from WMS services and cut orthophotos. Since the COWI-WMS and GST data sets are presenting a large redundant area, respect to the area where the coastal erosion between Hirtshals and Løkken is going to be investigated, then both data sets are going to be cut in Global Mapper.

In order to optimize the speed of the image classification process and to avoid classification errors and noise, it is decided to cut the orthophoto within a defined polygon, used for all data sets, and illustrated in the figure 4.3 on the following page. In this way the image diversity is reduced and so, the problem in interest can be weighted more.

In other words, working with a smaller image, which has a less diverse land cover, improves the classification. Therefore, the chances to obtain a better result of the coastline extraction are bigger, since both supervised and unsupervised classification are relative to the diversity of the image.

Before the exporting the orthophotos, Global Mapper allows the user to adjust various image properties. However, it has been chosen to work with GeoTIFF format, which contains a high pixel quality compared to a .jpeg format. The orthophotos are exported as RGB bands, containing 24-bit color depth. Since GeoTIFF raster format uses more memory space than .jpeg format, the (LZW) compression algorithm is applied. The advantage of using LZW compression on GeoTIFF images is represented by the color fidelity and pixel quality.

Figure 4.3: *The polygon used for cutting the images, covering the area between Hirtshals and Løkken*

The orthophotos from 1954 to 2006, have the GSD defined to 25cm and the orthophotos from 2008 to 2015 have maintained their original GSD value from 10cm to 12.5cm. In figure 4.1 on page 18, it can be seen that the orthophotos from the year 1995, 1999 and 2002 have original GSD between 40cm and 80cm. In this situation, the export to 25cm GSD is not an improvement of the pixel quality. The only changes for the given data is, that the images have a more dense pixels within the one original pixel size.

Regarding the visualization of how well defined are the objects in the orthophotos, here is an the example of two orthophotos that are illustrated in the figure 4.4 on the facing page. The orthophoto from 2006 (*left*) have GSD of 25cm, while the orthophoto from 2015 (*right*) have GSD of 12.5cm. After the visual inspection, it is concluded that the given resolution quality of 25cm in the respective orthophotos, proved to be sufficient for the further work with coastal erosion.

Here are the final results of the exported data, which can be seen in the table 4.2 on the next page.

Figure 4.4: *The exported orthophotos from 2006 (left) and 2015 orthophoto (right)*

Maker	Year	GSD	Resolution	Size	color depth	File type
GST	2015	12.5 cm	125710x210131	1.6 GB	24 bit	GeoTIFF
GST	2012	10.0 cm	125710x210131	1.6 GB	24 bit	GeoTIFF
COWI	2010	12.5 cm	125710x210131	1.6 GB	24 bit	GeoTIFF
COWI	2008	12.5 cm	76320x114926	1.8 GB	24 bit	GeoTIFF
COWI	2006	25 cm	62855x105065	0.5 GB	24 bit	GeoTIFF
COWI	2004	25 cm	62855x105065	1.0 GB	24 bit	GeoTIFF
COWI	2002	25 cm	62855x105065	1.0 GB	24 bit	GeoTIFF
COWI	1999	25 cm	62855x105065	1.0 GB	24 bit	GeoTIFF
COWI	1995	25 cm	62855x105065	0.8 GB	24 bit	GeoTIFF
COWI	1954	25 cm	62855x105065	0.7 GB	24 bit	GeoTIFF
GST	1862-1899	N/A	10000x10000	0.1 GB	8 bit	GeoTIFF
GST	1928-1945	N/A	10000x10000	0.1 GB	8 bit	GeoTIFF

Table 4.2: *The final data overview and parameters*

4.2 Image inspection

Before working further with the prepared data, the visual inspection is performed on the RGB orthophotos. The goal of the visual inspection is to look for any errors on the imagery, that might affect the image classification process. In this way, the errors are then taken in consideration, when performing the image classification processes of the respective data.

The image classification processing can be affected by many factors. Regarding the downloaded orthophotos, several errors has been observed, which can potentially assign a wrong classification to the given pixel. For illustrative purpose, the orthophoto from 2008 is used, as an example of typical orthophoto errors that are encountered, see the figure 4.5 on the following page.

The main reason why the orthophoto from 2008 is having different color brightness, is because while collecting the images, the plane is flying from the offshore to the onshore area, and vice versa, and the camera sensors need to be adapted to a different light reflections from the ground. The visible horizontal seemliness are the actual flight route and the camera capturing visibility window, if looking on the distance along the beach and between shifted

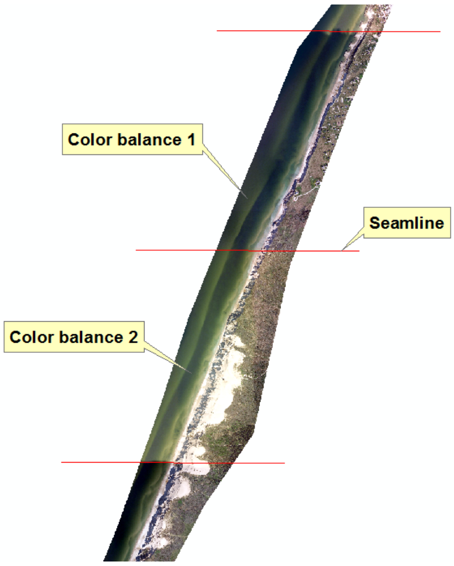

Figure 4.5: *An overview of the shading problem. 2008 data sets*

light brightness.[3]. Among this problem, other errors has been observed, such as:

Shades

In some parts of the orthophoto the shades are occurring along the erosion line. This effect is caused by the difference in height between the land and sand (beach side), sun angle and airplane position, see figure 4.6. The shades, in this particular situation, can give a classification error, when delineating a erosion line between sand and land.

Figure 4.6: *The shadow between the sand and land classes*

In this kind of situations, the user needs to be aware of the shade locations, because the shade colors usually vary from one location to other. Not picking the *shade* samples diverse enough, in the respective orthophotos, can result a poor shade classification.

Unbalanced colors

In general, all the downloaded orthophotos are color balanced. However, as it can be seen in the figure 4.7 on the facing page, along the coastline area the balance of the color is not fully achieved. The color balance is some situations is not possible, because there is a large difference between light sensitivity, at the moment when the camera had observed the

[3]Note: The given orthophoto has been cut.

land from the moving airplane, from offshore to the shore and vice versa. Working with orthophotos as explained here in this context, is challenging the user to pick good samples, when performing image classification processing.

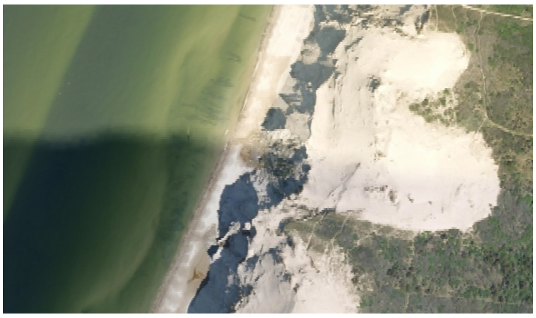

Figure 4.7: *The seam line and the color difference after the color has been balanced*

Different capturing time
The given orthophotos are also captured in different periods, between Hirtshals and Løkken segment, fact that is also resulting in color unbalance and different shade colors or locations.

4.2.1 Translation of the imagery

This section is about investigating the translation magnitude of the orthophoto from 1954 and the two historical maps from 1862-1899 and 1928-1945. The translation is calculated by comparing the position of the objects found on these maps and 1954 orthophoto with the GPS measurements of the same objects which can be still be found today. However, this test is performed in order to give the user an estimation of how large is the translation of the data sets, therefore the user being aware of these translations.

Since the given data is carried out in different years and using different instruments, it is also reasonable that the data is available in different quality, which also reflects on the data accuracy. In this situation, the orthophoto from 2015 along with the GPS measurements are used as the reference data. The 2015 orthophoto has the absolute coordinate accuracy of 2cm, which is concluded to be sufficient for visual verification of the GPS measured points, when comparing it to the chosen objects.

The translation between 2015 and 1954 orthophoto resulted in **3.3 m** and is presented in figure 4.8 on the next page:

The best solution for finding the translation of the orthophoto from 1954 is to know how many images were taken between Hirtshals and Løkken. In this way, it is then possible to make a more detailed translation of each orthophoto, when comparing to the GPS measurements of the objects which can be still found in the area (Rubjerg Knude lighthouse, Løkken water tower, etc) . However, this approach needs to have at least one object in each orthophoto, so it can be related with the measurements. This solution cannot be performed, since there is a lack of information regards the number of orthophotos and lack of objects found today between Hirtshals and Løkken.

The alternative idea of detecting the translation, is to observe as many remained objects as possible across all three data sets, where in this way the translation can be estimated.

Figure 4.8: *The image translation difference between orthophotos from 2015 (colored) and 1954 (monochrome)*

For this purpose, the location of the objects area had to be picked closest as possible to the erosion line.

The measuring plan

In a previous action, the plan of the chosen objects has been made, therefore the objects could be measured with a GPS instrument in the field. The chosen points were distributed evenly between Hirtshals and Løkken, except the area between points 22 and 23, because of the lack of these objects on respective data sets. During the measurements, not all of the objects in the plan were measured with the GPS because of accessibility restrictions. The figure 4.9 is illustrating the GPS points of interest (POI) (*left*) and the location of GPS measured points of the objects (*right*).

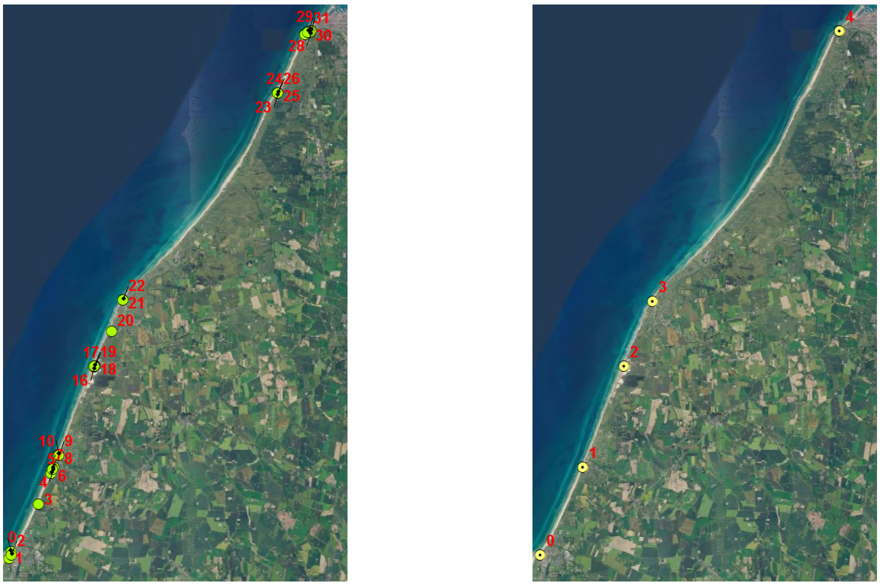

Figure 4.9: *The location of GPS (POI) points (left) and GPS measured points (right)*

Translation results

Since it was not possible to measure an object of interest directly, some of the GPS points were measured indirectly, for example the outer house corners or the GPS multipath signals. As an example on the house corners, the GPS instrument was offset 2m parallel from the wall corner, with 90° around the corner. The measured points are then constructed in ArcMap by creating a 2m circle in diameter for every measured point. When the circles are intersecting each other, then the constructed point of the corner is defined, as it can be seen in the figure 4.10.

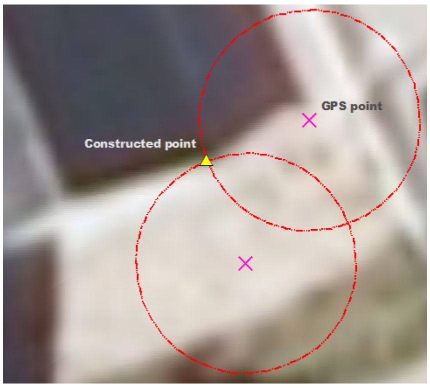

Figure 4.10: *The GPS point construction*

After all points have been constructed, the next step is to measure the translation between the GPS constructed points (*Red*) and the objects (*Yellow*) of interest on the data sets. The translation calculation approach is performed in ArcMap, by picking a GPS constructed point of the remained object and chose a second point by picking the pixel on the data sets that is representing the same remained object. Moreover, the actual translation distance result is the magnitude line of a vector $\left|Red\vec{Y}ellow\right|$ of the E and N coordinates. The distance between *Red* and *Yellow* points are calculated with simple euclidean distance equation. Here are the transition results listed in the tables 4.3 and 4.4 and illustrations of translation betwenn GPS constructed points and the respective data sets in figure 4.11 on the next page and figure 4.12 on page 27.

Orthophoto	GPS point No.	Object	Translation diff.	Translation direction
1954	0	Water tower Løkken	4.6m	South-East
	1	Bunker	3.3m	South-East
	2	Rubjerg Knude lighthouse	2.7m	South-West
	3	House-corner	3.3m	South-East
	4	Bunker	4m	South-East

Table 4.3: *The translation results between the orthophoto 1954 and the GPS measured points.*

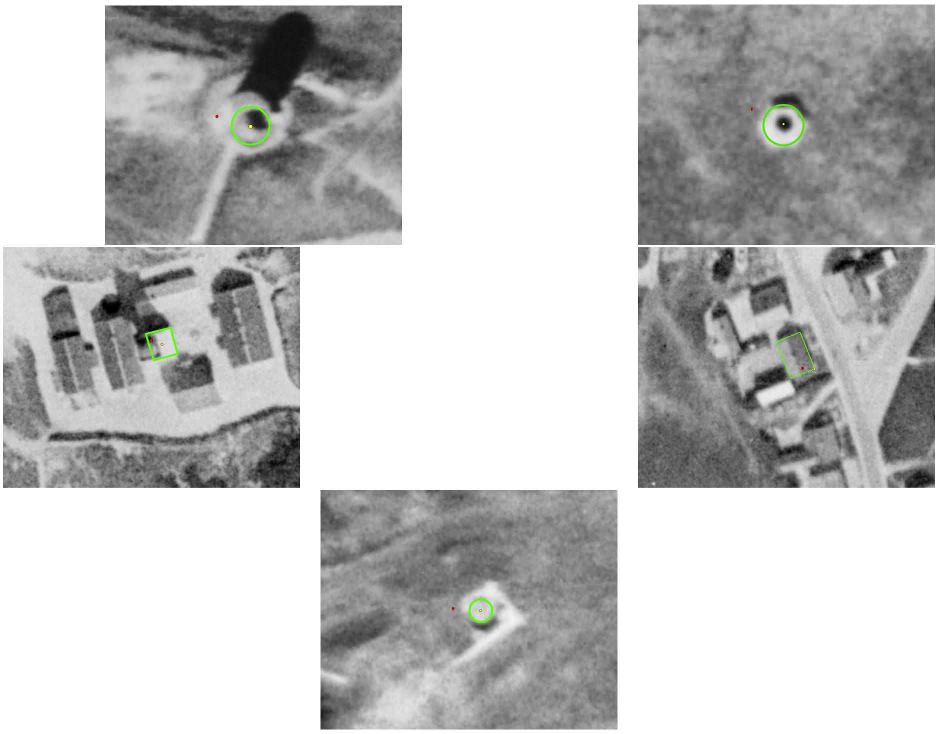

Figure 4.11: The translation difference between GPS points and objects on orthophoto from 1954.

Orthophoto	GPS point No.	Object	Translation diff.	Translation direction
1928-1945	0	Water tower Løkken	5m	South-West
	2	Rubjerg Knude light house	2m	South-West
	3	House-corner	13.5m	West

Table 4.4: The translation results between the historical map 1928-1945 and the GPS measured points.

The translation between the orthophoto from 1954 and the map from 1928-1945 have a big variation, as it can be seen in the presented tables. The orthophoto from 1954 have the largest translation at GPS point No.0 where is estimated to be 4.6m, while for the map the largest translation is estimated to be 13.5m. The smallest value was registered at GPS point No.2 in both data sets, 2.7m for orthophoto from 1954 and 2m for the map from 1928. The translation for the orthophoto from 1954 appears to be systematic in south-east direction for the most of the cases, while for the respective map, the translation direction is random.

The comparison between the historical map 1862-1899 and GPS measurement could not be performed, since there is no match with the remained objects near the coastline between Hirtshals and Løkken. In order to have an estimation of the translation, the historical map 1862-1899 is compared to the historical map 1928-1945. The roads and houses has been checked for translation along the coastline. The rough estimation resulted to be 5-15 meters in E and N coordinates.

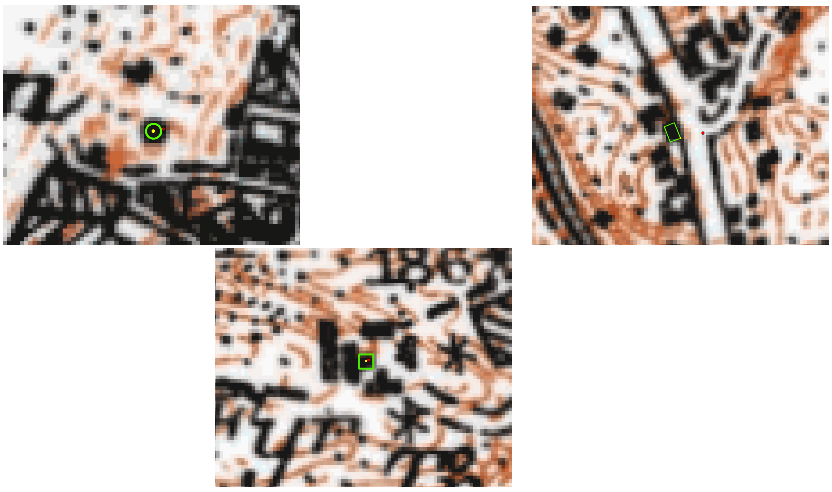

Figure 4.12: The translation difference between GPS points and objects on the historical from 1928-1945.

4.3 Software solutions

During this project work, three software which can be used for processing remote sensing data are going to be tested, using the same sample image, in order to understand better the algorithms used and how effective and accurate this software can be.

eCognition

eCognition Developer software is a powerful tool for extracting information out of an image, being most known for the *object-based image analysis*. It offers a various options of algorithms used for segmenting, classifying, reshaping, mapping and LIDAR data. Users can create their own algorithms or develop rule sets for the automatic analysis and extraction of remote sensing data.

ArcMap

ArcMap software offers two main solutions for classifying an image, supervised (which uses Maximum Likelihood classification) and Iso Cluster unsupervised classification. This subsection will present the tests held on both sample images using different parameters.

MatLab

The MatLab is a numerical computing software, which allows a user to program own mathematical models. Along the programming, the Matlab offers various toolboxes, that can be applied for specific task problems. Regarding classification of the images, the Matlab offers the "Image Processing" toolbox, which is intended for image classification processing.

5. Establishing the erosion line

5.0.1 Establishing the erosion line

The establishment of the erosion line in this project, will be based on the orthophotos mentioned in the section 4.1 on page 17. In most of the cases, the erosion line can be easily distinguished and observed considering the land covers which are delimiting it, the sandy beach and the land area covered by vegetation, as it can be seen in figure 5.1.

Figure 5.1: *The erosion line between sandy beach and land.*

However, in some cases, establishing the line between the sandy beach and the land can be difficult, due to the complexity of the land textures along the coastline. In order to illustrate the upper and lower erosion lines, a section view is created and illustrated in the figure 5.2.

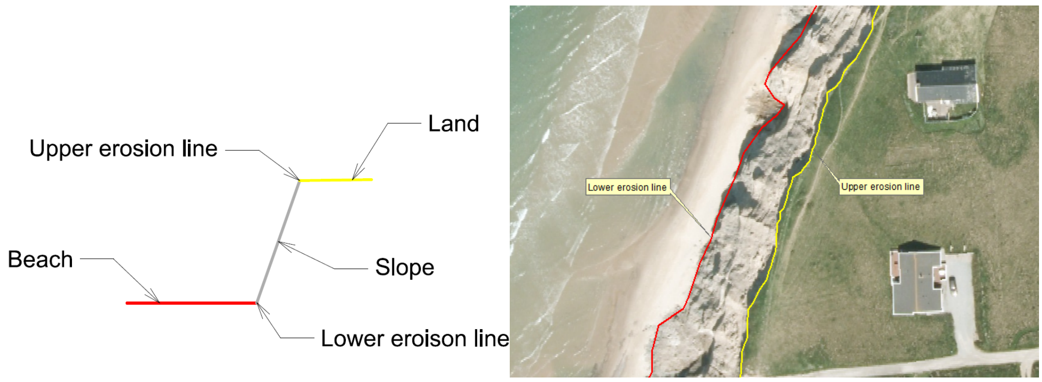

Figure 5.2: *The profile section of the erosion lines delimiting the land and beach (left) and the representation on the image*

By observing the area of interest along the shore, a classification of the line has been made, according to the most suited part of the erosion line (lower or upper part) which is going to be extracted, counting on the terrains location and situation. This establishment will be taken into account while processing all the data sets, and it is represented in figure 5.3. As it can be seen in the figure, in most of the cases the *upper line* is considered, offering the best delineation of the erosion.

In the Rubjerg Knude lighthouse area, the erosion line considered is fundamentally different than in the rest of the area. In this location, the line which delimits the sand dune from the land is going to be extracted. In this way, after the erosion lines are going to be calculated, an overview of how the sand dune evolution can be observed.

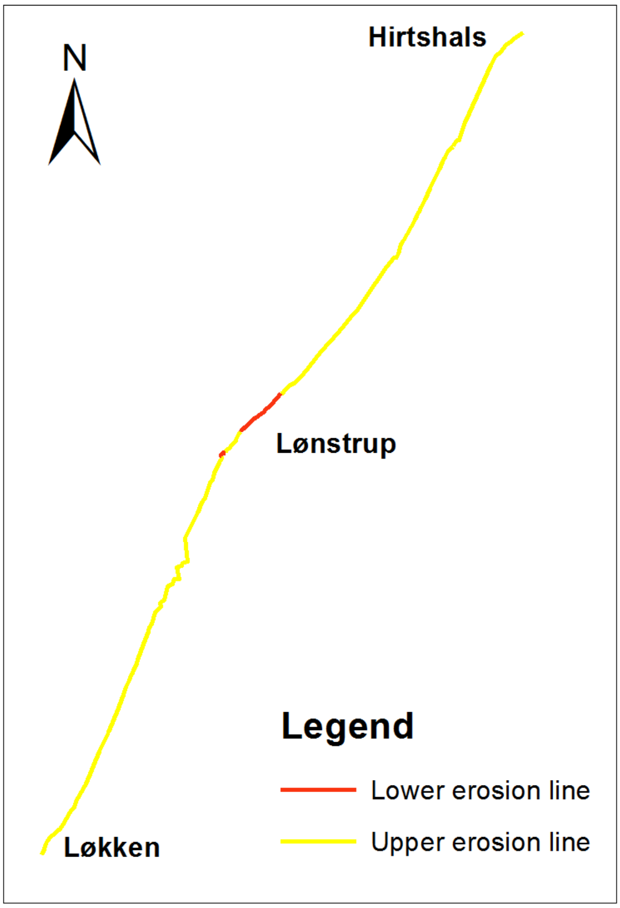

Figure 5.3: *This map represents the part of the erosion line considered during processing*

This establishment was verified using the available DHM data sets from 2007, and is going to be used when a decision have to be made regards which of the erosion lines should be used for a respective area. However, it should be also noted, that having the height model or DTM for each respective image set, the classification could be improved by merging this two data.

6. Problem statement

In the previous chapters, the purpose of the project was briefly introduced and presented. In the following part, the problem statement questions are introduced, approaching the study area to a more clear direction. The goal of this project is to extract the erosion lines according to each data set, on the segment between Hirtshals and Løkken by processing the images, using classifications and other tools. By having the erosion lines data, the analysis can then be done, in order to answer to the following questions:

The next questions are stated:

- What are the main differences in processing the images using the mentioned software?
- Is there a relation between the years when big storms occurred in Denmark and a larger erosion?
- Where are located the highest erosion / aggradation areas along the segment in interest?
- How much area was lost by erosion along the segment in interest in the last 61 years?
- What is the total length covered by erosion, aggradation or stable land along the segment Hirtshals - Løkken?
- Whats the area invaded by sand at Rubjerg Knude Fyr according to the study case period?
- Which of the constructions along the shore offered the best protection against erosion?
- How many houses and properties were affected along the segment?
- How many houses and properties are in danger?

The answers to these questions are going to be presented in Chapter 10 on page 73, based on the research and work done in the next chapters.

7. Software comparison

This chapter explains the tests held before starting processing the data. Counting on the large area which is involved in the project, and the time needed for processing, a sample area of the coastline is first selected and worked with.

The sample is going to be preprocessed using three different software which use remote sensing solutions: *eCognition Developer*, *ArcMap* and *MatLab*. The purpose of the tests is to present the approach this software have to the image processing, and understand better the differences in effectiveness, accuracy and the complexity of the tools available.

7.1 Picking the sample image

In order to understand better the software and the algorithms used, two images from different years are going to be processed, counting that the technology evolved a lot during the years, and the parameters are going to be different for each image. To be as relevant as possible, before the tests both images were clipped out using the same polygon area in ArcMap, which summarize a length of 2.35 kilometers, as it can be seen in the figure 7.1.

Figure 7.1: *The image sample from July 1995 (left) and January 2015 (right)*

The GSD is an important factor as well while classifying an image. In the available datasets the range being from **80** cm - **12.5** cm, on color images (1995 - 2015). Counting on this parameters too, it was chosen to test the 80 cm GSD (1995) and 12.5 cm GSD (2015) image. The images chosen for the tests are representing the oldest and the newest RGB imagery from the available data sets.

First, the **2015** image is downloaded from the GST database and it was taken during the month of January. That makes it harder to classify because of the similar colors of the landcovers between the beach area and the other parts of the picture. The rest of the images available are collected during summer, where the color difference between the vegetation, the texture of the soil or the sandy beach is more diverse.

While establishing the sample images, it was desired to find the most difficult area for testing the coastline extraction, where this line is hard to classify because of the texture or the time of the year when was collected, see figure 7.2.

Figure 7.2: *Example of an area from the sample image where the coastline is considered hard to define. Image from July 1995 (left) and January 2015 (right)*

Another important factor is the time consumed during image processing, therefore the test to be as relevant as possible, the size of the sample picked had to be big enough to show some differences in the time frames. In this case, the sample represents about **10 %** out of the total area which is going to be investigated during the project work.

Another detail that can be noticed from the top and which makes the classification easier, is that along the coastline there are three main shades of colors. First, the land which has no contact with the salted sea water and has a life cycle where vegetation grows involving different moisture during the year.

Second, the sand has two different shades of color, close to the established line, where the sand is dry and has a lighter shade which help extracting the information regarding the line, and the part which is close to the sea, where the sand is in contact with the water according to the tide, forming a darker shade of color, see figure 7.2.

Counting on the different time of the year when the pictures were taken for the same data set, it is hard to use just the land class for extracting the erosion line, because the vegetation in some parts of the image is not fully grown while in other parts it is. At the same time, the sand close to the erosion line have mostly the same shades of color during the whole year.

However, the best solution for extracting the erosion line is to use both classes in some of the cases where the **sand class** is not enough.

7.2 The software tests

7.2.1 eCognition Developer

During the work in the projects of the plant recognition[1] and object extraction[2], it was proven that *Nearest Neighbor* algorithm and the *Multiresolution segmentation* are the best for the job. This algorithms are explained in annex B on page 85. Using eCognition Developer and based on the experience gained in the projects mentioned above, the samples described are going to be processed and analyzed.

For the *Multiresolution segmentation* the best results occurred using the scale factor of *300*, while involving the composition of homogeneity criterion *shape* value of **0.1** and *compactness* **1**. A bigger scale would not delimit the sand and the land precise enough, the segmented objects being bigger and containing both land covers into the same image object. In this way, would be greater chances to get bigger errors extracting the coastline, see figure 7.3 and figure 7.4.

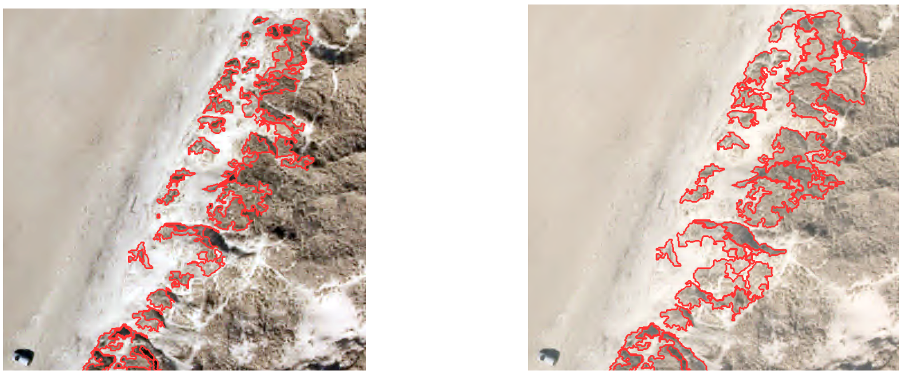

Figure 7.3: *Image segmentation. 50 scale (left) and 100 scale (right)*

Figure 7.4: *Image segmentation. 300 scale (left) and 400 scale (right)*

[1]Wrinkled Rose automatic recognition using drone pictures

[2]Mapping Giant Hogweed in Aalborg Municipality area using aerial imagery

Using a smaller scale, the objects over the coastline (in-land cover) containing the same colors as the first class (sandy beach) would bring considerable noise to the classification and deteriorate the line-shape.

During the **classification**, 6 number of classes were considered enough since the image content is not very diverse. In the feature space, which sets different parameters into consideration for the classifying algorithm, the **Mean value**, **Standard deviation** of the layers, and the **Std. to neighbor pixels** (pixel based feature) were used with the best results, considering the positive ratio between the object in interest (beach area) and the total size of the sample image.

Using *2D Feature Space Plot* tool, tests were held in a prior stage of the classification, in order to establish the best features which can subtract and differentiate the classes in the image. Counting on the correlation between the features, is easier to understand how are affecting the classification and which are the most suited to be used. The correlation value reflects the noisiness and the linear relationship between the features, where a high value (**1**) would show that the features are correlated (which would not affect the classification) and a low value (close to **0**) would mean that the features are going to make a great impact on the classification results, differentiating the classes better. In annex C on page 87, examples of the plots showing different results are presented.

The classification results, which represents the coastline extraction and mapping on the image, are presented in figure 7.5 and 7.6 on the facing page.

Figure 7.5: *Coastline classification using eCognition. 2015 data sets*

In the figures it can be noticed that the coastline is not continuous and the erosion occurred in-land, forming a interrupted pattern. However, in bigger picture, the coastline can be observed and delimited by the software using the right scale and other parameters, to automatically establish if the object or segment in interest, is composed out of more *sand* or *land* and by establishing the representative land-cover of the segment, the closest class is attributed to the image object.

In order to have a better overview of the process, the steps used by this method are presented in the flowchart D.1, in annex D on page 89.

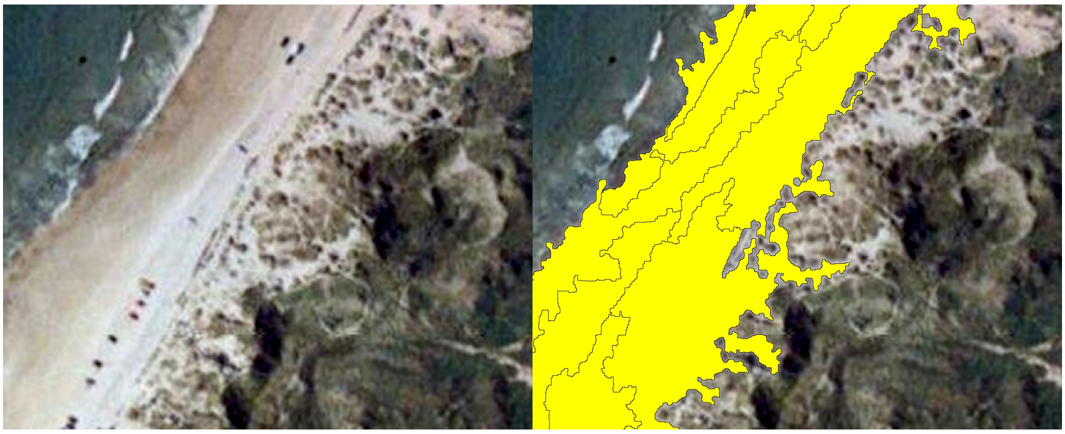

Figure 7.6: Coastline classification using eCognition. 1995 data sets

7.2.2 ArcMap

7.2.2.1 Supervised classification

The supervised classification extract spectral features using samples of land covers picked by the user. This method is performed by *Maximum Likelihood classification* on a set of raster bands using samples defined by the user and creates a classified raster as output. The algorithm used by the *Maximum Likelihood classification* is based on Bayes theorem of decision making and counts that all cells in each class sample are normally distributed. A more detailed description is presented in annex B on page 85.

As an a priori state, a signature file have to be created representing the samples which are going to be used by the classifier. This samples are selected by the user using a polygon, and are stored in a **.gsg** extention, see an example in figure 7.7.

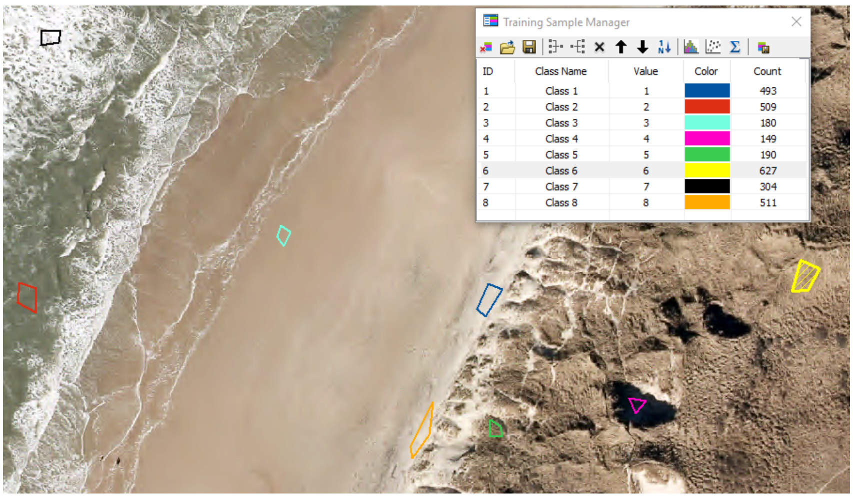

Figure 7.7: Creating the signature file. Picking the samples

Even though while picking the samples, the content is more important than the size, the results shows that bigger samples offers a better result of the classification, but the number of pixels in the training areas should not exceed 10**n** (where **n** is the number of bands in the imagery).

The *Reject fraction* tool offers the possibility to manipulate the classification. It refers about the ratio of pixels that will remain unclassified due to the lowest possibility of correct assignments. The default is **0.0**, which means that every cell will be classified. By increasing this value, some of the noise can be excluded.

A priori probability weighting offers the option to influence how the probabilities will be determined, having the next options: **equal, sample** and **file**. By selecting the **sample** option, the total number of cells sampled in the classes stored in the signature file will influence each future class relative to the samples size. A larger sample will have a bigger impact on the classification in interest.

During the next step, the image is classified and exported as a raster file, see figures 7.8, 7.9, 7.10 on the facing page and 7.11 on the next page.

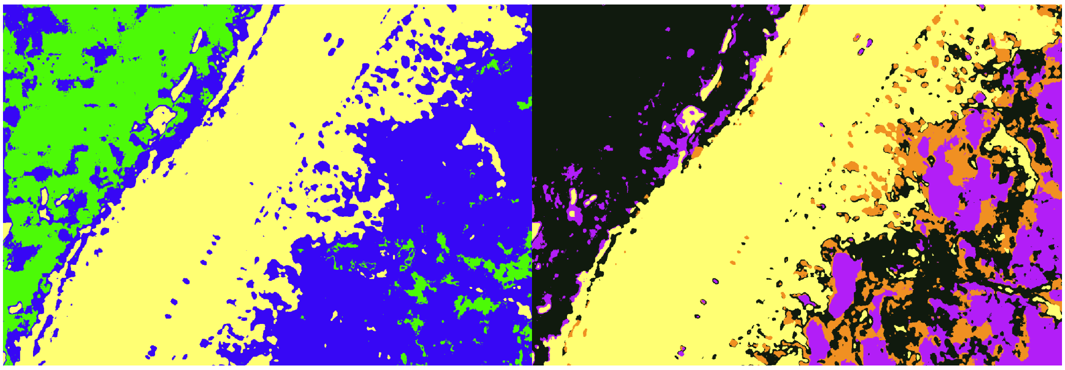

Figure 7.8: *Supervised classification using 3 classes (left) and 4 classes (right). 1995*

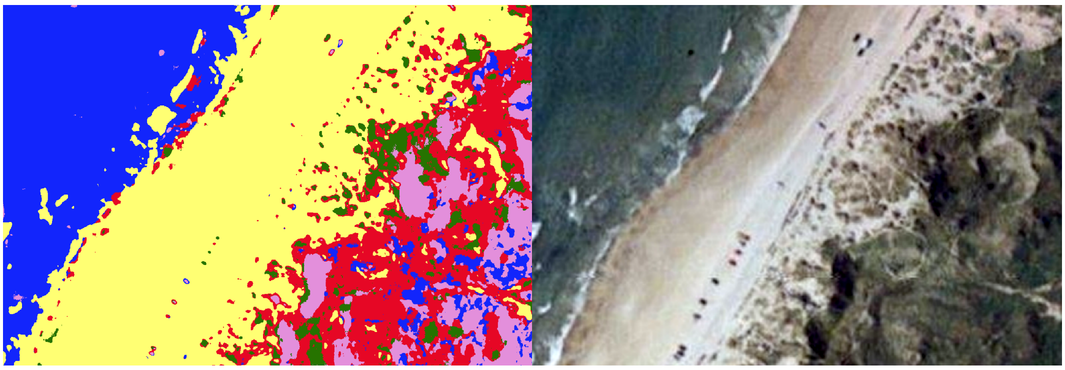

Figure 7.9: *Supervised classification using 5 classes (left) and the original image (right). 1995*

In figure D.2 in annex D on page 89, the steps of the method are presented.

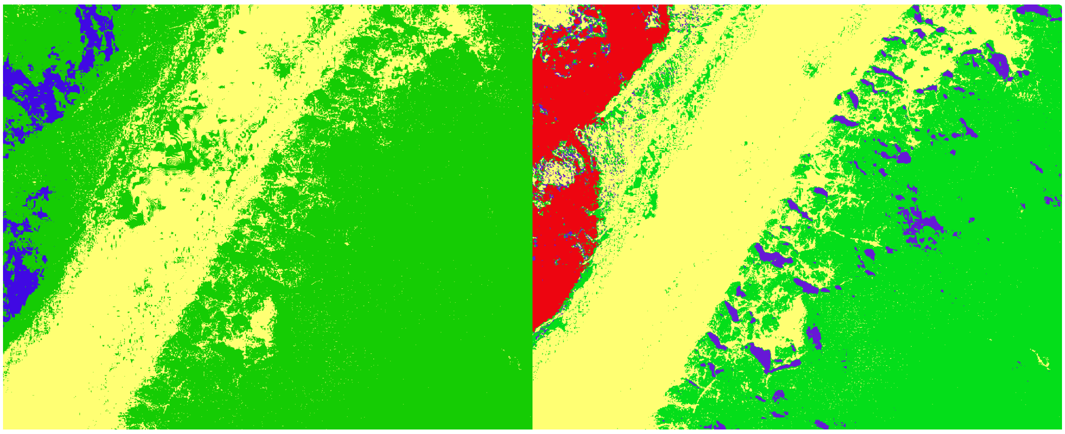

Figure 7.10: *Supervised classification using 3 (left) and 4 (right) classes. 2015*

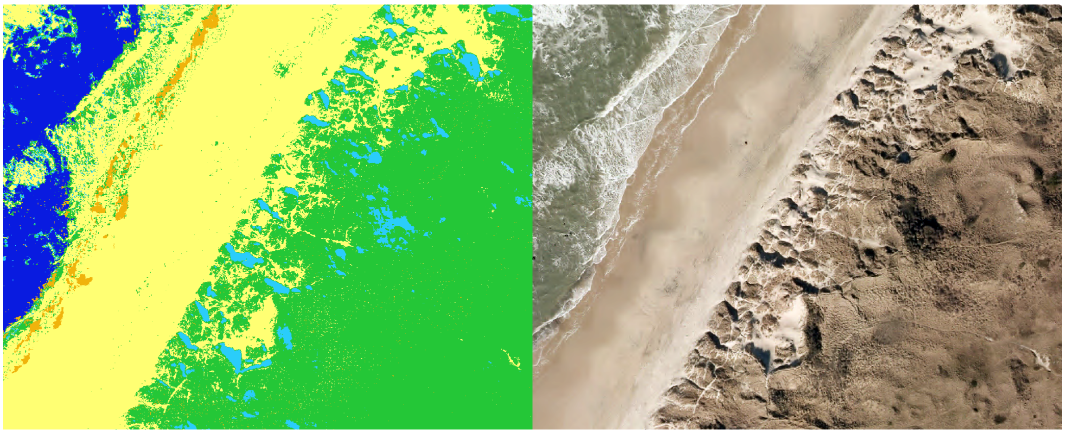

Figure 7.11: *Supervised classification using 5 classes (left) and the original image (right). 2015*

7.2.2.2 Unsupervised

This method uses both *Iso Cluster*, which uses ISODATA (Iterative Self-Organizing Data Analysis Technique) and *Maximum Likelihood classification* tools for extracting information out of an image. The algorithm is presented more detailed in annex B on page 85.

ISODATA applies user defined threshold values for the parameters used and runs the algorithm through iterations until the imputed threshold is reached, without necessarily knowing the number of clusters. Each cluster center is placed randomly, while the pixels are classified counting on the shortest distance to the center method. The user can define the standard deviation within the clusters, which are split if the standard deviation is greater than the user-defined threshold and merged if the distance defined is less.

This type of classification is more or less influenced by the data structure, where a very diverse image content would increase considerable the time of processing or the result, while it shown good results in classifying homogenous land-covers, with little user effort.

In this case, the data which is going to be processed is homogenous and structured, containing mainly 3 land covers (water, sand and land), therefore according to the theory, the time-frames for this type of classification should indicate good results.

During the next step, the image is classified and exported as a raster file, see figures 7.12, 7.13 on the next page, 7.14 on the facing page and 7.15 on the next page.

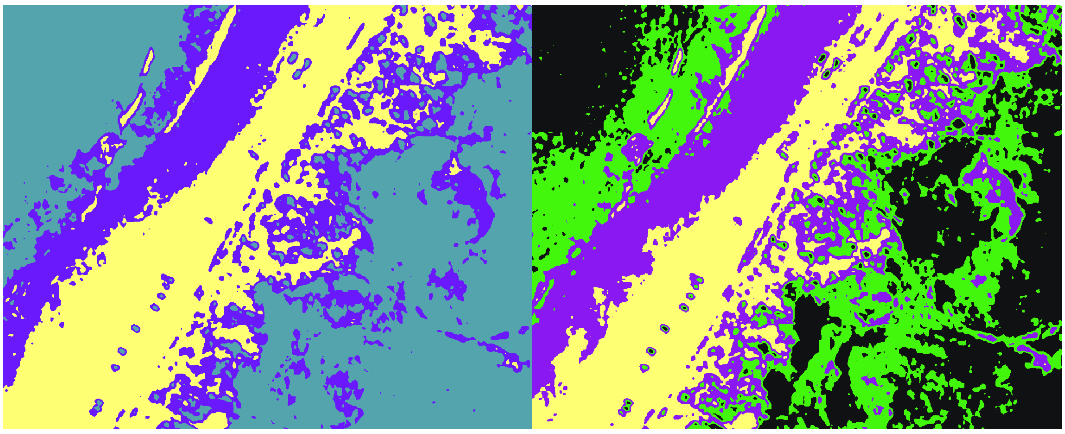

Figure 7.12: *Unsupervised classification using 3 (left) and 4 (right) classes. 1995*

The figure D.3 in annex D on page 89 is presenting the steps used by this method.

7.2.2.3 Exporting the raster file into polygons

From this point, using the tool ’Raster to polygon’, the class in interest is exported into the new file as polygons. Obtaining this new file, the geometry of the polygons can be calculated, resulting new data and statistics. At this stage, the polygons can be grouped according to their geometry, such as shape length or area, and where it can be noticed that the coastal line is represented by one or two main polygons with a considerable area.

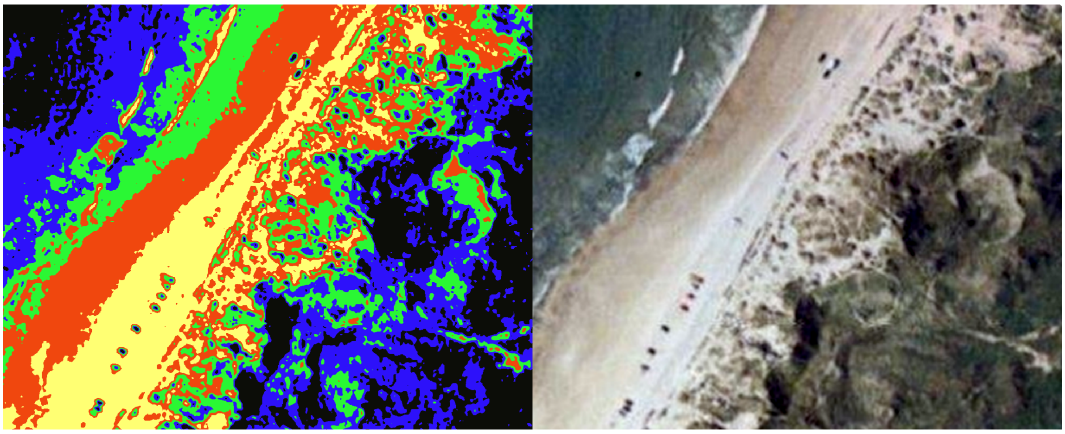

Figure 7.13: Unsupervised classification using 5 (left) classes and the original image (right). 1995

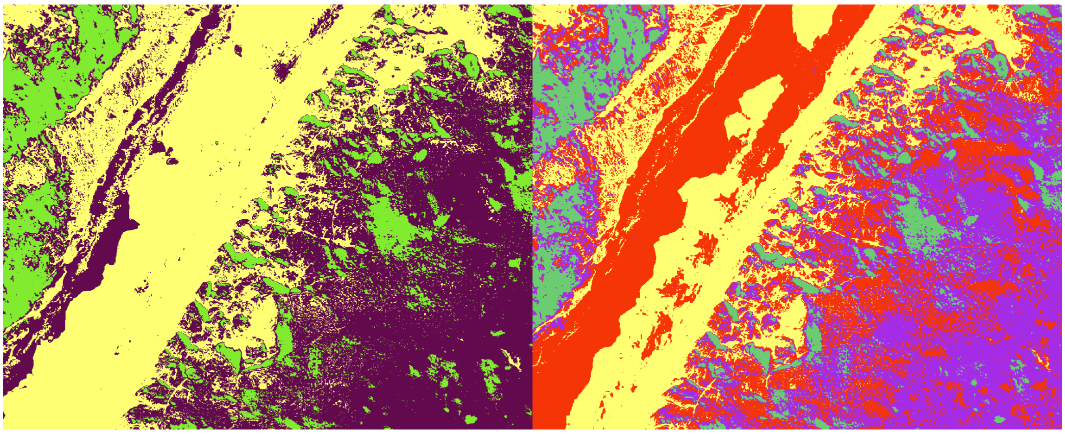

Figure 7.14: Unsupervised classification using 3 (left) and 4 (right) classes. 2015

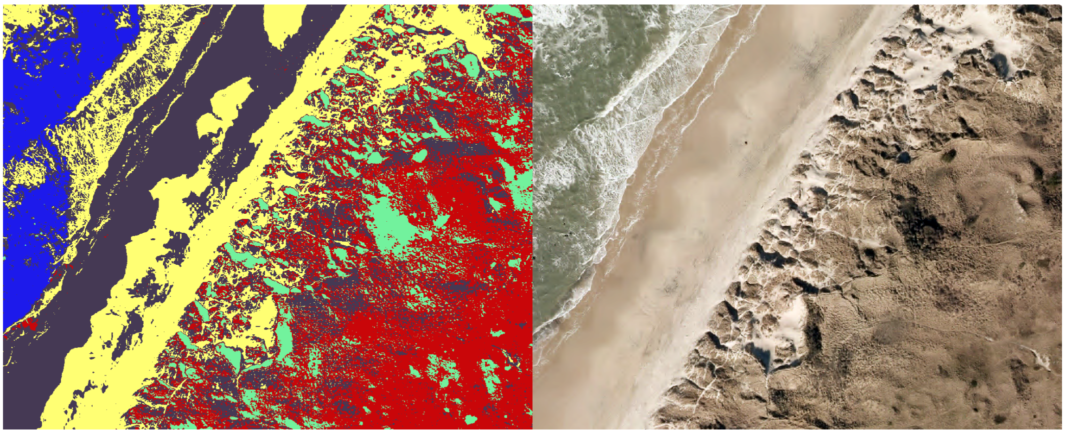

Figure 7.15: Unsupervised classification using 5 (left) classes and the original image (right). 2015

The polygons number resulted in the new file, are ranging between over 1000 polygons (1995 image, 3 classes) to over 160.000 (2015 image, 5 classes), where just one or two polygons are representing the coastline, with a considerable area, the rest having a mean area value of under $1m^2$, therefore are considered *noise*, even though are representing the same class.

By selecting the polygons in interest, a new export process is done, removing the noise and the final layer of the coastline is extracted, mapped and saved in a new final file.

7.2.3 Matlab

The Matlab software has been used, for performing an image classification. The image is processed using a Matlab-script, which is a supervised pixel based classification using Nearest Neighbor (NN) algorithm [13].[3] The given Matlab-script works in such a way, where the first step is to define classes in the script, which is entirely depending on the image information, as it can be seen in the figure 7.16. In the figures presented there are 4 classes: the circles which hold one color each: red, green, blue and the white background.

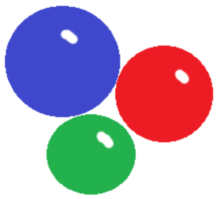

Figure 7.16: *Sample region*

The definition of the classes is important, because before picking the training sample on the given image, the user have to define the class name and relate the sample picked to the respective class in the script. The sample region gathers color information of the pixels from the image, operation done by drawing a polygon, as it can be seen in the figure 7.17.

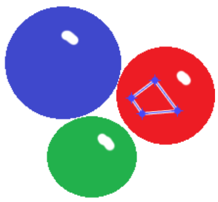

Figure 7.17: *Picking the training sample*

After the sample region has been picked, the given RGB pixel values of the image are then converted into the Lab color space (LAB) value. The LAB color is a three axis color system and contains all perceivable colors, where the L stands for lightness a and b for color-opponent, as it can be seen in the figure 7.18 on the facing page. In other words, the LAB color system is constructed to estimate color of a human vision. When working with images, this means that the luminosity and color is more flexible compared to the RGB color system. [14][15]

Before the NN-algorithm is initialized in the Matlab-script, the mean of the **a** and **b** values of the sample region for each and every classes is calculated. The next step in the script,

[3]The Matlab-script coding file can be found on the CD attached in the annex A on page 83.

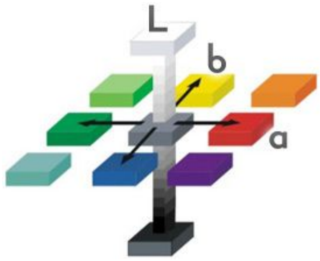

Figure 7.18: The LAB color system[15]

is to classify each pixel using NN-algorithm. The algorithm is using "Euclidean distance", which is basically calculating a distance between each pixel. The smallest distance between every pixel is resulting the closest match. At the end of the script, the class color is defined for each class, so the classification result can be illustrated according to the user preference, after the image has been processed in the script.

Matlab Test

The sample image that was used in the previous tests, cannot be processed in the Matlab as a one whole image. This is because the sample image has a high pixel resolution and when the image has been run for the first time in the Matlab-script, it has resulted a high RAM consumption of the given computer and Matlab have automatically aborted the image classification process.

Therefore the image sample must be split, in order to be processed in the Matlab-script. The solution for this problem was to use the ArcMap software and create three different polygons, where the image will be cut within polygons geometry, as it can be seen in the figure 7.19. In this way, it is ensured that the imagery is not heavy for image classification process, running one image part at a time.

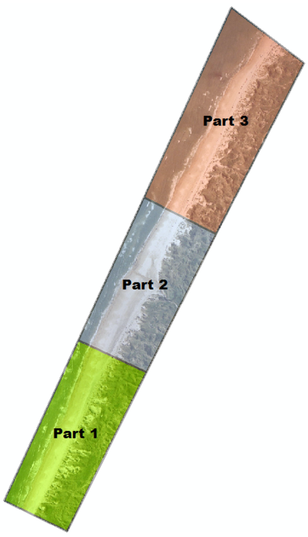

Figure 7.19: The divided image sample by using three polygons

During the classification, it was used 4 and 6 classes for the image sample “Part 3”, as it can be seen in the figure 7.20 and the figure 7.21. The classification processing on the orthophoto from 1995 with 4 classes, have resulted a more acceptable classification than the test with 6 classes, as it can be seen in the figure 7.20.

This can be seen by looking at the overall erosion line on the given image, where the test with 6 classes has a wrong classification in the northern area part. This test showed, that the image classification process with 6 classes is worst than using 4 classes for the 1995 orthophoto with 80cm GSD.

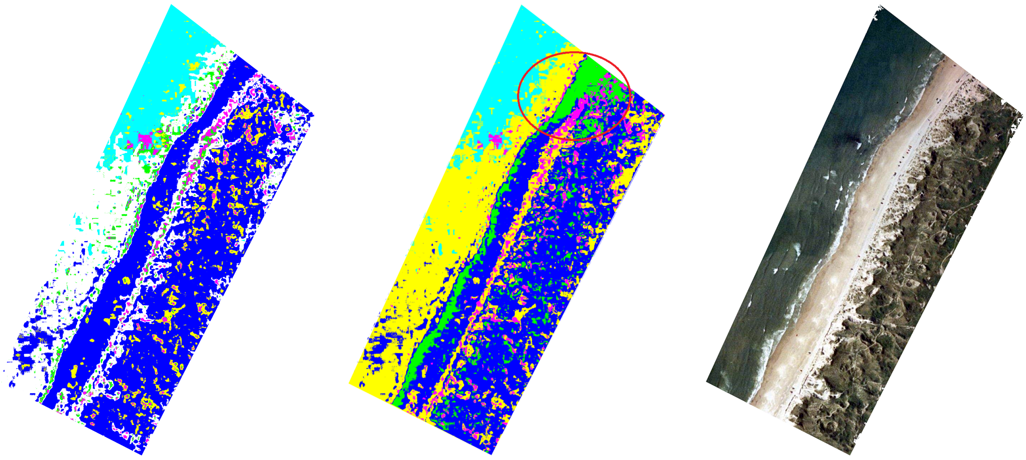

Figure 7.20: *The 4 and 6 classes performed on the image from 1995 and original orthophoto for comparison*

The image classification process is also performed on orthophoto from 2015 with GSD at 12.5*cm* with 4 and 6 classes, as it can be seen in the figure 7.21. Both images have a high detailed classification and delineation of erosion line along the total length of coast line. However, the image with 6 classification has slightly more detailed erosion line. This is because the algorithm has classified the smaller objects along the erosion line, which is concluded to be a acceptable classification.

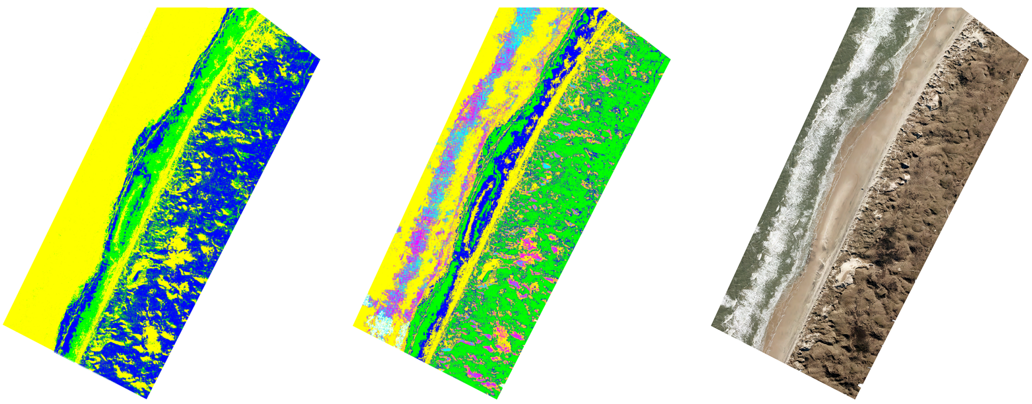

Figure 7.21: *The 4 and 6 classes performed on the image from 2015 and original orthophoto for comparison*

Since the processed image with 4 classes from 1995 and the image with 6 classes from 2015 are the most successful classifications, then further investigation will be performed, in order to have a closer look of classified erosion line. However, the further investigation is performed in ArcMap, because the current Matlab-script is not able to extract the classifications and make further classification analysis. In addition to this, the script has a possibility to add new coding features, where in the project time there will be no interest for this, since it is time consuming.

The resulted raster files have been imported in ArcMap, in order to extract the coastline classification and compare it to the original orthophoto from respective years, as it can be seen in the figure 7.22 and the figure 7.23 on the next page.

For illustrating of the classified erosion lines for the image from 1995 and 2015, the "RGB composite" and "raster to polygon" tool is going to be used. The RGB composite tool, allows the user to adjust the RGB bands on the given image, therefore the classification can be highlighted. This particular tool is chosen since the classification from the image 1995 is difficult to extract with the polygon tool. This is because the given classes are not able to be converted into each polygon, therefore when picking one polygon, several other classifications are also picked.

During the RGB composite adjustment performed on the image from 1995, as it can be seen in the figure 7.22, it is difficult to highlight one specific classification. This is because when choosing to extract the classification in interest, then the other classifications are interfering, when shifting between RGB color bands. Regarding the erosion line, the RGB composite is not able to extract a fine erosion line for this particular clustered location, due to the poorly defined classification of the image.

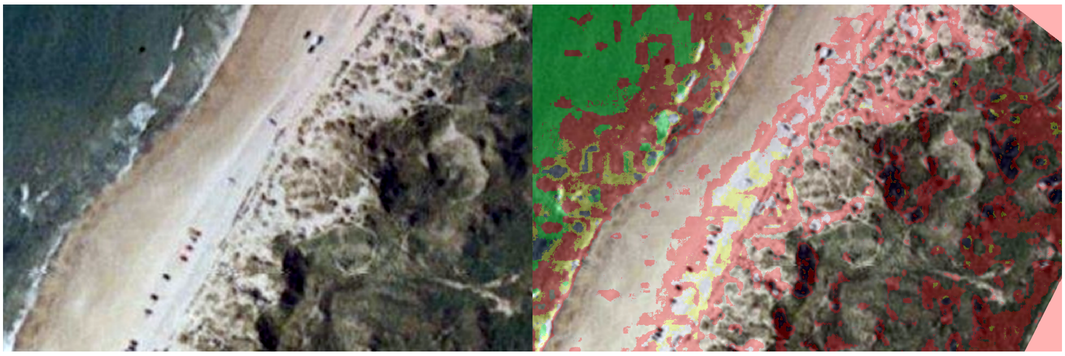

Figure 7.22: *Coastline classification using RGB band composite for 1995 data sets*

The RGB composite is also tested on image from 2015, in order to see classification extraction compared to the results of the image from 1995. However, the erosion line is well defined and can easily be seen, compared to the image classification results from 1995 data sets. This is also reasonable, since the classification of the image from 2015 is more precise and there is less interference between classes, when shifting between RGB bands.

In the figure 7.24 on the next page, the extraction of classes with polygons is illustrated. The extraction is showing that the beach line is not fully extracted for image 1995, due to the poor classification mentioned earlier. The classification from 2015 has been also converted into polygons and the results are showing higher accuracy.

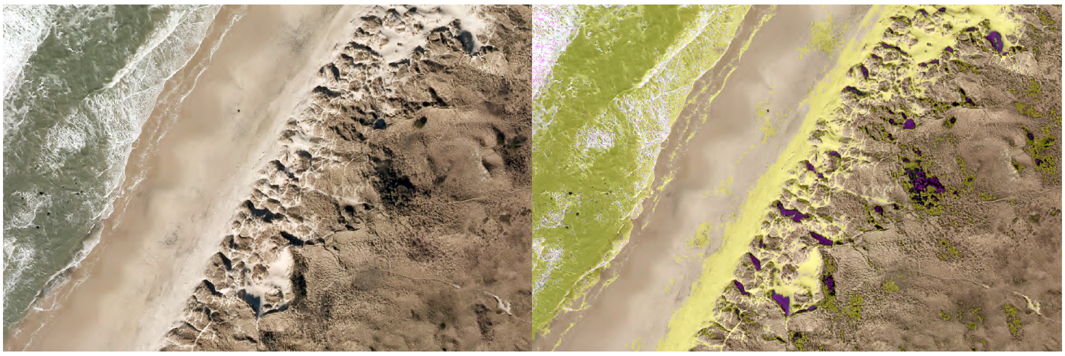

Figure 7.23: *Coastline classification using RGB band composite for 2015 data sets*

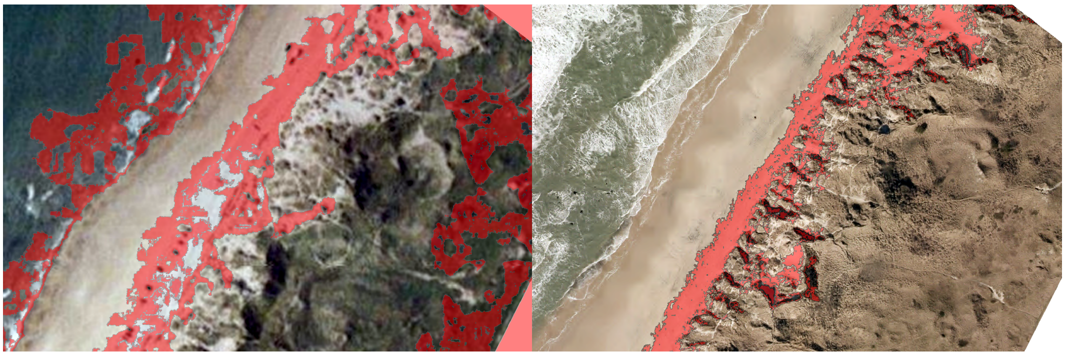

Figure 7.24: *Coastline classification using polygon for images 1995 (left) and 2015 (right) data sets.*

The flowchart presenting the steps taken into account by this method are presented in annex D on page 89, in figure D.4.

7.2.4 Time frames

Since the project is dealing with considerable large areas, involving many data sets, the time spent during processing the data is important and valuable. During this section, where different software were tested, the process time frames were recorded and presented in table 7.1 on the next page.

There are several factors which are influencing the speed of processing an image, from the image resolution and size, the software used, the hardware capability of the computer or on what device is the data is stored (external, harddrive). For the tests results to be as relevant as possible, two data sets from different years (1995 and 2015, involving different parameters) were tested in parallel using the same computer.

The frames presented in the table 7.1 on the facing page, are referring to the sample image (2.35 kilometers) used for the tests, and are including the time spent on creating the signature files, filtering the data, transforming the raster files into polygons or the segmentation and classification process in eCognition.

Software / Year	1995	2015
eCognition (scale 50)	14	29
eCognition (scale 100)	20	25
eCognition (scale 300)	15	20
eCognition (scale 400)	12	17
ArcMap (Unsupervised)	**8**	**12**
ArcMap (Supervised)	**12**	**16**
MatLab	15	15

Table 7.1: *The time frames of the tests. The values are represented in* ***minutes****.*

7.3 Conclusion of the planning

1. Having a large GSD value will decrease the image quality but will make it easier to classify and establish the coastline by the software, with the cost of a lower accuracy. Contrary, a small GSD value will increase the accuracy of the classification but will make harder for the user to extract the coastline because of the high detail imagery.

2. The pixel-based classification uses a pattern which groups the raster in objects where there is a continuity of the same class. If pixels of the same class are neighboring each other, there are going to be grouped in one polygon, contrary if the pattern is interrupted by other land-cover, the output will be a different polygon. This pattern allows to differentiate the output of the same class in different polygons sizes. This would not be possible in *Multiresolution* segmentation, because of the scale factor.

3. While Maximum Likelihood classify an image, it does not involve the scale factor, therefore groups the image objects in different sizes. After exporting the raster file into polygons, the area in interest is mainly represented by a few objects, making it easy to clean the *noise* afterward.

4. According to the time frames, ArcMap is the fastest / effective software when comes to processing the images, offering satisfying results for the project purpose. eCognition offers a wider variety of tools, which allow a more detailed analysis, but takes more time to process the data.

5. Counting on the homogeneity of the image, which contain mainly just three land covers (water, sand, land), the classification process does not need a large number of classes in order to differentiate the land covers.

6. The current Matlab-script cannot process the total sample image, because is using a large amount of RAM. This is not an effective solution, considering the length of the area in interest or the results obtained, comparing with the other two software tested. However, the script can be even further developed, in order to perform filtering of the classifications obtained. When compared to the other software solutions, MatLab shown good results in classifying images with small GSD (12.5cm), in contrast with the results obtained in classifying the images with large GSD (80cm).

7. Referring to the **test area** and the image diversity, the ArcMap processing results shown that there is not a significant difference in the line contour by using supervised or unsu-

pervised classifications. However, the *supervised* classification is going to be used in the project work, because is offering considering more tools and control in the process, which is very important considering that the whole segment is going to be processed at once, in order to be as **automatic** as possible.

8. The classification goal is to extract the coastline, therefore the most important procedure is to differentiate the land-covers which are forming it. Because of the image quality and diversity (images from the same year are collected in different periods of the year, resulting in color differences along the segment) and the large area involved (along the coastline the sand can have many different colors or it can be shaded by the high coast because of the angle between the camera and the sun), in some areas it is impossible to extract the coast line using just one class along the area in interest.

9. eCognition proved to be the best suited software for the image analysis, offering the best results in the coast line extraction. It offers a more advance approach involving a bigger variety of tools, where the user can manipulate the data in order to narrow the focus to the existing problem. Not the least, other data sets can be involved such as vegetation indices or LIDAR, which would help extract the coastline based on other parameters. However, since the project group could not rely on using the **eCognition license** during the project work, it was decided to use ArcMap for solving the task.

8. Data processing. The coastline extraction

8.1 The process

In the previous chapter tests were held involving different software, in order to understand better the differences between these approaches, classifying algorithms along with the parameters involved, and how to extract the coastline better and more effective. The project group was limited to choose between ArcMap and MatLab, since the license for eCognition Developer could be used just for a limited period of time.

Not the last, the meta-data of the processes is important and gives understanding of how the problem was narrowed during the project. This chapter will present the steps used for processing the images, from the start till mapping the geo-referenced line which was extracted.

The data was processed counting on the next steps:

1. Image classification

The images were classified using the supervised *Maximum Likelihood* classification. Because of the big differences in *GSD, color, luminosity, weather conditions, sun position, the season or the year* when images were taken, involving differences in technology according to the times, it is hardly possible to define a standard number of classes which can be used in all the images. However, the best results occurred using 4 classes for the images with a large GSD and 6 classes for the images containing a small GSD.

The classification goal is to delimit the classes which neighbor the coastline as accurate as possible. Mainly, the *sand* (beach area) class was used, but often where this class fail to extract the coastline because of different problems as ones as mentioned above which can occur, the neighboring class is used to continue the alienation.

1.1 Creating the signature file. Picking the samples

Again, the dissimilarities between the data sets, makes the automatic extraction hard to obtain, a signature file for each data set (year) being mandatory. As it was described in section 4.2 on page 21, the same orthophoto is composed out of many different images. Each class have more samples in the signature file containing different shades of the same class picked along the image, with the focus on the class in interest.

The **histogram** windows were used to compare more accurate the distribution of the multiple training samples used. In order to pick samples from different classes best as possible, they should not overlap each other in the histogram.

The **scatterplots** offer another way to check the accuracy of the samples picked by showing the correlation between the values of the samples picked in relation with the bands in

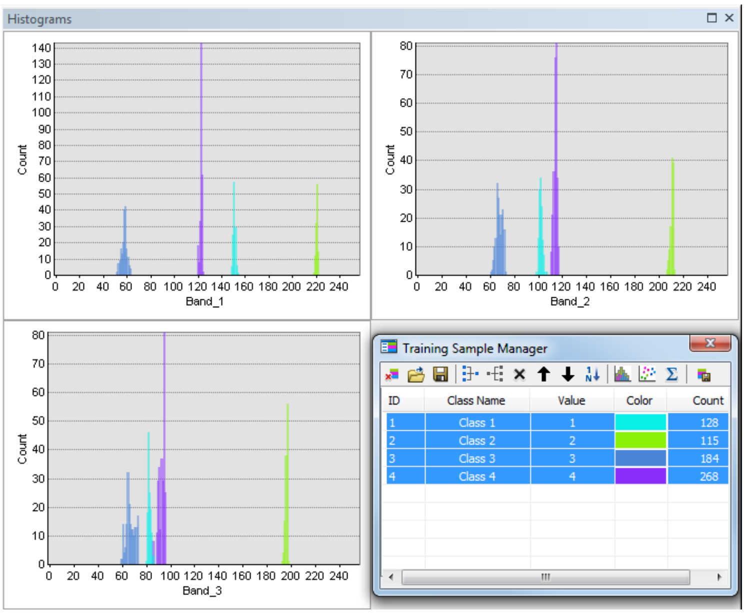

Figure 8.1: *The histograms representing 4 classes well defined*

interest. More, each sample is represented on a graphic showing the diversity of the colors spread along the scale in the sample picked. In the figure 8.2 there are exemplified some cases.

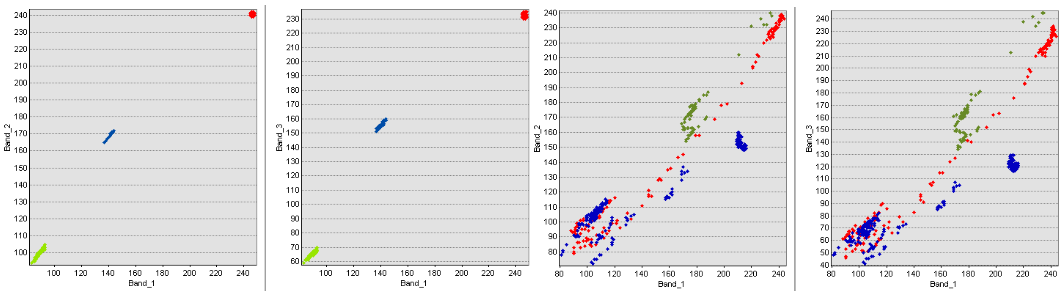

Figure 8.2: *Scatterplot representing an accurate sample pick (left) and scatterplot showing imprecise samples which contain many colors along the spectrum (right)*

Not the least, the **statistics** show information about the class samples picked by offering *Minimum, Maximum, Mean, Std. deviation and Covariance* values for each band in every class. The covariance is referring about evaluating the correlation of the cell values of each band from the raster image. However, the correlation is presenting how dependent are the cells values in the raster image bands.

2. Raster to polygons

Using this tool the classification raster with the class in interest is transformed into polygon features. Because there were used a relative small number of classes (4-6 classes) and counting on the area processed, the number of polygons obtained for each class is very large (approximately 200.000) depending on the image quality and diversity.

Since the classification used is pixel - based, the image is segmented into objects counting on the diversity of the image. The area of the objects is varying according to the image structure. In this way is easy to group them and select the ones in interest.

Therefore, using the area field, the polygons are organized according to the area coverage and the ones which are representing the coastline are selected. The largest polygons were found to be the ones which are representing the coastline along most of the shore. In some cases, where the line cannot be delimited by this class, the neighboring class polygon is used. The results obtained during the filtering and the percentage of the data left is presented in table 8.1.

Image	Polygons extracted from raster	Polygons filtered	Polygons left %
1862-1899	19.449	116	0,6
1928-1945	32.577	41	0,13
1954	176.135	51	0,03
1995	35.082	18	0,05
1999	48.538	61	0,12
2002	111.109	38	0,03
2004	212.441	30	0,01
2006	204.304	63	0,03
2008	84.288	52	0,06
2010	204.229	60	0,02
2012	9.797.572	6	x
2015	1.090.736	18	0,002

Table 8.1: *The process of the polygons extraction and filtering. Percentage of the polygons left*

3. Feature to line

This operation consist in creating lines using the polygons boundaries obtained in the previous action. A part of this lines represent the coastline, while the rest are considered **noise**. The evolution of the results is presented in table 8.2.

Image	Total lines	Final lines	Coastline %
1862-1899	25.592	498	1,94
1928-1945	39.658	270	0,06
1954	9.386	1.218	12,97
1995	19.937	462	2,31
1999	30.405	262	0,86
2002	7.222	989	13,69
2004	11.037	2.074	18,79
2006	234.690	4.424	18,67
2008	19.364	1.993	10,29
2010	7.828	1.064	13,59
2012	53.370	1.580	2,96
2015	685.029	x	x

Table 8.2: *Extracting the lines. Values*

For the first data set used (1995), the lines are picked using the function *Select features* and the final lines representing the coastline is exported. For the rest of the data sets, the function *Select by location* with a search distance of **5 m** is used, and the previous year final line as *Source layer* in order to select the lines which are neighboring the coastline. The noise left in the data set is removed and the final line is ready to be mapped.

In the figure 8.3 and figure 8.4 the process is presented step by step from the classification process until mapping the line.

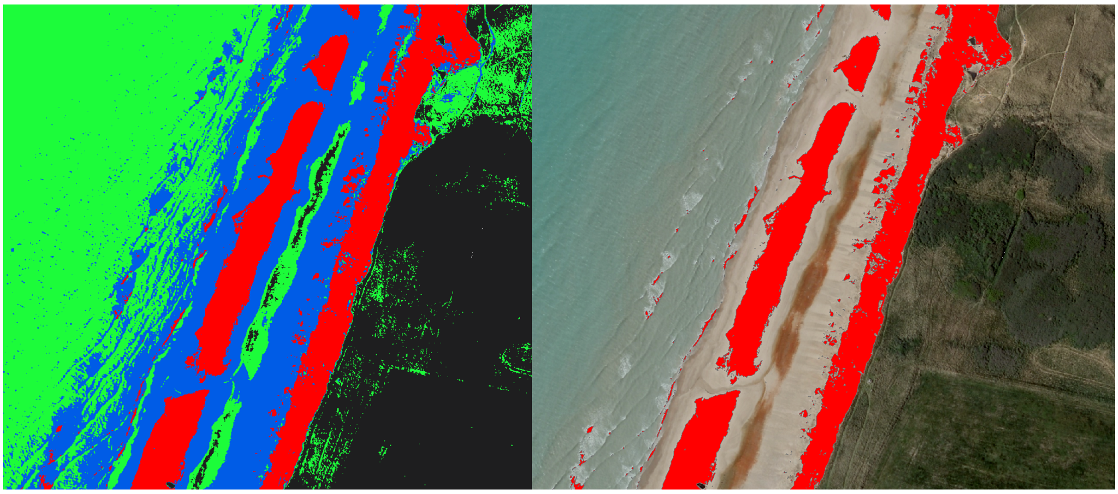

Figure 8.3: *The classification result (left) and the polygons exported representing the class in interest (right)*

Figure 8.4: *Transforming the polygons into lines (left) and the coast line mapped after the noise removal (right)*

The flowchart presenting all the steps taken into consideration while processing the images are presented in figure 8.5 on the next page.

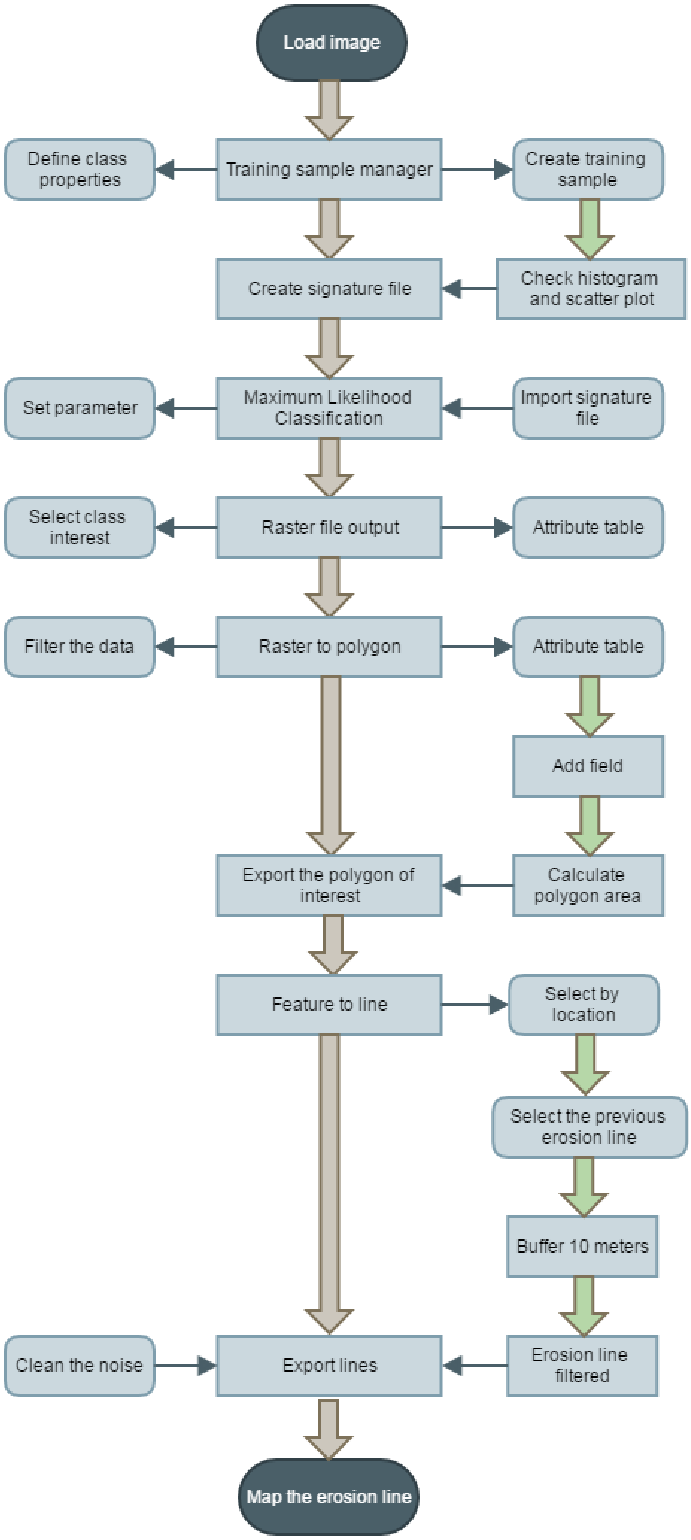

Figure 8.5: *The flowchart of the image processing*

8.2 Classification accuracy

After the classification process have been performed on the respective orthophotos, a careful visual inspection is done along the lines and it can be noticed that the classification results coordinate satisfying to the imagery real world objects to the smallest detail. However, there were several factors which affected the classification accuracy in this project: the GSD value, the training samples used for the classification and the color balance of the imagery. By having orthophotos with higher resolution quality, the objects on the land appear more clear than in the images with lower resolution. In this way, the training samples picked from the new data sets are more accurate than the ones picked from the images containing high GSD.

The classification accuracy also depends on the users experience while performing a training sample for supervised classification. In order to be efficient, the goal was to execute the image classification on the whole orthophoto representing the segment between Hirtshals and Løkken. By taking this decision, the users have encountered challenges while creating the training sample, because the objects colors along the defined stretch are unbalanced, making it harder to produce a solid and unique signature file, which represents and describe the whole image. The solution was to pick several samples for each class within each unbalanced color area, in order to ensure that most of color difference has been considered for the training sample.

As it can be seen in figure 8.6 and figure 8.7, the erosion line pattern from each data set is exemplified while following the same line shape, according to the coast morphology.

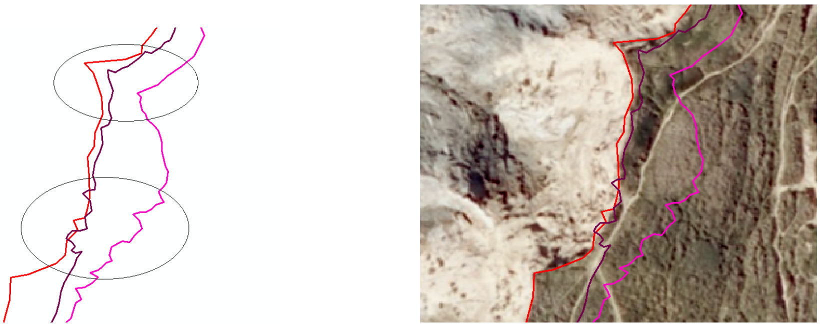

Figure 8.6: *The erosion lines following the same pattern (left) and 2010 image (right)*

Figure 8.7: *2012 image (left) and 2015 image (right)*

9. Final results and comparison

In chapter 8 on page 49 the process of the erosion line extraction process was presented and explained. The output of this process is **12 polylines**, one for each data-set, which delimit two different landcovers, the beach area (sand) and the land area (soil and vegetation). These polylines represent the erosion line and are going to be used for obtaining the next statistics and results.

Having this new data sets, obtained after the image processing, using just color differentiation and classification, other new statistics and comparisons can be obtained when combined and observed in relation with other data sets.

9.1 The image processing results

9.1.1 Erosion lines

In bigger picture, the lines are following a parallel pattern, respecting the shore line to the smallest detail along the area of interest. As it can be noticed in figure 9.1 on the next page, the erosion is systematic starting from the historical maps, and ending with the orthophotos covering the last 20 years, where the erosion line could be estimated more accurate, as it can be noticed in the line pattern. For the full representation, please see annex E on page 93.

Since the historical maps are not accurate enough and it is impossible to estimate the erosion line according to these maps (the historical maps are showing the coast line), the first orthopotho chronologically was used to relate and calculate the erosion.

However, in bigger picture, the historical maps give an important understanding of the erosion process, especially when such a long time interval is involved, more than 110 years.

9.1.2 Danish Digital Elevation Model 2007

Since the only *Digital Elevation Model* available is from the year of 2007, the **2006** erosion line result is used to check and confirm the height of the line extracted.

As it can be seen in annex F on page 95, the erosion line extracted from 2006 image is lying along a high elevation value, which confirm that this line is established to represent the top part of the sea wall. Along the whole image the erosion line is mostly intersecting with elevation lines with values over **15 - 20 meters** and in some remote cases touches values of minimum **5 meters**. The elevation model confirms a good erosion line extraction.

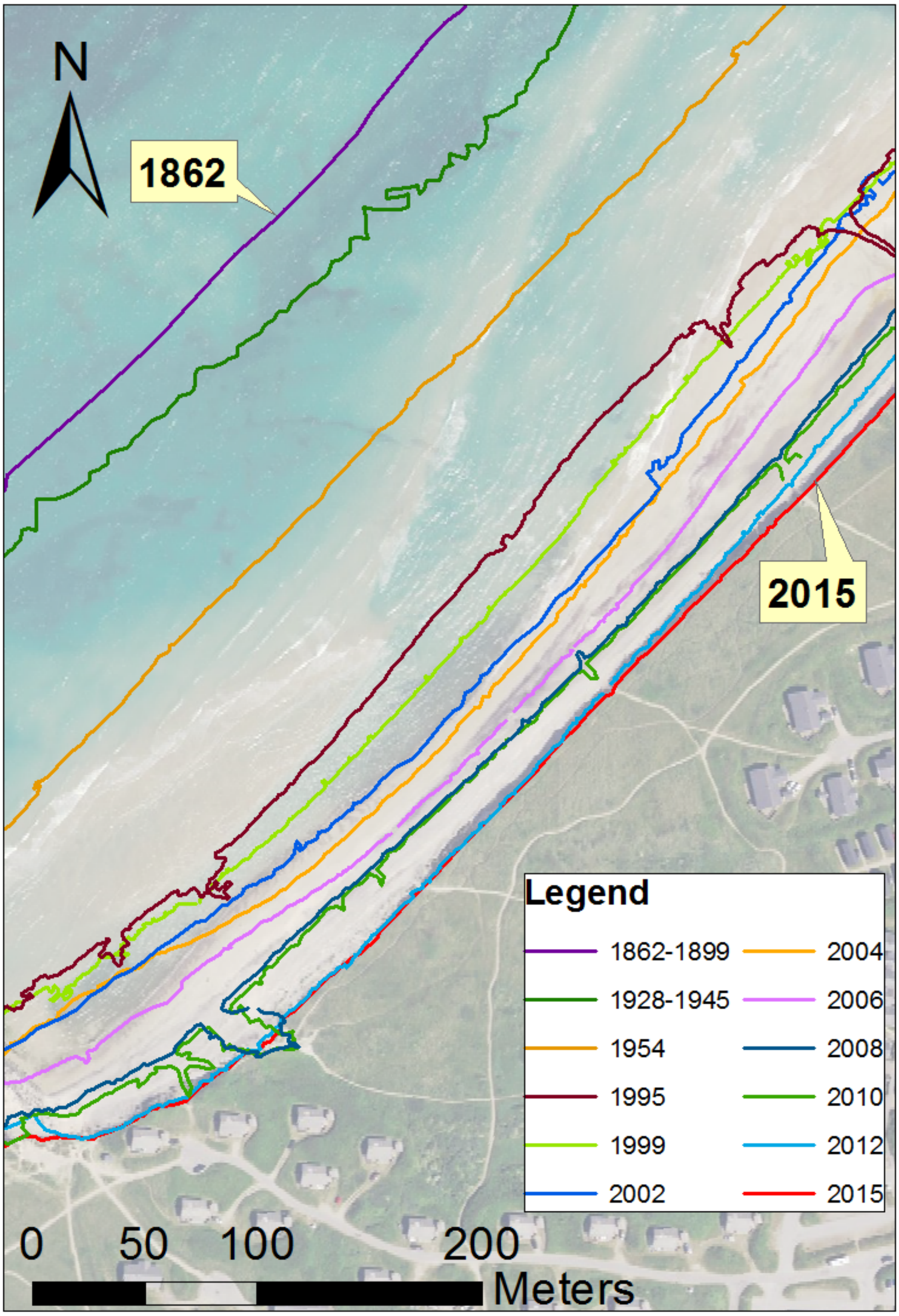

Figure 9.1: *The erosion lines. From the oldest data-sets (left) to the newest (right)*

Not the least, the DEM was used to extract the coastline according to the height measurements. The elevation lines from the DEM, which best suit the coastline according to the image[1], are situated between a height of **3 - 4 meters** above the sea level, with a good delimitation along the image. Finally, for the **2006** data sets, both coast line and erosion line are extracted, and at this point both lower and upper part of the cliff (sea wall) profile is available and mapped for the whole area. An example is presented in figure 9.2.

Figure 9.2: *The coastline extracted from the DEM (light blue) and the erosion line obtained from the image processing (red)* ***2006*** *data sets*

Having these two lines mapped, it is easier to have an overview of the sea wall, by observing the distance relation between these lines and understand better how **steep** the coast wall is.

9.2 The study case

The study case is describing the overall situation along the area of interest, counting on 2 data sets, **1954 - 2015**, summarizing the situation in the last **61 years**. Obtaining this layer, the erosion behavior and pattern can be observed over a long period of time.

In order to estimate easier the erosion along the area, a erosion classification is established and presented in the table 9.3.

		Erosion			
Aggradation	**Stable**	**1**	**2**	**3**	**4**
more + 5 m	**± 5 m**	[-5 ; -20]	[-20 ; -50]	[-50 ; -100]	more - 100 m

Figure 9.3: *Erosion classes and values for the study case*

[1]The image used for DEM comparisons is from 2006 data sets again, being the closest one to the year of the DEM production (2007)

The values expressed in the table are describing the differences in distance of the mentioned lines. This relation express the intervals and the direction of the migrating landscape through years.

This layer was obtained by selecting automatically the lines according to the values established in the classification intervals. In this way, 6 continuous lines representing the classes described are obtained and mapped along the segment according to their location. In annex G on page 97 the map showing the erosion situation for the study case period is presented.

In table 9.1, the parameters for each process is presented. The longest segment describes the largest interval of the erosion line class without being interrupted by other class, while the total length of the segments along the area investigated in this project offers an easy overview of the situation which occurs during the study case.

			Erosion			
Process	**Aggradation**	**Stable**	***1***	***2***	***3***	***4***
Longest segment (m)	1450	2600	1273	951	1408	2080
Total length (m)	**3990**	**6419**	**4617**	**4323**	**7687**	**4117**

Table 9.1: *The erosion values according to each class. Study case*

9.3 The detailed analysis

The detailed analysis is covering the last **20 years** (1995 - 2015), and is composed by **9 data sets**. Having the erosion lines available for almost every two years, the acceleration of the erosion can be observed and used for some of the cases among other studies which need a detailed analysis.

Since in this analysis are involved different periods of time, the erosion values will be different than the **study case**. In the table 9.4, these established values are noted:

		Erosion			
Aggradation	**Stable**	**1**	**2**	**3**	**4**
more + 5 m	**± 5 m**	**[-5 ; -20]**	**[-20 ; -40]**	**[-40 ; -60]**	**more - 60 m**

Figure 9.4: *Erosion classes and values for the detailed analysis*

This layer was automatically obtained by selecting the erosion lines which represent the relevant period of time (1995 and 2015), according to the classes mentioned in the table 9.4. The output of this operation is the **erosion line** which indicates the erosion activity in that specific area. In annex H on page 99 the map showing the erosion situation for the last 20 years is presented.

In table 9.2 on the next page, the detailed analysis erosion results are presented:

			Erosion			
Process	**Aggregation**	**Stable**	***1***	***2***	***3***	***4***
Longest segment (m)	819	2951	702	218	269	811
Total length (m)	**1943**	**13216**	**8704**	**2075**	**1489**	**3880**

Table 9.2: *The erosion values according to each class. Detailed analysis*

9.3.1 Rubjerg Knude Lighthouse dune coverage

In the location of the Rubjerg Knude lighthouse, a strange effect is occurring, caused by the the sea winds from the west. Except the coastal erosion happening in the area, the land neighboring the lighthouse is progressively covered by a sand dune. Counting on the dominant transport direction and the North Sea winds it can be anticipated that the sand comes from the south of the lighthouse, towards east.

It was decided not to extract the erosion line located in the cliff area, which would have been very hard to extract based only on the orthophotos and image classification, but to inspect the coverage of the dune which could highlight interesting results.

The extracted lines from the respective orthophotos, are presenting the sand dune coverage direction for each data set, not the erosion lines at the cliff which are neighboring the sea, as it can be seen in the figure 9.5.

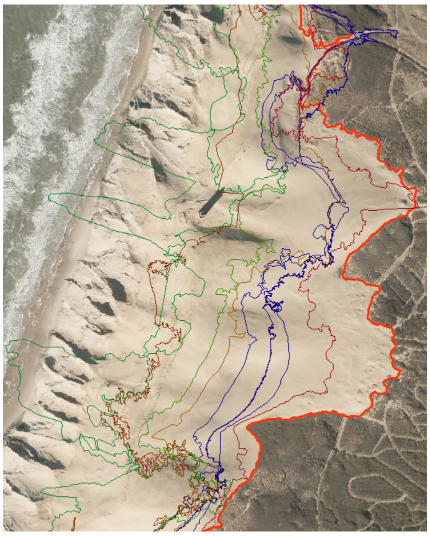

Figure 9.5: *The sand dune coverage according to each data set. Orthophoto from 2015*

In this section, the sand dune coverage is going to be investigated by using the 2015 line as reference and comparing the rest of the lines (1954 - 2012) with it. The process is about calculating the area coverage of the dunes for the respective years, and then compare it.

The process
Before the areas can be calculated and compared, the first step in this approach is to create the boundary lines, which are represented by thick blue line around the Rubjerg Knude dune area, as it can be seen in the figure 9.6 on the next page.

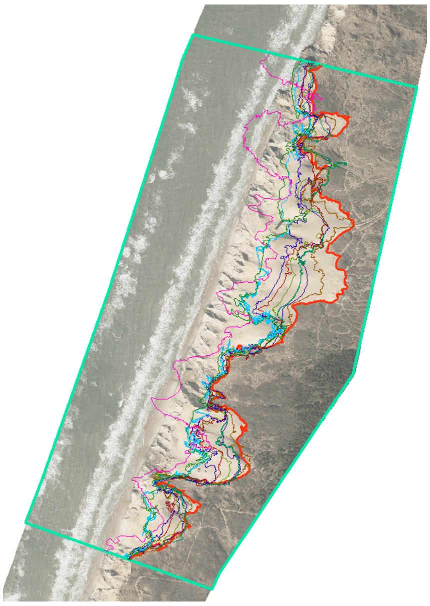

Figure 9.6: *The boundary line of interest illustrated with light blue color*

The definition of the boundary is decided by the actual sand dune stretch along the beach line. The boundary lines are created in ArcMap as a polygon, where then the extracted erosion lines can be cut within the defined boundary, in this way obtaining new polygons for each year. After the extracted erosion lines for the Rubjerg Knude has been cut, the next step is to merge each erosion line separately with reference line 2015 as one object in ArcMap. The merged lines are then finalized, by closing the gap between them and then be converted to a polygon shapefile. Here is the process presented in two steps, illustrated in the figure 9.7.

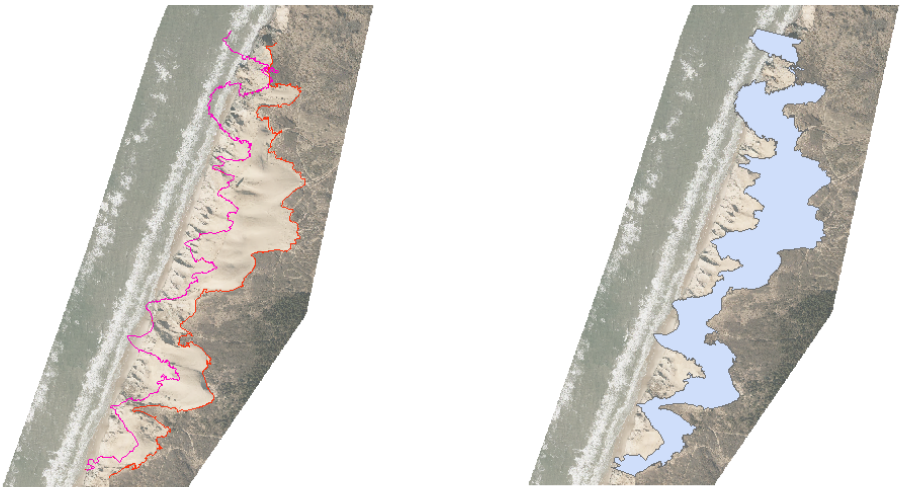

Figure 9.7: *The process from lines (left) to a polygon (right).*

After all polygons have been created, the area of all respective years compared to the reference erosion line from 2015 are calculated. Along the this calculation, the difference between every second year is also calculated, as it can be seen in the table 9.3 on the next page. The area results between the reference line and the respective years, are showing that are getting larger because of the sand migration. However, the difference of the area for every second year resulted to be approximately 2.20*ha*.

Sand dune coverage										
Year	**2015**	**2012**	**2010**	**2008**	**2006**	**2004**	**2002**	**1999**	**1995**	**1954**
2015	0 ha	3.7 ha								
2012	3.7 ha		2.4 ha							
2010	6.1 ha			0.5 ha						
2008	6.6 ha				2.3 ha					
2006	8.9 ha					0.7 ha				
2004	9.6 ha						2.5 ha			
2002	12.1 ha							4.7 ha		
1999	16.8 ha								0.7 ha	
1995	17.5 ha									7.6 ha

Table 9.3: *The sand dune area between each data set.*

9.4 Protection constructions impact

Since the coastline shape result out of the natural constant fight between the sea and the land, it is expected that any artificial input or path change done along it, will have an effect on the shoreline. This section is describing the impact of the constructions built along the area.

9.4.1 1. Løkken pier

The pier was constructed before 1954, so the evolution of the coastline can be monitored for the whole study case, with a detailed analysis in the last 20 years, see figure 9.8.

Figure 9.8: *The erosion line according to the images from 1954, 1995, 2015, and the detailed evolution*

The aggradation segment has a length of **885 meters**. In the northern part of the segment the aggradation stops after around 300 meters from the pier base, while in the southern part goes for more then 500 meters, counting on the area considered for the project.

Since these two parts of the segment are showing different results the aggradation is calculated separately for the northern part (N) and the southern part (S). In table 9.4, the aggradation values are presented in average.

Study case	**N**	**S**
1954-2015	***45 m***	***102 m***

Table 9.4: *The aggradation expressed in meters for each segment*

The detailed analysis offer an overview where the aggradation pattern can be observed for each of the data sets. It can be noticed that the aggradation occurred systematically over each year.

9.4.2 2. The waterbreakers. Lønstrup

In the **study case** the area around the waterbreakers in Lønstrup was mapped as **Erosion 2** and **3**, which indicate a high erosion for that segment. However, since the waterbreakers were built in 1982, their effect could not be noticed in this study, therefore the detailed analysis is going to be used to observe their impact on the area after they were constructed.

In figure 9.9 on the facing page the erosion lines from the all data sets are presented and it can be observed that the lines are overlapped, which indicates that the land is stable in this area, with a detailed representation (red rectangle). In average, the parallel distance between the erosion lines is **2 - 4 meters**, for the last 20 years of monitoring. However, in order to understand better the importance of the waterbreakers installed in that area, it can be noticed how erosion starts in the southern part of the waterbreakers, where the shore is not consolidated (black rectangle).

On the other hand, the protective dam which continue north of the waterbreakers, insured the coast effectively for **1500 meters** until the area where the groynes are constructed. Again, the erosion lines have a parallel pattern with a distance of **2 - 5 meters** in average and getting apart up to **18 meters** in the area where are getting closer to the groynes zone. As it can be seen in figure 9.10 on the next page the erosion lines are overlapped for the most of the segment, while getting closer to the end of the dam, the erosion starts again.

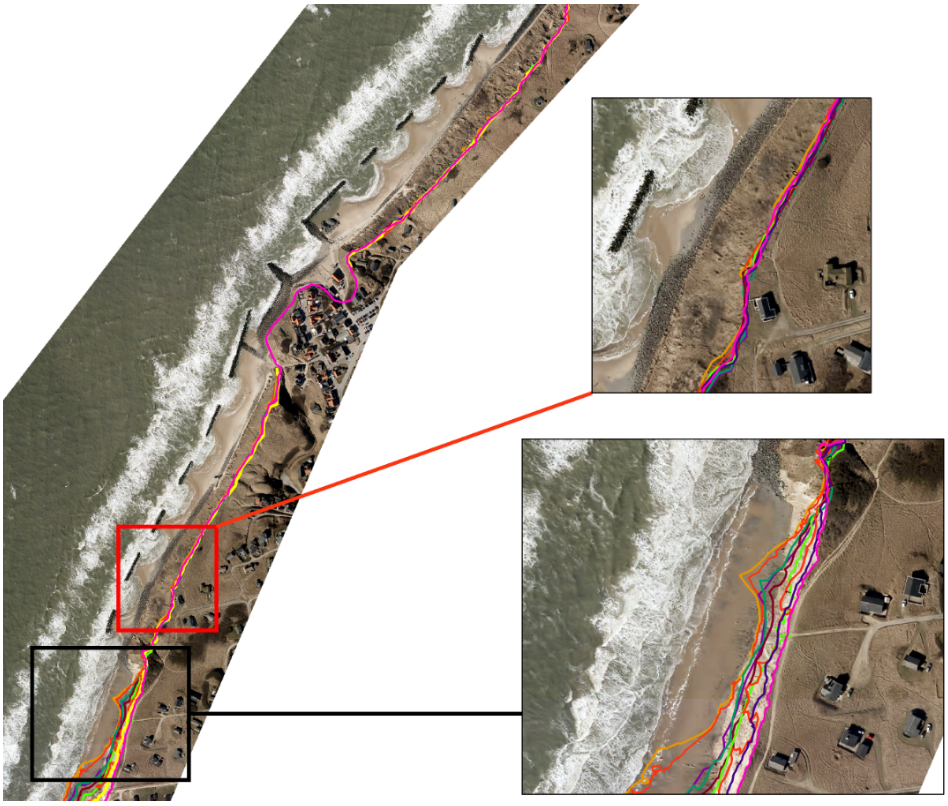

Figure 9.9: *The erosion lines pattern along the protected area along with a detailed representation of the lines (red) and the erosion lines pattern along the unprotected area in the south of the waterbreakers (black)*

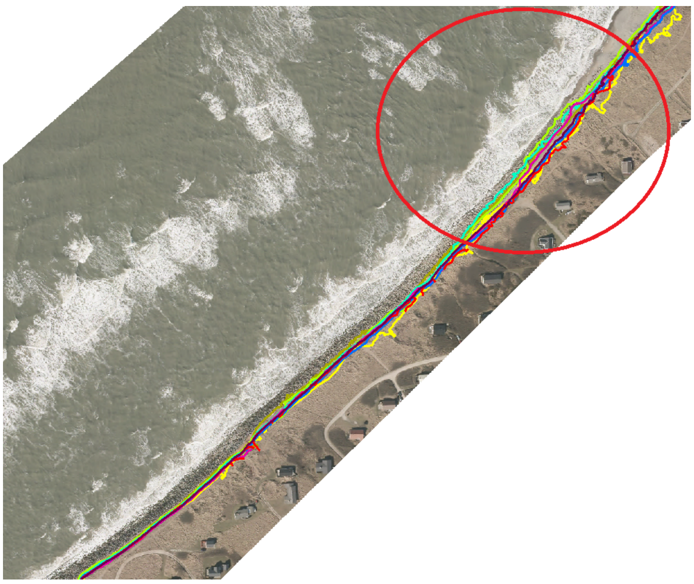

Figure 9.10: *The erosion lines along the dam. As it can be seen in the upper part of the image, the erosion lines show a higher erosion, where the* ***dam protection ends***

9.4.3 3. The groynes at Skallerup Klit

This 4 structures are closing the continuous protection built in the area, being located in the northern part of the **dam** presented above. In this case, the erosion lines are showing different results, and more, are exemplifying the **lee side erosion** described in figure 2.12 on page 14.

As it can be seen in figure 9.11, the groynes contain 3 sectors, and where the erosion occur differently according to each sector position. Not the least, it can be seen that the erosion is proggresive in this area, growing from sector to sector. In table 9.5, the erosion values are presented.

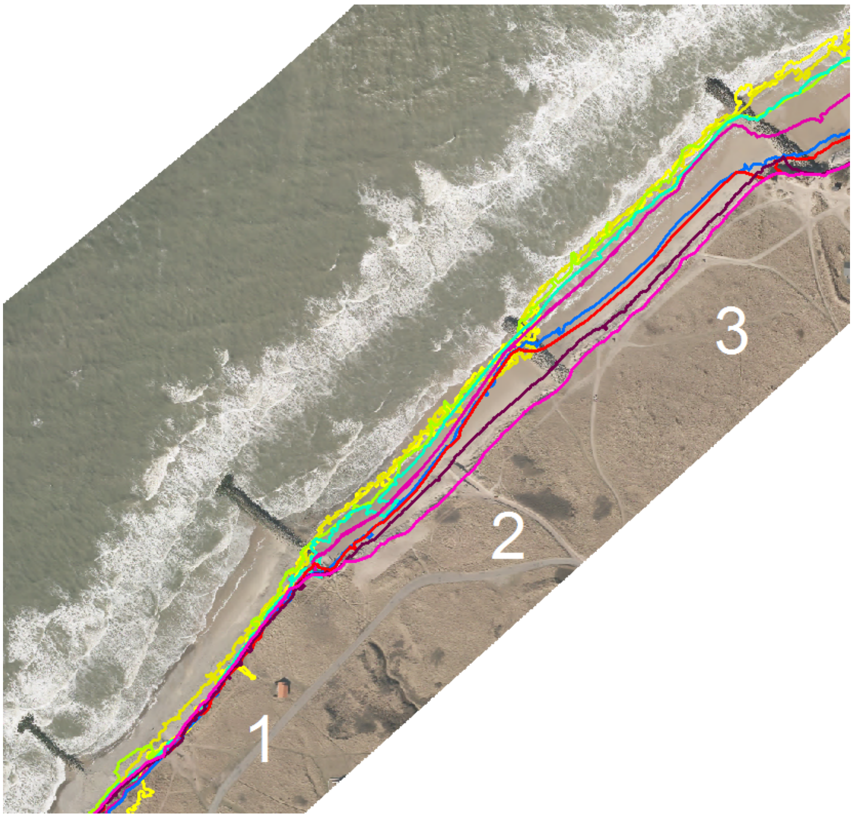

Figure 9.11: *The groynes sectors*

Sector	**1**	**2**	**3**
Erosion	10 m	39 m	51 m
Area lost	$297m^2$	$6.618m^2$	$9.249m^2$

Table 9.5: *The erosion for each sector in the groynes area*

In the figure 9.12 on the next page, this effect can be seen by observing the erosion lines pattern. It can be noticed an accelerated erosion in the northern part of the groynes area, for about **700 meters**, while further up the erosion stabilize.

It is important to mention that the segment where the accelerated erosion occurred, has more or less the same linear distance as the groynes, which confirm the **lee side erosion** theory

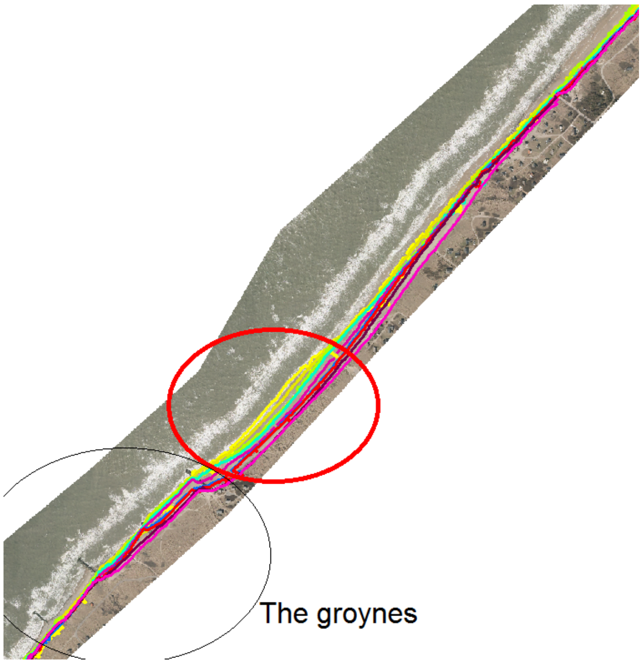

Figure 9.12: Erosion lines pattern validate the lee side effect

presented in 2.4 on page 13. At the same time, the groynes position is the last one out of the protection network (from south to north) installed in the area (waterbreakers, dam and groynes), which could mean that the whole protection network could have contributed to this secondary effect.

9.4.4 4. The evolution of the coastline on the east side of Hirtshals harbor

The Hirtshals harbor was built before the established **study case** period, so in this case the analysis can be done for both cases. Counting on the water and sediment flow direction plus the harbor construction it was expected to find aggradation in the area.

In figure 9.13 on the next page, the coastline evolution is presented. The aggradation is progressive and it stretches for **810 meters** segment. In average, for this area the aggradation is about **45 meters** with a peak of **110 meters**. The area gained in total, by this process resulted to be **2.1 ha**.

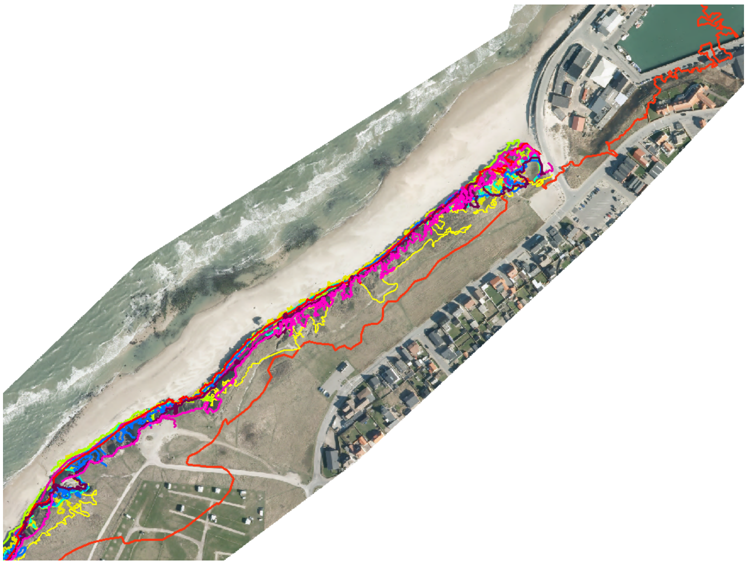

Figure 9.13: The erosion lines showing the aggradation evolution. The red line is representing the erosion line from 1954

9.5 Cadastral plan overlap

People that are living on private properties along the beach, are often encountering problems caused by the erosion effect, where in most of the cases is continually destroying properties over the time, where the worst case scenario is to loose a property totally.

In this section several analysis are going to be performed, where the first analisys is going to investigate the situation regards the number of the *properties* or *parcels* affected, counting on the cadastre map, while the second analysis, will narrow the research in certain locations in order to analyze the house loss. In the end, the situation of the properties and houses situated near the shore which will be summarized, and more using a buffer line a prediction of the properties close to the erosion line is also going to be analyzed and discussed.

9.5.1 The properties affected by erosion

In this analysis, the erosion line 2015 and cadaster map have been used for identifying the properties directly affected. The cadastre map is downloaded from GST-server with last updated version from middle of april 2016. Beside the private properties the data also contains roads, which have been taken in consideration and filtered out.

The procedure used for identifying this properties, was to highlight the cadastre lines that are intersecting the 2015 erosion line in ArcMap. After the properties have been highlighted, the roads have been removed using the attribute table. After the filtering operation was performed, a number of **232** private properties was discovered to be affected between 1920 and 2016 on Hirtshals - Løkken segment. As it can be seen in figure 9.14 on the facing page

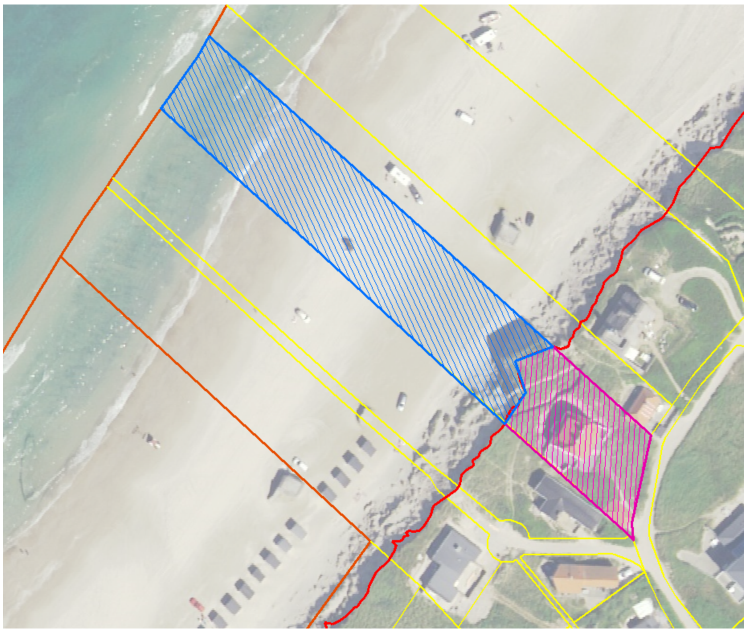

Figure 9.14: *Property loss due to erosion*

9.5.2 The house loss

In order to find the loss of the houses, a comparison using two erosion lines and the image was made, for example 1954-1995; 1995-1999, 1999-2002, etc. Therefore, every house that is located between any of the erosion lines, should be lost by erosion. As well, the address data from GST is used to verify the location of the houses. In other words, if a house is observed on 2012 orthophoto, between 2012-2015 erosion lines, then the orthophotos from 2015 is also checked, in order to see if the house is still there. As a result, if the house is not observed on the orthophoto from 2015 on the same location, then the house is lost between 2012-2015. The house loss statistics have been mapped in ArcMap for each year, by registering a point on the house loss location, as it can be seen in the figure 9.15 on the next page.

After all house losses have been registered, the next step is to count the house losses for each year in attribute table. The results are illustrated in the chart presented in figure 9.16 on the following page.

Between 1954-1995, **26** house losses have been observed, which result to the average of **1.5** houses lost per year. From 1999 to 2010 (11 years) the results indicate a constant house loss, where in average 1-2 houses per year are lost with a total of 7 houses. However, between 2010-2015 (5 years) the house loss has increased up to 17 houses, which is indicating an accelerated erosion, when comparing to the previous years.

In order to illustrate the given house loss, the registry of the house loss is mapped together with the "study case" line between 1954-2015. The main purpose of this map is to present the pattern of the house loss, respect to the "study case" line and to show how the data is corresponding to each other, as it can be seen in the figure 9.17 on page 69. For a better view the map is inserted in the annex I on page 101.

Figure 9.15: *The house located between erosion lines 2012-2015 on orthophoto 2012 (left) and house loss registered on orthophoto from 2015 (right).*

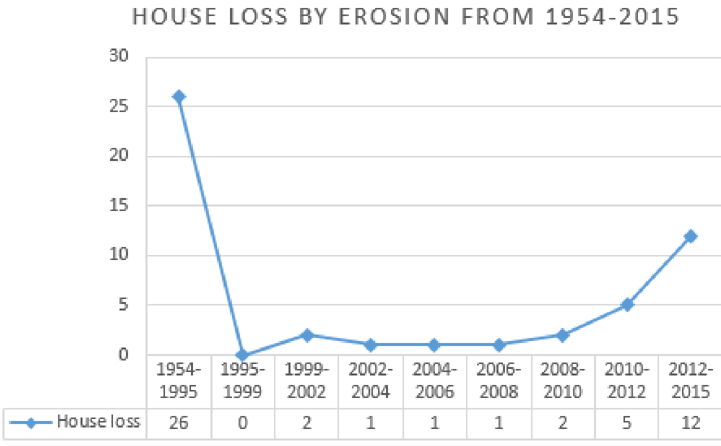

Figure 9.16: *The house loss illustrated on the chart*

In the given map it can be seen that the house loss mostly occur in three towns along the shore: Nørlev, Lønstrup and Lyngby. In Nørlev town, a large amount of houses are lost since there is no coastal protection in this part of the area, with a total number of 18 houses, where the loss occurred between 1954-1995, 1999-2002, 2010-2012 and 2012-2015. As well in Lyngby area there is no coastal protection, and a total number of 16 house losses have occurred between the years 1954-1995 and 1999-2015.

In contrast to these two towns, the northern part of Lønstrup that has coastal protection since 1981, shown a house loss between 1954-1981, but afterward stopped after the groynes were constructed.

9.5.3 Prediction of the house loss

In the previous subsection, the house loss analysis have been presented and discussed. In this part, the problem will focus on investigating the situation regarding the houses in dan-

Study case map 1954-2015 & lost houses (Hirtshals-Løkken)

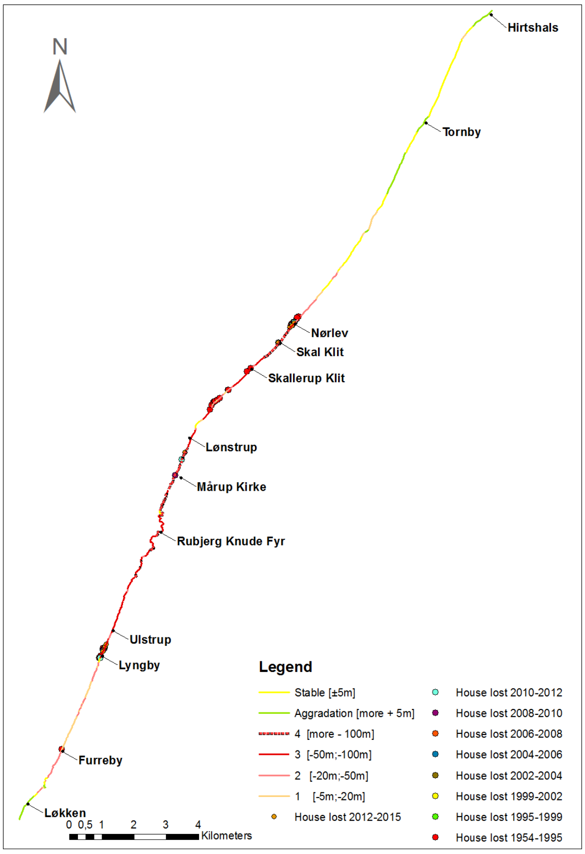

Figure 9.17: *The house loss along the* ***study case*** *line*

ger, very close to the erosion line, by using the knowledge gained in this section. However, the question in this context is:

Can the house loss be predicted?

Based on the gained knowledge in this project and in this chapter, the answer is **no**. First of all the storms, which proved to have a great impact are in general random and difficult to predict. Secondly, the pedology of the soil is also an important factor, when investigating the erosion magnitudes on land. This topics are only mentioned in this project, in order to note their influence on the erosion line magnitude at the shorelines.

The investigation regards the prediction of the house loss in the given area, counts on setting a buffer line from the most recent erosion line and involving the address data layer in ArcMap. In this way, the analysis shows only the amount of house loss, that are within the defined buffer. For this purpose, the buffer line from 2015 erosion line is created with 10m (red) and 20m (green), as it can be seen in the figure 9.18 on the next page.

Before the analysis is initialized, the address data needs to be filtered, respect to the "study case" line values. By performing the filtering in this way, those houses that are located in within the "stable" and "aggradation" values, are then being filtered from rest of the address

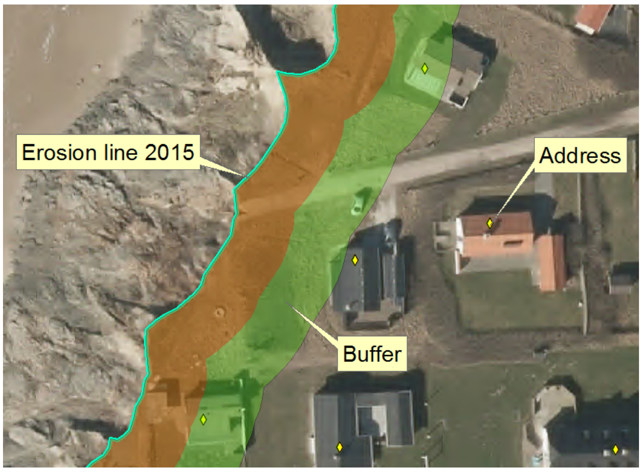

***Figure 9.18:** The buffer line 10m and 20m in Lyngby area.*

data. This means that the houses with respective addresses which are located within the **erosion values 1-4** are at potential risk. These houses that are at potential risk, are then being searched within the buffer.

The analysis is initialized by searching the address location within 10m and between 10m - 20m buffer line in ArcMap. After the search process is done, the affected houses are highlighted and mapped. The amount of the highlighted houses can be found in the attribute table of address data. The final results are illustrated in tables 9.6 and 9.7.

Buffer at 10m					
Town	Skallerup Klit	Skal Klit	Lønstrup	Lungby	Furreby
Amount	4	3	1	1	1
Total	**10**				

***Table 9.6:** The results using buffer line within 10m*

Buffer at 20m							
Town	Ulstrup	Skallerup Klit	Skal Klit	Lønstrup	Lungby	Furreby	Nørlev
Amount	2	1	2	6	6	15	1
Total	**34**						

***Table 9.7:** The results using buffer line within 20m*

Part conclusion

In the tables 9.6 and 9.7 the results are quite different. The analysis for the buffer with 10m, has resulted in 10 houses, which are placed along five towns. However, the buffer with 20m has 34 houses that are at risk and are located along seven towns. A total number of 44 houses are at risk within the 20m from the erosion line.

The buffer line between 10m and 20m is showing that a large number of houses are at risk. In Furreby, which is in Løkken town area, 15 houses are identified to be at risk. However, only 1 house was lost in this location between 1954-1995, confirming the study case map which indicates this part of the segment as *stable*.

9.5.4 Storms inventory

Earlier in the section 1.1.2 on page 5 in the figure 1.5 on page 6, the strongest storms have been noted from year 1999 to 2015, in order to see how much impact these storms have on the erosion along the west coast area. Based on these information, for the Rubjerg Knude location, it can be seen that the sand migration is larger when storms occur, especially for the years 1999-2002 with **4.7ha** and 2012-2015 with **3.7ha**.

Between 2010 - 2015 (5 years) the research shown that there is an increased number of house losses (**17 houses**), compared with the rest of the detailed analysis period 1995 - 2010 (15 years - **7 houses** lost). The results are presenting a direct proportional relation between the storms and the house losses.

10. Conclusion

The goal of this project was to investigate and monitor the erosion activity along the coastline, on a segment between Hirtshals and Løkken, which stretches for 31 kilometers. This location offers an interesting research, counting on the high activity of the sea in the area, combined with the vulnerable soil structure, where even for a relative short period of time (61 years), the landscape proved to have a interesting geomorphology and dynamic.

More than that, the human intervention which in this case is exemplified by the constructions into the sea, offered the chance to observe the impact of this constant evolution and how is affecting the communities living in the towns neighboring the shore. This project work involved a large area, dealing with different real life problems and where remote sensing technology proved to be an efficient tool, which ensemble a great output of data which can be after interpreted and used counting on the problem which need to be solved.

This section of the project will answer the questions from Chapter 6 on page 31, called *Problem statement*:

What are the main differences in processing the images using the mentioned software?

There are 2 main differences between the software solutions presented in this project: **accuracy** (which refers to the complexity of the parameters which can be involved into the process) and **effectiveness** (refers to the time frames and the size of the file which can be processed).

eCognition offers a great complexity of tools, a wider perspective of manipulating the available data and the possibility of mixing different data sets at once, making it easier to classify the information. By using this software an automatic extraction of the coastline could be created, by developing a rule set which can include *vegetation indices*. Being a object recognition software which uses *segmentation*, offers the possibility to observe these image objects values according to the parameters in interest, resulting in a better differentiation of objects, resulting in a more accurate classification, and therefore data extraction. The user can have a great impact in manipulating the process, counting on the project goal.

ArcMap proved to be efficient for the project work, even though the supervised classification which uses *Maximum likelihood* method is less accurate than the object based classification, which uses *Nearest Neighbor* algorithm. However, counting on the project goal and on the *homogeneity* and low diversity of the objects in the images used, ArcMap classification tools were considered enough for extracting the erosion lines and except a very few clustered areas along the segment where it had difficulties classifying the image, it proved to be efficient and accurate regards the project goal.

MatLab is a powerful software, where the user can program own algorithm, in order to achieve the desired task goal. Regarding classification test, the given script is based on the *Nearest Neighbor* algorithm. The given script is showing the basic approach, of how to make a supervised image classification by using built-in "Image processing" tools in the Matlab. In the testing phase, using the image sample with high GSD, the script has showed a positive an accurate result, which can be compared to the eCognition and ArcMap software. The given script has also showed limitations, such as; high consumption of RAM and lack of classified data export possibilities. Not the last, the script offers the possibility to make further programming, if the interest is to develop the script.

Is there a relation between the years when big storms occurred in Denmark and a larger erosion?

In section 1.1.2 on page 5 the relevant storms history and intensity was presented on a time scale in order to relate it with the results obtained later in the study. All of the study cases investigated during this project shown that **the erosion activity and house loses are directly proportional with the storms occurrence and intensity**. Not the least, the area around Rubjerg Knude lighthouse offers a good overview about how much activity was registered between these time intervals with real numbers, making it easier to understand the relation between these two events by the quantity of sand deposited.

Where are located the highest erosion / aggradation areas along the segment in interest?

There are 3 places where erosion occured more violent: **Skallerup Klit**, south of **Lønstrup** and at **Rubjerg Knude lighthouse** area, while the greatest aggradation was detected at the southern part of the pier in Løkken. In table 10.1 the results are presented for both study cases, and they represent the peak value of the erosion for each area according to the time interval.

	Location	***20 years***	***61 years***
Erosion	Skallerup Klit	89 m	157 m
	South of Lønstrup	67 m	172 m
	Rubjerg Knude	272 m	357 m
Aggradation	Løkken pier	58 m	145 m

Table 10.1: *Highest values of erosion/aggradation registered. They represent the highest values of the parallel distance between the erosion lines*

How much area was lost by erosion along the segment in interest in the last 61 years?

Using the erosion lines from the first and last data set (1954 - 2015) the surface of land lost during the study case could be calculated. The value is presented in table 10.2:

Time interval	1954 - 2015
Total area (m)	**145 ha**

Table 10.2: *The area lost. Expressed in hectares*

What is the total length covered by erosion, aggradation or stable land along the segment Hirtshals - Løkken?

The area studied during this project is divided in 6 classes and the values are presented in table 10.3 on the next page. By observing the results, the evolution of this processes across time can be observed.

			Erosion				
	Aggradation	**Stable**	**1**	**2**	**3**	**4**	**Total lenght**
20 years	1.943 m	**13.216 m**	8.704 m	2.075 m	1.489 m	3.880 m	**31.307 m**
61 years	3.990 m	6.419 m	4.617 m	4.323 m	7.687 m	4.117 m	**31.153 m**

Table 10.3: *The length covered by each process along the segment.*

Whats the area invaded by sand at Rubjerg Knude Fyr according to the study case period?

In the last 61 years, the sand dune covered **25.1 ha** of land. In table 9.3 on page 61, the results for each data set are presented and it can be noticed that the sand dune is expanding each year. At this location, many studies can be done, and a perspective is mentioned in the next chapter.

Which of the constructions along the shore offered the best protection against erosion?

The *waterbreakers* together with *the dam* located in Lønstrup proved to offer the best protection along the shore. Before they were built, the area was registered as *Erosion 4*, more precise the erosion detected in the area between 1954 - 1995 was in average **60 m**, and after the protection was built, it **stabilized**. The groynes shown to **slow down** the erosion process but with higher losses than the other constructions.

How many houses and properties were affected along the segment?

A total number of **50** houses were lost and **261** properties were affected by the erosion phenomenon within the area of interest, in the last 61 years. Out of the total number of properties affected **232** are *private* and **29** are *public* properties.

How many houses and properties are in danger?

Within *20m* from the shore line, there are **110** properties and **44** houses in danger according to the erosion map, where **10** houses are in a immediate danger, being within **10m** from the shore line.

11. PERSPECTIVE

The main challenge in this project was to map and evaluated the erosion phenomenon using remote sensing, which proved to be an efficient tool. In the next part are going to be discussed some of the improvements which can be brought to the research and the results.

A great improvement of the data collection would be to take the pictures using drones. Using this method the GSD value would be greatly improved, up to **3** centimeters, because of the closer distance of flight in relation with the surface of interest. Flying a drone would allow to collect the data in a short period of time, if not the same day, counting on the size of the area in interest. This would improve the classification process because the classes would have a better color distribution across the image and so, making it easier to differentiate them. The *shading* problem could be eliminated as well, by taking the pictures considering the sun position on a certain time and counting that the images would be corrected and processed following the purpose of the project.

Depending on the context, the time of the year would be important too, especially where vegetation can make a difference, being found all the way along the segment, and counting that the erosion is in a direct relation and proportional with the vegetation loss along the shoreline. Here other image layers such as NIR will allow to involve vegetation indices, which bring an improvement in differentiating the classes in interest or establish new ways to define erosion.

eCognition Developer would help extracting the erosion line more accurate from many points of view, based on this project research and the previous projects[1]. Other data sets could be mixed, such as the DTM data, which during the classification process with a height threshold involved, the noise would be filtered therefore gaining in accuracy and the time frames of the project. eCognition is a object recognition software, and would make it easier to extract information out of an image, its complex tools allows a wider approach, which leads to a better focus on the problem.

The migrating sand dune at *Rubjerg Knude* lighthouse can provide precious information about the weather activity. Statistics regards the area covered by this dune were calculated in this project. A great improvement would be to use DTM data to calculate the volume of this dune. Not the least, using this data a model of the dune can be done, which would offer valuable information about the wind direction, sediment transport or climate change.

What can be done ?

Collecting data using bathymetric LIDAR sensors, which can measure down to 50m below the sea level, would allow a more detailed study of the **seabed** and would help comprehend better the type of waves that are produced in the area, which are a result of the whole

[1]Wrinkled Rose automatic recognition and Mapping Giant Hogweed in Aalborg Municipality area

geomorphology present in the area and therefore influencing the shape of the shore line. Constructions on the seabed which could absorb out of the wave energy would diminish the wave impact to the shore.

A natural solution based on the same principle would be to plant **eel-grass** populations which proved to help prevent erosion and maintain shore line stability. These plants help stabilize the seafloor sediments with their long spreading roots and absorb out of the wave energy, slowing the water flow. In this way, the plants help promoting deposition and stabilization. The specialty literature, mention that the erosion caused by storms and wave energy is substantially dampened in areas with productive eel-grass beds. In figure 11.1, a map representing the populations of eel grass in Denmark between 1880 - 1930 is presented, and as it can be noticed the west part of the Danish coast have consistently less plants then the east cost. This could be an effect of the higher activity of the harsh North Sea, but if these plants could be introduced in the area they might slow down the erosion.

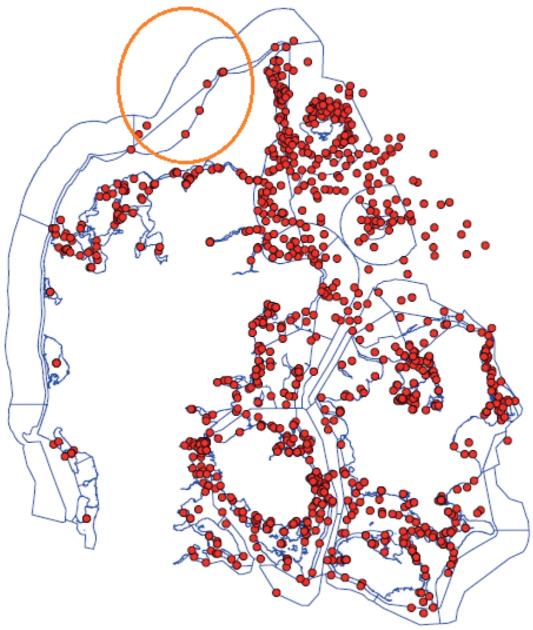

Figure 11.1: *A map presenting the eelgrass populations along the Danish shore*

Since it is clear that is hard to find a solution for the whole coastline, a plan could be made, which will establish areas that are in a certain degree of importance by the land use and stability. By observing the erosion process behavior, the areas in danger and the effectiveness of the protective constructions, an overview of the situation could be realized using remote sensing solutions.

A more expensive solution would be to increase coastal feeding by sand nourishment. This operation would help preserving the area, and the sediment transport to the north would be increased.

In a future where the climate changes more and more, the sea level keep rising resulting waves that have more energy and the storm occurrence is more often, it can be easy concluded that the erosion is accelerating. However, **remote sensing** proved to be a great tool for monitoring the erosion phenomenon and its effects, and counting on the speed the technology is evolving, the image quality, the speed of data processing, the price and not the least, even new parameters which are not yet considered will be more affordable and used by more and more people which will lead to more and more research. When an action involving a relative large area requires finding a solution or tracking a problem, there is no better way than observing it from above.

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A. CD CONTENT

The folder names

1. Earlier projects
2. Nearest Neighbor Matlab script
3. Erosion lines 1862-2015 (shapefile)
4. Study case (61 years)
5. Detailed analysis (20 years)

B. Algorithms

Nearest neighbor algorithm (NN)
The nearest neighbor algorithm is a supervised classification, which is using sample training values of objects that are corresponding to a class in the raster image. After the training samples are chosen, the classification of the objects in the raster image are based on the nearest sample neighbors.[16]

Multiresolution segmentation
The multiresolution segmentation is an algorithm that recognizes the image pixel or group of pixels as objects. However, the given algorithm starts by observing one pixel and thereby iteratively begins to group pixels or objects. The algorithm iterates until the image objects cannot be further merged by respecting the maximum homogeneity of each object. The scale and shape parameters, are used for manipulating the homogeneity, so the objects can fit for the desired task.[17]

Maximum likelihood
The maximum likelihood algorithm is using two principles:

- The pixels for each class sample are normal distributed in multidimensional space
- Bayes theorem of decision making

When creating a classification with maximum likelihood, the algorithm is using both the covariances and variances of the class signatures, where every class sample is assumed to be normally distributed. A class is defined by the covariance matrix and mean vector, where these two values are describing the characteristics of the pixel value. In order to solve the membership of pixels to the given class, the statistical probability is used. Selecting "EQUAL" in ArcMap as a prior option, then every pixel is classified to the class, which is determent by being the highest probability member.

If the occurrence of some classes is higher or lower than the average, then the probability "File" option should be applied. This means, that in a priori file, the weights for the given class are specified. Using this option, the pixels are assigned more accurately to the relevant class.

Using the *a priori* option "SAMPLE", then the probabilities are assigned to all classes, which are sampled in the input signature file. This means, that the signature file will correspond to the amount of pixels that are taken in every signature. Having classes that are holding less pixels than average in the sample, will then receive low weight and vice verse.[18]

Iterative Self Organizing Data Analysis Technique Algorithm - ISOData
The ISODATA is a unsupervised clustering classification method. A clustering means in this situation, that the algorithm iteratively self organize the grouping of the samples in each represented band of the raster image into the set of clusters.

In the iterative process, the minimum euclidean distance is used for calculating the assigned pixel to the cluster. The given algorithm starts to place clusters randomly in each raster band, where each candidate pixel is assigned to the center of the cluster using the shortest distance (minimum euclidean distance).

During the iteration the clusters are either split or merged, which is decided by standard deviation values and distance between cluster distance. If the clusters are split, then it indicates that the clusters are one or greater of the standard deviation. The merged clusters are performed, when the minimum distance is reached. However, if a cluster consist of fewer pixels than specified from the user in the initial phase of the algorithm, then the pixels are eliminated.[19]

In the figure B.1, it is exemplified how the clusters are grouping :

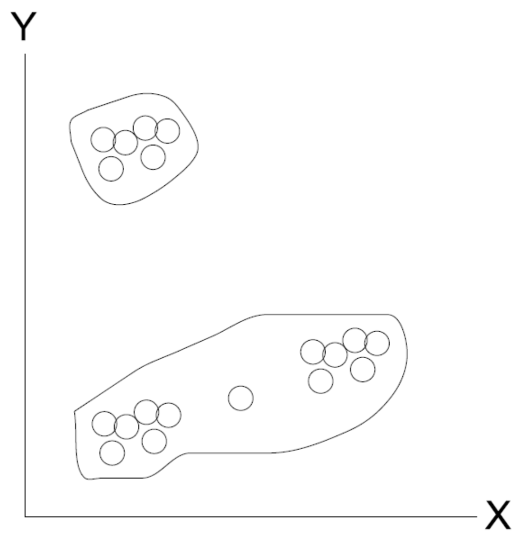

Figure B.1: *The example of cluster grouping*

C. Sample statistics

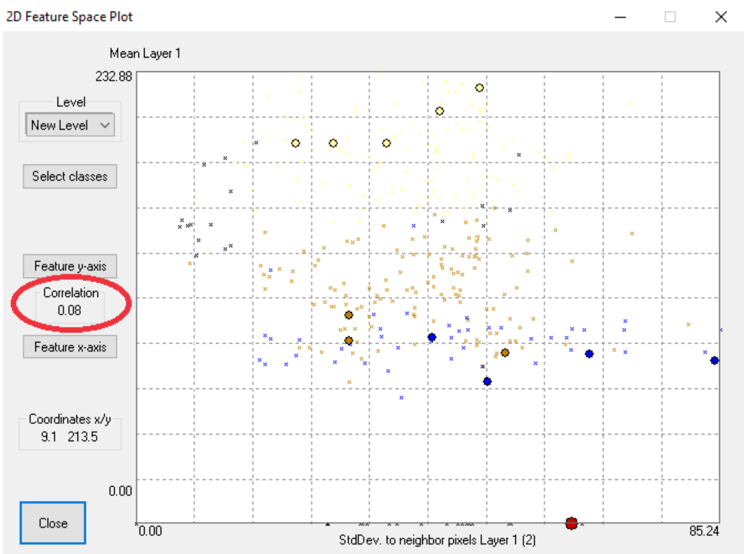

Figure C.1: *The space plot exemplifying* ***0.08*** *correlation between (Mean layer 1 = Red and StdDev. to neighbor pixels). The features used are having a great impact in the classification process (Nearest Neighbor)*

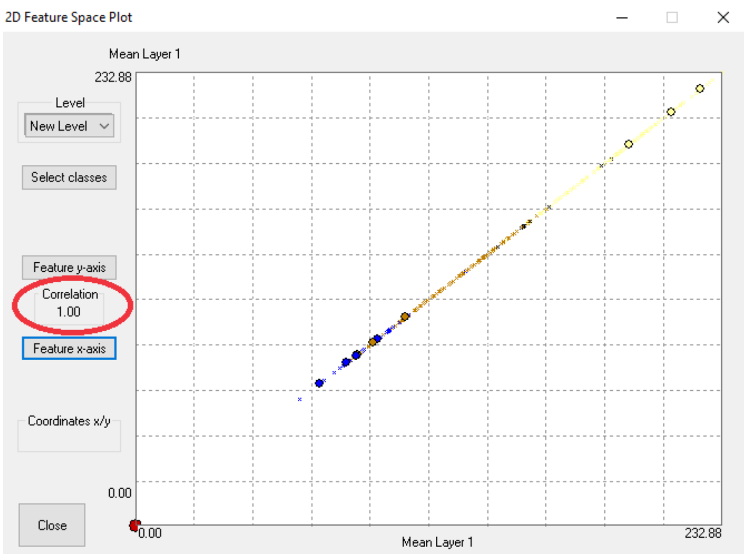

Figure C.2: *The space plot exemplifying* ***1.00*** *correlation between the same layers. The features used are having almost no impact in the classification process (Nearest Neighbor)*

D. Software flowcharts

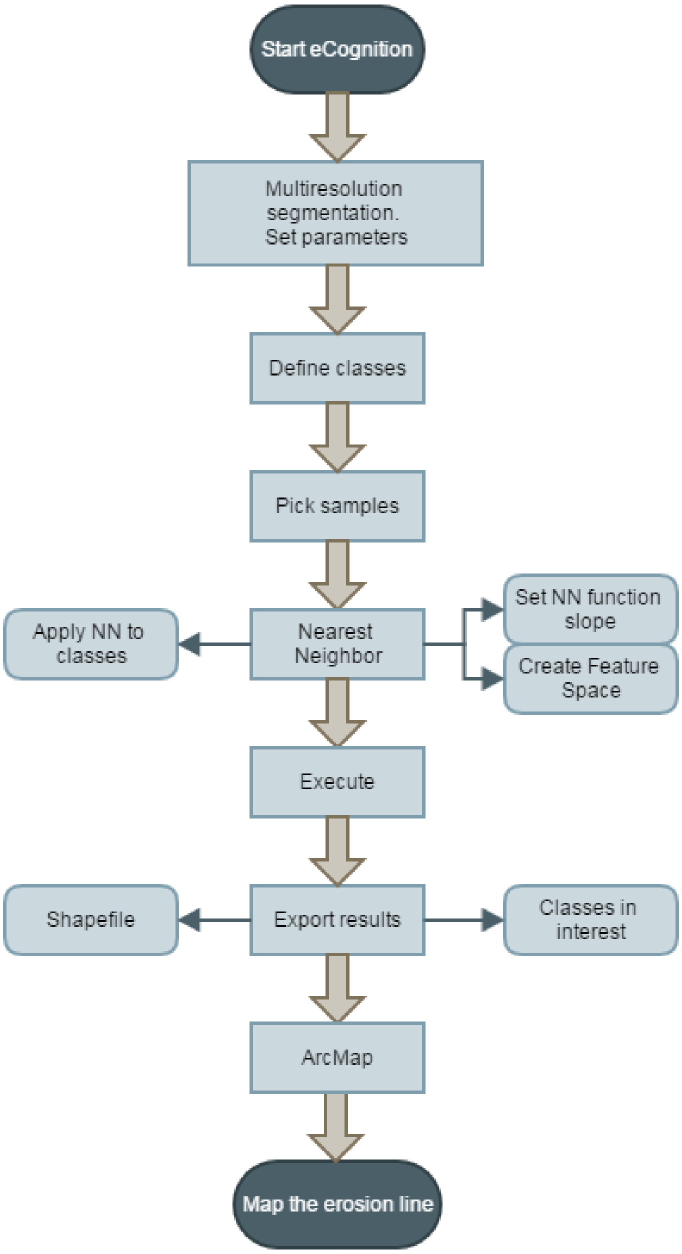

Figure D.1: *The eCognition flowchart*

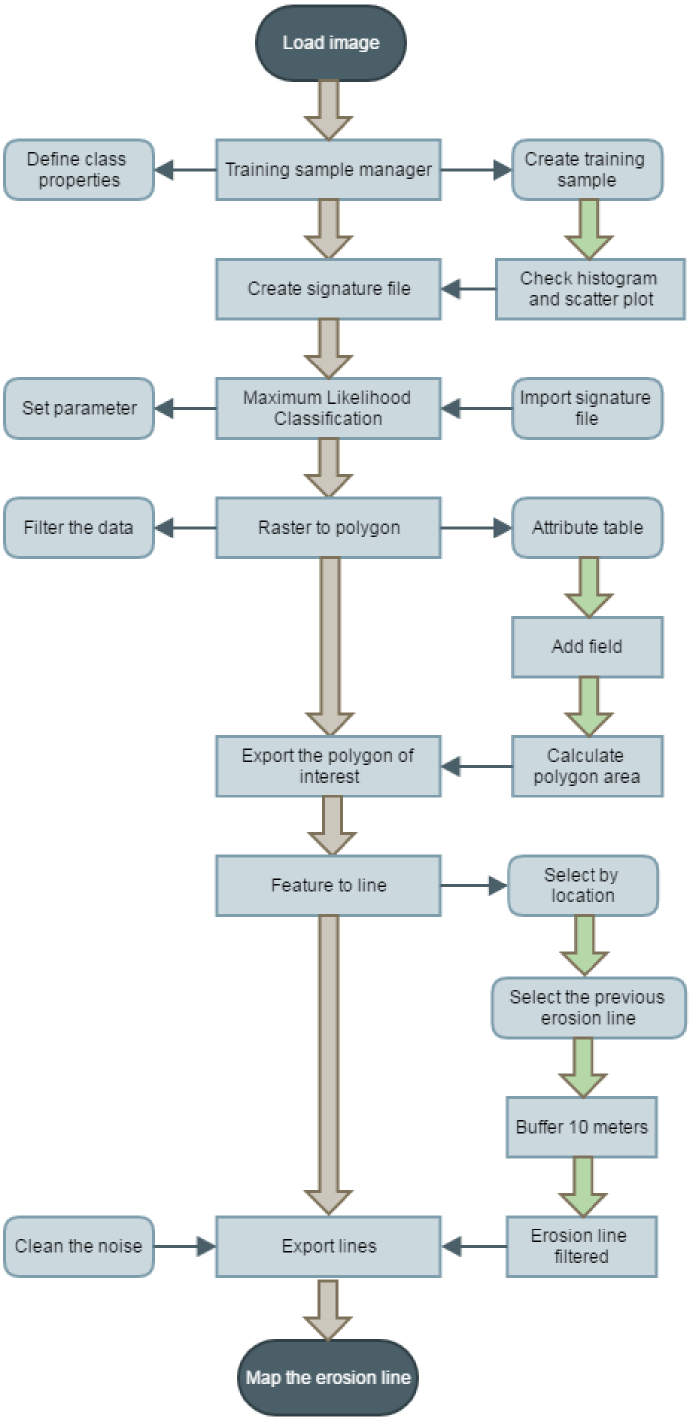

Figure D.2: *The ArcMap supervised classification flowchart*

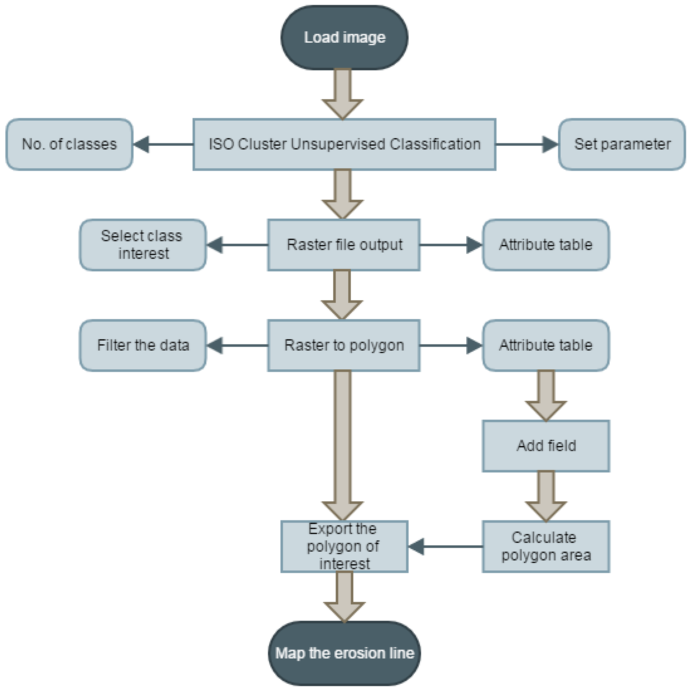

Figure D.3: *The ArcMap unsupervised classification flowchart*

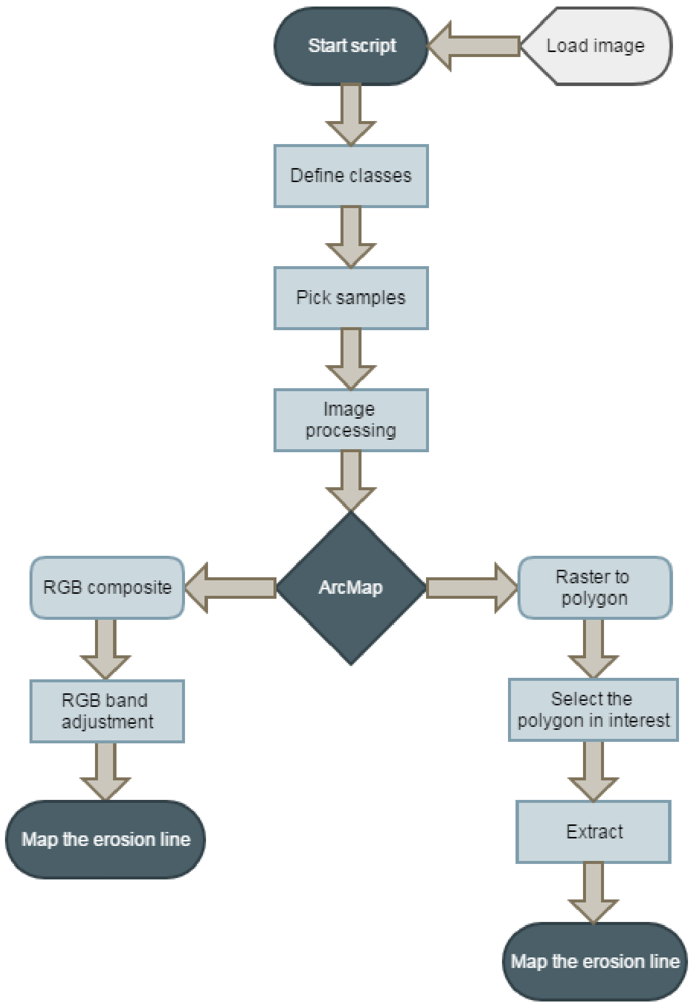

Figure D.4: *The Matlab script supervised flowchart*

E. Erosion lines 1862-2015

F. DEM 2007

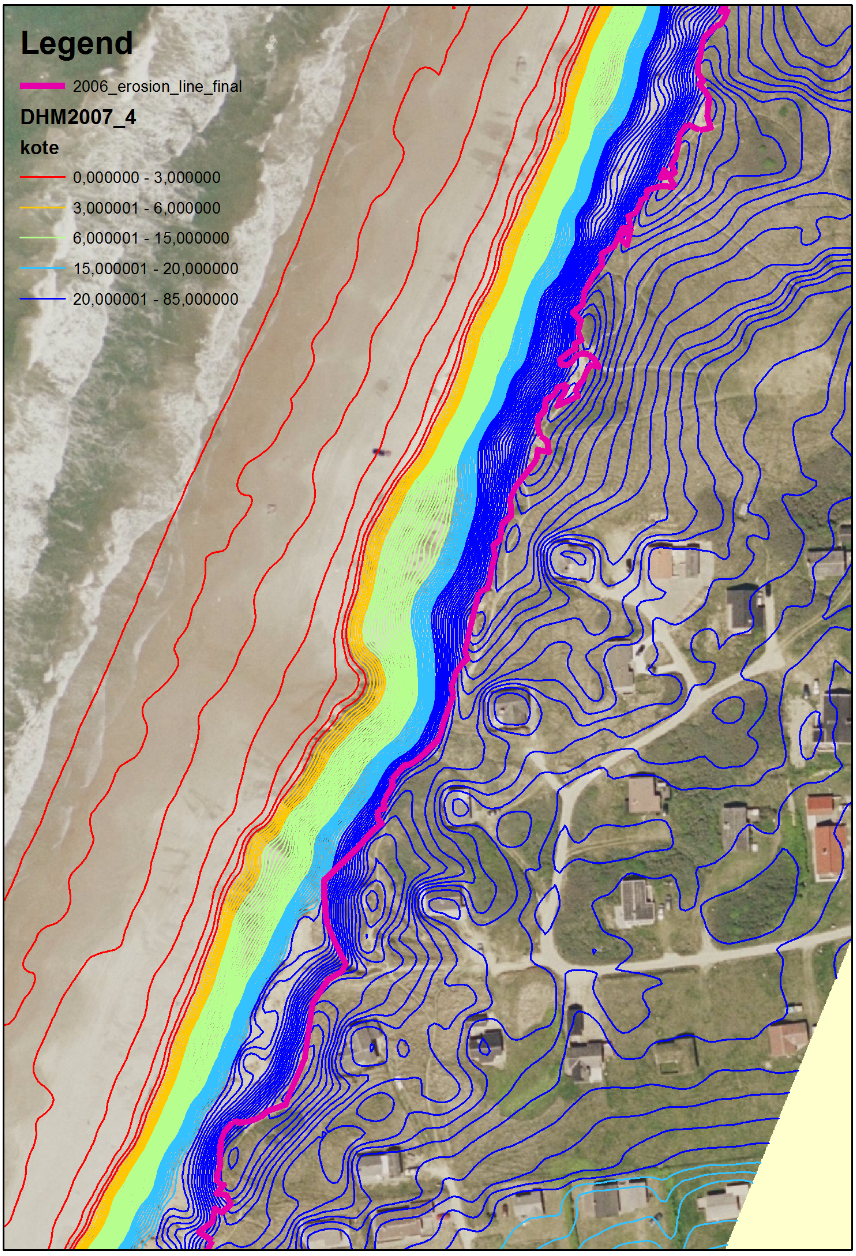

Figure F.1: *wdsdsdsdsd*

G. Study case map 1954-2015

H. Detailed analysis 1995-2015

I. House loss map 1954-2015