A study on how sea defence strategies alter the response of the coast to variations in sea level by monitoring shoreline evolution

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Abstract

This study assesses the impact of coastal defences implemented at Rosses Point beach and Strandhill beach in Co. Sligo, Ireland on variations in vegetation edge to assess the effect that the coastal defences have had on the response of the coastline to changes in sea level. Both areas have experienced coastal defence aimed at protecting valuable tourism assets such as the Sligo golf course located in the hinterland of Rosses Point beach and Strandhill town at Strandhill beach. Variations in vegetation edges are assessed by plotting vegetation edges at the sites from dated imagery and analysing them in ArcMap using the DSAS system to calculate rate of change statistics. The dated imagery was collated from Google Maps Pro and GeoHive and dates from 1995 to 2021. These statistics include Shoreline change envelope (SCE), End Point Rate (EPR) and Net Shoreline Movement (NSM). EPR is used to analyse shoreline change as either accretion or erosion. This research finds that the coastal defences have assisted in stabilising the vegetation edge, as post their instalment vegetation edge parallel to the defences have stabilised and accreted in places. Since 1995 Rosses Point’s vegetation edge has retreated by 4m and Strandhill’s vegetation edge has retreated by 1m despite a large storm event in 2007. In this case, the coastal defences have assisted the stabilisation of the coastline. This shows that armouring coastal systems where protection of anthropogenic development out ways the value of natural environmental processes can alter the response of the coastline in this case stabilising the vegetation edge of the study sites.

Introduction

Shoreline Variation

Shoreline evolution is a variable we still are limited in predicting (Stive et al., 2002). It can vary greatly both as a result of anthropogenic development and changing climate-induced change. This results in a large variation both spatially and temporally when calculating a rate of change statistics for a specific coastal zone (Stive et al., 2002).

Shoreline evolution is a coastal response to variations in sea level. Variations in the eustatic volume of the ocean are an important boundary condition for coastal systems. Eustatic sea-level historically has been measured using fossil shoreline evidence. A sea-level curve is used to represent variations in sea level throughout geological history (Cronin, 1999). However, the sea-level curve is increasingly being disregarded as ‘eustasy’ is being seen as a quaint oversimplification. This is (among other factors) due to minor vertical adjustments of the lithosphere happening ubiquitously. This means assessing the global sea-level variation is difficult and as shoreline evolution is a coastal response to sea-level variation, therefore, predicting and recording a set regression or progression of a coastline is never completely accurate.

Previous efforts to measure shoreline variability have aimed at quantifying it mainly as beach mobility. Beach mobility is defined as a standard deviation of a shoreline relative to its linear trend (Dolan and Hayden, 1978). This is seen as a function of the morphodynamic state of the beach. Therefore, a current beach form including its present shoreline is only a characteristic morphology of the beach as the current beach form is within the beach's range of mobility (Short et al., 1982).

Coastal defence

Coasts are a key source of economic structure for most governments across the world due to the tourist appeal of sightseeing and coastal activities. Due to this, many coastal zones particularly beaches in many forms are regularly developed beside and upon by humans.

This interference in the natural coastal zone results in human defences being implemented to halt shoreline evolution as the variation in coastal dynamics does not account for anthropogenic development (Aiello et al., 2013). Many beaches globally have had their natural renourishment cycles disrupted and halted due to coastal defences that alter the natural sediment balance in coastal zones resulting in the narrowing and lowering of sandy beaches (Brown et al., 2002).

A widespread anthropogenic response to shoreline evolution is defence. This is attempted by both hard and soft engineering in coastal zones. Hard engineering generates solutions working to prevent natural coastal change such as groynes and rock armouring, whereas soft engineering attempts to work with the natural coastal changes (Bulleri et al., 2010). Soft engineering is typically characterised by beach re-nourishment, beach re-profiling or reseeding projects.

Portballintrae is an example of when poor management of sea defence has resulted in a once wide, sandy, sediment-rich beach system turning into a sand deprived narrow beach resting upon gravel in some areas. Oblique imagery of the location from 1938 has shown the prime of the beach bearing a stark contrast to that of the present day. Over 75 years, it was calculated to have lost a volumetric amount of sand around 60,000m3 (Jackson, 2012). The loss of sand has been attributed to the rebuilding of Leslie’s Pier in 1895. Before its reconstruction, the headlands could refract much of the wave energy entering the bay. This with shoaling processes over the low angle dissipative shoreface resulted in generally low energy waves reaching the shoreline. The Pier resulted in the diffraction of waves down a 200m zone after this high energy reconnects to the shoreline resulting in an easterly artificial energy gradient. This meant longshore currents displaced sediment and exposed the beach's bedrock and gravel resulting in large amounts of sediment being displaced to deeper waters impeding natural replenishment.

In response in 1904 and the 1970s groynes were put in place in an attempt to halt this process. In 1997 beach nourishment took place but the sand was extracted from inland quarries with a new set of six 26m replacement groynes and a 150m palisade to protect the western cliffs. These groynes have been extended and beach nourishment has continued since. Resulting in changes in surface elevation and glorified sand locked pits between the groynes. This resulted in costs of £250,000 between the 1970s and 1990s (Jackson, 2012).

In 1992 the National Coastal Erosion Committee published a report to cope with coastal erosion which was mostly ignored. Instead, a policy vacuum with politics and economics prioritised over environmental considerations was used to deal with coastal erosion. This resulted in few authorities using the same procedures to deal with erosion (Cooper et al., 2013).

It is important to change how the public view intertidal ecosystems to understand how it protects the coast by attenuating wave energy and ameliorating the impact of storms (Woodroffe et al., 2002).
As may be expected in this study the solution may be not to alter coastal processes but to manage human interactions with the coast. Human interactions within coastal systems are viewed in three separate ways. Firstly, as Perturbations where for example sand is reworked or moved by humans to help nourish eroded beaches.

As a boundary condition, where humans could have altered the sediment load in a river as a result of land clearing for agriculture or deforestation. This can also be seen in coastal zones where sand and gravel have been removed for mining. This can have knock-on effects where a beach is naturally used to replenish another, now will deplete as it has lost its source of sand.

As an intrinsic adjustment, for instance, dredging when navigation requires a lower water depth for boats. It’s when a human adjustment creates negative feedback. Typically, it is done when a threat is identified to communities and in response, human activity re-directs the threat to prevent damage to communities. Its main problem is that the recovery for humans greatly exceeds that of the natural geomorphological recovery. (Woodroffe et al., 2002).

Human interactions can have a larger effect on the coast than natural processes in some instances. Especially so when coastal armouring is implemented based on engineering alone and without the consideration of coastal processes from scientific understanding. For instance, a large study on coastal defence across the Caribbean Sea of Columbia assessed the impact of 289 different defence structures. In Cartagena, a large tourist zone produced a high K value of 0.60 showing maximum armouring impact on the coast (Rangel-Buitrago et al., 2011). Some harbour areas within the tourist zone exceeded 1 where the coast was completely armoured. When unmonitored the effect of hard coastal defences can have an immense effect on the coast.

Study Area

Studying areas such as Portballintrae (Jackson, 2012) outlines a key need for assessment of coastal zones where human interference has resulted in shorelines not being able to conduct natural processes, especially in the case of natural beach replenishment cycles. At Strandhill and Rosses Point assessing how the rock armouring has affected the stability of the coastline will show if coastal processes have been considered when engineering was implemented.

A key misunderstanding of coastal processes in Ireland is erosion. In Ireland, it has been viewed as a problem and not an element of a greater natural process, mostly as it is viewed as a threat to coastal infrastructure. This is seen at Strandhill as the rock armouring was placed to protect Strandhill village in 2002 and the Water treatment plant in 2011 (McGuinn et al.). The core reasoning for sea defences being constructed is to protect valuable infrastructure. Strandhill is no exception to this and was also affected by the economic growth of the Celtic Tiger in the 1980s and 1990s when intensive coastal development began (McGuinn et al.). Strandhill in this time saw houses and holiday home developments, from here the population began to rise and a need to protect the infrastructure arose.

Although the defences constructed at Strandhill are post-Celtic Tiger assessing their impact on the environment is key to ensuring coastal processes are not being altered or interrupted so that the mistake of the past are not repeated.

Considering human interactions as previously discussed in terms of intrinsic adjustment, boundary conditions and perturbations is important when looking at the reasoning for attempted defence in coastal zones (Woodroffe et al., 2002).

At the coastal systems of Strandhill and Rosses Point, the human interactions at the coast can be viewed in these three ways.

In terms of perturbations, many tourists and locals using the beach recreationally is an example of this kind of interaction as the coastal system works back to its pre-disturbance morphology after recreational activities such as sandcastle building or walking on the beach. The complex dune system at Strandhill has been replenished with sediment and reseeding efforts (https://cleancoasts.org/tag/strandhill/) which is another example of a perturbation. In terms of boundary conditions, much of the alterations in shoreline shape due to rock armouring (predominantly) have permanently altered the boundary condition (state) of the coastal zone. Intrinsic adjustments are when the coastal zone reaches a certain threshold and humans alter it to a previous level as it has affected how they interact with the zone (Woodroffe et al., 2002). For instance, post-storm Strandhill used machinery to reshape the beach face returning it to one of its earlier states.

Both Strandhill and Rosses Point beach put Anthropogenic development ahead of Coastal processes for several reasons, but little research into how the attempts at protecting the Anthropogenic development have affected the coastal features of the zone can be found.

The core aim of this study is to assess the impact that the coastal defence strategies implemented at both study locations have had on the ability of the coastline to respond to variations in sea level. By looking at how the coastal zone's shoreline variation response has been affected by the defence's implementations.

This will be achieved by, collating temporal shoreline positions at two sites from high-resolution imagery found in online sources to produce an overall SCE. The high-resolution imagery will be compared to fieldwork results presenting the current shoreline position recorded using a GPS device. Key coastal defences will be identified using a mix of aerial survey material online, GIS material and ground photography. The data will then be interpreted using statistical software to evaluate the effect that the coastal defences have had on the response of the coastline.

Methodology

Study location

Figure 1 shows the Strandhill beach(left) and Rosses Point beach (right). Strandhill is a popular seaside village located 9km West of Sligo Town. It has seen ever-increasing tourism activity in the past century and with this has developed an ever-increasing strain on the local environment. In 2002 Sligo County Council constructed a new extension to the promenade and added the 300m of rock armour to protect the village costing a contract value of £428,000 (Ashleigh Contracting, 2002). The rock armour was extended by a further 200m in 2011 to protect the wastewater treatment plant.

The local community of Strandhill in collaboration with the local council have carried out dune seeding projects, such as on the 25th of March 2017 (https://cleancoasts.org/tag/strandhill/). The local community organised an event with CleanCoasts to plant Marram grass along the dunes on Strandhill.

With the increase in tourism, the local population has also risen. In the 2011 Census carried out by the Central Statistics Office in Ireland, the population of Strandhill was submitted as 1,596 (Central Statistics Office, 2011). This has doubled since the Census of 1996 when the population was 764 (Central Statistics Office, 1996).

In 2003 the Sligo Council introduced a new local area planning system which prompted new housing developments until the financial crash in 2008. Following the financial crash in 2016, a second Strandhill Local Area Plan was enacted aimed at promoting tourism-related infrastructure, maintaining the Natura 2000 sites, and protecting archaeological heritage sites. It also designated Strandhill as a 'Gateway Satellite of Sligo with special functions' being tourism (Sligo County Council, 2016).

Figure 1: Study locations: Left: Strandhill Right: Rosses point

Rosses point (figure 1) is a blue flag beach located 8.5km Northwest of Sligo. It is a 2km stretch of beach which in its hinterland homes the County Sligo Golf course (figure 1). The dune system is ungrazed. These factors severally lower the dune's ecological value as seen in a Coastal Monitoring Report (Ryle et al., 2009). It evaluated the dune state (embryonic, fixed, and mobile) at Rosses Point as unfavourable-inadequate. Due to trampling, lack of grazing and presence of facilities e.g., the car park and the golf course. The beach is considered by various agencies to be of high tourist amenity value. This allows coastal protective measures to be enforced with little resistance as dune protection is a major priority and natural retreat is not possible due to the golf course's presence.

Rosses Point homes two west-facing sandy beaches flanked by two rocky headlands. North of which a sand spit with an embryonic dune resides. The beach is well protected from waves propagating from the North Atlantic by Raghley Island and other geomorphological features in the area. Bromore point separates the two beaches. Here situates a concrete extension on a ramp that was replaced in 2008 and a 310m rock armour revetment built by the County Sligo Golf club after suffering significant damage (Sligo County Council, 2016). The south of the beach is protected by an artificial breakwater extending from Coney Island to Blackrock Lighthouse. The beach is fronted by a shoal which assists in attenuating large energy waves before they reach the beach (Sligo County Council, 2016).

Despite the geomorphological and man-made protections local to the beach, it has succumbed to erosion. Particularly during significant storm events related to notable surges that increase water depth and enable offshore swell waves to propagate inshore and dissipate large energy loads on the dune systems (Sligo County Council, 2016). Increased water levels also significantly attenuated the effect of the shoal.

Study Procedure

The study was conducted on Strandhill and Rosses Point Beach in County Sligo, Ireland. Data were obtained as secondary data from Google Earth Pro, GeoHive and Floodinfo.ie. Primary data was collated from a GPS device and a camera at the study sites. The GPS device was used to track current shoreline positions for the two study sites and the camera was used for ground photography of the coastal defences and geomorphology of the area. Google Maps Pro was used to collect data on shoreline variation from 2009 to 2021 and GeoHive map viewer was used to collect data on shoreline variation from 1995 to 2005. GeoHive was also used to record a historical map from 1906. This provides 10 records at Strandhill, and 11 at Rosses Point with a historic map record for each site. Helicopter oblique imagery was used from Floodinfo.ie to present the geomorphology of the study sites as of 2003. The Digital Shoreline Analysis System (DSAS) was used to analyse the shorelines temporally to generate rate of change statistics at each site. DSAS is a GIS-based system created by the United States Geological Survey (Thinh et al., 2017). Two different DSAS systems are available the one selected for this study is the Environmental System Research Institutes (ESRI) ArcGIS system and the DSAS web (Thinh et al., 2017). Two sample areas were used to conduct this study those being the two study areas.

Firstly, using the Coast of Ireland Oblique Imagery Survey- 2003 from the Floodinfo.ie in the Coastal Map view, the study sites' geomorphology and defences were identified and recorded. This data set was recorded in 2003 by a series of Aerial Oblique Digital Photographs taken from a helicopter as part of the Irish Coastal Protection Survey.

A high watermark is the commonly used assessor of shoreline location due to its ease of identification on aerial photographs and its historical use on maps (Dolan et al., 1983). Although a good assessor of shoreline evolution it can still vary daily due to variations in tidal maximum and short-term storm-induced change (Hanslow, 2007). The data available in Google Earth Pro and GeoHive does not record the time of day for each image (GeoHive only records year of imagery) making it difficult to tell the high-tide mark from the low-tide mark. Due to this, vegetation edge was assessed in the DSAS system. Vegetation may be affected at both sites by human interference and animal grazing however it is more reliable than assessing tidal marks which can vary based on time of year and time of day.

Next, in Google Earth Pro using the add path tool the position of the Vegetation edge in each year (that it was recorded) was mapped for both Rosses Point Beach and Strandhill Beach. They were then saved and exported as kml. files which then were then converted to layers using the conversion tool in ArcMap and merged using the Merge (Data Management) tool (Fernández et al., 2018).

GeoHive is a State-owned Geospatial Data Hub which allows basic measurement and viewing tools (Government of Ireland, 2021). However, data measurements cannot be exported and are volatile but, images of maps can be saved as TIFF files. Therefore, maps of the study locations were saved and imported into ArcGIS Pro. In ArcGIS Pro, the Georeferencing tool was used to complete the Georectification process. Fixed buildings and roads at the study sites on the maps were linked with the basemap by adding control points until a 3rd order polynomial transformation could be complete (Herbei et al., 2010). This gives the most accurate Georeference possible in ArcGIS Pro. The vegetation edge was then recorded by creating a new shapefile for each line, then using the create features tool which allows line features to be made. Allowing the vegetation edge to be digitised and then imported into ArcMap.

DSAS is not available in ArcGIS so ArcMap 10.5.1. was used instead. In ArcMap, the newly merged files were buffered to give a baseline for DSAS at each site. Once the baseline was digitised from the buffer the DSAS tool was used. The DSAS tool projected transects onto the shorelines and showed in a Line File the SCE of the shorelines. The DSAS tool also creates a transects point shapefile which was exported into Excel. This data showing the shoreline change against time was then converted to graphs for comparison. Data on the SCE, NSM and EPR were then analysed. The EPR was used to present the spatial patterns of shoreline change at the sites.

The NSM (Jonah et al., 2016) calculated the distance between the oldest and the youngest shorelines in each transect and the SCE presents the total change in shoreline movement across all shoreline positions (Oyedotun, 2014).

Finally, the Ground Truthing Fieldwork was carried out. Images of the study areas were taken to show the current state of the coastal zone, and any changes to the defensive strategies at Strandhill and Rosses Point were also recorded. Then using a GPS tracker application on a mobile phone, vegetation edge at the two sites was recorded. This data later was processed using DSAS with the oldest recorded vegetation edge (01/01/1995) and the latest record (2/22/2021).

Results

Mapping and Photography

Raghley island protects the bay area from wave action propagated from the North Atlantic as seen in figure 2. This combined with the southwestern protection of Coney Island and the shoal (Bunger bank) elevates and dissipates most wave energy approaching the shoreline. Cluckhorn is an artificial breakwater extending from Coney Island to the Blackrock lighthouse which provides significant protection from wave propagation coming from the south across Donegal Bay. The Landmasses southwest of the Ballysodare Estuary, Easkey and Rathlee assist in dissipating significant amounts of wave energy along their shorelines prior to arriving at either study location. The bathymetry of the seafloor between Raghley and Maguin's island travelling eastward to Rosses point gradually decreases helping dissipate much wave energy approaching Rosses Point (Sligo County Council, 2016).

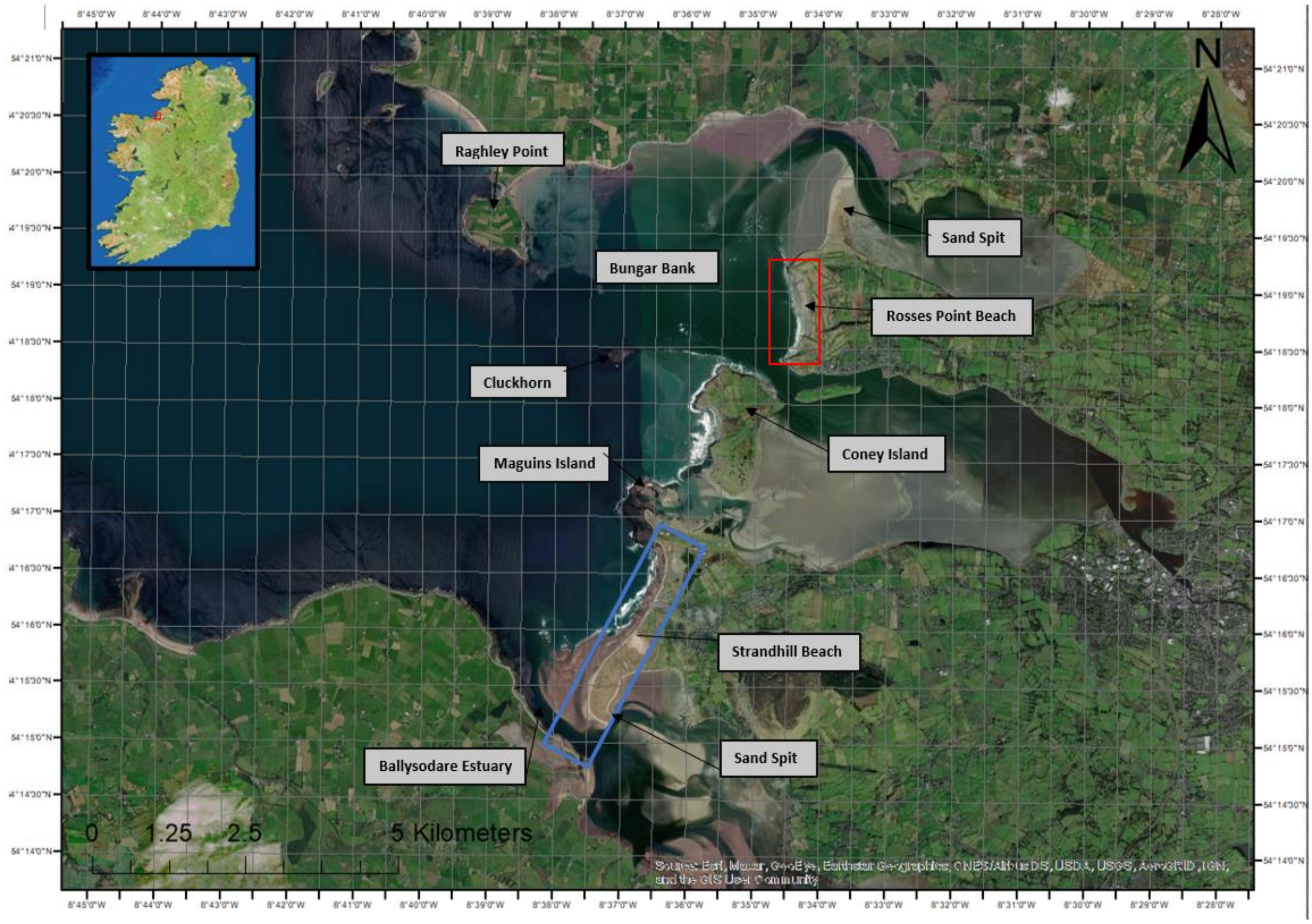


Figure 2: The geomorphological features of the study sites.

Figure 3 shows the coastal defences installed at the two sites in 2003 and as of 2022. The top left image shows the concrete ramp access to Strandhill beach and the rock armouring which at this time extended 310m from the town towards the sand spit (figure 2). The ground photography image in the top right of figure 3 shows Strandhill at low tide on the 19th of February 2022 at 14:45. The bottom left image shows the access ramp at Rosses Point beach in 2003 previous to its concreting in 2007. The bottom right image presents Rosses Points' current rock armouring and new concrete ramp extending from Bromore Point 400m North. The image was taken during high tide on 21/02/22 at 10:36.

Figure 3: Top left: Oblique imagery (2003) of rock armouring and beach access ramp at Strandhill at low-tide, Top right: Present rock armouring and access ramp at Strandhill, Bottom left: Oblique imagery (2003) of unarmoured Bromore point at Rosses Point and Bot

Figure 4 shows the geomorphological features at the study sites which were recorded during the Oblique imagery survey (2003). The top left image shows the Strandhill beach sand spit which southernly extends from Strandhill town (figure 2). The top right image shows the Ballysodare estuary inlet which is enclosed by the Strandhill sand spit and the Portavade beach. The bottom left image presents the Sandspit north of Rosses Point lower (figure 2). Small embryonic dunes can be seen forming in figure 4. The bottom right image shows the sand spit north of Rosses Point with a strong dune system built upon it in Google Earth Pro as of 2/10/21.

Figure 4: Oblique imagery (2003)- Top left: Strandhill beach sand spit, Top right: Ballysodare Estuary opening, Bottom left: Sand spit at Rosses Point Lower, Bottom right: Sand spit at Rosses Point from Google Earth Pro 2/10/21.

Rosses Point

The SCE and NSM measure the distance of shoreline change at Rosses Point and are presented in an exported ArcMap in figure 5. The SCE shows that transects 2-6 and transect 22 experienced the largest rates of change along the shoreline. SCE always returns positive values and therefore other statistics must be relied upon for marking the change as accretion or erosion. Transect 4 experienced the largest rate of change being 68.91m.

NSM can return negative and positive values allowing distinction between accretion and erosion. Transects 2-7 returned the largest erosion values. Transect 4 displayed the largest record of erosion of -68.9m. Transects 18-21 returned the largest records of accretion. Transect 22 returned the largest accretion value of 48.82m. The results of the NSM show an average erosion of -4.5143m across all transects at Rosses Point (table 2).

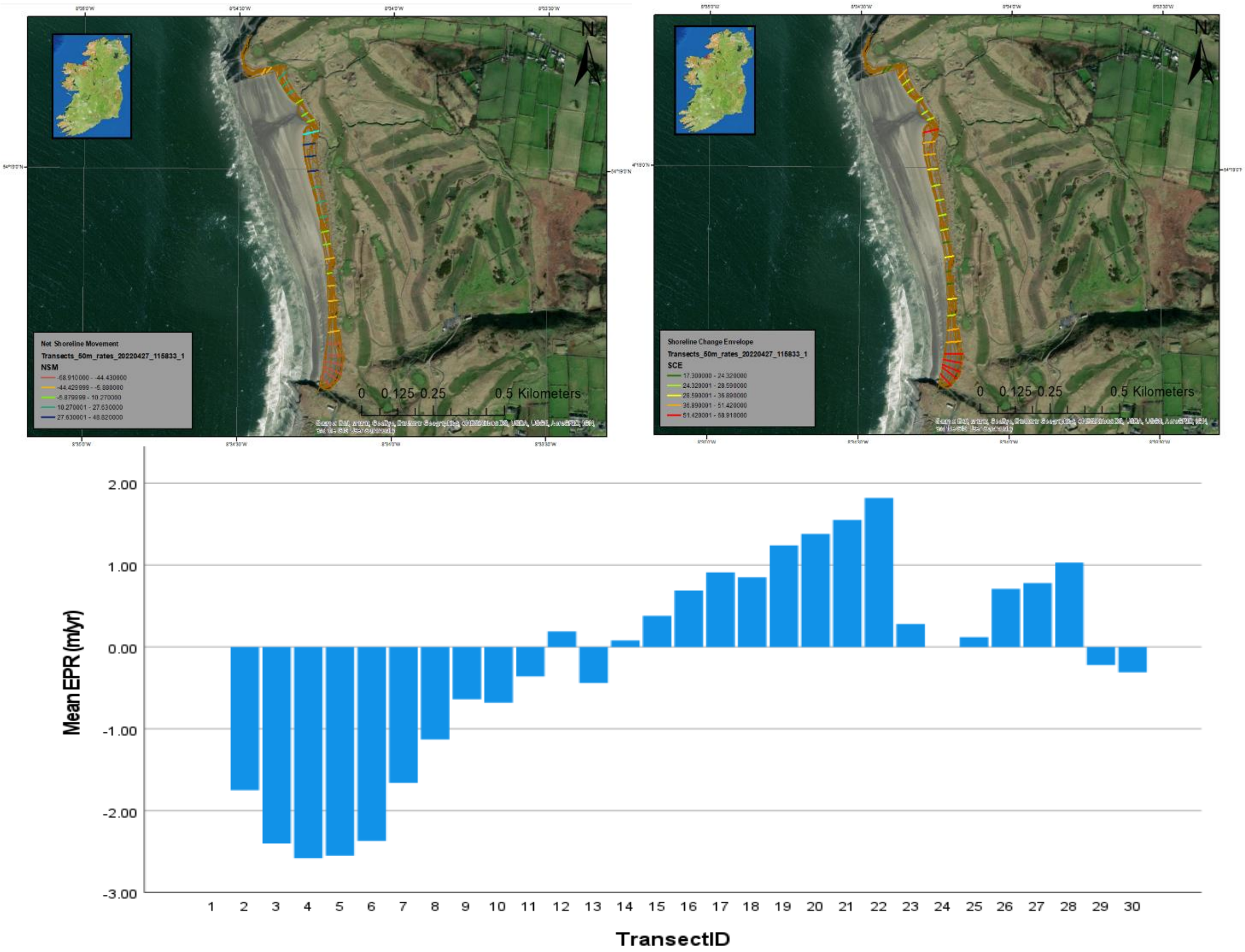


Figure 5: DSAS rate of change statistics of Rosses Point, Top left- Net Shoreline Movement, Top right- Shoreline Change envelope, Bottom- End Point Rate.

The EPR is presented graphically in figure 5 for Rosses Point. The rate of shoreline change is calculated by dividing the distance of shoreline displacement in meters by the elapsed time between each shoreline’s date recorded (years) (Thieler et al., 2009). The mean EPR calculated for Rosses Point is -0.1693m/yr. The lowest result calculated was -2.58m/yr at transect 4 and the highest calculated was 1.82m/yr at transect 22 (table 1).

In figure 6 shoreline variation at Rosses Point, each year across multiple transects is presented. The distance refers to the distance from the baseline (from which the transects were digitised) to the shoreline's intersection. The buffer was cast 100m from the most landward edge of the combined shorelines to present this data. Each graph is grouped by the feature identified at each zone. Transects 3-6 reflect the zone where the largest instalment of rock armour seen in figure 3 is located. Transects 14-20 reflect the zone south of a small estuary on the Rosses Point beach. Transects 25-29 reflect the zone north of the small estuary and south of the northern headline at Rosses Point. The trend from transects 3-6 shows a steep erosion from 1995 to the present day. Transects 14-20 reflect an accretion until 2005 and then varying accretion and erosion across the vegetation edge until 2021. Transects 25-29 reflect an accretion until 2005 and then varying increases and decreases in vegetation edge propagating towards the seafront.

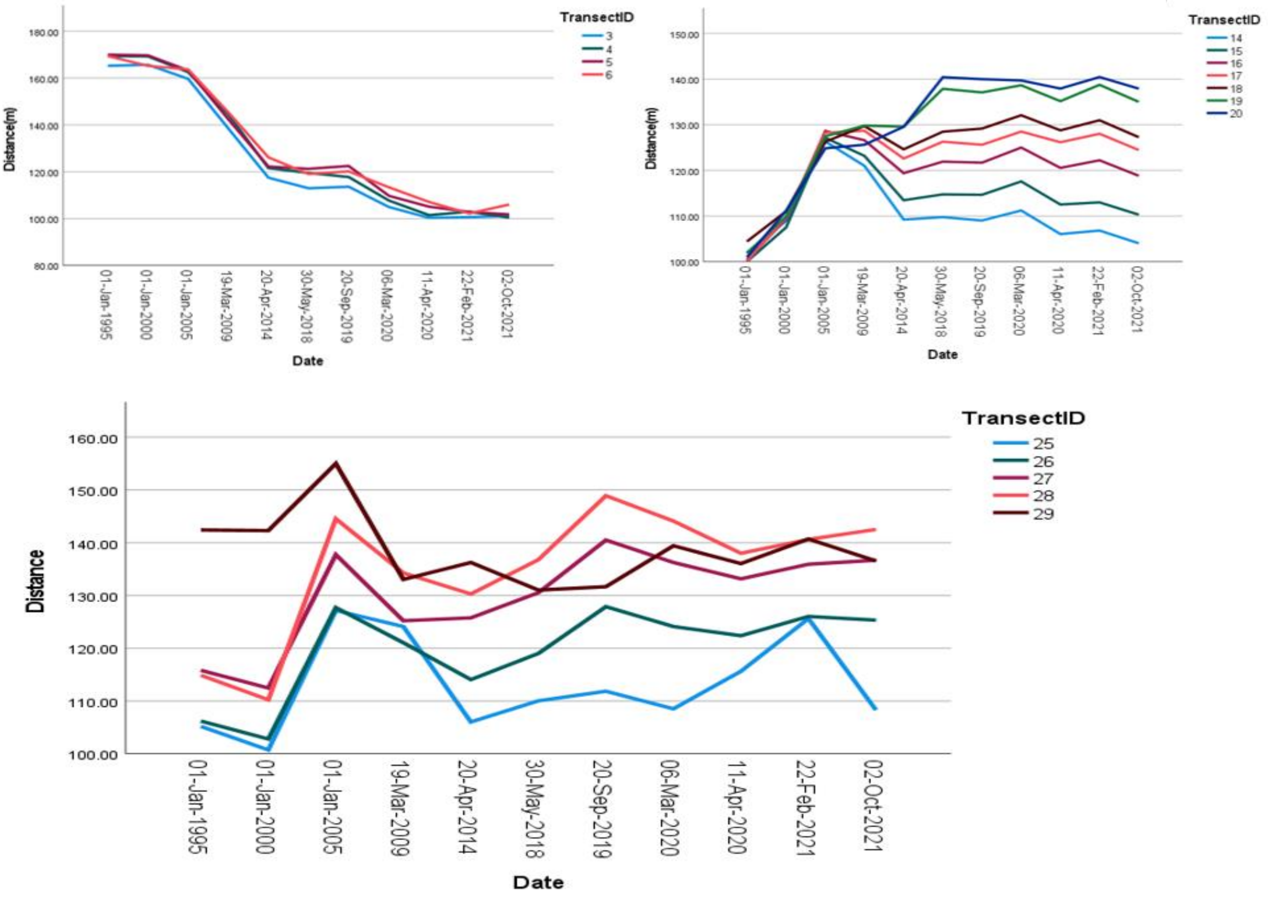


Figure 6: Shoreline Change against time at Rosses Point. Top left: Transects 3-6, Top right Transects 14-20 and Bottom: Transects 25-29.

Figure 7 shows the historic shoreline of Rosses Point beach digitised in ArcMap compared with the 1995 digitised shoreline and the GPS shoreline recorded on 19/02/2022. Historic maps are not accurate enough to be processed in ArcMap as they are hand-drawn and do not account for all coastal features as can be seen above where the small estuary at Rosses Point has no marking on the historic vegetation edge record. However, they can be presented for visual comparison.

Figure 7: Historic (1906), 1995 and Fieldwork (2022) Vegetation Edges for Rosses Point.

Strandhill

Figure 8 presents the rate of change statistics for Strandhill beach. The SCE for Strandhill shows the greatest rates of change occurred at Transects 9, 38 and 42. Transect 9 returned the greatest rate of change value of 56.83m.

In terms of NSM figure 8, shows that transects 8-11 recorded the greatest rates of erosion. Transects 36-38 and 41-42 recorded the greatest rates of accretion along the shoreline. Transect 9 recorded the largest rate of erosion being -29.85m. Transect 37 recorded the largest rate of accretion being 37.54m. The results of the NSM show an average erosion of -0.7254m across all transects at Rosses Point (table 2).

The average EPR for Strandhill is -0.281m/yr (table 1). The lowest result calculated was -1.14m/yr at transect 9 and the highest calculated was 1.43m/yr at transect 37.

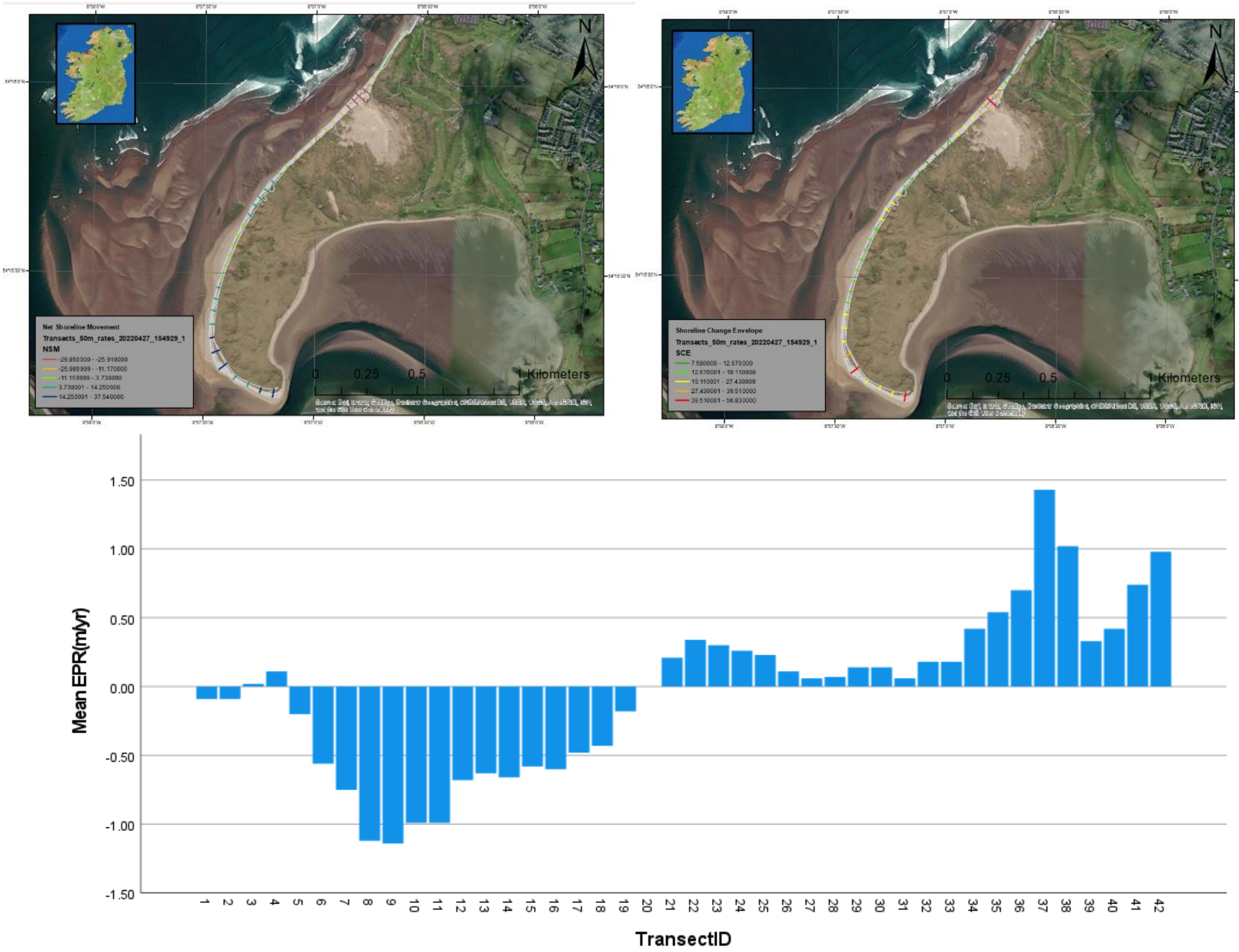


Figure 8: DSA. rate of change statistics of Strandhill, Top left- Net Shoreline Movement, Top right- Shoreline Change envelope, Bottom- End Point Rate.

Figure 9 presents the variations in shoreline position recorded each year across multiple transects for Strandhill. Transects 6-12 reflect the mobile dune system at Strandhill. Transects 26-32 reflect a portion of the fixed dune front at Strandhill and transects 33-36 reflect part of the sand spit at the end portion of Strandhill beach. There is an erosion between 1995 and 2000 present across all transects but the graphs deviate from each other past then. The mobile dune system shoreline distances show a general erosion of the vegetation edge whereas the sand spit portion reflects a gradual accretion from 2000 to 2021. The fixed dune portion of the beach accretes until 2014 and then erodes based on the record in 2015 then plateaus until 2021.

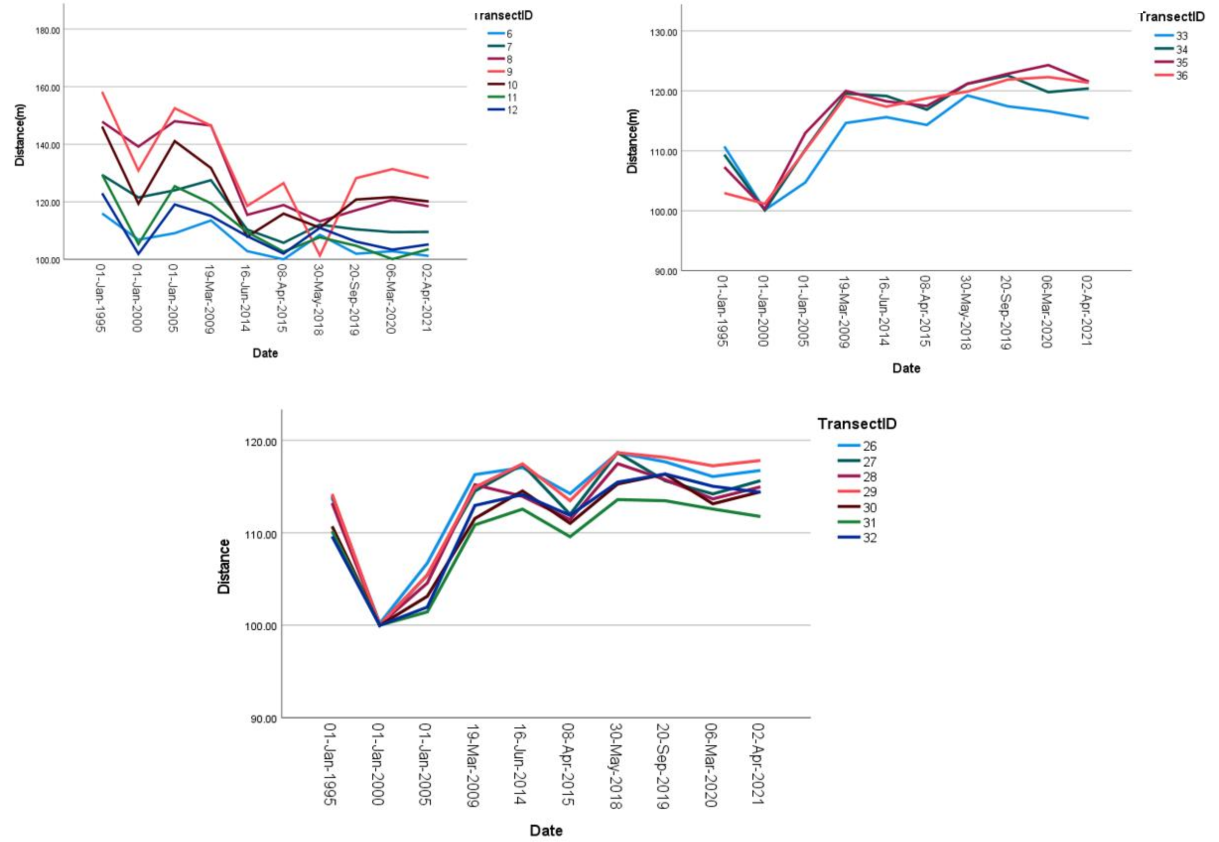
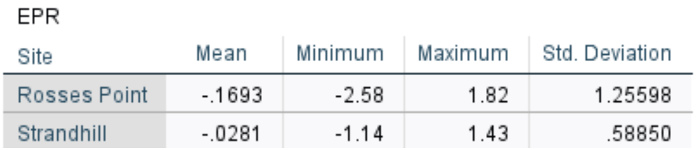


Figure 9: Shoreline Change against time at Rosses Point. Top left: Transects 3-6, Top right: Transects 14-20 and Bottom: Transects 25-29.

Figure 10 presents the historic shoreline position from the 1906 GeoHive map compared to the earliest recorded shoreline position from DSAS (1995), and the GPS recorded vegetation edge from 17/02/2022. This shows a gentil erosion since 1906.

Figure 10: Historic (1906), 1995 and Fieldwork (2022) Vegetation Edges for Rosses Point.

Table 1: Rate of Shoreline Change from 1995-2021 obtained from EPR (m/yr)



EPR

Site	Mean	Minimum	Maximum	Std. Deviation
Rosses Point	-.1693	-2.58	1.82	1.25598
Strandhill	-.0281	-1.14	1.43	.58850

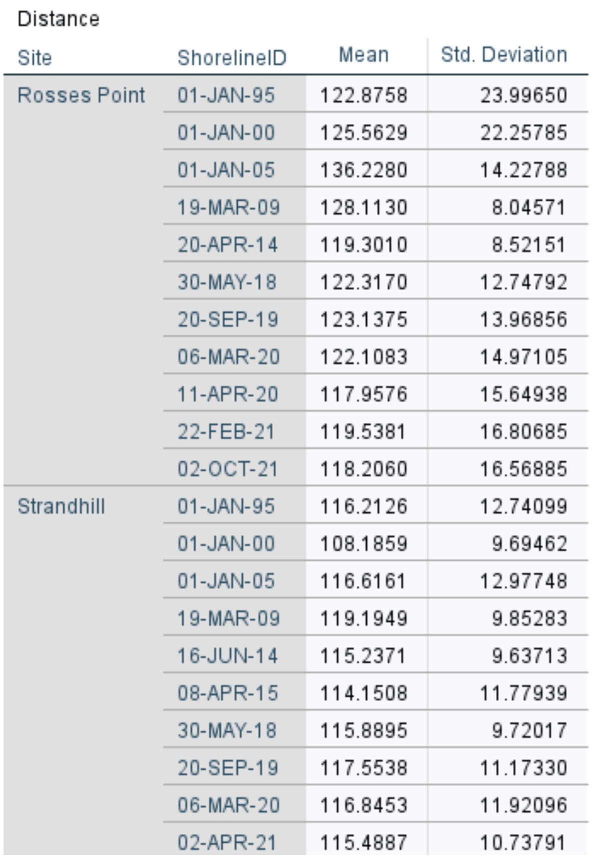
Table 2: Net Shoreline Movement from 1995-2021 (m)

NSM

Site	Mean	Minimum	Maximum	Std. Deviation
Rosses Point	-4.5143	-68.91	48.82	33.59175
Strandhill	-.7245	-29.85	37.54	15.44969

Discussion

Table 3: Mean Shoreline by year for Rosses Point and Strandhill beach (m)



Site	ShorelineID	Mean	Std. Deviation
Rosses Point	01-JAN-95	122.8758	23.99650
	01-JAN-00	125.5629	22.25785
	01-JAN-05	136.2280	14.22788
	19-MAR-09	128.1130	8.04571
	20-APR-14	119.3010	8.52151
	30-MAY-18	122.3170	12.74792
	20-SEP-19	123.1375	13.96856
	06-MAR-20	122.1083	14.97105
	11-APR-20	117.9576	15.64938
	22-FEB-21	119.5381	16.80685
	02-OCT-21	118.2060	16.56885
Strandhill	01-JAN-95	116.2126	12.74099
	01-JAN-00	108.1859	9.69462
	01-JAN-05	116.6161	12.97748
	19-MAR-09	119.1949	9.85283
	16-JUN-14	115.2371	9.63713
	08-APR-15	114.1508	11.77939
	30-MAY-18	115.8895	9.72017
	20-SEP-19	117.5538	11.17330
	06-MAR-20	116.8453	11.92096
	02-APR-21	115.4887	10.73791

Distance

The shoreline change seen in figure 6 for transects 3-6 is as expected, as previous to the armouring of Rosses Point beach this section was experiencing a natural retreat supplemented by storm events. The beach is granted natural protection as seen in figure 2 from the geomorphic features of the coastal zone however they do little to protect the shoreline during short term storm events which dislodge large amounts of sediment from the sandy beachfront and alter the fixed dune system which supports the golf course in the hinterland of the beach. The rock armouring installed at Rosses Point required the southern section of the northern beach to be realigned this resulted in a retreat being observed in the transect results of figure 6 when in truth this area was converted to rock armouring. The transect results from 14-20 and 25-29 reflect the storm event which occurred in 2007 as the vegetation edges retreated as seen in the imagery from 2005 to 2009 which shows the greatest decline in shoreline distance from baseline recorded in DSAS. The results from the DSAS calculations at Rosses Point indicate regression in vegetation edge of -0.1693m/yr (table 1). This shows overall a statistically insignificant rate of change at Rosses Point across all transects. However, transects 2-6 which cover the large rock armouring and concreted ramp seen in figure 3 experienced rates of -2.58m/yr too -1.75m/yr. Negative values reflecting erosion continue as the transects extend north up the shorefront but alter to accretion from transect 14 onward. This reflects the unarmoured section of the shorefront seen in figure 6. These results vary in accretion from 0.08m/yr to 1.82m/yr. This is consistent with the NSM statistics were in the unarmoured section of the shorefront vary from 48.82m to 0.07m. The erosional trends seen at Rosses Point are consistent with the armouring installed at the site and show the suitability of armouring this area to protect the Golf course located in the hinterland of the shorefront. However, from assessing the rate of change statistics and consulting the dated imagery the overall movement of the vegetation edge is very low and reflects a low rate of change across the shorefront. The statistics would indicate that the armouring has affected the undefended shoreline as it has slowed the retreat of the shoreline since 2014 as seen in table 3 reflecting that the coastal defence has altered the response of the coastline at this beachfront. Figure 7 reinforces the statistics as variation in shoreline from 1995 and the GPS recorded vegetation edge in 2022 show a low variation visually of the shoreline. It shows the accretion in the southern half of the beach and the erosion in the northern half from 1995 to the present day. The historic line however does not align with the northern headland of the beach showing the inaccuracy of using historical mapping for the rate of change statistics as it cannot be relied upon to be drawn accurately for measurements. Overall, Rosses Point beach shows that when a coastal zone is given tourism and economic importance over environmental natural stability coastal protection can be implemented to alter the response of the coastline in a way to stabilise the vegetation edge. As this study does not measure high-tide or low-tide marks for the shoreface it cannot conclude if the coastal defences have altered the cross-section of the beach or the sediment load of the beach. The site has maintained its coastal features such as the sand spit north of the beach (figure 4) which has seen little movement and the embryonic dunes have slowly built up since 2003. The northern estuary has maintained a strong presence also.

Strandhill has experienced low rates of change based on the DSAS calculations. The average EPR rate -0.281m/yr concludes a low variation in vegetation edge at this site. The variations in EPR are low across the entire site. The section with the mobile dune system in its hinterland (transects 6-12) experiences the largest rates of erosion annually ranging from -0.56 to -1.14. This is to be expected at a mobile dune systems vegetation edge and does not reflect a significant erosional effect on the vegetation edge. The larger rates of accretion at Strandhill occur around the sand spit at the southern end of the beach (figure 4). The largest rate of annual accretion record is 1.43m/yr at transect 37. This reflects a low variation in vegetation edge movement in this location. This is supported by the NSM seen at Strandhill as the larger rates of movement have occurred at the sand spit with the largest result at transect 37 being 37.54m. The shoreline variations between the transects reflect slow erosion at the mobile dune system, a slight accretion since 2000 along the beach fixed dune front and an accretion at the sand spit of Strandhill. Based on the historical vegetation edge recorded in figure 10 it would infer a gradually retreat in the last century but as previously discussed historical maps are unreliable when calculating statistics so the exact shoreline position cannot be included in the DSAS calculation. Comparing 1995 to the 2022 GPS reading, Strandhill has experienced a low rate of shoreline variation, and this is reflected in table 3. The mean distance between the baseline of the DSAS calculation and the transect intersections for the shorelines for 1995 was 116m and from the last 2021 reading was 115m. The buffer that the baseline runs across was calculated at 100m from the shorelines. This shows a negligible movement in vegetation edge position at Strandhill showing the stability of the coastal system. The armouring installed in 2003 could be noted as affecting stabilising the system as the transects (figure 9) all noted an erosion in position from the 1995 imagery (figure 10) compared to the 2000 imagery. After this, the fixed dune-backed portions of the vegetation edge accreted and stabilised from 2005 to 2014.

Both Rosses Point and Strandhill reflected a positive effect of coastal armouring even when tourism and economic concerns are valued over environmental concerns of hard engineering strategies as both vegetation edges reflected erosional rates previous to their armouring and slight accretional rates post armouring.

Conclusion

In conclusion, through monitoring the vegetation edge variation from 1995 to 2021 the impact that the coastal defences at Strandhill and Rosses Point have had on the response of the coastline in terms of shoreline variation has been stabilisation. The defences have proven to assist in stabilising the movement of the vegetation edge at both sites. However, furthered assessment on the effect of the coastal defences especially the more recent armouring at Rosses Point is needed to evaluate long-term change. From the DSAS results presenting the annual rate of change statistics, the study sites have experienced low rates of change. The shoreline changes over time according to the graphs in figures 6 and 9 show a stabilisation period post-implementation of the defences. The coastal defences could have a greater effect on other coastal responses to sea level variation at the study sites. This would require further studies to analyse other coastal response in the area.

This study could be furthered by recording the vegetation edges at the sand spit north of Rosses Point to assess (using DSAS) the rate of change in that location and at the southern beach at Rosses Point. Also, a study into the variations in sediment load distributions at either beach would assist in accurately measuring the interference by the coastal defences in the natural replenishment cycle of the coastal zones. If accurate imagery of high and low tide at the study sites could be collated this study could be supplemented by processing that information in the DSAS system. A more accurate GPS reader could be used to track vegetation edge as the GPS app used has an uncertainty of 2m when tracking a walked path. A study assessing the salinity change in the estuarine systems north of Rosses point and South of Strandhill (figure 3) and a study on the displacement of coastal plant life in the area may present a more critical view of the coastal defences and supplement this study.

References

- Aiello, A., Canora, F., Pasquariello, G. and Spilotro, G., (2013) Shoreline variations and coastal dynamics: A space–time data analysis of the Jonian littoral, Italy. *Estuarine, Coastal and Shelf Science*, *129*, pp.124-135.
- Ashleigh contracts, (2002) http://www.ashleighcontracts.com/projects/strandhill-coastal-defences-and-slipway-sligo/ [Accessed 24/04/2022]
- Brown, A.C. and McLachlan, A. (2002) Sandy shore ecosystems and the threats facing them: some predictions for the year 2025. *Environmental Conservation*, *29*(1), pp.62-77.
- Bulleri, F. and Chapman, M.G. (2010) The introduction of coastal infrastructure as a driver of change in marine environments. *Journal of Applied Ecology*, *47*(1), pp.26-35.
- CleanCoasts, (2017) https://cleancoasts.org/tag/strandhill/ [Accessed: 27/10/21]
- Cooper, J.A.G., W.T. Jackson and Pilkey, O.H. eds. (2012) *Pitfalls of shoreline stabilization: Selected case studies* (Vol. 3). Springer Science & Business Media, pp. 93-103
- Cronin, T.M. (1999) *Principles of paleoclimatology*. Columbia University Press.
- de Sanjosé Blasco, J.J., Gómez-Lende, M., Sánchez-Fernández, M. and Serrano-Cañadas, E. (2018) Monitoring retreat of coastal sandy systems using geomatics techniques: Somo Beach (Cantabrian Coast, Spain, 1875–2017). *Remote Sensing*, *10*(9), p.1500.
- Dolan, R. and Hayden, B. (1983) Patterns and prediction of shoreline change. *CRC* Handbook of Coastal Processes and Erosion, pp.123-149.
- Dolan, R., Hayden, B. and Heywood, J. (1978) Analysis of coastal erosion and storm surge hazards. *Coastal Engineering*, *2*, pp.41-53.
- Donadio, C., Vigliotti, M., Valente, R., Stanislao, C., Ivaldi, R. and Ruberti, D. (2018) Anthropic vs. natural shoreline changes along the northern Campania coast, Italy. *Journal of Coastal Conservation*, *22*(5), pp.939-955.
- Geograph.ie, Ordnance Survey (2008) https://www.geograph.ie/photo/978541 [Accessed 25/04/22]
- Government of Ireland and Ordnance Survey Ireland (2021) Government of Ireland. https://webapps.geohive.ie/mapviewer/index.html [Accessed 01/11/2021]
- Hanslow, D.J. (2007) Beach erosion trend measurement: a comparison of trend indicators. *Journal of Coastal Research*, pp.588-593.

- Herbei, M.V., Ciolac, V., Şmuleac, A., Nistor, E. and Ciolac, L. (2010) Georeferencing of topographical maps using the software ARCGIS. *Research Journal of Agricultural Science*, *42*(3), pp.595-606.
- Irish Government, Central Statistics Office (1996) Census 1996: https://www.cso.ie/en/census/census1996reports/ [Accessed 28/10/21]
- Irish Government, Central Statistics Office (2011) Census 2011: https://www.cso.ie/en/census/census2011reports/ [Accessed 28/10/21]
- Irish Government, Central Statistics Office (2016) Census 2016: https://www.cso.ie/en/census/census2016reports/ [Accessed 28/10/21]
- Jayson-Quashigah, P.N., Addo, K.A. and Kodzo, K.S. (2013) Medium resolution satellite imagery as a tool for monitoring shoreline change. Case study of the Eastern coast of Ghana. *Journal of coastal Research*, (65 (10065)), pp.511-516.
- Jonah, F.E., Boateng, I., Osman, A., Shimba, M.J., Mensah, E.A., Adu-Boahen, K., Chuku, E.O. and Effah, E. (2016) Shoreline change analysis using end point rate and net shoreline movement statistics: An application to Elmina, Cape Coast and Moree section of Ghana's coast. *Regional studies in marine science*, *7*, pp.19-31.
- McGuinn, C., Bartlett, A. and Bartlett, J., STEADY AS SHE GOES! STRANDHILL, AN INTEGRATED TOURISM BRAND. Institute of Technology, Sligo [Accessed 27/10/21]
- Oyedotun, T.D. (2014) Shoreline geometry: DSAS as a tool for historical trend analysis. *Geomorphological Techniques*, *3*(2.2), pp.1-12.
- Pranzini, E. and Williams, Cooper J.A.G., A.T. eds. (2013) Coastal erosion and protection in Europe, London, UK: Routledge, pp. 209-224
- Rangel-Buitrago, N., Anfuso Melfi, G. and Stancheva, M. (2011) Effects of coastal armouring in the Bolivar department (Caribbean Sea of Colombia). Pp. 97-104
- Ryle, T., Murray, A., Connolly, K. and Swann, M. (2009) Coastal Monitoring Project. *Unpublished survey for the National Parks & Wildlife Service, Department of Environment, Heritage and Local Government, Dublin*.
- Short, A.D. and Hesp, P.A. (1982) Wave, beach and dune interactions in southeastern Australia. *Marine geology*, *48*(3-4), pp.259-284.
- Sligo County Council, Coastal Flood and Erosion Risk Management Study - Rosses Point/Drumcliff Bay, IBE1062 Rev04 (2016) http://www.sligococo.ie/media/RPointCFERMFina161216.pdf [Accessed 05/03/2022]

- Stive, M.J., Aarninkhof, S.G., Hamm, L., Hanson, H., Larson, M., Wijnberg, K.M., Nicholls, R.J. and Capobianco, M. (2002) Variability of shore and shoreline evolution. *Coastal engineering*, *47*(2), pp.211-235.
- Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L. and Ergul, A. (2009) *The Digital Shoreline Analysis System (DSAS) version 4.0-an ArcGIS extension for calculating shoreline change* (No. 2008-1278). US Geological Survey.
- Thinh, N.A. and Hens, L. (2017) A Digital Shoreline Analysis System (DSAS) applied on mangrove shoreline changes along the Giao Thuy coastal area (Nam Dinh, Vietnam) during 2005–2014. *Vietnam Journal of Earth Sciences*, *39*(1), pp.87-96.
- Woodroffe, C.D. (2002) *Coasts: form, process, and evolution*. Cambridge University Press. pp. 478.