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Assessment of changes in the Historical Shoreline of the South of Walney Island, Cumbria

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ABSTRACT

Walney Island is the 4th largest English or Welsh island, approximately 12.5km long, and 1km at the widest point, orientated from North-west to South-east. It is situated at the South West corner of Cumbria, and separated from the mainland by Walney Channel. The island is defined as a barrier isle comprised largely of glacially deposited layers of sand, gravel and till. The island's composition and location is such that it is subject to dynamic coastal processes. This paper reviews historical maps to evaluate how coastal evolution has affected the structure of the island, using Ordnance Survey maps dating from 1840, with additional input from Landsat imagery. Techniques used in the paper are based on ArcGIS and Digital Shoreline Analysis Software (DSAS) used with 7 historical maps to track land loss for individual points and shoreline sections at the South end of the island. The report uses footprint analysis to assess the evolution of the island over the past 170 years. Union analysis was used on 4 coastal sections identified in the footprint analysis: an erosive Western-South West coastline, an accretive Southern Coast, a complex South End spit, and a stable Eastern Coast. The area of the South end of Walney is now almost the same as it was in 1840 having declined to a minimum in the 1950s. The study identified average loss on the West coast of over 120 metres of shoreline, averaging 0.7 metres/year, and a maximum of over 350 metrers. The south facing coast has gained shoreline at a rate of 0.3 metres per year. The southern spit had significant losses occurring in the period around the First World War. The Eastern coast is protected from sea storms, and has remained stable, although salt marshes have developed or been brought into consideration in two locations on the shore. The paper provides background material to support local decision making for coastal defences.

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ABBREVIATIONS

DSAS	Digital Shoreline Analysis Software
ECI	Confidence of EPR
EPR	End-Point Analysis
ESRI	Environmental Systems Research Institute
GIS	Geographical Information System
HA	Hectares
LANDSAT	Land Remote-Sensing Satellite
LMS	Least Median Square
LRR	Linear Regression Rate
M	Meters
NSA	New Shoreline Analysis
OS	Ordnance Survey
SCE	Shoreline Change Envelope
UK	United Kingdom
USGS	United States Geological Survey

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The evolution of Cumbria has seen mountain-building, glaciation, inundation, coastal erosion and constant weathering. This has resulted in a varied and unique coastline, with the projects focus lying on the island of Walney, at the south-western point of the county. The changing sea level has played a huge part in the alteration of its coastal profile, which in turn influences the nature and severity of coastal erosion, a key factor in transforming the coastal landscape, with a landward retreat and the formation of coastal features (British Geological Survey, 2012). In particular, this increased erosion has thus led to the formation of vast beaches due to accumulation of erosion products (sand and stones). This has led to extremes of deposition and erosion often co-habiting within a short distance of shoreline.

The erosive nature of coastal flooding is a widely recognised phenomenon, with inundation of the land occurring most frequently due to tidal differences during the day (Tide Forecast, 2007), and the additional yearly extreme tides - spring and the neap tide. The placement of the study area is at the north-western edge of the second largest bay in the UK, Morecambe Bay, which experiences a large tidal range reaching 10.47m in height at spring tide, with an ebbing tide which can fall back to 12km in distance (UKMPA, 2001). Recently Walney's spring tide has reached a height of 9.77m, a difference of 2.69m higher than the year average (Tide Forecast, 2007), placing much of low-lying Walney at risk. Storm surges are caused by low atmospheric pressure storms, which pull the tidal level up 1cm for every pressure millibar dropped (Haigh, 2015).

The largest shift in sea level change within Europe occurred during the Pleistocene ice age. At its peak, an estimated 30% of the Earth's surface was engulfed in ice, with ice sheets between 1,500-3,000m thick resulting in a 100 meter drop in sea level (Lambert et all, 2014). With much of the weight lying over continental land mass, this led to changes in the loading mass of the Northern Hemisphere, and the UK within it. The result of the glacial depletion from 32,000 years ago has led to a long-term gradual isostatic re-adjustment, with north Great Britain rising, and the south sinking as a consequence. The present suggestions of the isostatic alterations are projected in figure 1, which highlights location along the coast as an mm change per year under varied coloured boxes. These boxes are grouped within 0.5mm worth of change. The 0.0 line demonstrates the fulcrum of the re-adjustment, with Barrow-in-Furness at +0.7mm change per year (Climate N.E, 2010). The recent land-level changes recorded as part of the Continuous GPS records show that in the last decade uplift movements are slower than the established average (Rennie, 2011). Bingley et al have shown the gradual depletion of isostatic change occurring in Scotland, meaning the eustatic mechanisms of global sea level rise will become more prominent in the region (Bingley et al 2007).

The human influence along the coasts has altered the coastlines significantly. The biggest shift within Britain began with the industrial revolution with industry flourishing along accessible

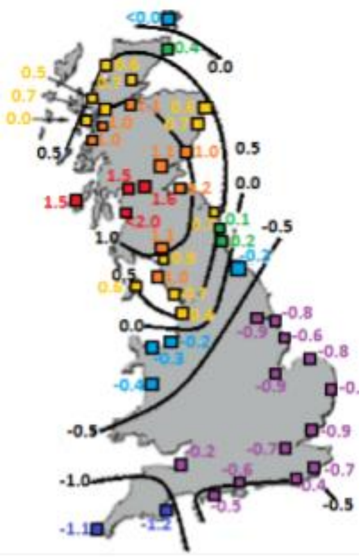


Figure 1: Rates of Isostatic Rebound in Great Britain in mm/yr. (Climate N.E., 2017)

coastal areas. Human intervention has resulted in many estuaries becoming developed, and rivers being channelized and dredged. Walney Channel between the east side of the island and the mainland has been subject to many such changes, perhaps most significantly in the 19th century to support shipbuilding industries (Dredging Point, 2010). As Britain became wealthier in the 19th century, large investments in coastal leisure and defences were emplaced to protect shoreline enterprises from the sea and weak cliffs, and to draw people to beaches protected by groynes. These coastal changes produced long lasting effects, with protective sediment being locked within groynes, and soft cliff areas left exposed becoming endangered from the sea, leading to the decline in level of many European coastal beaches, with an additional impact from rising sea levels.

The coastal evolution factors clearly demonstrate that the coastal zone is an area of natural dynamism and prone to significant changes over time and geographical extent. The factors mentioned do not occur at the same rate, leading to a complex coastal response with erosion and accretion rates differing as particular factorial thresholds are exceeded at different points in time, with some causing a more dramatic coastal evolution. These factors may become further influenced by current activities, such as coastal defences, whilst others may have been influenced by activities in past decades, such as the gradual retreat of the icecaps widely associated with global warming. The ability to review the coastal evolution throughout the last millennium emphasises the particular care needed to ensure a wider perspective on the decisions made today, and the repercussions it may introduce. (Futurecoast, 2002).

1.2 SCOPE OF WORK AND RESEARCH AIMS

This work seeks to contribute to the field of coastal geomorphology by assessing the speed of change in relation to the erosive and accretive nature of the malleable geology of a barrier island. Explicitly, the first aim of the project will focus on the altering coastline as recorded by Ordnance Survey dating from 1840, with additional input from Landsat imagery which dates from the 1940's, compressing this information with the use of pre-existing statistical techniques and methodology from multiple sources, and using them in conjunction.

The barrier isle in question refers to Walney Island, lying off the coast of Cumbria, England The Barrow Council coastal plan concentrates on the Central and Northern end of Walney where the majority of the population is centred, and where there are well-developed existing coastal defences. Conversely the Southern end is poorly protected, with Victorian defences having decayed and currently there are no plans for protection. The focus of this work was therefore made as the Southern end where the effects of natural accretion and erosion would be most evident.

The project aims to analyse the rate of change on yearly, decadal and centurial scales in order to assess the historical impacts the island has faced, and in addition, to review current and future problems the island may face.

1.3 RESEARCH OBJECTIVES

In order to achieve the research aims to the highest standards, it is important to discuss further objectives which are interwoven between the aims presented, in order to establish the clearest understanding of the subject.

<u>Research Objective 1:</u> To composite the historic Ordnance Survey map, with highly specified recent USGS Landsat images of Walney Island to identify the evolution of the features over time. This is the framework of the expected project, allowing further expansion.

Research Objective 2: To georeference the Landsat images to the contemporary OS map, in order to ensure the accuracy of the work. The georeferenced images are to be composited with the possibility of additional non-digitised maps, dating before the original Ordnance surveys were conducted. These maps were drawn up by Peacock in 1833, and Cragg in 1797. The questionable quality of the work means that these may only be of qualitative rather than quantitative use.

Research Objection 3: The third aim is to develop accurate erosion and accretion rates of the southern end of Walney on a yearly, decadal and centurial basis. It would be of significant local interest to predict the future changes of Walney. There is some trepidation at the prospect of the island splitting amongst all those who inhabit Walney and Barrow in Furness. The knowledge gathered about probable future changes of Walney, could assist those requesting coastal defences (an ongoing local issue), and those who work within the council. On a similar theme, producing a history of the saltmarsh growth along the eastern coast of Walney would be valuable for those working along the SSI sites of the coast. However, the recording of the saltmarshes along Walney seems to be limited. This may cause the data to be too limited to work with historically, but the current position and prospects may be established using the Landsat images available.

CHAPTER TWO: REVIEW OF LITERATURE

Coastal geomorphology is a constant, present feature of the coastline where numerous complex natural processes occur simultaneously. These are broadly divided into physical, chemical and biological pressures (Pethick, 1984). These pressures operate differently in consequence of regional and local coastal characteristics and the different equilibriums in place. Human intervention on coasts has brought another layer of complexity to bear, with sediment starvation, sediment trapping, coastal degradation and water-level changes having damaging effects upon the equilibrium in place (Jackson, 2013). Different publications have been assessed in this literature review to understand the historical context of geological and human interactions with Walney's coastline, as well as exploring the methodology of analytical techniques of Ordinance Survey maps, and how these alter throughout the centuries.

2.1 STUDY AREA – WALNEY ISLAND

Figure 2: Bartholomew Half-Inch Map of Lancashire (Bartholomew, 1922), location map provided by Digimap, 2017

The geomorphology of Walney and selected regions of Furness has been discussed within several reports, the most specific to Walney itself composed by V.J May in 'Sand Spits and Tombolos – GCR site: Walney Island' in 2007. This work defines Walney as the 4th largest English and Welsh island, approximately 12.5km long, and 1km at the widest point, with an orientation of North-west to South-east (Steers, 1981). The island is bounded by Walney Channel to the east and the Irish Sea to the west (English Heritage, 2014). The shape of the island is defined as a barrier isle, as it hosts an elongated ridge facing the sea, and a lagoonal area on the landside (Allaby: p.54). This is visually represented in Figure 2. The geology of the island, and much of Furness, is largely a function of the last glaciation period where retreating glaciers deposited layers of sand gravel and till (Steers, 1981). Walney later became separated from Furness because of eustatic sea-level rise (English Heritage, 2014). This narrative follows the same course as projected within Richard Johnson's book 'The Geomorphology of North West England' dating from 1985. This book provides an in-depth explanation of the geology of the island, which is still recognised on the British Geological Society's site. The account of both shows the solid geology as: Sidmouth Mudstone, Triassic Mudstone, Siltstone and Sandstone, topped by superficial geology of Diamiction Till (BGS, 2008). May's piece accounts this softer geology as the cause for the undefined low-lying till cliffs, which are fronted by shingle beaches due to erosion along the conglomerate based cliffs.

The very nature of the island's existence has played a big part in the development of Barrow-upon-Furness, due to the protection is provides, as described by Trescatheric within his 1985 edition of 'Walney: a wall in the Sea' - "Walney Island is a Barrier against the Westerly gales from the Irish Sea, giving protection to the deep anchorage of Piel and later the port of Barrow". This piece provides a condensed history of the inhabitation and development of Walney, with one particular chapter 'The Forces of Many Flowing Tides of the Sea' referring to the historic battle with the sea. This focuses on historic large storms which took large swaths of cliff-face between the sections of land between: Thorney Nook to South End Farm. These records are more formally discussed within William Rollinson's 1971 essay 'Coastal Changes on Walney Island: An Historic Appraisal'. Both documents discuss the first implemented inundation defences during the 15th century, and once these fell into disrepair, Rollinson's piece discusses the land loss throughout the 18th and 19th centuries, with intricate details of the coastal sections losing the most land, and in what time frame. Rollinson's article was highly informative, and included an outline of the southern tip's changing coastline, as seen in Figure 3, and covers all known recordings of the Walney coastline to the date of this paper; starting with J.Cragg's 1797 original outline of the island, followed up by R. A. Peacock in 1833, two OS maps and three separate recordings by geomorphologists.

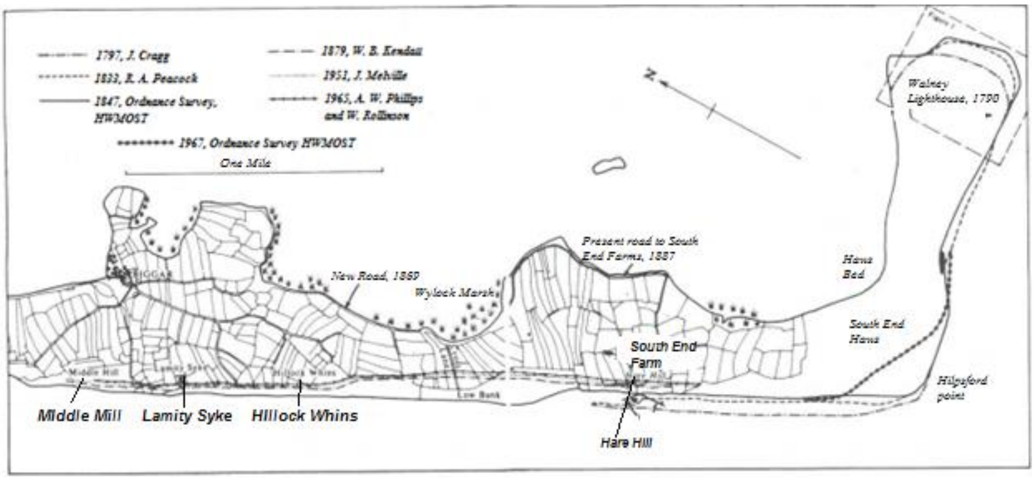


Figure 3: Surveys of Walney Island in the late 18th, 19th and 20th centuries (Rollinson, 1971)

The map within figure 4 shows the losses along the central section of the boulder cliffs between Middle Mill and Hare Hill, with the detailed loss composed within Table 1. Much of the coastline has altered, with the width of Walney at Low Bank reduced by half since these records began (Rollinson, 1971). The erosion of this island seems to have peaked throughout the 19th century, possibly due to the booming trade in removing beach material for paving (Marshall, 1958). This study identified areas of erosive weakness along the coast, and sections of the spit with great levels of accretion, which can be re-assessed within this project. However the difficulties of using this information lie within the data recording techniques used for the historic maritime and coastal mapping of Walney largely stem from the unknown techniques used, with the exception of the OS maps. This makes the reliability of this data questionable (Withers, 2014). This data also lacks the detailed positioning of each recording, other than those mentioned within table 1, making the use of this map for other projects limited.

Years Recorded	Section of Cliff	Loss of Land (m)
1879 – 1882	Lamity Skye	6
1889 – 1904	Lamity Skye	22.3
1904 – 1965	Lamity Skye	21.3
1842 – 1879	Hillock Whins	21.3
1879 – 1904	Hillock Whins	43 (1.5 per year)
1951 – 1965	Hillock Whins	3
1842 – 1879	Hillock Whins – Hare Hill	87.1
1879 – 1904	Hillock Whins – Hare Hill	38.1
1904 – 1951	Hillock Whins – Hare Hill	24.4
1951 – 1965	Hillock Whins – Hare Hill	6

Table 1: Surveyed changes of the Coast of Walney 18th, 19th and 20th centuries (Rollinson, 1971)

The fear of erosion was most recently addressed by the 'Walney Island Flood and Coastal Erosion Strategy' (Ellis, 2014), where Biggar village and Tummer Hill were noted as having significant risk from flooding, similar locations as noted within Rollinson's essay. The current inundation concern areas are shown in Figure 4, the Environmental Agency flood map which projects the 0.5% risk or higher chance per year. It is also theorised that 50ha of agricultural land will become unusable by the year 2100 due to the yearly inundation occurring along arable farmland.

The South of Walney Island is characterised by an extensive sand dune system within the South End Haws spit

Figure 4: Flood Risk of Walney Island (Environment Agency, 2017).

system – mostly composed of shingle and sand. The elongated low-lying storm beaches composed of shingle are backed by glacial till cliffs with the highest reaching 15m (Historic England, 2011). The north-south orientation of this central coastline means that the cliffs are particularly vulnerable to storm systems arriving from the Irish Sea, annual high tides (Halcrow, 2011). These have led to an on-going erosional trend which has been damaging farmland for at least the last 100 years, with records demonstrating this has occurred throughout Walney's history (Trescatheric, 1985). It has been estimated that this coast is eroding at a rate of 1.3m per year, with a prediction of 0.2-0.6m per year, with an ever-increasing flood risk (Atkins, 2000). Future prediction of shoreline evolution state that the spits current growth, noted within figure 3, will eventually become halted by Walney Chanel and the on-going dredging taking place (Dredging point, 2010) causing the spit to transform into a more rounded profile (Halcrow, 2011).

It can be summarised that south Walney Island has a long history of coastal changes, with high levels of erosion along the western cliffs, and accretional growth along the South Haws and frequent inundation periodically effecting the arable farmland. The limited housing along this section of the coast has led to the council not implementing any defences along this section to retain the natural integrity of the spit and the easterly marshes – allowing the SSSI site to continue to flourish. There has been previous research into the changing coastline of Walney. Barrow Borough Council has conducted research alongside Atkins Global and Halcrow consultancies in order to produce detailed coastal management schemes. However, the most prominent account of the coastal changes was produced by William Rollinson, who produced a similar composition of noted mapping changes.

2.2 Coastal Cartography: History and Development

The historical significance of cartography has been heavily discussed by multiple authors. The fascination with and thirst for knowledge of the wider world is ingrained within human nature, with the oldest known map dating from 30,000B.C. (Clottes, 2000). The skill of map making has followed mankind through the ages, and the knowledge behind maps has been developed to allow the accurate depiction of kingdoms or countries, as seen within 'Mapping through the ages: The History of Cartography' (Dempsey, 2011) and 'Maps and their makers: An introduction to the history of cartography' (Kish, 1955). Together, the articles focus on the progress made during four stages in human history - prehistoric, ancient civilization, the enlightenment period, and ending with the development of computerised mapping technology. Both are deeply fascinated with the early stages of map production and development, with the focus largely relating to the pre-enlightenment period.

The historical consequences are further discussed from the perspective within Smith's article 'The Why theory in the history of cartography?' allowing a philosophical approach to the separation of two forms of cartography interpretation; history and critical thinking. A similar approach is taken in Harley's 'The New Nature of Maps: Essays of the History of Cartography', with Harley's essays focusing upon the historical detail, whilst Smith deals deeply with critical theory. Both of these essays project an interest in the cartographers' 'knowledge by description', which defines historical maps as historical artefacts relating to the knowledge possessed by the designer. Smith's article focuses on the critical analysis of the 'styles of thinking' of historical civilizations. Harley's article touches on the alteration of cartography succeeding the Enlightenment of Europe and North America (1715-1789), which were designed with specific accuracies such as; precise surveying methods, addition of keys or explanation, scale bars etc., allowing a definite cartographic map. Both articles, and the larger opinion, agree upon the inclusion of evaluating a historical perspective, with focus drawn to the geographical knowledge available to history. This is still a developing paradigm, having been formally introduced in 1987 within Volume 1 of 'The History of Cartography', which looks into the bygone maps of different civilizations to determine the historical view of the world, and selection of knowledge.

Ordnance Survey (OS) history and development is noted within Tim Owen's book on the condensed history of OS 'Ordnance Survey: Map Makers to Britain since 1791', which was officially founded by William Roy in the summer of 1791, although the society had been active from the 1750's.

The mapping of tidal features is one feature included within the production of OS maps, which allows the possibility of demonstrating sea-level rise, beach erosion and accretion, with tidal lines dating back to the 18th century maps The background to this is covered within 'Ordnance Survey data collection and mapping of tidal features', gathered by Brian Baily in 2010 Covering a similar topic, but with greater focus on the photogrammetric technique, is Peter Collier's 'The development of the photogrammetric mapping of tidal lanes by the OS' in 2011. Both describe coastal mapping as being some of the few long-term datasets usable to note coastal changes over the last 200 years, with limited consistency due to the previous low priority of the subject matter.

One significant feature which is repeatedly used, yet altered, is the definition of high and low tide mean. Collier's essay discusses the altering positions of the 'tide line' throughout OS history, referred to the Parish boundary limit, which until 1868 only extended to the high water line. In Baily's essay, it is noted that 1882 was the point where the marking of mean/ordinary tides marking began, slightly contradictory to the information provided by Collier. The official location of the high tide line has altered throughout the history of OS, the dates of which are marked within Table 2. It is noted within this essay that previous to 1868 publications, the tide tine referred to the typical sea/land interface, not for a particular time. Within Baily's essay on ground and photogrammetric survey accuracy, it was discussed that throughout OS history, OS have instructed surveyors to exercise care whilst recording high and low tidal ranges - with determination to record the high-tide in all cases, but placing less necessity on the low-tide ranges. However this same guidance, allows for lax protocols for bad weather conditions, despite noting the unpredictability of the potential tidal effect instigated by meteorological conditions. This essay also refers to Morecambe bay, proximate to the region of interest, as a problematic region of study due to the unstable nature of the sands and mudflats; a problem largely affecting the low tide positioning.

Tidal Line Variations	Abbreviations for Tidal Lines	Dates Activated
Highest/Lowest water mark for ordinary tides	H/LWMOT	Dec 1868 – Aug 1935
High/Low water mark of medium tides	H/LWMMT	Aug 1935 – March 1965
Mean high water / Mean low water	MHW / MLW	March 1965 - present

Table 2: The alterations of tide line classification as shown by the Ordnance Survey from 1868 - Present. (Baily, 2011)

The difficulties of measuring coastal change using the differing tidal lines used in surveying and OS maps can be separated into two key issues – the first may be seen as errors relating to data collection, the other can be viewed as data presentation (Maling, 1989). This refers to the collection being correct, but under differing data assembly – as within table, 2. The tide lines visible on Ordnance Survey potentially may be useful to indicate sea level rise, beach erosion and accretion or beach narrowing by comparing the movement of these lines for geomorphological research (Baily, 2011). In theory, Ordnance Survey map provide a timeline of changes in shoreline position extending back 200 years, with historic maps having more inaccuracies than the earlier OS maps– with editions marking the high and low spring tide up to 1879. From this period, tide lines were marked as L/HWMOT (Table 2) which were defined as "those of high and low water of ordinary tides (i.e. tides half way between neaps and springs) which define the limit of the foreshore" (Ordnance Survey, 1882), the surveyors of this time were instructed to follow tide tables to determine the L/HWMOT, but if not available to approximate the tide. The surveyors of 1905 followed a similar approach in which recording "tides half way between a spring and a neap, and should generally be taken at the fourth tide before new and full moon" (Oliver, 2005), the labelling altering to MH/LW. This name alteration is not significant as the definitions remain the same (Sutherland, 2011).

As technology improved, the art of cartography changed with it. The development of computers allowed the development of digitalised GIS with several key factors leading the development; the formulation of computer technology, the development of special process theory in relation to social geography and regional sciences, finally the increasing social awareness of the changing world and environmental problems. The key factors of the development of the subject are discussed at great length within the paper produced by Jordi Marti-Henneberg in 'Geographical Information Systems and the Study of History' in 2011. The article refers to 1962 as the start of the GIS revolution, with private companies and governmental figures having primary access to this technology frpm the 60's onwards, through to the 80's where GIS became publicly available. This was due to web-based cartography and GIS sites becoming freely available (MacEachren, 1998). From 2004 Google maps in particular facilitated wider access.

Overall, it can be seen that once standardised methods of measuring became widespread from British OS maps they became precise and widely usable. Earlier maps cannot be wholly relied upon due to slight inaccuracies in the work – especially for uninhabited coastlines, a class South Walney falls within. Nevertheless, the tide lines visible on Ordnance Survey may potentially be useful to indicate sea level rise, beach erosion and accretion or beach narrowing by comparing the movement of these lines for geomorphological research. When reviewing the digitalised historic maps, it is important to understand that collections of L/HWMOT and MH/LW were taken at approximate times, limiting the accuracy. However, if they were collected in a timely manner, the levels in tide tables were set to the nearest 0.1m, leaving a maximum error of 0.05m (Sutherland, 2011) – with aerial photography setting a limit of ± 0.3m error, with an absolute maximum and inferred standard deviation of 0.1m (Ryan, 1999).

2.2 Analytical Techniques and Approaches

N. Levine's essay 'Land Use, Erosion and Habitat Mapping on an Atlantic Barrier Island, Sullivan Island, South Carolina' published in 2012, follows a similar methodology as S. Dornbusch's 2012 essay 'Retreat of Chalk Cliffs in the eastern English Channel during the last century'. Both of these focus on the historical changes facing coastlines using a combination of Ordnance Survey maps, and the use of USGS orthophotos to record the greatest length of history available. Levine's work included a table of the accuracy available to the footage, which is similar to the building of Figure 5 in Rollinson's work, where he quoted 'Maps prior to the 19th century should be treated with the greatest reserve, both from a qualitative and especially a quantitative point of view' (Carr, 1962). Within Dornbusch's essay, a further step of georeferencing the maps was included, although the reason was not noted. It is possible this was a precaution to improve the accuracy of the work due to the earliest map dating to 1873. K.A, Addo in 2008, took a similar approach to measuring the shoreline recession within the Ghanaian coastline off Accra. The data used is quite different to the previous two papers, using bathymetric data from 1904, digital topographic maps from 1974 to 2002 and orthophotos from the year 2002. As these maps became stitched together, a few features did not exist on the older bathymetric map, although the vertical accuracy remained high at 95% confidence interval. This project constructed the shape of the current shoreline, building out to the historic. This allowed the production of 50 meter intervals from the century of change. The data was analysed using linear regression, as this is the most commonly applied statistic to expressing rates of change. Addo then used the knowledge gained to predict the future change for the following 250 years. Within Dornbusch's methods he digitalised the difference between the oldest and the most recent image, turning it into a polygon, then sectioned the distance every 50 meters; this was later calculated by noting the distance, and dividing it by 50 in order to note the average retreat in meters. Levine used a different approach, in order to differentiate the changes per data set added. To complete this he inserted each change into a raster catalogue, and conducted a footprint analysis on the mosaic dataset. The changes in the islands footprint then show the areas of accretion and erosion, the changes of which can be viewed within Figure 5, in which the outline is projected from the 2006 aerial photography as a base.

By reviewing these three articles, it can be seen how multiple pieces have followed a similar approach in terms of broad analysis of the different historic datums. The available data for each project has varied – but with the bulk of the material based from Ordnance mapping or LANDSAT images of the select regions. Those focusing on a small island, such as Levine's study on Sullivan's island (Figure 5) can project the changes for a complete feature with ease, due to the small sample size.

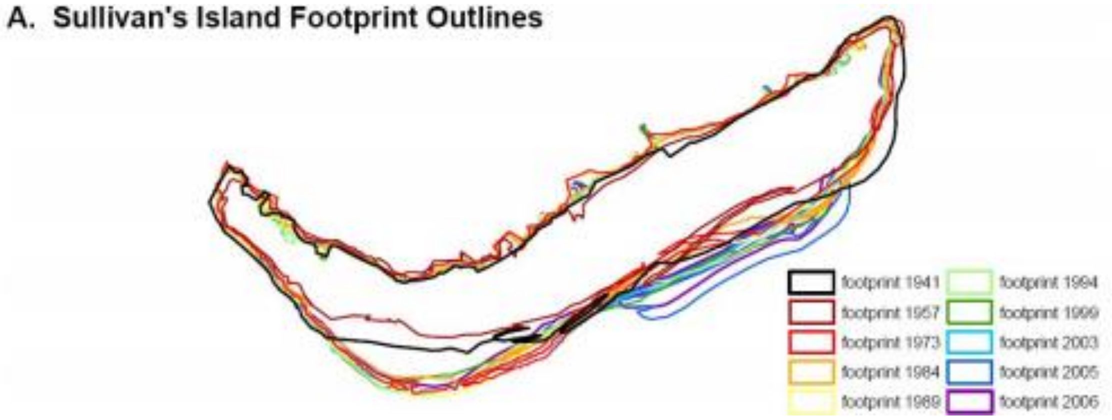


Figure 5: Sullivan's Island Footprints (Levine, 2012)

CHAPTER 3: METHODOLOGY

3.1 Software Used

In order to conduct the relevant analysis of coastal change in Walney, the software used was ESRI's ArcGIS 10.4.0. This software enables the discovery, use and adaption of maps from multiple sources with the capability to host multiple third-party add-on software and scripts.

The majority of the statistical analysis was conducted within ArcGIS, with additional input from the Digital Shoreline Analysis System (DSAS) 4.0, a product produced by United States Geological Survey (USGS) Woods Hole Coastal and Marine Science Centre – allowing the calculation of shoreline change.

3.2 Study Area

The focus of this study was the determination of the altering coastline on Walney Island of the lower 1.3 miles of storm ridden westerly coast, the 2.49 mile-long protected easterly coastline, and the 2.26-mile-long South End Haws spit. The break-down of the different areas of focus are drawn within figure 6, with this region purposely split into three sections due to the varying alterations predicted. The background to this assumption was gathered from Rollinson's map of Walney Island (Figure 3). The Geology of this section of Walney can be reviewed within figure 7, where a breakdown of the bedrock and superficial material can be reviewed.

Figure 6: Section of focus: Walney Island, Cumbria. (Google Earth, 2017)

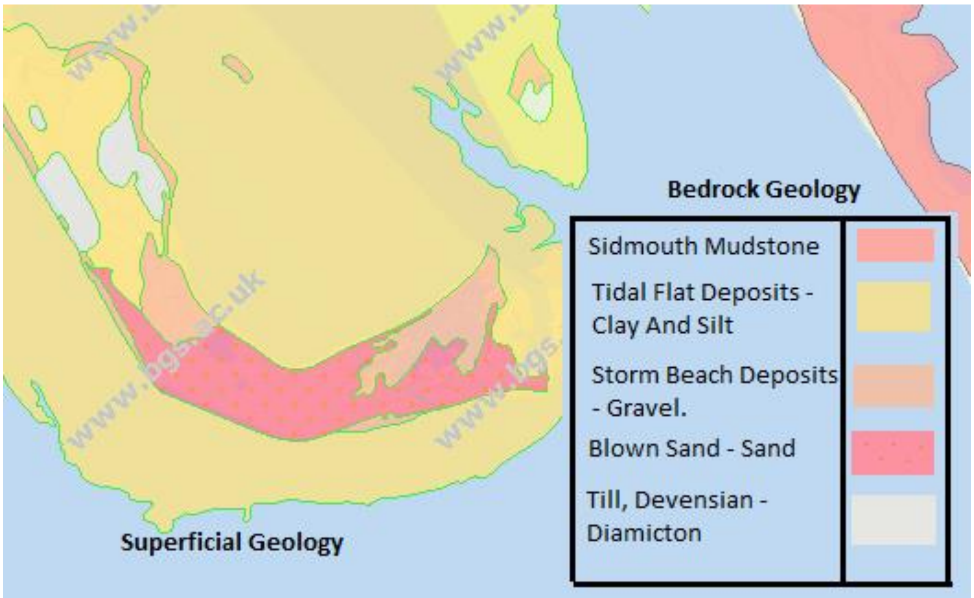


Figure 7: Superficial and Bedrock Geology of Walney Island (British Geological Society, 2017)

The overbearing bedrock geology of the region – mudstone – is a malleable material, and is very prominent along the cliffs of the westerly coastline, and is heavily eroded in annual high tides and storms. The superficial geology is another soft feature, with much of the exposed sediments being loose sands and gravel as part of the elongated South End Haws.

3.3 Data Collection

This project has been designed to investigate how the coast has altered from the recording of the first OS map of the region to the present day. The project uses two basic forms of data collection for analysis: historic OS maps and aerial photography analysis of the island's shape, and prevalent alterations to the form.

To undertake this project, it was necessary to collect multiple reliable historic maps in order to formulate a meaningful insight into coastal change on Walney. Unfortunately, this requirement has resulted in the excluding of a number of hand drawn maps from the 18th century due to a lack of confidence in the precision of the map recording before the 1840's. The reliable historic maps used were obtained through EDINA's digimap, as 'Original Sheets'; guaranteeing the tiles have been scanned and georeferenced as tiff files allowing the instantaneous use of the documents. The first published OS of Lancashire dates from 1849. For the first seventy years of OS maps, it was only the intermediate Country (1:10560) Series which covered the sparsely inhabited island, with only three maps taking place throughout this timescale.

Dating from 1945, the mapping of Britain altered slightly with the induction of the National Grid Series. However, due to the remoteness of Walney, it took until 1957 for it to become re-assessed using the new triangulation model. (1:10560) and to once again record the coastline of south Walney For the short period of time they were recorded a new OS edition was published every 12 years on average, with the specifics dates visible within table 3. By the end of the 1990's, the recording methods altered to become fully digitalised, signalling the end of the available historic OS maps of the island. The combined maps used throughout this process are thus mentioned within figure 8 as a combined image.

Published Year	Product	Scale Imperial	Edition	County	High Tide Marking	Data Source
1849	County Series 1:10560	6" – 1m	1st Ed	Lancashire	Ordinary High Water Mark (OHWM)	Landmark Information Group
1892	County Series 1:10560	6" – 1m	1st Ed	Lancashire	Ordinary High Water Mark (OHWM)	Landmark Information Group
1919	County Series 1:10560	6" – 1m	2ndRev	Lancashire	Ordinary High Water Mark (OHWM)	Landmark Information Group
1957	National Grid 1:10560	6" – 1m	-	-	High Water Mark (HWM)	Landmark Information Group
1967	National Grid 1:10560	6" – 1m	-	-	High Water Mark (HWM)	Landmark Information Group
1989	National Grid 1:10000	5ft – 1m	-	-	Mean High Water Mark (MHWM)	Landmark Information Group

Table 3: Map Sheet Information for Historic OS maps (Digimap, 2017

Imagery Date / Time	Range	Heading	Tilt	Root Mean Error
18/4/2014 / 12:00am	3.730km	0.00°	0.00°	1.961
30/12/2003 / 12:00am	3.730km	0.00°	0.00°	2.189

Table 4: LANDSAT Imagery recording information (Google Earth, 2017)

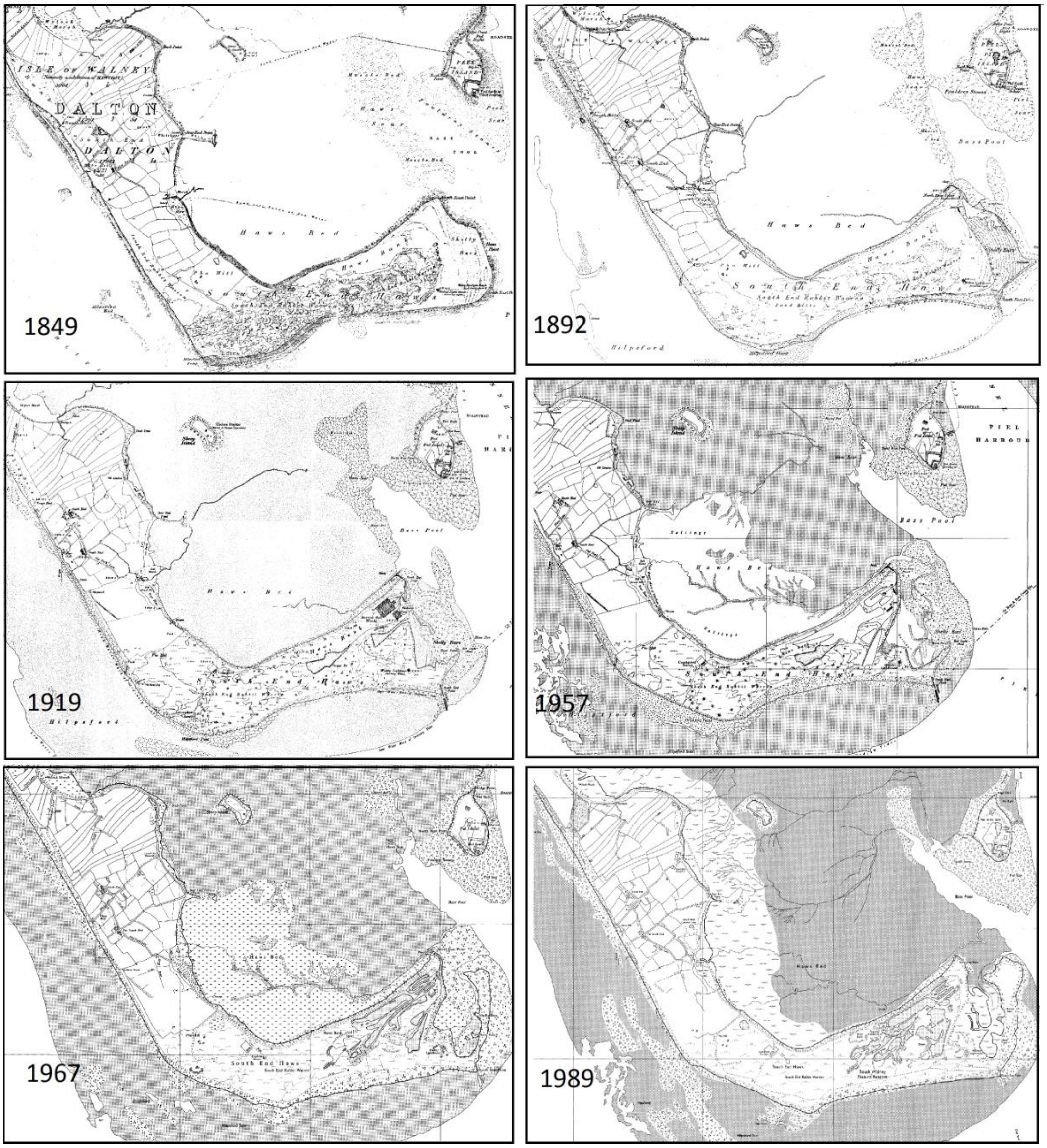


Figure 8: Compact image of the used historic OS maps (Digimap, 2017)

Due to the scarcity of year-specific Ordnance Survey maps post-1990’s, the later records are taken from freely available LANDSAT images provided by NASA. The available materials have been integrated within Google Earth in collaboration with Carnegie Mellon University and the U.S. Geological Survey (USGS), providing easy access to thirteen years of NASA Landsat imagery dating from 1999 to 2011. Through this access site, two images were downloaded as tiff files – 2003 was recorded using the Landsat Enhanced Thematic Mapper Plus (ETM+) as a resolution of 30-meters and 2014 (USGS, 2016), which was recorded using Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), providing a resolution of 30 meters (USGS, 2016) (table 4), as can be reviewed within figure 9. These were selected due to the image quality at this point was high, providing a clear outline of the Island, with a visible coastline for provision of accuracy. These provide a decadal difference for Walney; however older material was ignored due to the poor clarity of the image which would have impeded the accurate recording of the island shape.

Figure 9: Compact image of the 2003 and 2014 LANDSAT images (Digimap, 2017)

Due to the nature of image extraction from Google Earth, these images were manually georeferenced in order to align the Landsat images to the digitalised historic OS maps. This was accomplished by importing the images into ArcGIS and the file georectifed to British National Grid with a D_OSGB_1936 datum set. Once imported, the image was georeferenced with the use of 9 highlighted spots as noted within figure 9. These geolocation points used, as reviewed within table 5, were obtained through Google Earth, and once placed, repositioned the Landsat images to the true location, integrating the images into the raster catalogue. The 2003 Landsat image provided a root mean square (RMS) error of 2.189 meters in 2003, and 2.012 RMS for the 2014 Landsat image (Table 4), the positioning of which is noted within figure 10.

Map Position	Longitude	Latitude
Top Right	3° 6'5.17"W	54° 5'33.60"N
Middle Right	3° 6'2.18"W	54° 4'4.51"N
Bottom Right	3° 6'4.31"W	54° 2'39.02"N
Top Middle	3°10'19.53"W	54° 5'33.06"N
Middle-Middle	3°10'24.24"W	54° 4'7.97"N
Bottom Middle	3°10'13.80"W	54° 2'42.57"N
Top Left	3°14'18.88"W	54° 5'30.53"N
Middle Left	3°14'20.32"W	54° 4'5.94"N
Bottom Left	3°14'18.00"W	54° 2'38.64"N

Table 5: Coordinates used to georeference LANDSAT images (Google Earth, 2017)

Figure 10: Positioning of 2003 LANDSAT image post georeferencing (ArcGIS, 2017)

3.4 Coastline Analysis

For each map included, it was vitally important to digitise the exact shape and size of the island's footprint within ESRI's ArcGIS – process which was conducted by hand. To accomplish this, it was necessary to draw a polygon by tracing the high tide marker present within each layer, a process which can be seen in figure 11. The footprint analysis is based upon the size of the land above the high tide, yielding important data to if the total area has increased, or reduced, and presents clear evidence of a moving coastline or feature.

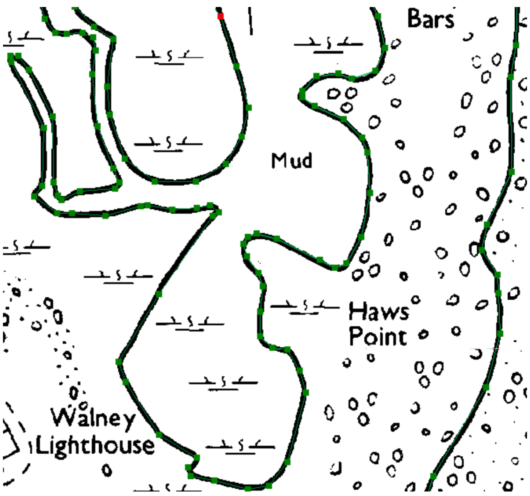


Figure 11: Method implemented to accurately trace high tide outline (ArcGIS, 2017)

The digitalisation of Walney's coastal change can first be accomplished through the manipulation of the individual polygons produced for each map. The appropriate tool accessible through ArcGIS 10.4 is the union tool – which calculates the geometric relationships between multiple overlaying polygons, with the calculated output producing data on the values for the intercepting positions, and the values for the differences between each polygon. This data can be used to calculate the differences between the progressing timeline.

The DSAS extension has the capability to enhance the functionality of ESRI ArcGIS, enabling the calculation of shoreline rate-of-change statistics from multiple historical shoreline positions.

The first required inputs of the programing are the sequential temporal vector shoreline positioning – which initially require the alteration of map polygons into polylines using the tool 'Feature to line' (Data Management Tools -> Features -> Feature to Line). The collection of these new positioning polylines were then appended (Data Management -> General -> Append) into one file which was created within a Personal Geodatabase using specific requirements as noted within figure 12.

Shoreline			
Field Name	Data Type	Properties	
OBJECTID	Object ID		Fields are generated automatically when new shapefile class is created
Shape	Geometry	Line	
Shape_Length	Double	Precision=0; Scale=0	
ID	Long Integer	Precision=0	
DATE_	Text	Length=10 (mm/dd/yyyy)	User-created
ACCURACY	Short Integer, Long Integer or Float (any numeric)	Precision=0	User-created

Figure 12: Shoreline Field Requirements (Thieler, 1994)

The second input requirement is the addition of a baseline, which is used as the starting point for the transects yet to be produced, and is a vital component of the shoreline analysis process due to the impact the location of the baseline has on the transect calculations. The generation of the baseline was conducted by creating a new polyline shapefile using ArcCatalog, and manually drawing and editing the line using standardised methods. This polyline was drawn landward 20 meters from the most landward shoreline position. This file was edited to host multiple baseline field requirements as noted in figure 13.

Baseline			
Field Name	**Data Type**	**Properties**	
OBJECTID	Object ID		Fields are generated automatically when a new shapefile class is created
Shape	Geometry	Polyline	
Shape_Length	Double	Precision=0; Scale=0	
ID	Long Integer	Precision=0; Value=1	Optional user-modified
OFFshore	Short Integer	Precision=0; Value=1	User-created
CastDir	Short Integer	Precision=0	User-created

Figure 13: Baseline Field Requirements (Thieler, 1994)

Once the required layers were produced, transects were set through the use of USGS' DSAS toolbar – during this process it is required to set transect parameters, which vary dependent upon the data. These are separated into: baseline parameters; shoreline parameters; and transect parameters – of which the selected classes can be reviewed within figure 14. An example of the final product relating to the associated parameters can be seen in figure 15.

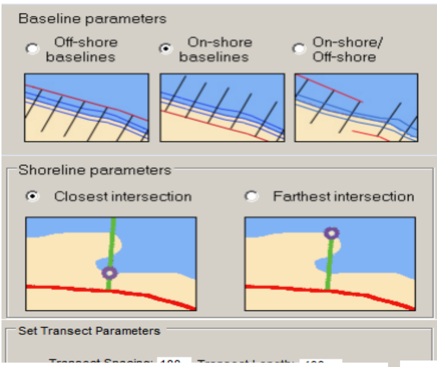


Figure 14: Parameter Settings (DSAS, 2017)

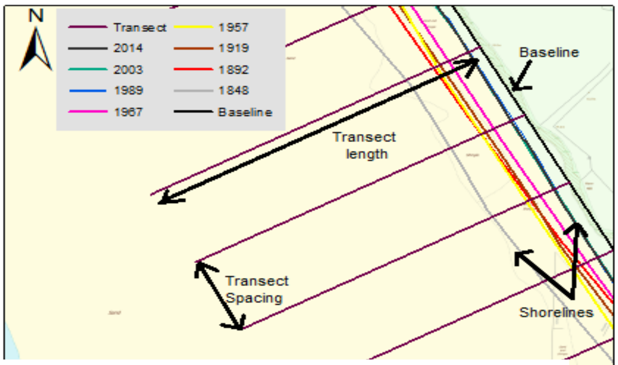


Figure 15: Placement of parameter requirements within the final piece (ArcGIS, 2017)

3.5 Statistical Analysis

Data analysis was carried out using linear regression, consistent with the analysis used by Levine, Addo and Dornbusch. The statistical analysis was conducted using the USGS DSAS toolbar which provides the following data for data transects: End Point Rate (EPR), Shoreline Change Envelope

(SCE), New Shoreline Analysis (NSA), Least Median Squares (LMS) and Linear Regression Rate of change (LRR).

The EPR is a measure of the erosion or accretion rate in metres per year over the whole period, and is evaluated per transect, and calculates the difference between the oldest and the newest dataset (1847 and 2014) by dividing the calculated shoreline movement over the period by the time period. This provides information on the overall change, but does not contain further detail on the individual magnitude between different maps. Where there have been changes in accretion and erosion for a given location, this information is not captured, and is only evident from data quality measures

Shoreline Change Envelope (SCE) and New Shoreline Analysis (NSA) provide overall erosion or accretion information. The SCE provides end-to-end change, whilst the NSA compares maximum and minimum data within the whole period.

Least Median Squares (LMS) and Linear Regression Rate of change (LRR) provide data quality information. The LRR is computationally simpler, but is susceptible to influence from outliers. Good agreement between the two implies consistent behaviour and well controlled data.

The LRR is supplemented with the input of the standard error of estimate – which reflects the degree to which the points diverge from the best-fit regression line, providing a measure of accuracy of the data.

3.6 Data Quality

Accuracy of shoreline data drawn on the map often limits the map accuracy, which affects any subsequent analysis such as shoreline rate-of-change calculations.

Ii is important for the shoreline accuracy to be quantified so the quality of the subsequent data analyses can be assessed. There are several methods in place in order to limit inaccuracies. Map transformations: where errors in map data are reflected in the accessible map as a consequence of the transformation of manually collected data by digitizing it to geographic coordinates using numerous calibration points. These points are displaced at a rate of 0.125 mm within a 1:20,000 map scale, an error of 2.5m (Thompson, 1987).

Different High Tide Markers: Within the project, there is a total of three different high tide calculations used; OHWM, HWM and MHW (Table 3). Several concerns arise with the different tidal recordings noted, as this is a key record of coastal change while referring to coastal geomorphological change (Baily, 2009). To account for this all recordings are taken with a reasonable error limit, which throughout the project stays at a minimum of 4.4m.

Photo Transformation: Landsat provides a wonderful source for understanding changes over the last 4 decades, with vast improvements from 2003 with higher quality images being produced. The ability to access images for a student are limited – leaving Google Earth as the prime point of reference. Due to the limitations of this software, the LANDSAT image is only accessible by a singular tiff. file. This limits the quality available, even whilst covering a small area, limiting the functionality when digitising the coastline of this image. The specifics of recording time are not recorded which may impede the successful recording of the High Tide Mark. The georeferencing of these images followed a similar error mark of the 1:20,000 scale maps – with a root mean error of 2.1m (on average).

Shoreline rate-of-change: The measurement baseline and shore-perpendicular transect locations which combine to determine shoreline rate-of-change. However, the ability to accurately determine this – the input data must have a high calibre of accuracy, however due to the points taken above for error rates of scaling issues (2.5m), LANDSAT images (2.1m) and tidal differences (4.4m) – there is on average a 4.7m error rate.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Analysis of Change

4.1.1 Footprint Analysis

The footprint analysis (using ArcGIS 10.4) of the different historic maps demonstrates ongoing and progressive changes in the shoreline of Walney Island (figure 16). The west coast progresses inwards as a direct consequence of coastal erosion, whilst South End Haws has clearly altered shape in every map. The most significant erosion has occurred on the 'knee' between the west and south coast, and more complex deposition on the island southern tip. The shape of the eastern coast shoreline has evidently stayed more or less stable, although there has been the addition of two salt marshes within the maps dating onwards in the 20th century. These differences are clearly supported by the altering area of South Walney, as evident within table 6.

The total footprint area of Walney began to decrease from the recording of the first OS map, with a starting size of 311.413 ha 1848, an area which fell to its minimum in the 1957 County Series map, with a total area of 264.7168 ha – this decrease seems to be related to a high erosive rate. From this period onwards, the total area of the island has steadily increased, most probably due to the growth of the South End Haws. The individual changes per map series can be reviewed in the union analysis in figures 17 – 23.

Year Published	Footprint Area (ha)
1848	311.413
1892	307.5708
1919	276.3317
1957	264.7168
1967	279.9541
1989	286.7667
2003	291.0957
2014	291.9464

Table 6: Total Area of each map produced recorded in hectares – data obtained through ArcGIS 10.4, 2017

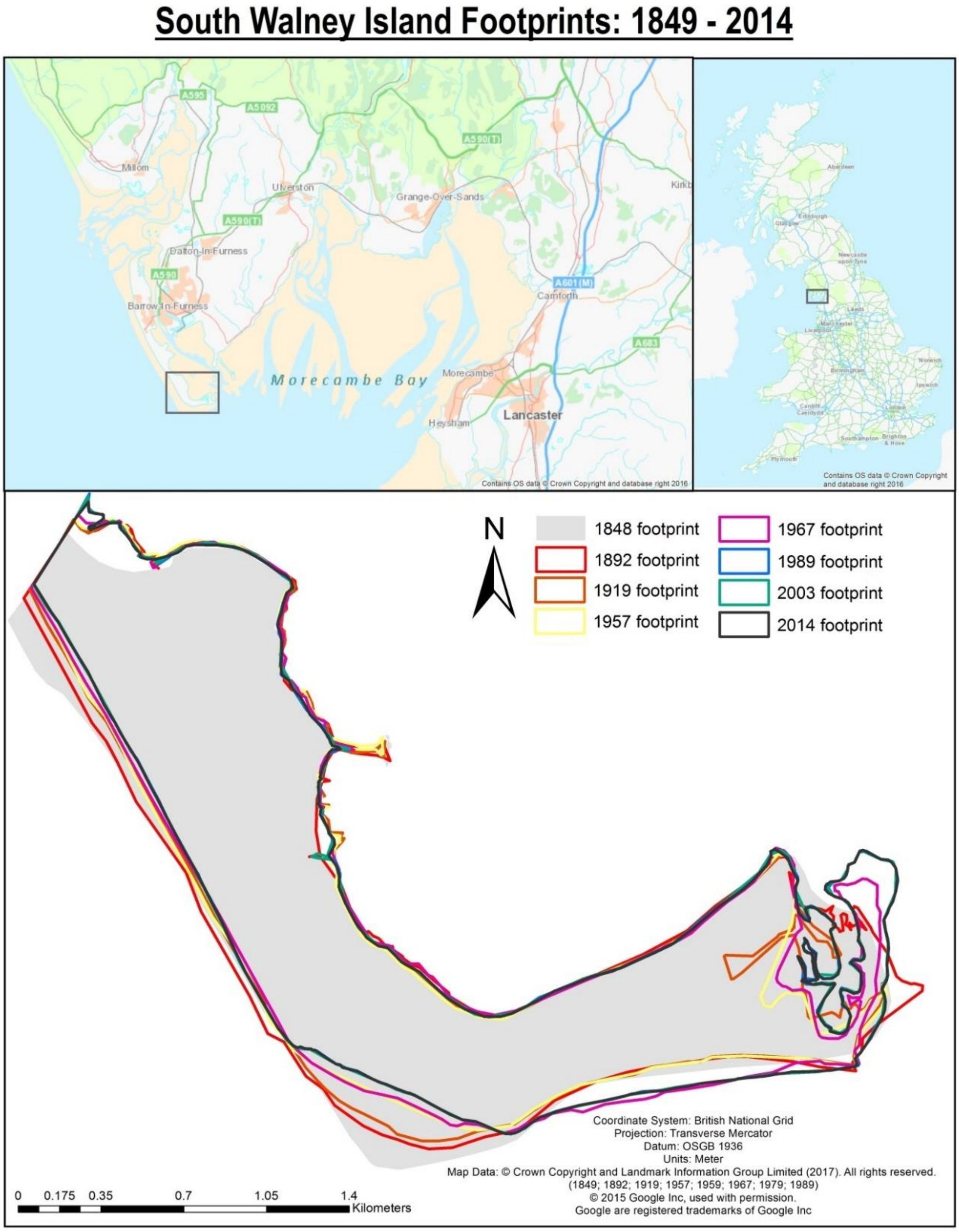


Figure 16: Image overlay of the high tide markings of all OS and LANDSAT maps– Produced within ArcGIS 10.4, 2017

4.1.2 Union Analysis

A union analysis was carried out for the different maps from 1849 through to 2003 using ArcGIS 10.4. Note that the total area used was slightly different to the footprint analysis, but was consistent for all the union analyses.

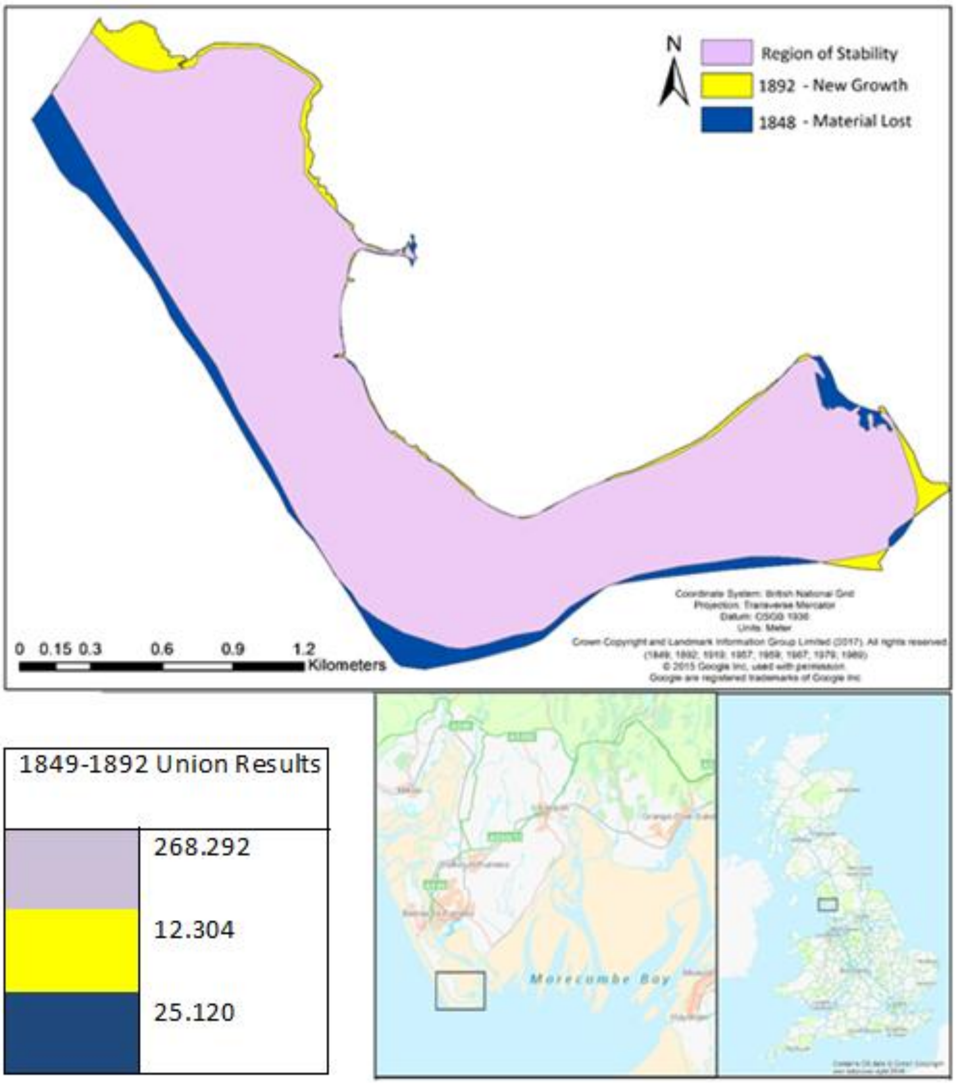


Figure 17: Results of Union: 1848 – 1892, as measured in hectares – produced within ArcGIS 10.4, 2017

In figure 17, it can be seen that a significant shift in the island shape occurred in the years 1849 - 1892 – with wide scale loss of land visible (blue segments of the island union) totalling 25.1 hectares. These segments show a large erosive period throughout the 43-year gap along the western edge and 'knee'. The 12.3 hectares of growth within this period are added primarily by the northern saltmarsh (Wylock Marsh), within the high tide range. South End Haws underwent significant change, with both growth and loss at the sand spit. The likely cause of this is either due to the improvement in recording methodology or due to the swiftly shifting nature of the feature.

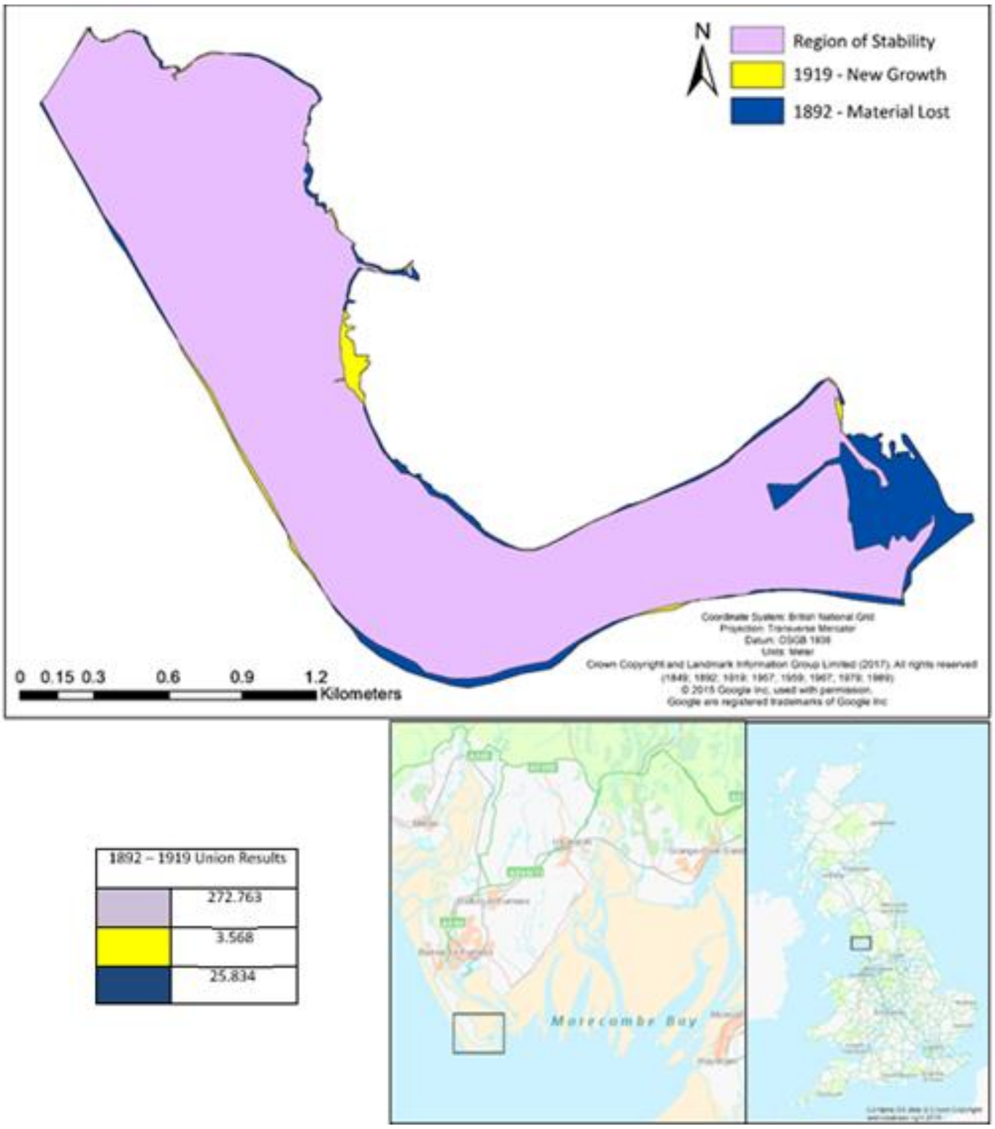


Figure 18: Results of Union: 1892 – 1919, as measured in hectares – produced within ArcGIS 10.4, 2017

The alterations in the period 1892-1919 shown in figure 18 represent a period of 27 years. This period saw the largest losses in the analysis. There was a significant segment of loss present along the South End Haws mouth of much greater magnitude than present in figure 17, possibly a consequence of the shifting sands of Morecambe Bay or changes related to shipbuilding activity in Barrow during WW1. The western and eastern sides of the southern tip of the island both experienced erosion resulting in the island narrowing here. Scar-End also witnessed significant change throughout this period, with the sands connecting the island to Walney being removed. Interestingly; the land loss during this period was virtually identical to the loss apparent within the 1848-92 period – despite figure 18 occurring in half the time (27 versus 43 years). The 3.57-hectare gain is mostly of consequence of the addition of Haws Bed Marsh to the High Tide mark – either due to the inclusion of the surveyor or due to natural development of the site.

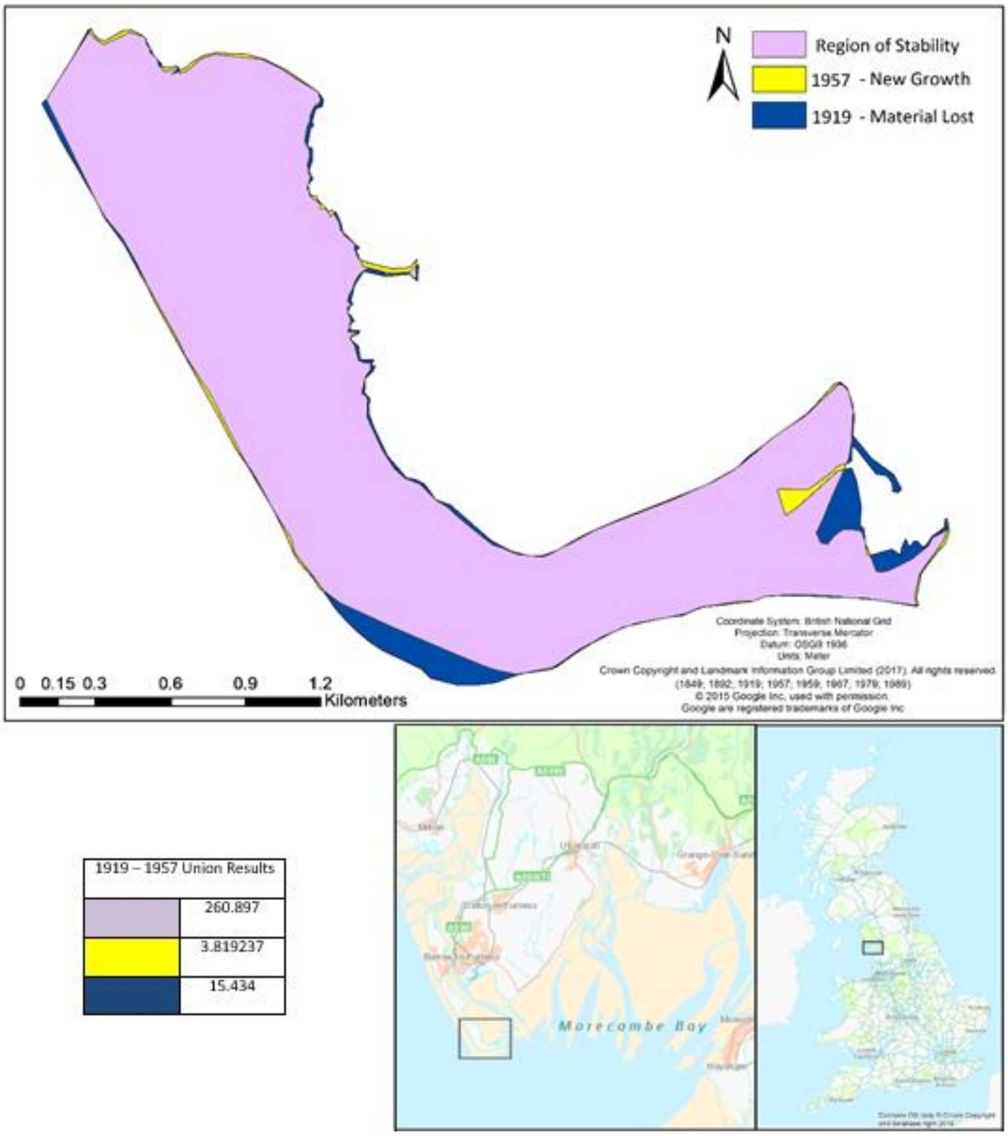
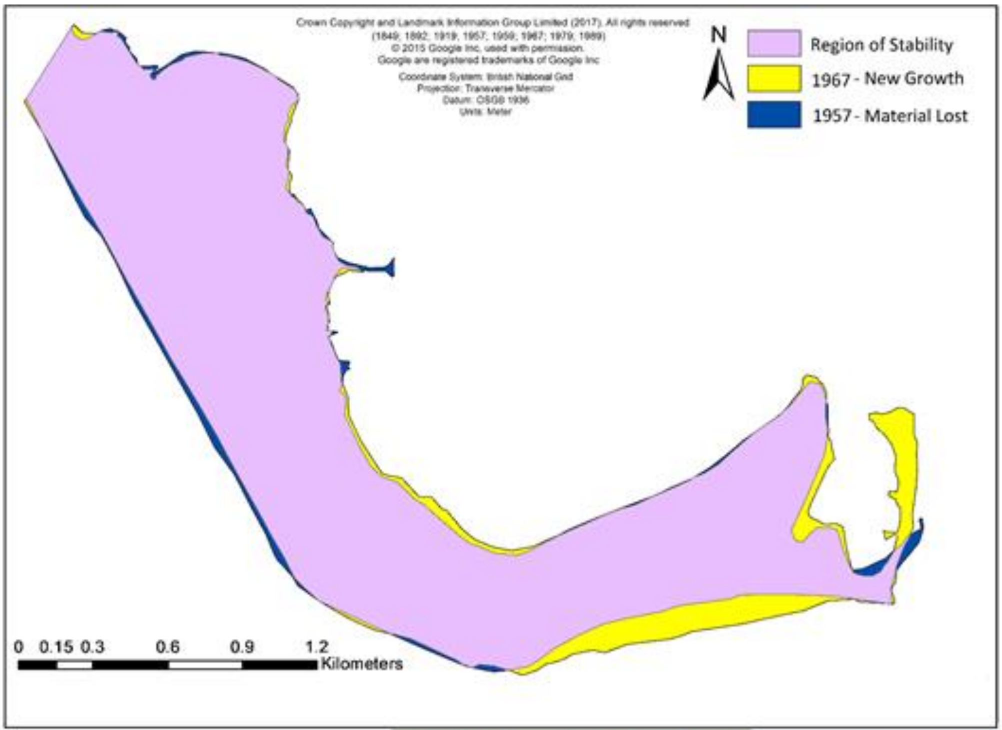


Figure 19: Results of Union: 1919 – 1957, as measured in hectares – produced within ArcGIS, 2017

Figure 19 represents alterations to Walney between the years 1919 and 1957 – a 38-year period. The largest changes are the large decline in the width of the southern 'knee', and continued losses at the spit of the island. The elongated western coast witnessed a mix of both land loss and gain; a similar alteration seen in figure 18. The South End Haws saw numerous changes to the configuration of the spit mouth – with the two branches widening significantly. Minimal new material was accreted within the union, despite the long time period. The overall change of 19 hectares is a minimal alteration in comparison to the total difference in figures 18 (29 ha) and 17 (37 ha), although the net loss per year is similar to figure 17.



1957 – 1967 Union Results	
	257.686
	22.267
	7.030

Figure 20: Results of Union: 1957 – 1967, as measured in hectares – produced within ArcGIS, 2017

The union in figure 20 represents a 10-year period from 1957 to 1967. This is the first period in which there was an increase in land mass of Walney – with an increase of 22.267 hectares. Much of this accretion was present along the South End Haws, with the Southern coast increasing and evidence of the mouth elongating. The second point of growth is present along the inner-edge of the southern point, likely because of the Haws Bed Marshes health improving and its extent increasing. Erosion during this time period continued along the elongated western coast. There was additional removal of sediments along Scar-End, and the northern regions of the saltmarsh.

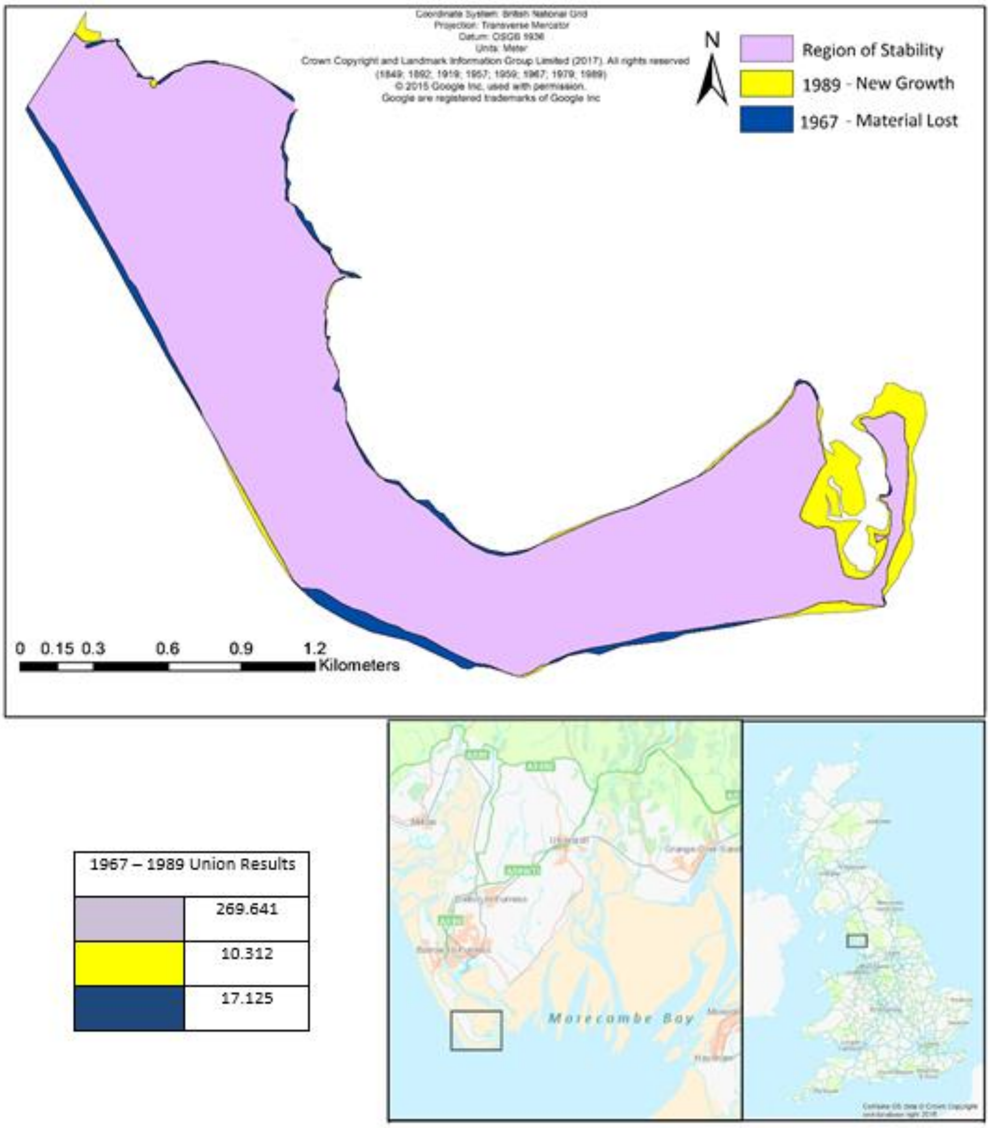
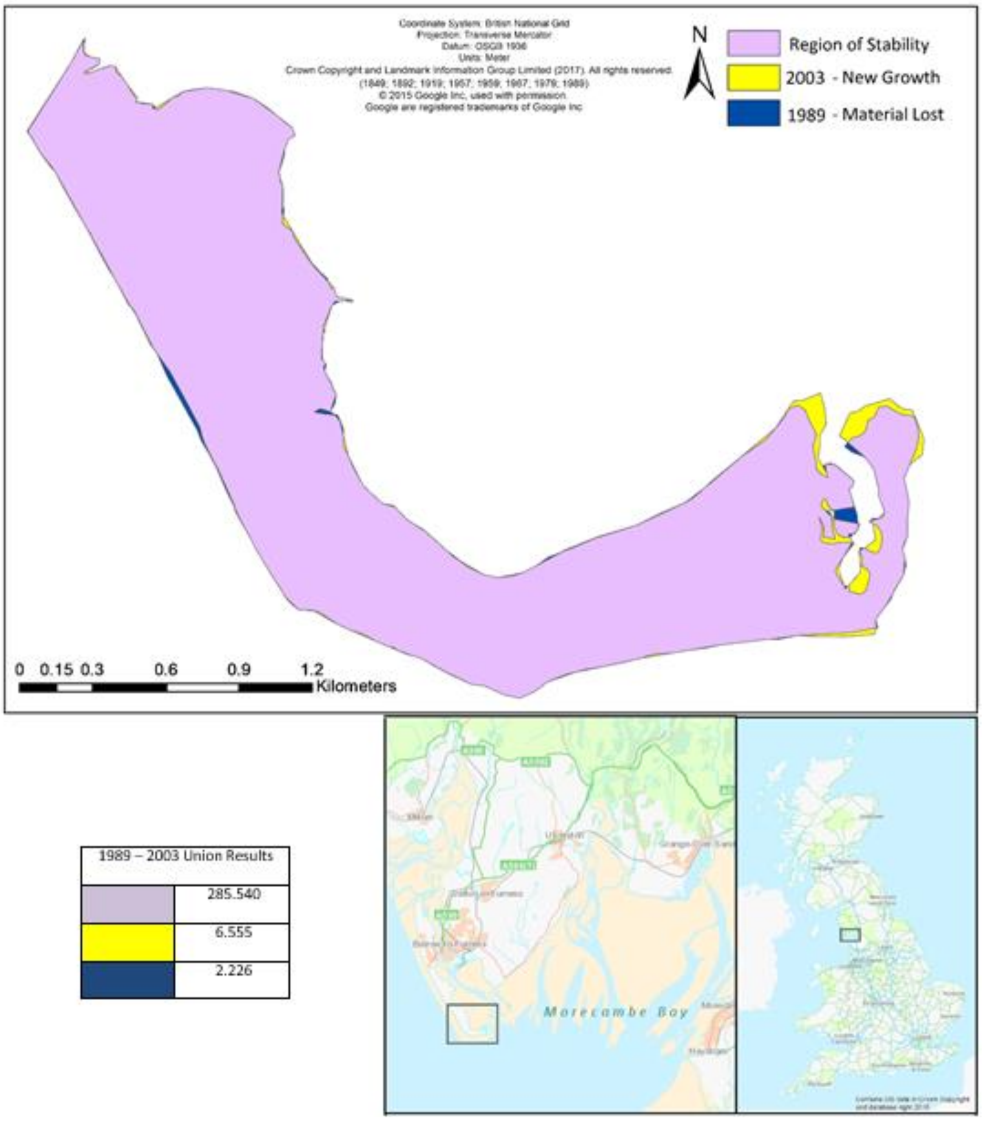


Figure 21: Results of Union: 1967 - 1989, as measured in hectares – produced within ArcGIS, 2017

Figure 21 focuses on the changes evident between the years 1967-89, with the largest change evident at the development of the spit mouth. However there were more generalised losses, with the overall change in land loss greater than accretions, 17.12 hectares against the new growth of 10.31 hectares within the union. Erosion was evident along the western coastline and along the northern stretches of the saltmarsh, causing an overall large loss of land.



1989 – 2003 Union Results	
	285.540
	6.555
	2.226

Figure 22: Results of Union: 1989 – 2003, as measured in hectares – produced within ArcGIS, 2017

The alterations present between 1989 and 2003 are small, as can be seen within figure 22, with the greater proportion of Walney's shoreline remaining stable in this time frame. There was some land removal, with total loss of 2.23 hectares in the 14 years visible through this union. This occurred along the western coast, and within sections of the spit. Accretion was also minimal at a 6.56 hectare gain. This was mostly visible throughout the South End Haws, with the altering sands impacting the shape during the union.

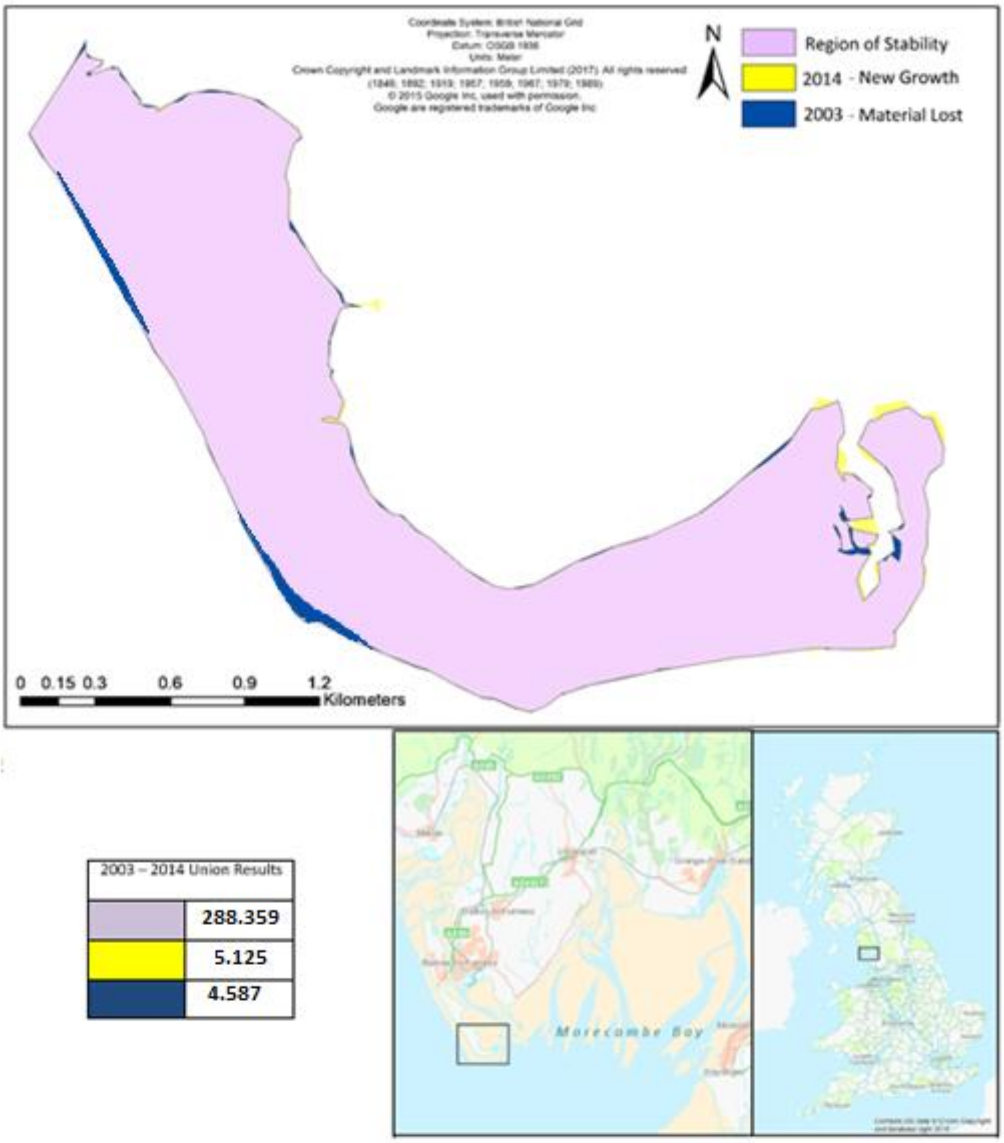


Figure 23: Results of Union: 2003 - 2014, as measured in hectares – produced within ArcGIS, 2017

The alterations present between 2003 and 2014 are small, as can be seen in figure 23, with a net 0.5-hectare change in land area. This was due to small adjustments along the western coast, and within small sections of the spit. Accretion was minimal at a 5.24 hectares, smaller than figure 22 with a 6.56-hectare gain present. This was mostly visible throughout the South End Haws, and the re-development of Scar-End, withchanges in sand distribution impacting the shape during the union.

4.2 Digital Shoreline Analysis Software

4.2.1 Overview of Finalised Product

With the use of the USGS DSAS, it was possible to analyse the varying shape of Walney, and the multiple positions of the South End Haws.

USGS DSAS works by generating orthogonal transects at a user-defined separation and then calculates rates-of-change and associated statistics that are reported in an attribute table.

In this modelling exercise, transects are straight lines at right angles to the shoreline, along which observations are made or measurements taken. The finalised transects mapped here in relation to the multiple overlaying high tide outlines of Walney may be seen in figure 24. The transects are 50 metres apart and are ordered (number 1) from the the north-west corner of the insert map, leading on to the last (number: 108), lying on the north-east tip of the section of the island. Every 10 transects (500 metres apart) are numbered on the projection to aid comprehension.

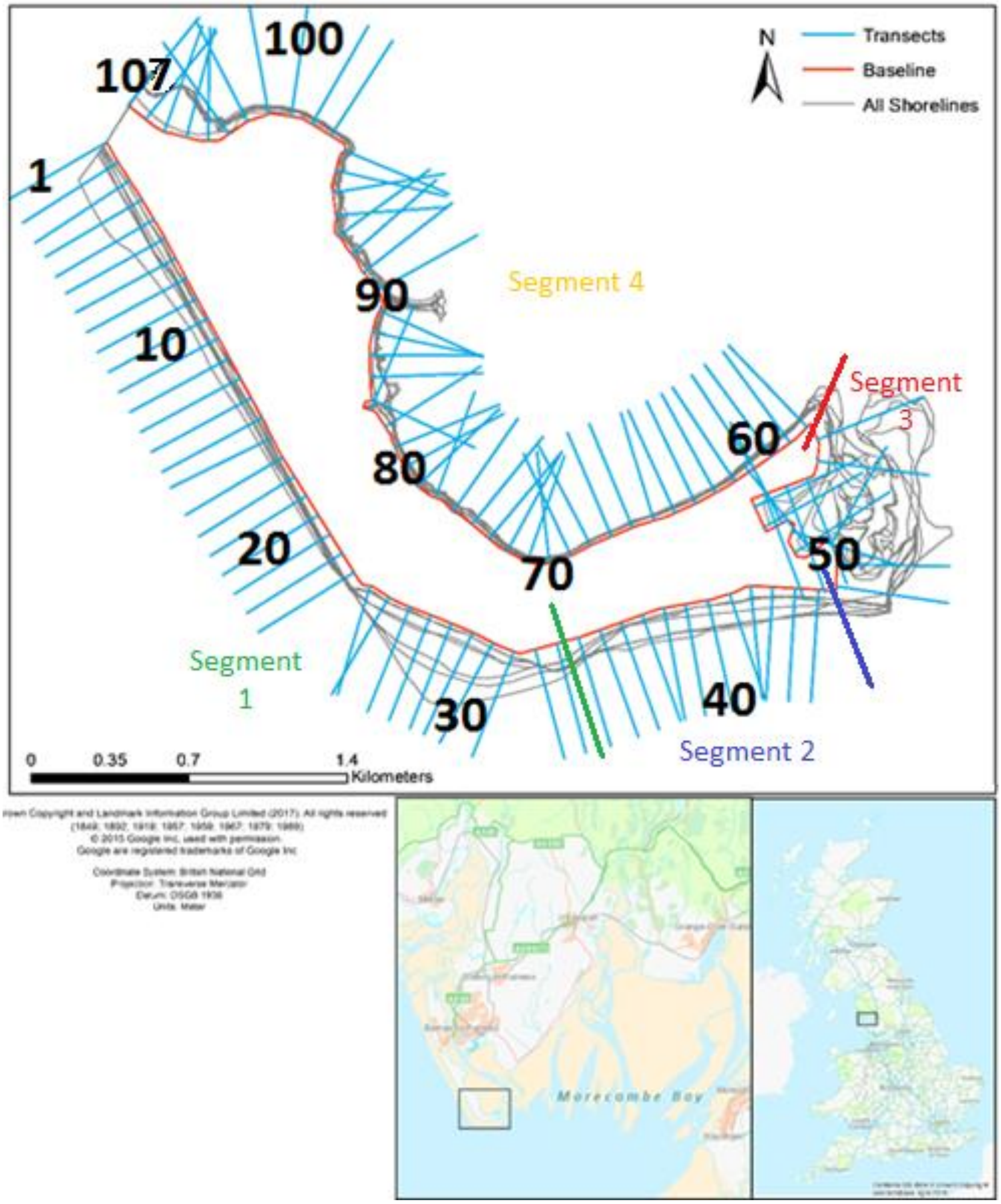


Figure 24: Transects overlaying complete data set, using the requirements to utilise the USGS DSAS - Produced on ArcGIS, with the assistance of USGS DSAS 2017

4.3 Statistical Analysis

To process the data produced by the DSAS efficiently, and to derive meaningful interpretation, it is necessary to divide the research area into shoreline segments. This was done by inspection of the footprint and union analysis. The more transects per segment the more consistent an overall conclusion can be made, but at a risk of missing local behaviours. The baseline for construction of the analysis was drawn at 20 metres above the high tide mark. Note that in the analysis, NSA values are negative (-) showing erosion/land loss. Positive value represents seaward advance. In effect SCE and NSA represent numerically similar data but with different signs due to baseline use.

Each segment is defined by set of defined processes which produce a clear set of outcomes (such as long term erosion or accretion). These areas are described below (derived from Figure 23).

- Erosive Western Coastline: Transects 1 – 34
- Accretive Southern Coast: Transect 35 – 45
- South End Haws Mouth: Transects 46 – 58
- Stable Eastern Coast: Transects 59 – 107

<u>Segment 1: Transects 1-34 (N = 33)</u>

	EPR - End-point Rate (m/yr)	Confidence of EPR (± m/yr)	SCE- Shoreline change Envelope (m)	NSA - New Shoreline Analysis (m)	LMS - Least Median Squares	LRR - Linear Regression Rate of Change (m/yr)
Mean	-0.688	0.043	119.458	-114.2	-0.599	-0.65

Table 7: Statistics of shoreline change within segment one (Created using DSAS results within Excel 2016, 2017)

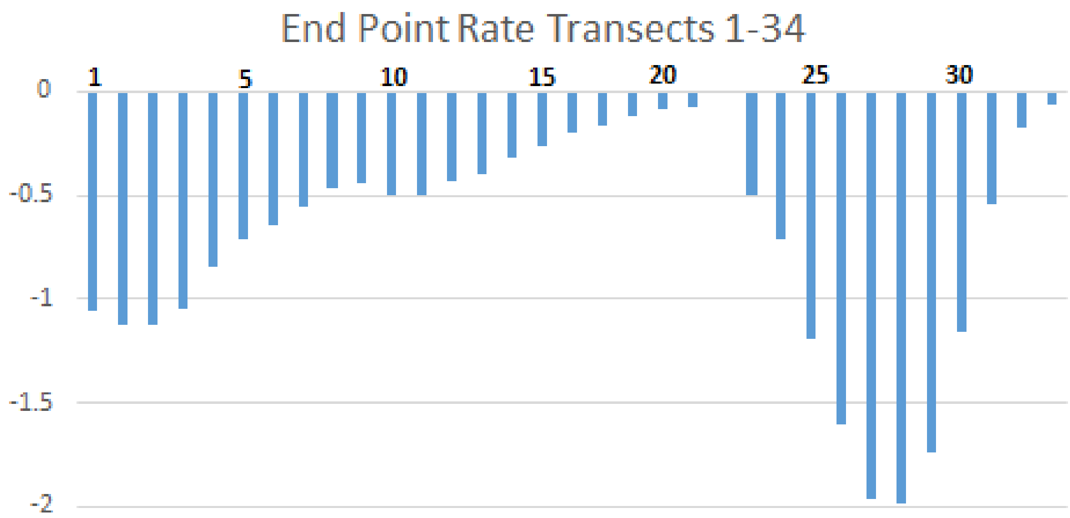


Figure 25: End-point rate of change within segment one (created using DSAS data, within Excel 2016, 2017)

The results of the statistical analysis as obtained from the DSAS for segment one are shown in figure 24 and table 8. The mean EPR of the western coast is a loss of 0.7 m per year. However inspection of the transects shows that that this average is not wholly representative due to the nature of the erosive section. The transects presented represent two distinctly angled sections of coast – the long west facing section of coast is within transect 1-21, whilst the west-south 'knee' is represented in transects 23-33 (figure 24). Both have a rise and fall in EPR. The peak EPR of these two sections are: -1.13 and 1.99 respectively, with these extremes averaging at a loss of 1.56 m/year. The confidence of EPR is at 5%, the normal error for this feature, showing minimal error.

Table 8 also presents the SCE and NSA, which represent the total changes for the data, over the period and maximum to minimum. With values of 119 meters and 114 metres, these are similar values, implying consistent and long term erosion.

Segment 2: Transects 35-45 (N = 10)

	EPR - End-point Rate (m/yr)	Confidence of EPR (± m/yr)	SCE- Shoreline change Envelope (m)	NSA - New Shoreline Analysis (m)	LMS - Least Median Squares	LRR - Linear Regression Rate of Change (m/yr)
Mean	0.326	0.043	97.421	54.325	0.72	0.49

Table 8: Statistics of shoreline change within segment two (Created using DSAS results within Excel 2016, 2017)

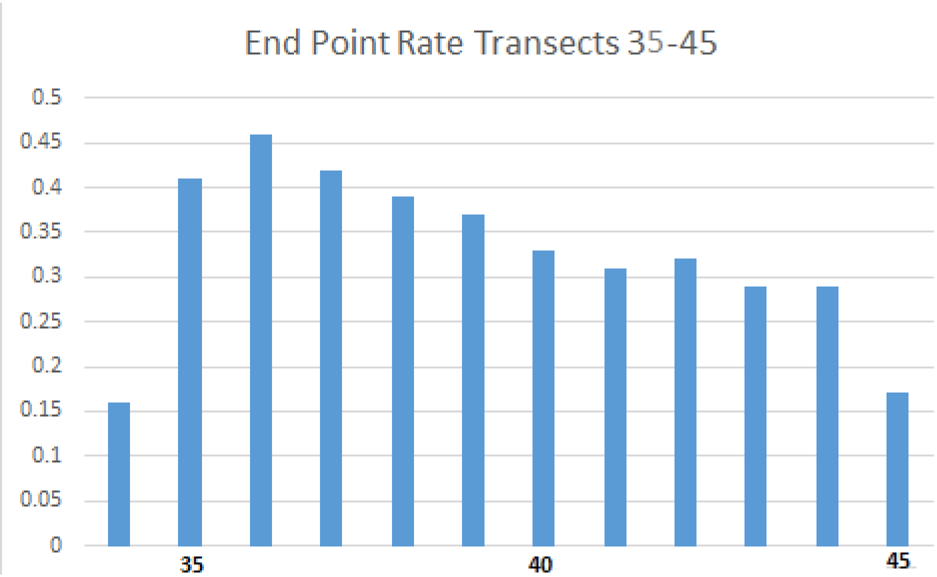


Figure 26: End-point rate of change within segment two (created using DSAS data, within Excel 2016, 2017)

The results of the statistical analysis as obtained through DSAS for segment 2 are shown in table 9 and figure 25. The mean EPR presents a 0.3m growth of average, per year. The accuracy of this figure remains at ±0.43 m, or 5%, the minimum requirement. The EPR for the small segment is viewable within figure 25 largely presenting natural peaks and dips in the accretion gathered which once referred to figure 23, can be attributed to the angle of the island southern coast. The total magnitude of the coastal change of 97.4 m is noted within the SCE, this figure differs from the figure determined within NSA which presents the actual difference between the newest-oldest figure, which presents a 54.3m growth. This 43-meter difference is due to the fluctuation in the coastal dynamics, as can be seen in figures 17-23.

Segment 3: Transects 56-58 (N = 12)

	EPR - End-point Rate (m/yr)	Confidence of EPR (± m/yr)	SCE- Shoreline change Envelope (m)	NSA - New Shoreline Analysis (m)	LMS - Least Median Squares	LRR - Linear Regression Rate of Change (m/yr)
Mean	0.972	0.084	201.693	66.799	1.963	0.69

Table 9: Statistics of shoreline change within segment three (Created using DSAS results within Excel 2016, 2017)

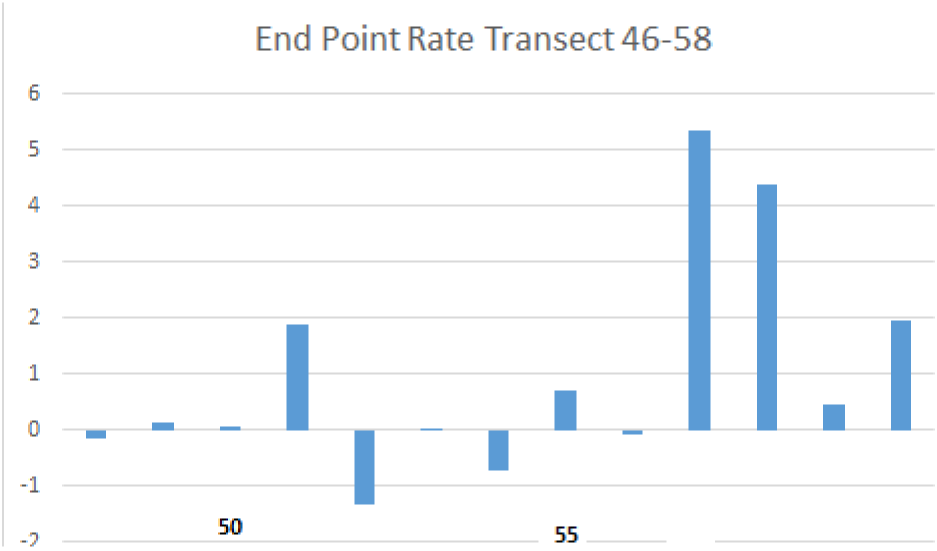


Figure 27: End-point rate of change within segment three (created using DSAS data, within Excel 2016, 2017)

Table 10 represents the shoreline of the South End Haws spit – a section of coast which has a varied history, with swiftly moving sands affecting the results. Figure 26 shows this unstable behaviour, with transects experiencing vastly different results. The vastly different values in NPA and SCE (66.8 metres and 201.67metres) illustrate the changing nature of the shoreline on average, due to the altering growth of the sediment banks forming this spit or perhaps the change in angle of the transects within the spit. The comparison of LMS and LRR indicates significant impact of outliers (1.96 and 0.69). The inconsistencies in the data truly present themselves when comparing adjacent transects 51 (+1.9 m) and 52 (-1.34 m).

Segment 4: Transects 59-107 (N = 58)

	EPR - End-point Rate (m/yr)	Confidence of EPR (± m/yr)	SCE- Shoreline change Envelope (m)	NSA - New Shoreline Analysis (m)	LMS - Least Median Squares	LRR - Linear Regression Rate of Change (m/yr)
Mean	0.057	0.043	42.614	8.922	-0.074	0.01

Table 10: Statistics of shoreline change within segment four (Created using DSAS results within Excel 2016, 2017)

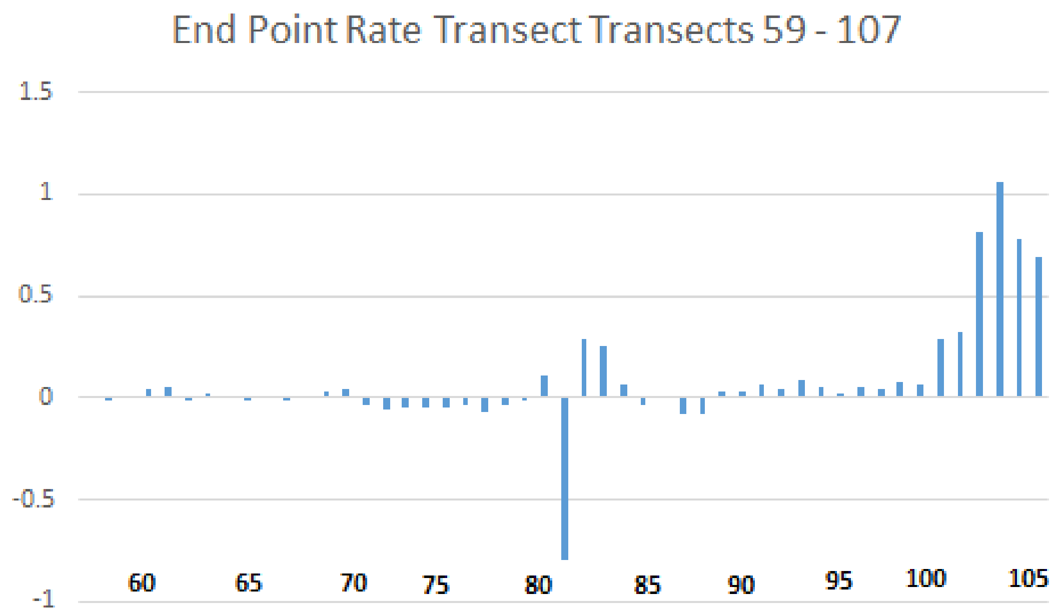


Figure 28: End-point rate of change within segment four (created using DSAS data, within Excel 2016, 2017)

The results of the statistical analysis for the last segment reflect the (relative) stability of the eastern coast. The mean of EPR is 0.06m growth per year, with a confidence of 0.043. However, inspection of figure 27 shows some outliers contradicting stability. These inconsistencies have caused the LMS and LRR to diverge from equality (0.01 and 0.075). These divergent results show a lack of conformity in the accretion and erosion rate. By reviewing the difference between SCE and NSA this is a visible issue – with a 32m difference between the two (SCE:42.5, NSA:8.9). The possible cause of these issues may be inferred as variations in the recording of High Water Mark which can be seen within figures 17 and 18, and with the exclusion of saltmarshes in maps pre-dating the 20th century. Testing this and reworking this analysis to exclude outliers 101-107 gives the results in Table 12. The SCE and NSA are closer, but there are clearly still issues with stability of data as the LMS and LRR still differ significantly.

Segment 4 (Revised): Transects 59-101 (N = 42)

	EPR - End-point Rate (m/yr)	Confidence of EPR (± m/yr)	SCE- Shoreline change Envelope (m)	NSA - New Shoreline Analysis (m)	LMS - Least Median Squares	LRR - Linear Regression Rate of Change (m/yr)

Table 11: Statistics of shoreline change within segment four - revised (Created using DSAS results within Excel 2016, 2017)

Mean	0.0075	0.043	21.185	1.277	-0.0395	-0.010

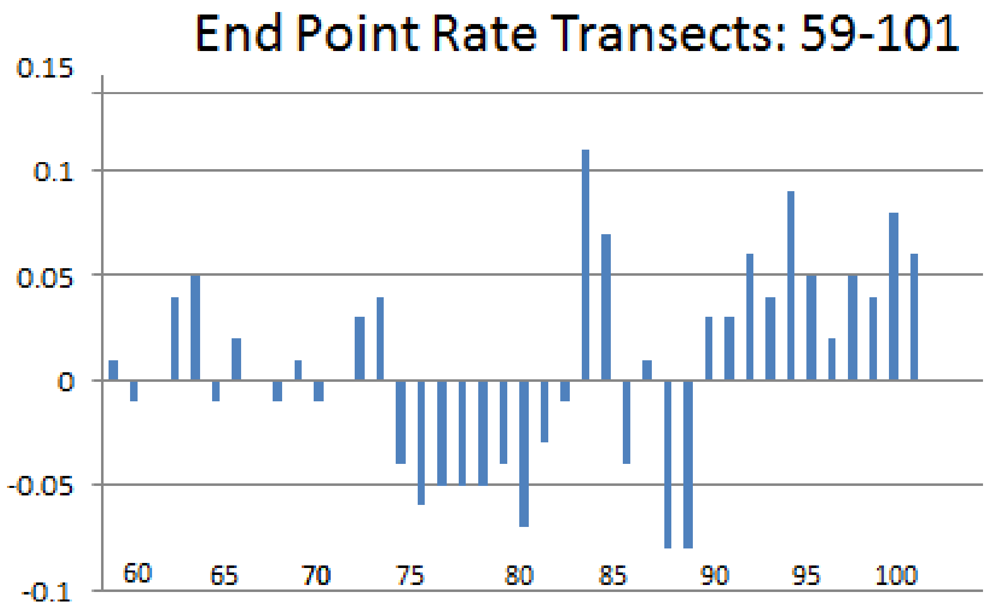


Figure 29: End-point rate of change within segment four revised (created using DSAS data, within Excel 2016, 2017)

4.4 Analysis of Change Discussion

Year	Initial Area	Stable area	New Growth	Area lost	Net loss/gain	Net loss/gain per year	Area at end of period
1849-1892	293.41	268.29	12.3	25.12	-12.82	-0.30	255.47
1892-1919	255.47	272.76	3.57	25.83	-22.26	-0.82	250.50
1919-1957	250.50	260.89	3.82	15.43	-11.61	-0.31	249.28
1957-1967	249.28	257.69	22.27	7.03	15.24	1.52	272.93
1967-1989	272.93	269.64	10.31	17.12	-6.81	-0.31	262.83
1989-2003	262.83	285.54	6.56	2.23	4.33	0.31	289.87
2003-2015	289.87	288.36	5.12	4.59	0.53	0.04	288.89

Areas in hectares

Table 12: Collected data from union analyses

Table 12 brings together the results from the union analyses evaluating area loss and gain over the period from 1847 to the present day. The general pattern was loss of area for the century 1850-1950, with subsequent stabilisation and increase in area. The period 1957-67 can be seen as the most significant with a change to a large net accretion.

1967-89 had both significant accretion and depletion. More recently greater stability has occurred, although this does not tally with local perceptions.

There are long periods when a net loss of 0.3 hectares/year applies. (1849-92, 1919-57 and 1967-89)

	EPR - End-point Rate (m/yr)	Confidence of EPR (± m/yr)	SCE- Shoreline change Envelope (m)	NSA - New Shoreline Analysis (m)	LMS - Least Median Squares	LRR - Linear Regression Rate of Change (m/yr)
Section 1	-0.688	0.043	119.458	-114.2	-0.599	-0.65
Section 2	0.326	0.043	97.421	54.325	0.72	0.49
Section 3	0.972	0.084	201.693	66.799	1.963	0.69
Section 4	0.057	0.043	42.614	8.922	-0.074	0.01
Revised 4	0.0075	0.043	21.185	1.277	-0.0395	-0.01

Table 13: Consolidated statistics of shoreline change for all sections (Created using DSAS results within Excel 2016, 2017)

The EPR analysis represents the overall change from oldest to newest map position per transect, with the analysis of the overall region focus presented within table 13.

Overall there is a consistent loss of land on the Western coast (Section 1) at a rate of 0.7 metres per year over the past 170 years.

loss of land present along the first 36 transects, as can be witnessed within figure 24. Transect one contains no data, which alters the represented flow of land loss, however transect 2 witnessed an overall loss of -1m. The originally flow of erosion experiences a steady decrease in severity from transect 2-23, reaching a turning point from 0m change. The earlier transects of this segment experienced higher intensity of erosion in consequence of the island's south-east's position, with higher focus of waves damaging the outwardly facing coast. The segment facing 24-29 experienced an extreme peak of erosion of -2m, likely due to erosive waves impacting the angled corner of the southern tip, leaving this section vulnerable. The gradual effects of this can be witnessed within figures 17-23 in which the erosive aspect increased and decreased in speed over the time period noted. From transect 31 onwards – there is a gradual decline in erosive effects, and from 35 this trend passes 0 meters, reaching a growth of 0.5m. The overall gain of land through transects 36-51 was relatively stable between 0-0.5 meters of growth. The data recorded between transects 52-61 represent the frequently altering spit mouth. This feature has shown great levels of changes through the historic OS maps, as can be reviewed within figures 17-23, leading to a complicated set of results present within table 9. Due to the angles of the baseline within the spit it has set the multiple transects to interact with features unconnected to its location – an obvious example of this is witnessed in transect 57 which crosses the northern mouth piece, but also reads the figures present within the southern mouth piece; leading to an outlier in the results. From transects 59 onwards, the mapping is reasonable stable; staying ±0.2m within 0m: other than the locations of the two saltmarshes which were added and removed from the High Tide Marker – leaving these two features as outliers of the recorded data.

CHAPTER FIVE: CONCLUSIONS

There were three research objectives which were largely successfully completed:

1. To use historic Ordnance Survey maps and recent USGS Landsat images of Walney Island to identify the evolution of coastal features over time, and provided the basis of the project
2. To georeference the Landsat images to the contemporary OS map to ensure the accuracy of the work. Earlier maps proved unsatisfactory for inclusion.
3. To develop accurate erosion and accretion rates of the southern end of Walney.

The originally envisaged methodology of using historical maps did not prove viable, but this was anticipated following literature research. OS maps from 1840 were available and of sufficiently good quality to use alongside other more recent sources such as Landsat imagery, allowing detailed work to be carried out on accretion and loss of shoreline of the subject barrier island, Walney, off the South West coast of Cumbria.

ArcGIS and Digital Shoreline Analysis Software (DSAS) were used with 7 historical maps to map land loss and shoreline rate of change for individual points and shoreline sections at the South end of the island.

The island was analysed using footprint analysis over the periods of the historical maps, identifying the evolution of the island over the past 170 years. Following the footprint analysis, the coast was then subject to union analysis in 4 sections identified in the earlier work: an erosive Western-South West coastline, an accretive Southern Coast, a complex South End Haws Mouth, and a stable Eastern Coast.

The area of the South end of Walney is now almost the same as it was in 1840 having declined to a minimum in the 1950s, but is now configured very differently. The West coast has lost over 120 metres of shoreline, and a maximum of over 350 metres at the inflexion between west and south-west facing shores, averaging 0.7 metres/year, with a maximum of just under 2 metres/year. Conversely, the south facing coast has gained shoreline at a rate of 0.3 metres per year. South End Haws Mouth had significant losses occurring in the period around the First World War. It has subsequently developed in a complex manner being subject to more varied tidal and weather patterns than the western coast. The Eastern coast is protected from sea storms, and has remained more stable, although salt marshes have developed or been brought into consideration in two locations on the shore. These likely account for a small overall accretion of 0.1 metres/year.

The approach used in this work would suit application to the whole of Walney since the accretion process at the South end of Walney benefits from sand carried down from the north of the island. This would be a more complex study, as there are more defences and interactions with human activity further north.

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APPENDIXES

Appendix one:

Transect No.	Transect Distance (m)	End Point Rate (EPR)	Confidence of EPR (ECI)	Shoreline Change Envelope	Net Shoreline Analysis	Least Median Squares	Linear Regression
1	100	-1.06	0.043	176	-176	-0.36	-0.86
2	200	-1.12	0.043	187.7	-185.48	-0.47	-0.95
3	300	-1.13	0.043	188.61	-186.86	-0.46	-0.95
4	400	-1.05	0.043	174.24	-174.24	-0.46	-0.89
5	500	-0.85	0.043	141.34	-141.34	-0.51	-0.74
6	600	-0.71	0.043	117.23	-117.23	-0.47	-0.64
7	700	-0.64	0.043	105.75	-105.75	-0.65	-0.56
8	800	-0.55	0.043	91.03	-91.03	-0.55	-0.49
9	900	-0.47	0.043	78.86	-77.6	-0.39	-0.45
10	1000	-0.44	0.043	76.09	-73.48	-0.34	-0.42
11	1100	-0.5	0.043	84.73	-83.28	-0.47	-0.45
12	1200	-0.5	0.043	83.33	-83.33	-0.49	-0.43
13	1300	-0.43	0.043	72.18	-72.18	-0.43	-0.36
14	1400	-0.4	0.043	66.02	-66.02	-0.38	-0.32
15	1500	-0.32	0.043	53.28	-53.28	-0.31	-0.25
16	1600	-0.26	0.043	43.16	-42.46	-0.28	-0.22
17	1700	-0.2	0.043	39.89	-33.49	-0.2	-0.16
18	1800	-0.16	0.043	37.04	-25.83	-0.1	-0.09
19	1900	-0.12	0.043	34.52	-19.98	0.07	-0.05
20	2000	-0.09	0.043	33.6	-15.73	0.09	-0.05
21	2100	-0.07	0.043	28.28	-11.75	-0.07	-0.05
22	2200	-0.01	0.043	12.15	-2.18	0	0.02
23	2300	-0.5	0.043	83.11	-82.63	-0.72	-0.59
24	2400	-0.71	0.043	117.93	-117.14	-1	-0.84
25	2500	-1.19	0.043	199.48	-198.27	-1.74	-1.38
26	2600	-1.6	0.043	266.86	-266.36	-1.66	-1.73
27	2700	-1.96	0.043	326.11	-326.11	-2.25	-2.03
28	2800	-1.99	0.043	331.31	-330.7	-2.37	-2.07
29	2900	-1.74	0.043	288.06	-288.06	-2.04	-1.83
30	3000	-1.16	0.043	192.01	-192.01	-1.37	-1.21
31	3100	-0.54	0.043	89.39	-89.39	-0.05	-0.46
32	3200	-0.18	0.043	68.36	-29.29	0.6	-0.1
33	3300	-0.06	0.043	54.48	-10.13	0.04	0.02
34	3400	0.16	0.043	67.21	26.14	0.33	0.28
35	3500	0.41	0.043	109.08	68.08	0.62	0.56
36	3600	0.46	0.043	106.34	76.92	0.65	0.64
37	3700	0.42	0.043	118.48	69.81	0.87	0.62
38	3800	0.39	0.043	125.19	64.95	0.9	0.62
39	3900	0.37	0.043	112.16	61.74	0.93	0.6

40	4000	0.33	0.043	111.5	54.98	0.87	0.57
41	4100	0.31	0.043	117.17	51.75	0.87	0.56
42	4200	0.32	0.043	104.9	52.65	0.87	0.55
43	4300	0.29	0.043	90.13	47.88	0.84	0.48
44	4400	0.29	0.043	77.86	47.97	0.7	0.38
45	4500	0.17	0.043	29.04	29.04	0.19	0.13
46	4600	-0.14	0.043	91.14	-23.25	0.53	-0.13
47	4700	0.14	0.043	430.58	23.65	0.25	0.24
48	4800	0.05	0.043	11.59	8.09	0.04	0.04
49	4900	1.9	0.076	373.48	180.3	7.17	2.88
50	5000	-1.34	0.076	127.56	-127.56	-1.23	-1.38
51	5100	0.04	0.043	18.52	7.25	0.05	0
52	5200	-0.74	0.076	194.16	-70.08	-0.21	-0.54
53	5300	0.69	0.076	150.56	65.17	3.06	1.19
54	5400	-0.09	0.131	9.76	-6.1	-0.09	-0.08
55	5500	5.36	0.223	203.57	203.57	5.19	-1.003
56	5600	4.38	0.177	224.23	210.33	4.37	4.8
57	5700	0.44	0.043	391.42	73.82	0.53	0.74
58	5800	1.95	0.043	395.45	323.2	2.36	2.32
59	5900	0.01	0.043	16.72	1.09	0.19	0.03
60	6000	-0.01	0.043	17.72	-2.44	-0.02	0
61	6100	0	0.043	15.61	0.59	0.02	-0.01
62	6200	0.04	0.043	18.05	7.25	0.05	0.01
63	6300	0.05	0.043	19.36	7.99	0.05	0.01
64	6400	-0.01	0.043	14.44	-1.63	-0.07	-0.05
65	6500	0.02	0.043	17.15	3.02	-0.05	-0.02
66	6600	0	0.043	14.74	0.24	-0.09	-0.04
67	6700	-0.01	0.043	8.8	-1.21	-0.05	-0.02
68	6800	0.01	0.043	11.06	1.2	0.02	0
69	6900	-0.01	0.043	9.4	-1.05	0	-0.01
70	7000	0	0.043	10.83	0.07	0.03	0.01
71	7100	0.03	0.043	7.95	5.09	0.04	0.03
72	7200	0.04	0.043	21.54	6.93	0.07	0.07
73	7300	-0.04	0.043	21.46	-6.87	-0.03	-0.04
74	7400	-0.06	0.043	26.27	-9.44	-0.05	-0.05
75	7500	-0.05	0.043	35.76	-9.12	-0.07	-0.08
76	7600	-0.05	0.043	38.31	-8.97	-0.1	-0.07
77	7700	-0.05	0.043	27.49	-7.93	-0.07	-0.04
78	7800	-0.04	0.043	19.28	-6.84	-0.03	-0.03
79	7900	-0.07	0.043	34.33	-12.33	-0.05	-0.09
80	8000	-0.03	0.043	18.56	-4.66	-0.03	-0.03
81	8100	-0.01	0.043	14.38	-1.78	-0.02	-0.01
82	8200	0.11	0.043	25.79	17.53	0.02	0.13

83	8300	-0.8	0.043	349.96	-332.39	-2.14	-2.69
84	8400	0.29	0.043	72.85	48.31	-0.37	0.28
85	8500	0.26	0.043	55.63	42.78	-0.12	0.27
86	8600	0.07	0.043	17.36	11.66	-0.07	0.07
87	8700	-0.04	0.043	34.79	-6.75	-0.04	-0.11
88	8800	0.01	0.043	13.41	1.46	0	-0.01
89	8900	-0.08	0.043	16.22	-12.51	-0.12	-0.08
90	9000	-0.08	0.043	21.84	-12.92	-0.25	-0.09
91	9100	0.03	0.043	30.73	5.22	-0.17	-0.05
92	9200	0.03	0.043	19.44	4.62	0.03	0.03
93	9300	0.06	0.043	40.03	9.33	-0.27	-0.03
94	9400	0.04	0.043	24.76	6.84	-0.17	-0.03
95	9500	0.09	0.043	31	15.75	-0.16	0.01
96	9600	0.05	0.043	25.74	8.93	0.07	-0.01
97	9700	0.02	0.043	12.56	3.98	-0.05	0
98	9800	0.05	0.043	16.8	8.54	0	0.04
99	9900	0.04	0.043	17.38	7.37	-0.09	0.02
100	10000	0.08	0.043	27.66	12.98	0.04	0.08
101	10100	0.06	0.043	32.7	9.85	-0.09	0.03
102	10200	0.29	0.043	74.49	48.9	-0.18	0.07
103	10300	0.32	0.043	85.02	53.74	-0.25	0.18
104	10400	0.81	0.043	164.39	134.07	-0.25	0.49
105	10500	1.06	0.043	189.62	176.49	-0.02	0.78
106	10600	0.78	0.043	157.08	130.26	0.21	0.65
107	10700	0.69	0.049	91.67	83.96	1.04	0.85