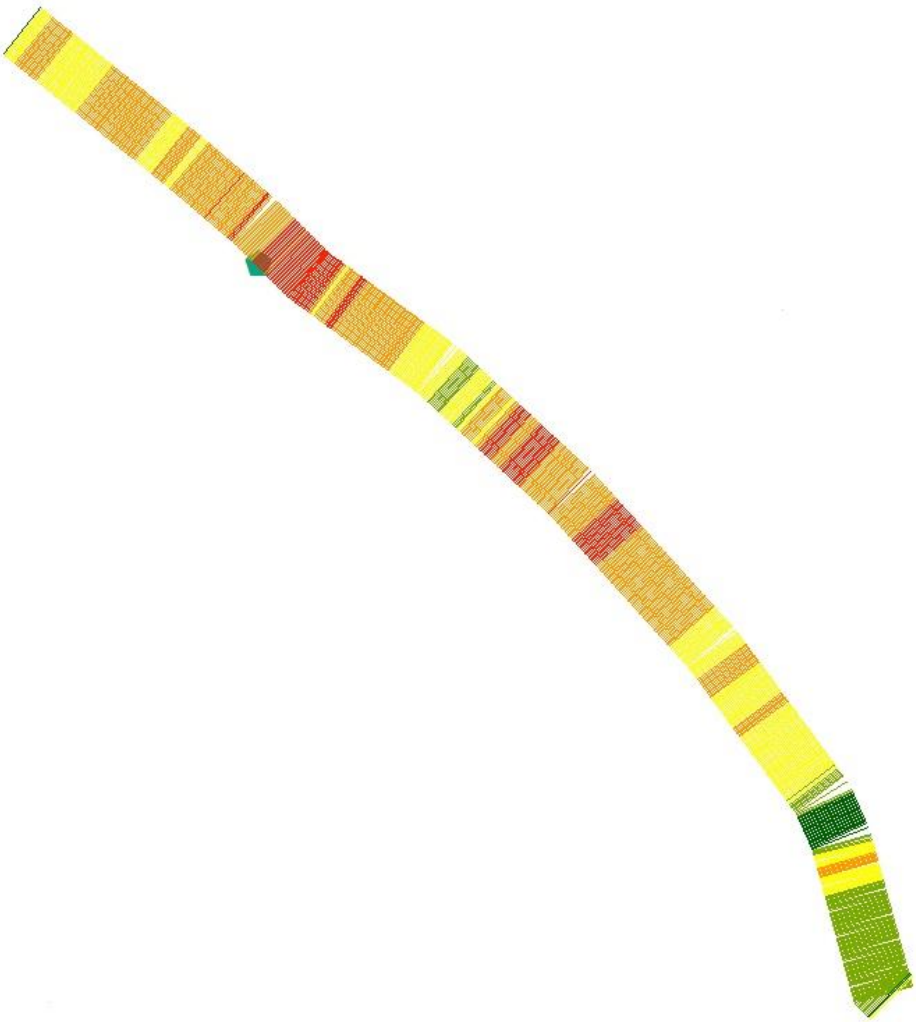
Assessing the shoreline movement and its impact on historical sites.

Master thesis

By

Alexandra Luisa Højgaard Wood

11th of April, 2109



AALBORG UNIVERSITY COPENHAGEN

Master of Science (MSc) in Technology, Surveying, Planning and Land Management / Geoinformatics

AALBORG UNIVERSITY
STUDENT REPORT

Aalborg University Copenhagen
A.C. Meyers Vænge 15
2450 Copenhagen SV
Secretary: Janni Rise Frellsen
Tel: (+45) 99 40 25 35
Email: jrl@plan.aau.dk

Title:
Assessing the shoreline movement and its impact on historical sites.

Study program:
Master of Science (MSc) in Technology,
Surveying, Planning and
Land Management,
Cand.tech in Geoinformatics.

Project period:
5th of July 2018 – 11th of April 2019

Participants:
Alexandra Luisa Højgaard Wood

Supervisor:
Jamal Jokar Arsanjani

Page count: 55

Abstract:

The purpose of this project is to create a general overview of the consequences of coastal erosion the United Kingdom experiences. It focuses on how GIS work and coastal monitoring can be applied to salvage archaeology and how it can prove beneficial for the archaeological field. The project explores different case studies suffering from coastal erosion. The case studies have different historical aspect, but they are all vulnerable archaeological sites. By using the software-extension, DSAS, to study End Point Rate of the shorelines, assessment of coastal movement can be made. This project will look into in what way GIS work can supplement archaeolgocial studies.

Preface:

This thesis spanned from 5th of July 2018 to 11th April 2019 and was the final project and completion of the Master of Science in Geoinformatics at Aalborg University Copenhagen. This project went through changes and phases, but the final result would combine my archaeological background with my current studies of geoinformatics.

For this, I would like to thank my supervisor, Associate Professor Jamal Jokar Arsanjani, for inspiring me to choose this subject. He was being patient and supportive when I could not, and guided me through this process. I would also express my gratitude towards my mother because my mother – obviously – is the best. I would also extend my appreciation to my friend Jakob Pernov for his support, for feeding me when I forgot to feed myself and for his at-times-great advices. Lastly, I would like to give thanks to Elyse Meaker, who not only helped me avoid atrocious grammar but towered over me like a prison-guard, making sure I kept the deadlines I made for myself. I owe them all a nice wine and dinner.

Abbreviations

AMBUR	Analyzing Moving Boundaries Using R
BGS	British Geology Survey
DSAS	Digital Shoreline Analysis System
EPR	End Point Rate
ESRI	Environmental Systems Research Institute
LRR	Linear Regression Rate
SCAPE	Scottish Coastal Archaeology and the Problem of Erosion
UAVs	Unmanned Aerial Vehicle
UK	United Kingdom
UNESCO	United Nations Educational, Scientific and Cultural Organization

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1. Introduction:

Coastal change plays a large role when discussing the environmental change in today's political, social, environmental and cultural climate. Coastal change has a huge impact on cultural-historical fields, such as archaeological sites located along the coast. Fieldwork is time-consuming, which is not available when salvage archaeology needs to be implemented. The reason behind this is that salvage archaeology often correlates with a lack of time, before destruction of any sort is about to occur. Geographical Information System (GIS) is an immense help within the archaeological field. GIS can provide a range of high-quality, low-cost solution, and the potential for helping out the archaeological field is highly evident. Creating an assessment of shoreline movement could support the archaeological field when assessing what sites to manage, in order to either restore, protect or excavate before it is lost. This project will look into the erosion-rate of five different shorelines. At those shorelines, historical sites can be located, which will be described as the case studies. These case studies share the common factor of either being subjected to complete destruction or be almost at the point of destruction. All the case studies are kept within the borders of the United Kingdom. These areas include England, Northern Ireland and Scotland.

1.1. Salvage Archaeology

Salvage archaeology – also known as rescue archaeology and preventative archaeology – is the collection of archaeological material that has to be undertaken within a brief period of time at excavation sites in imminent danger of either new construction projects, or environmental issues such as natural disasters, warfare, flooding, climate changes or coastal erosion (Archaeology wordsmith, 2019). In this case, the focal point is on the erosion of the shorelines.

Archaeological fieldwork is under normal circumstances undertaken with great care and patience, spanning from several months to many years. However, salvage archaeology differs by having a short amount of time to save and record vital information. Information on coastline movement could prove helpful in determining the time frame necessary for reclamation of a specific site.

1.2. Shorelines

Merriam-Webster defines *shoreline* quite simply as "the line where a body of water and the shore meet", which in its simplest form is justified, yet it is far more complicated than that (Merriam-webster, 2019).
The coastline paradox is the idea that the length of the coast is undefinable (Mathworld, 2019). It is the observation that a coastline does not have a well-defined length and that the length depends on the number of measurements put into place. The more in detail, the closer the coastline is observed, the longer the shoreline will be in length as can be seen in figure 1.

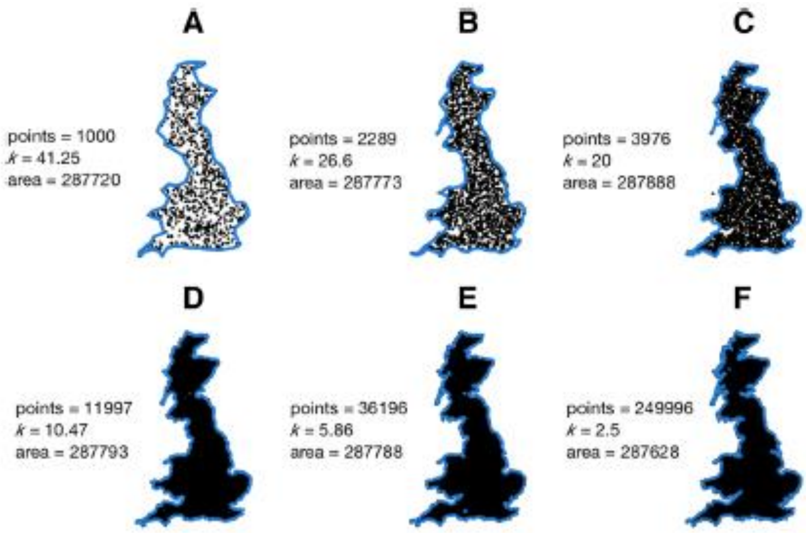

Figure 1. Coastline paradox (Gardiner, 20018).

The use of *shoreline indicators* is a feature typically used as a proxy to represent a "true" shoreline and has been adopted by coastal researchers as a more fitting description. Due to the dynamic nature of this feature, it is likely to remain as such; the idea of creating a collective definition that encompasses every aspect of shorelines – such as the application utilised to retrieve data and the natural elements in direct contact with the shoreline – still has a long way to go.

However, common shoreline indicators are utilised. The spatial relationship between different indicators can be observed in figure 2 and these tend to be the most commonly used. Shorelines indicators can be gathered through different data sources, such as historical photographs, coastal maps, aerial photography, GPS shorelines and remote sensing (boak, 2005).

Remote sensing will be introduced in this project in the shape of satellite images, from which the data will be obtained.

Detection techniques in obtaining shorelines will rely on unsupervised classification, supported by manual visual interpretation from the satellite images. Shoreline detection comes with a range of challenges, such as the stage of tides, wave energy, position of the groundwater exit point as well as mineralogy and sediments to name a few (Boak, 2005).

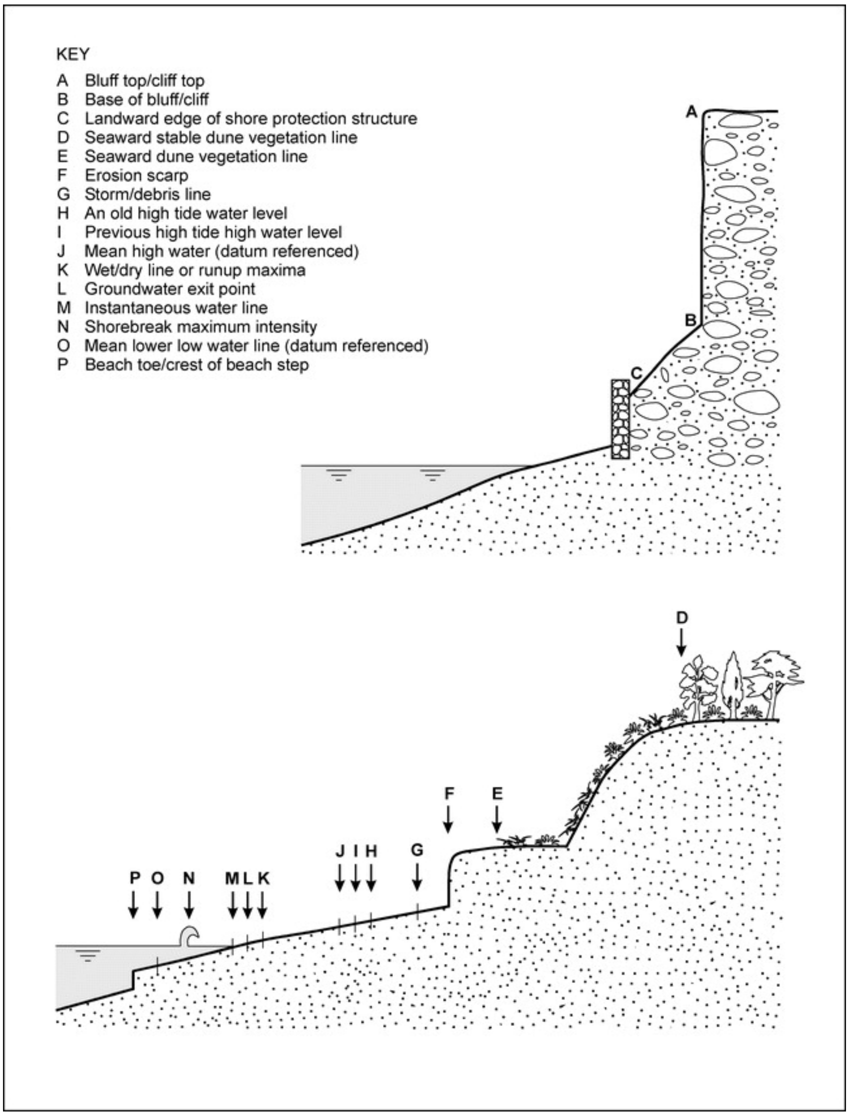

Figure 2. Most common shoreline indicators (Boak, 2005).

1.3. Tools

The software used for this project came from the Environmental Systems Research Institute (ESRI) and included both of their ArcGIS software; ArcMap and ArcGIS Pro.
Datasets were collected from USGS.gov, and the software used was ArcGIS Pro for processing the datasets and ArcMap for converting the data to the Digital Shoreline Analysis System (DSAS), which is a software extension to ArcMap. The DSAS vs. 4.4 was released in 2017 and is designed for ArcMap vs. 10.4 and 10.5. ArcMap vs. 10.5 is the software utilised.

1.4. End Point Rate

End Point Rate (EPR) measures the length of movement between the oldest and the most recent shoreline. By dividing the distance with the time elapsed between two points, it calculates how far the coast has moved with a rate of change (figure 3). The only requirements for EPR's to be calculated are two shorelines with different timestamps. However, the disadvantage with this method is excluding additional information from timestamps amid the oldest and the most recent, which could display cyclical trends and changes (Thieler, 2017).

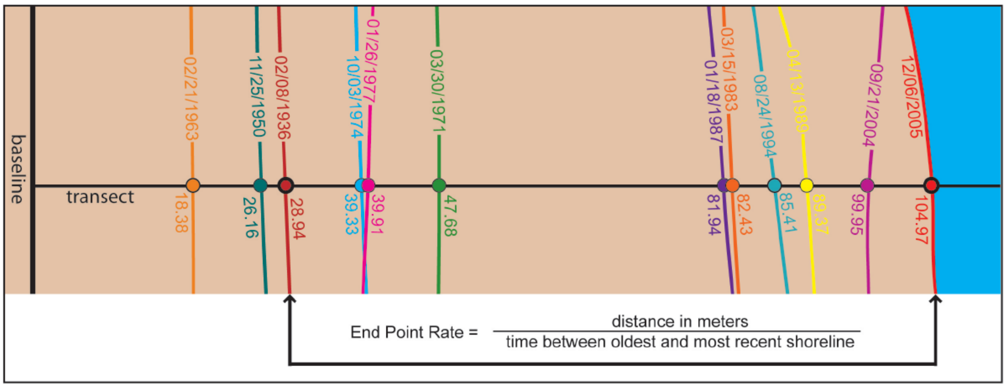

Figure 3. An example of measuring EPR's. The End Point Rate equals the distance in meters divided by the time elapsed between the oldest (28.94) and the most recent (104.97) shoreline. The EPR is calculated to 1.09m/y (meters per year).

1.5. Problem Statement:

Salvage archaeology suffers from having a short amount of time to execute an immensely large amount of work. If coastal changes could be predicted with high accuracy, more time could be spent on analysing the archaeological finds with more accuracy and how to manage the site. By observing satellite images and using supporting software extensions, certain assessments can be made. How this specific direction of GIS will benefit the archaeological field will be explored further. To showcase this, five case studies will be presented and examined. Shorelines were extracted and an assessment of how much the shorelines move per year was made. The case studies all include historical sites placed along the coast of different locations scattered around the UK, which show tendencies of a cost with a high movement rate.

1.6. Research Questions:

1. What consequences do archaeological sites suffer due to coastal changes?
2. How will the predictive modelling prove useful for the topic of archaeological historical sites?
3. How reliable is predictive modelling in terms of predicting coastal changes?

2. Data and case studies

In the following chapters, tools and methods will be presented. This includes a presentation of what data was acquired, how it should be processed, which satellite images were used and an explanation of the software-extension, DSAS, that has been the main tool during this project. It will also give a short presentation of the available data, in this case, the satellite images and from where they were extracted.

2.1. Available data (Landsat)

Free satellite imagery is available online and is of such high quality that it can be used for research projects or scientific research. In 1972, the first Earth-exploring satellite, with the intent purpose of documenting the landmasses of the earth, was launched (Landsat, 2019a). The Landsat series has run for over 40 years and has provided the longest temporal record of moderate resolution multispectral data of the earth's surface (Landsat, 2019b). This is thanks to Landsat 1, which operated during a period spanning from 1972 to 1978.

The data provided is also freely available, for anyone to retrieve, at the earth explorer (USGS, n.d.a) provided by the United States Geological Survey (USGS).

USGS (figure 4) provide data, information and science covering natural hazards, water, energy, minerals, natural resource, ecosystems and the impacts of climate changes. They deploy missions in more than 400 locations across the United States. They develop tools and provide free data such as satellite images (USGS, n.d.a).

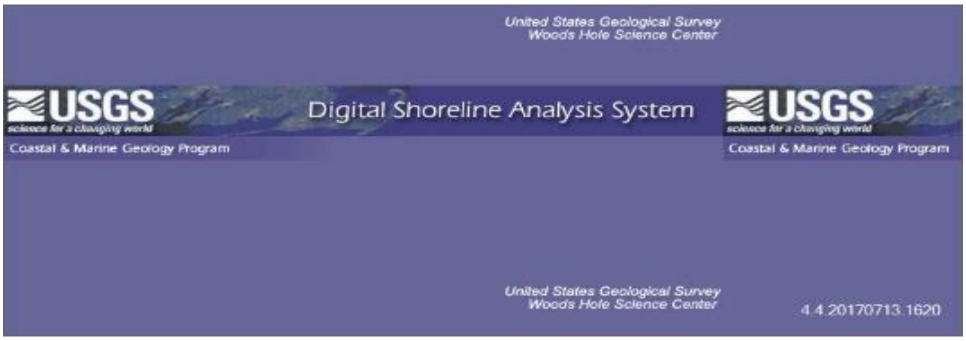

Figure 4. Satellite images provided by USGS

2.2. Case studies

When determining which areas should be studied, a few parameters were defined in order to determine when this method could prove useful.

The most important characteristic is that the archaeological site must be located along a coastline. It must also be situated along coastlines that are susceptible to coastal erosion, meaning the geography should not consist of rocky coast, be situated far above sea level or in other way possess any features that would interfere with the erosion of the coastline. The issues of sea levels and ground levels were disregarded during this project, as the available data, did not come with a table or a definition of the height or types of coastlines, and therefore it was not possible to determine with accuracy whether the site would lie far above sea level. Observations, whether the coast was particularly susceptible to coastal erosion, due to weak minerals, is not possible to deduce, based on the satellites images alone. An alternative was to find records and descriptions of whether the sites were in particular danger of erosion or not.

Five different historical sites and their connected coasts have been chosen as case studies and will undergo a coastal analysis in terms of coastal retreat (erosion) and addition (accretion). They are all located within the UK (see figure 5), which includes cases in Northern Ireland, Scotland and Norfolk. The reason for these specific sites is due to the large parts of the UK coastline that suffers from damage and loss of land, which can be observed via satellite imagery, photo documented history and other observations. A short historical background of each of the sites will be presented. Some of the following cases are on-going, some have already suffered total destruction and some are not yet considered areas of high vulnerability, but could potentially receive that label in the near future. The benefit of knowing the erosion pattern along the coasts of these vulnerable sites becomes evident when authorities have to make certain decisions in regard to implementing actions. Historical sites ought to be either preserved, documented or restored. With the addition of GIS work, the most advantageous solution could be implemented on historical sites, in all stages of destruction. This project could provide additional knowledge for these historical sites, which can be implemented anywhere with a coast.

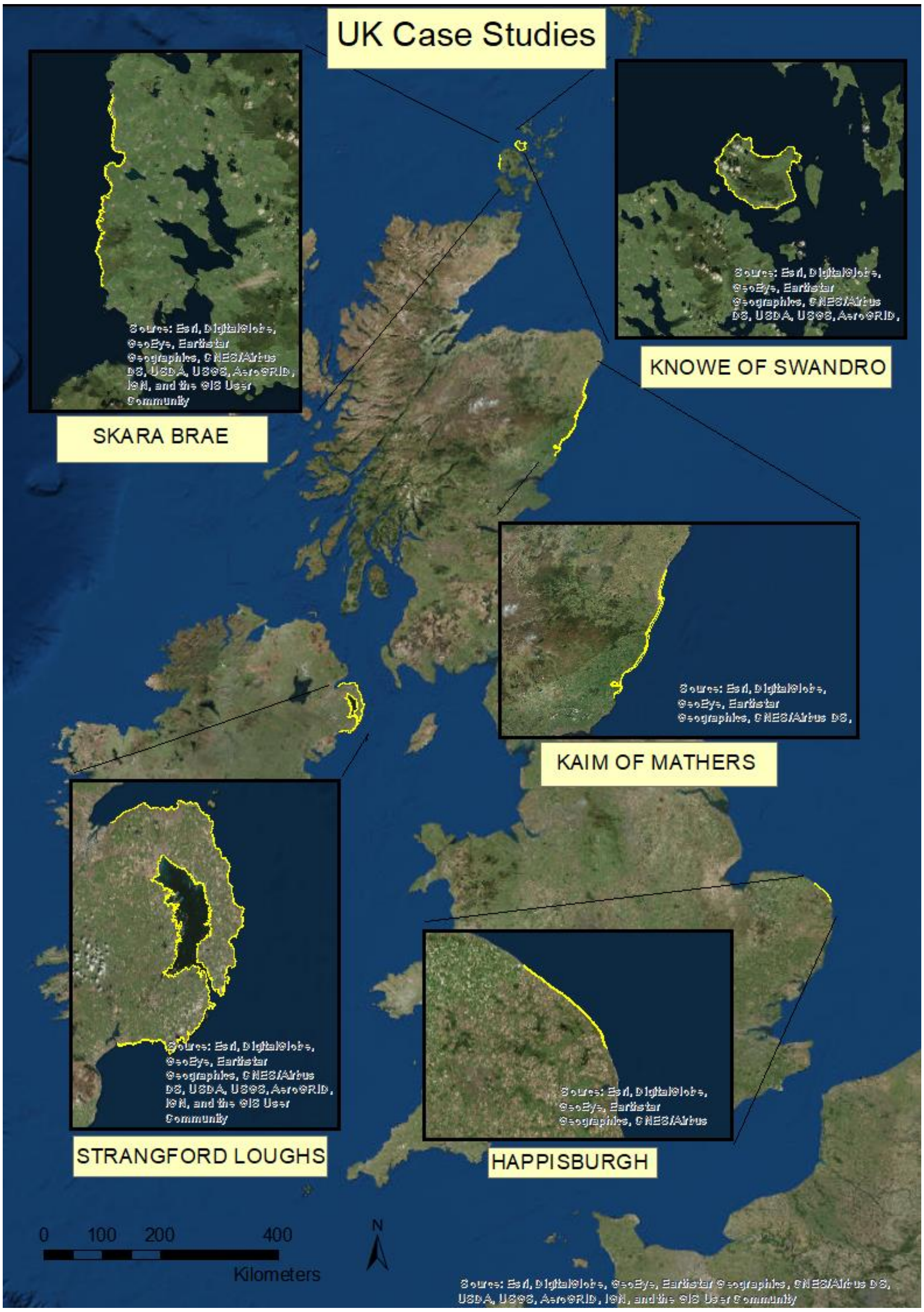

Figure 5. The case studies located in different parts of the UK

2.2.1. Happisburgh

Happisburgh is a village in the English county of Norfolk, on the eastern part of England. The archaeological site nearby held evidence for some of the earliest human remains (Ashton, 2014). Happisburgh is located towards the North Sea, which suffers greatly from coastal collapse.

Happisburgh is an incredibly important historical heritage site, both from a European and local point of view, therefore, Happisburgh will be the main focus of this research project. The remaining sites were chosen based on their cultural heritage, as well as their geographical location, as the eastern shorelines of the UK have suffered greatly from loss of land. This has been covered in detail in national news due to the loss of homes for a large number of people (The Guardian, 2012; The Daily Mail, 2015). However, it is not just the homes of people that need to be considered; early evidence of human interaction with the sea can be observed, such as the case of Happisburgh (Ashton, 2014). Transportation, fishing and intercultural exchanges take place along the coastlines and it is, therefore, a natural assumption that cultural history can be discovered hiding amongst the banks (National Trust, n.d.). However, settling along the coast comes with a price, and due to climate change, a rich source of archaeological history stands to be washed away.

This site was chosen as it is a part of the UK that has suffered a lot of coastal retreat, and it is not the first time Happisburgh is in the focal view of coastal erosion. Historical documents indicate that 250m of land have been lost to the North Sea between 1600 and 1850, according to British Geology Survey (BGS) (Poulton, 2006). It holds valuable historical merit and is a good example of rescue archaeology and how it has to take place fast. The site has proved to hold great importance for the archaeological community, as the earliest evidence of hominin footprints outside of Africa had been discovered (Ashton, 2014). However, Happisburgh is located along an inter-tidal zone of a rapidly eroding coastline, which is not uncommon for archaeological sites, as the coastline provides a vast amount of food-related resources (Ashton, 2014).

In May 2013 an excavation was commenced, which lasted less than three weeks, due to the time restrictions. The reason behind this short excavation-period was due to the rapid destruction of the coast due to wave action. The footprints hold a large value as study indicates that these were the oldest known hominin footprints to have been discovered outside of Africa, and date back to 1 million and 0.78 million years ago (Ashton, 2014).

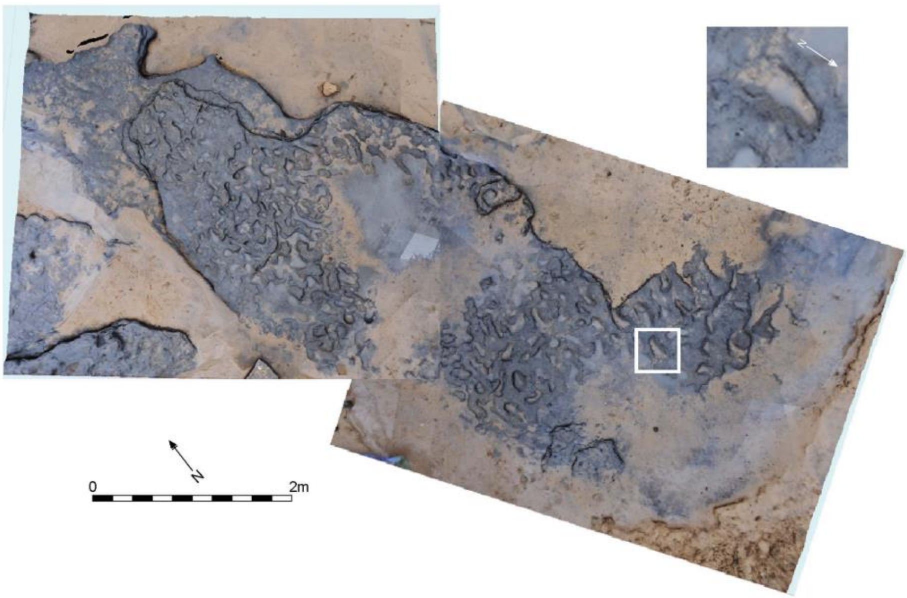

Figure 6. The footprints found at Happisburgh (Ashton, 2014).

The site was discovered when an area of laminated silt was exposed due to wave erosion, which revealed undisturbed bedding surfaces where a series of hollow imprints could be seen (see figure 6). The excavation had to be executed as quickly and thoroughly as possible. Over time the features became less distinct and by the end of

May 2013, they had been completely removed by successive tidal cycles (Ashton, 2014).

However, the modern day village of Happisburgh is also suffering from coastal erosion, with water eroding the land, and the village diminishing every year. Poulton (2006) notes that especially Norfolk is a high-risk area (see figure 7) with a lot of coastal destruction. The increase of rapid coastal collapse, the rising sea levels and climate change are serious issues for many of these coastal communities. Coastal erosion is a very complex study, in which several aspects must be considered such as onshore environment, offshore environment, weather and climate change, strength and variability of geological material and at last the influence of engineered structured, such as groynes and sea walls (Poulton 2006). Happisburgh is an interesting case study, when it comes to evaluating at which rate the coast changes. The archaeological site holds a great interest for this specific project. However, Happisburgh shows that not only does historical knowledge stand to be lost from the fast-retreating coastlines, so do the homes and lives of the current coastal communities.

Figure 7. View of the footprint surface directed north (Ashton, 2014).

2.2.2. Skara Brae

Skara Brae is located on the Orkney Islands, north of Scotland. The islands are located on the West Bank, at the coordinates W°59.0487° N, 3.3417° W. Skara Brae holds the best-preserved Neolithic buildings (see figure 8) in Northern Europe (Dinley, 2000), dating back about 5000 years, estimated around 3100-3000 BC. This predates sites such as Stonehenge and the earliest of the Egyptian pyramids and Skara Brae is also part of the United Nations Educational, Scientific and Cultural Organization (UNESCO) world heritage site (Simpson, 2006).

Figure 8. Skara Brae holds some of the best preserved Neolithic buildings, as can be seen on this photo (Orkneyjar, 2019).

2.2.3. Knowe of Swandro

Just like the previous case of Skara Brae, Knowe of Swandro is located on the Orkney Islands, in northern Scotland. It is a subdivision of the excavations taking place along the Bay of Swandro, and as it is an ongoing excavation, a final publication is yet to be made. All information gathered stems from field reports that are published after every excavation-season.

The Bay of Swandro is a multi-period historical site, that shows signs of occupation from c. 3800 BC (early to middle Neolithic) to the Norse period in 1468 AD. The current focus of the ongoing excavation is in Knowe of Swandro, due to the imminent danger of total destruction the sites are undergoing. Knowe of Swandro consists of a large mound situated behind a boulder beach on the Bay of Swandro, with a Norse settlement nearby. The remains consist mainly of the ruin of a circular stone tower, and has been dated to be of Iron Age (The Swandro-Orkney Coastal Archaeological Trust, 2018).

The Bay of Swandro is an ongoing excavation (see figure 9) that is in the process of gathering funding to continue the excavation (The Swandro-Orkney Coastal Archaeological Trust, 2018). Knowe of Swandro is an excellent and very current example of the issues historical sites suffer when trying to fight both time and finances in order to gather as much historical knowledge as possible (The Swandro-Orkney Coastal Archaeological Trust, 2019).


Figure 9. The on-going excavation of Knowe of Swandro (Visit Scotland, 2019).

2.2.4. Strangford Lough

Strangford Lough is located in Northern Ireland and shows signs of settlement dating back to 7000BC, as evidenced by the abundance of discarded Mesolithic shells found. It also holds burial sites, which have been dated to around 4000 BC (National Trust, n.d.). Strangford Lough also holds a rich tapestry of history and covers the early Christian period (from the mid-6th century), the Vikings (between the 9th and 11th centuries) and the Anglo-Normans (1177 AD) (National Trust, n.d.).

Strangford Lough encompasses a rich abundance of historical sites such as churches, tombs, tower houses, wells and a number of castles (see figure 10). All these sites available are located along the coast (Visit Strangford Lough, n.d.), and Strangford Lough is a great example of how the coast and the ocean were utilised by people throughout history, and why so much archaeological material can be located along the shores.

Figure 10. Skretrick castle (built in the mid-15th century) is one of the many historical monuments along the coast of Strangford Lough (Visit Strangford Lough, n.d.).

2.2.5. Kaim of Mathers

Kaim of Mathers is located on the eastern side of Scotland. It is the most modern representation of archaeological sites on this list, as the historical building seems to stem back from the 15th century. The castle was occupied only for a short time, as the exposed location and subsequent erosion resulted in only part of the castle remaining to this day (see figure 11). The building is deemed by SCAPE (the Scottish Coastal Archaeology and the Problem of Erosion) to be a site at high risk of complete destruction. SCAPE works with the public and volunteers to gather information and researches the eroding heritage sites along the coast of Scotland.

Figure 11. The consequences of coastal erosion can be observed at Kaim of Mathers, where the remains of the tower still stand (CastlesFortsBattles, 2019).

3. Methodology

3.1. Digital Shoreline Analysis System (DSAS):

DSAS (figure 12) is a user-friendly software extension, with an extensive user manual for beginners that goes through the installation procedures and explains which inputs are required and how to apply them. It is readily available and works within Esri's ArcGIS software. It focuses on computing rates-of-change for any boundary-change issue, and can work within a long range of real-life-issues that could occur. Where it mostly focuses on coastal changes, it can also compute future changes of other identified features, such as land use and cover boundaries, glacier limits and riverbanks (USGS, n.d.b)

Figure 122. The software-extension, Digital Shoreline Analysis System.

Where the focus has been mainly on coastal environment, it has also proven useful for computing boundary-change related issues, as long as the object is a clearly-defined feature at discrete times, such as city boundaries or glacier movement. The current version of DSAS is v. 4.0 (20147) and is compatible with ArcGIS 10.4 and 10.5 only. It is supported on Windows 7 and 10 operating systems and the system needs to meet the following requirements:

- Microsoft .NET Framework 4.5.2 (or higher)
- ArcGIS Desktop 10.4 or 10.5 DSAS is **not** compatible with ArcGIS v.10.3 or lower.
- .NET Support Feature for ArcGIS (Available on the ArcGIS installation media)
- Freely available MATLAB component runtime library utility

Requirements found in DSAS manual (Thieler, 2017).

3.2. Data processing

The data was extracted from USGS in which satellite images from different time stamps were chosen (figure 13). The only parameters for the chosen images were as following:

- The earliest obtainable satellite image that is deemed applicable for this project
- Satellite mosaics that cover the same area
- Satellite images free of noise or obstructions such as clouds and heavy shadows
- The satellite images must have been taken with at least 2 years in between them.

After these parameters were established, the years were arbitrarily chosen and the month of the year had no bearing for this project as long as the previous parameters were upheld.

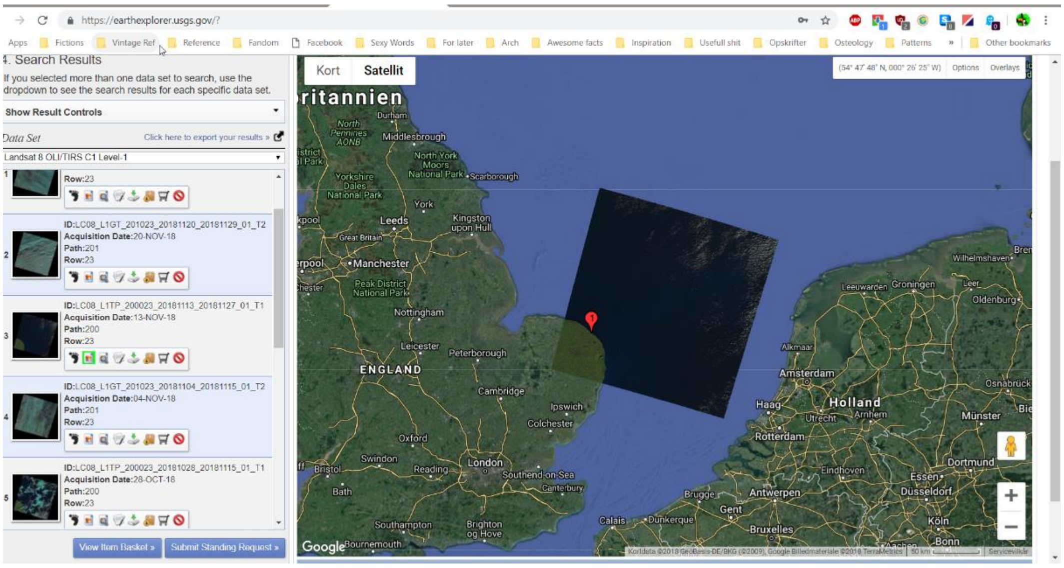

Figure 133. The satellite images available and the structure of the search engine.

3.3.1. Satellites:

The following table shows the list of satellite images used:

Table 1. Metadata for the Landsat spacecraft and timestamps covering Happisburgh.

LandsatLook Natural Color			
Acquisition Date	**Spacecraft identifier**	**Landsat Product Identifier**	**Landsat Scene Identifier**
13-11-2018	Landsat 8	LC08_L1TP_200023_20181113_20181127_01_T1	LC82000232018317LGN00
30-11-2016	Landsat 8	LC08_L1TP_201023_20161130_20170317_01_T2	LC82010232016335LGN01
03-11-2011	Landsat 5	LT05_L1TP_201023_20110930_20161005_01_T1	LT52010232011273KIS00
12-05-2009	Landsat 5	LT05_L1GS_201023_20090519_20161026_01_T2	LT52010232009139MOR00
19-06-2000	Landsat 7	LE07_L1TP_201023_20000619_20170211_01_T1	LE72010232000171EDC00
03-08-1990	Landsat 5	LT05_L1TP_201023_19900803_20170129_01_T1	LT52010231990215KIS0
22-09-1982	Landsat 1-5	LM04_L1TP_201023_19820922_20180414_01_T2	LM42010231982265AAA03
01-11-1972	Landsat 1-5	LM01_L1TP_216023_19721101_20180429_01_T2	LM12160231972306AAA04

The following years were selected:

- 1972, 1st of November[1].
- 1982, 22nd of September
- 1990, 3rd of October
- 2000, 19th of June
- 2009, 9th of May
- 2011, 3rd of November

[1] Which was the earliest timestamp available.

- 2016, 30th of November
- 2018, 13th of November

The projection is WGS_1984_Web_Mercator_Auxiliary_Sphere.

Table 2. Metadata for the Landsat spacecraft and timestamps covering Skara Brae.

LandsatLook Natural Color		Skara Brae	
Acquisition Date	**Spacecraft identifier**	**Landsat Product Identifier**	**Landsat Scene Identifier**
02-06-2018	Landsat 8	LC08_L1TP_206019_20180702_20180716_01_T1	LC82060192018183LGN00
18-05-2010	Landsat 5	LT05_L1TP_205019_20100518_20180128_01_T1	LT52050192010138MTI00
27-08-1972	Landsat 1	LM01_L1TP_222019_19720827_20180428_01_T2	LM12220191972240AAA06

Table 3. Metadata for the Landsat spacecraft and timestamps covering Knowe of Swandro.

LandsatLook Natural Color		Knowe of Sandro	
Acquisition Date	**Spacecraft identifier**	**Landsat Product Identifier**	**Landsat Scene Identifier**
19-06-2016	Landsat 8	LC08_L1TP_205019_20160619_20180528_01_T1	LC82050192016171LGN02
03-08-2009	Landsat 5	LT05_L1TP_205019_20090803_20161022_01_T1	LT52050192009215KIS00
10-06-1975	Landsat 1	LM02_L1TP_222018_19750610_20180425_01_T2	LM22220181975161GMD07

Table 4. Metadata for the Landsat spacecraft and timestamps covering Strangford Lough.

LandsatLook Natural Color		Strangford Loughs	
Acquisition Date	**Spacecraft identifier**	**Landsat Product Identifier**	**Landsat Scene Identifier**
02-07-2018	Landsat 8	LC08_L1TP_206022_20180702_20180716_01_T1	LC82060222018183LGN00
11-06-2007	Landsat 5	LT05_L1TP_205022_20070611_20180118_01_T1	LT52050222007162MTI00
15-07-1975	Landsat 2	LM02_L1TP_222022_19750610_20180425_01_T2	LM22220221975161GMD07

Table 5. Metadata for the Landsat spacecraft and timestamps covering Kaim of Mathers.

LandsatLook Natural Color		Kaim of Mathers	
Acquisition Date	**Spacecraft identifier**	**Landsat Product Identifier**	**Landsat Scene Identifier**
25-06-2018	Landsat 8	LC08_L1TP_205020_20180625_20180704_01_T1	LC82050202018176LGN00
05-05-2008	Landsat 5	LT05_L1TP_204020_20080505_20180126_01_T1	LT52040202008126MTI00
09-06-1975	Landsat 1	LM02_L1TP_221020_19750609_20180425_01_T2	LM22210201975160XXX01

Choosing which years to examine came down to the parameters established earlier, but also to avoid too large of a sample size to ease computation costs. Eight timestamps were deemed appropriate as a large timeframe is covered, starting from the earliest available satellite images to the newest. In 2013, the exposed archaeological site of Happisburgh was damaged due to erosion (Ashton, 2014), so the change from 2011 to 2016 was particularly interesting. Several timestamps were incorporated to observe if a general trend could be observed and analysed.

All images were visually inspected to ensure that the previous parameters were upheld and that the images chosen did not contain any interferences. Afterward, the images were exported to ArcGIS PRO where the data was further processed and prepared for analysis via DSAS.

3.3. Extracting shoreline:

In the following chapter, the method for extracting data will be presented. The shoreline extraction workflow is outlined below (figure 14).

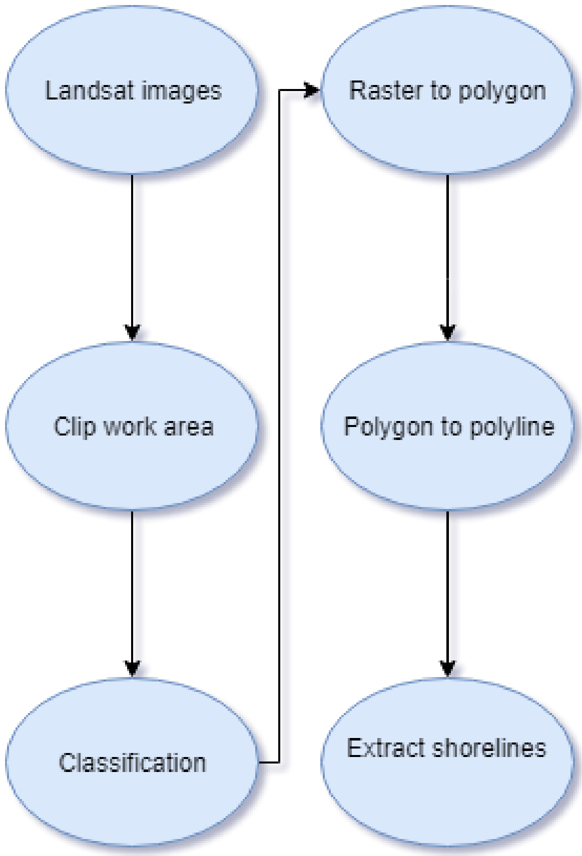

Figure 14. Flowchart showing the following process.

After the images had been obtained, following the parameters defined earlier in this project, the selected images were imported into ArcGIS Pro. The satellite images were processed initially in ArcGIS Pro. The extraction of the shoreline was executed in ArcGIS Pro, and the DSAS tool was run in ArcMap. The procedure was as follows.

Figure 15. Defining the work area.

First, the exact location of Happisburg needed to be defined (figure 15). Satellite images were imported into ArcGIS Pro, but because the saved files were located in southern Africa, the files had to be manually georeferenced. By manually georeferencing the satellite images, based on common geological attributes, a visual assessment of the images was implemented. This has the benefit of visually quality controlling the images, hence ensuring that the coastlines and landmasses lined up. A solid area of eastern Norfolk was defined and saved as a polygon to use for boundaries. Because the satellite images were manually georeferenced the size of the work area was kept relatively small in order to ensure good results.

In order to georeference as precisely as possible, a basemap in ArcGIS Pro was used as a reference-layer to avoid inconsistencies as the different timestamps will vary depending on what year they have been taken. In figure 16 the swipe tool could quickly give an assessment of whether or not all satellite images matched up.

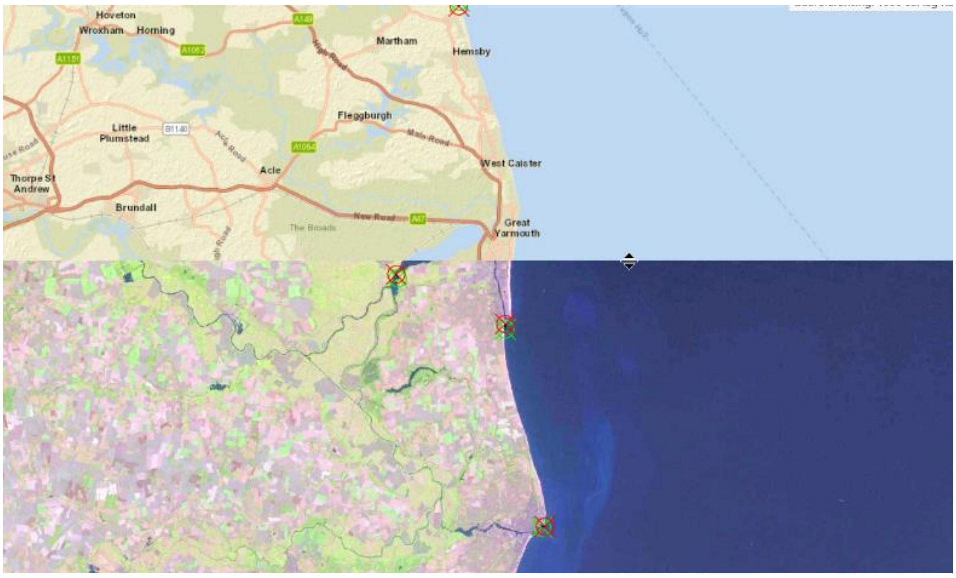

Figure 16. Georeferencing, ensuring high location-precision.

The entire area of the satellite mosaics was necessary and to keep the area clearly defined a smaller section of the images were chosen. All the satellite images were cut to the defined area as can be seen in figure 17, and the rest of the extraction of data was based on that polygon.

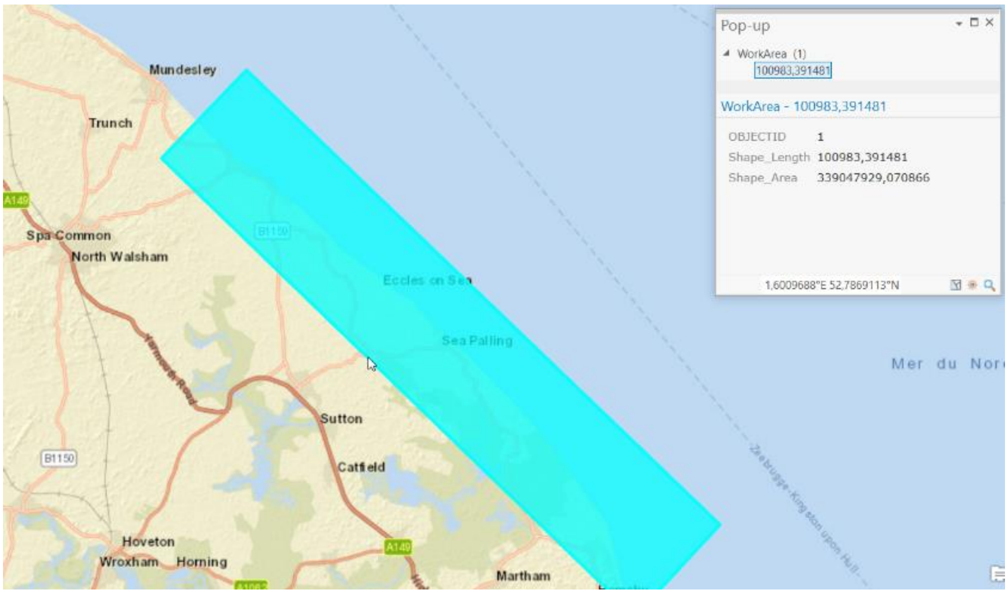

Figure 17. Close up of the work area.

Following up, the next step was to classify water and landcover; this was done by running the ISO unsupervised classification tool, and due to the areas limited size, it was a fast and very precise result (figure 18). There were a few issues with one of the satellite images, due to what seemed to be innocuous cloud cover, which did require cleaning up manually and ensuring quality control.

Figure 18. Classifying the work area in two categories; landmass and water.

Once all the classified images were up to standard, the "raster to polygon" tool was deployed which resulted in clean polygon files (figure 19).

Figure 19. Raster to polygon.

The last action to undertake in ArcGIS Pro was utilizing the ”polygon to line” tool, and by then the coastal lines were now defined as simple, but informative, polylines ready to use in ArcMap, which are displayed in figure 20.


Figure 20. All the shorelines colour-coordinated by colours.

Manual work was necessary to ensure that the data converted to DSAS was up to standard, and that no disturbances of any sort would be the cause of false results. Due to the sample size, the tools in ArcGIS Pro were processed very fast and a result could be obtained relatively quickly. Quality controlling and obtaining the images were time-consuming, but the technical aspects went smooth and without further delays.

3.4. Shoreline specifications

After extracting a proper shoreline, the shapefiles were exported to ArcMap, for further analysing. In ArcMap, a new personal geodatabase was created in order for the DSAS software extension to run. In the new personal geodatabase, all the shapefiles and data will be stored. The geodatabase will also function as a storage location for all program-generated transects feature classes and related statistical output tables (figure 21).

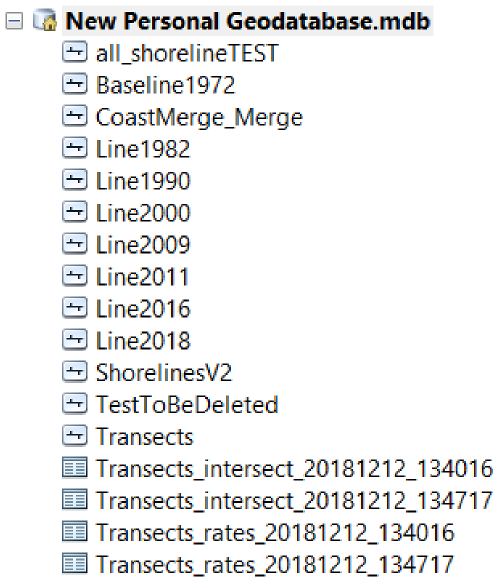

Figure 21. An example of the personal geodatabase with the necessary files. The baselines, the merged coasts, the shorelines representing the different timestamps, and the transects and rates numbers can be observed in the bottom of the database.

DSAS requires that the unit is set in meters in a projected coordinate system and all the shorelines must be merged or appended into one single feature, within the personal geodatabase.

Specific shoreline field requirements must also be added to the attribute table:

Field name	Data type		
OBJECTID	Object ID	Auto-generated	
SHAPE	Geometry	Auto-generated	
SHAPE_Length	Double	Auto-generated	
Date_	Text	User-created	Length=10 or Length=22
Uncertainty	Any numeric	User-created	

Figure 22. Shoreline field requirements (Thieler, 2017).

In figure 22 the shoreline requirements can be observed. Some are auto-generated, some are user-generated. The *uncertainty* field represents an uncertainty value for positional measurements. The *uncertainty* field should ideally account for both natural uncertainties, such as tides, wind, waves and so on, as well as any human errors when digitising. The *uncertainty* field represents an uncertainty value for positional measurements. It is a useful addition, in order to allow room for uncertainties and still attain accurate results. For this project, the value for uncertainty was set to default, as time did not allow an in-depth calculation of how those values ought to be defined. Uncertainty includes tides, weather conditions, time of year and possible georeferenced mistakes.

3.5. Creating a baseline

Once the required fields had been added and the attribute table is up to date, a baseline was required. The baseline should be established adjacent to either the earliest of timestamps or the latest of timestamps. During this project, the baseline was set adjacent to the earliest of the timestamps, 1972, as the focus of this project is looking into how much landmass has been lost over time and how much can be expected to disappear in the future.

There are three ways to define a baseline, either creating an entirely new feature, create a buffer around an existing shoreline or use a preexisting baseline. This project will create a new feature class offshore, which will function as the baseline. To ensure that the baseline matches the requirements of the DSAS tool, it must require the following:

1. Must be a feature class within a personal geodatabase.
2. Must be in a projected coordinate system in meter units.
3. May consist of a single line or be a collection of segments.
4. Each baseline segment must be placed entirely onshore or offshore with respect to the shorelines.

On figure 23 an attribute table of the newly created baseline can be seen. The polylines each represents a shoreline from the different years. The last point of this checklist requires further fields to be added to the attribute table, although some of these fields will not prove themselves necessary, according to this project (figure 24).

The checklist was acquired from the DSAS manual, which accompanies the software (Thieler, 2017).

Table

CoastMerge_Merge

OBJECTID *	Shape *	LEFT_FID	RIGHT_FID	Shape_Leng	Year	ID	OFFshore	CastDir	Date	Uncertainty	Shape_Length
1	Polyline	3	2	43825,270132	1972	1	<Null>	<Null>	01/01/1972	<Null>	43825,269963
2	Polyline	37	35	45370,054008	1982	2	<Null>	<Null>	01/01/1982	<Null>	45370,054318
3	Polyline	8	7	44011,485227	1990	3	<Null>	<Null>	01/01/1990	<Null>	44011,484995
4	Polyline	5	4	43512,310666	2000	4	<Null>	<Null>	01/01/2000	<Null>	43512,310589
5	Polyline	57	56	46517,813394	2009	5	<Null>	<Null>	01/01/2009	<Null>	46517,813528
6	Polyline	3	2	44117,62882	2011	6	<Null>	<Null>	01/01/2011	<Null>	44117,628867
7	Polyline	6	5	44146,162212	2016	7	<Null>	<Null>	01/01/2016	<Null>	44066,752681
8	Polyline	15	13	43938,928071	2018	8	<Null>	<Null>	01/01/2018	<Null>	43938,928099

1 (0 out of 8 Selected)

Figure 23. The merged coastlines. Each coastline has an objectID and a unique year number.

Field name	Data type		
OBJECTID	Object ID	Auto-generated	Required
SHAPE	Geometry	Auto-generated	Required
SHAPE_Length	Double	Auto-generated	Required
ID	Long Integer	User-created	Required
Group	Long Integer	User-created	Optional
OFFShore	Short Integer	User-created	Optional
CastDir	Short Integer	User-created	Optional

Figure 24. Baseline requirements.

3.6. Set parameters:

Once the necessary input has been implemented, the geodatabase created and all feature classes have been added, the DSAS can now run, and transect locations and calculations of change statistics can be created. Next is to run the DSAS application and to produce results to be analysed. The following will describe the method of which input has to be entered, according to the DSAS manual (Thieler, 2017)

3.7. Cast transects:

Cast transects is one of three major elements when setting the parameters. When choosing the baseline location a choice could be made between onshore, offshore or onshore/offshore combination. A manual baseline was made offshore from which the numbers would be run, and thus the choice of offshore was made. The desired distance between the transects and the length of them was dependent on the site. The transect length needed to extend from the baseline to the farthest shoreline, and can later be clipped to not overextend farther than that. Once the transect had been cast, the EPR could be calculated.

Once the EPR has been calculated, the statistics can then be obtained thanks to the cross-sections of the transects and the coastlines. The table was joined with a rates-file, which contains the EPR-output.

4. Results:

In the following chapter the results for each case study will be analysed, examined and evaluated. The parameters, such as transect distance and transect lengths, applied for each case study will differ, due to both size and focal point of each area. However, these will be explained in their respective sub-chapters.

4.1. Happisburgh:

The coast of Happisburgh covers a length of about 42-45km. The reason for the range of the length is due to the shoreline paradox, which is why only an estimate will be presented, and not an exact number. The length provided was chosen to see if results could be compared, and observe if any erosion or accretion occurred along the shores. As mentioned earlier, Happisburgh suffers from land loss every year. Therefore, as an addition to observing the shoreline change at the historical sites, it would also be interesting to investigate if land loss is a trend occurring along the coast of Norfolk or if it is Happisburgh specifically which is experiencing erosion.

The city of Happisburgh can be located in figure 25. As mentioned in previous chapters, the Neolithic site of Happisburgh has washed away in 2014, another indication that creating an estimate of how quickly shorelines erode can be of great service to the field of preservation.

The years of the shorelines are represented by colours, making it easy to distinguish each year from the next. By merely visually assessing the image, it can clearly be observed that the shoreline has moved from the earliest timestamp (year 1972) till the latest (year 2018).

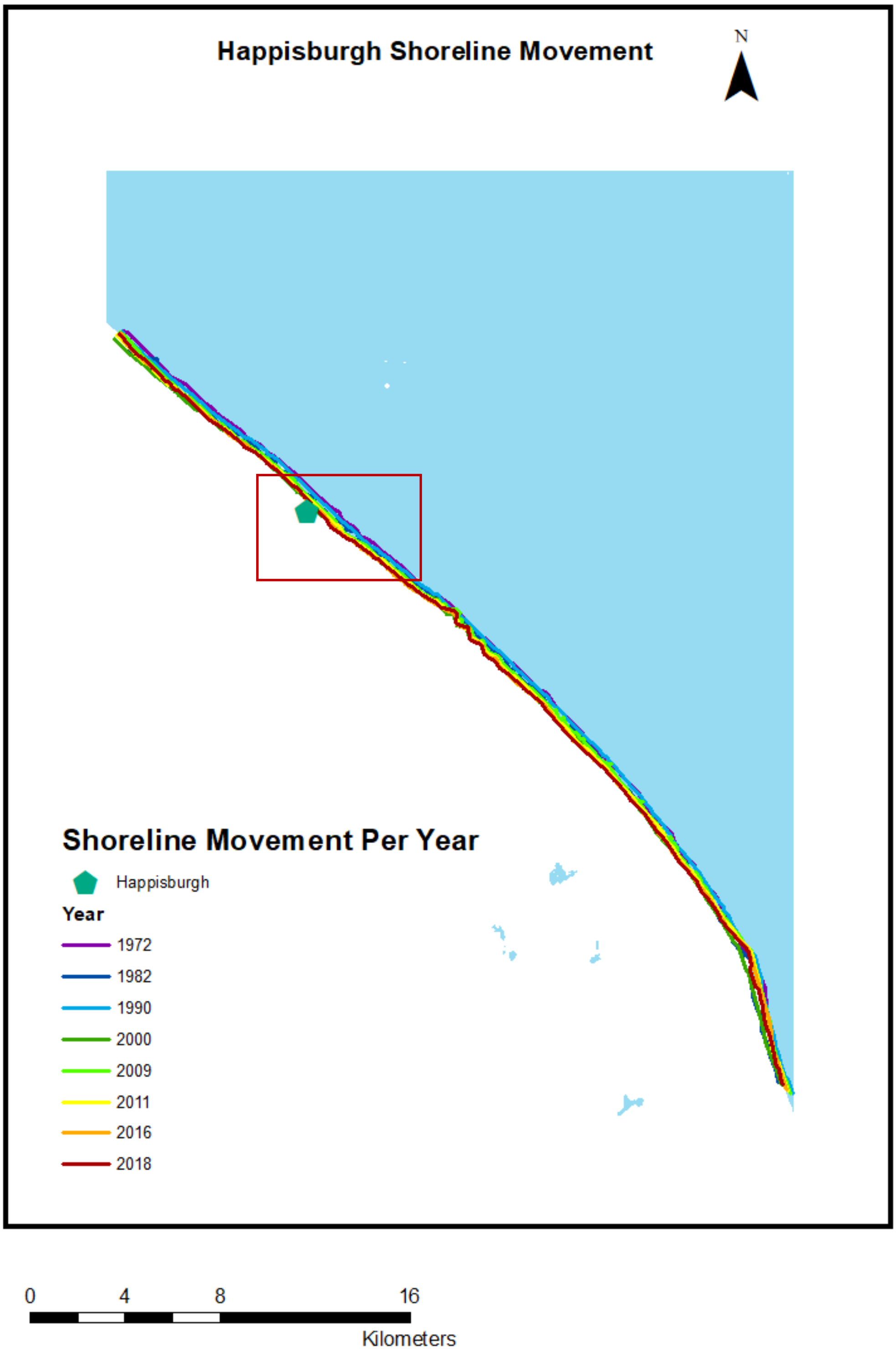

Figure 25. Shoreline movement per year. Purple represents the earliest year (1972) and red represents the latest (2018).

A baseline was created onshore and the transects were cast with a distance of 50m between each of them and each transect had a length of 1000m. The 50m transect distance was chosen both to create a visual that could be easily analysed when zoomed out to the full extent of the measured coast but also to attain as many EPR-outputs as possible, to achieve a thorough analysis of shoreline changes (see figure 27).

Figure 26. A close-up of the transects with a distance of 50m between each transect.

Once the EPR has been calculated, the statistics can then be obtained thanks to the cross-sections of the transects and the coastlines. The table was joined with a rates-file, which contains the EPR-output. Figure 26 shows a close-up of Happisburgh, displaying the transects, the ONshore baseline and the merged coasts. The transects cover most of the different shorelines, with an almost equal distance between them. Choosing a distance rate between each transect of 50m ensured that a satisfactory quantity of EPRs could be obtained. The transects can then be clipped to the extent of the latest and the most recent shoreline.

A visual representation can be seen in figure 27 where the green colour represents both static coast and accretion and the colours yellow to red, represent the severity of erosion. Red represents an erosion rate of -14.1 to -10 m/y, (meter per year), orange covers an erosion rate of -9.9 to -7 m/y, yellow covers an erosion rate of 3.9 to 0.000001 m/y and green has an accretion rate of 0.0 to 2.7 m/y.

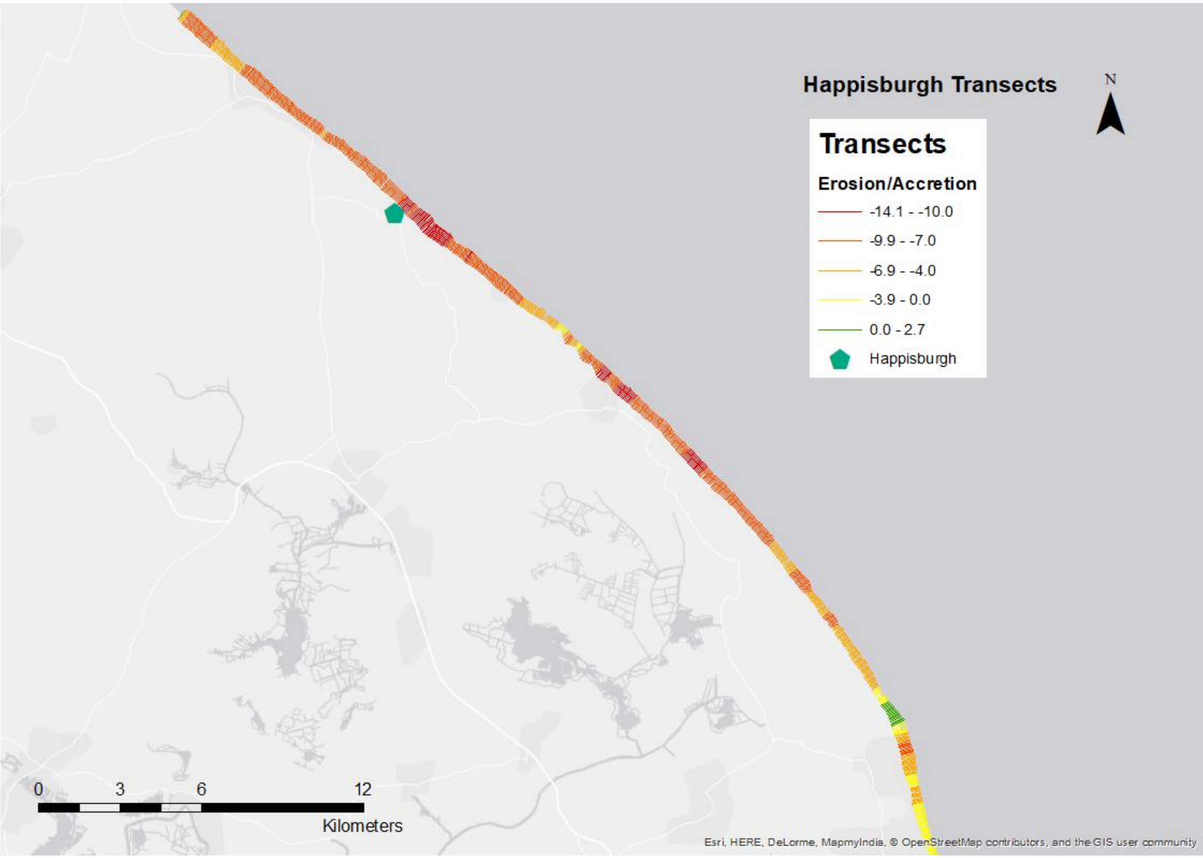

Figure 27. The coast of Happisburgh as it shows erosion or accretion. The erosion/accretion rate is set to meter per year. The shoreline change rates are spatially displayed by use of colour symbology and transect length.

As can be seen on figure 27 there seems to be a trend in which the uppermost coast, and especially the area around Happisburgh town, has a declining coastline, whereas further south there seems to be a trend of the landmass building up. This could be due to a build-up of residue from the eroding coast coming from the north and moving down south. Happisburgh is also exposed directly to the North Sea. The general trend for the specific location of Norfolk is that the currents run north to south (Sündermann, 2011), which could explain the buildup of land south of Happisburgh. This is of course very simply put, however, the study of ocean currents is outside the scope of this project.

Figure 28 shows a closeup of the location of Happisburgh. The highlighted polyline on this image represents the transect with the highest number of EPR, between 1972 and 2018. This shows that the highest EPR number that can be traced at Happisburgh has a number of -14.16 meter, over a time span of 46 years.

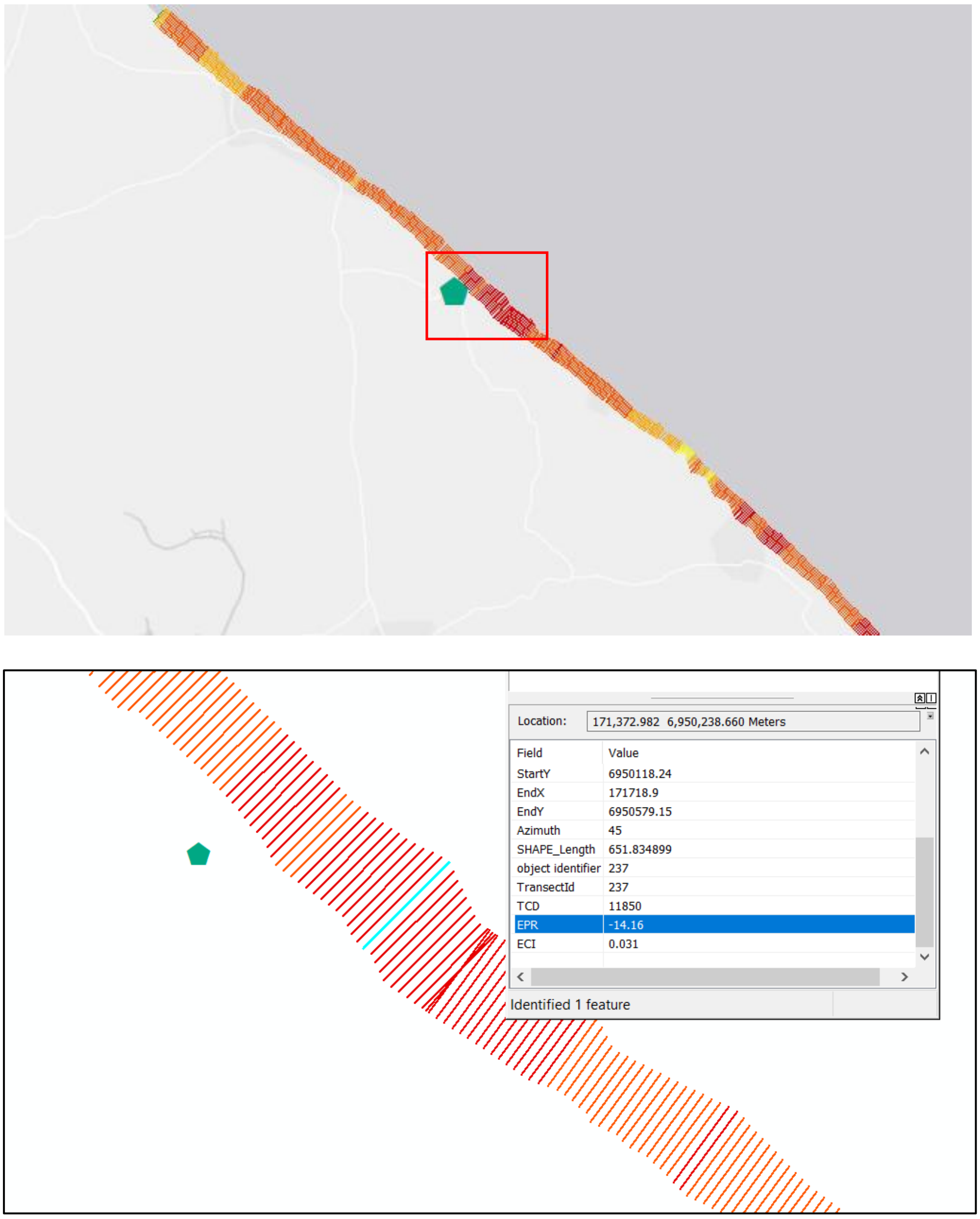

Figure 28. The highest erosion-rate observed at Happisburgh.

In 2014 the Neolithic site of Happisburgh was completely destroyed. On figure 29 the change between 2011 and 2016 can be observed. It was within these two timestamps that the Neolithic site of Happisburgh had vanished.

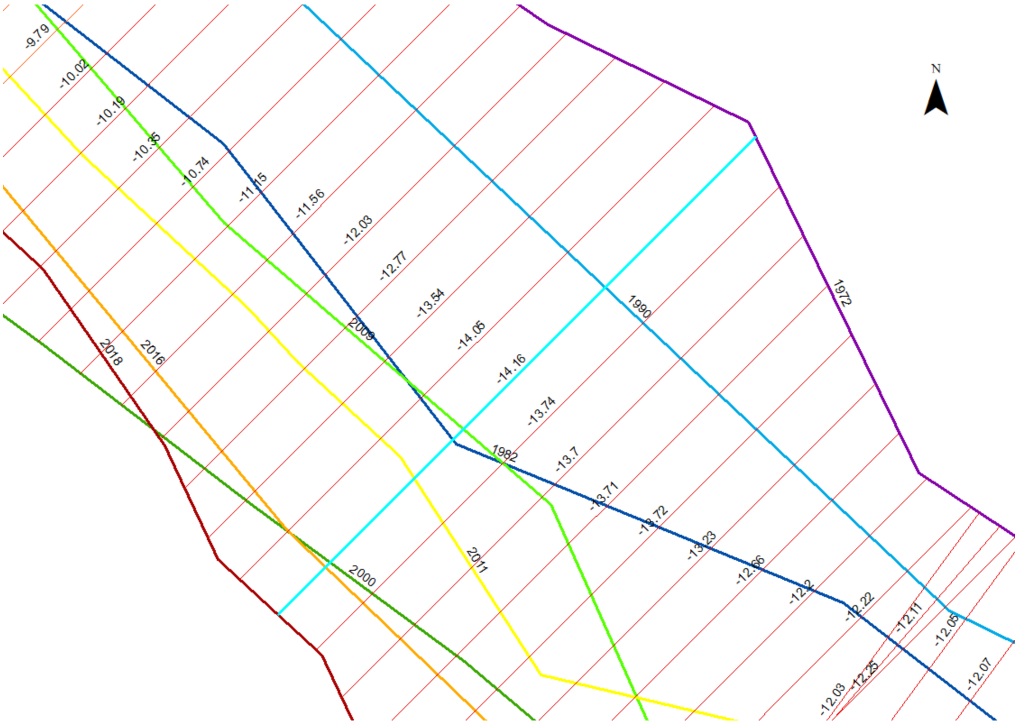

Figure 29. The figure shows a close-up of the coastlines with corresponding dates.

The map on figure 27 does not show a prediction of future shoreline-action, but it does provide aid and a general idea of what future changes might come into play. By creating a visual of the coast with the EPR's, the evolution of the coast is displayed. Based on historical data, it will provide information for future archaeological excavations, with salvage archaeology as the focal point.

For the following sites, a similar approach has been taken, in order to see what state of coastal erosion the case sites are in. To secure transparency, it will here be noted that most of the remaining sites will display unclipped transects, ensuring the visual assessment will give a more complete and easier assessed picture.

4.2. Skara Brae

Skara Brae is located on the western side of the Orkney Islands. Figure 30 shows the exact location of the historical site, inward in a small alcove of the island, in a position that could seem slightly more protected from the open waters compared to the other areas of interest. Figure 30 also shows the coastlines and how they have moved. Extending the work area outside of the small section of the historical site of Skara Brae, provided an opportunity to observe whether Skara Brae is less likely to suffer coastal erosion compared to the rest of the coast. The shoreline of Skara Brae is the only site orientated towards west. The work area of the coast has a length of ca. 15km, but just as in previous cases, the length is just an estimate and not an exact measurement of coastal length.

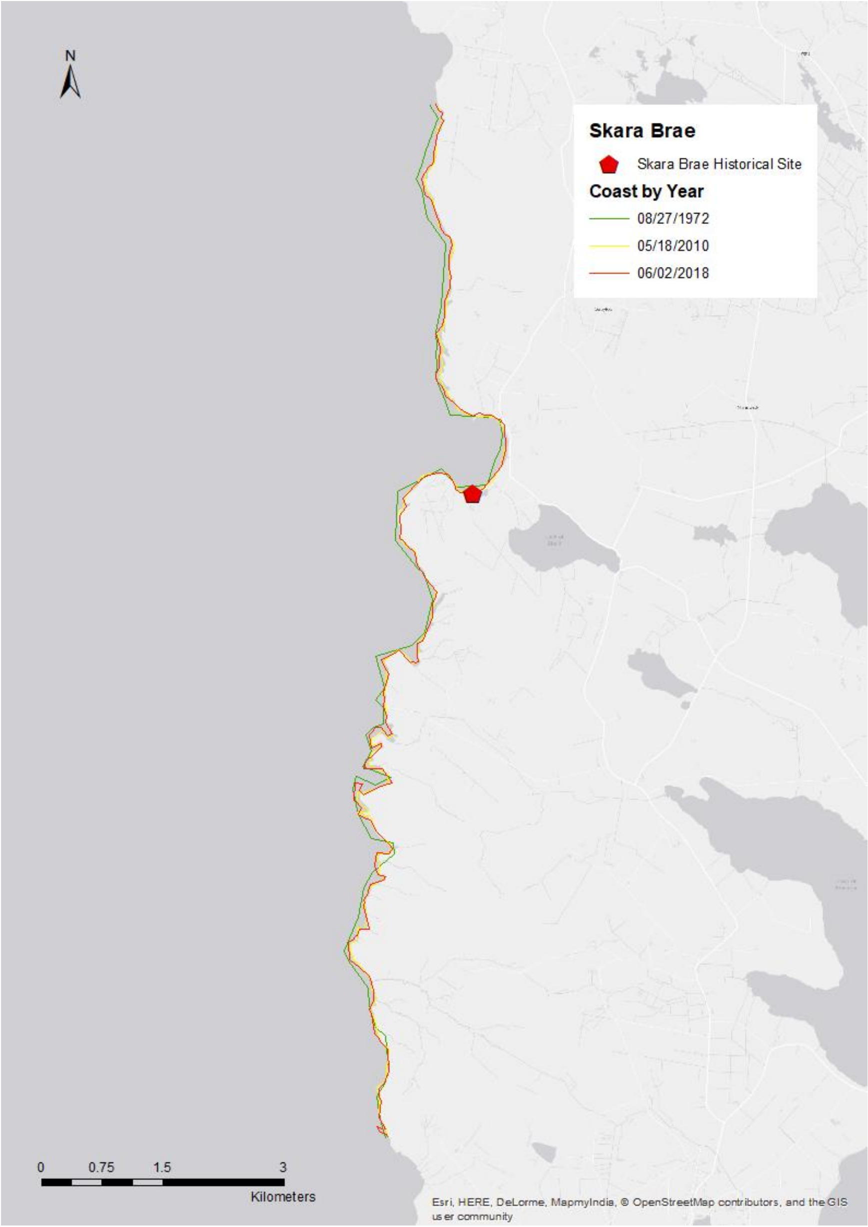

Figure 30. Green coastlines corresponding with the year 1972, the red 2018.

When casting the transects, the shape of the coast must be taken into consideration. Not all case studies have a relatively straight shoreline as the one of Happisburgh. Because Skara Brae has a more complexly shaped coastline than a case study such as Happisburgh, a lot of editing had to take place (which will be seen in the upcoming case studies as well).

The curve of the shoreline is cause for complications when casting transects, due to the curve of the shoreline (see figure 31). However, moving the transects to ensure a cross point between transect and shoreline ensured an improved coverage of the shore. Once the transects were cast, it was possible to go in manually and redirect the different transects in angles not automatically covered. Thus, shoreline that had moved, but not been registered previously, could now be accounted for (see figure 32).


Figure 31. Scattered transects before editing.


Figure 32. Transects after editing.

The transects were set offshore with a distance of 40m and the length set to 600m. The result can be seen in figure 33, where an EPR between -3.499999m and -0.000001m is the most prevalent. From the map, it appears that the general trend along the coast of Skara Brae is an erosion rate between -3.499999m and -0.000001m. There does not seem to be any difference between the majority of the coast and the historical site of Skara Bra, however, the trend of accretion further down south does appear in this case as well.

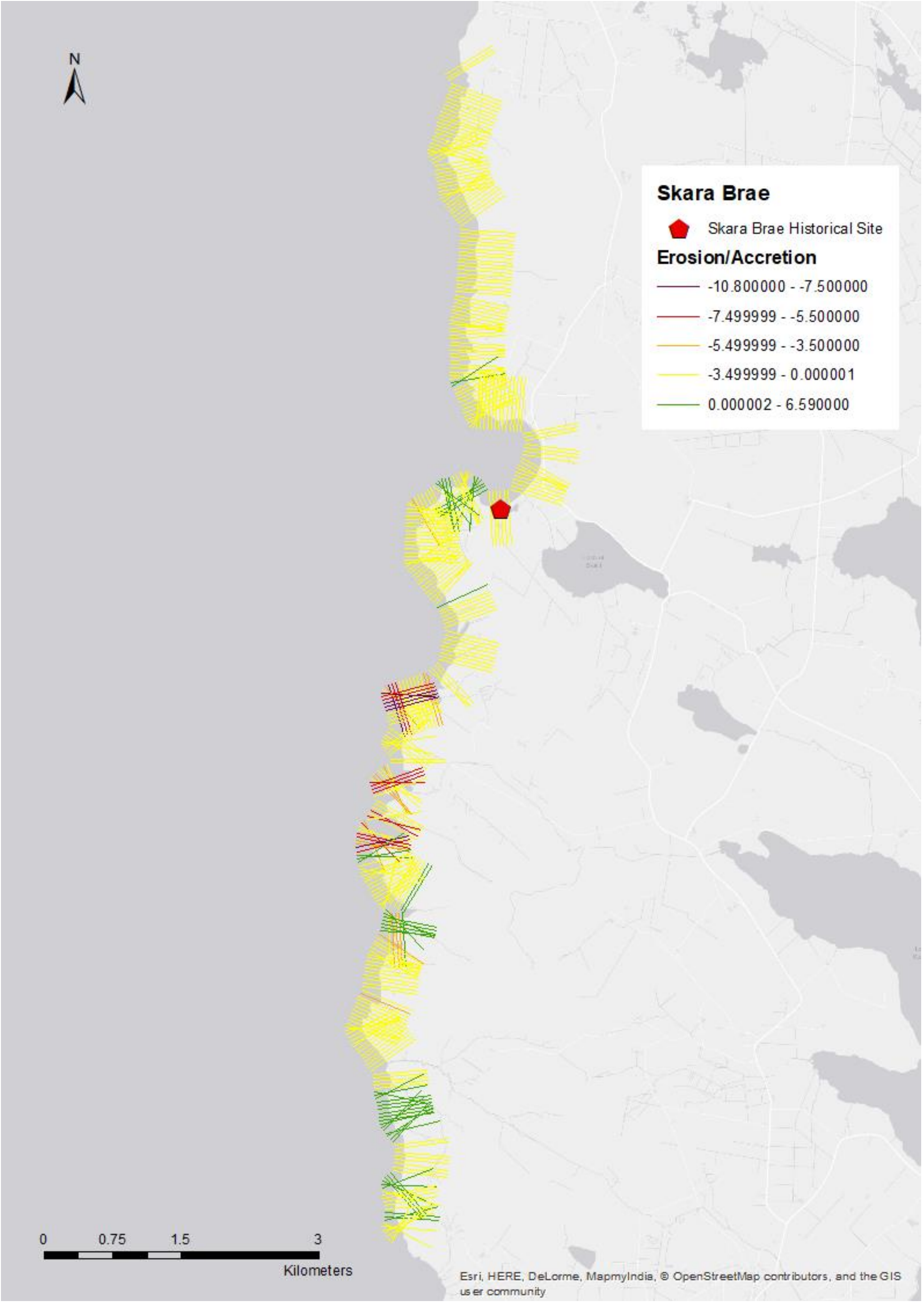

Figure 33. Transects along Skara Brae. The yellow category is the most prominent.

4.3. Knowe of Swandro:

Because Knowe of Swandro is placed on a smaller island, the coast of the entire island was extracted. It measures about 32km. The distance between the transects was set to 20m and the length of each transect was 350m.

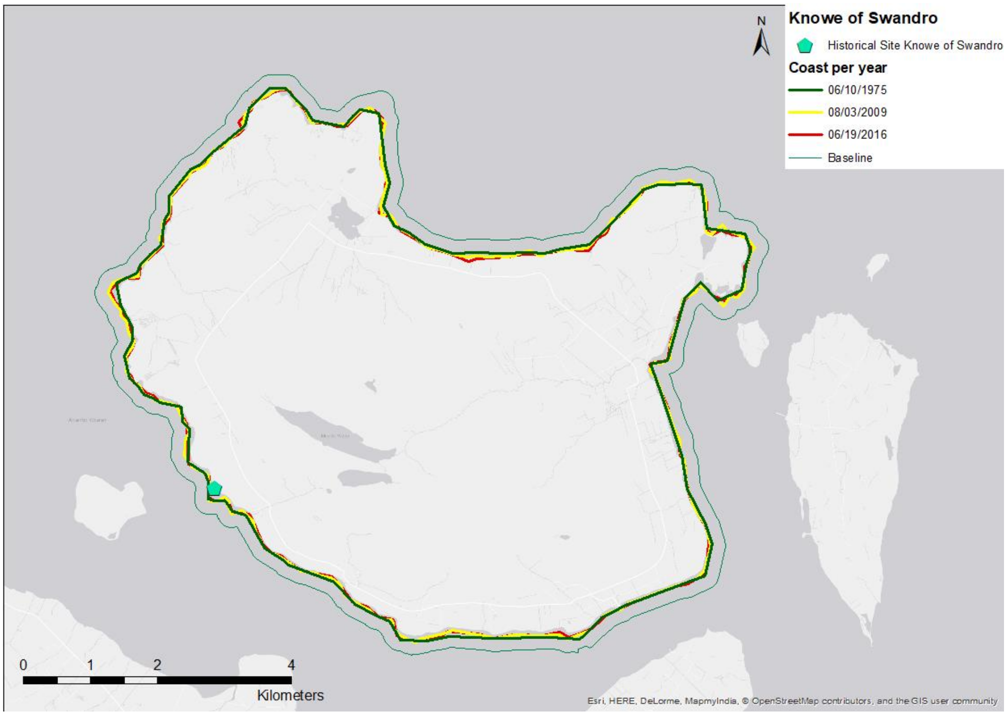

Figure 34. Shorelines of Knowe of Swandro.

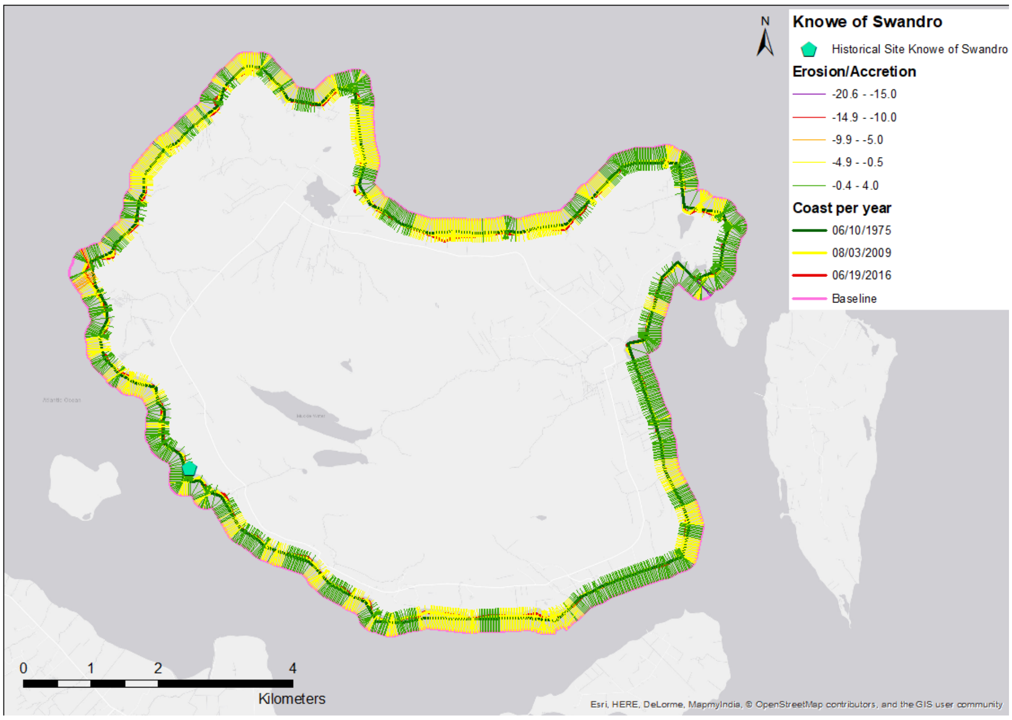

Figure 35. Knowe of Swandro transects.

Once the transects were cast, it could be observed that on figure 35 the majority of the coast show signs of a coastline that shows tendencies of accretion as well as an erosion rate of -4.9m and -0.5m. It can likewise be observed in the figure that erosion takes place in the northern areas of the island, but what is most relevant is to look further down south, towards Knowe of Swandro. Knowe of Swandro is an ongoing excavation which is in the process of being destroyed by coastal erosion (The Swandro-Orkney Coastal Archaeological Trust, 2018). However, it seems to show that accretion is a more common phenomenon in that area.

An explanation could be that despite accretion happening, actual destruction of the site could still occur, due to coastal changes. Silt, sand and debris can move and create an image of accretion. Another factor could also be the quality of the satellite images utilized. In the following chapter, the quality of satellite images and the impact on the results will be discussed.

4.4. Strangford Lough

Strangford Lough is one of the more complicated sites to extract. Most of the historical sites are scattered all along the coast, and not in a specific area. This means that no single-site focus can be implemented, as can be seen in previous cases, such as Kaim of Mathers and Happisburgh. Strangford Lough is, therefore, a larger area, which also encompasses a more complicated coastline, with a large part of the coast laying protected, as can be seen in figure 37. The overall length of the work area covers about 180 km, which did provide challenges, due to the sheer size of the files. Strangford Lough also contains a large amount of smaller islands (see figure 36 for examples) scattered along the coast. For this case, it was decided to remove all landmasses not directly connected to the coast of Northern Ireland.

Figure 36. Examples of smaller islands scattered along the coast of Strangford Lough that had to be removed for simplicity.

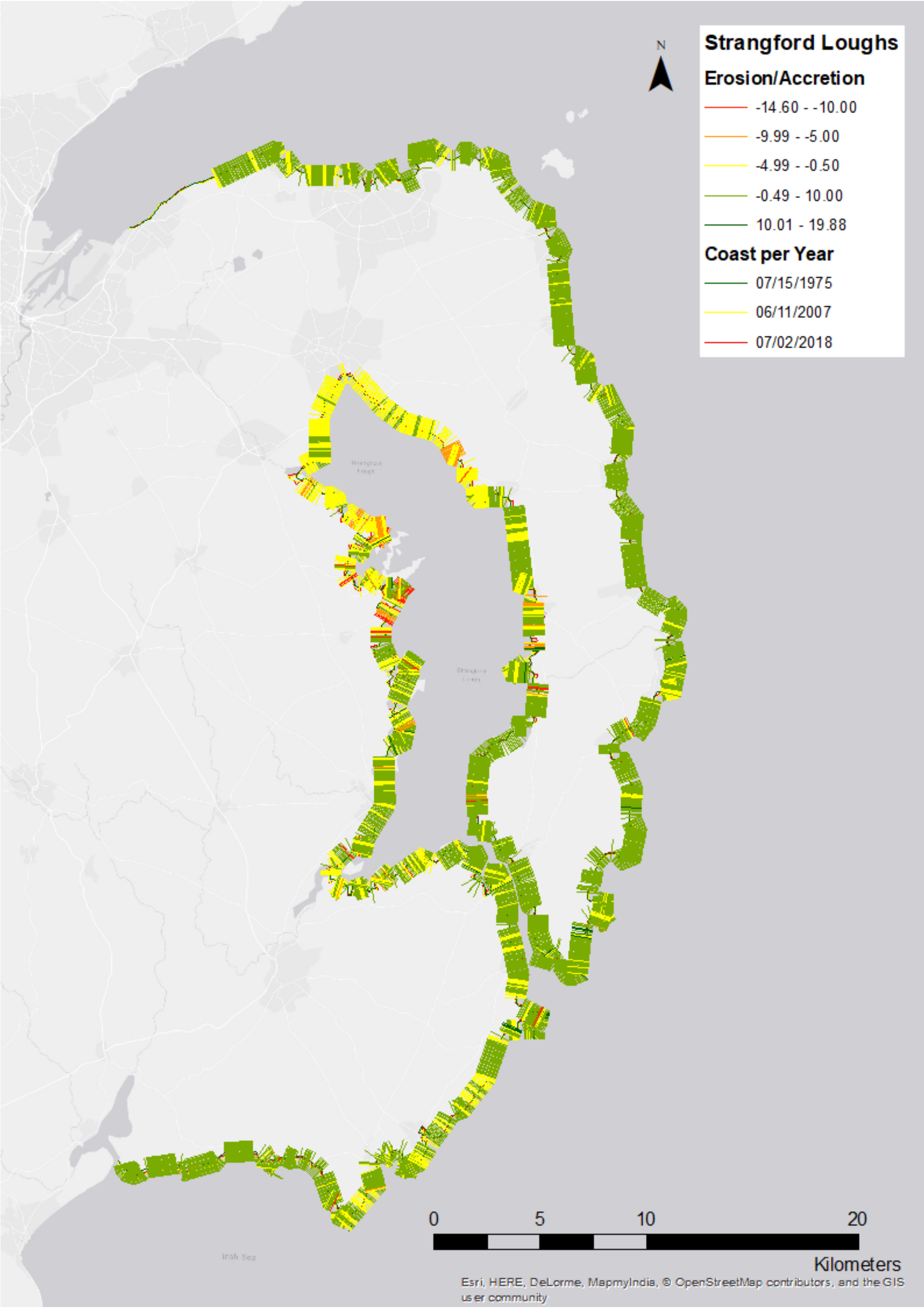

Figure 37. Strangford Lough. The transects along the coast of Strangford Lough, which shows a higher capacity of coastal erosion, with elements of accretion.

Strangford Lough had areas that were too steep and/or crevices that were too narrow to create satisfactory results. An improved map could be achieved by focusing on smaller areas rather than incorporating a large study area or performing an analysis of smaller sections of the coast. As can be seen in figure 37, the majority of the coast is protected from the ocean by landmass, however, the protected shoreline, as well as the exposed shoreline both, show a significant level of erosion.

The highest EPR is -14.6m, which is higher than examples at Happisburgh, yet the majority of the shoreline provides numbers of accretion. The results from Strangford

Lough can be called into question, as a number of factors were not incorporated. It could potentially also be interesting to see the movement of the smaller islands along the coast, to record their movement, if any.

The results of Strangford Lough were not satisfactory, and after revision, a different approach would have to be undertaken. The coast of Strangford Lough should have been divided into smaller sections in order to ensure precision and to make visual assessment easier to approach. With smaller sections, transects could have been manually observed in order to fix or remove obscure transects. Strangford was by far the largest dataset to work on, which compared to the other case studies, cannot be recommended. Smaller areas of interest are advisable, in order to achieve optimal results.

4.5. Kaim of Mathers

Much like Happisburgh, Kaim of Mathers is located on a long, relatively even stretch of coast, with only a few curves. The location of Kaim of Mathers, much like Happisburgh, is exposed directly to the North Sea. The length of the study area covers over 78km, and the historical site can be observed in the south (see figure 38).

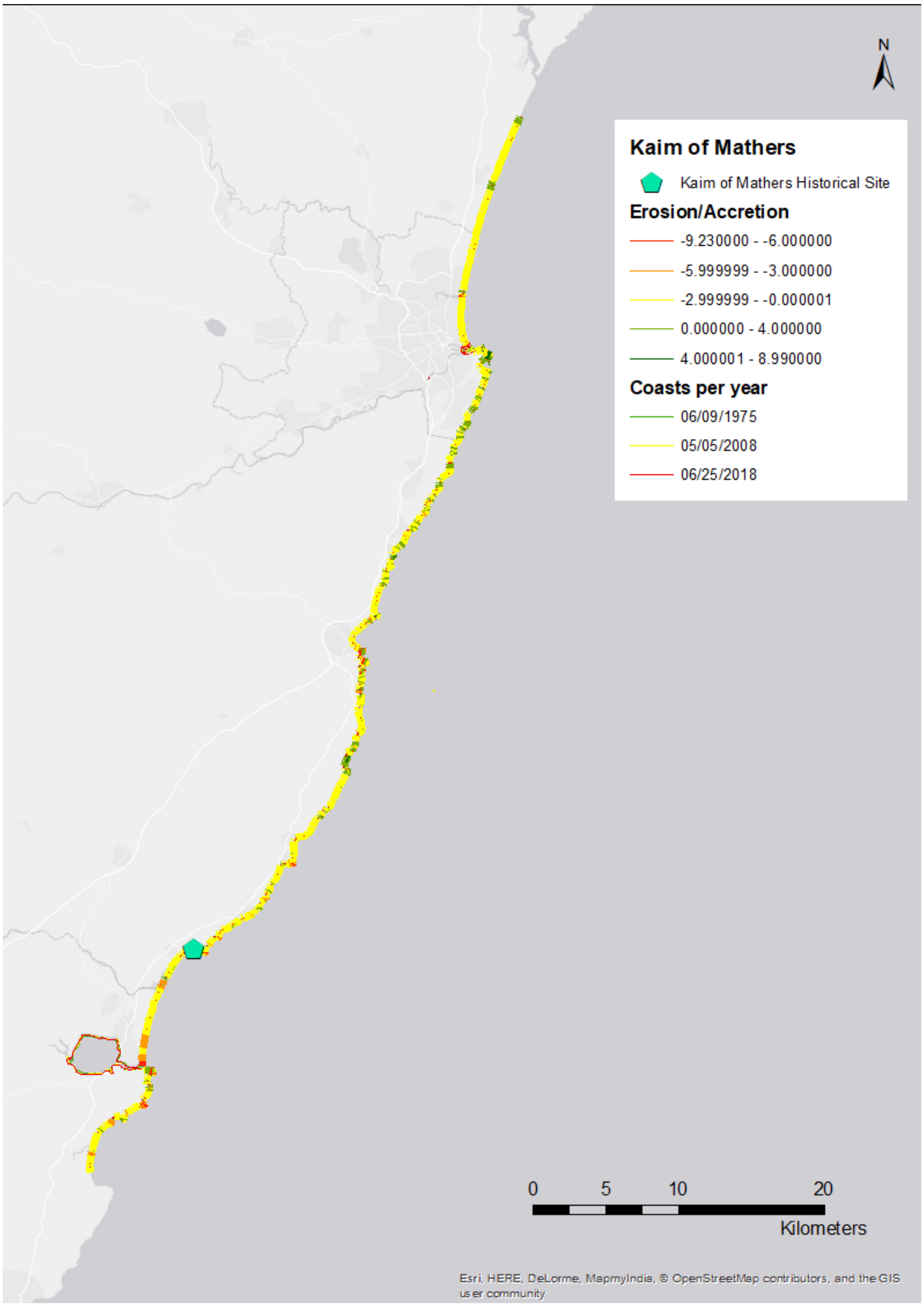

Figure 38. Kaim of Mathers. A transect of the shoreline.

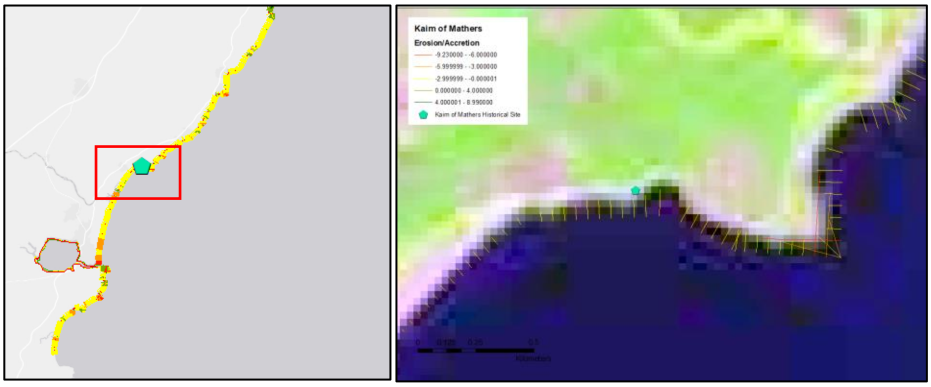

Figure 39. A close-up of the coastal movement of the historical site on Kaim of Mathers. The image shows a high erosion rate of -2.999999m to -0.000001m over the last 43 years.

On figure 39 a close-up of the location of the tower has been shown. The different transects represent different EPR's. The most remarkable of the EPR results show that up to 2.76m have been lost over a period of 43 years.

4.6. Resume

The results are cumbersome but visually compelling. The shoreline changes happen regularly, and in grave cases, such as Happisburgh, the erosion is up to 14m over a 40 year period.

At the initial phase of the project attempts to incorporate larger areas of land to create an overall map of coastal erosion or accretion was done, but in order to generate serviceable results, smaller sections of the shorelines were extracted and worked upon instead. It is not outside the scope of this project to incorporate larger sections of the coast, but it requires more manual assessment and time.

5. Discussion:

This chapter will go through the discussions according to the content list, so first, the datasets will be discussed, then the methodology. The research questions will then be listed and discussed as they were presented, followed by a discussion of challenges and limitations. Finally, a discussion of future implementation will take place. This project focuses on how remote sensing can support modern archaeology and how they can be utilized as an inexpensive tool. This project is not an analysis of the evolution of the coastline and how it moves, but rather how archaeology can use the DSAS tool and how GIS can be a support for a field that relies heavily on volunteers and funding.

5.1. Datasets discussion

The timestamps were chosen based on their time of year, but there had not been any specific requirements for the timestamps to cover the same months. The project would very likely have benefitted if the datasets for all of the areas of interest were confined to the same time of year. However, because these are satellite observations, natural obstructions, such as cloud coverage, did interfere with many of the images. Low-quality pictures were also a challenge, which meant that pictures that were free of noise had to be favoured over images with matching dates.

In the case of Happisburgh, a conscious attempt to keep the time of year coherent was made. However, two timestamps are obtained from the summer months (the years 2000 and 2009), which were due to the improved quality of the images at this specific time of year, and their quality was favoured over datasets with matching dates.

Other projects that have looked into shorelines and archaeology have used other types of basemaps such as aerial photography obtained with Unmanned Aerial Vehicles (UAV's), which seem to be the most commonly used methods (Westley, 2015) and are favoured over satellite images. These methods would with all likelihood ensure updated and more precise images, with higher quality and more pronounced details. However, using aerial photography is more time consuming as well as expensive for the user, and also covers a much smaller area. In order to retrieve maps past 1972, it will require obtaining historical maps, digitalising them and georeferencing using static points that appear throughout the years.

What this method can do, which smaller areal crafts cannot, is give an overall analysis which covers a bigger area, just by looking at the map one would quickly be able to recognize a trend and swiftly assess where shoreline retreat is the most pronounced. If the historical sites along the shoreline of the country are known, this method is much faster and cheaper and would prove a valuable resource for rescue archaeology.

The amount of shorelines representing different timestamps for the different sites was a deliberate choice. Due to the time constraints within this project, one site was chosen to contain more timestamp images (Happisburgh), and the remaining sites would only be represented by three timestamps. This was done in order to observe a general trend, and perhaps strengthen any attempts to assess shoreline changes, yet it became evident throughout the process that only two timestamps were necessary for the EPR to be calculated. The shorelines amidst the latest and the most recent year could potentially have displayed certain trends and cyclical changes and supported erosion and accretion rates obtained through this method, but this was out of the scope for this project, due to time constraints. It is a factor that will be mentioned in the chapter of future implementation (Chapter 5.6).

5.2. Methodology discussion

There are fields that would benefit from undergoing a mathematical assessment; the uncertainty field is one of them, as it would account for natural uncertainties such as wave direction and tidal changes. How to convert these natural occurrences into numbers that would benefit this project could not be undertaken due to certain limitations of this project, such as in-depth knowledge and expertise in tidal changes and geomorphology, as well as the approach and how to define the value of natural uncertainties. A method to create a numeric value for each uncertainty was not possible for this project due to time constraints.

5.3. Research questions

1. What consequences do archaeological sites suffer due to coastal changes?

The destructive impact of coastal retreat on archaeological sites is a well-recognized phenomenon (Westley, 2015). It is also a field with an incredibly limited number of studies dedicated to coastal zones containing historical sites and how such zones should be managed (Carrasco, 2015). What interventions should then be performed all depends on the historical sites. Each area must take into consideration how much time a specific site has before it could suffer irretrievable damage. Should the focus be on preserving the site or gathering data? Should it be on preserving constructions or documenting them? Each historical site must assess what needs to be done; first-hand experience indicates that every excavation is different, and field directors take different approaches depending on their school of thought or simply what tools are available for the project.

2. How will the predictive modelling prove useful for the topic of archaeological historical sites?

Satellite images have proven a useful tool and despite not taking environmental factors into considerations, the strength in this method is in the timeframe it encompasses. The satellite images collected span almost 40 years, from the early 70's to 2019. The retreat of the coast is therefore not just a fluke that occurred due to a tidal change or a wave from a boat but shows that the coast is experiencing exponential loss or growth, and should therefore be considered the general trend. Observing this trend, an assessment of how the shoreline will behave in the near future can be a good tool for future archaeological projects. Researching the behaviour of the entire shoreline would prove useful in order to determine what shores behave in what manner. Additionally, an analysis of a general tendency of coastal retreat could bring into light initially which sites to focus on. Where is the retreat of the shoreline most pronounced? Which sites need to be assessed first in order not to suffer complete destruction before a deliberate choice can be made? This is how the predictive modelling supported by DSAS could prove useful.

3. How reliable is predictive modelling in terms of predicting coastal changes?

There is a long list of factors of high importance when looking at the shoreline retreat. Mistakes can easily be made with this method and mistakes can lead to false results. The data processing was done manually, which in itself is not an issue, however, this leads to a higher risk of errors occurring. Because some of these satellite images are not georeferenced, this must be done manually, thus, the precision may be off. The importance of having the satellite images match up as precisely as possible is significant and if the slightest mistake is made the numbers are off.

To show full transparency, it will be mentioned here that this project has only looked into a few parameters in terms of coastal changes. The project has taken into account the physical changes that are visible on satellite images, without accounting for elements such as tidal changes, tide averages, human interference, wave direction and other environmental elements. Coastal types are also a key component not considered in this project, but it is a factor that ought to be implemented, as sandy banks behave differently than rocky cliff sides. These are without a doubt very important features that play a big role when talking about coastal changes. However, these are also very large features which, due to the size, time and nature of this project, were not implemented. Nonetheless, these are features that are interesting to implement in the future, as they would refine the results, ensure the quality of the results and create a functioning conclusion.

Creating a shoreline for this project was done automatically, using unsupervised classification, but did require manually adjustment in order to follow the shoreline, as can be seen on the satellite images. There were instances where the coastline was difficult to determine due to the uncertainties of shoreline-definitions (see figure 40) or where the quality of the images made it impossible to observe an adequate coastline.

Figure 40. A close-up of Strangford Loughs showcasing a reoccurring issue when trying to differentiate between land, silt, swamp, water, etc.

5.4. Challenges

Challenges occurred when working with the DSAS software extension, which did require a downgrade form ArcGIS Desktop vs. 10.6 to ArcGIS desktop vs. 10.5.1. The datasets were very flexible, in terms of the parameters set for which satellite images to choose, therefore finding acceptable land cover was uncomplicated and eased the project. There was no need for further complicating the project, as long as the images collected were straightforward and of high quality. Locating satellites images for Norfolk prior to 1972 is not possible, but for this project, the timestamps collected sufficed. Datasets prior to 1972 would have to take form of historical maps.

When creating transects, issues did occur when reaching the curved shorelines. An example of this can be viewed in the following figure 41 from Strangford Lough. Due to the curve of the shoreline, and the angle from which the transects protrude from the baseline, several gaps can be observed throughout the shorelines. As can be seen in this example, the gaps between the transects can cause incorrect overall results as shoreline changes can be visually observed, but they are not included in the final result.

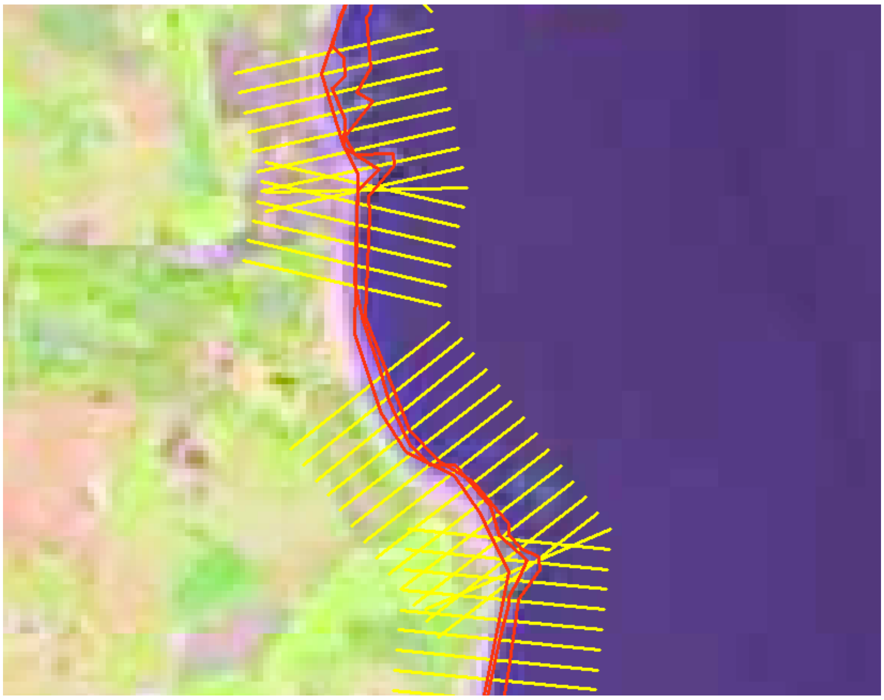

Figure 41. An example of transects not being distributed with the same distance along the coasts.

No specific solution for the uneven spaces between transects could be detected, apart from the example of Skara Brae (chapter 4.2) in which each transect was manually edited. The possibility of adding more transect numbers was also an option, however, it would not be a solution in this case of figure 41. The angle of the shoreline interferes, disrupting the distance between the transects. When looking into other possibilities, the Analyzing Moving Boundaries Using R (AMBUR) package showed potential (Jackson, 2012). The package is for the R software environment, it is an open-source solution, and like DSAS, provides support for analysing and visualising historical shoreline change. DSAS is developed specifically for commercial GIS software, whereas AMBUR allows the import and export of geospatial data in shapefiles format to both commercial and open source solutions, and shows potential to be an alternative, and free, solution. The package introduces other methods of casting transects, such as *near* and *filtering* (see figure 42) which prevents transects from crossing over themselves and conforms them to curved shoreline segments. The *near* and *filtering* transect methods will probably not solve all issues, but they show potential in reducing a quantity of problematic transects (Chester, 2011).

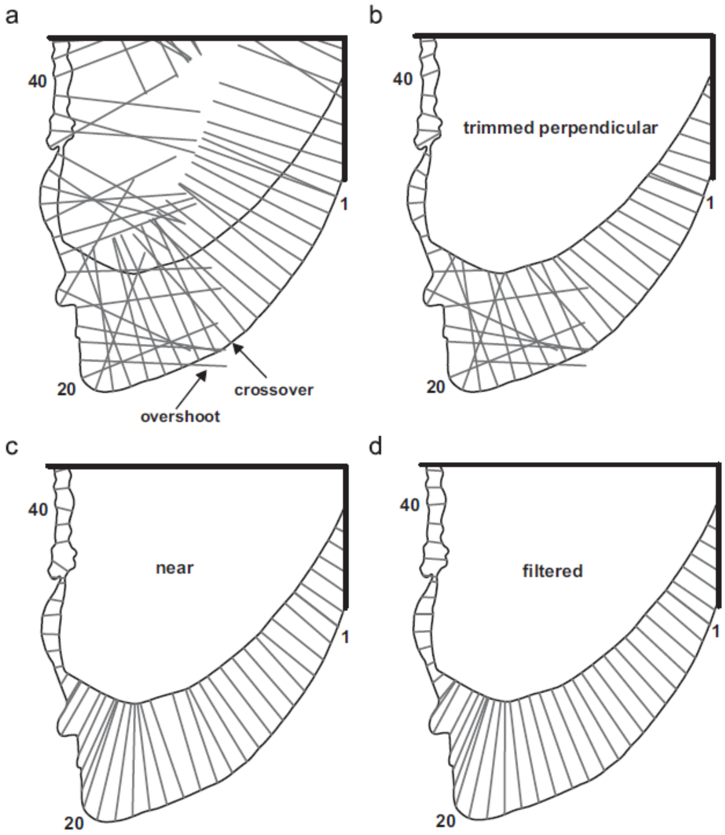

Figure 42. The difference between the transect methods, and a potential solution to avoid transects crossing over themselves and conforms them to the curved shoreline (Chester, 2011).

Other issues when casting the transects were the false result in terms of erosion/accretion as can be seen in figure 43 where the transects, at Skara Brae, crossed the landmass and connected with a wrong shoreline. This could be due to the OFFshore baseline versus ONshore baseline but no further investigation or search for this solution has yet taken place.

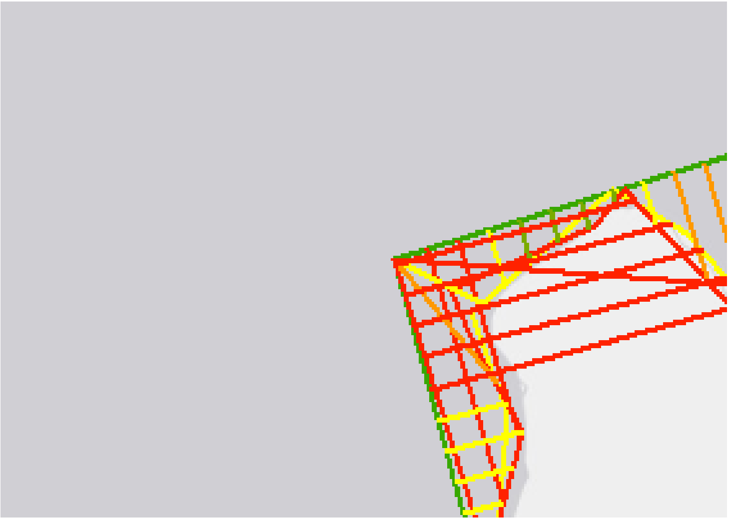

Figure 43. An example of transects crossing landmass, resulting in false numbers.

Examples of further issues that occurred, were cases of obscured EPR's. On figure 44 can be seen an example of another EPR issue. This image is from

Strangford Lough and shows two different transects located next to one another. However, one holds an EPR of 69.65m, and the neighbour an EPR of -62.98. This is probably due to the transects not aligning with coastline 1975, and for the purpose of the results, and to display them as truthfully as possible, the two transects were simply, manually removed.

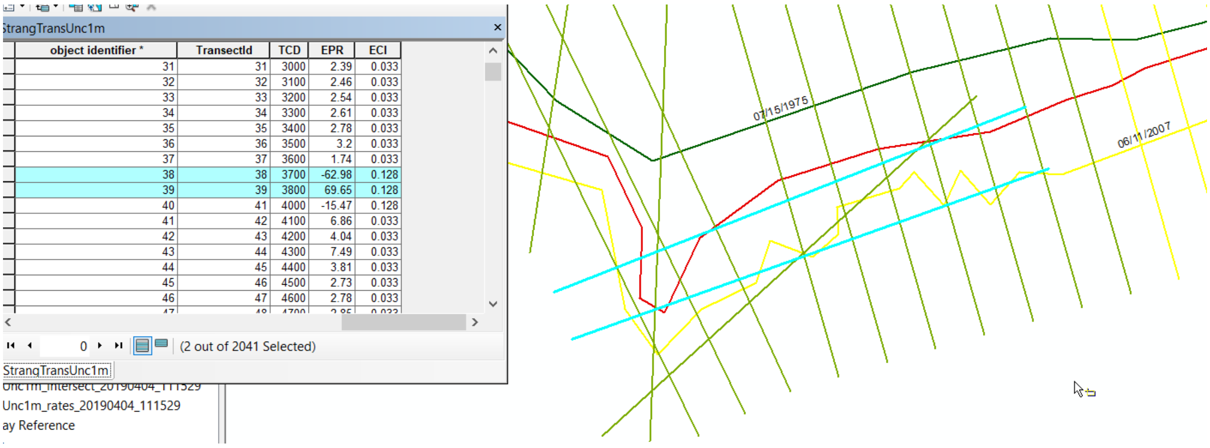

Figure 44. An example of EPR numbers not adding up.

5.5. Limitations

Methodological limitations became more evident as the project progressed. The further this project progressed, the more evident became the lack of knowledge within coastal management and geomorphological changes. The project would have benefitted from more data collected about tidal changes, geomorphological knowledge and any changes based on human interference. This could have attributed to the field of uncertainty and the option for creating a value for the uncertainty level could have been implemented.

Satellite images were also limited to images without any obstructions, such as bad weather conditions. It was therefore not possible to rely on using data covering the same time of year, in order to create as exact an image as possible, but rather a visual assessment of each satellite images was necessary which was time-consuming. In order to retrieve images as far back as possible, aerial photography can be of great use in order to create a broader understanding of shoreline movement. These photographs need to be scanned and georeferenced in order to be of use, which requires control points that might not be available. For this, the focal point of this project relied purely on easily available satellite images. One of the issues with Landsat satellite images is that despite the quality achievable today, the quality of the resolution of each satellite, is not the same. Early Landsat models, such as Landsat 1, 2 and 3 has a resolution of 60m pr. pixel, Landsat 4, 5 & 7 has a resolution of 30m pr. Pixel, but Landsat 8 (panchromatic) can come down to 15m pr. Pixel (USGS, n.d.c). This results in distortion and uneven coastal extraction when the system determines whether a pixel is part of landmass or water. Determining whether a pixel is part landmass or water also comes down defining the shoreline. Defining the shoreline is a complex process, as mentioned earlier with the shoreline paradox, complicated by what a shoreline ought to be defined as. Sandy beaches and rocky coast, vegetation line and high waters. It needs to be evaluated carefully when initiating the project. Sediment movement and ocean current are also beneficial factors to understand.

The final significant aspect: human inference and natural cycles have to be analysed as well, but this aspect was not explored further during this project.

Happenings observed throughout the different timestamps could potentially explain certain trends and cycles, that could explain certain shoreline movements. If they could be explored further, they could possibly show a pattern of how certain coastlines move the way they do. Trends could then be applied and implemented into the overall picture of coastal erosion or accretion.

Assessing coastal shifts based on shoreline trends has proved cumbersome and a very complicated process with factors far exceeding the scope of a project such as this. Nonetheless, analysing the results and observing the trends have been accumulated, is still of interest as they can still give an indication of how the shoreline will change. The purpose of this project was not to predict an exact shoreline change but to determine whether assessing the shoreline movement could be of benefit to the study of archaeology. The potential for creating an erosion map with the focal point of salvage archaeology is beneficial and useful. This method proves to be a low-cost, high-result assessment tool based on timestamps that could guide patrons to which cultural heritage sites are located in high-risk areas.

5.6. Future Implementation:

To avoid loss of historical heritage urgent action needs to be taken, and as demonstrated earlier, this method would be a useful tool for future work. Because of available data and a work frame is available and approachable for the majority of people in the archaeological field, it would be a great tool for researching coastal management of historical sites. Salvage archaeology benefits from tools that are fast, cheap and reliable. This method could encompass all three elements, and it shows the potential between combining satellite imagery, GIS and archaeology. However, a great number of changes would be necessary. It would be important to ensure that the datasets match up and that the errors in aligning the coastlines per year are kept to a minimum. It could also prove important to ensure that elements such as tidal change and wave direction were to take into consideration, as well as categorizing the different coastal types and looking into the geomorphology of the coasts.

For future implementation, an in-depth analysis of the different shorelines would be beneficial. As previously mentioned, an understanding of the trends and cycles could potentially ensure a better understanding of the shoreline movements. Exploring what tools DSAS holds in terms of trend-analysis would be vital.

These areas cover a very small sample of the UK and only take the east area of the country into considerations. It would be interesting to see the degree of change, if any, on the western side as well. To summarize; with more time and more knowledge gathered a full country-covering map, showing the general trends of the coastlines could benefit the preservation and conservation of historical sites. To further aid the archaeological field, a useful tool would be to create a *danger map.* A map to visually show the shoreline movement, based on the assessment displayed earlier in this project. For future implementation, such a map would be the goal.

The approach of the method is up to standard and shows great potential. The results rely on the data input and the preparation of said data.

6. Conclusion

This project is a bridge between GIS, especially satellite imagery and the Digital Shoreline Analysis System, and archaeology. An example of using complex systems to benefit history.

One of the premises for this project was to create a vulnerability map covering the UK, which would assess the possible coastal erosion in places where historical sites are located. However, because of the quality of the satellite images, the accuracy is not as good as was hoped for at the beginning of this project. The earliest satellite images do not go further back than 1972, and those images suffer from large pixelation due to the quality that was achievable at the time.

This method shows valuable potential for coarse observation on a larger scale, and with further research and more optimized data preparation, this method shows great benefit for the field of archaeology. It supports a coarse overview of shoreline-movement, it helps to quickly assess what areas are of higher risk and thus what historical sites are in need of salvage archaeology. It is also important to note that this method is less resource-consuming than other methods, but during this project a large amount of time was acquired to visually assess the data, the shapefiles, the satellites images and every step of the process as a whole, to ensure high-quality results. This project was designed from the perspective of an archaeologist and looking into how GIS could support future work. What is valuable for the archaeological field are low-cost, high-quality results.

Overall, this is a great tool for coastal-related archaeology in regard to salvage archaeology and shows great potential for further collaboration between archaeology and GIS.

7. Bibliography

Archaeology Wordsmith (2019). *Salvage*. Accessed 10.04.2019

https://archaeologywordsmith.com/search.php?q=salvage

Ashton, N., Lewis, S. G., De Groote, I., Duffy, S. M., Bates, M., Bates, R., … Stringer, C. (2014). Hominin footprints from Early Pleistocene deposits at Happisburgh, UK. *PLoS ONE*, *9*(2), 1–13. https://doi.org/10.1371/journal.pone.0088329

Boak, A. E. H., Turner, I. L., Boak, E. H., & Turner, I. L. (2005). Shoreline Definition and Detection : A Review Shoreline Definition and Detection : A Review, *2005*(214), 688–703. https://doi.org/10.2112/03-0071.1

Carrasco, A. R., Ferreira, Ó., Matias, A., & Dias, J. A. (2007). Historic monuments threatened by coastal hazards at Boca do Rio, Algarve, Portugal. *Coastal Management*, *35*(2–3), 163–179. https://doi.org/10.1080/08920750601042278

CastlesFortsBattles (2019). *Kaim of Mathers*. Accessed 09.04.2019.

http://www.castlesfortsbattles.co.uk/grampian/kaim_of_mathers.html

Dictionary (2019). *Salvage archaeology*. Accessed 01.11.2018

https://www.dictionary.com/browse/salvage-archaeology

Dineley, M., & Dineley, G. (2000). From Grain to Ale Skara Brae a case study. *Neolithic Orkney in Its European Context*, 196-200

Esri, ArcGIS Pro. (n.d.). Accessed 14.12.2018

https://pro.arcgis.com/en/pro-app/

Esri, ArcMap. (n.d.). Accessed 14.12.2018

https://desktop.arcgis.com/en/arcmap/

Gardiner, J. D., Behnsen, J., & Brassey, C. A. (2018). Alpha shapes : determining 3D shape complexity across morphologically diverse structures, 1–16.

GN (2019), *Grønlands Naturinstitut*. Accessed 01.02.2019

http://www.natur.gl/

Happisburgh - first known settlement in northern Europe. (n.d.). Accessed 14.12.2018

http://www.happisburgh.org/history/archaeology

Jackson, C. W., Alexander, C. R., & Bush, D. M. (2012). Application of the AMBUR R package for spatio-temporal analysis of shoreline change: Jekyll Island, Georgia, USA. *Computers and Geosciences*, *41*, 199–207. https://doi.org/10.1016/j.cageo.2011.08.009

Landsat (2019a). *Landsat 1.* Accessed 01.01.2019

https://landsat.gsfc.nasa.gov/landsat-1/

Landsat (2019b). *About Landsat.* Accessed 01.01.2019

https://landsat.usgs.gov/about-landsat

Liu, Y., Huang, H., Qiu, Z., & Fan, J. (2013). Detecting coastline change from satellite images based on beach slope estimation in a tidal flat. *International Journal of Applied Earth Observation and Geoinformation*, *23*(1), 165–176. https://doi.org/10.1016/j.jag.2012.12.005

Mathworld (2019). Coastline Paradox. Accessed 02.02.2019 http://mathworld.wolfram.com/CoastlineParadox.html

Merriam-webster (2019). *Shoreline*. Accessed 09.04.2019

https://www.merriam-webster.com/dictionary/shoreline

National Trust (n.d.). *Strangford Lough through the ages*. Accessed 08.04.2019

https://www.nationaltrust.org.uk/strangford-lough/features/strangford-lough-through-the-ages

Orkneyjar (2019). *Skara Brae*. Accessed 09.04.2019

http://www.orkneyjar.com/history/skarabrae/skarab1.htm

Poulton, C. V. L., Lee, J. R., Hobbs, P. R. N., Jones, L., & Hall, M. (2006). Monitoring Coastal Erosion using Terrestrial Laser Scanning. *Preliminary Investigation into Monitoring Coastal Erosion Using Terrestrial Laser Scanning: Case Study at Happisburgh, Norfolk*, (for 2006), 45–64.

Rasuly, A., Naghdifar, R., & Rasoli, M. (2010). Monitoring of Caspian Sea coastline changes using object-oriented techniques. *Procedia Environmental Sciences*, *2*, 416–426. https://doi.org/10.1016/j.proenv.2010.10.046

Rescue. (n.d.). Accessed 14.12.2018

http://rescue-archaeology.org.uk/

SCAPE (2019). Scotland's coastal heritage at risk. Accessed 22.03.2019 http://www.scharp.co.uk/

Simpson, I. A., Guttmann, E. B., Cluett, J., & Shepherd, A. (2006). Characterizing anthropic sediments in north European Neolithic settlements: An assessment from Skara Brae, Orkney. Geoarchaeology, 21(3), 221–235. https://doi.org/10.1002/GEA.20101

Sündermann, J., & Pohlmann, T. (2011). A brief analysis of North Sea physics. *Oceanologia*, *53*(3), 663–689. https://doi.org/10.5697/oc.53-3.663

The Daily Mail (2015). Britain's vanishing communities: Hundreds of homes set to disappear into the North Sea over the next century as rampant coastal erosion devours roads and villages. Accessed 01.12.2018

The Guardian (2012). Yorkshire is disappearing up to three times as fast as last year. Accessed 01.12.2018. https://www.theguardian.com/uk/the-northerner/2012/sep/24/coastal-erosion-yorkshire-north-sea-lost-towns

The Swandro-Orkney Coastal Archaeological Trust (2018). *An introduction to the work of the Swandro-Orkney Coastal Archaeology Trust*, (April).

The Swandro-Orkney Coastal Archaeological Trust (2019). Accessed 01.01.2019

https://www.swandro.co.uk/

Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., and Ergul, Ayhan, 2017. Digital Shoreline

Analysis System (DSAS) version 4.0 — An ArcGIS extension for calculating shoreline change (ver.4.4, July 2017): U.S. Geological Survey Open-File Report 2008-1278

https://pubs.er.usgs.gov/publication/ofr20081278/

U.S. Geological Survey. (n.d.). Accessed 14.12.2018

http://www.usgs.gov/

USGS. (n.d.a). EarthExplorer - Home. Accessed 14.12.2018

https://earthexplorer.usgs.gov/

USGS (n.d.b). Digital Shoreline Analysis System. Accessed 14.12.2018

https://www.usgs.gov/centers/whcmsc/science/digital-shoreline-analysis-system-dsas?qt-science_center_objects=0#qt-science_center_objects

USGS (n.d.c). *What are the bands designated for the Landsat satellites.* Accessed 08.04.2019

https://www.usgs.gov/faqs/what-are-band-designations-landsat-satellites-0?qt-news_science_products=7#qt-news_science_products

Visit Scotland (2019). *The knowe of Swandro.* Accessed 09.04.2019

https://www.visitscotland.com/info/see-do/the-knowe-of-swandro-p1428251

Visit Strangford Lough (n.d.). *Theme: A self guided tour to learn more about archaeology*. Accessed 08.04.2019 http://www.visitstrangfordlough.co.uk/Suggested-Itineraries/Archaeology

Westley, K., & McNeary, R. (2015). Assessing the Impact of Coastal Erosion on Archaeological Sites: A Case Study from Northern Ireland. *Conservation and Management of Archaeological Sites*, *16*(3), 185–211. https://doi.org/10.1179/1350503315z.00000000082