Roinn Cumarsáide,
Fuinnimh & Acmhainní Nádúrtha
Department of Communications,
Energy & Natural Resources

Geoscience Research
GSI
Suirbhéireacht Gheolaíochta Éireann
Geological Survey of Ireland

Geological Survey of Ireland Research Programme
- Short Call 2015, Final Report -

Name of Lead Investigator	Colman Gallagher
Email	Colman.gallagher@ucd.ie

Organisation name	University College Dublin		
Organisation type:	☒HEI	☐Public Sector (other)	☐Private Sector
Department/section	School of Geography		

Project Title	Quantifying coastal evolution Donegal Bay using remote sensing approaches
Contract No.	2015-sc-037

INFOMAR
Integrated Mapping for the Sustainable Development of Ireland's Marine Resource

Tellus
Understanding Underground

Marine Institute
Foras na Mara

2. Project information:

Title of project	Quantifying Coastal Evolution Using Remote sensing Approaches
Did you make any formal amendment to the project workplan/budget?	☐ yes ☒ no If yes, please specify:

Project Report (*max 1500 words, excluding figures and headings*):

(i) Objectives and scientific/engineering targets beyond the state of the art

Shoreline changes and near-shore-beach-dune interaction is highly complex; however, there is increasing recognition of the significance of nearshore bathymetry and the dynamics of nearshore bars and rip current cells on shoreline changes and beach dynamics and in turn on the dynamics of coastal dunes and barriers (Gallagher and Thorp, 1997; Aagaard et al., 2004; Houser and Mathew, 2011; Gallagher, 2012; Lynch et al., 2013). Because of the expense of obtaining elevation changes over substantial distances along shore and due to lack of viable remote sensing techniques, only a few studies have tried to quantify beach dune mophodynamics along Irish coastlines. Recent advances in global positioning systems (GPS), and light detection and ranging (lidar) sensor technologies and computational breakthroughs have paved the way for collection and processing of highly accurate and spatially as well as spectrally dense data of the highly dynamic coastal environment (Kempeneers et al., 2009; Gallagher and Balme, 2011; Gallagher and Balme, 2015). The collection and analysis of such a unique data set can provide myriad of opportunities for advancing both our understanding of collective alongshore and cross-shore sediment transport by waves, as well as aeolian sediment transport and coastal dune development (Short and Tembanis, 2004; Lynch et al., 2013).

Since 2000 the Irish National Seabed Survey (INSS) and Integrated Mapping for the Sustainable Development of Ireland's Marine Resources (INFOMAR) have provided highly accurate and spatially dense data on Ireland's nearshore-offshore territories. Topographic and bathymetric elevation and backscatter (intensity) data were collected using lidar and MBES technologies. This project has made use of available, high-resolution bathymetric/topographic elevation and geophysical data to map approximately 10 km^2 of the nearshore-beach-dune systems along Murvagh peninsula, Donegal bay on the North-western coasts of Ireland (Figure 1). The determination of sediment volume, and morphology will be an important component of any future evaluation of the region's capacity to host industrial activity (Garcia et al, 2014) as well as to better understand the sediment budget and shoreline evolution. Near/off-shore seabed geology and geomorphology forms the architecture upon which biological habitats build. This study has tried to quantify the relationship between the shoreline change rates and beach/dune morphology, to sediment availability and pathways as well as future evolution of the Donegal bay systems. This will provide new knowledge in a region with significant development potential to ensure best practice, including the highest levels of environmental protection, in any development. Therefore this project fits two of the priorities of the European research framework Horizon 2020 through excellent science and providing opportunities for competitive industries.

The overall objectives of the investigation were to:

1. Compile volumes of data collected during the INSS, INFOMAR, and additional programmes into benchmark information such as bathymetric/topographic lidar; MBES bathymetric and geophysical data; historic aerial/satellite imagery; topographic lidar data from OSI, and GSI;
2. Extract shoreline, compute new shoreline rates of change, correlate shoreline type and setting using historic aerial/satellite imagery, lidar and field survey data;
3. Evaluate the areal change in geomorphic units across nearshore-beach-dune system using topographic and bathymetric lidar, aerial photographs, and field surveys of selected beach-dune profiles;
4. Evaluate the relationship between shoreline change rates and beach-dune morphodynamics, to near/off-shore sediment supply and morphology;
5. Develop conceptual models of the future evolution of the beach dune system based on quantitative measurement of shoreline change rates and sediment volume, and an assessment of major geomorphic controls.

(ii) Implementation (including reference to timelines, milestones, management)

Task 1: **(January 2016 – March 2016)**

Baseline data collection

a) Compile highly accurate and spatially dense bathymetric/topographic lidar data 3000 m seaward of the land/water interface or to laser extinction along the study area;
b) Compile highly accurate and spatially dense MBES bathymetric and geophysical data along the study area;
c) Compile available historic aerial and multispectral areal satellite imagery 1500 m buffer of the shoreline (500 m landward and 1000 m seaward)

Task 2: (January 2016- June 2016)

Extract shoreline, compute new shoreline rates of change, correlate shoreline type and setting using historic aerial/satellite imagery, lidar and field survey data

In this investigation, vegetation line was used as the shoreline proxy for long term shoreline change analysis As shown in Figure 2, at first historic shoreline positions were delineated from 1955, 1973, 1995, 2000, 2005 and 2015. Digital shore line analysis system (DSAS) (Thieler et al., 2009) was be used to generate shore-normal transects at an interval of 50 m along the shoreline and to update the historical and expected future rate of shoreline change along the study area. Later these transects, with reference to a baseline seaward of shoreline positions, was used to calculate the rate of shoreline change and associated statistical parameters using several statistical models. DSAS was be used to calculate the average annual rate of shoreline change (AARSC) and to predit future shoreline positions in a GIS environment. Figure 3 shows the calculated AARSC over the last 7 decades based on historic aerial photos. As the tidal currents are in a northerly direction and dominant wind direction is shoreline is in a North-westerly direction, the net sediment support through hydrodynamic as well as aerodynamic processes, distal end of the peninsula is having accreting (~1 m/year) compare to proximal end. The shoreline position was projected 60 years into the future at 50 m interval along shore (Figure 3). The rate of change of natural, unarmored shorelines was correlated with the type of shoreline and relative wave energy as determined by available fetch, shoreline orientation, and wind climate. This comparison provides insight into the process of shoreline change and used to identify shoreline types and area having the most severe erosion problems. The average annual shoreline change rates and shoreline-type mapping results are presented in a geodatabase feature class and it could be a useful tool for contingency planning in the event of natural or man-made disasters as well as for developing an environmental sensitivity/vulnerability map of the study area.

Task 3: **(April 2016 – September 2016)**

Evaluate areal change in geomorphic units across beach-dune system and development of algorithms for automatic extraction of geomorphic features along the study area

Unique data set from Task 1 and 2 in combination with field surveys using GPS, and 2008 topo-bathy lidar data, was used to quantify the morphology of beach-dune system along the study area. Spatial and temporal patterns of areal changes in geomorphic units such as beach-intertidal area, Aeolian sand dunes, modified Aeolian sediment dunes, inland dunes, forest, saltmarshes, agriculture/grassland, and forest were digitized as polygons from 1955, 1973, 1995, and 2013 orthophotos. Figure 4 shows the spatial distribution of geomorphic units in 2013 and percentage distribution of coastal geomorphic units. Mapping and subsequent change-rate analyses of geomorphic units was conducted in the ArcGIS/ENVI environment. As a first step towards mapping and change-rate analysis of geomorphic units, the study area was be classified into two distinct coastal reaches on the basis of their geomorphic characteristics and shoreline change rates. Later on, ground penetrating radar was used to get a better understanding of the subsurface geomorphology along three cross shore profile (one in reach A and two in reach B). Coastal reach boundary and profiles are shown in Figure 5. Subsequently, the area and the change rates of geomorphic units was calculated using Arc Scripts (see table 1). As evident in table 1, in 1955 the whole peninsula was covered with Aeolian sand dunes and by 1973 these mobile dunes get stabilized over time with vegetation. By 2013, most of the distal end of the peninsula was fully stabilized. At the same time, height and width of dune area is decreasing towards the proximal end. Percentage distribution of coastal geomorphic units during the period of investigation was used to present the total area occupied by each of these geomorphic units and areal change rates during periods of measurement (see Figure 4).

Task 4: **July 2016 – December 2016**

To evaluate the relationship between shoreline change rates and beach-dune morphodynamics, subsurface geomorphology and sediment budget

Finally, short-term sediment volume and beach-dune sediment budget was quantified using the seasonal field survey (March/2016 and November/2016), and by using topographic and bathymetric lidar information and its fusion with RGB aerial imagery. As shown in Figures 7, 8, in May/2016, terrestrial laser scanner was used to generate high resolution DEM of the coastal reach A. Figure 8 show the range in elevation of beach dune system along reach A and its accuracy in comparison to real time kinematic GPS survey. In addition, statistical methods were used to identify major controls and their significance to spatial and temporal variation in beach-dune morphology and volumetric change rates for the entire study area, as well as for individual coastal reaches, were determined. Then spatial and temporal patterns of topographic changes in coastal reaches over the study period was critically analyzed using three-dimensional models of the beach-dune system, elevation-change models, and selected profiles along and across coastal reaches. All these profile lines and selected features were overlain on most recent DEMS generated using differential GPS system to visualize, analyze, and quantify short-term evolutionary trends. In addition, volumetric changes associated with geomorphic units such as beach/intertidal sand flats, foredunes, mobile inland sand dunes, fixed inland sand dunes, and wetlands were closely examined to further advance our understanding of the linkages of shoreline changes to nearshore bathymetry and beach-dune morphodynamics.
Moreover, in October 2016, unmanned aerial vehicle was used to collect highly accurate and spatially RGB aerial imagery and DEM of reach A (see Figures 10, 11). In addition, in November 2016, ground penetrating radar (GPR) was used to critically evaluate the subsurface morphology of primary, secondary and tertiary dunes along the study area (see Figure 6)
Finally, as shown in Figure 12, a sediment-budget approach was used to summarize input, through-flow, and output, as well as net deposition, during periods of measurement for the study area as a whole and for individual areas of interest along/across coastal reaches.
Moreover, attempts were made to generate DEMs using terrestrial laser scanner (see Figures 7 & 8) and unmanned aerial vehicle (see Figures 10 &11). In addition, image-fusion techniques and break in elevation and geometry of neighbouring lidar point clouds were used to develop algorithms in MATLAB program to automatic extraction geomorphic features such as crestline, toe line and high water line (see Figure 9). Monitoring of these geomorphic features could allow us to better understand the coastal processes and major controls on its evolution. The output of these geomorphic features are shape (ESRI) file format. ArcGIS spatial and 3D analyst extensions

were be used to calculate the aerial and volumetric change analysis for areas of interest, and the result will be exported into Grid (ESRI) formats (see Figure 12)

Task 5: October – December 2016

Develop conceptual models of the future evolution of the beach dune system based on quantitative measurement of shoreline change rates and sediment volume, and an assessment of major geomorphic controls

Based on the results from linear change rates of average annual shoreline position, a predictive model of 2100 shoreline position is proposed. As shown in Figure 14, it is obvious that the current accretion rate will continue to increase towards the distal end. At the same time, northward extension of the peninsula will be slowed down due to presence of deep navigation channel. It is also possible that abundant sediment supply will ultimately result in moving more and more sand inland through aelian processes resulting in increase in height of the embryo dunes along this section. Currently, the beach dune system fully stabilized with marram grass and chances of eroding these high dunes are slim (see Figure 13).

In addition a simple conceptual model of future evolution of the beach dune system was attempted based on quantitative measurements of shoreline change-rates, areal change rates of geomorphic units as well as volumetric changes in sediment volume. A representative cross section from coastal reach A and coastal reach used to demonstrate this model. Position of these cross-sections used from reach A and reach B are shown on Figure 5. Most important controls on the evolution of Murvagh peninsula will be the bedrock geology, extent of exposed glacial till and sources of sediment supply, as well as relative sea level rise. As shown in Figure 15, cross section AB will have abundant supply of sand to offset the projected 3mm/year of sea level rise. Therefore along coastal reach A (profile AB), the dunes will increase in height and width over time. However, along coastal reach B (cross section ED), erosion will dominate over the next couple of decades. Glacial till beneath the sand along this section has already been exposed by wave action, and with the passage of storms, these bluff will become unstable and slump back to beach due to undercutting and slowly migrate landward.

Task 6: December 2016
P*resentations, reports, decision maker fieldtrips, and integration with outreach materials*

Research methodologies developed as part of this investigation and results as well as inference will be included in a formal report and served through UCD research repository. Vector layers of GIS data files will also be made available for download through UCD research repository. Raw datasets will be distributed upon request. Presentations and fieldtrips for GSI and other interested parties will be conducted at their expense and the results will be incorporated into UCDs ongoing outreach activities through Earth Institute.

(iii) Outputs (please use bullet points)

- Historic shoreline positions in 1955, 1973, 1995, 2005, 2013 using aerial imagery (Shape files)
- Shoreline position in March/2016 and November/2016 using differential GPS (Shape files)

- Long term shoreline change rates (Shape files)
- Spatial distribution of geomorphic units in 1973, 2000 and 2013 (shape files)
- Subsurface of geomorphology of beach dune system using GPR (raster)
- Areal change rates in geomorphic units (shape file)
- Terrestrial lidar point cloud data (raster)
- UAV base aerial imagery and digital terrain model (raster data)
- Volumetric change rates beach dune sediment budget (raster data)
- Predicted shoreline positions in 2100 (Shape files)

Impact/value of the project (M*ax 500 words*):

Along shorelines of the North western Irish coast, there is concern that a lack of sediment supply, rising sea level and climate change will have an impact on sediment circulation pattern, which in turn will lead to destabilization of nearshore-beach-dune systems through erosion, overwash, and backshore transgression. This investigation has made use of the high-resolution bathymetric/topographic elevation and geologic/geophysical data collected as part of INSS and INFOMAR programs to map approximately 10 km^2 of the beach dune geomorphology along the Donegal bay system. The relative significance of seasonal/annual/decadal processes versus response of nearshore–beach-dune system to broader geomorphic controls (relative sea level rise, storms) was assessed. Results from this feasibility study has proved that approaches and methodologies developed in this pilot study could be used for developing an integrated system of modelling shoreline change and sediment budgets that will integrate measurements over different spatial and temporal scales along Irish coastline.

As presented in this investigation a better understanding of average annual shoreline and geomorphic change rates as well as volumetric changes in beach dune sediment budget over the last 7 decades could be particularly useful to coastal-zone managers, scientists, and the public involved in shoreline erosion/accretion investigation, pre-and post-storm surveys, oil spill response, ESI mapping, habitat mapping, near-shore beach-dune, and wetland restoration studies along the study area. We will present the results of this investigation to the public, managers, policy makers, scientists and engineers through the UCD Earth Institute (EI) website, conference presentations, outreach programs, and field trips for local decision makers.

Results from this investigation on quantifying coastal evolution on a decadal scale using remote sensing approaches along Donegal bay and eventually elsewhere, are potentially of great value for emergency preparedness (identifying highly vulnerable areas for populations and infrastructure), insurance risk assessments, urban planning, coastal habitat management, sediment budget, beach renourishment and inlet dredging strategies, and setback lines and building standards for coastal structures. Near real-time forecasting using short term seasonal monitoring is potentially another valuable planning asset for emergency managers. We intend the outcomes of this investigation as a pilot study to take a leadership role in studying storm surge impacts and geo-hazards on coastal communities by fostering early career scientists (post-doctoral and graduate/undergraduate), and through the extensive outreach apparatus of the UCD EI (non-technical publications, websites, media relations). The UCD EI is a leader in the development of programs to train secondary school teachers, and students, and this investigation will be used as foundation for developing partnership with coastal communities through inviting participation in field, laboratory, and classroom study.

General dissemination of data and information

A central commitment of the proposal was public dissemination of outputs in order to better equip our society to adapt to geohazards, climate change, population growth, economic development and resource constraints. New tools and prototypes developed as part of this investigation will be added to new and existing web resources at UCD, including downloadable reports. The inferences from this project could be used to increase societal resilience by learning how best to use the INFOMAR datasets to inform better coastal environmental policymaking, planning, education and training. Consequently, the results from this investigation can contribute to development of the scientific and human resource capacity needed for sustainable use of coastal resources. During the course of this investigation, project members have given a talk at INFOMAR annual seminar and final results will be presented at conference of Irish Geographers and a number of public and scientific presentations. The visual aids from these presentations will also be made available on web.

Third Level Education Impact

The proposed study included partial funding for a postdoctoral researcher. Approaches and methods developed as part of this investigation will help in the integration of the results from the various strands of the geoscience programme at UCD and GSI and aid in refining research questions, methodologies and datasets that will ultimately be of benefit to stakeholders. The outcomes of PI's research are already made available freely to the public and he will introduce the methodologies to students working on similar coastal projects and computational assignments. PI will incorporate the research findings of this investigation into his undergraduate modules. These modules reach approximately 250 students per year. These activities will encourage cross pollination of students interested in geosciences, coastal resources management, and societal impact of climate change.

Timeline for the Project

The project was started on February 2nd 2016 as there was delay in hiring formalities with UCD HR and finance department. Postdoctoral fellow, Sojan Mathew has been in charge of various tasks and he has been conducting this research in a phased approach to take advantage of outputs from one task as inputs to another task. Synthesis activities was conducted throughout the study under the supervision of PI. Mile stone for various tasks and its completion date are listed earlier. Initial results of the proposed investigation was presented at INFOMAR annual conference at Marine Science Institute, Galway on 19th October, 2016. Final results and findings of this project will be presented at Conference of Irish Geographers in March, 2017. Moreover, we envisage to submit at least one manuscript based on methodologies and results as well as outcomes of investigation to a remote sensing or coastal research journal.

Appendix 1 – Publications & Presentations:

See cover page for formatting.

Mathew, S., Truong Hong, L., Pellicer, X., Gallagher, C. 2016. Quantifying Coastal Evolution along Donegal Bay using remote sensing approaches. INFOMAR Annual Conference, Marine Science Institute, Galway, November 19, 2016.

Appendix 2 – Any additional information not included above:

References:

Aagaard, T., et al. (2004). Sediment supply from shore-face to dunes: linking sediment transport measurements and long-term morphological evolution. Geomorphology. Vol. 60: 205-224

Balme, M.R., **Gallagher, C.**, Hauber, E. (2013). Morphological evidence for geologically recent young thaw of ice on Mars: a review of recent studies using high resolution imaging data. Vol. 37(3): 289-324.

Gallagher, C., Thorp, M.B. (1997) 'The Age of Pleisocene raised Beach near Fethard, Co. Wexford, using Infra Red Stimulated Luminescence (IRSL). Irish Geography. Vol. 30(2): 68-89.

Gallagher, C. (2002). The morphology and palaeohydrology of a submerged glaciofluvial channel emerging from Waterford Harbour onto the nearshore continental shelf of the Celtic Sea. Irish Geography, 35(2):111-132.

Gallagher, C., Sutton G. and Bell T. (2004). Submerged ice marginal forms in the Celtic Sea off Waterford Harbour, Ireland: implications for understanding regional glaciation and sea level changes following the last glacial maximum in Ireland'. Irish Geography. Vol. 37(2): 145-165.

Gallagher, C., Balme, M.R. (2011). Landforms indicative of recent northern high latitude thaw on Mars' In: Balme M., Bargery A., Gallagher C. and Gupta S (eds). Martian Geomorphology. London: The Geological Society of London, Special Publication 356.

Gallagher, C., Balme, M.R. (2015). New insights on the roles of ice, water and climate change in recent landscape development on Mars, Geography. Vol. 100(2), 84-93.

Garcia, X., Monteys, X., Evans, R.L., Szpak, M. (2014). Constraints on a shallow offshore gas environment determined by a multidisciplinary geophysical approach: The Malin Sea, NW Ireland,Geochemistry, Geophysics, Geosystems. Vol:15, 4, 867

Houser, C., Mathew, S. 2011. Alongshore variation in foredune height in response to transport potential and sediment supply: South Padres Island, Texas. Geomorphology, 125, 62-72

Kempeneers, P., Deronde, B., Provoost, S., Houthuys, R. (2009). Synergy of airborne digital camera and lidar data to map coastal dune vegetation. Journal of Coastal Research: special issue: Vol. 53: 73-82.

Lynch, K., Delgado-Fernandez, I., Jackson, D. W. T., Cooper, J. A. G., Baas, A. C. W., Beyers, J. H. M. (2013). Alongshore variation of aeolian sediment transport on a beach, under offshore winds'. Aeolian Research, Vol. 8:11-1.

Short, A.D., Tembanis, A.C. (2004). Decadal scale patterns in beach oscillation and rotation Narrabeen beach, Australia: Time series, PCA and Wavelet Analysis. J. Coastal Research. Vol. 20 (2): 523-532.

Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., and Ergul, Ayhan, (2009). Digital Shoreline Analysis System (DSAS) version 4.0— An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2008-1278.

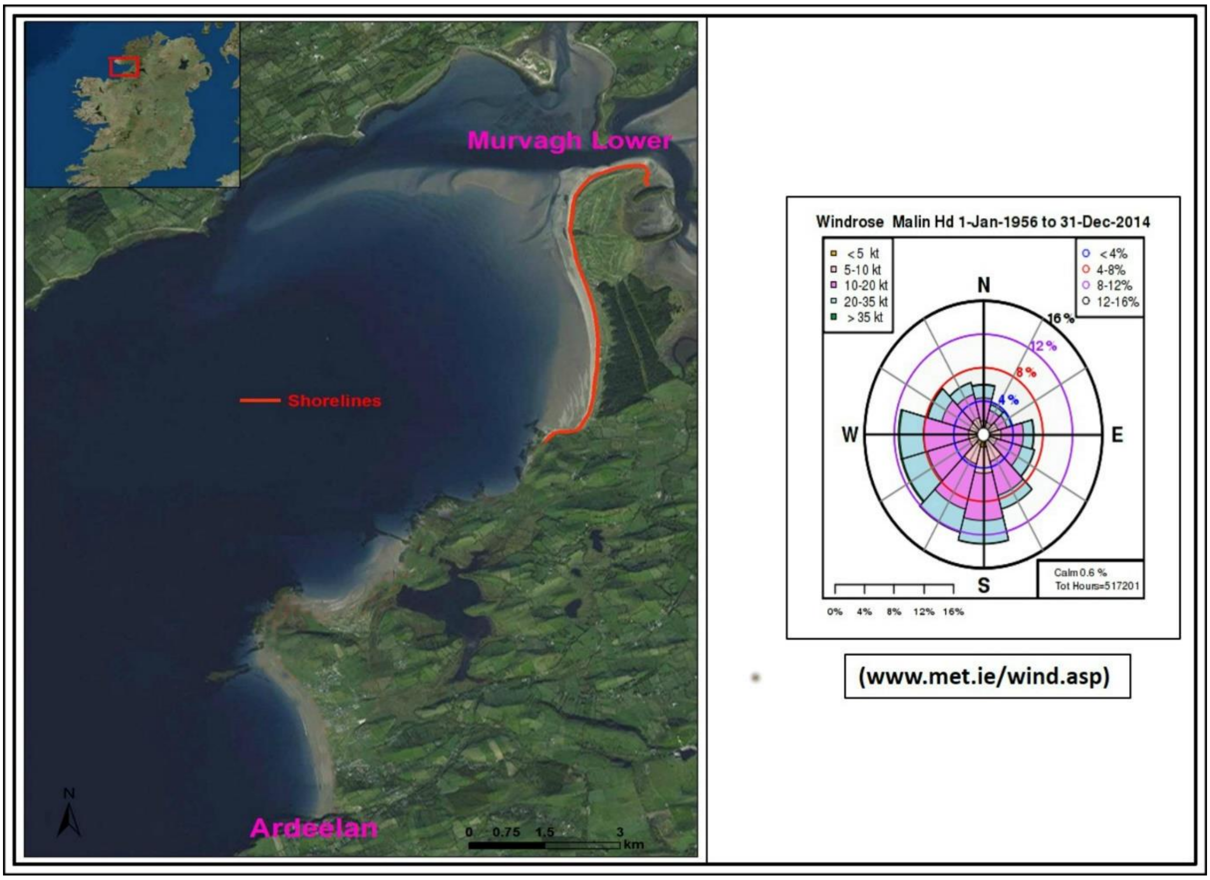


Figure 1: Map of Study area with shorelines along Murvagh peninsula, Donegal Bay and Wind roses showing dominant wind direction from 01/1956 to 12/2014.

Figure 2: Map showing the historic shoreline position in 1955, 1973, 1995, 2000, 2005 and 2016 and a blow up of the same

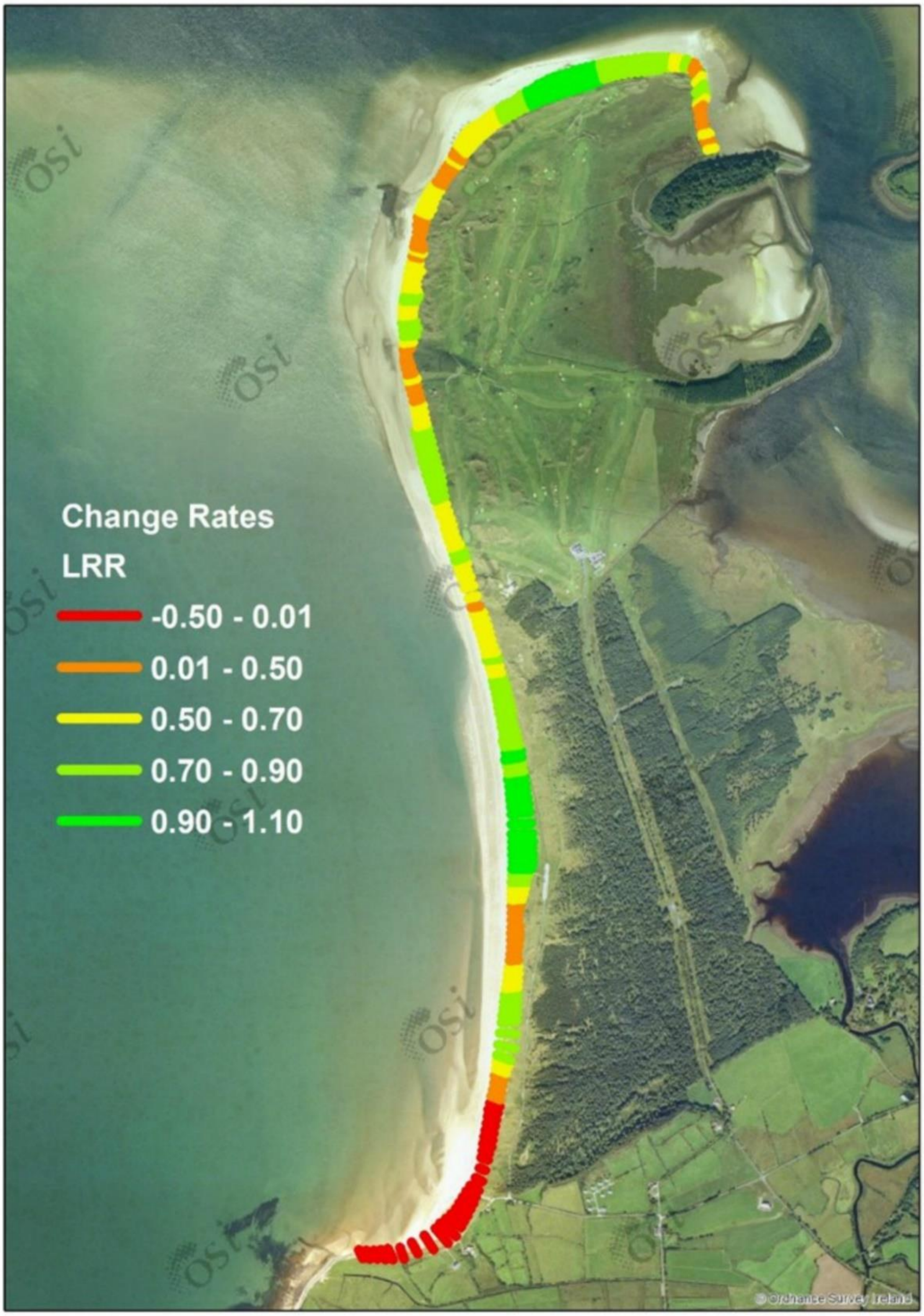
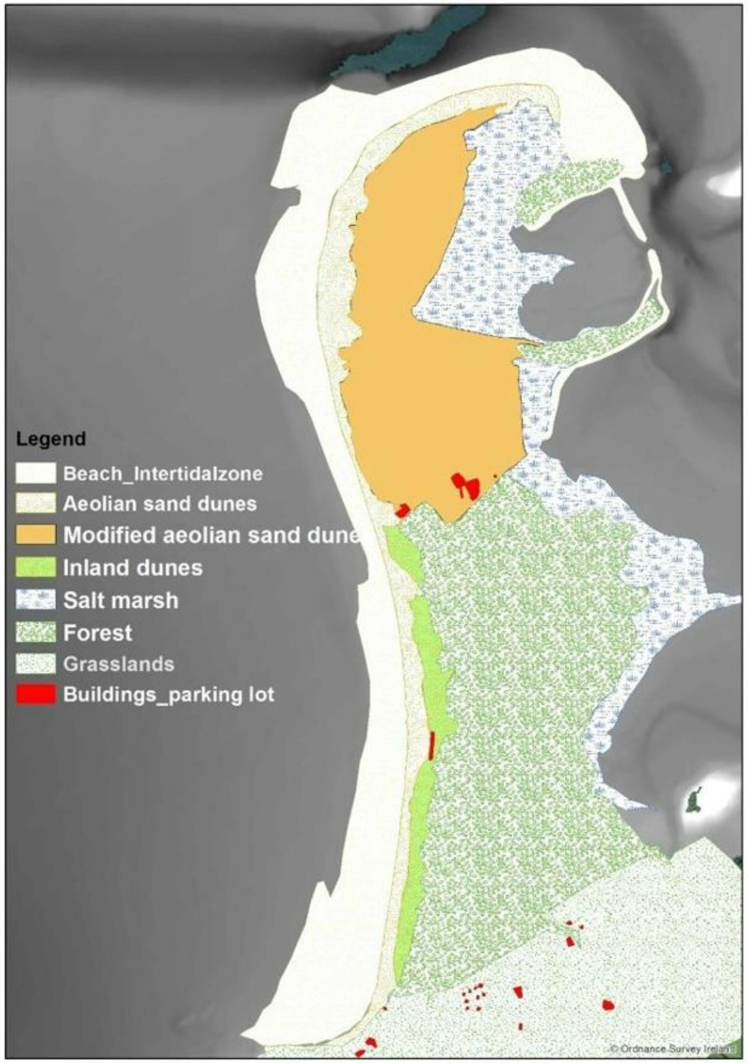


Figure 3: Historic shoreline change rates the Study area based on 1955, 1971, 1995, 2000, 2005, and 2013 aerial photos



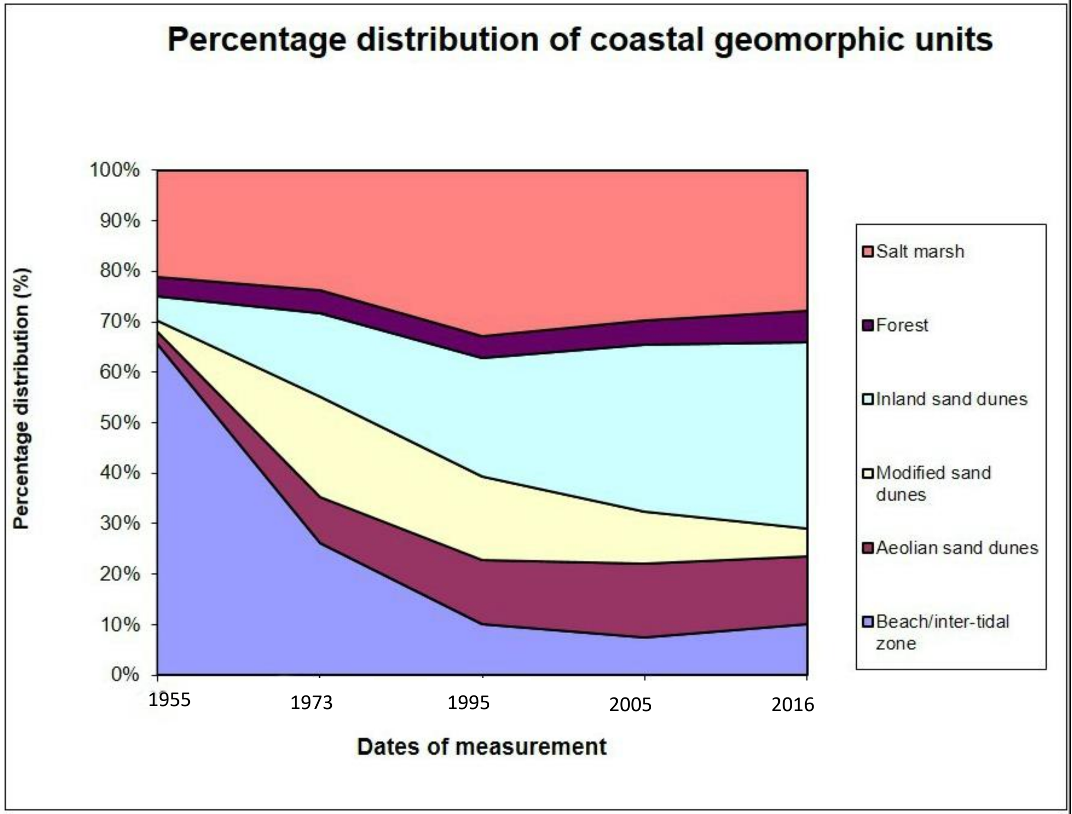


Figure 4: Major geomorphic features and percentage areal change rates across the study area

Figure 5: Coastal reaches of interest with an overlay of GPR and Conceptual model cross section along Murvagh Peninsula

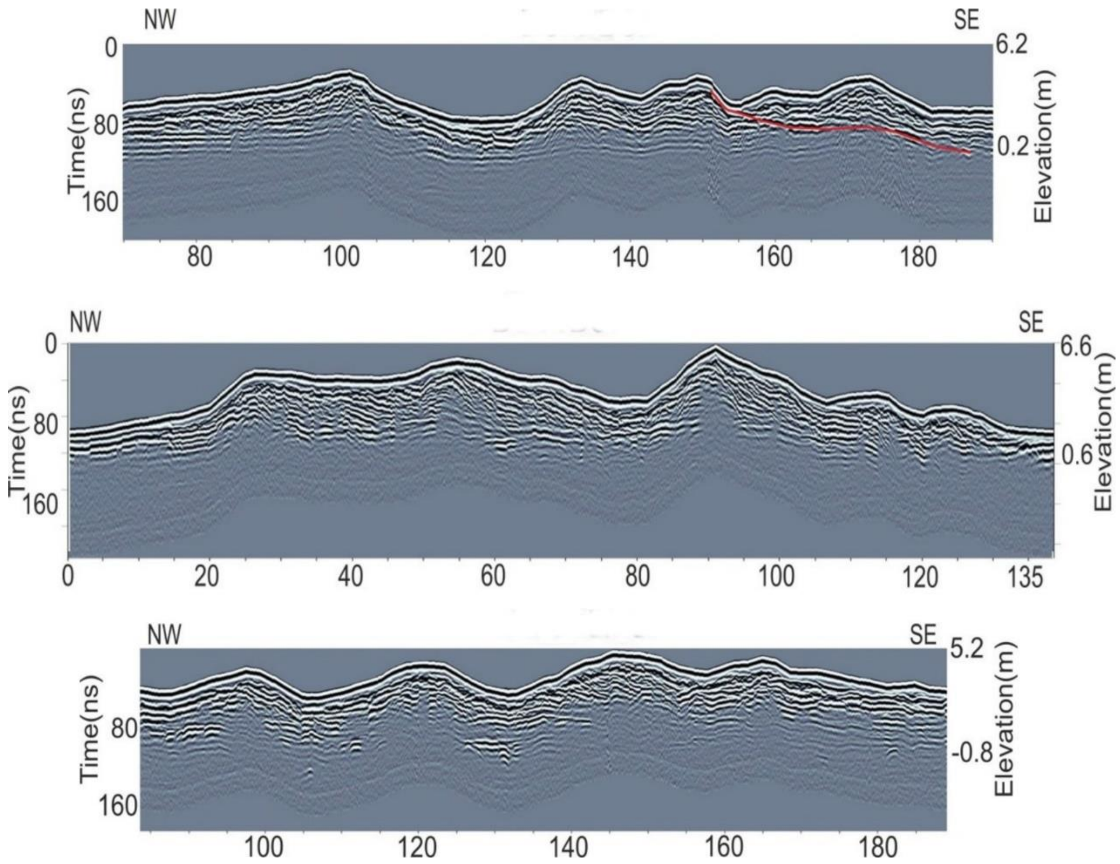
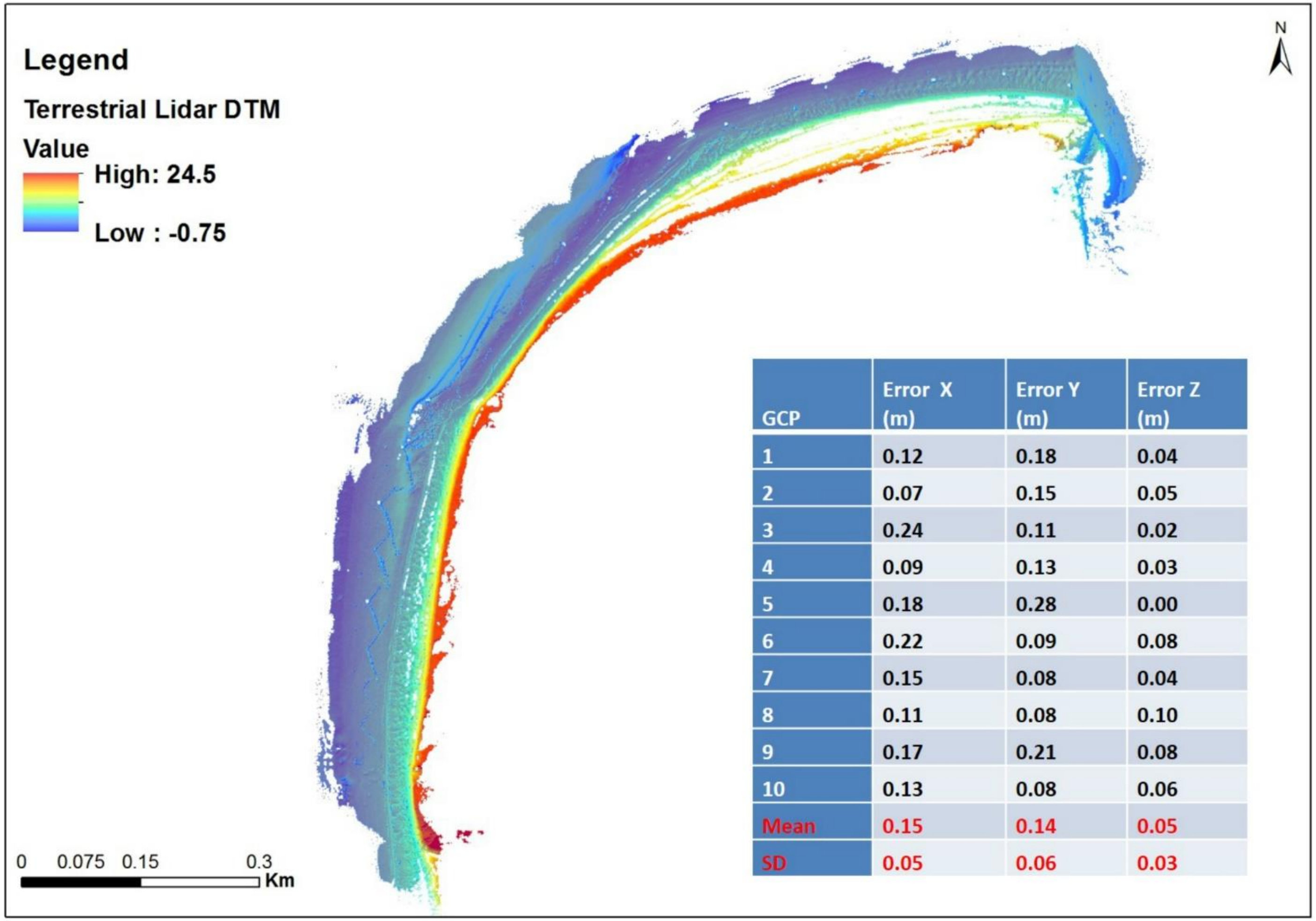


Figure 6: GPR profiles of line AB, CD, EF in coastal reaches and B showing the subsurface geomorphology of primary, secondary and tertiary dunes. Profile locations are shown on Figure 5.

Figure 7: Terrestrial laser scanning of Murvagh Peninsula



GCP	Error X (m)	Error Y (m)	Error Z (m)
1	0.12	0.18	0.04
2	0.07	0.15	0.05
3	0.24	0.11	0.02
4	0.09	0.13	0.03
5	0.18	0.28	0.00
6	0.22	0.09	0.08
7	0.15	0.08	0.04
8	0.11	0.08	0.10
9	0.17	0.21	0.08
10	0.13	0.08	0.06
Mean	0.15	0.14	0.05
SD	0.05	0.06	0.03

Figure 8: Digital terrain model using terrestrial scanner and accuracy assessment using control points

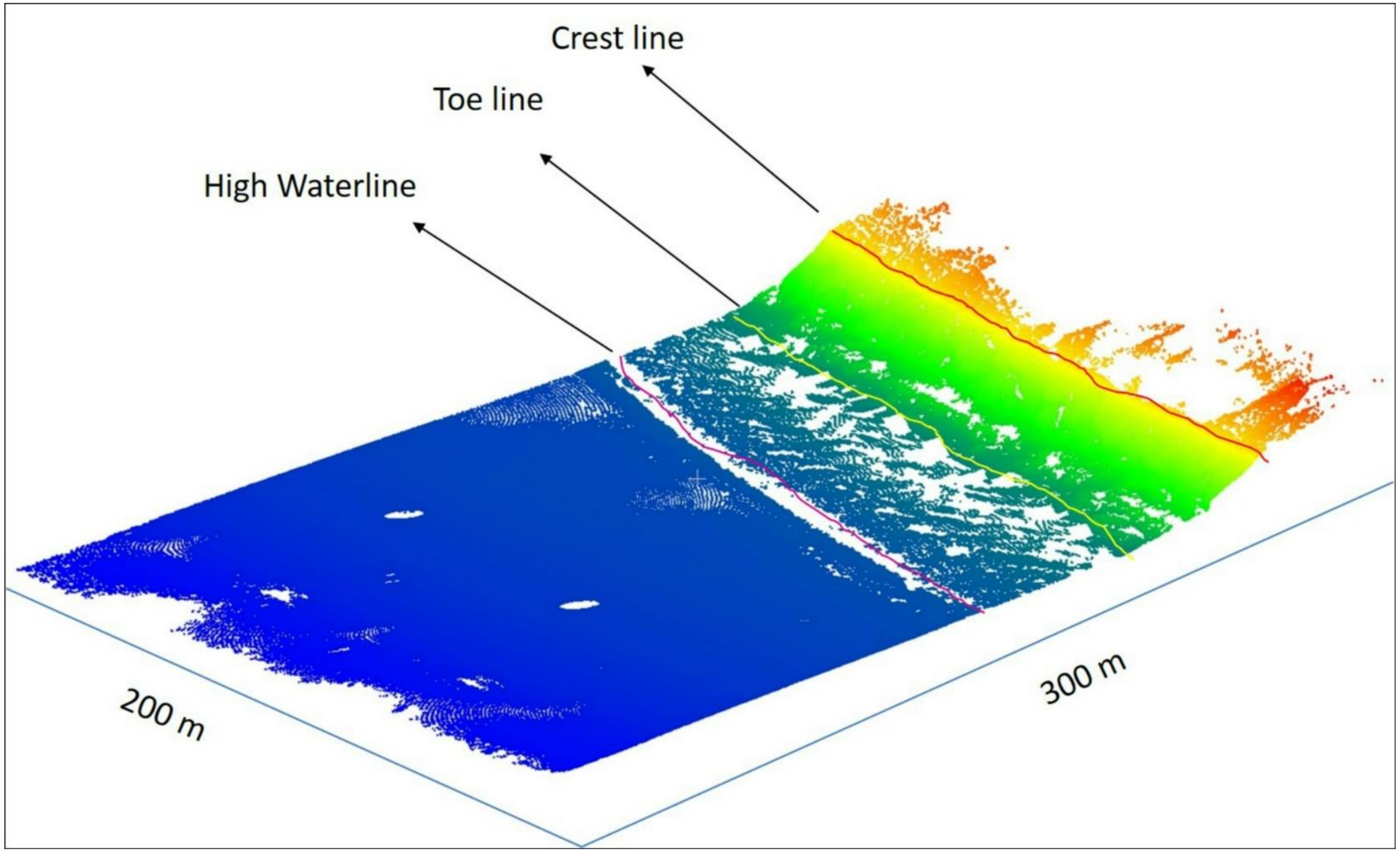


Figure 9: Semi-automatic extraction of coastal geomorhich features using Matlab co

UTM EASTING	UTM NORTHING	Height	CALCULATED EASTING	CALCULATED NORTHING	CACULATED HEIGHT	DELTA X	DELTA Y	DELTA Z
553897.54	6052109.34	8.96	553897.562	6052109.338	8.967	-0.02	0.00	0.00
553823.29	6052414.28	11.01	553823.29	6052414.282	11.025	0.00	0.00	-0.02

Figure 10: Operation of unmanned aerial vehicle for collecting high resolution RGB imagery and digital surface model

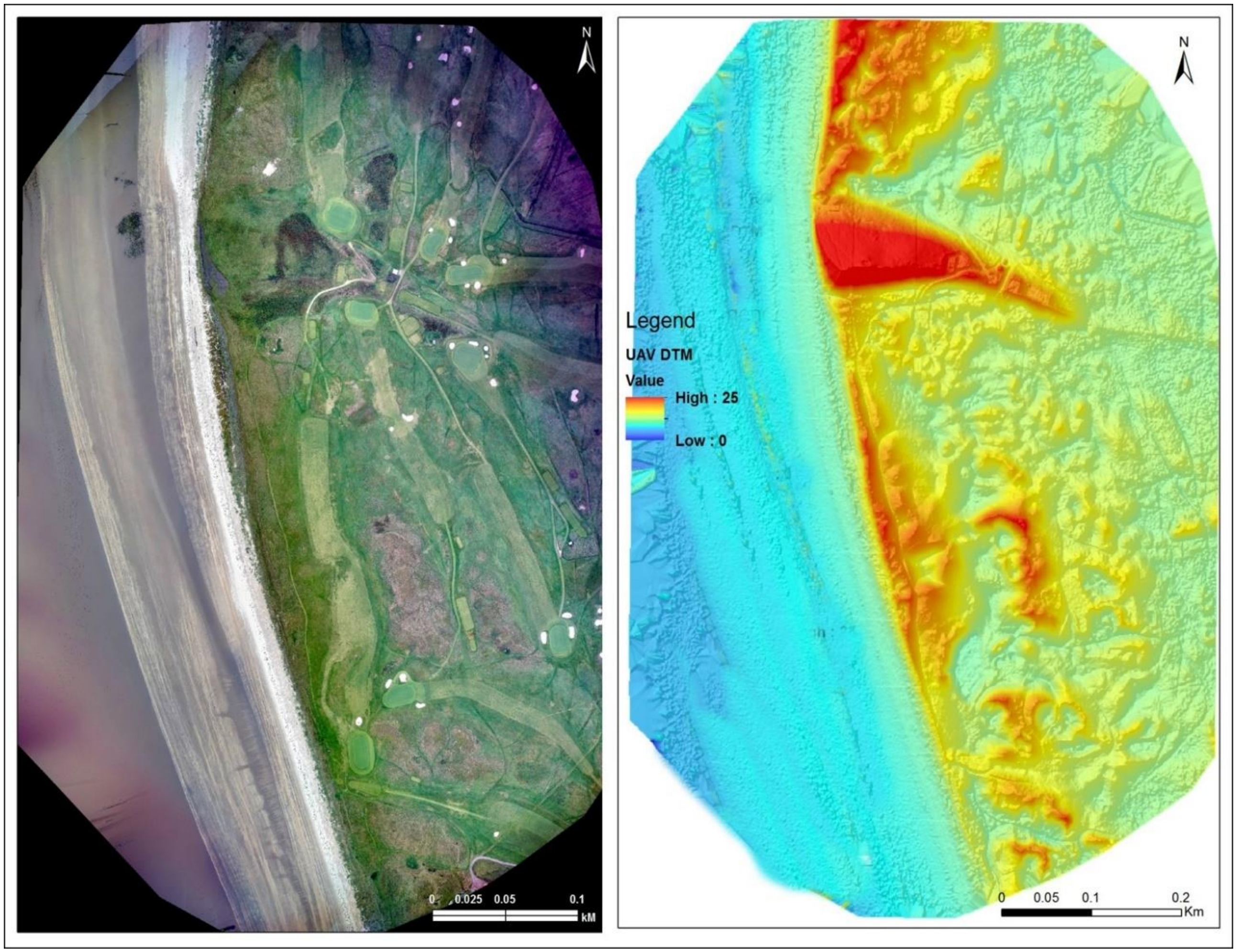


Figure 11: Map showing RGB mosaic imagery (left) and digital surface model (right)

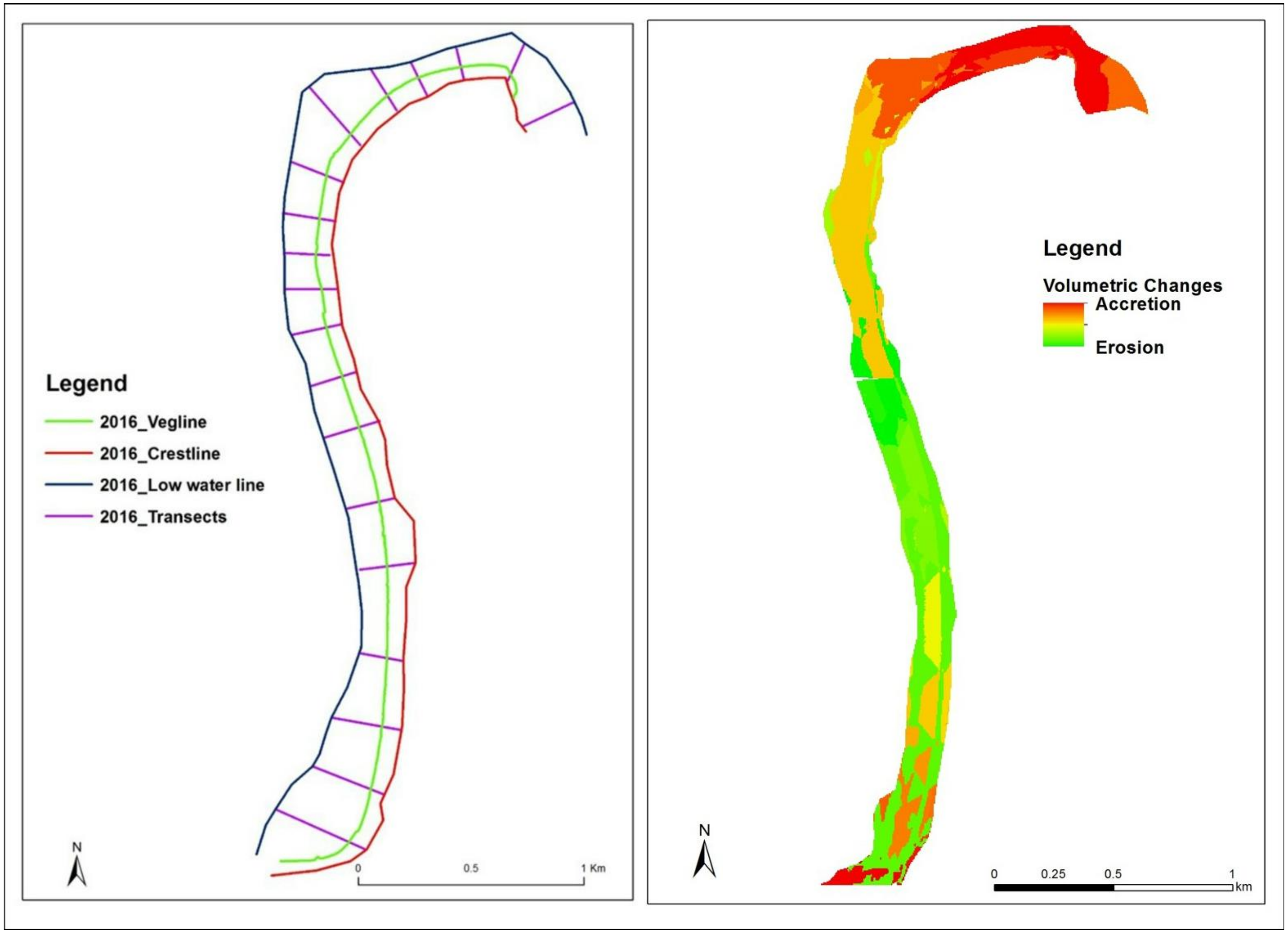


Figure 12: Volumetric changes and sediment budget

Figure 13: Oblique views of distal end showing the stability of beach dune system

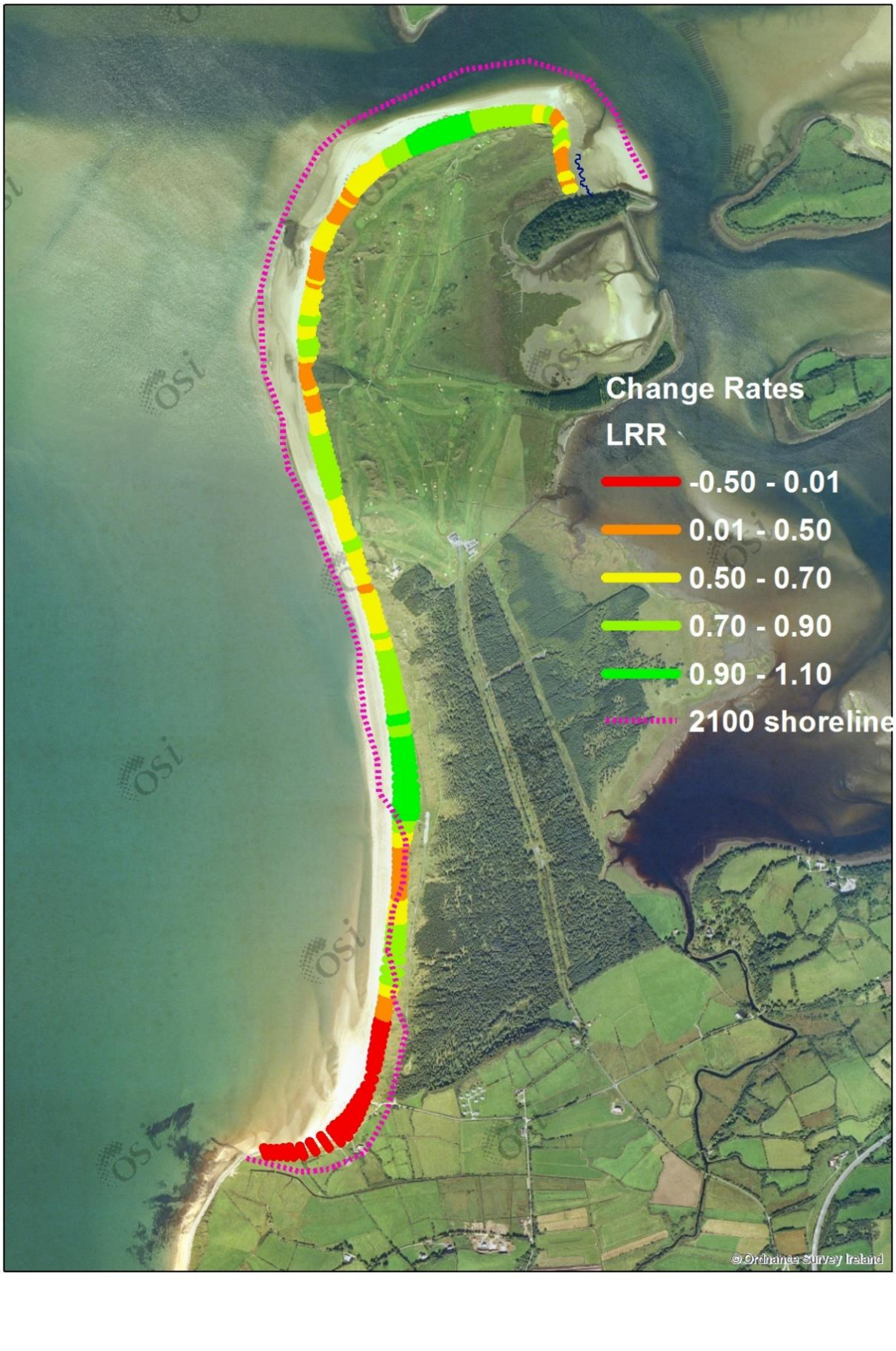
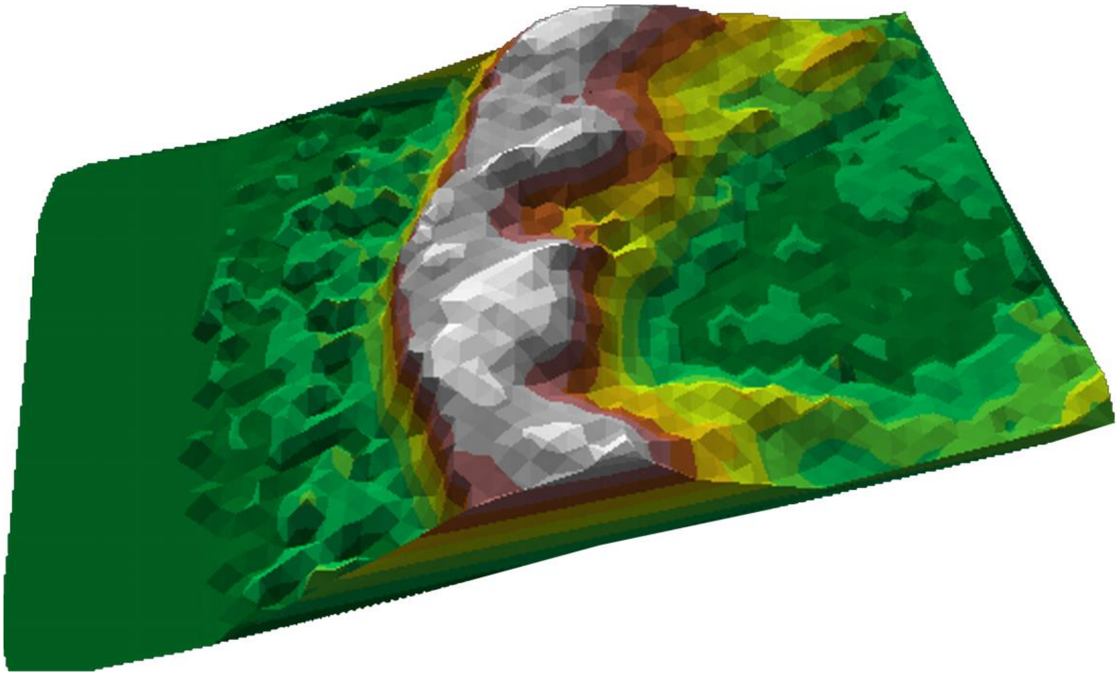
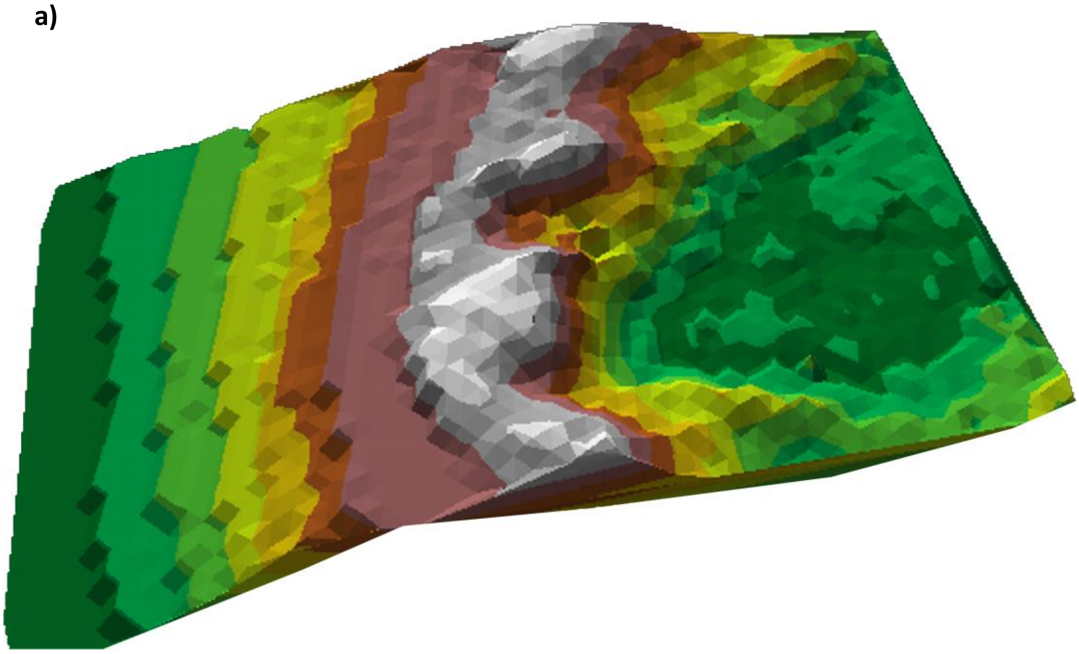


Figure 14: Prediction of 2100 shoreline position based on average annual shoreline change rates



a)



b)

Figure 15: Conceptual model of a) future evolution cross section AB in reach A, and b) cross section EF in reach B based on linear, areal and volumetric changes. Geographic location of the cross section profile is shown on Figure 5.

Table 1: Volumetric change-rate per unit length in coastal reach A and coastal reach B

	Total volume (m^3)		**Volume Change (m^3)**		**Volume change-rate ($m^3m^{-1}a^{-1}$)**	
	reach A	**reach B**	**reach A**	**reach B**	**reach A**	**reach B**
2008	1.49×10^3	1.29×10^3				
2016	2.05×10^3	1.04×10^3	0.56×10^3	-0.25×10^3	0.28	-.08