Cushendun Coastal Scoping Report and Monitoring Coastal Change to Inform Future Management

KPAL Report No: 110225

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Kenneth Pye Associates Ltd

Scientific Research, Consultancy and Investigations

Cushendun Coastal Scoping Report and Monitoring Coastal Change to Inform Future Management

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1.0 Report scope and purpose

This study was commissioned by the National Trust (NT) with funding provided by the Department of Agriculture, Environment and Rural Affairs (DAERA) Strategic Strand Environment Fund. The NT owns significant areas of land at Cushendun, County Antrim, Northern Ireland (Figure 1 & Table 1). The overall purpose of the study was to provide better information to inform the future management of the Trust's assets in the area which include several historic buildings, a café, shop, pub, two car parks, a rock breakwater adjacent to the mouth of the River Dun and a small harbour on its northern side.

Figure 1. Location of land owned or leased by the National Trust at Cushendun. Individual land / property compartments and their dates of acquisition are shown in Table 1 (base aerial photography flown 2022 by Bluesky, supplied by DAERA)

Table 1. Land at Cushendun owned or leased by the National Trust, identified on Figure 1

ID on Figure 1	Name	Acquired	Type
1	Milltown Cottage Covenant	20/05/1969	Covenant
2	Folio 13932 Lands of Cushendun	09/12/1965	Freehold
3	Folio 13931 Lands of Cushendun	15/07/1954	Freehold
4	Foreshore occupied by breakwater for 20 years	01/06/1988, 08/04/1993	Leasehold
5	Foreshore and bed of river for 20 years	01/06/1988, 08/04/1993	Leasehold
6	Lands of Cushendun	15/04/1954	Freehold
7	Foreshore of Glendun River	06/02/1984	Freehold

The main tasks of the study were to:

- gather all existing data for Cushendun Bay and understanding additional data needs
- design a monitoring scheme to understand current coastal erosion and accretion patterns
- implement the monitoring scheme
- model the potential changes in erosion and accretion patters if the breakwater was removed and over a range of future climate scenarios
- include estimated costings and methodology for staged removal of the breakwater and other options for the coastal management in Cushendun Bay.

2.0 Study methods

The study has used a number of methods:

(1) review of published and ‘grey’ literature, photographs and other historical media depicting Cushendun Bay and the harbour area

(2) review and analysis of data relating to tides, tidal currents, river flows, waves, sediment supply and transport pathways – including data from the Northern Ireland Coastal Observatory and DAERA map viewers

(3) collation and analysis of historical map, chart, aerial photography, satellite and LiDAR data, ground topographic survey data, sediment information (principally managed using Golden Software Surfer GIS software)

(4) identification and review of existing numerical modelling data relating to hydrodynamics and coastal change

(5) synthesis of relevant climate, sea level and extreme water level projection data for the area, including UKCP18 climate change projections

(6) site survey visits (including RTK-GNSS topographic surveys) in February 2024, May 2024, November 2024 and February 2025

3.0 Historical and environmental background

3.1 Historical background

The modern settlement of Cushendun consists of two main parts which lie on the north and south sides of the small River Dun estuary; these are now linked by a stone bridge which was originally constructed in the late 1850s and widened in the 1970s. The northern part, which contains the Main Street and a number of 19th and early 20th century buildings of heritage importance, lies within the historical township of Cushendun. The southern part, which includes the wharf, former hotels and a large block of modern appartments, lies within the township of Slean. A short distance upstream is the village and townland of Knocknacarry where there is another stone bridge crossing and a weir associated with a former mill. The group of buildings north of the Milltown Burn at Rockport, including Castle Carra, lies within the townland of Ballycleagh.

There is a long history of settlement around Cushenden (derived from the Irish *Cois-abhann-Duine* meaning “the end of the brown river”. Archaeological investigations of the area in the 1930s by a team from Harvard University identified Mesolithic flint artefacts in an area just upstream of Cushendun bridge (Movius *et al*., 1940). Similar artefacts were found in the vicinity of Castle Carra during excavations by NIEA in the period 1995-2004; their context has been radiocarbon dated back to c. 6400 BCE (McSparran, undated). There are a number of megalithic monuments in the area, including standing stones near the gate lodge of Glenmona Lodge circular mound (Cruik-na-Dhuine), 28 m in diameter, 3.5 m high and of uncertain age and origin, lies within the grounds (Welsh & Welsh, 2007).

One of the oldest ‘roads’ in Ireland runs from Clough in central Antrim via Glendun to Cushendun and was probably used as a drove for centuries and possibly millennia since Cushendun Bay provides the closest sheltered location for sea crossings to Scotland. A castle (Carra Castle) was built at the northern end of Cushendun Bay (now known as Rockport) in the 13th or 14th century as part of a network of coastal fortifications. Early settlement in the area appears to have occurred in the northern part of Cushendun townland and neighbouring Innispollan townland, close to the Milltown Burn, and Rockport may take its name from an early harbour in this location (there is a today a concrete jetty and sheltered mooring built in the 1930s).

Prior to the 16th century, Glendun, like the other Antrim Glens, was heavily wooded but much clearance for agriculture was taken during the later 17th and early 18th centuries. Flax became widely grown for the developing linen industry. There was significant cattle trade from Antrim via Cushendun to the Kintyre area of Scotland between the 15th and earl 17th centuries, and again in the second half of the 18th an early 19 centuries. Cattle were moved down the Glendun drove road to Cushendun harbour for embarkation via a wooden pier onto boats which returned with horses and sheep (Roberts, 2007). A scheduled daily passenger ferry service also operated from Cushendun to Dunaverty in Kintyre between1709 and 1833 (McDonnell, undated a; Roberts, 2007). It was reported in 1817 that vessels of 50 tons could cross the bar at the mouth of the harbour at high tide, and that 12 -16 boats involved in fishing could be seen drawn up on the neighbouring beach (Brett, 1997).

In 1733 part of the Cushendun townland was sub-leased by the White Family to Lachlan McNeill of Ballyucan who built the first Cushendun House. It was modified and expanded on a number of occasions and finally burned down in 1928 (Brett, 1997).

Rockport Lodge was built by Major General O'Neill in c.1813 as a summer shooting and bathing lodge on an area of rock projecting into the water (Brett, 1997 p28). Many individuals subsequently leased the property over the years, both before and after the freehold was sold by the Cushendun Estate to the National Trust. Glendun Lodge was probably also built by General O'Neill some time between 1812 and 1833. It was described in 1835 as the summer residence of Major James Higginson (Brett, 1997). Between 1924 and 1959 it was occupied by Ada McNeill, cousin of Ronald McNeill. Following her death it was sold by the Cushendun estate to a descendant of the White Family. Glenmona Lodge was built by the McNeill's around 1834 as a modest two-story house. The Ordnance Survey Memoir published in 1835 described it as the summer residence of Michael Harrison who subsequently expanded and improved the property. Glenmona had several tenants over the years until 1911 when Ronald McNeill, then Unionist MP for a Kent constituency, gained control of the Cushendun estate and moved into it. As a result of McNeill's stance on the matter of Irish independence the house was burnt down by the IRA in 1922. It was rebuilt from the remaining shell in 1923-24 to designs by Clough Williams Ellis who had previously designed The Square in 1912 and Maud Cottages in 1926 (the latter named after Ronald McNeill's wide, Elizabeth Maud Bolitho who died in 1925). After his political retirement Robert McNeill returned to Cushendun in 1929 and died there in 1934.

Before c.1800 Cushendun village only had road connection to the north, although the River Dun could be forded on foot or horseback at times of low flow. A wooden bridge was built some time before 1833 (McDonnell, undated b), and a stone bridge was built slightly further to the east between 1854 and 1856. Both bridges and a ford are shown on the Ordnance Survey Six-inch map surveyed in 1857 (see Appendix 2).

The construction of the Royal Military Road in 1833-34 greatly improved access to Cushendun and from the later 1830s both parts of Cushendun developed as a commercial centre and as an upmarket destination for visitors who came to enjoy the romantic setting, sea bathing and fishing. The area became very popular with artists and literary figures around this time (Curl, 1976; Gallagher & Rogers, 1992; DOENI, 1996; Brett, 1997). A Church of Ireland parish church was constructed in 1840 (re-built 1865 and again modified in 1974). The Main Street and many of the key village buildings were also built in the 1840s.

In 1826 the Slean township on the south side of the River Dun was bought by Nicholas De La Cherois Crommelin Sr., an entrepreneur whose Huguenot ancestors had moved to Ireland from Picardy. In c.1830 Crommelin Snr. built a 'cottage' on the site of The Caves House south of Cushenden Caves. He had plans to develop a new harbour on the coast linked by a railway line to iron workings and other industries on land he had bought further inland in 1800, an area subsequently known as Newtown Crommelin. A number of plans for new port facilities were prepared by James Donnell in the late 1820s, and in 1833 a plan for a new harbour near The Caves (to be known as Port Crommelin) drawn up by Sir John Rennie received parliamentary approval. It was never built, the requirement being removed by the construction of an alternative stone pier at Red Bay, but the planned outline of Port Crommelin is shown on the Ordnance Survey Six-inch map published in 1833. In the following years Nicholas Crommelin Sr. experienced financial difficulties and in 1847 had to sell many of his assets, initially moving to The Caves House, which he had expanded considerably, and then to Rockport where his son Nicholas Crommelin Jr, lived; Crommelin Sr. died there in 1863 (Brett, 1997). Crommelin Jr. subsequently made further improvements to the quay on the south side of the Dun River mouth designed by James Donnell and developed an adjoining small industrial estate which included a steam-powered scutching (flax processing) mill and rope works, opened in 1865. Due to this and other poor financial investments Crommelin Jr. was declared bankrupt in 1868 and moved to Blackheath near London. The scutch mill struggled and finally closed in 1884.

In the mid-19th century vessels of up to 50 tons were regularly accommodated within Cushendun harbour which at that time was larger than at the present time. A small fishing industry developed which included both offshore trawling and salmon and sea trout netting at the river mouth. A coastguard station including lookout, boathouse, warehouse and staff of 12 men was established on the north side of the river mouth in 1821-22 and remained operational until the early 20th century. The boathouse was relinquished in 1900 and all the coastguards had left by 1920 (Roberts, 2007). The Coastguard Lookout is shown on the Ordnance Survey Six-inch map surveyed in 1920-21 but the buildings were probably demolished around the time of construction of Maud cottages in 1925-6).

During the early 20th century a number of hotels were developed on the site of the old industrial buildings alongside the quay on the south side of the river, substantially increasing the number of visitors during the 1920s and 1930s. The Anchorage Hotel opened around 1920 and was extended and re-named the Glendun Hotel after its purchase by the Elliott Family in 1927. The Cushendun Hotel also opened in 1927 on part of the site of the old mill which had been purchased by Mrs Mary McBride around 1920, and the Bay Cafe (later the Bay Hotel) was built by the Mr. Elliott near Fisherman’s Point in 1936 (Cushendun Building Preservation Trust, undated; McDonnell, undated a). With the increased availability of the motor car after World War II the number of summer and weekend visitors increased. Several bed and breakfast guesthouses opened in the 1950s followed by Cushendun Caravan Park in 1969. However, following the start of ‘The Troubles’ in that year the tourist industry went into decline from which it has never fully recovered. All three of the main hotels have since closed. The Bay Hotel was demolished in the late 1990s and has been replaced by flats.

Following the death of Ronald McNeill the Cushendun estate passed to his daughter, Esther Rose, who married Major Geoffrey Moss and resided in England. Glenmona was used as a holiday home by the family for some years but many aspects of the estate became neglected during and after the Second World War. The estate was eventually sold by Mrs. Moss to The National Trust in 1954 with assistance from the Ulster Land Fund. Further areas close to the beach (including The Warren) were acquired by the Trust in 1965 using funds from Enterprise Neptune. When the Whites Family originally granted a sub-lease at Cushendun to the McNeills they retained rights to retain the land immediately behind Cushendun Strand known as The Warren and in 1802 enclosed it with a wall. In 1848 Strand House was built on The Warren to provide accommodation for the priest of the newly established parish of Cushendun; it was eventually sold to Ronald McNeill in the early 1920s (McSparran, 1988).

In 1980 Cushendun was designated as a Conservation Area by the Department of the Environment for Northern Ireland on the basis of its cultural and architectural heritage and its environmental setting (Figure 2):

“The Conservation Area of Cushendun is composed of two major areas, (i) the built-up area (ii) the surrounding countryside and coastal area. The two are closely integrated by areas of woodland. Much of the surrounding hill land is not included in the Conservation Area, but complements Cushendun's setting. Hence any development taking place outside the Conservation Area should be related in design and scale not only to its own location but also to its visual effect on Cushendun” (DOENI, 1980).

The text and illustrations in the original guide to the Conservation Area published in 1980 were revised and expanded in 1996 (DOENI 1996).

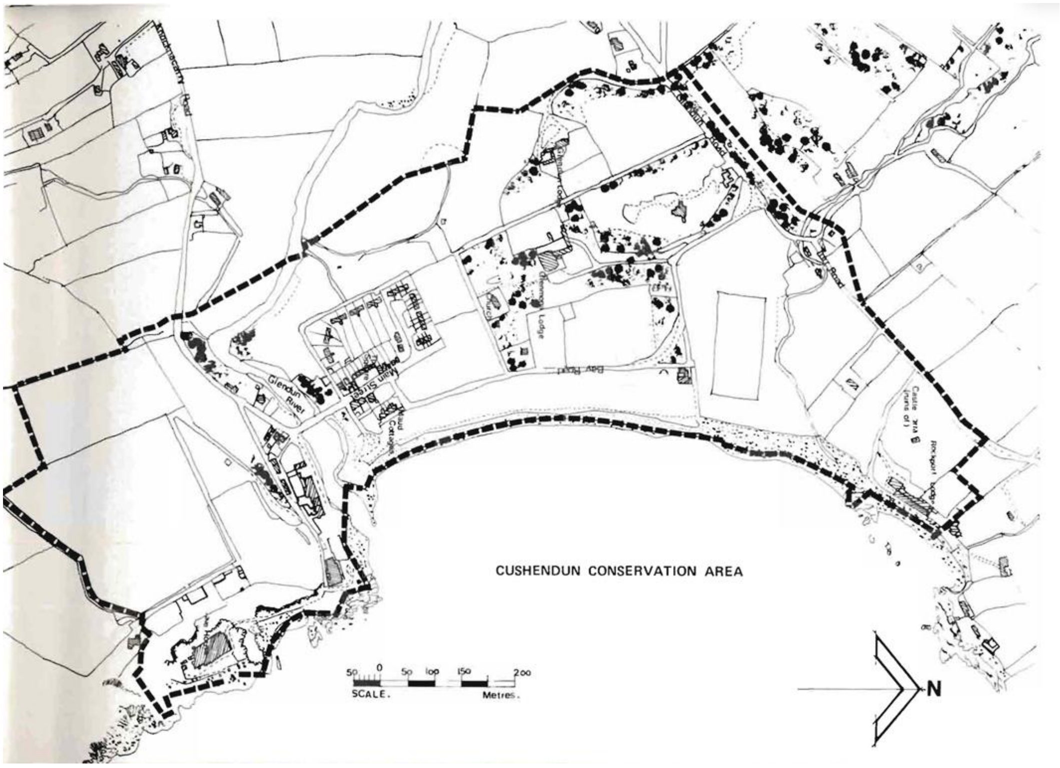


Figure 2. The extent of Cushendun Conservation Area as defined by DOENI (1980)

3.2 Geomorphological and geological setting

The River Dun (otherwise known as the Glendun River and Glendun Burn) drains a steep catchment which includes the mountain peaks of Slieveanorra and Slievannee at its head (Figure 3). Glendun is a relatively steep sided valley which in its lower part cuts through glacial till, glacio-lacustrine alluvium and raised beach deposits (Prior, 1966; Carter, 1982; Roe & Swindles, 2008; Figure 4). Evidence indicates that during the last glaciation a lobe of ice moving out from the Lough Neagh area and northwards up the northern Irish Sea was deflected landwards into the lower Glendun valley (Prior, 1970). At some point glacio-fluvial discharge became trapped, forming a short-lived pro-glacial lake. During and following the retreat of the ice rising sea level in the early Holocene resulted in a marine transgression. Prior (1966) suggested that prominent terrace on the north side of lower Glendun, with a surface elevation of c.16 - 18 m ODB, represents an erosional Late-glacial marine bench, but the relatively sheltered location of the features makes this unlikely and it is more likely to have been formed by fluvioglacial or lacustrine deposition. The Dun River subsequently cut down through these deposits. During a following period of marine transgression estuarine sediments accumulated as far upstream as Knocknacarry behind and a gravel barrier extending southward from the high ground to the north of Glendun. Subsequent isostatic recovery caused the land to rise relative to the sea, leaving the barrier beach deposits and estuarine sediments as raised terraces with a surface elevation of 6 – 8 m OD and 4 – 6 m ODB, respectively. At one time the Milltown Burn appears to have flowed along a shallow valley behind raised gravel and sand barrier which underlies The Warren and Glenmona

Lodge. This ‘valley’ is now largely dry and has a surface level of c. 3.5 m ODB cut into the underlying glacial till.

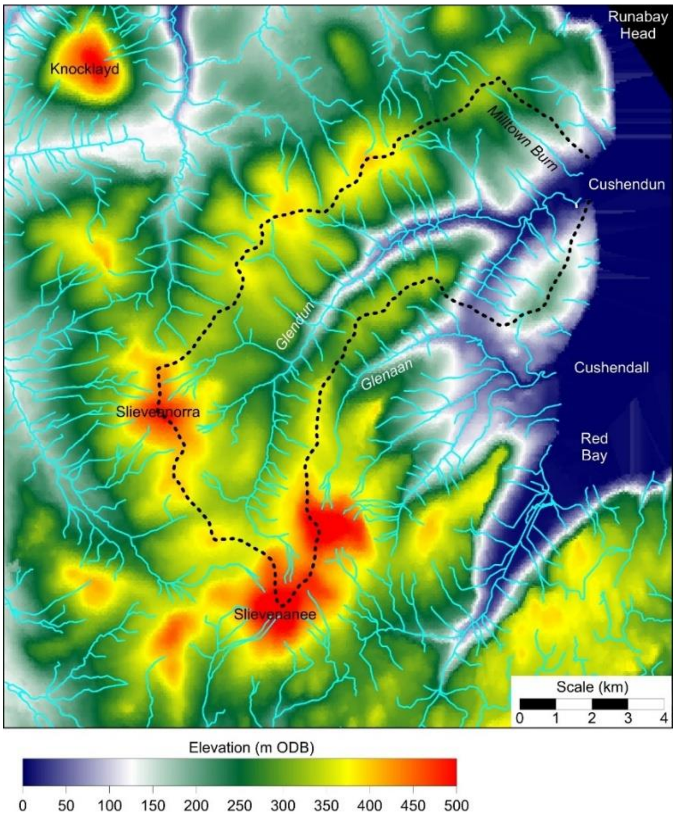


Figure 3. Digital terrain model of the catchment of the River Dun (watershed shown with a black dashed line; watercourses shown by light blue lines (based on OSNI Open Data

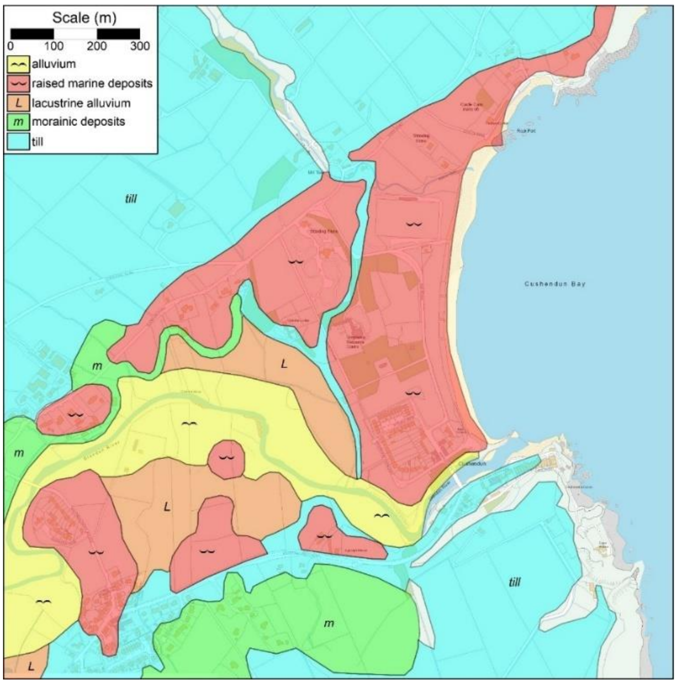


Figure 4. Superficial geology of the Cushendun area (based on British Geological Survey of Northern Ireland mapping). Base map OSNI open data

The underlying bedrock geology of the coastal area consists of Late Precambrian metamorphic rocks in the north and Devonian conglomerates and pebbly sandstones in the south. A significant WSW – ENE trending fault with downthrow to the south separates the two along the line of the lower Gendun valley (GSNI, 2009; Figure 5). Rocks exposed on the foreshore in northern Cushendun Bay near Rockport consist mainly of grey and greenish-grey quartz schist and albite-chlorite-biotite schists belonging to the Glendun Formation. These are cut by pinkish brown porphyry sheet intrusions which are probably related to a larger intrusion of Cushendun Granite which occurs about 1 km inland. There is also a cross-cutting dark-coloured metabasite (diorite) intrusion north of the pier at Rockport. This site is of national and internation significance and has been designated as a Northern Ireland Earth Science Conservation Review (ESCR) site (Porter, 2003).

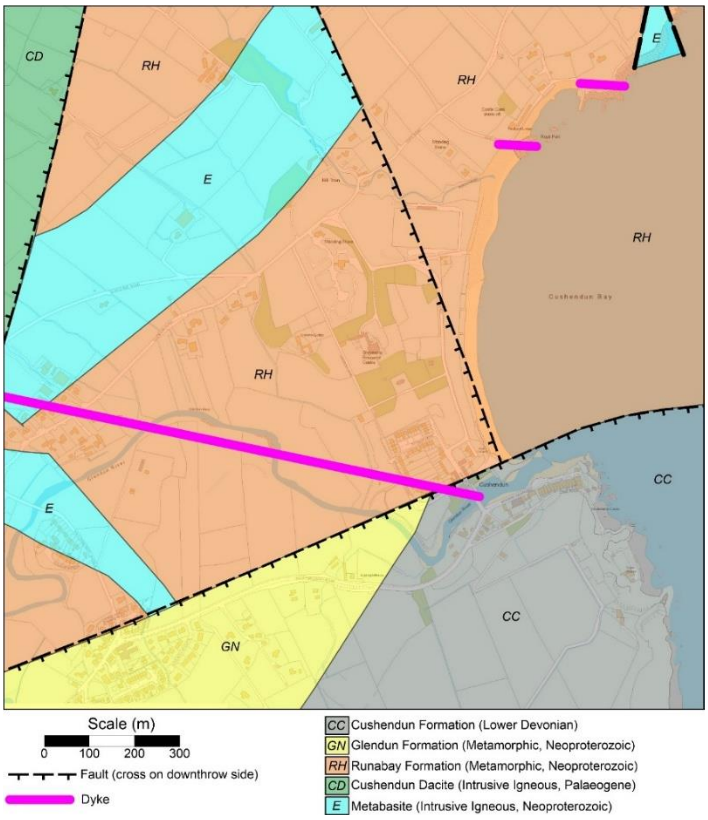


Figure 5. Bedrock geology (British Geological Survey of Northern Ireland mapping. Base map OSNI open data

The Devonian sequence exposed between Cushendun Hotal and Cave House has also been designated as a ESCR site (Doughty, 2006). The sequence here exposes the lower part of the Cushendun Formation and consists of tick beds of reddish-coloured conglomerate interbedded with coarse red coloured sandstones. The conglomerates are clast-supported with a sandy matrix and contain a high proportion of well-rounded polycyclic vein quartz and quartzite pebbles. They represent flash-flood alluvial fan and alluvial floodplain deposits formed in a desert and/ or semi-arid environment. In places the conglomerate beds can be seen to be infill scoured depressions in the sandstone beds. Some of the clasts in the conglomerate reach up to 25 cm in diameter although 10 - 15 cm is more typical. The Cushendun Caves and Cave Tunnel leading to the Caves House are largely natural features formed by marine erosion at a time of slightly higher relative sea level (c. 3 - 4 m above present). Marine erosion has also formed impressive stacks and arches in the rocks. The small active beaches found at the head of the coves between the rocky headlands and pinnacles are composed of pebbles and cobbles derive from the conglomerates. There is a 150 – 200 m wide intertidal and subtidal rock platform to seaward of the cliffs formed by wave erosion.

Figure 6 presents a composite digital terrain model of the area based on airborne 2021 DAERA LiDAR of the coastal strip, OSNI 10 m terrain data for the inland area, and 2019 Admiralty multibeam bathymetric data for the nearshore area. The DTM has been annotated to show the major geomorphological features interpreted from geological information, air photography, LiDAR and field surveys. A number of illustrative topographic long-profiles across the area are shown in Figure 7.

The Caves House sits on a raised marine bench equivalent in height to the base of the caves but is fronted by an artificial terrace of made ground formed during landscaping for of the House grounds in the 19th century. Made ground also occurs on both sides of Cushendun harbour. The original surface at the Gaelic Football ground and along the seaward side of The Warren has also been heavily modified by levelling.

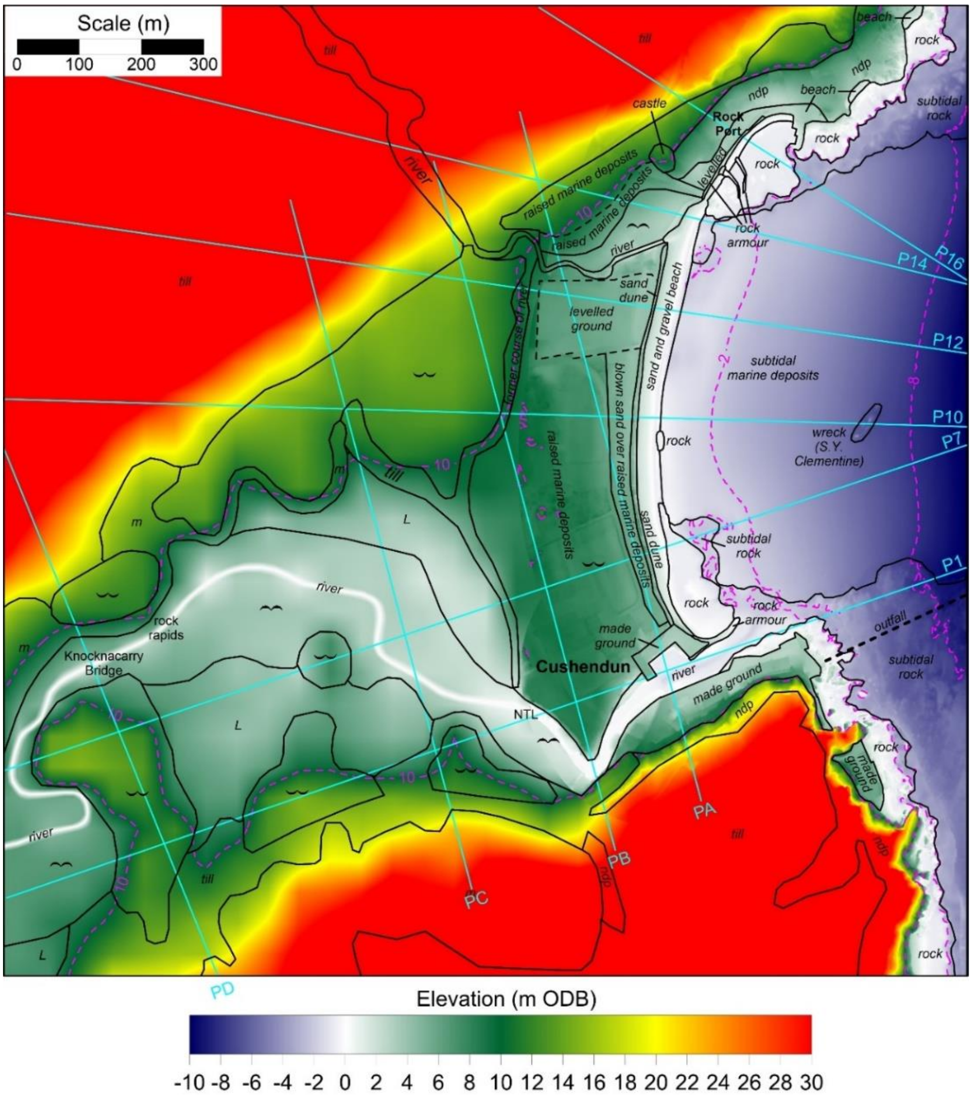


Figure 6. Geomorphological and superficial geological features overlaid on a combined topographic and bathymetry DEM constructed using 2021 LiDAR (0.25 m grid), Admiralty multibeam bathymetry surveys in 2019 (2 m grid), and OSNI 10 m terrain data. Cyan lines indicate locations of cross-profiles shown in Figure 4. Dashed magenta lines indicate contours at +10, -2 and -8 m ODB

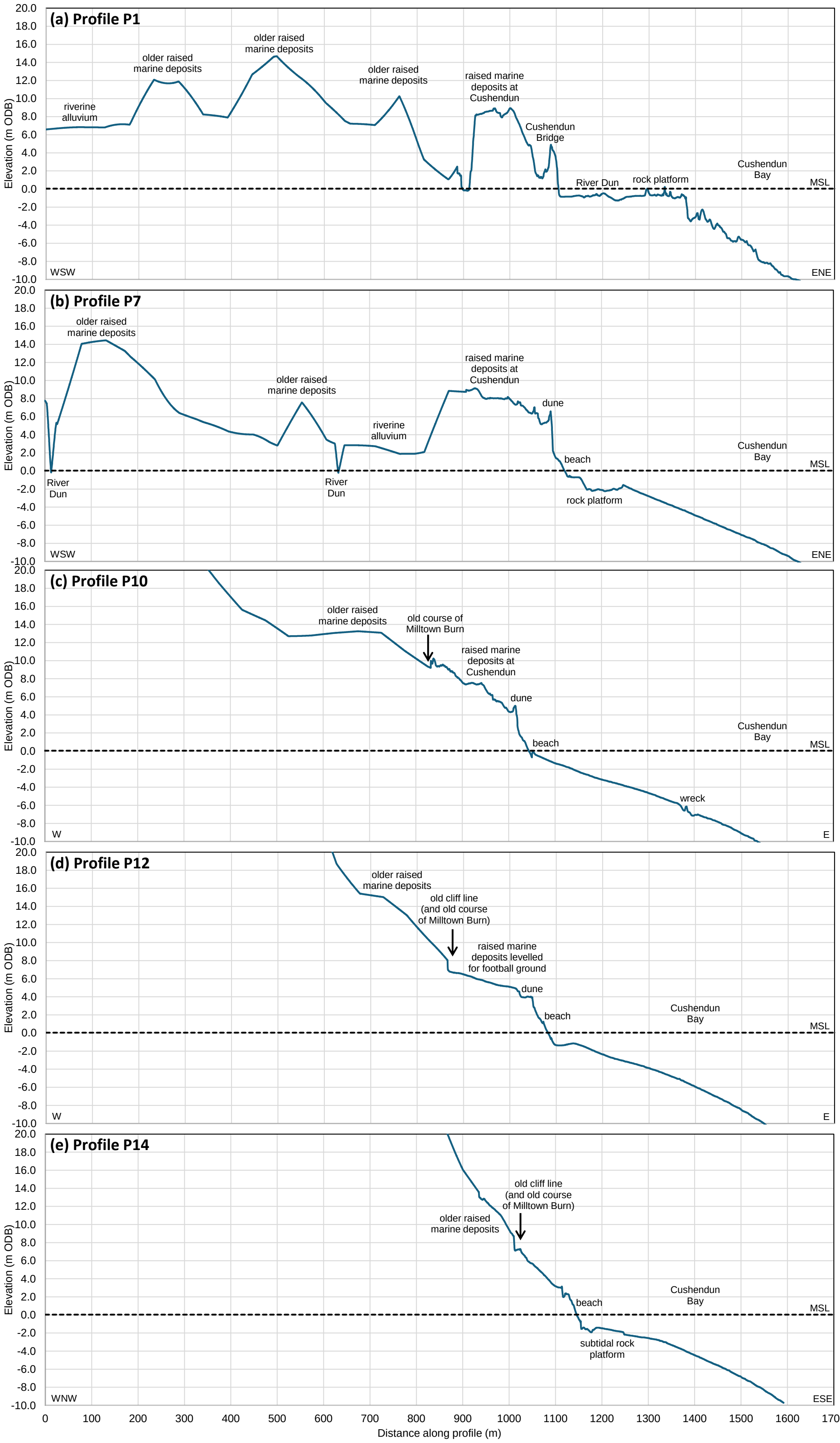


Figure 7. Topographic sections extracted from the combined topographic and bathymetric DEM

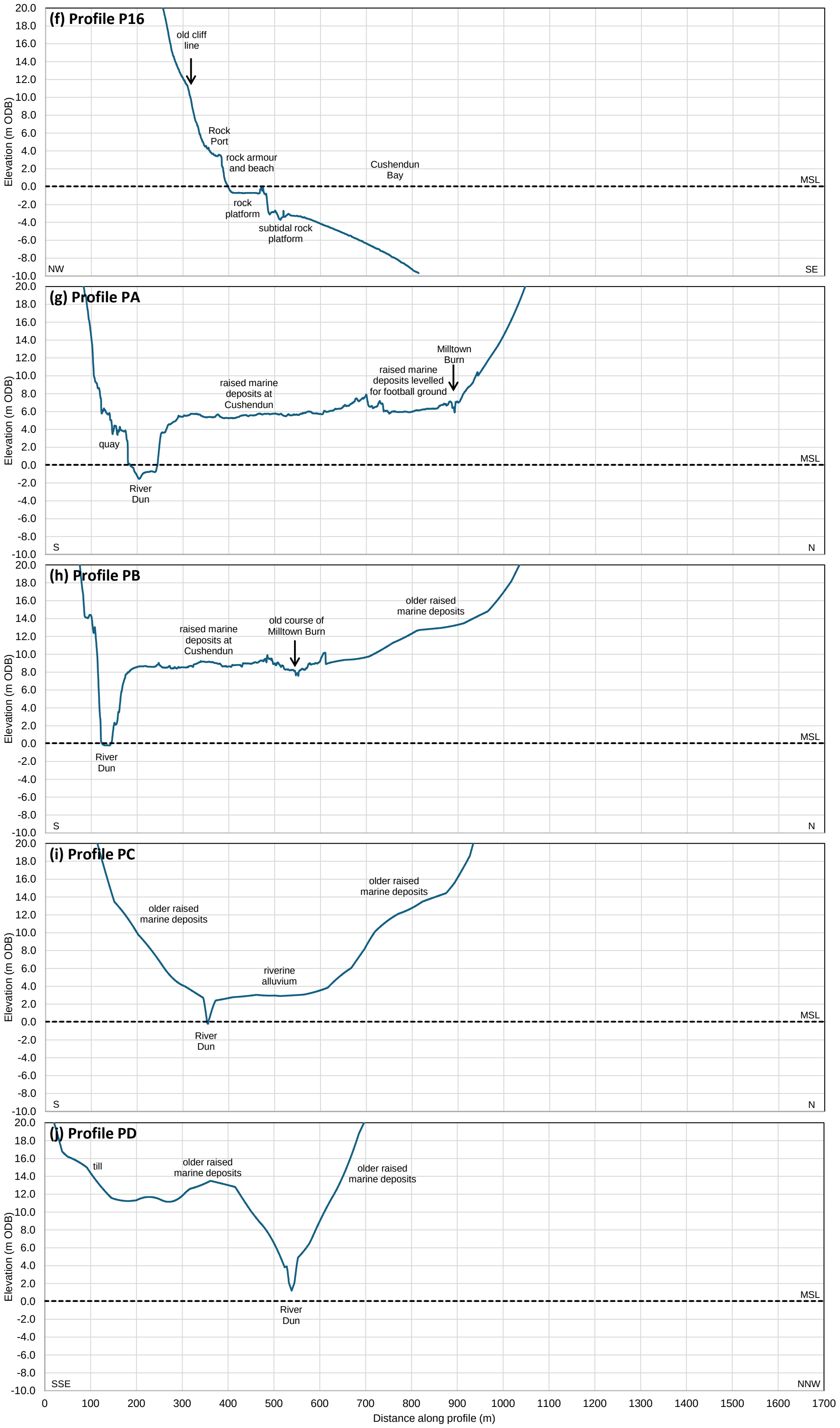


Figure 7 continued

3.3 Designated areas

The whole of the Dun catchment including Cushendun Beach lies within the Antrim Coast and Glens Area of Outstanding Natural Beauty (AONB). The northern part of the catchment also lies within the Antrim Hills Special Protection Area (SPA). Cushendun Bay below mean high water, excluding the Glendun River mouth and Cushendun harbour, lies within the Red Bay Special Area of Conservation (SAC), while the coastal fringe of Cushendun Bay is designated as a Local Wildlife Area by the Northern Ireland Environment Agency (NIEA) (Figures 8 & 9).

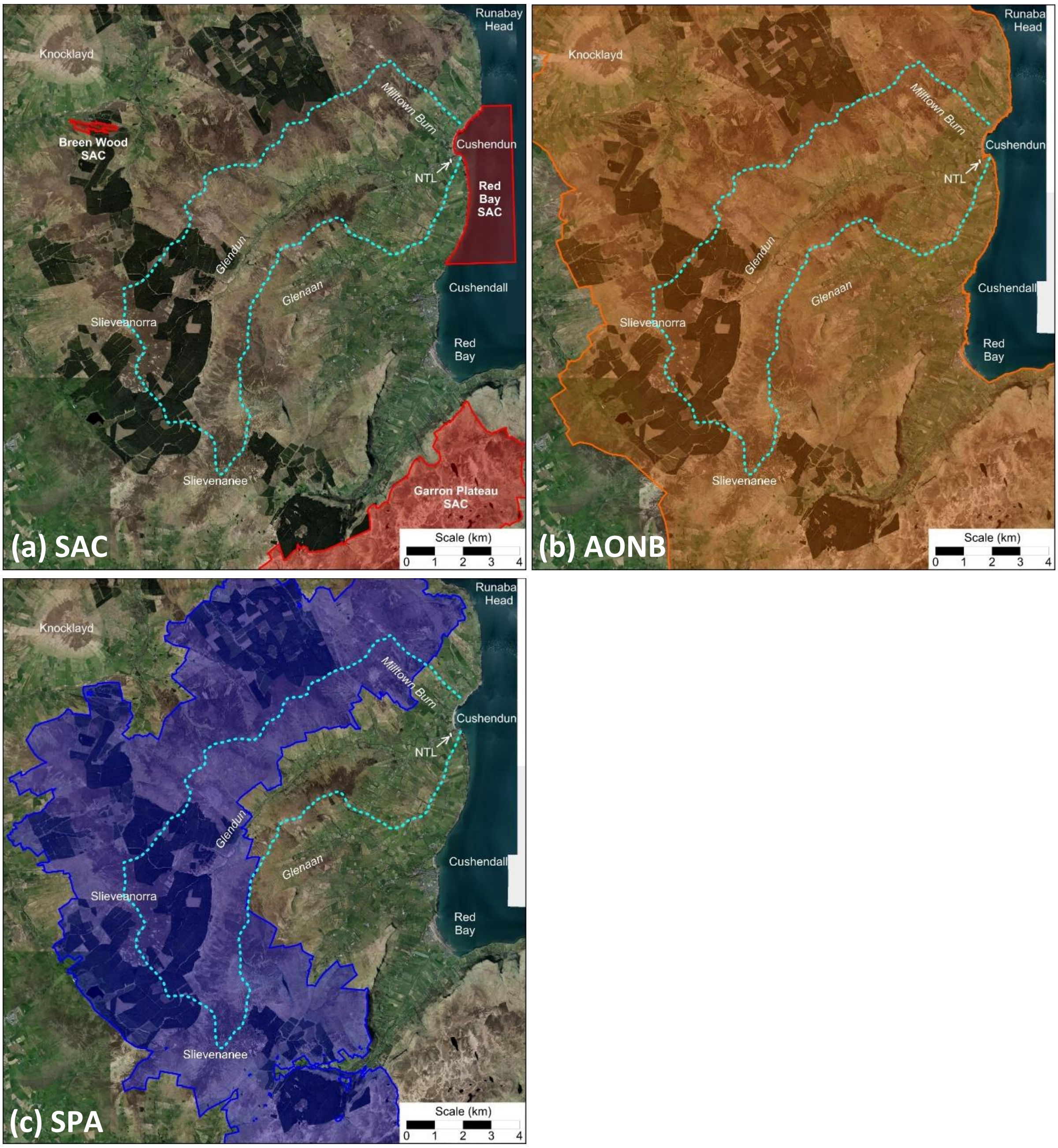


Figure 8. The catchment of the River Dun (watershed shown with a cyan dashed line) overlaid with conservation designations: (a) Special Conservation Areas (SAC, shaded red); (b) Antrim Coast and Glens Area of Outstanding Natural Beauty (AONB, shaded orange); (c) Antrim Hills Special Protection Area (SPA, shaded dark blue). Base aerial photograph flown 2007 (source: OSNI)

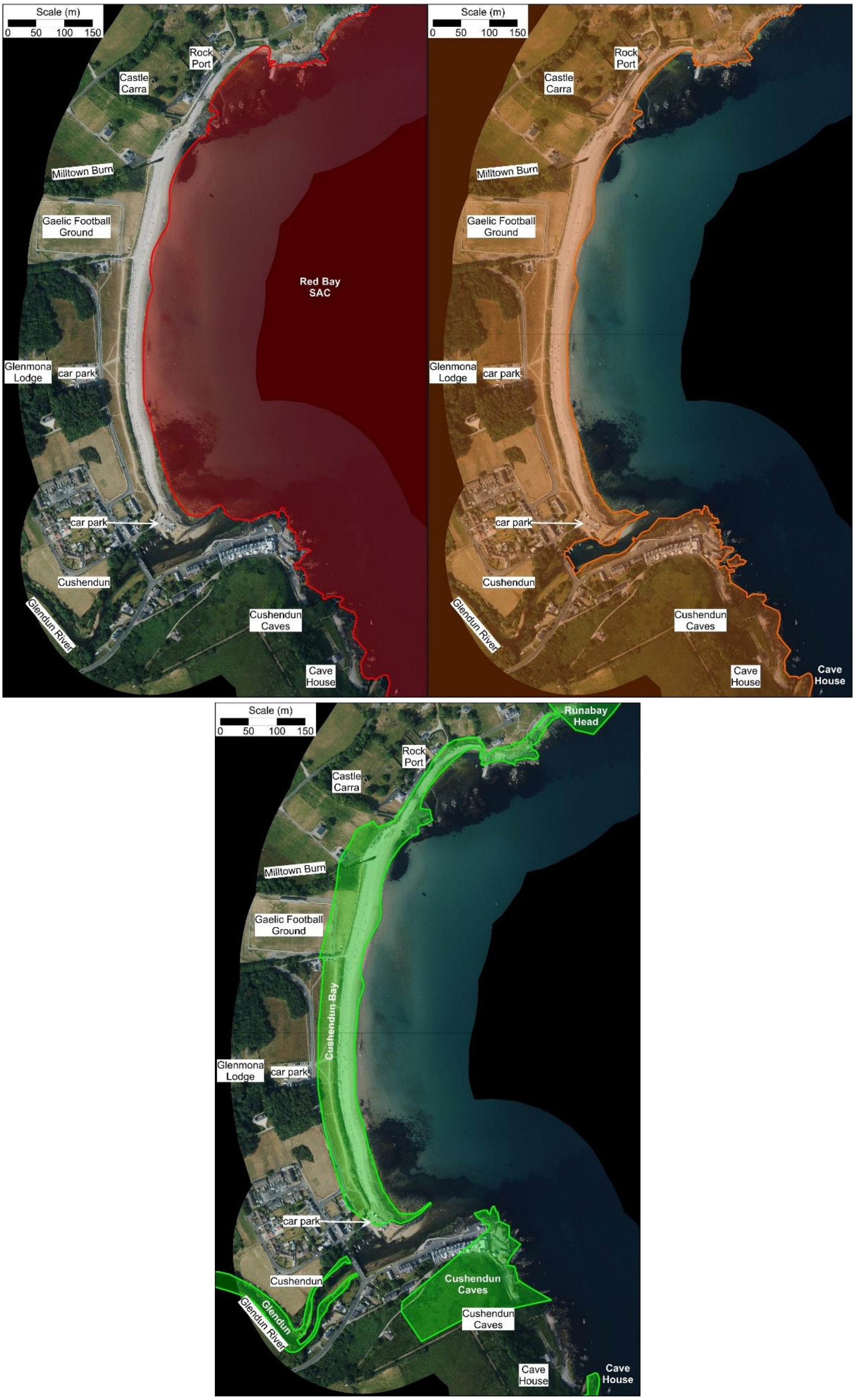


Figure 9. Conservation designations at Cushendun: (a) Red Bay SAC (shaded red); (b) Antrim Coast and Glens AONB (shaded orange); (c) area identified as a Priority Habitat: Local Wildlife Site by NIEA (shaded green). Base aerial photograph flown 2022 by Bluesky, supplied by DAERA

3.4 Tides and tidal levels

Cushendun Bay experiences a semi-diurnal tidal regime and has a small tidal range (mean spring tidal range c.1.6 m and mean neap tidal range c. 1.0 m; Table 2). The foreshore and the backshore are both relatively narrow.

Table 2. Mean tidal levels (in m relative to Ordnance Datum Belfast) along the open coast of Northern Ireland, taken from Admiralty Tide Tables (2024) and the Coastal Boundary Study 2018 Update (McMillan *et al*., 2019). Chart Datum is not stated at Cushendun, Red Bay or Newcastle, so values for these ports have been estimated based on the levels of MSL at adjacent stations and MHWS calculated by McMillan *et al*. (2019)

	Admiralty Tide Tables (2024) (m ODB)										McMillan *et al*. (2019)	
	HAT	MHWS	MHWN	MSL	MLWN	MLWS	CD	STR	MTR	NTR	HAT	MHWS
Warren Lighthouse	1.22	0.92	0.52	nd	nd	nd	-1.38	nd	nd	nd	nd	nd
Portrush	1.36	0.86	0.36	0.05	-0.44	-0.74	-1.24	1.60	1.20	0.80	1.38	0.91
Ballycastle Bay	0.88	0.48	0.18	0.03	-0.12	-0.42	-0.82	0.90	0.60	0.30	nd	nd
Cushendun	**1.04**	**0.74**	**0.44**	**0.04**	**-0.56**	**-0.86**	**-1.06***	**1.60**	**1.30**	**1.00**	**nd**	**nd**
Red Bay	1.0	0.8	0.7	nd	-0.5	-0.6	-0.8*	1.4	1.3	1.2	nd	nd
Larne	1.57	1.07	0.77	0.04	-0.93	-1.33	-1.73	2.40	2.05	1.70	1.57	1.08
Bangor	1.89	1.49	0.89	0.04	-0.91	-1.51	-2.01	3.00	2.40	1.80	1.90	1.47
Donaghadee	2.24	1.74	1.14	nd	-1.16	-1.76	-2.26	3.50	2.90	2.30	2.27	1.72
Portavogie	2.74	2.04	1.24	-0.01	-1.26	-2.06	-2.66	4.10	3.30	2.50	2.71	1.99
Killard Point	1.96	1.36	0.66	nd	-1.94	-2.64	-3.14	4.00	3.30	2.60	2.65	2.00
Ardglass	2.66	2.06	1.06	-0.14	-1.44	-2.44	-3.14	4.50	3.50	2.50	2.63	2.00
Killough Harbour	2.76	2.16	1.46	nd	nd	nd	-3.14	nd	nd	nd	2.73	2.10
Newcastle	2.6	1.8	0.8	nd	-1.9	-2.9	-3.35*	4.6	3.6	2.6	2.4	1.8
Kilkeel	1.96	1.46	0.86	-0.32	-1.74	-2.44	-3.24	3.90	3.25	2.60	1.94	1.40
Cranfield Point	1.97	1.67	1.17	nd	-1.33	-2.23	-3.13	3.90	3.20	2.50	1.94	1.62

Figure 9 and Table 3 show a comparison between tidal levels recorded at the Bangor Class A tide gauge and measured at the same time points by RTK-GNSS at Cushendun on 7th May 2024, a day with fair weather, standard pressure and low wind speeds i.e. no surge). The high and low waters occurred 10 minutes earlier at Cushendun than at Bangor. High Tide was observed to be about 87 cm lower at Cushendun than at Bangor. Low water on the open coast beach was found to be 98 cm lower but inside the harbour the low water level was found to be only 83 cm lower due to effect of river flow.

Table 3. Comparison of the times (GMT) and elevations (m ODB) of high and low waters recorded at the Class A gauge at Bangor on 7th May 2024, and the levels recorded at Cushendun by RTK-GNSS on the same day. For low waters, values recorded on the open coast (beach) are discriminated from values recorded beside the slipway in Cushendun harbour

Location	High tide time	Low tide time	High tide level (m ODB)	Low tide level (m ODB)
Bangor	09:53	16:23	1.55	-1.60
Cushendun open coast	nd	16:15	nd	-0.98
Cushendun harbour	09:41	16:15	0.68	-0.83

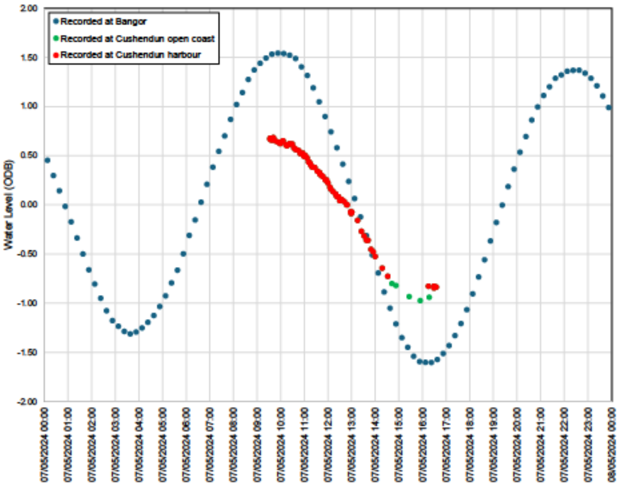


Figure 9. Comparison of tidal levels recorded at the Class A gauge at Bangor on 7th May 2024, and the levels recorded at Cushendun by RTK-GNSS on the same day. For low waters, the graph discriminates between values recorded on the open coast (beach) and beside the slipway in Cushendun harbour

Observed high tidal levels can be a metre or more higher than predicted levels due to the effect of meteorological surges. While the level highest predicted astronomical tide (HAT) at Cushendun is approximately +1.04 m ODB the estimated 1 in 1 year high water level is 1.61 m ODB and the 1 in 200 year extreme level is 2.40 m ODB. Modelling by UKCP18 suggests that the 1 in 1 year level at Cushendun could increase by 11 - 25 cm by 2050 and by 32 - 89 cm by 2100 (50th percentile model output values for the RCP4.5 emission scenario and 95th percentile value for the RCP8.5 emissions scenario. Even larger potential increases are projected for the 1 in 200 and higher magnitude extreme water levels (Table 4).

The increases in mean sea level for the Cushendun area projected under different emissions scenarios are shown in Figure 10. For coastal planning purpose published guidance is that a account should now taken of the 70th and 95th percentile model output values for the 'high' RCP8.5 emissions scenario. In the latter case this would imply a total possible rise in MSL at Cushendun of c. 35 cm by 2050 and c. 83 cm by 2100, relative to present day (2025).

Table 4. Extreme water levels (in m ODN) for a point c.2.5 km offshore from Cushendun (Chainage Number _76), calculated as part of the Environment Agency Coastal Boundary 2018 Update Study (EA, 2019), and extrapolated levels for the years 2050 and 2100 under two UKCP18 climate scenarios (RCP4.5 and RCP8.5 with 50th, 70th and 95th modelled outputs) (www.ukclimateprojections-ui.metoffice.gov.uk/products).

Return period (years)	2018	2050				2100			
		RCP4.5 50th %ile	RCP8.5 50th %ile	RCP8.5 70th %ile	RCP8.5 95th %ile	RCP4.5 50th %ile	RCP8.5 50th %ile	RCP8.5 70th %ile	RCP8.5 95th %ile
1	1.61	1.72	1.76	1.79	1.86	1.93	2.14	2.23	2.50
2	1.71	1.82	2.08	1.89	1.96	2.03	2.24	2.33	2.60
5	1.83	1.94	1.98	2.01	2.08	2.15	2.36	2.45	2.72
10	1.93	2.04	2.08	2.11	2.18	2.25	2.46	2.55	2.82
20	2.05	2.16	2.20	2.23	2.30	2.37	2.58	2.67	2.94
25	2.08	2.19	2.23	2.26	2.33	2.40	2.61	2.70	2.97
50	2.18	2.29	2.33	2.36	2.43	2.50	2.71	2.80	3.07
75	2.24	2.35	2.39	2.42	2.49	2.56	2.77	2.86	3.13
100	2.29	2.40	2.44	2.47	2.54	2.61	2.82	2.91	3.18
150	2.35	2.46	2.50	2.53	2.60	2.67	2.88	2.97	3.24
200	2.40	2.51	2.55	2.58	2.65	2.72	2.93	3.02	3.29
250	2.43	2.54	2.58	2.61	2.68	2.75	2.96	3.05	3.32
300	2.46	2.57	2.61	2.64	2.71	2.78	2.99	3.08	3.35
500	2.55	2.66	2.70	2.73	2.80	2.87	3.08	3.17	3.44
1000	2.67	2.78	2.82	2.85	2.92	2.99	3.20	3.29	3.56
10000	3.14	3.25	3.29	3.32	3.39	3.46	3.67	3.76	4.03

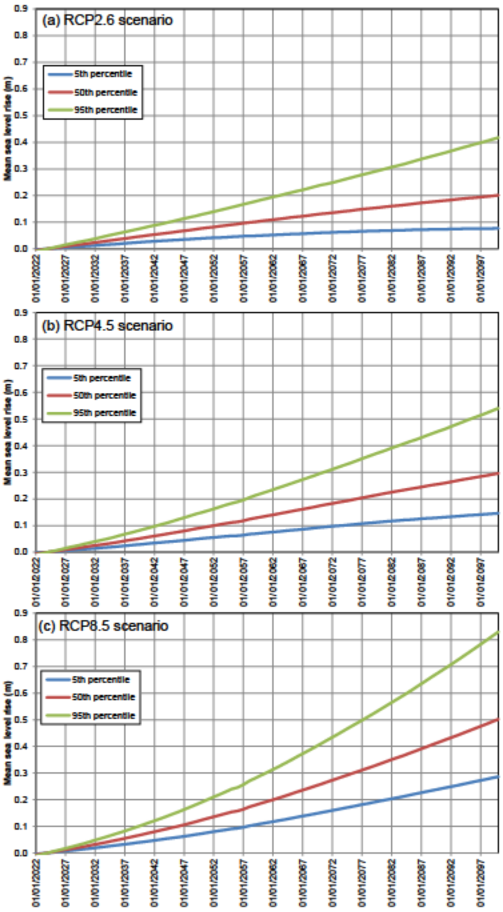


Figure 10. Projections of future mean sea level at Cushendun under three possible future atmospheric emissions scenarios (RCP2.6, RCP4.5 and RCP8.5). Data source: UCKP User Interface- (www.ukclimateprojections-ui.metoffice.gov.uk/products , accessed 17/06/2024)

Figure 11 provides a schematic illustration of the 2018 and 2100 1 in 1 and 1 in 200 still water levels relative to the land at three locations around Cushendun Bay. At Rockport the projected 2100 1 in 200 still water level would reach the level of the concrete road in front of Rockport Lodge. In the centre of the bay the 1 in 200 still water level would stand approximately half-way up the dune cliff at the back of the beach, and at the southern end of the bay the 2100 still water level would be about 1 m below the surface level of the NT harbour car park. The water depth immediately in front of the rock revetment in this area would be more than 3m, allowing waves to reach the revetment (if it was still in existence) without breaking.

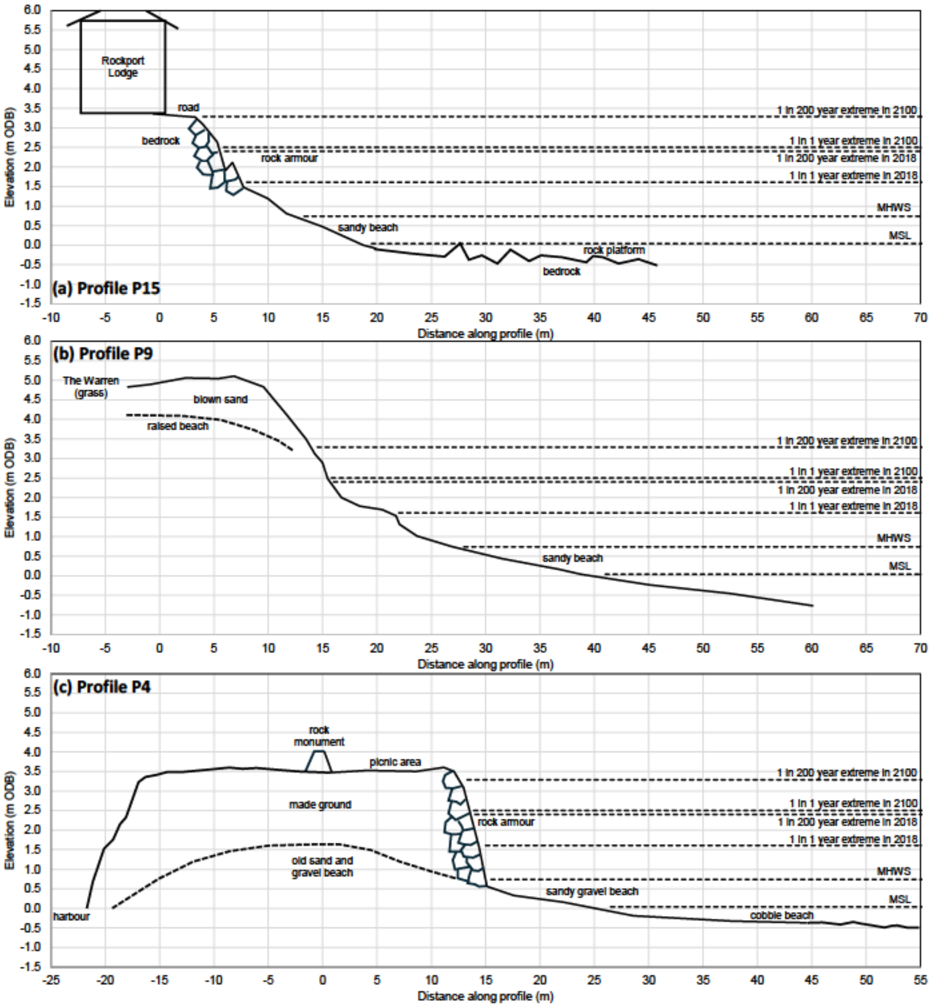


Figure 11. Three selected profiles at Cushendun, showing mean tidal levels and 1 in 1 and 1 in 200 year extreme tidal levels for the present (base year 2018), and in the year 2100 under an extreme RCP8.5 scenario (95th percentile values)

3.5 *Winds and waves*

The prevailing regional winds in the Cushendun area are south-westerly but the most influential winds and waves within Cushendun Bay are directed from the northeast, east and southeast. The maximum linear wave fetch lies in a northeasterly direction towards the Ayrshire coast, but larger waves passing through the North Channel can be refracted into Cushendun Bay from the north-east, and larger southerly waves moving up the Irish Sea from the south and south-east can be refracted into Cushendun Bay. Hindcast wave modelling for the period 1979-2012 showed that the dominant wave direction in the northern Irish Sea is from the south (Gallagher et al., 2014). In the Cushendun Bay area wave trains from more than one direction commonly interact. Figure 12 shows a modelled wave scenario on 20th October 2024 when fairly large southerly waves were generated off the Antrim coast during the passage of significant depression (Storm Ashley). On this occasion the significant wave height (Hs) at the entrance to Cushendun Bay was predicted to be around 2.6 m. As southeasterly waves enter the Bay they are refracted around Fisherman's Point and spread out, reducing in height due to the combined effects of diffraction and bottom friction. There is also a reduction in crest-to-crest wavelength and wave breaking begins to occur when the water depth becomes equivalent to approximately half the wave length. Hence waves break first over elevated areas of the sea-bed such as rock outcrops and nearshore banks. Such features also induce further local wave refraction and wave focussing on sections of the shoreline behind. As a result there can be significant variations in alongshore breaking wave height.

No measured or modelled wave data are available for the inshore area of Cushendun Bay but field observations made during the present study between February 2024 and February 2025 indicated that around the time of water on high spring tides and with waves entering the bay from the SE the largest breaking wave heights occur on the central section of Cushendun Strand, but during period of wave approach from the NE and E largest waves impact on the southern half of the beach and the rock armour fronting the NT harbour car park.

Carter (1991, p35) concluded there is wave-induced sediment transport into the southern part of the bay from the SSE and a dominant onshore-offshore sediment exchange between the beach and nearshore bars, with southerly net alongshore sediment drift along the southern part of the beach. Observations and data analysis in the present study suggest that net rates of alongshore sediment transport are low within Cushendun Bay, but periodically there is a significant net sub-tidal drift of sediment past Cushendun Caves into the Bay from the south. Much of this sediment moves towards the harbour mouth where it contributes to the bar and the accumulation of sediment inside the harbour mouth. There is very little evidence of net southerly sediment transport along Cushendun Strand at the present time, and since at least the 1970s this area has experienced net sediment loss, resulting in faster rates of backshore erosion than in the northern half of the bay where accumulation of shingle has taken place around the outlet of Milltown Burn.

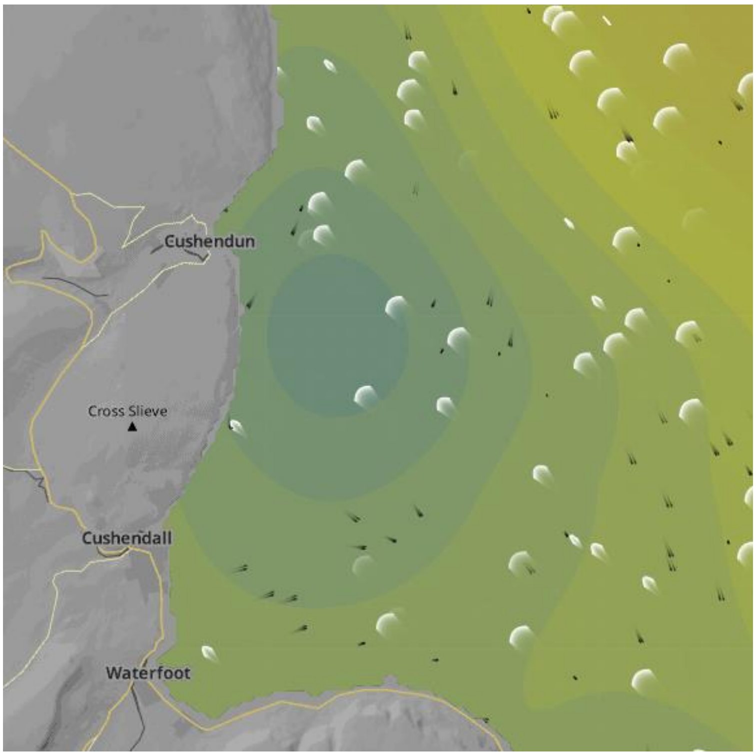


Figure 12. Modelled wave approach directions and relative heights off the Antrim coast during the passage of Storm Ashley on 20th - 21st October 2024 (Source: Ventusky)

3.6 Beach sediments

The supratidal, intertidal and shallow subtidal parts of Cushendun beach consists of mixed sand and gravel. No information is available about the deeper sub-tidal areas. There is considerable spatial and temporal variability in the proportions of sand and gravel on the mid and upper beach which reflects variations in wave conditions. In general, the northern half of the bay between the outfall of Mill Burn and Rockport contains more gravel and less sand. Rock outcrops extensively on the foreshore in this area. In the southern half of the bay the mid and upper beach on average contains more sand, with the result that dunes are better developed behind the beach in this area. There is a significant intertidal rock outcrop just north of the National Trust café car park. Scattered loose rocks in this area may represent the remains of an old rock groyne which it is suggested may have existed in this area in the early 19th century (R. McDonnell pers. Comm.)

Sediment samples were collected for particle size analysis from six locations during site visits in May 2024 and September 2024 (locations shown on Figure 12 and sample details given in Table 5).

Figure 12. Locations of sediment samples collected on 7th May 2024 and 19th September 2024. Base Aerial photography flown 28/08/2021 by Bluesky and supplied by Northern Ireland Coastal Observatory

Table 5. Sediment samples collected from Cushendun beach and dunes on 7th May 2024 (analysed by dry sieving) and 19th September 2024 (analysed by laser diffraction)

ID	Date sampled	Easting	Northing	Description
C1	07/05/2024	324969.97	432725.62	Upper beach, south end near National Trust car park
C2	07/05/2024	324963.10	432845.88	Lower beach step near low tide mark, south of break in timber wall
C3	07/05/2024	324946.59	432842.39	Upper beach between shingle cusps, south of break in timber wall
C4	07/05/2024	324924.19	432867.71	Eroding dune cliff. 1.5 m above the top of the beach, south end of beach
C5	19/09/2024	324920.85	432977.42	Upper foreshore, mid-bay by beach access path
C6	19/09/2024	324932.36	433143.63	Backshore
C7	19/09/2024	324921.57	432878.94	Eroding dune cliff behind gap in sleepers, just below a thin humic layer

The analysis results (Table 6) show that the gravel is typically 5 - 22 mm in size with a median (D_{50}) of approximately 10 mm. The beach and dune sands are typically medium to coarse with a D_{50} of 270 - 425 µm.

Table 6. Particle size summary statistics of sediment samples collected from Cushendun beach and sand dunes on 7th May 2024 (analysed by dry sieving) and 19th September 2024 (analysed by laser diffraction)

ID	Mean (µm)	Primary Mode (µm)	Secondary Mode (µm)	D10 (µm)	D50 (µm)	D90 (µm)	Gravel (>2 mm) (%)	Sand (63-2000 µm) (%)	Mud (<63 µm) (%)
C1	253.5	215.0		180.8	246.6	409.8	0.2	99.8	0.0
C2	10280.5	9600.0		5322.4	9819.1	21372.8	100.0	0.0	0.0
C3	1135.7	4800.0	427.5	297.4	798.4	5580.5	45.3	54.7	0.0
C4	368.4	427.5		217.7	364.8	614.8	0.0	99.8	0.2
C5	270.7	269.2		188.3	270.4	392.8	0.0	100.0	0.0
C6	328.6	324.4		211.4	326.4	523.7	0.0	100.0	0.0
C7	408.8	390.9		229.2	404.5	745.3	0.0	98.4	1.6

The gravel is typically very well rounded to well rounded and equant to sub-equant in character (Figure 13). White, translucent and pick quartz are the dominant lithological clast type, followed by Old Red Sandstone, granite / microgranite, quartzite and dolerite. Provenance is probably mainly directly from local rocks with some reworked glacial till-derived material.

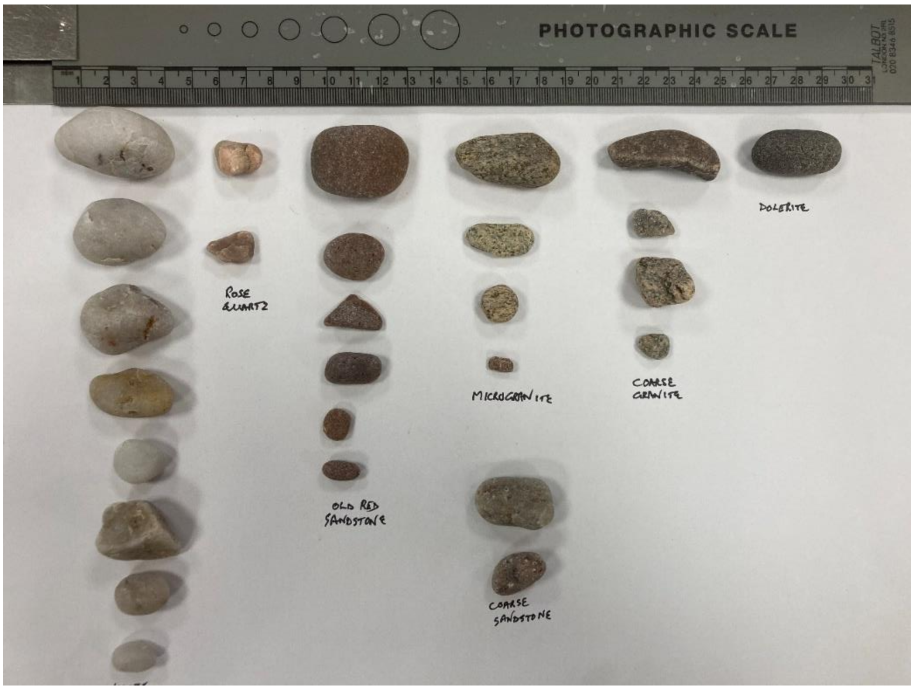


Figure 12. Gravel clast types in sample 6 taken on 19th September 2024

The distribution of gravel and sand on Cushendun Beach shows considerable temporal as well as spatial variability. Short-term variations occur due in response to changes in tidal and wave conditions. Periods of storm waves and large tides tend to selectively remove sand from the upper beach and move it into the shallow subtidal area, leaving a lag which is enriched in gravel. During very large storms gravel may also be moved into the sub-tidal zone and also thrown landwards onto the top of the dunes and shingle ridge which is found in the northern part of the bay near Milltown Burn.

Historically a considerable quality of sand and gravel was removed from Cushendun beach for agricultural and construction purposes. Indeed, in many parts of Ireland sand has been removed and used to improve heavy agricultural soils at least since the early Middle Ages, and at Cushendun an agreement was reached in the late 19th century which allowed local farmers to remove ten loads of sea sand or gravel free, with a charge of 9d (4p) a load thereafter (Carter *et al*., 1992). In former times the amount of sand and gravel removed was limited by the need to shovel the material by hand into a horse-drawn cart, but in the second half of the 20th century the increasing use of tractors and excavators resulted in much larger quantities being removed. Carter *et al*. (1992) reported from direct observations carried out one day a week (randomly selected) over 52 weeks in 1990 that 5 instances of sand and/or gravel removal and concluded from this an indirect evidence (such as vehicle tracks and exaction pits) that removal occurred on at least 35, and possibly as many as 270 days each year, involving an estimated sediment volume of 530 m^3 (equivalent to 1230 tonnes). Most of the extraction occurred in the spring / early summer and from the central and northern parts of the beach. Beach level monitoring over the same period indicated recession of the low dune cliff and shingle ridge at the back of the beach in this area by 2 -3 m in 1990. No instances of sand removal from the southern third of the beach were recorded, although recession of the dune cliff of up to 3.5 occurred in this area over the monitoring time period. Severe erosion in this southern area became evident from 1987 onwards (Carter & Bartlett, 1990). Examination of historical ground photographs of the beach (see Appendix 3) suggests that over the past century there has been a significant reduction in the proportion of sand on Cushendun beach, relative to gravel, which may at least in part be due to selective removal of sand. Although extraction appears not to occur on the same scale as in the past, it appears not to have ceased altogether.

4.0 Evidence of change from historical maps and photographs

4.1. Evidence form historical maps

In order to assess likely future coastal changes it is important to first understand the nature (and ideally the causes) of changes which have occurred on different time scales in the past. Historical maps, aerial photographs, ground photographs, charts and plans can provide useful information in this regard, sometimes qualitative and sometimes quantitative.

Ordnance Survey Six-inch and Twenty-Five-inch map editions provide a particularly useful starting point in understanding historical change over the last 150 - 200 years (the First Edition County Series map of Cushendun was surveyed in 1833 – see Appendix 2). The frequency and quality of map revisions varies from area to area and between mapping epochs, but provided adequate care is taken in interpretation the analysis of such maps can provide a useful indicator of shoreline changes on decadal to centennial timescales.

An analysis of historical shoreline changes based on historical maps, broadly similar to that undertaken in Phase 1 of the *Dynamic Coast* project in Scotland (Rennie *et al*., 2021), was commissioned by DAERA and undertaken by Ulster University in 2022-23 (Grottoli *et al*., 2023). Graphical and mapping outputs from the project are now available on the Northern Ireland Coastal Observatory viewer developed by DAERA in collaboration with ESRI.

Figure 13 shows the locations of transects which were used in the Ulster University study to quantify change in Cushendun Bay. Table 7 shows the dates of the maps and aerial photographs used in their analysis and also the dates and sources used to undertake a comparative analysis in the present study which selected 17 positions for RTK-GNSS surveys of the beach and coastal edge (Figure 14; see following section).

Table 7. Historical maps, aerial photographs and ground surveys used to measure change in the seaward edge of vegetation or sea defence at Cushendun in this study and DSAS analysis by Ulster University (2023)

Description	Tide lines and vegetation line survey date	Used in this study	Used in DSAS analysis
Six-inch Ordnance Survey map, published 1837	1832	✓	✓
Six-inch Ordnance Survey map, published 1862	1846	✓	✓
Six-inch Ordnance Survey map, published 1906	1903-1904	✓	✓
Six-inch Ordnance Survey map, published 1935	not revised		✓
1:10,000 Ordnance Survey map, published 1976	1973	✓	✓
Aerial photography (Google Earth)	13/05/2001	✓	
Aerial photography (OSNI)	2003		✓
Aerial photography (OSNI)	2007		✓
Satellite image (Google Earth)	24/07/2011	✓	
Satellite image (NI Coastal Observatory)	August 2021	✓	✓
Ground RTK-GNSS	07/05/2024	✓	

At each of the 17 survey locations a zero-reference point was defined behind the shoreline shown on the OS Six-inch map surveyed in1832. The distance from this point to the seaward edge of vegetation shown on each subsequent map or aerial image was then measured (Table 8). The change in this distance between each epoch is shown in Table 9 and the average annual rate of change at each profile is shown in Table 10. It is evident from these tables that erosion has been episodic, with relatively high rates of erosion at a majority of profiles between 1832 and 1846 and between 1973 and 2001. Between 2001 and 2011 progradation occurred at all profiles, partly due to dune toe protection interventions. However, since 2011 most profiles have experienced a return to slow erosion, wit the exception of profiles P14 - P17 (just south of Milltown Burn to Rockport), where further accretion of gravel has occurred.

Table 11 shows the long-term average rate of erosion / accretion at each profile over the period 1832 – 2024 calculated by two methods (linear regression rate) and end point analysis method, compared with the long-term average rates at the same locations determined in the Ulster University study. The results for profiles P6 - P16 are very similar. Data for the other profiles are not directly comparable due to differences in the orientation / definition of the transect lines.

The changes in vegetation edge position over time determined in our analysis are plotted graphically in Figure 14. Profiles P6 to P14 all show a long-term recession (erosion trend), there has been no net overall change at P15 while at P16 and P17 there has been a long-term net progradation trend due to shingle accumulation.

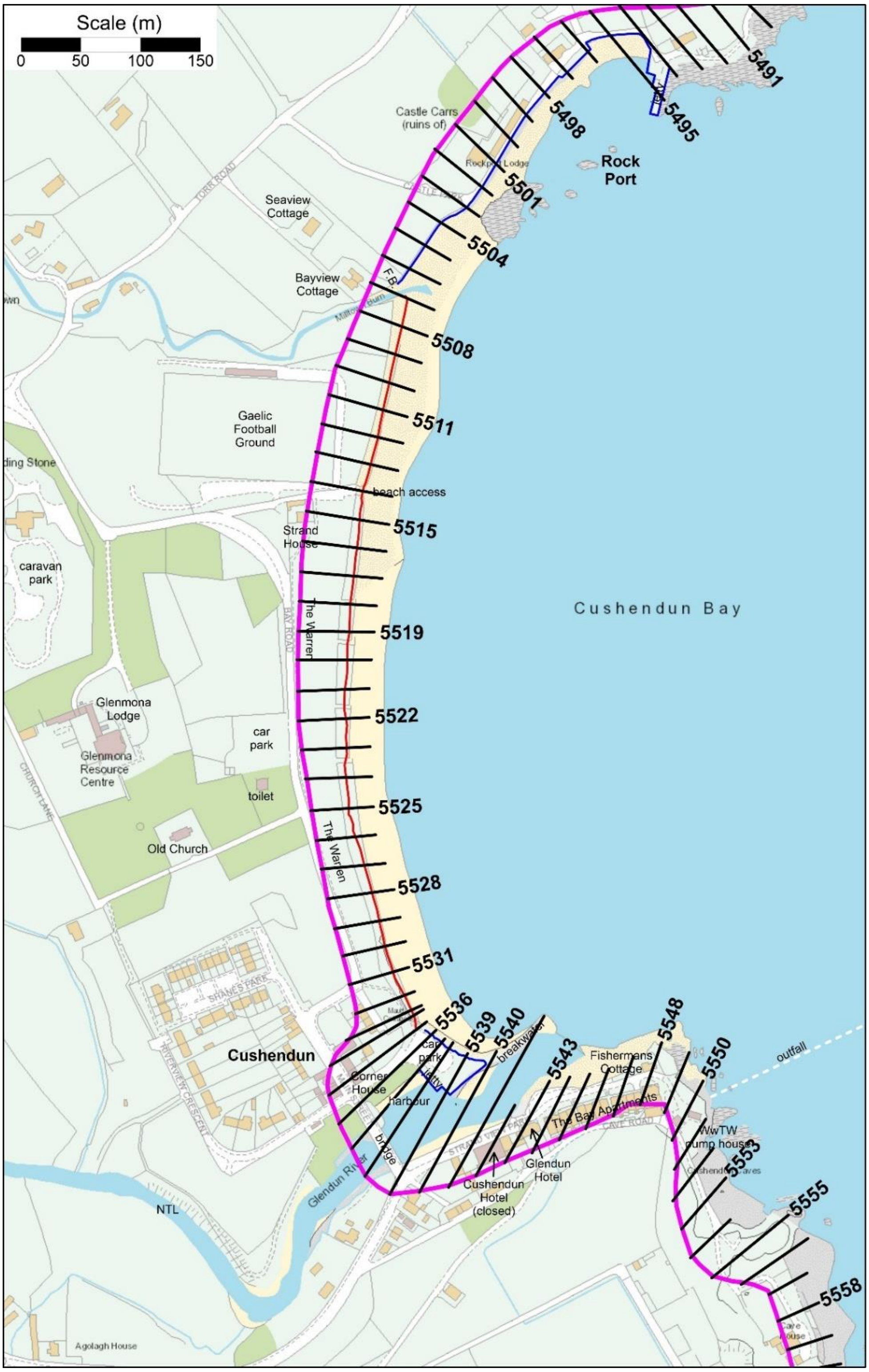


Figure 13. Locations of Transects (black lines) used in DSAS historical shoreline analysis by Ulster University (2023) and supplied via the Northern Ireland Coastal Observatory. The pink line indicates the notional baseline used in the DSAS analysis, the red line indicates the dune toe and the blue line the seaward limit of vegetation (usually the top of defences or seaward side of paths or roads) surveyed in May 2024. Transects are spaced at 25 m intervals along the baseline. Those Transects coinciding with KPAL RTK-GNSS monitoring profiles, and other transects with rates of change given in this report, are labelled with the Transect Number

Figure 14. Locations of profiles used for RTK-GNSS topographic monitoring in this study. The red line indicates the dune toe and the blue line indicates the seaward limit of vegetation (usually the top of defences or seaward side of paths or roads) surveyed in May 2024

Table 8. Distance (m) from the profile start point of the seaward edge of vegetation or sea defence indicated in historical Ordnance Survey maps (surveyed in 1832, 1846, 1903 and 1973), aerial imagery dated 13/05/2001, 24/07/2011 and 28/08/2021, and surveyed by ground RTK GNSS on 07/05/2024

Profile	1832	1846	1903	1973	2001	2011	2021	2024
P1	nd	nd	nd	nd	0.0	0.0	0.0	0.0
P2	nd	nd	nd	nd	0.0	0.0	0.0	0.0
P3	nd	nd	nd	nd	13.5	13.2	13.2	13.2
P4	nd	nd	nd	nd	13.1	13.1	13.1	13.1
P5	19.9	8.6	8.6	30.6	24.7	24.7	22.0	22.2
P6	32.8	31.0	39.4	37.7	27.5	28.9	27.7	27.6
P7	31.6	44.6	46.8	42.2	30.4	31.8	31.7	31.7
P8	48.0	48.2	52.6	47.5	37.4	38.5	35.7	33.2
P9	58.4	53.3	58.4	54.6	40.6	42.1	41.8	41.8
P10	65.8	56.6	64.8	58.6	46.3	47.1	47.3	47.8
P11	59.4	50.8	53.2	57.7	34.5	39.7	38.9	38.9
P12	48.6	44.6	42.7	31.7	28.4	30.8	31.1	31.1
P13	59.3	58.0	53.2	37.3	36.1	43.2	42.6	42.0
P14	33.4	17.2	24.8	15.0	16.4	18.6	18.5	18.5
P15	9.0	3.0	8.2	8.2	8.2	8.2	8.2	8.2
P16	6.6	13.2	16.8	16.8	17.6	17.6	17.6	17.6
P17	7.8	9.8	14.2	15.2	16.9	19.9	21.9	22.8

Table 9. Change in distance (m) between the seaward edge of vegetation or sea defence in 1832 and subsequent surveys (based on measurements from Ordnance Survey maps surveyed in 1832, 1846, 1903 and 1973), aerial imagery dated 13/05/2001, 24/07/2011 and 28/08/2021, and RTK GNSS ground survey on 07/05/2024. Note that no ‘backshore’ was present at profiles P1 to P4 between 1832 and 1973

Profile	1832	1846	1903	1973	2001	2011	2021	2024
P1	nd	nd	nd	nd	0.0	0.0	0.0	0.0
P2	nd	nd	nd	nd	0.0	0.0	0.0	0.0
P3	nd	nd	nd	nd	3.5	3.2	3.2	3.2
P4	nd	nd	nd	nd	3.1	3.1	3.1	3.1
P5	0.0	-11.3	-11.3	10.7	4.8	4.8	2.1	2.3
P6	0.0	-1.8	6.5	4.9	-5.4	-3.9	-5.1	-5.2
P7	0.0	13.0	15.3	10.6	-1.2	0.2	0.1	0.1
P8	0.0	0.2	4.6	-0.6	-10.6	-9.6	-12.4	-14.8
P9	0.0	-5.1	0.0	-3.8	-17.7	-16.3	-16.6	-16.6
P10	0.0	-9.2	-1.0	-7.3	-19.5	-18.7	-18.5	-18.0
P11	0.0	-8.6	-6.2	-1.7	-24.9	-19.7	-20.5	-20.5
P12	0.0	-3.9	-5.8	-16.9	-20.2	-17.8	-17.5	-17.4
P13	0.0	-1.4	-6.2	-22.0	-23.2	-16.1	-16.7	-17.3
P14	0.0	-16.2	-8.5	-18.4	-17.0	-14.8	-14.9	-14.9
P15	0.0	-6.0	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
P16	0.0	6.6	10.2	10.2	11.0	11.0	11.0	11.0
P17	0.0	2.0	6.4	7.3	9.1	12.1	14.1	14.9

Table 10. Rate of change (m/yr) between epochs in the position of the seaward edge of vegetation or sea defence indicated on historical Ordnance Survey maps surveyed in 1832, 1846, 1903 and 1973, aerial imagery dated 13/05/2001, 24/07/2011 and 28/08/2021, and RTK GNSS ground survey on 07/05/2024

Profile	1832-1846	1846-1903	1903-1973	1973-2001	2001-2011	2011-2021	2021-2024
P1	nd	nd	nd	nd	0.00	0.00	0.00
P2	nd	nd	nd	nd	0.00	0.00	0.00
P3	nd	nd	nd	nd	-0.04	0.01	0.00
P4	nd	nd	nd	nd	0.00	0.00	0.00
P5	-0.81	0.00	0.31	-0.21	0.00	-0.27	0.07
P6	-0.13	0.15	-0.02	-0.37	0.15	-0.12	-0.03
P7	0.93	0.04	-0.07	-0.42	0.13	-0.01	0.00
P8	0.02	0.08	-0.07	-0.36	0.11	-0.28	-0.81
P9	-0.36	0.09	-0.05	-0.50	0.15	-0.03	-0.02
P10	-0.66	0.14	-0.09	-0.44	0.08	0.02	0.15
P11	-0.61	0.04	0.06	-0.83	0.51	-0.08	0.00
P12	-0.28	-0.03	-0.16	-0.12	0.24	0.03	0.02
P13	-0.10	-0.08	-0.23	-0.04	0.71	-0.06	-0.20
P14	-1.16	0.13	-0.14	0.05	0.22	-0.01	0.00
P15	-0.43	0.09	0.00	0.00	0.00	0.00	0.00
P16	0.47	0.06	0.00	0.03	0.00	0.00	0.00
P17	0.14	0.08	0.01	0.06	0.30	0.20	0.28

Table 11. The linear regression rate and end point change rate (m/yr) between 1832 and 2024 from analysis of historical OS maps and aerial imagery in this study, compared with results of the Ulster University analysis between 1832 and 2021. Where profiles coincide within a few metres they are shown in the same row. Note that no 'backshore' was present at profiles P1 to P4 between 1832 and 1973 so no data ('nd') is indicated; values for corresponding profiles in the Ulster University analysis (Transects 5536 to 5540) are measured from the south side of the River Glendun (Transects 5539 and 5540), and west of the harbour (Transect 5536) so are not directly comparable. Transect 5495 crosses the beach at an oblique angle, leading to an apparently large positive rate of change compared to shore-perpendicular profile P17 at the same location

Profile	This study		Ulster University DSAS (2023)		
	Linear regression rate (1832-2024)	End point rate (1832-2024)	Transect	Linear regression rate (1832-2021)	End point rate (1832-2021)
			5558	-0.01	0.01
			5555	0.03	0.00
			5553	-0.05	-0.11
			5550	-0.03	0.01
			5548	0.07	0.09
			5543	0.14	0.11
P1	nd	nd			
P2	nd	nd			
P3	nd	nd	5540	0.43	0.38
P4	nd	nd	5539	0.55	0.50
P5	0.06	0.01	5536	0.44	0.43
P6	-0.03	-0.03	5531	-0.03	-0.03
P7	-0.04	0.00	5528	-0.05	0.00
P8	-0.07	-0.08	5525	-0.06	-0.06
P9	-0.08	-0.09	5522	-0.08	-0.09
P10	-0.09	-0.09	5519	-0.09	-0.09
P11	-0.09	-0.11	5515	-0.11	-0.11
P12	-0.10	-0.09	5511	-0.10	-0.09
P13	-0.10	-0.09	5508	-0.11	-0.10
P14	-0.05	-0.08	5504	-0.10	-0.11
P15	0.01	0.00	5501	0.00	-0.01
P16	0.04	0.06	5498	0.03	0.03
P17	0.07	0.08	5495	0.37	0.34
			5491	0.04	0.08

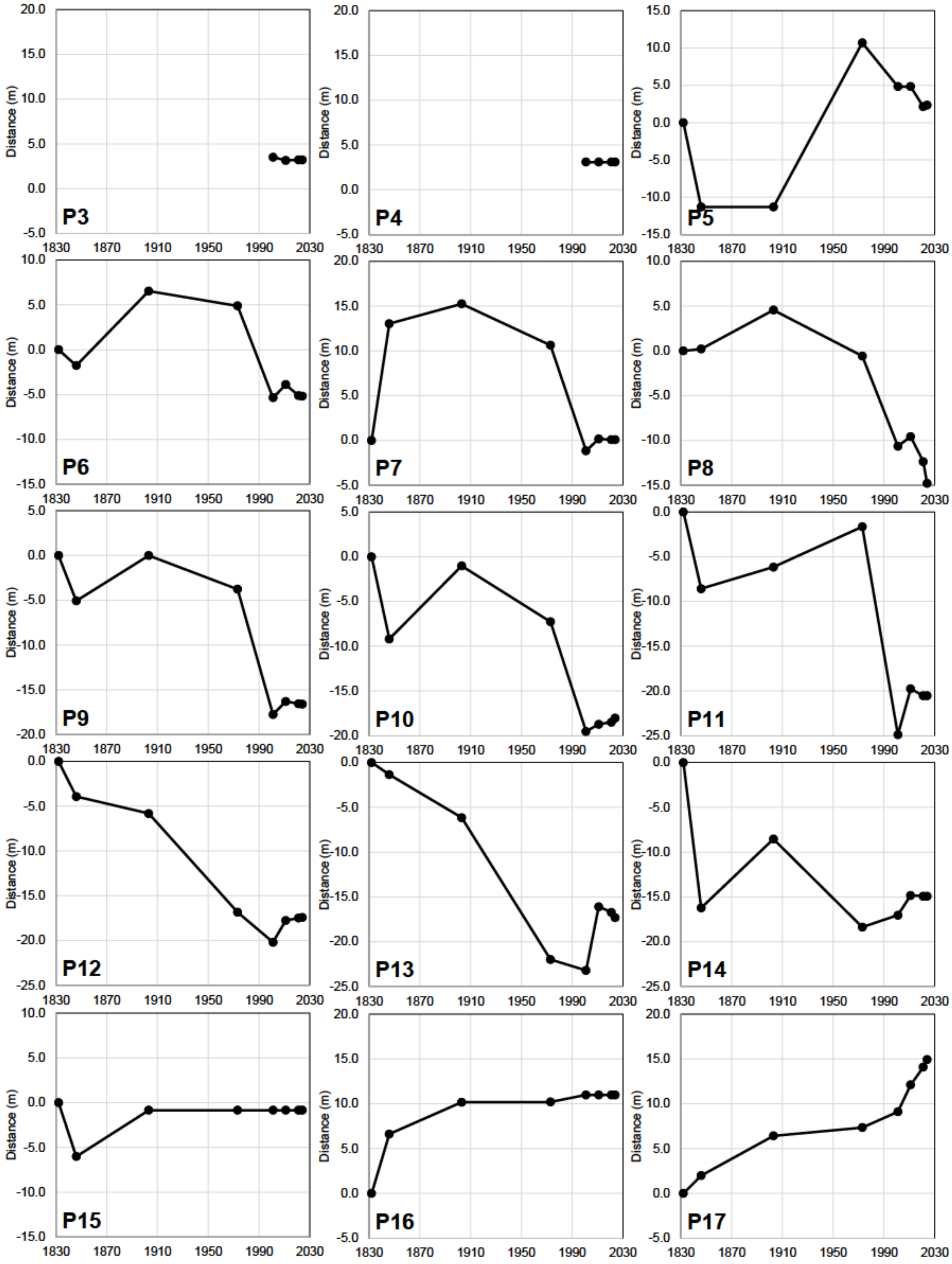


Figure 15. Distance (m) between the seaward edge of vegetation or sea defence in 1832 and subsequent surveys taken from historical Ordnance Survey maps (surveyed in 1832, 1846, 1903 and 1973), aerial photographs flown on 13/05/2001, 24/07/2011 and 28/08/2021, and ground RTK-GNSS in May 2024

5.0 Coastal monitoring framework

5.1 Previous assessments of coastal monitoring requirements

A Gap Analysis undertaken for DAERA by Amey and HR Wallingford (2018) identified that no formalised regional coastal monitoring framework of the type established in England in the 1990s and early 2000s exists in Northern Ireland. They concluded that “the data currently available is insufficient to develop the necessary Coastal Erosion Vulnerability mapping, and more information and data is required to bring the understanding of coastal erosion to a comparable level with our UK counterparts”. Jackson & Cooper (2023) also noted that, with exception of a small number of beaches on the north coast and in Dundrum Outer Bay, most beaches in Northern Ireland lack information about morphology and change on monthly, seasonal, long-term and episodic timescales. Their opinion was that the development of a monitoring programme could provide essential information to inform coastal management by local authorities and Northern Ireland government. Recommendations regarding the type, frequency and methods of monitoring were made in their report and 15 key, high priority sites were identified, one of which is Cushendun. To date, however, a systematic monitoring programme along the lines suggested has not been initiated.

5.2 Coastal monitoring framework for Cushendun Bay

One of the main tasks in the present study was to develop and implement a coastal monitoring scheme for Cushendun Bay which can be carried forward into the future and used to inform coastal management. A comprehensive coastal monitoring framework should include regular measurement of a number of attributes and reference to adequate baseline information. Monitored attributes can include:

(1) Topography and morphology (supratidal and intertidal)
(2) Bathymetry (subtidal)
(3) Marine water levels (tidal levels, surges, longer term averages e.g. annual mean sea level)
(4) Waves and currents
(5) Riverine inputs (discharge)
(6) Bed sediments (particle size, shape, mineralogy, chemical composition especially contaminant levels)
(7) Suspended sediments (particle size, shape, mineralogy, chemical composition, contaminant levels)
(8) Water chemistry and quality (salinity, temperature, pH, nutrient levels, coliforms
(9) Terrestrial ecology (especially supratidal and intertidal vegetation community type and composition)
(10) Marine / estuarine ecology (subtidal vegetation type, distribution and composition
(11) Local weather conditions (temperature, precipitation, wind etc.)

From the perspective of coastal flooding and erosion risk management (FCERM) attributes (1) to (6) are particularly important. A number of methods can be employed for the monitoring of these attributes and choice will inevitably be influenced by factors such as availability of funding, equipment and trained personnel. Some attributes may require almost continuous monitoring while others may only require surveys every few months or years. Since resources are usually finite, the intensity and frequency of monitoring is often determined using a risk-based approach (risk being defined as the product of hazard x consequence). In some circumstances, periodic site walkover inspections may suffice. In others, near-continuous surveillance using remote sensing technologies or ground-based instrumentation may be required. Citizen science may have a role to play, including the uploading of photographs and verbal reporting of simple measurements to a notified website. Since 2020 DAERA has instigated a programme of Northern Ireland-wide coastal monitoring using airborne LIDAR and aerial photography. The first airborne survey of the whole coast was undertaken in 2021; the data can now be viewed on the Northern Ireland Coastal Observatory website. A second series of surveys was commissioned in 2024 with a view to completion in 2025. It is hoped that further surveys will be conducted every few years in the future

5.3 RTK-GNSS ground topographic surveys

While airborne LIDAR is extremely useful for monitoring three-dimensional change across large areas, more frequent topographic information may be required in sensitive areas subject to rapid change and to understand the magnitude of short-term variations. For the purpose of this study it was decided to use a combination of LIDAR analysis and RTK-GNSS topographic monitoring along selected cross-shore profiles at Cushendun. Figure 16 shows a Digital Terrain Model (DTM) constructed using the original 2021 airborne LIDAR survey which were supplied for the purposes of the project, meshed with bathymetric data for Cushendun Bay obtained from the UK Government Opendata website. Superimposed on the DTM are the profile lines selected for topographic change monitoring on the beach and frontal dunes. The start and end point co-ordinates for each profile are listed in Table 12. Ground surveys were carried out on four occasions during the project, February, May and November 2024 and February 2025. The profiles for each survey are compared visually in Figure 18. Quality control data for the surveys are included in Appendix 4.

Table 12. Location of the start and end points, and bearing from grid north, of beach and dune monitoring profiles at Cushendun. Eastings and Northings are in metres relative to Irish National Grid.

Profile	Start		End		Bearing
	Easting	Northing	Easting	Northing	
P1	325003.28	432647.64	324993.59	432642.66	242.75
P2	325003.33	432647.87	325008.74	432640.19	144.85
P3	325024.34	432664.88	325060.79	432731.65	28.63
P4	325010.10	432668.82	325052.94	432733.83	33.38
P5	324967.77	432684.55	325029.26	432736.95	49.56
P6	324928.81	432743.74	324992.28	432762.40	73.61
P7	324905.96	432814.35	324986.99	432834.23	76.22
P8	324885.36	432882.91	324964.16	432890.43	84.55
P9	324874.31	432964.38	324965.87	432962.61	91.11
P10	324871.50	433042.68	324959.29	433038.18	92.93
P11	324889.29	433134.65	324963.45	433123.21	98.77
P12	324914.95	433219.31	324976.77	433206.19	101.98
P13	324924.50	433311.46	325014.92	433283.60	107.13
P14	324973.95	433378.89	325020.36	433351.16	120.87
P15	325028.08	433420.29	325054.67	433404.21	121.16
P16	325067.04	433495.21	325110.25	433464.02	125.82
P17	325136.16	433548.96	325147.64	433477.19	170.91

The distances between each profile start point, the seaward limit of vegetation and selected tidal contour levels, together with the amount of change between surveys, are shown in Table 13-18. A clear seasonal patter is evident with sediment gain and seaward movement of the upper beach tidal contours in the spring and summer (February – May and May – September 2024) and sediment removal and landward movement of the upper tidal level contours over the winter of 2024-25. Movement of the lower tidal level tidal contours shows a reverse pattern, reflecting the effect of higher winter storm waves moving sediment from the upper to the lower parts of the intertidal beach (and also to the subtidal zone). During the spring and summer periods constructive waves progressively move sediment back up the beach.

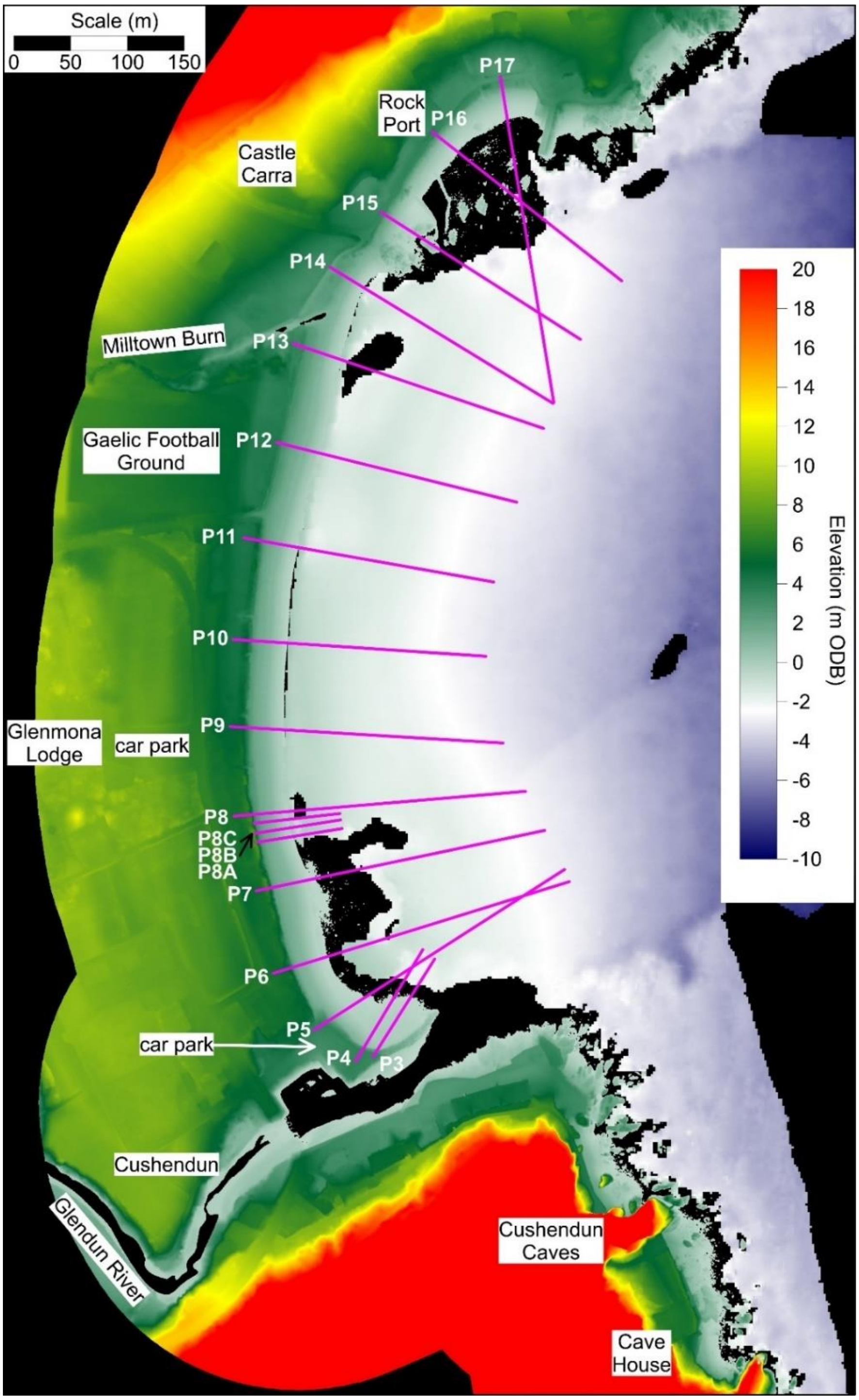


Figure 17. Combined LiDAR DTM flown 28/08/2021 by Bluesky and satellite-derived bathymetry survey on 26/08/2019 undertaken by Fugro for UKHO and DAERA (supplied via Admiralty Marine Data Portal). Pink lines show recommended ongoing monitoring profiles (originally surveyed by KPAL) extended to -3 m ODB to cover the gap between the LiDAR and bathymetry (no data shown in black)

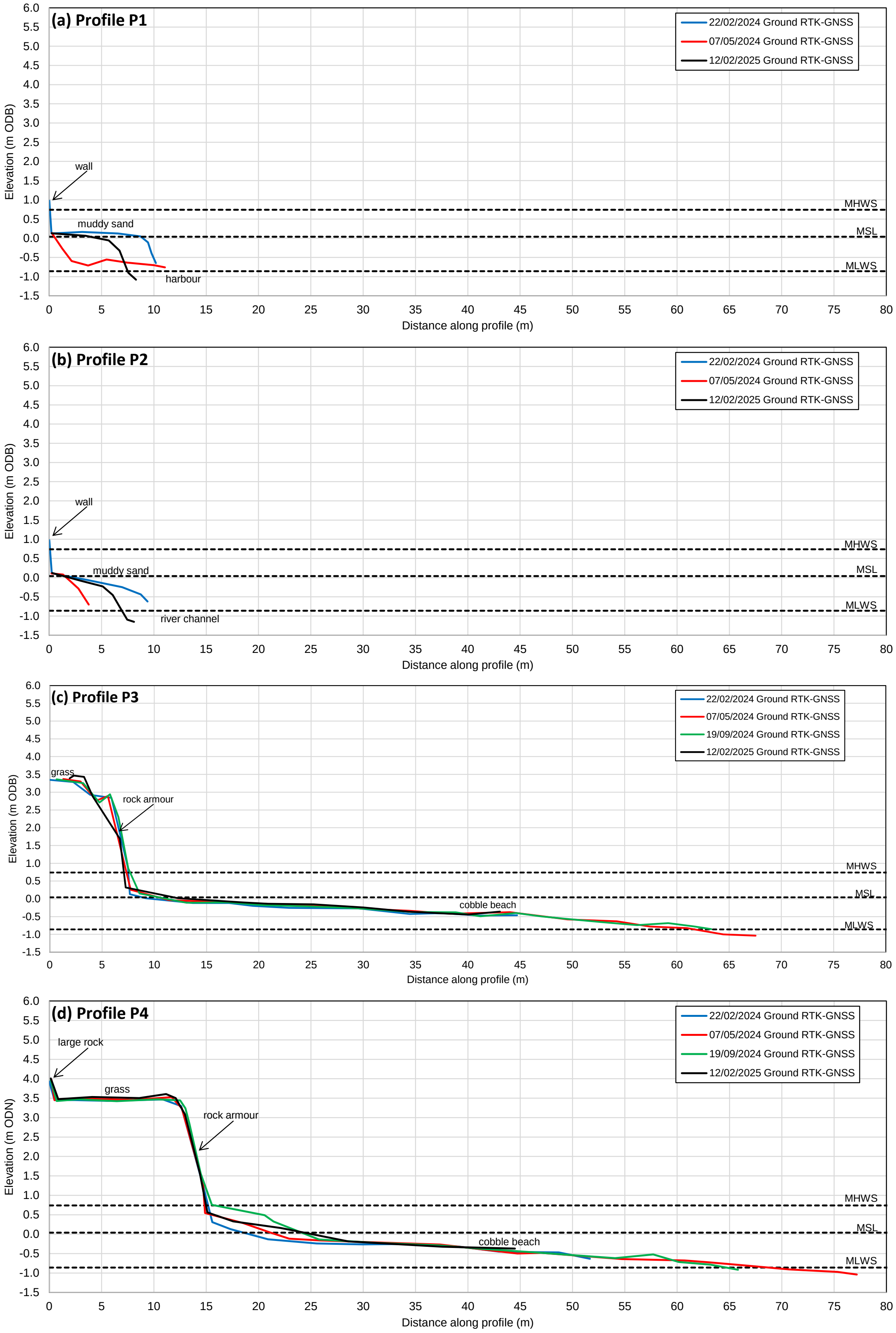


Figure 18. Profiles surveyed 22/02/2024, 07/05/2024, 19/09/2024 and 12/02/2025. Note that there was no sediment to survey on Profiles P1 and P2 on 19/09/2024 due to removal by dredging the previous May

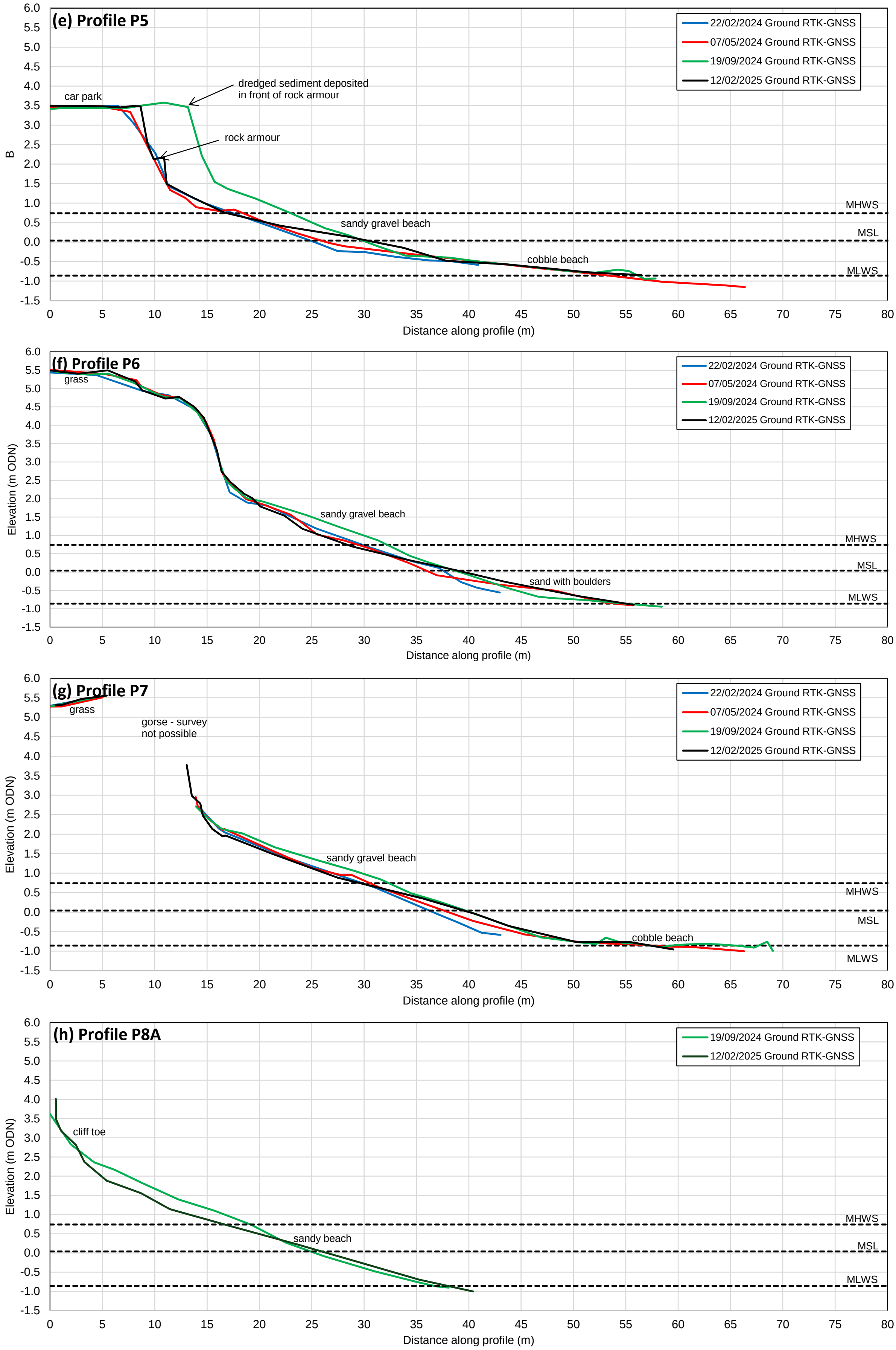


Figure 18 continued

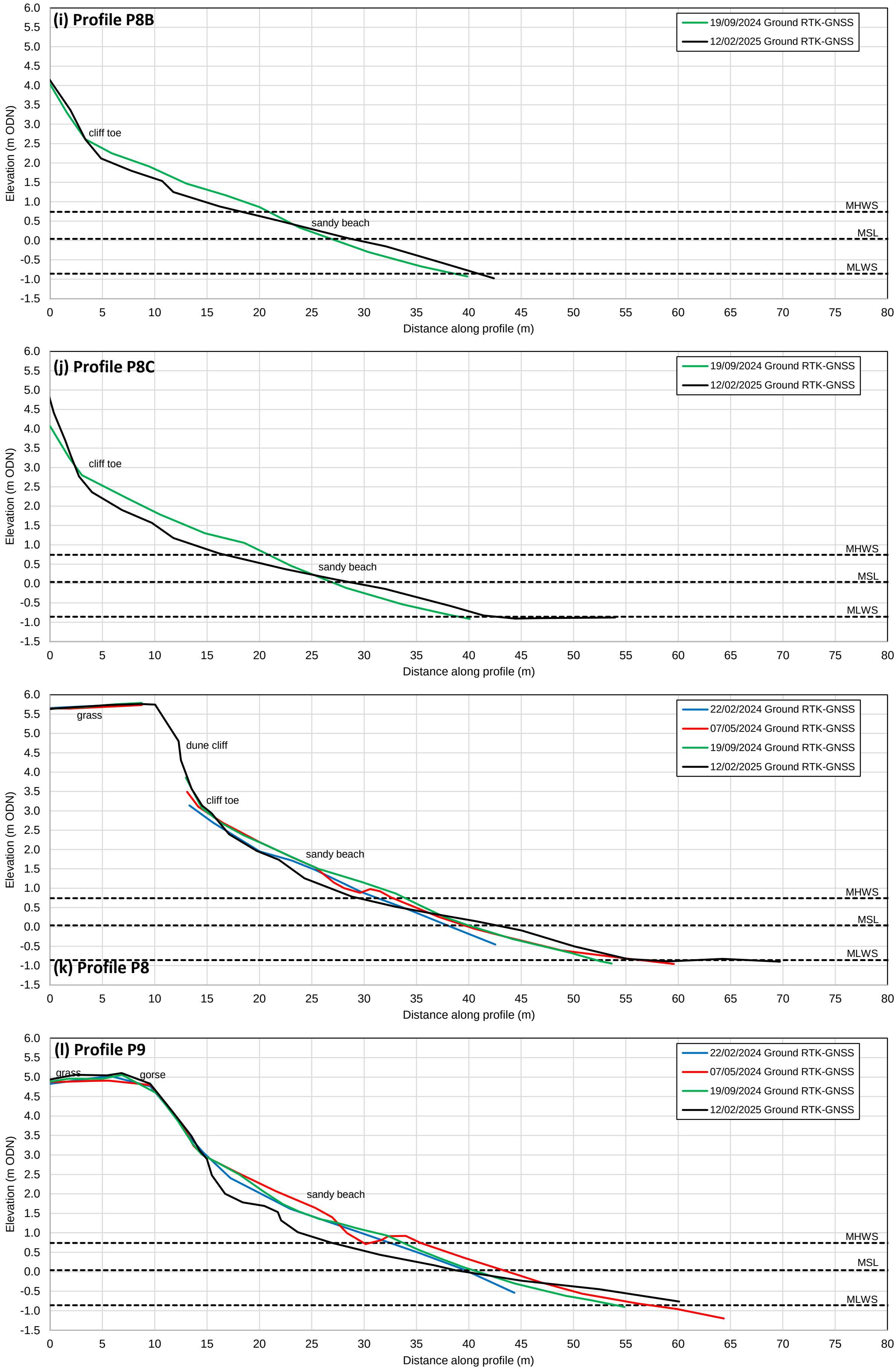


Figure 18 continued

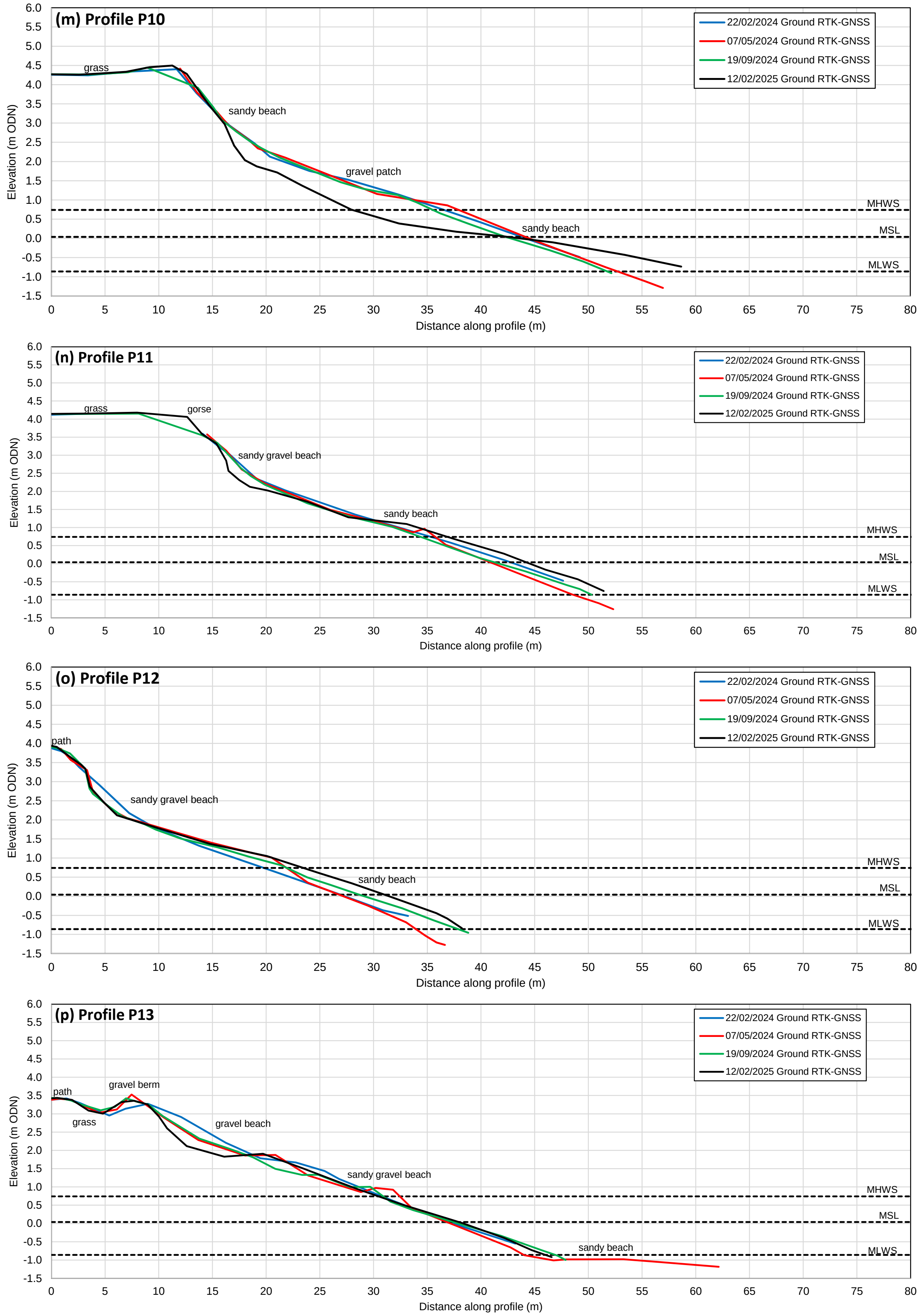
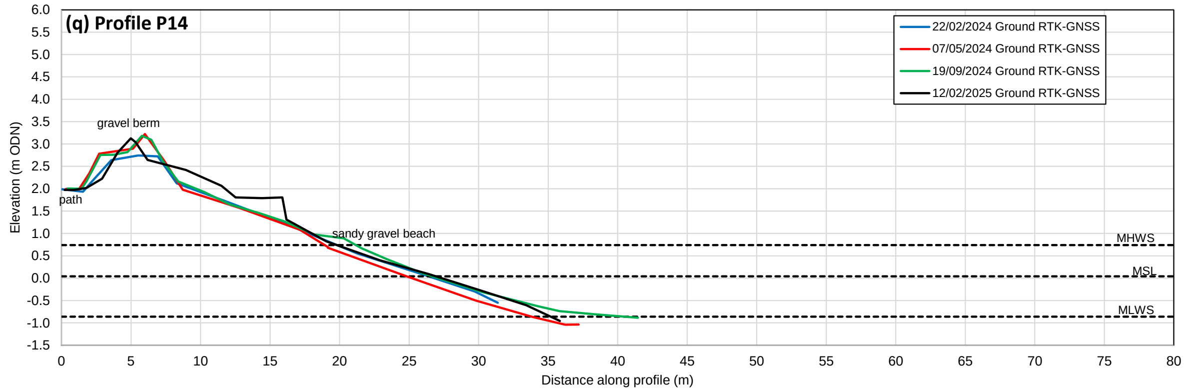
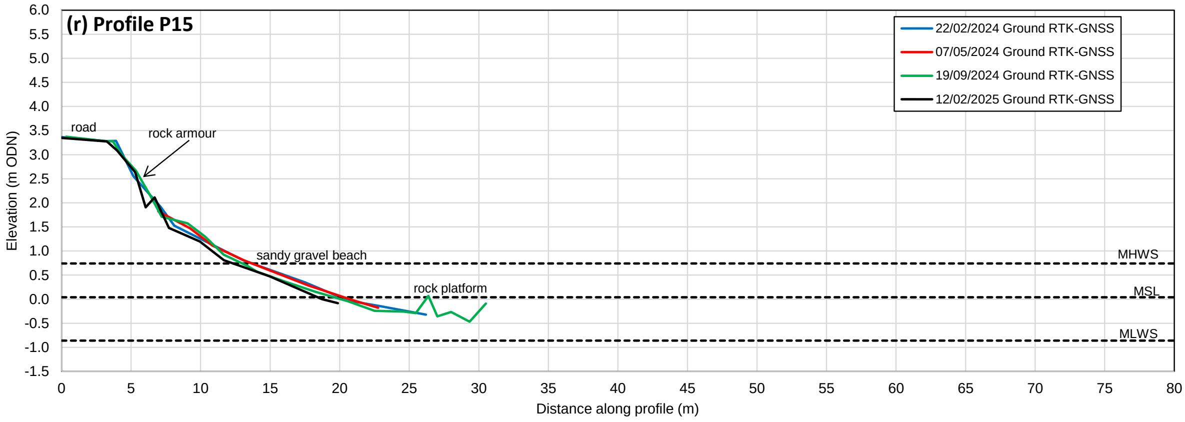
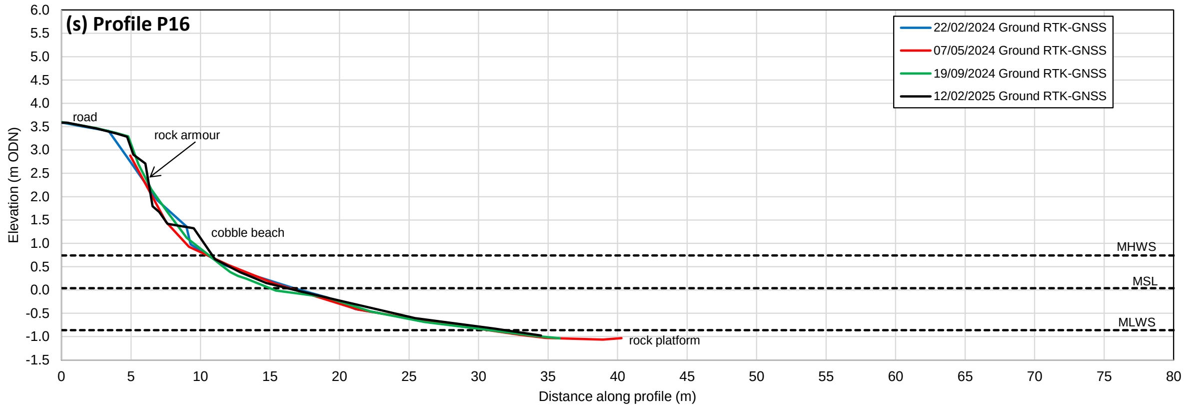


Figure 18 continued







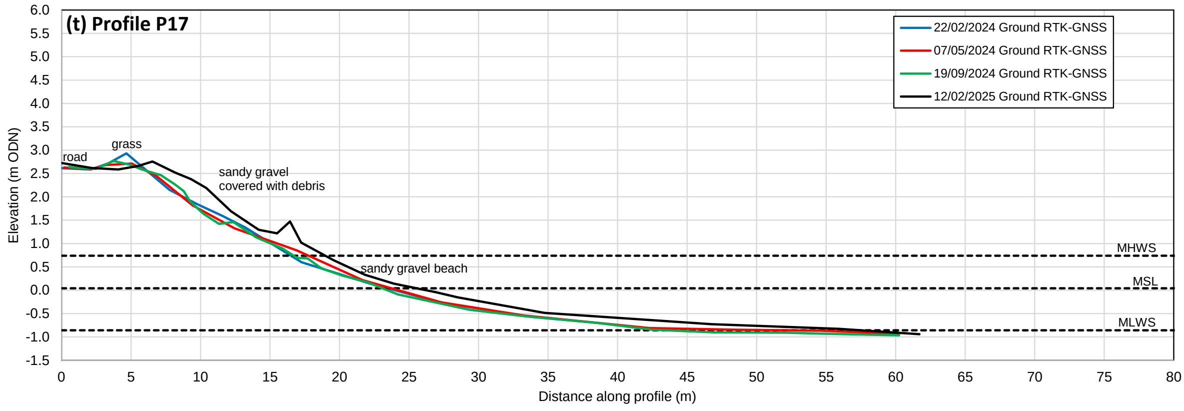


Figure 18 continued

Table 13. Distance (m) between the profile start point and the seaward edge of vegetation or sea defence surveyed by ground RTK GNSS on 22/02/2024, 07/05/2024, 19/09/2024 and 12/02/2025, and change between surveys

Profile	Distance from start of profile (m)				Change in contour position (m)			
	22/02/2024	07/05/2024	19/09/2024	12/02/2025	22/02/2024-07/05/2024	07/05/2024-19/09/2024	19/09/2024-12/02/2025	22/02/2024-12/02/2025
P3	16.1	16.3	17.2	16.0	0.2	0.9	-1.2	-0.1
P4	16.3	15.6	16.2	16.3	-0.7	0.6	0.1	0.0
P5	25.9	26.1	30.3	26.0	0.2	4.2	-4.3	0.1
P6	27.7	27.6	28.0	28.7	-0.1	0.5	0.7	1.1
P7	31.3	31.3	32.3	32.3	0.0	1.0	0.1	1.0
P8A	nd	nd	32.5	33.1	nd	nd	0.5	nd
P8B	nd	nd	32.3	33.7	nd	nd	1.5	nd
P8C	nd	nd	33.6	33.3	nd	nd	-0.3	nd
P8	32.9	33.8	34.1	35.1	0.9	0.3	1.0	2.2
P9	41.8	41.8	41.7	43.3	-0.1	-0.1	1.7	1.5
P10	47.5	47.4	48.2	48.4	-0.1	0.8	0.2	0.9
P11	39.3	39.0	39.0	39.2	-0.3	0.1	0.1	-0.1
P12	29.1	30.4	30.4	31.2	1.3	0.0	0.8	2.1
P13	39.4	39.9	39.4	42.5	0.5	-0.5	3.1	3.1
P14	19.1	19.0	18.7	24.4	-0.1	-0.2	5.7	5.3
P15	13.0	12.9	13.1	13.0	-0.1	0.2	-0.1	0.0
P16	22.3	22.2	22.2	22.5	-0.1	0.0	0.3	0.2
P17	20.2	20.1	20.1	20.1	-0.1	0.0	0.0	-0.1

Table 14. Distance (m) between the profile start point and the HAT contour (1.04 m ODB) surveyed by ground RTK GNSS on 22/02/2024, 07/05/2024, 19/09/2024 and 12/02/2025, and change between surveys

Profile	Distance from start of profile (m)				Change in contour position (m)			
	22/02/2024	07/05/2024	19/09/2024	12/02/2025	22/02/2024-07/05/2024	07/05/2024-19/09/2024	19/09/2024-12/02/2025	22/02/2024-12/02/2025
P3	15.9	15.6	16.0	15.7	-0.3	0.4	-0.3	-0.3
P4	15.6	15.5	15.9	15.5	-0.1	0.4	-0.4	-0.1
P5	29.0	27.9	34.9	29.0	-1.1	7.0	-5.9	0.0
P6	37.4	36.0	40.0	36.0	-1.4	4.1	-4.1	-1.4
P7	43.7	43.5	46.4	43.0	-0.2	2.9	-3.4	-0.7
P8A	nd	nd	46.9	43.4	nd	nd	-3.5	nd
P8B	nd	nd	47.0	43.2	nd	nd	-3.8	nd
P8C	nd	nd	49.2	43.8	nd	nd	-5.3	nd
P8	48.3	47.4	50.7	45.9	-0.8	3.3	-4.7	-2.3
P9	56.4	55.4	57.7	50.7	-1.0	2.3	-6.9	-5.7
P10	64.3	63.8	64.0	56.7	-0.5	0.2	-7.3	-7.6
P11	54.7	54.4	54.2	56.4	-0.2	-0.3	2.3	1.8
P12	43.2	46.7	44.9	46.7	3.4	-1.8	1.9	3.5
P13	60.7	59.3	59.9	60.1	-1.4	0.5	0.2	-0.7
P14	34.4	34.3	34.7	34.7	-0.1	0.4	0.0	0.3
P15	16.3	16.3	16.1	15.5	-0.1	-0.1	-0.6	-0.8
P16	22.3	21.8	22.3	23.2	-0.4	0.5	0.8	0.9
P17	27.3	27.6	27.2	27.6	0.3	-0.4	0.4	0.2

Table 15. Distance (m) between the profile start point and the MHWS contour (0.74 m ODB) surveyed by ground RTK GNSS on 22/02/2024, 07/05/2024, 19/09/2024 and 12/02/2025, and change between surveys

Profile	Distance from start of profile (m)				Change in contour position (m)			
	22/02/2024	07/05/2024	19/09/2024	12/02/2025	22/02/2024-07/05/2024	07/05/2024-19/09/2024	19/09/2024-12/02/2025	22/02/2024-12/02/2025
P3	16.1	15.9	16.3	16.3	-0.2	0.4	0.0	0.2
P4	15.9	15.5	16.5	16.5	-0.3	1.0	0.0	0.7
P5	32.0	33.0	37.5	37.5	1.0	4.5	0.0	5.5
P6	40.4	40.0	42.7	42.7	-0.4	2.8	0.0	2.3
P7	47.0	47.7	49.5	49.5	0.7	1.8	0.0	2.5
P8A	nd	nd	49.7	49.7	nd	nd	0.0	nd
P8B	nd	nd	49.8	49.8	nd	nd	0.0	nd
P8C	nd	nd	51.4	51.4	nd	nd	0.0	nd
P8	50.9	52.3	53.5	53.5	1.4	1.2	0.0	2.6
P9	59.7	57.2	60.9	60.9	-2.5	3.8	0.0	1.3
P10	67.5	68.9	66.5	66.5	1.4	-2.4	0.0	-1.0
P11	58.1	58.5	57.1	57.1	0.4	-1.4	0.0	-1.0
P12	46.3	48.5	48.5	48.5	2.1	0.0	0.0	2.1
P13	63.3	64.9	63.4	63.4	1.7	-1.5	0.0	0.1
P14	36.8	35.9	38.1	38.1	-0.9	2.2	0.0	1.3
P15	18.6	18.6	17.9	17.9	0.0	-0.7	0.0	-0.7
P16	23.6	23.5	23.6	23.6	-0.1	0.1	0.0	0.1
P17	29.0	30.2	29.2	29.2	1.3	-1.1	0.0	0.2

Table 16. Distance (m) between the profile start point and the MHWN contour (0.44 m ODB) surveyed by ground RTK GNSS on 22/02/2024, 07/05/2024, 19/09/2024 and 12/02/2025, and between surveys

Profile	Distance from start of profile (m)				Change in contour position (m)			
	22/02/2024	07/05/2024	19/09/2024	12/02/2025	22/02/2024-07/05/2024	07/05/2024-19/09/2024	19/09/2024-12/02/2025	22/02/2024-12/02/2025
P3	16.2	16.1	16.7	15.9	0.0	0.6	-0.8	-0.3
P4	16.2	17.1	21.5	17.1	0.9	4.5	-4.4	0.9
P5	35.2	35.9	40.1	36.2	0.7	4.2	-3.9	1.0
P6	43.5	43.0	44.9	43.1	-0.5	1.9	-1.8	-0.4
P7	49.9	50.6	52.1	51.4	0.7	1.5	-0.7	1.5
P8A	nd	nd	51.9	51.3	nd	nd	-0.6	nd
P8B	nd	nd	51.9	51.8	nd	nd	-0.2	nd
P8C	nd	nd	53.7	52.0	nd	nd	-1.7	nd
P8	53.9	55.1	55.8	54.2	1.2	0.8	-1.6	0.3
P9	62.8	65.8	63.5	58.6	3.0	-2.3	-4.9	-4.2
P10	70.7	71.5	69.2	62.7	0.9	-2.3	-6.5	-8.0
P11	61.4	60.2	59.9	63.0	-1.2	-0.2	3.1	1.6
P12	49.4	50.0	50.9	53.4	0.6	1.0	2.4	4.0
P13	65.9	66.0	65.5	66.0	0.1	-0.5	0.5	0.1
P14	39.4	38.2	40.2	39.5	-1.1	2.0	-0.7	0.1
P15	21.5	21.2	20.2	20.1	-0.2	-1.0	-0.1	-1.4
P16	25.6	25.8	24.9	25.5	0.1	-0.9	0.6	-0.2
P17	31.4	32.5	31.4	31.4	1.0	-1.0	0.0	-0.1

Table 17. Distance (m) between the profile start point and the MSL contour (0.04 m ODB) surveyed by ground RTK GNSS on 22/02/2024, 07/05/2024, 19/09/2024 and 12/02/2025, on monitoring profiles at Cushendun, and change in position between surveys

Profile	Distance from start of profile (m)				Change in contour position (m)			
	22/02/2024	07/05/2024	19/09/2024	12/02/2025	22/02/2024-07/05/2024	07/05/2024-19/09/2024	19/09/2024-12/02/2025	22/02/2024-12/02/2025
P3	17.5	19.0	19.1	20.5	1.5	0.0	1.5	3.1
P4	19.2	21.8	24.8	25.0	2.6	3.0	0.3	5.8
P5	39.3	40.4	44.3	44.7	1.1	3.9	0.4	5.4
P6	48.0	46.5	49.2	49.5	-1.6	2.7	0.3	1.4
P7	53.4	54.8	56.8	56.6	1.4	2.1	-0.2	3.3
P8A	nd	nd	55.5	56.5	nd	nd	1.1	nd
P8B	nd	nd	55.7	57.7	nd	nd	2.0	nd
P8C	nd	nd	57.4	59.1	nd	nd	1.7	nd
P8	57.5	59.1	59.5	62.2	1.6	0.4	2.7	4.7
P9	66.8	70.5	67.6	65.9	3.6	-2.9	-1.7	-0.9
P10	74.7	75.1	73.3	73.4	0.3	-1.8	0.1	-1.4
P11	65.5	63.6	64.0	66.9	-1.9	0.4	3.0	1.5
P12	53.5	53.3	55.2	57.6	-0.1	1.9	2.4	4.1
P13	69.5	69.3	69.9	70.4	-0.3	0.6	0.5	0.9
P14	43.4	41.8	43.6	43.9	-1.6	1.8	0.2	0.5
P15	24.9	25.2	24.5	23.3	0.3	-0.7	-1.2	-1.6
P16	29.7	29.3	28.0	29.2	-0.4	-1.4	1.2	-0.5
P17	35.9	36.2	35.6	35.9	0.3	-0.7	0.4	0.0

Table 18. Distance (m) between the profile start point and the MLWN contour (-0.56 m ODB) surveyed by ground RTK GNSS on 22/02/2024, 07/05/2024, 19/09/2024 and 12/02/2025, and change between surveys

Profile	Distance from start of profile (m)				Change in contour position (m)			
	22/02/2024	07/05/2024	19/09/2024	12/02/2025	22/02/2024-07/05/2024	07/05/2024-19/09/2024	19/09/2024-12/02/2025	22/02/2024-12/02/2025
P3	nd	57.6	57.9	nd	nd	0.3	nd	nd
P4	51.0	51.5	51.8	nd	0.5	0.3	nd	nd
P5	54.6	57.4	57.6	57.3	2.8	0.2	-0.3	2.6
P6	nd	59.6	55.8	59.3	nd	-3.8	3.5	nd
P7	59.4	62.3	63.1	64.2	2.9	0.7	1.1	4.8
P8A	nd	nd	62.8	64.1	nd	nd	1.4	nd
P8B	nd	nd	62.8	66.1	nd	nd	3.3	nd
P8C	nd	nd	64.6	68.5	nd	nd	3.9	nd
P8	nd	67.7	67.6	70.5	nd	-0.1	3.0	nd
P9	nd	77.9	75.5	82.3	nd	-2.4	6.8	nd
P10	nd	80.8	80.0	86.6	nd	-0.7	6.6	nd
P11	nd	68.7	70.4	72.7	nd	1.7	2.3	nd
P12	nd	58.6	61.5	63.2	nd	2.9	1.8	nd
P13	nd	74.4	76.5	75.9	nd	2.1	-0.6	nd
P14	nd	47.4	50.3	49.9	nd	2.9	-0.4	nd
P15	nd	nd	nd	nd	nd	nd	nd	nd
P16	nd	37.1	36.9	37.8	nd	-0.2	0.9	nd
P17	nd	46.3	45.9	48.8	nd	-0.4	2.8	nd

Table 19. Distance (m) between the profile start point and the MLWS contour (-0.86 m ODB) surveyed by ground RTK GNSS on 22/02/2024, 07/05/2024, 19/09/2024 and 12/02/2025, and change between surveys

Profile	Distance from start of profile (m)				Change in contour position (m)			
	22/02/2024	07/05/2024	19/09/2024	12/02/2025	22/02/2024-07/05/2024	07/05/2024-19/09/2024	19/09/2024-12/02/2025	22/02/2024-12/02/2025
P3	nd	70.2	nd	nd	nd	nd	nd	nd
P4	nd	69.4	65.4	nd	nd	-4.0	nd	nd
P5	nd	67.7	70.5	nd	nd	2.7	nd	nd
P6	nd	64.5	65.4	65.5	nd	0.9	0.2	nd
P7	nd	74.7	74.5	74.5	nd	-0.2	0.0	nd
P8A	nd	nd	67.3	68.6	nd	nd	1.3	nd
P8B	nd	nd	67.6	69.9	nd	nd	2.3	nd
P8C	nd	nd	69.6	73.2	nd	nd	3.6	nd
P8	nd	76.0	71.8	86.5	nd	-4.2	14.7	nd
P9	nd	84.5	81.2	nd	nd	-3.2	nd	nd
P10	nd	83.7	82.7	nd	nd	-1.0	nd	nd
P11	nd	71.3	73.0	nd	nd	1.7	nd	nd
P12	nd	60.5	64.4	nd	nd	3.9	nd	nd
P13	nd	76.5	79.4	78.5	nd	2.9	-0.9	nd
P14	nd	50.7	57.3	52.1	nd	6.6	-5.2	nd
P15	nd	nd	nd	nd	nd	nd	nd	nd
P16	nd	43.7	43.8	44.9	nd	0.1	1.1	nd
P17	nd	65.3	56.1	68.0	nd	-9.2	11.9	nd

5.4 Monitoring of changes in upper beach level by reference to fixed posts

While ground topographic surveys carried out two or three times a year (normally in late winter and late summer) can allow quantification of seasonal changes in beach levels and sediment volume (expressed as volume per metre width above a pre-defined datum), they may miss the impact of individual storms or sequences of storms. For this reason a supplementary simple method of measuring upper beach levels at Cushenden was tried. The method makes use of the fact a series of wooden railway sleepers and sections of telegraph pole have been sunk into the upper beach to act as a permeable wave break and protection for the dune toe against erosion (see photographs in Appendix 1). The first sleepers we installed in the 1980s. Some have since been lost and replaced by sections of telegraph pole. Fourteen of the posts were selected as local beach level monitoring points (Figure 19).

During the May 2024 survey the level of the top of each selected post and the beach level immediately adjoining (in front) of each post was determined using the RTK-GNSS survey equipment, thereby providing a measurement of the distance between the top of each post and the beach level. As a cross-check the distance between post top and beach surface was also measured using a retractable metal tape measure. Each selected post was marked with yellow paint (supplemented in February 2025 by yellow waterproof tape) to facilitate ready identification. The positional coordinates of the top and bottom of each post are shown in Table 20. The RTK-GNSS measurement process was repeated during the field surveys carried out in September 2024 and February 2025. Additionally, measurements were made by National Trust personnel using a tape measure following a significant storm in October 2024 (Storm Ashely) and in mid-January 2025. The results are summarized in Table 21. There was relatively little change at any of the posts between the May and September 2024 surveys but between 19 September and 23 October there were drops in beach level of 12 - 19 cm at posts H, I & D, whereas between posts C and G the beach levels rose slightly (4 - 8 cm). This reflected storm wave activity during Storm Ashley. Even though the storm did not coincide with a large spring tide, waves evidently caused erosion of the upper beach in front of the

Gaelic football ground. This is also the section of the frontage where the highest waves were observed during the February 2025 survey. It would appear that during big storm events waves move sediment from the upper to the lower beach and also laterally away from this area towards the south and the north.

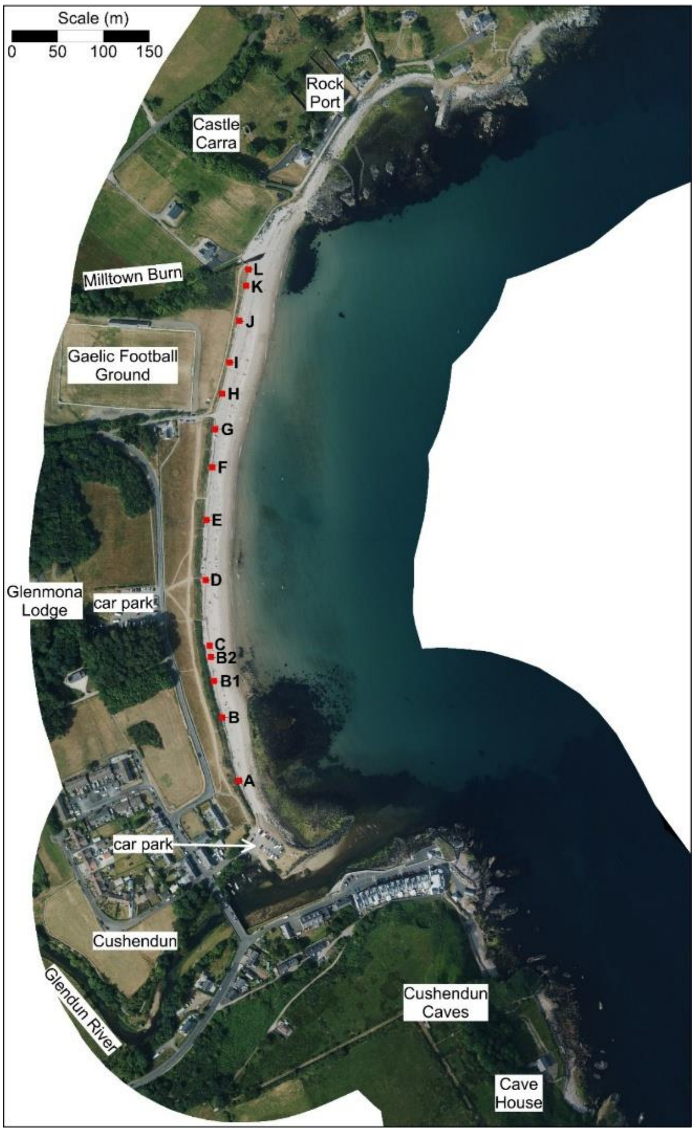


Figure 19. Aerial photography flown 28/08/2021 by Bluesky and supplied by Northern Ireland Coastal Observatory, overlaid with locations of posts and sleepers selected for use in beach level monitoring

Between 23 October 2024 and 16 January 2025 there was a significant rise in beach level at all posts except B and H. Despite the occurrence of a further significant storm on 23 January (Storm Eowyn), a further rise is beach levels occurred at almost all posts between 16 January and 12 February 2025. Although strong south-westerly winds were experienced across Northern Ireland during this storm they did not generate particularly large southerly / south-easterly waves in the northern Irish Sea and the maximum wind strengths occurred during a period of relatively low neap tides.

Table 20. Wooden posts and sleepers at Cushendun selected for use in beach level monitoring, with levels of the top of the post and the level of beach sediment at the bottom of the post surveyed on 07/05/2024 by KPAL using RTK-GNSS

Post	Position	Easting	Northing	Elevation (m ODB)	1D CQ (mm)	2D CQ (mm)	GDOP	VDOP
Post A	Top	324956.603	432753.163	3.753	0.012	0.008	2.5	1.8
	Bottom	324956.836	432753.156	1.981	0.013	0.011	2.5	1.8
Post B	Top	324938.655	432822.327	3.350	0.013	0.009	2.4	1.7
	Bottom	324938.509	432822.469	2.106	0.012	0.012	1.7	1.3
Post C	Top	324924.730	432900.609	2.757	0.012	0.010	1.7	1.3
	Bottom	324924.821	432900.563	2.168	0.013	0.010	1.6	1.2
Post D	Top	324920.375	432972.336	3.085	0.012	0.010	1.6	1.2
	Bottom	324920.513	432972.150	2.284	0.013	0.010	1.6	1.2
Post E	Top	324921.524	433037.824	2.971	0.014	0.010	1.6	1.2
	Bottom	324921.597	433037.823	2.382	0.014	0.010	1.6	1.2
Post F	Top	324927.236	433095.585	3.344	0.015	0.011	1.6	1.2
	Bottom	324927.362	433095.591	2.274	0.016	0.011	1.6	1.2
Post G	Top	324930.801	433137.262	3.595	0.015	0.011	1.6	1.2
	Bottom	324930.946	433137.272	2.408	0.015	0.011	1.6	1.2
Post H	Top	324938.472	433175.811	3.214	0.018	0.012	1.6	1.2
	Bottom	324938.550	433175.807	2.181	0.017	0.012	1.6	1.2
Post I	Top	324946.318	433210.239	3.094	0.015	0.010	2.0	1.5
	Bottom	324946.450	433210.197	2.146	0.014	0.009	2.0	1.5
Post J	Top	324957.017	433255.608	3.423	0.015	0.010	2.0	1.5
	Bottom	324957.120	433255.616	2.522	0.016	0.010	2.0	1.5
Post K	Top	324964.505	433294.133	3.365	0.012	0.008	2.0	1.5
	Bottom	324964.605	433294.159	2.960	0.012	0.009	2.0	1.5
Post L	Top	324966.930	433311.674	3.343	0.013	0.009	2.0	1.5
	Bottom	324966.999	433311.580	3.020	0.012	0.009	2.0	1.5

Table 21. Beach levels below the top of wooden posts and sleepers at Cushendun selected for use in beach level monitoring, surveyed on 07/05/2024, 19/09/2024 and 12/02/2025 by KPAL using RTK-GNSS, and on 23/10/2024 (after Storm Ashley) and 16/01/2025 by National Trust. *change calculated from difference between October and February as post was not measured in January

Post no.	Beach level below post top (m)					Change in beach level (cm)				
	07/05/2024	19/09/2024	23/10/2024	16/01/2025	12/02/2025	May-Sep	Sep-Oct	Oct-Jan	Jan-Feb	Overall May-Feb
Post A	1.77	1.73	1.69	1.70	1.69	-4	-4	+1	-1	-8
Post B	1.24	1.20	1.18	1.10	1.42	-5	-2	-8	+32	+18
Post B1	nd	0.69	0.72	0.73	1.10	nd	+2	+2	+37	nd
Post B2	nd	0.86	nd	1.26	1.26	nd	nd	nd	0	nd
Post C	0.59	0.64	0.71	1.03	1.08	+5	+8	+32	+4	+49
Post D	0.80	0.83	0.82	1.22	1.31	+2	-1	+41	+9	+51
Post E	0.59	0.57	0.61	0.76	1.11	-2	+4	+15	+35	+52
Post F	1.07	1.08	1.14	1.33	1.38	+1	+6	+19	+5	+31
Post G	1.19	1.18	1.22	1.31	1.48	-1	+4	+9	+17	+29
Post H	1.03	1.04	0.92	0.90	1.17	+1	-12	-2	+27	+13
Post I	0.95	0.90	0.74	nd	0.99	-5	-16	nd	+25*	+4
Post J	0.90	0.90	0.71	0.87	1.03	-1	-19	+16	+16	+13
Post K	0.41	0.41	0.43	0.58	0.69	0	2	+15	+11	+29
Post L	0.32	0.31	0.30	0.82	0.87	-1	-1	+52	+5	+55

6.0 Issues associated with the harbour and breakwater

As noted in earlier sections of this report, Cushendun Harbour has experienced a long history of modifications. At the time of the first OS Six-inch survey in 1832 the mouth of the river / estuary had an open, trumpet-shaped form. By 1846 sediment had started to accumulate as a small spit and associated bank on the north side of the entrance adjacent to the Coastguard Station. An attempt may have been made to control this accumulation by building a low rock groyne, but this was levelled by the manager of the scutch mill and rope works in the 1860s, the imported rocks used to build it being left scattered on the foreshore in front of what is today the NT café car park (R. McDonnell pers. comm.). The sand accumulation to the south of the Coastguard boathouse continued to increase in extent and height the later 19th century, forming a bank which became partly vegetated. Dredging of the harbour entrance may have been carried out around the time that improvements were made to the quay adjacent to the mill (in the 1860s and 1870s). No groyne structure is shown on the OS maps surveyed in 1903-4 or 1920-21 but an oblique aerial photograph from the late 1920s seem to show a low rock groyne extending seawards from a sand spit on the north side of the channel (photograph A3.9 in Appendix 3). This, or a similar feature, is shown on the OS 1:10,000 map surveyed in 1973 (Figure 20).

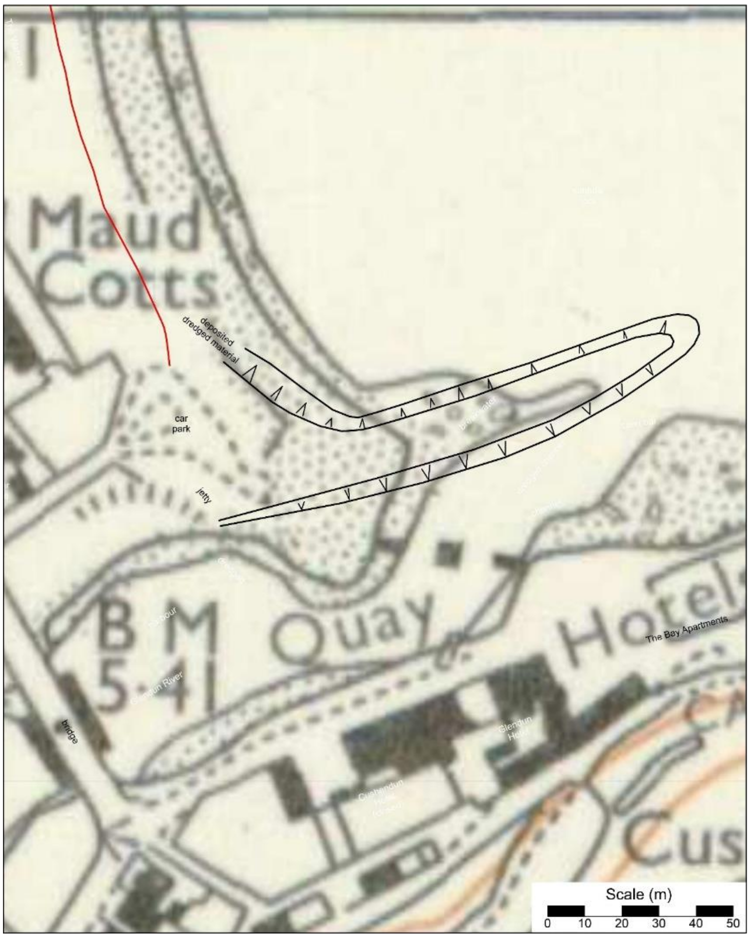


Figure 20. Extract from OS 1:10000 map surveyed in 1973 and published 1976 with superimposed breakwater outline taken from Figure 21

Around 1979 or 1980 The National Trust built a much larger rock groyne which projected further seaward and was both wider and higher than the present structure (Figure 21).

Although no written records of events around this time have been identified, it is reported that the construction was undertaken without expert design advice and perhaps without planning permission (R. McDonnell pers. comm.). Following numerous complaints about the unsightly nature of the structure and the adverse effect it was having on fishing in the estuary mouth, in 1988 the Trust sought further advice from consulting engineers Kirk McClure Morton (KMM) who carried out a survey of the existing breakwater (Figure 21) and made suggestions for changes.

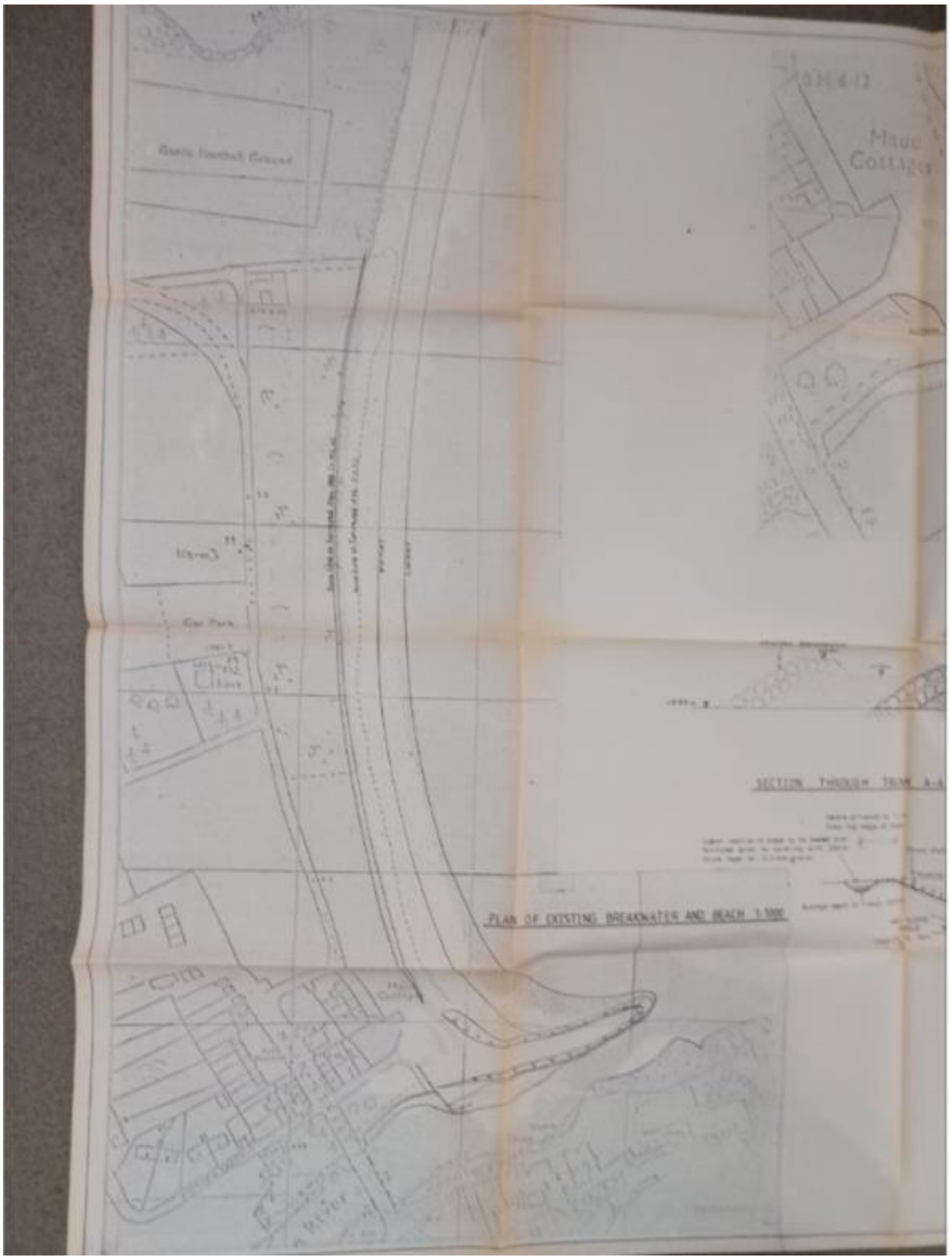


Figure 21. Plan of existing breakwater in May 1988 (from report by Kirk McClure Morton, July 1988)

KMM concluded that the problem of sediment accumulation within the harbour was due to a combination of factors but primarily to a lack of scouring power of the river to remove bedload which it transported along its course and which was deposited as the entrance widened and current speeds reduced. They also suggested that "while there does not appear to be a dominant direction of drift, one can nevertheless conclude that waves generated by strong north easterly winds will move beach material southwards. Without a protective groyne, this material would be washed into the river mouth”. Investigations by KMM divers indicated substantial reserves of sediment within the central part of Cushendun Bay, in the form of a highly mobile bank composed of sand, shingle and shell, which would potentially be available for landward transport by long period waves. Flow tracking experiments indicated that although from 6 hours before to 4 hours after High Water flows were generally in a northward direction, secondary reverse currents close to the beach towards the river mouth were recorded.

Following KMM recommendations the terminal rock groyne was shortened, made narrower and given a curved, more tapered form. The rock revetment protection in front of the NT car park was moved back and given a modified profile. KMM also recommended that the eroding dunes immediately to the north of the revetment should be regraded, replanted and provided by a protective stone mattress. However, the NT evidently preferred an alternative method of placing railway sleepers in front of the dune toe to act as a semi-permeable wave break and sediment trap. Figure 22 shows the present modified plan form of the rock grown and associated rock revetment which protects the NT car park.

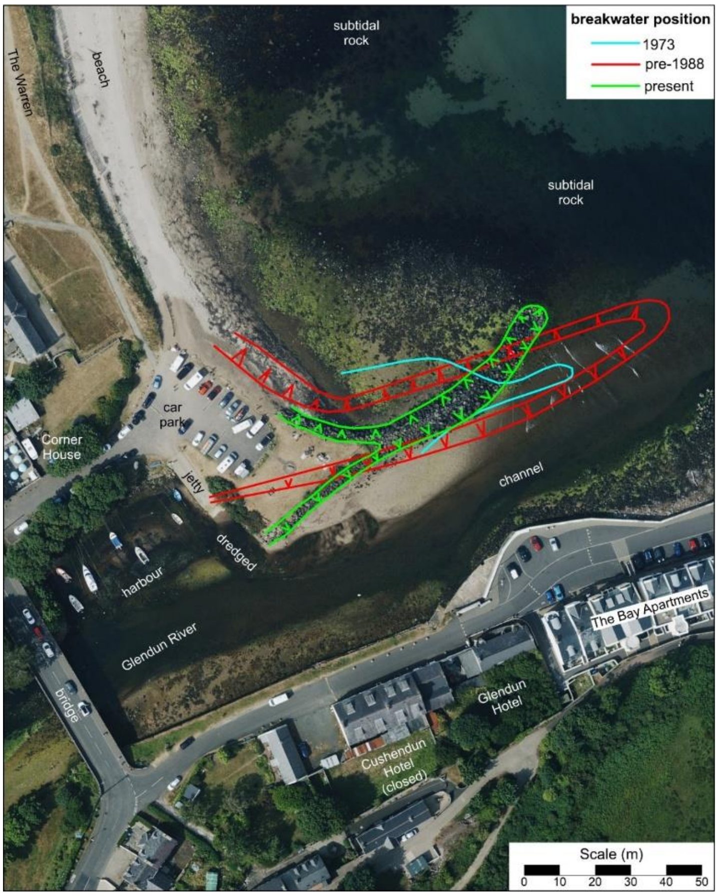


Figure 22. DAERA 2022 aerial photography of the harbour and present (post 1988) breakwater (outlined by green lines), showing also the superimposed outlines of the small breakwater shown on the 1973 / 76 OS 1:10000 map (blue line) and the plan of the 1979/ 1980 existing breakwater shown on the plan in the July 1988 report by Kirk McClure Morton (red lines)

Since the modified breakwater and revetment were constructed there have been continuing problems of sediment accumulation within the channel between it and the quay on the southern side of the river mouth. At low tide the channel sometimes becomes so shallow that it is easily possible to walk from one side to the other. Observations made in May 2024 as part of this study recorded the existence of an inner bar orientated at an oblique angle across the channel (see photographs in Appendix 1). In addition, a high bank of sand and gravel was piled up against the southern side of the breakwater, as can also be seen in Figure 22. A number of small sand banks, emergent at low tide, were also evident within the small mooring area between the NT car park / picnic area and the stone bridge. For several years the National Trust has carried out an annual dredging campaign to remove this material using and excavator and tractor and trailer, with the material being deposited on the seaward side of the rock revetment which protects the adjacent car park. Photographs of the dredging operation conducted in May 2024 are included in Appendix 1. The effect of depositing sediment in front of the rock revetments is to provide a sacrificial buffer which reduces wave energy in the short-term but the material is dispersed with a few months. Approximately half of the sediment deposited in this location in May 2024 had already been lost by the time of the September 2024 survey and virtually noting remained at the time of the February 2025 survey. Erosion continues to affect the unprotected dune cliffs in front of Maud cottages, such that the rock revetment now stands ‘out of line’ with the curve of the general shoreline.

Boat owners using the moorings and adjacent slipway have complained that still water conditions behind the new breakwater / car park structure, leading to accumulation of soft silt and organic matter brought down by the river or washed into the harbour by tidal and/ or wave action. Decay of this material periodically causes a deterioration in water and bed sediment quality within the mooring area. Significant amounts of organic matter were seen during the site visits in February 2024 and February 2025, on the latter occasion consisting mainly of kelp torn up from the bed of the bay and transported into the harbour by a combination of flood tides and waves (see Appendix 1).

The options with regard to these problems are:

- continue with present practice and repair the breakwater and revetment as necessary
- remove part or all of the outer part of the breakwater but retain the revetment and car park
- remove all of the outer part of the breakwater and realign the revetment, reducing the area of the car park
- completely remove the breakwater, rock revetments and car park, effectively reinstating the open harbour mouth conditions which existed in the early to mid 19th century

These options are illustrated as modified LiDAR-based DEMs in Figure 23.

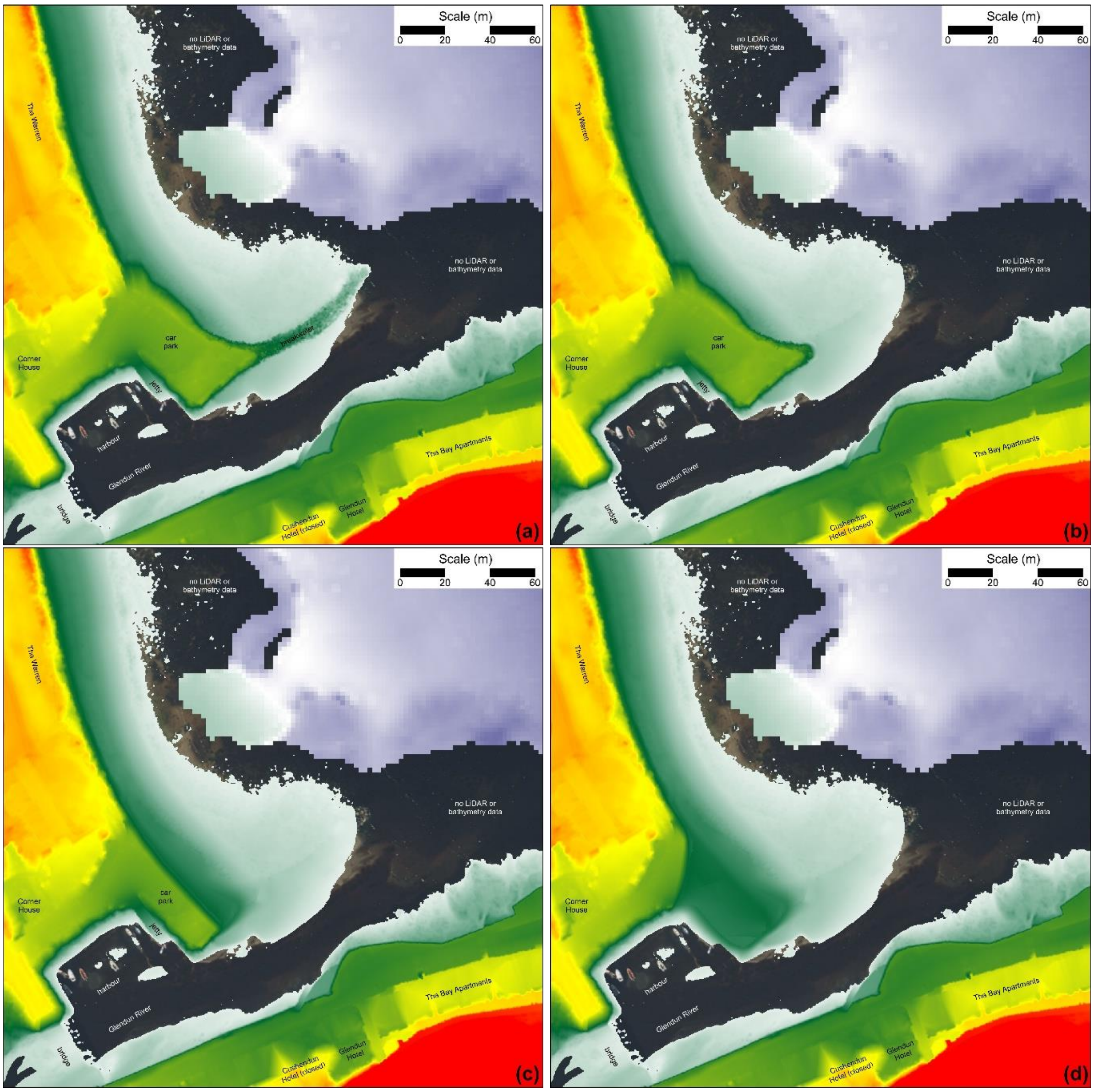


Figure 23. DEMs of Cushendun Harbour, based on 2021 DAERA LiDAR (0.25 m grid) and Admiralty surveys in 2019 (2 m grid): (a) present configuration; (b) with breakwater removed; (c) with breakwater and half the car park removed and rock armour set back; (d) with car park and breakwater entirely removed, leaving the underlying sand and gravel bank in place

Following a short inspection at the same time as the KPAL site survey in February 2024, Glennerster Consulting made a preliminary assessment of the feasibility of removing the breakwater but retaining the two adjoining revetment limbs to protect the car park (variants of the second option identified above). It was concluded that removal would be a relatively straightforward process and that some of the rock removed from the breakwater (c. 500 t) could be used to upgrade the two revetments which show local signs of block collapse. The rest could either be stored in a suitable holding area, sold or crushed on site for disposal. The costs of removing the outer 50 m of the breakwater were estimated to be in the region of £81,000, and the cost of removing the entire structure in the region of £220,000 to £240,000. It was noted that work to remove part or all of the breakwater would result in greater wave penetration into the river and small harbour, and the seawalls on the south side of the river would be subject to greater wave impact and detailed investigations of their structural integrity should be undertaken before any decisions are taken.

The options of also realigning the northern revetment and of completely removing it together with the car park were not considered in the preliminary Glennerster (2024) assessment report. However, the additional element of revetment realignment and reconstruction might double the cost of removing the entire breakwater and total removal of the car park would be a much bigger task again. With any of the options, considerable costs could be associated with the need to undertake a full environmental impact assessment with associated ground and structural investigations not only for the south shore sea walls but also the road bridge crossing.

With regard to the issue of sediment and organic matter accumulation within the boat mooring area, removal of the breakwater alone would be unlikely to result in significant improvements and indeed might result in greater transport of material into the inner area from where it would be difficult to flush out naturally. Realignment of the northern revetment would also probably produce only minimal improvement. Total removal of the structures and car park would allow tide and wave over topping at least during spring tides, resulting in greater flushing in the mooring area. Boats appear not to be moored in the area during the winter months so damage from wave action is unlikely to present a major problem. As long as a residual sediment bank is retained as a protective feature on the north side of the river entrance wave action impacting on the bridge would be limited. However, any increase in scour around the bridge supports, whether due to tides, waves, or river flows, would be likely to increase the risk of collapse and require mitigation measures to be undertaken.

As shown schematically in Figure 11, still water levels are projected to increase progresively towards 2100 due to the effects of climate change and this will increase the wave power impoacting on the breakwater and the northern revetment. Without major works to upgrade the revetment failure at some point in the relatively near future is highly likely. Should such an event occur the Trust would be faced with the choice of leaving the rubble in place, to degrade and disperse naturally, or removing it and the fill behind in accordance with the total removal option outline above.

As water levels increase the undefended shore to the north will show a tendency to retreat more quickly, and any realignment of the northern car park revetment in the short term would be likely to be outflanked relatively quickly. Any benefits associated with this option would therefore be short lived and probably would not justify the costs involved.

In the medium to longer term (2050 - 2100) the rate of erosion of the low dune cliffs in front of Maud Cottages is likely to acclerate even with the existing rock revetment in place. If this is removed than the dune erosion rate will be even higher and there could be a high risk the properties would be lost within 30 to 50 years. Demolition and removal prior to collapse induced by erosion would be preferable, and indeed might be required by the Local Planning Authority.

7.0 Erosion and flood risk at Rockport

Although The National Trust owns Rockport Lodge it does not own the concrete road which runs along the front and provides access to other houses at Castle Park, or the protective rock armour revetment on the seaward side of the road. The defences appear to have bene built in the 1960s or 1970s and show evidence of localised failure which has allowed waves to undermine the seaward edge of the access road in some places. Localised collapse of the edge of the road was evident during the site visit in February 2024. Although repairs have been made since that time the road remains vulnerable to further damage during storm events (Figures 24 & 25 and photographs in Appendix 2).

The main house and associated outbuildings at Rockport Lodge are sited on ground which is slightly below the level of the concrete road and are at risk of flooding from spray generated by breaking waves. The house is partially protected a surrounding low wall although gateways rely on sandbags for protection against overtopping water. As water levels and nearshore wave heights increase with climate change such wave splash overtopping will become more frequent and more serious. However, mitigation measures could be simply employed, for example by building a low wall along the seaward side of the access road. Due to the fact that the house and outbuildings have a foundation of rock at shallow depth the short to medium term risk of loss due to coastal erosion is considered low.

Figure 24. Aerial photograph of the Rock Port area flown July 2022. Source: Bing

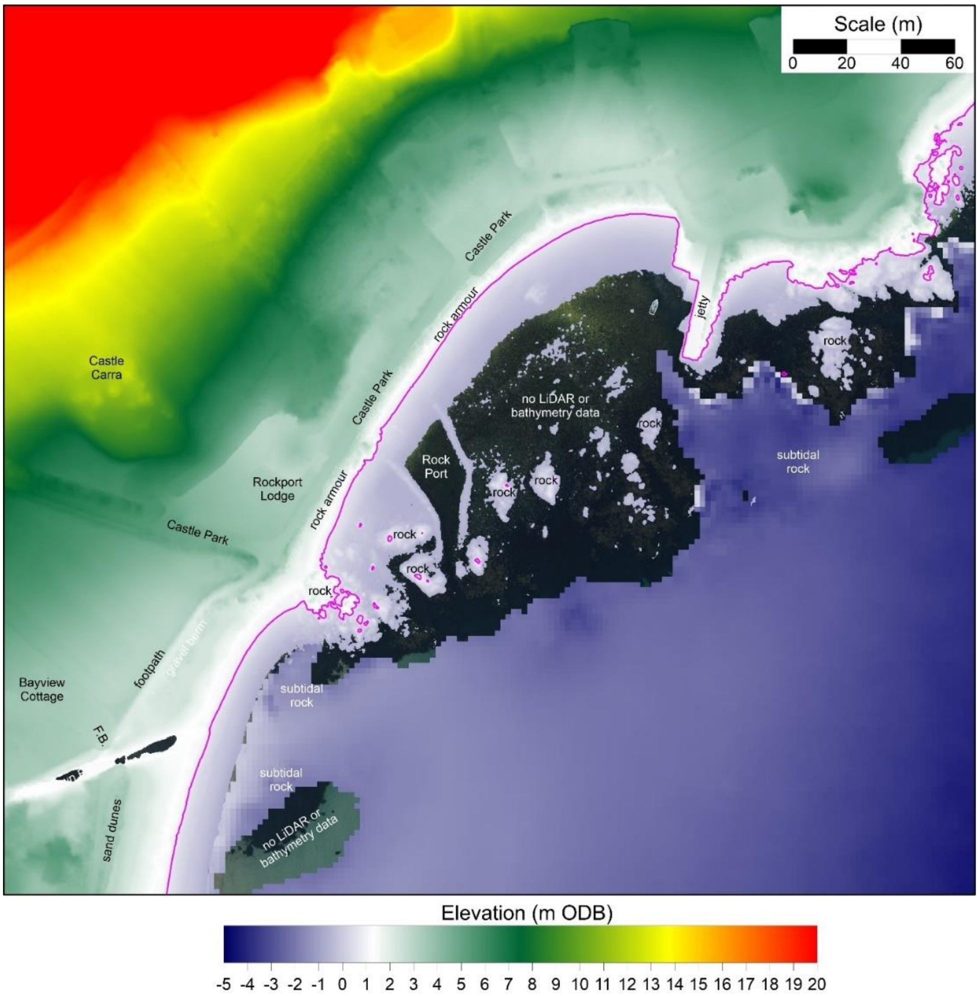


Figure 25. DEM of the Rock Port area, taken from 2021 LiDAR (0.25 m grid) and Admiralty surveys in 2019 (2 m grid). Base aerial photograph is displayed where no data is available, flown August 2021 (contemporaneous with the LiDAR survey). The pink line is the MHWS contour (0.74 m ODB) taken from the LiDAR survey

8.0. Conclusions and recommendations

The direct risk to National Trust buildings and other property assets from erosion and coastakl flooding is considered low in the short term but Maud Cottages will become increasingly vulnerable to erosion in the medium term and the flood risk at Rockport Lodge will increase over time as sea levels rise. Since construction of hard defences to defend Maud Cottages would not be consistent with its *Shifting Shores* policy their loss in the medium to longer terms may need to be accepted. However, ther risk from flooding at Rockport could be reduced by relatively simple measures and the property is considered to be at low risk from erosion.

Further investigations and consultation with interested parties are required before a final decision is made regarding management options for the breakwater and harbour car park. This includes a need for structural assessment of the sea wall on the southern side of the river mouth and of the bridge foundations.While a strategy is being worked out for this area some mainteance work is required to ensure that the integrity of the two revetment wings to the breakwater is maintained, at least for a period of 10 years.

Ths study has developed a framework for monitoring of the beach and frontal dunes which should be continued into the future. If airborne LiDAR surveys are commisioned by DAERA every two or three years analysis of this data may be sufficent to keep a watching brief on the erosion situation. However, if there is a hiatus in such centralised survey work it is recommended that the Trust commissions its own aerial survey work, either using drone-based LIDAR and aerial imagery or ground-based RTK-GNSS surveys, at least every two years.

It is considered important that Trust continues to engage with the local community and to keep them informed of the further assessment work and practical intervention work which it proposes to carry out.

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Appendix 1

Ground photographs taken during the site visits

Photographs taken 7 May 2024


Banba

McBRIDES

Photographs taken 19 September 2024


Banba

Photographs taken 12th February 2025


CUSHENDUN
WARNING


12/02/2025 13:54


12/02/2025 14:01


12/02/2025 14:01


12/02/2025 14:04


12/02/2025 14:10


12/02/2025 14:13


12/02/2025 14:16


12/02/2025 15:05


12/02/2025 14:26


12/02/2025 14:31


12/02/2025 14:34


12/02/2025 15:15


12/02/2025 15:12


12/02/2025 15:13


12/02/2025 16:48


CUSHENDUN
12/02/2025 15:16


12/02/2025 17:30


12/02/2025 16:59


12/02/2025 17:00


12/02/2025 17:01


12/02/2025 17:01


12/02/2025 17:02

12/02/2025 17:03

12/02/2025 17:03


12/02/2025 17:03


12/02/2025 17:30


12/02/2025 17:31


12/02/2025 17:32


12/02/2025 17:32


CUSHENDUN
12/02/2025 17:32


12/02/2025 17:32


12/02/2025 17:34

Appendix 2

Historical maps and aerial photographs

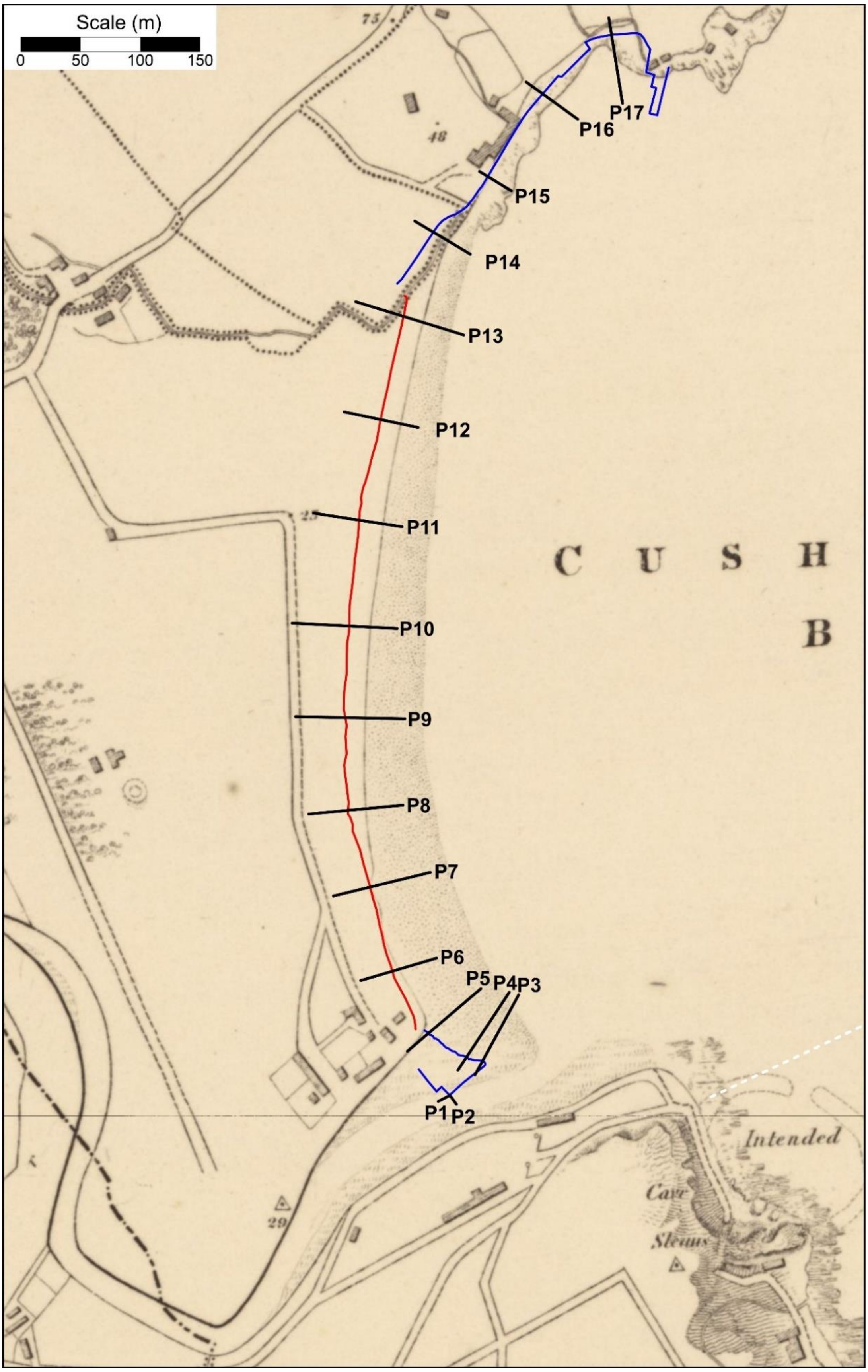


Figure A2.1 Six-inch Ordnance Survey map surveyed 1832 and published in 1837, overlaid with the position of the dune toe (red line), sea defences (blue line) and cross-shore profiles (black lines) surveyed in May 2024

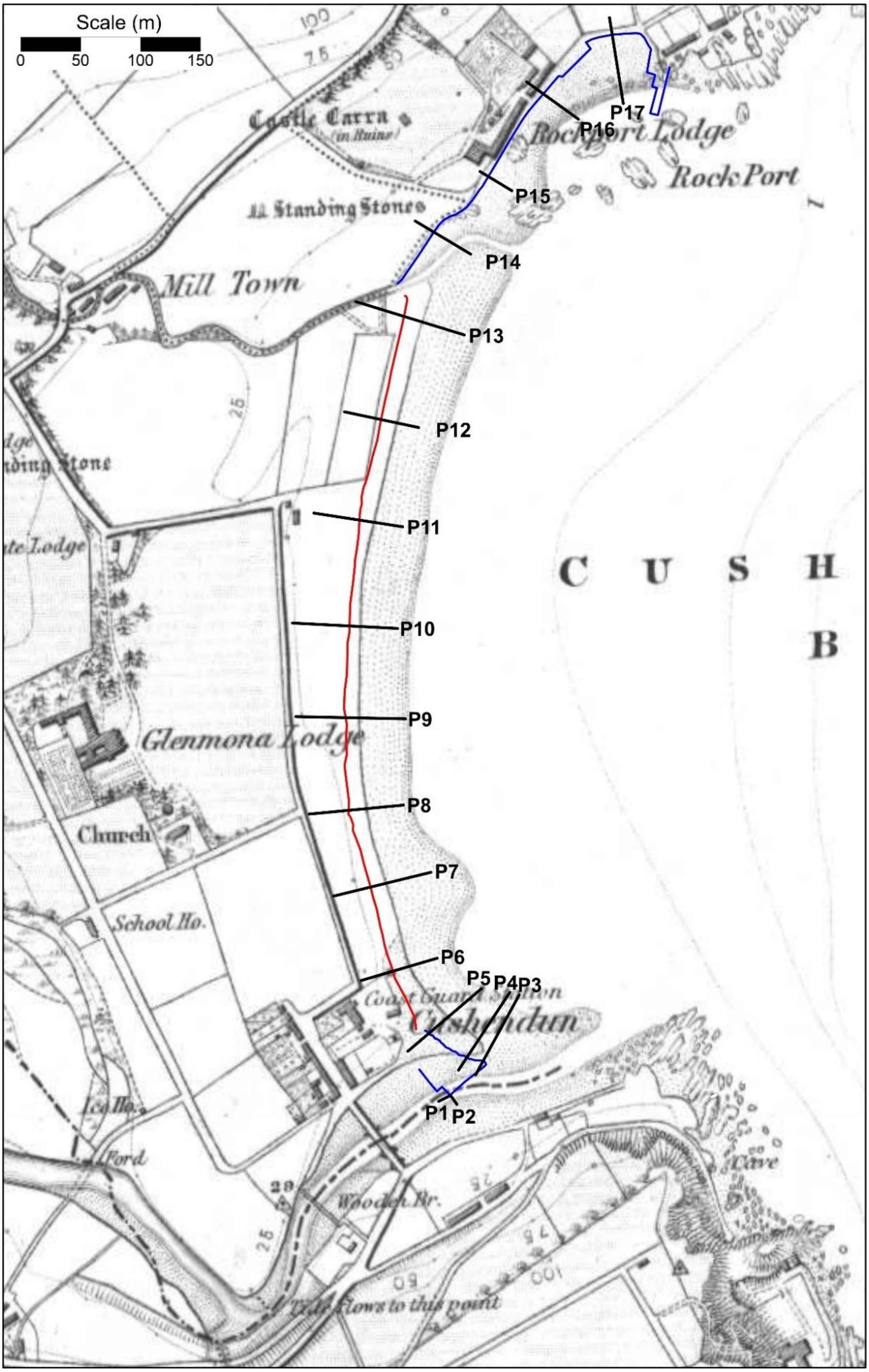


Figure A2.2 Six-inch Ordnance Survey map surveyed 1846 and published in 1862, overlaid with the position of the dune toe (red line), sea defences (blue line) and cross-shore profiles (black lines) surveyed in May 2024

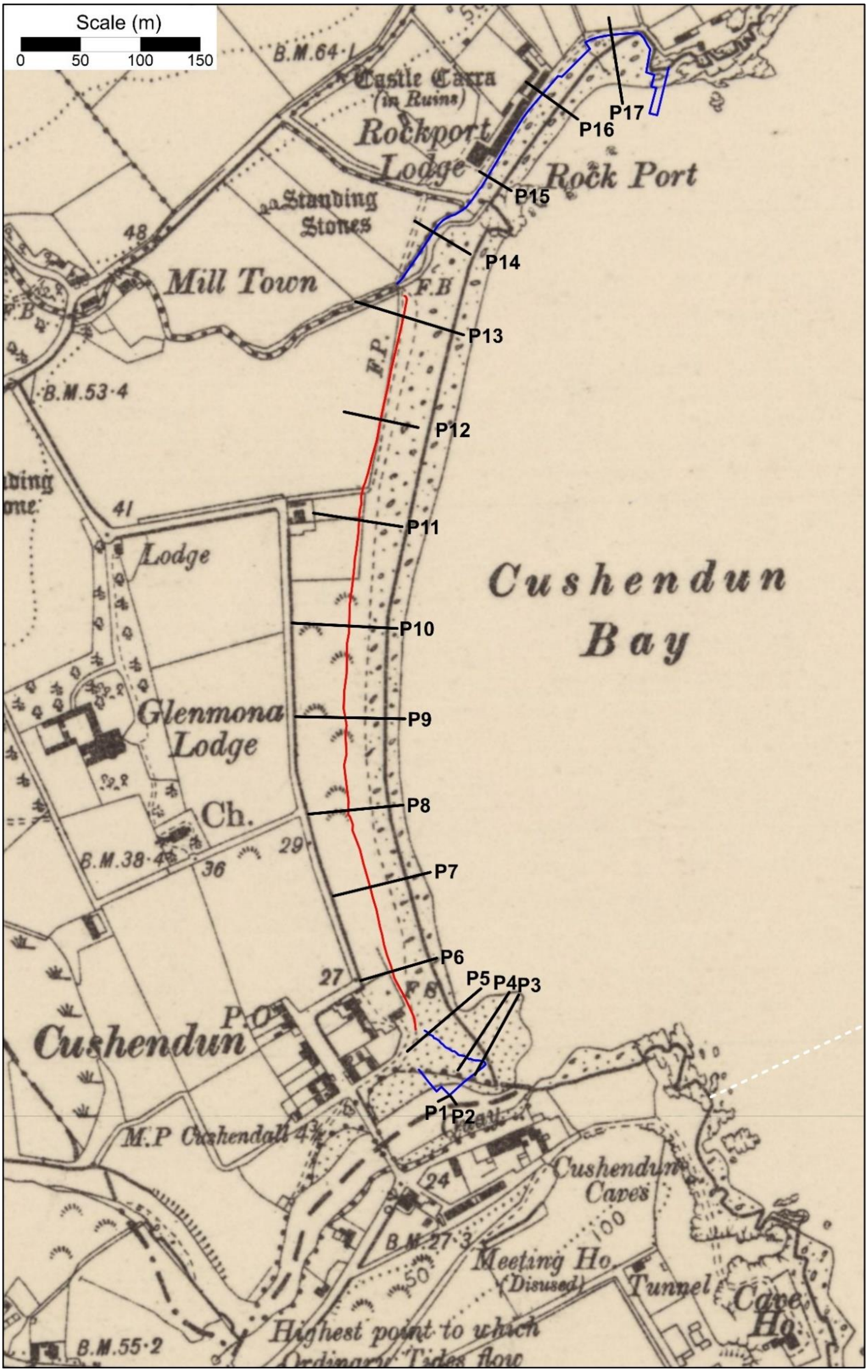


Figure A2.3 Six-inch Ordnance Survey map surveyed 1903-04 and published in 1906, overlaid with the position of the dune toe (red line), sea defences (blue line) and cross-shore profiles (black lines) surveyed in May 2024

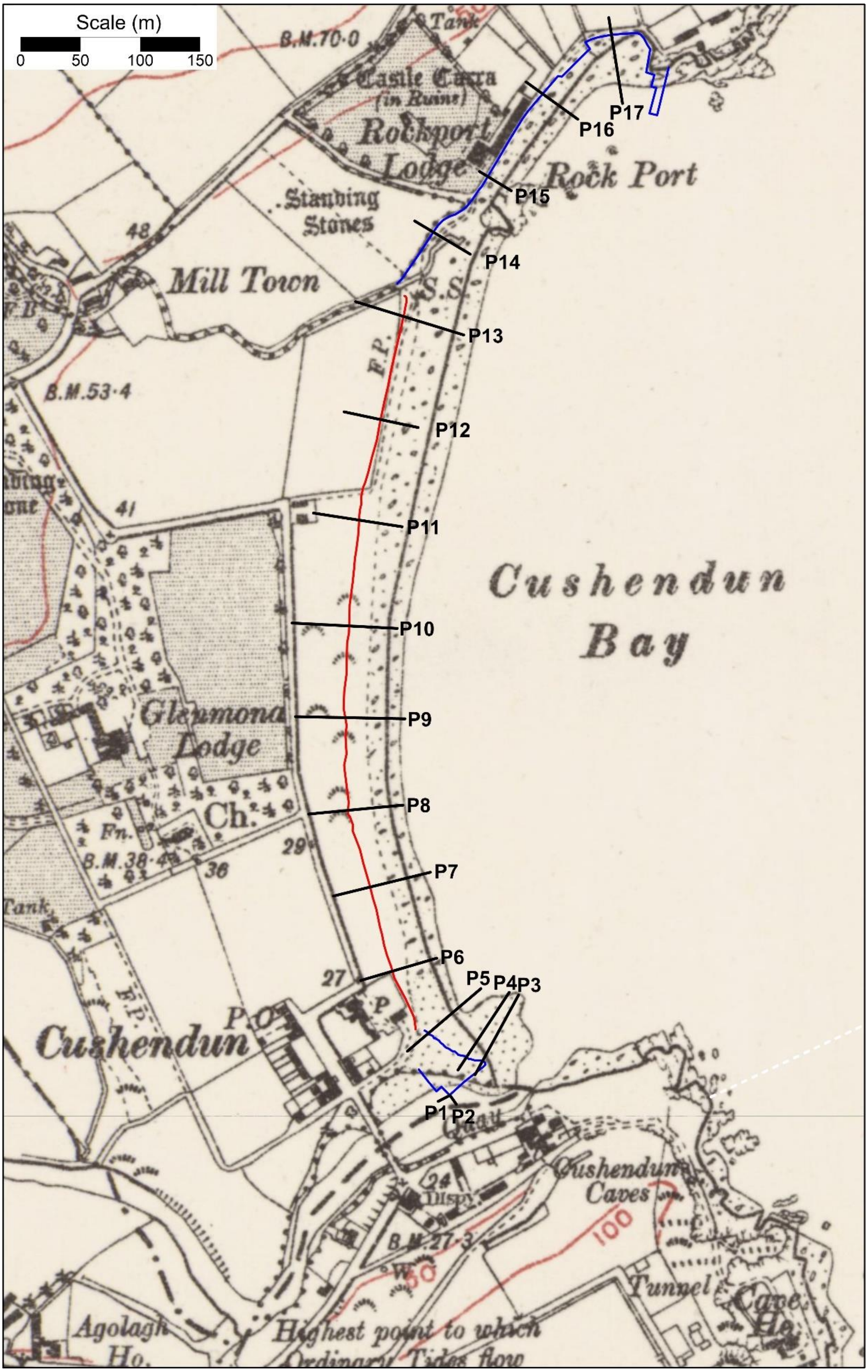


Figure A2.4 Six-inch Ordnance Survey map revised 1921-22 (not tide lines), published 1935, overlaid with the dune toe (red line), sea defences (blue line) and cross-shore profiles (black lines) surveyed in May 2024

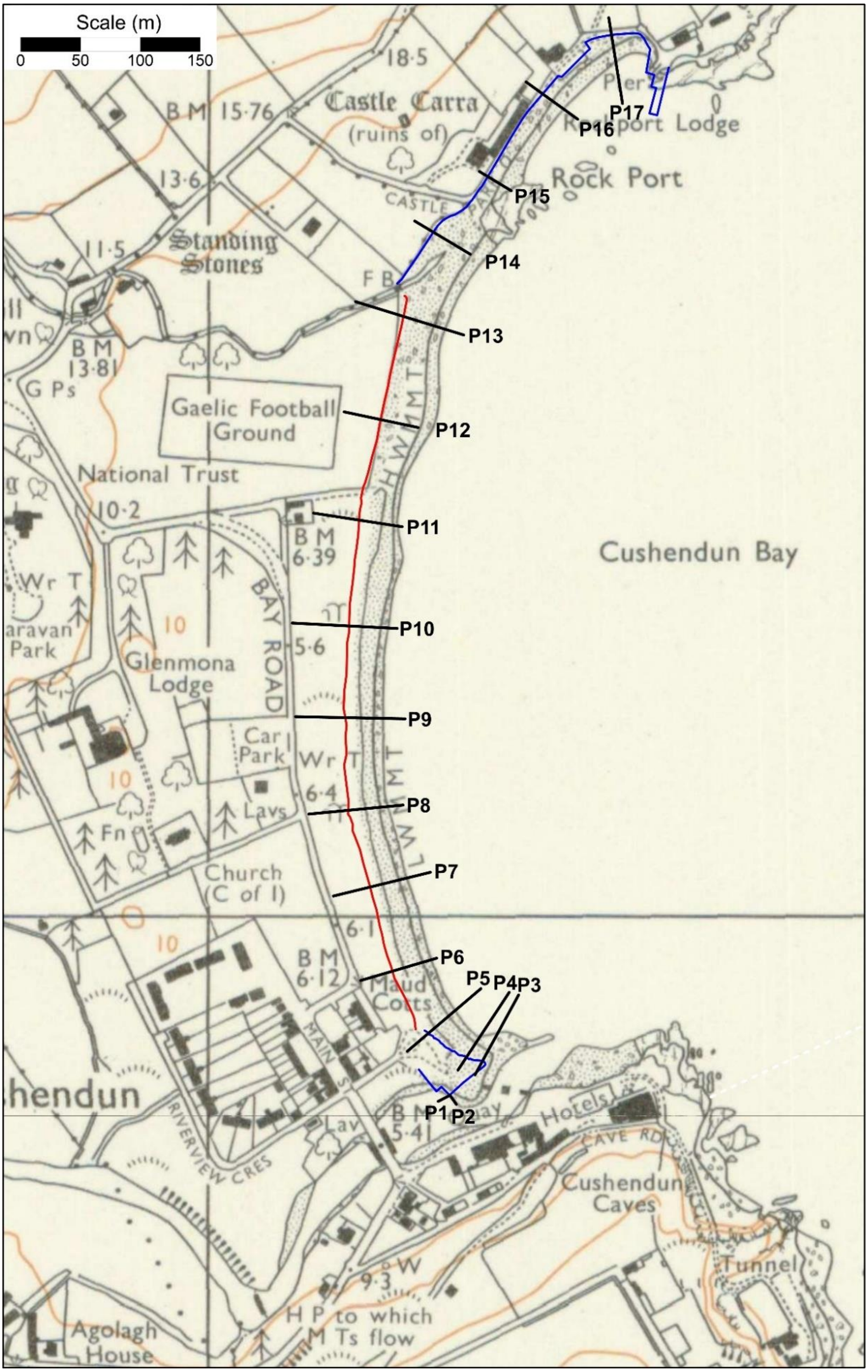


Figure A2.5 1:10,000 scale Ordnance Survey map surveyed 1973 and published in 1976, overlaid with the dune toe (red line), sea defences (blue line) and cross-shore profiles (black lines) surveyed in May 2024

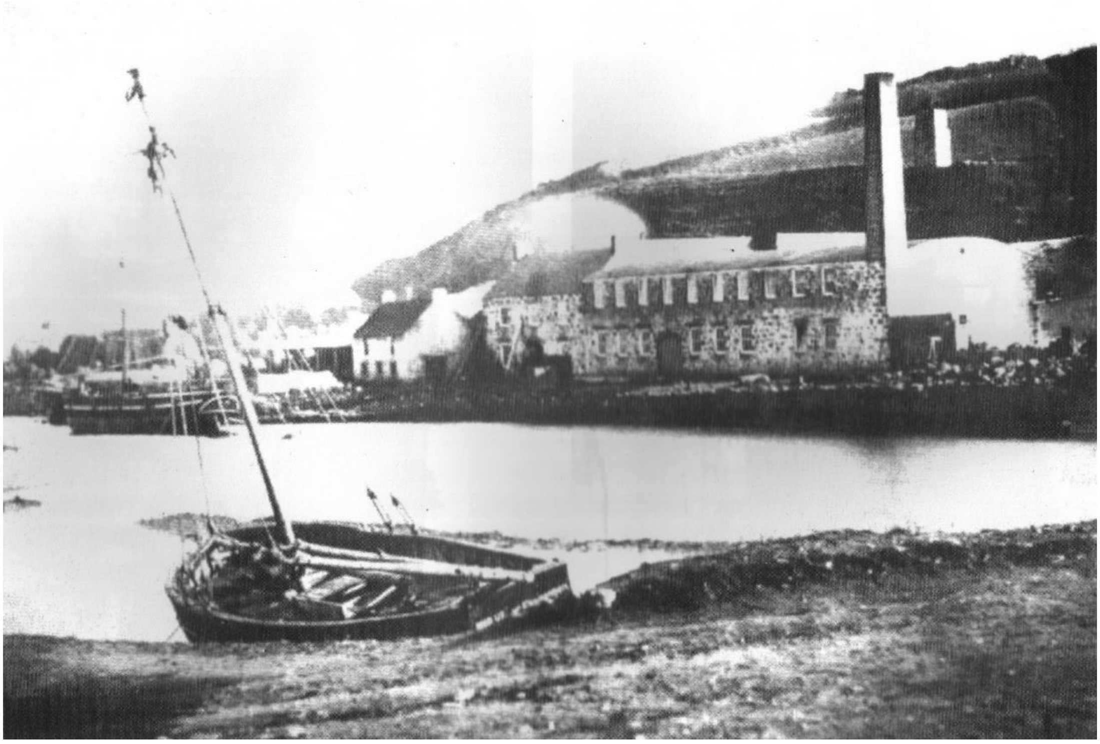
Figure A2.6 Aerial photo flown 13/05/2001, overlaid with the position of the dune toe (red line), sea defences (blue line) and cross-shore profiles (black lines) surveyed in May 2024. Source: Google Earth

Figure A2.7 Aerial photo flown 24/07/2011, overlaid with the position of the dune toe (red line), sea defences (blue line) and cross-shore profiles (white lines) surveyed in May 2024. Source: Google Earth

Figure A2.8 Aerial photograph flown *c*. July 2022, overlaid with the position of the dune toe (red line), sea defences (blue line) and cross-shore profiles (white lines) surveyed in May 2024. Source: Bing

Appendix 3

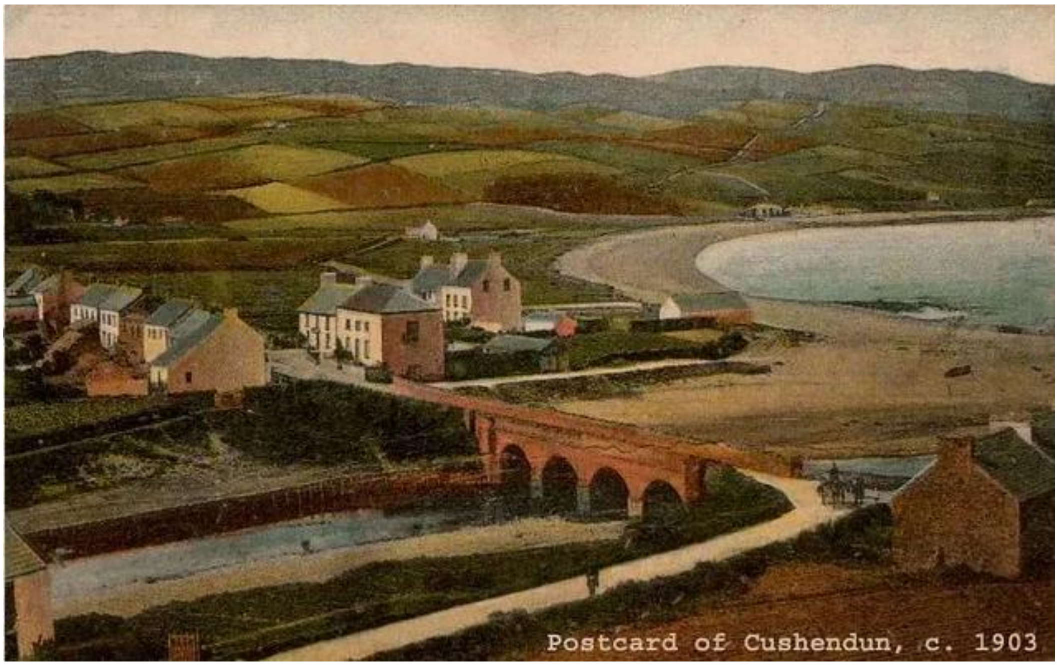
Historical ground photographs



Photograph A3.1 The scutch mill and rope works c.1865

Photograph A3.2 Upstream side of Cushendun Bridge late 1880s (from Kirk McClure Morton, 1988)

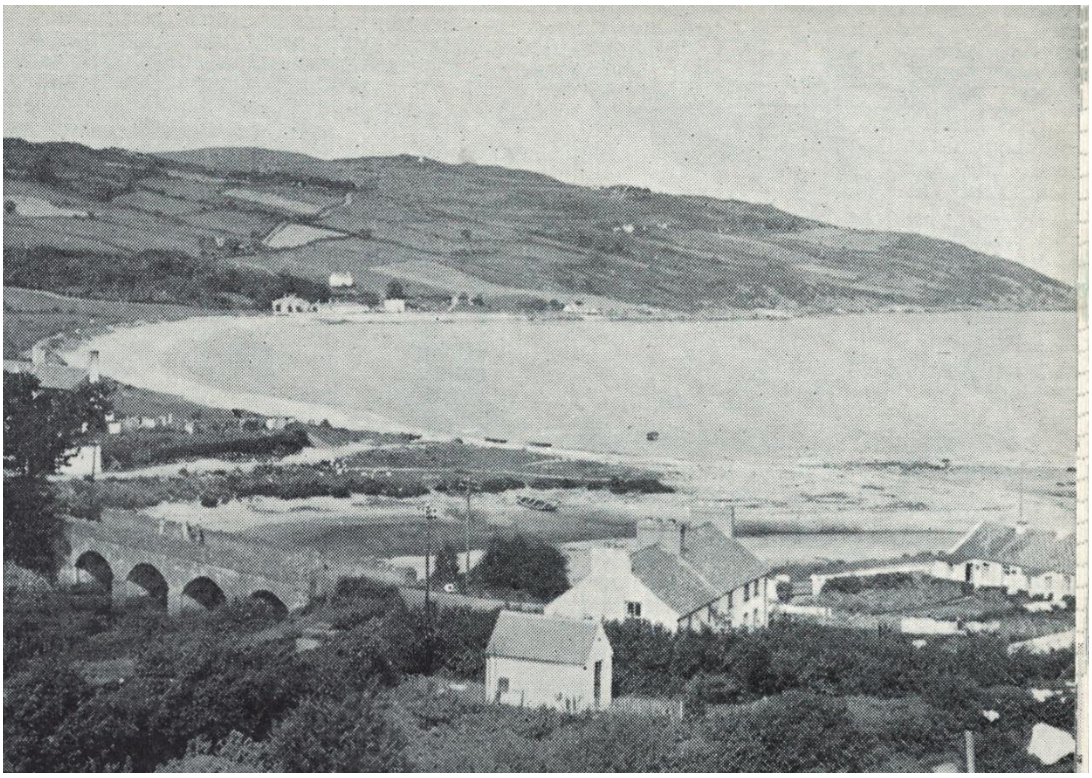
Photograph A3.3 Cushendun Bridge and Harbour 1895



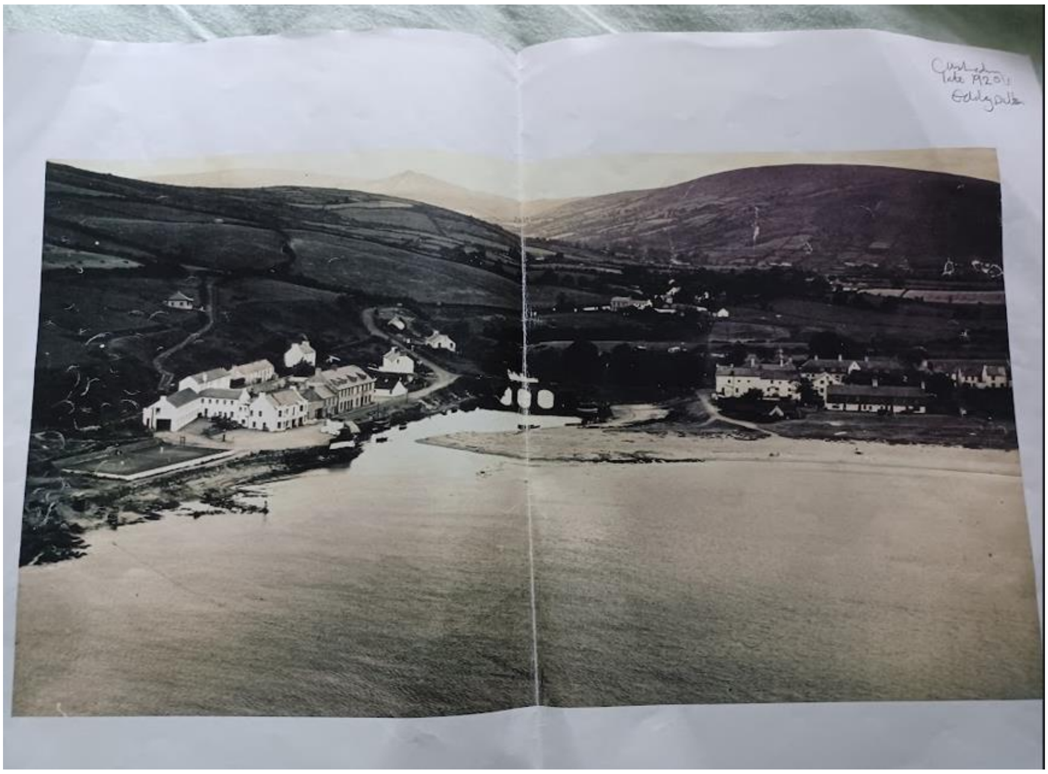
Photograph A3.4 Cushendun Bridge and Harbour c.1903

Photograph A3.5 Cushendun Bridge and Harbour c.1907

Photograph A3.6 View of Cushendun Bay from the SW c.1910



Photograph A3.7 Cushendun Bridge and Harbour c.1910



Photograph A3.8. Oblique aerial view of Cushendun Habour entrance Late 1920s? From Kirk McClure Morton (1988) report. Note fish nets across harbour entrance

Photograph A3.9 The Caves House and Fisherman's Point area late 1920s?

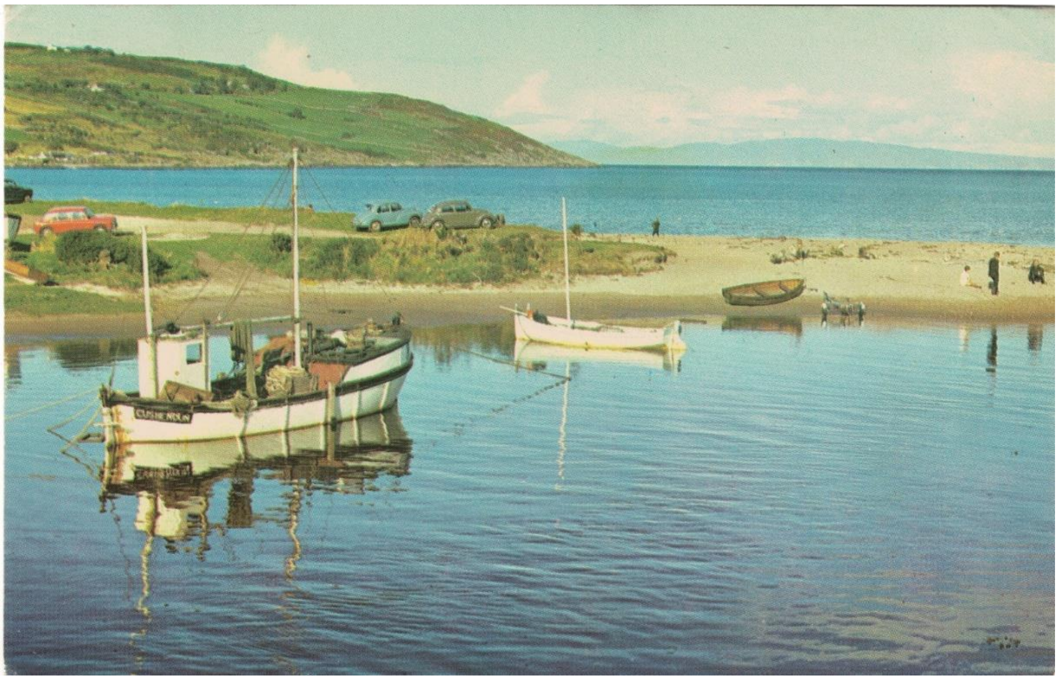
Photograph A3.10 The harbour 1950s?

Photograph A3.11 Southern end of bay 1950s? Note steep, wide beach with a high proportion of sand

Photograph A3.12 Rockport late 1960 / early 1970s? Note abundant sand on the upper beach

Photograph A3.13 View towards Cushendun Bridge from Fisherman's Point Late 1960s?

Photograph A3.14. Cushendun Harbour Late 1960s? Photograph on the wall of McBride's pub

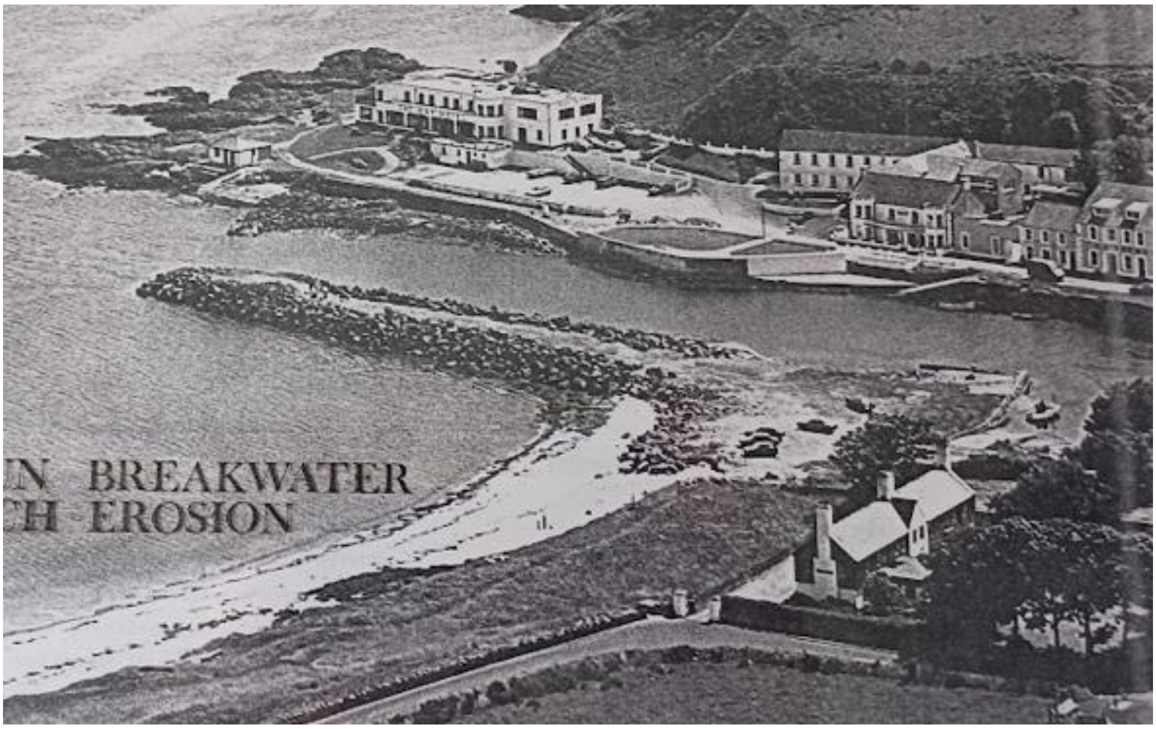


Photograph A3.15 Early 1970s postcard with 1982 postmark

FIGURE 4: LANDSCAPED AREA

Photograph A3.16 Later 1970s? From Kirk McClure Morton (1988)

Photograph A3.17 Malachy McSparron, Randall McDonnell & John Hume 1980 (from McDonnell, 2009, p115. Note the original high NT breakwater at the top left



Photograph A3.18 The original 1979/80 breakwater - Front cover of Kirk McClure Morton (1988) report

Appendix 4

RTK-GNSS ground survey quality control data

Table A4.1 Summary of quality control error values and the Geometric and Vertical Dilution of Precision (GDOP and VDOP) values in the positions and elevations surveyed on 22nd February, 7th May and 19th September 2024 surveys. The Coordinate Quality (CQ) values indicate the likely error in coordinate space (in millimetres), while the DOP values provide a measure of the quality of the satellite constellation being used to calculate the positions (1.0 is perfect precision; 1.0-2.0 is considered excellent, 2-5 is considered good). The OSNet Reference Stations used for these surveys were Station 081 (a radio mast near the A2 near Ballypatrick at 317611.725E, 438616.098N, 157.067 m ODB) and Station 076 (a radio mast near the B64 between Kilrea and Garvagh at 288563.005E, 413917.922N, 91.244 m ODB).

Parameter	1-D CQ (horizontal) (mm)				2-D CQ (vertical) (mm)			
	22/02/24	07/05/24	19/09/24	12/02/25	22/02/24	07/05/24	19/09/24	12/02/25
n	608	657	729	591	608	657	729	591
Mean	14	13	12	20	11	10	9	15
StDev	3	3	3	5	2	2	1	4
10th percentile	10	10	9	13	9	9	8	10
50th percentile	14	13	11	20	11	10	9	15
90th percentile	18	16	15	27	14	12	11	20
Max	28	40	25	35	25	26	16	26
Min	8	9	7	8	8	8	6	8

Parameter	GDOP				VDOP			
	22/02/24	07/05/24	19/09/24	12/02/25	22/02/24	07/05/24	19/09/24	12/02/25
n	608	657	729	591	608	657	729	591
Mean	1.8	1.7	1.6	1.6	1.0	1.2	0.9	1.0
StDev	0.2	0.3	0.4	0.2	0.2	0.2	0.2	0.1
10th percentile	1.5	1.3	1.4	1.4	0.8	0.9	0.8	0.9
50th percentile	1.7	1.6	1.5	1.6	1.0	1.1	0.9	1.0
90th percentile	2.2	2.0	1.8	1.8	1.2	1.5	1.0	1.1
Max	3.1	4.9	9.2	2.6	1.8	2.7	4.7	1.6
Min	1.4	1.3	1.3	1.3	0.8	0.9	0.7	0.8

Table A4.2 Points on the tarmac surface of the southern car park at Cushendun beside the harbour surveyed by KPAL using RTK-GNSS on 07/05/2024, and elevations interpolated at the same points from the LiDAR DTM flown 28/08/2021 by Bluesky and supplied by Northern Ireland Coastal Observatory. The average horizontal (1D CQ) error of the RTK-GNSS survey was 13 mm. The average difference between the RTK-GNSS and LiDAR surveys is 8 mm, which is within the error tolerances of both techniques.

Easting (m)	Northing (m)	1D CQ (mm)	2D CQ (mm)	GDOP	VDOP	RTK-GNSS (m)	LIDAR (m)	Difference (mm)
324980.234	432679.376	14	12	1.7	1.1	2.988	2.986	-2
324985.301	432677.767	13	11	1.5	1.0	3.104	3.126	22
324990.548	432674.472	12	10	1.4	0.9	3.188	3.190	2
324995.331	432671.183	12	10	1.4	0.9	3.250	3.232	-18
324999.812	432673.539	13	11	1.4	0.9	3.302	3.308	6
324995.810	432676.602	13	10	1.4	0.9	3.294	3.285	-9
325000.972	432679.464	13	10	1.4	0.9	3.401	3.408	7
324996.864	432683.643	12	10	1.4	0.9	3.399	3.378	-21
324991.153	432681.622	12	10	1.5	1.0	3.277	3.266	-11
324987.011	432681.688	15	12	1.5	1.0	3.222	3.213	-9
324992.084	432687.829	14	11	1.4	0.9	3.401	3.389	-12
324987.879	432692.071	12	10	1.4	0.9	3.407	3.413	6
324983.243	432695.548	12	10	1.4	0.9	3.449	3.455	6
324977.395	432696.684	12	10	1.4	0.9	3.514	3.524	10
324973.891	432692.883	11	9	1.4	0.9	3.444	3.407	-37
324979.490	432690.597	12	10	1.4	0.9	3.329	3.315	-14
324976.727	432686.656	13	11	1.4	0.9	3.235	3.222	-13
324980.123	432683.581	13	11	1.4	0.9	3.161	3.143	-18
324970.044	432685.037	14	12	1.5	1.0	3.332	3.304	-28
324966.156	432679.728	15	12	1.5	1.0	3.360	3.330	-30
Means:		13	11	1.4	0.9			-8

Table A4.3 Points on the tarmac surface of the jetty at the northern end of Cushendun Bay surveyed by KPAL using RTK-GNSS on 07/05/2024, and elevations interpolated at the same points from the LiDAR DTM flown 28/08/2021 by Bluesky and supplied by Northern Ireland Coastal Observatory. The average horizontal (1D CQ) error of the RTK-GNSS survey was 13 mm. The average difference between the RTK-GNSS and LiDAR surveys is 8 mm, which is within the error tolerances of both techniques.

Easting (m)	Northing (m)	1D CQ (mm)	2D CQ (mm)	GDOP	VDOP	RTK-GNSS (m)	LIDAR (m)	Difference (mm)
325175.424	433474.574	13	9	2	1.3	1.004	1.010	6
325178.445	433487.496	12	9	2	1.3	1.027	1.052	25
325176.387	433491.621	12	10	2	1.3	1.279	1.291	12
325175.264	433486.812	11	9	2	1.3	1.000	1.006	6
325173.350	433479.373	12	9	2.1	1.4	0.953	0.976	23
325171.496	433471.938	13	9	2.1	1.4	0.949	0.976	27
Means:		12	9	2.0	1.3			16

Table A4.4 Points surveyed on Benchmark 1 (a metal nut on the slipway at Cushendun) on four surveys on 22/02/2024, 07/05/2024, 19/09/2024 and 12/02/2025

Date	Easting	Northing	Elevation (m ODB)	1D CQ (mm)	2D CQ (mm)	GDOP	VDOP
22/02/2024	324977.313	432669.752	2.040	12	9	1.7	1.1
	324977.313	432669.753	2.037	12	9	1.7	1.1
	324977.312	432669.750	2.033	12	9	1.7	1.1
Average	324977.313	432669.752	2.037	12	9	1.7	1.1
07/05/2024	324977.317	432669.752	2.039	11	10	1.6	1.0
	324977.314	432669.758	2.040	11	10	1.6	1.0
	324977.311	432669.753	2.036	10	9	1.5	0.9
Average	324977.314	432669.754	2.038	11	10	1.6	1.0
19/09/2024	324977.295	432669.779	2.048	15	11	1.5	0.9
	324977.293	432669.782	2.051	15	11	1.5	0.9
	324977.294	432669.786	2.051	14	10	1.5	0.9
Average	324977.294	432669.782	2.050	15	11	1.5	0.9
12/02/2025	324977.311	432669.791	2.058	14	12	1.6	1.0
	324977.312	432669.791	2.058	13	11	1.6	1.0
	324977.312	432669.790	2.055	13	11	1.6	1.0
Average	324977.312	432669.791	2.057	13	11	1.6	1.0
Differences (mm)							
02/2024 to 05/2024	1	2	1				
02/2024 to 09/2024	-19	30	13				
02/2024 to 02/2025	-1	39	20				
05/2024 to 09/2024	-20	28	12				
05/2024 to 02/2024	-2	37	19				
09/2024 to 02/2025	18	9	7				