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Historic and contemporary dune inventories to assess dune vulnerability to climate change impacts

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Abstract: The overall status of dune health in Ireland is assessed as 'inadequate' and declining due to the on-going losses and pressures which signify the urgent need for integrated, problem- and community-focussed coastal management plans. Historically, Ireland has only being monitoring the health of our coastal dunes very intermittently. This research reviews published coastal dune inventories in Ireland (Kinahan and McHenry, 1882; Young, 1977; Curtis, 1991; Quigley, 1991; Ryle *et al.,* 2009; Delaney *et al.,* 2013) and uses one of the most current inventories (Coastal Monitoring Project 2004-2006 in Ryle *et al.,* 2009) to map the current distribution of dunes in thirteen coastal counties in the Republic of Ireland and assess the vulnerability of these dune ecosystems to projected changes in storminess. The CMP Report data was downloaded into a GIS and a filter query was applied to identify the dune area extent in each county and isolate the three major dune categories (Fixed, Embryonic and Mobile) which are critical for beach-dune sediment budgets *via* sediment exchange processes. The polygon features for each dune category (a total of 179) were designated a shoreline orientation based on the cardinal and ordinal wind directions. Counties Donegal (36%), Mayo (24%) and Kerry (14%) contain 74% of the total dune area in Ireland (c.76sq. km). Fixed dunes comprise 93% of the total dune area of interest in this study; mobile (5%) and embryonic (2%) dunes have a much smaller areal extent. The severity of the impacts from storms depends not only on the character (size, duration, direction) of the extremes but also on the exposure and vulnerability of coastal ecosystems and communities to these extremes.

Keywords: *ecosystem goods and services, dune habitat, coastal management, storms; climate change*

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Introduction

Beach-dune ecosystems are an integral element of Ireland's natural heritage and are of considerable scientific, conservation, and recreational value. However, these critical ecosystems have a legacy of poor management practices in Ireland that continue to adversely impact their health and preservation (Quinn, 1977; Young, 1977). They are under threat from a number of sources: primarily natural episodic and chronic erosion, pressures from coastal developments and agricultural practices, tourism and recreational activities (Carter *et al.,* 1992; Sinnot and Devoy, 1992; Power *et al.,* 2000; McKenna *et al.,* 2005, 2007; Devoy, 2016; Farrell, 2018).

The evidence is unequivocal that the resilience of Irish coastal dunes is decreasing and in some cases, especially where mobility is not a valid response from anthropogenic pressures, these fragile ecosystems are disappearing completely (NPWS, 2013). The past record and future forecasts for the long term health and stability of these systems is not encouraging. If future climate change projections hold true, we can expect the triggers that push these ecosystems equilibria beyond thresholds to be exceeded more frequently with increased coastal erosion and flooding risks and loss of critical and protected habitat. Loureiro and Cooper (2018) report in this special issue that winters are becoming more energetic and stormier in NW Ireland with evidence of storm clustering. Irish rural and urban coastal populations already feel threatened, not just from the recent weather events, but also from the suite of climate change projections that highlight a future ocean-climate that is characterised by more extreme storminess in the NE Atlantic in the vicinity of Ireland (Feser *et al.,* 2014).

This research reviews published coastal dune inventories in Ireland and uses the most current inventories (Sections 1.2 to 1.5) to determine the current distribution of dunes in each county in Ireland and assess the vulnerability of these dune ecosystems to climate change projections, specifically, changes in storm track direction in the NE Atlantic. As Rooney (2010, 71) stated during the international dune conference held in Liverpool in 2008, '*(w)ithout a thorough and up to date understanding of the distribution, extent, geomorphological type, vegetation, condition, use and value of our coastal dunes it is difficult to make robust and sustainable management decisions*'.

Coastal dunes: an undervalued and underappreciated natural resource

Everard *et al.* (2010) assessed the potential contribution of ecosystems goods and services (EGS) of coastal sand dunes in the UK and continental Europe and their findings are equally relevant to Irish dunes. They list the substantial provisioning, regulatory, cultural and supporting services provided by coastal sand dunes (Table 1). Jones *et al.* (2011) conducted similar analyses of the high financial and cultural values of EGS in UK coastal margins (dunes, machair, saltmarsh, shingle, sea cliffs, coastal lagoons) and identified knowledge gaps in research, including lack of basic data such as extent and trends. They calculated that coastal margin EGS have substantial value, being estimated at £48 billion (3.46% of UK Global National Income). Applying a similar valuation method (based on

1998 national GNP) and proportional contribution (3.46% of GNI) as Jones *et al.* (2011) to Ireland estimates an aggregated value of €2.57 billion but this figure should only serve as an indicator of the potential equivalent value for Ireland's coastal margin EGS and highlights a knowledge gap that exists in Ireland to guide future research. Norton *et al.* (2018) conducted an economic assessment of coastal, marine and estuarine ecosystems in Ireland but explicitly directed users not to use their aggregated single value (€3.58 billion) as a representation of the total economic value (TEV) as it oversimplified their approach which comprised of disparate techniques (see their Table ES.1).

Table 1: Ecosystem Goods and Services provided by sand dunes (from Everard et al., 2010, Table 3, 480-483).

Provisioning Services	**Cultural Services**
Freshwater	Cultural Heritage
Food	Recreation and Tourism
Fibre and Fuel	Aesthetic Value
Genetic Resources	Spiritual and Religious Value
Mineral Extraction	Inspiration for Art, Folklore, Architecture
Landscape for Industrial Use	Social Relations
	Educational Resource
Regulating Services	**Supporting Services**
Air Quality Regulation	Soil Formation
Climate Regulation	Primary Production
Water Regulation	Nutrient Cycling
Natural Hazard Regulation	Water Recycling
Pest Regulation	Photosynthesis
Disease Regulation	Provision of Habitat
Erosion Regulation	
Water Purification and Waste Treatment	
Pollination	

Coastal dunes are ecosystems with diverse plant communities and an occurrence of rare, sometimes narrowly endemic species (Marcenò *et al.,* 2018) which is reflected in the four EU Annex I priority habitats located within Irish dune systems (NPWS, 2013). Varandas Martins *et al.* (2018) report that the vast majority of Irish coastal dune wet depressions are protected by the EU Habitats Directive as humid dune slacks (HDS; habitat code 2190) as they support unique biodiversity and are important niche habitats (e.g., Natterjack toad (*Bufo calamita*)) within the wider dune landscape (Houston, 2008;

Jones *et al.,* 2011). In Ireland, dunes are particularly important for controlling coastal erosion and protecting low lying coastal areas from flooding by stabilising the sediment and promoting soil retention in vegetation root structure. This has ramifications for coastal protection if projected changes of extreme weather and climate events (fewer but more intense storms, but with high uncertainty on details) are realised (Matthews *et al.,* 2014; Desmond et al., 2017; Loureiro and Cooper, 2018). Dunes are a large reservoir of sand that is continually replenished *via* aeolian (wind) processes when beach levels are high and prevailing winds are directed onshore. This sediment reservoir contributes to nourish adjacent sandy beaches during storm erosion events when the back beach is lowered and dunes become vulnerable to scarping from increased wave run up. This seaward directed sediment exchange provides the first line of defence against storm surge for tourist-related businesses, ocean front properties, land for aquaculture and agriculture, and wildlife habitat (Barbier *et al.,* 2011). This sediment exchange between the beach and dunes is also critical for these ecosystems to maintain their multi-faceted EGS functions.

Historic Dune Inventories of Ireland

Historically, Ireland has only being monitoring our coastal dunes very intermittently (Table 2). Kinahan and McHenry (1882) mapped '*sand dunes or aeolian drift*' as part of a land reclamation survey in the late 19th century. They identified a total of 89 sites in thirteen counties in the Republic of Ireland covering a total area of 15,997ha. The number of locations, areal coverage, and proportion coverage nationally mapped for each county are: Donegal (14; 6,686ha; 41.8%), Sligo (7; 919ha; 5.8%), Mayo (12; 2,610ha; 16.3%), Galway (9; 704ha; 4.4%), Clare (4; 295ha; 1.8), Kerry (7; 980ha; 6.1%), Cork (2; 180ha; 1.1%), Waterford (2; 132ha; 0.8%), Wexford (15; 521ha; 3.3%), Wicklow (8; 531ha; 3.3%), Dublin (3; 202ha; 1.3%), Meath (1; 78ha; 0.5%), Louth (1; 120ha; 0.8%), Down (1; 640ha; 4%), Antrim (1; 160ha; 1%), and Derry (2; 912ha; 5.7%). The full list of Kinahan and McHenry (1882) is available in Appendix 3 of Quinn (1977) who also presented a largely unannotated small scale map (1: 1,000,000) of the Republic of Ireland's '*major sand dune systems*'. A total of 136 sites are marked on the map (note: Curtis (1991) incorrectly stated that Quinn (1977) listed 91 dune sites in the whole of Ireland). No other site information is provided, e.g., dune health.

Young (1977) reported, in an unpublished M. Phil. thesis, the distribution and ownership of major dune systems in the Republic of Ireland. This work is illustrated in a small scale map in Cabot (1977, Figure 1). Of the total of 110 dune systems mapped, 94 (85%) were in private ownership, seven in part private – part public ownership (6%), and nine (8%) are in entirely public ownership. The dunes were dominantly along the west coast (85%) and east coast (13%). The south coast only had 2% of dunes. The total area coverage of the dunes was reported as 14,300ha. No information related to dune type or health was listed.

Table 2: Dune inventories in Ireland ([1]Island of Ireland; [2]Republic of Ireland only; [3]fixed, mobile, embryo dunes; [4]all dune categories; [5]representative sites chosen by NPWS).

Source	Title	Location	Sites[1,2]	Total Area*	Dune type categories	Conservation Monitoring
Kinahan and McHenry (1882)	A Handbook on the Reclamation of Waste Lands, Ireland. Dublin: Hodges Figgis and Co., 1882	County / Townland list	892	15,997ha	1	No
Quinn (1977)	Sand Dunes: Formation, Erosion and Management	Point locations on c.1:1,000,000 map	1362		1	No
Young (1977) in Cabot (1977)	Planning for the Use of Irish Dune Systems	Point locations on c.1:1,000,000 map	1102	14,300ha	3 *Private, Public, Private/ Partly Public Ownership*	No
Curtis (1991) in Quigley (1991)	A site inventory of the sandy coasts of Ireland	Point locations on c.1:333,333 map	1911 168 RoI; 23 NI		3 *Sandhill; Dune; Machair*	No
Doody 2008 (using Quigley 1991 data)	Sand dune inventory of Europe, 2nd edition	Point locations on c.1:1,000,000 map	452	13,905ha	7 *Strandline; Foredune; Dune grassland; Machair; Dune Heath; Dune Slack; Woodland*	No
Ryle et al. (2009)	Coastal Monitoring Project (2004-2006)	GIS polygons	1812	7,630ha3 10,900ha4	3 10 *(See Table 3)*	Yes
Delaney et al. (2013); NPWS (2013, 1-3)	Monitoring survey of Annex I sand dune habitats in Ireland. Referred to as Sand Dune Monitoring Project (2011); also reported in NPWS (2013). Status of Protected EU Habitats and Species in Ireland: – Volume 1 (Overview) – Volume 2 (Habitats) Volume 3 (Species)	GIS polygons	395	3,619ha3 5,121ha4	3 10 *(See Table 3)*	Yes

Curtis (1991) was the first comprehensive dune inventory that listed location, area (where possible), dune type (*sandhill*, *dune*, *machair*), and status (conservation and management interest). A total of 191 dunes areas were identified (168 in the Republic of Ireland; 23 in Northern Ireland) of which 98 were designated as ASIs in 13 counties in the Republic of Ireland: Donegal (19), Sligo (6), Mayo (15), Galway (7), Clare (5), Kerry (9), Cork (7), Waterford (4), Wexford (10), Wicklow (5), Dublin (8), Meath (2), and Louth (1). Northern Ireland had dunes listed for Down (8), Antrim (10), and Derry (5) but with no equivalent RoI ASI designation. The impetus for the Curtis (1991) study was twofold: (i) dunes were being increasingly stressed from recreational and agricultural pressures; and (ii) the European Union for Dune Conservation (EUDC) was producing an inventory of coastal dunes throughout Europe, including a general review of the habitat and conservation status.

In November 1991, the first inventory of sand dunes in Europe was published (Doody, 1991). A total of seven different dune types were listed in the inventory: *bay dunes*, *spit dunes*, *ness dunes*, *offshore barrier island dunes*, *climbing dunes*, *hindshore dunes*, and *deltaic dunes* (see Figure 2, Doody 2005, p46). The revised second edition (Doody, 2008) has 45 dune sites listed for Ireland (see Doody and Curtis, 1991, pp. 40-41 for list and small scale map). These sites were derived from a survey (using the Quigley (1991) inventory) supported by the Irish National Parks and Wildlife Service as part of a process of designating Areas of Scientific Interest (41 of the 45 sites). The total area covered by these sites was 13,905ha. The dune types in Ireland were classified into seven vegetation categories dependent on distance from beach: *strandline*, *foredune*, *dune grassland*, *machair*, *dune heath*, *dune slack*, and *woodland*. No information related to dune type or health was listed.

Articles 11 and 17 of EU Directive on the Conservation of Habitats, Flora and Fauna (92/43/EEC)

The National Parks and Wildlife Service (NPWS) in Ireland, in their role as the management and scientific authorities for the country, supported a survey of all known sand dune sites in Ireland (181 in total, not including four sites that were not visited owing to access problems) from 2004 to 2006. The Coastal Monitoring Project 2004-2006 (referred to as CMP hereafter, Section 1.4) is published in Ryle *et al.* (2009) and was the first comprehensive survey of Irish dune systems. It now serves as the baseline for comparison with future surveys (e.g., see Sand Dune Monitoring (SDM) project, Section 1.5). The legal obligation requiring a national scale survey stemmed directly from Articles 11 and 17 of the EU Directive on the Conservation of Habitats, Flora and Fauna (92/43/EEC), commonly referred to as the Habitats Directive. Article 11 specifies that Member States carry out surveillance of the conservation status of the natural habitats and species listed in Annexes I (habitats), II, IV, and V (animal and plant species). Article 17 requires Member States to report the results of the surveillance to the European Commission every six years including a report on the implementation of the '*measures to maintain or restore natural habitats and wild species listed in the Annexes to the Directive at a favourable conservation status*'.

There are a total of 231 Annex I habitats identified in EU Member States, 71 of which are designated as priority sites (European Commission, 2007). Ireland has a total of 16 Annex I coastal habitats of which ten occur in sand dune systems (Table 3). Of these coastal dune habitats, four are listed as priority habitat (Table 3). Priority Annex I (*Natural habitat types of community interest whose conservation requires the designation of Special Areas of Conservation*) natural habitats and wild fauna, and flora are afforded special protection as the EU considers them to be in danger of disappearance and because their global distribution is largely within the EU.

Sand dune habitat monitoring and assessment I: CMP

The CMP provided the basis for the first Irish Article 17 report in 2007 and covered a total of ten sand dune habitats (Table 3). The report assessed habitats on the basis of their Range, Area, Structure and Function, and Future Prospects. Each parameter received a score of 'Favourable' (green), 'Unfavourable-Inadequate' (amber), or 'Unfavourable-Bad' (red). A description of these parameters is given in Table 4. The summary findings of the CMP were not encouraging and the management regimes in place for the dune systems and their unique habitats, in terms of maintaining or improving their ecological condition, were listed as '*largely unsatisfactory*'. It is very worrying that six out of these ten sand dune habitats were assessed overall as '*Unfavourable-Inadequate*' while the remaining four were '*Unfavourable-Bad*', including two of the Annex I priority habitats (fixed dunes and machair). No dune system in Ireland achieved '*Favourable*' status (Table 5A). An overview of the major pressures reported in the first Annex I report lists both natural (erosion from storms and high tides) and human impacts from land use and management (grazing, recreation, sand and gravel extraction, reclamation, pollution, invasive species, burning, erosion, and trampling). The extent to which coastal sites are impacted by these pressures differs in each location.

Table 3: Annex I coastal habitats in Ireland. The left column lists ten coastal sand dune habitats. The right column lists coastal non-dune habitats. The four digit codes are equivalent to those listed in the Natura 2000 standard data-entry form. The asterisk indicates a priority habitat that is protected using SAC designations.

	Code	Habitat Name (Dunes)
UPPER BEACH	1210	Annual vegetation of drift lines
	1220	Perennial vegetation of stony banks
	2110	Embryonic shifting dunes
LANDWARD ↓	2120	Shifting dunes along the shoreline with Ammophila arenaria (white dunes)
	*2130**	Fixed coastal dunes with herbaceous vegetation (grey dunes)
	2140*	Decalcified fixed dunes with Empetrum nigrum
	2150*	Atlantic decalcified fixed dunes
	2170	Dunes with Salix repens ssp argentea
	2190	Humid dune slacks
	21A0*	Machairs

Code	Habitat Name (other)
1230	Vegetated sea cliffs of the Atlantic and Baltic coasts
1310	Salicornia and other annuals colonising mud and sand
1320	Spartina swards
1330	Atlantic salt meadows
1410	Mediterranean salt meadows
1420	Mediterranean and thermo-Atlantic halophilus scrubs

Table 4: A description of the Conservation Assessment terms used in sand dune habitat surveys.

Conservation Assessment	Description
Favourable	Habitat can be expected to prosper without any change to existing management or policies
Unfavourable – Inadequate	Change in management or policy is required to allow the habitat to prosper, but the danger of extinction is not high
Unfavourable – Bad	Habitat is in danger of disappearance

Table 5A: National overview of conservation assessments from the Coastal Monitoring Project (Ryle *et al.*, 2009). Green: Favourable; Yellow: Unfavourable – inadequate; Red: Unfavourable – bad. The asterisk identifies EU Annex I priority sites.

Habitat Code	Habitat Name	Range	Area	Structure and Functions	Future Prospects	Overall
1210	Annual vegetation of drift lines					
1220	Perennial vegetation of stony banks					
2110	Embryonic shifting dunes					
2120	Shifting dunes along shoreline with Ammophila arenaria					
2130*	Fixed coastal dunes with herbaceous vegetation					
2140*	Decalcified fixed dunes with Empetrum nigrum					
2150*	Atlantic decalcified fixed dunes					
2170	Dunes with Salix repens ssp argentea					
2190	Humid dune slacks					
21A0*	Machairs					

Table 5B: National overview of conservation assessments from the Sand Dune Monitoring Project published in NPWS (2013) and Delaney et al., 2013. Green: Favourable; Yellow: Unfavourable – inadequate; Red: Unfavourable – bad; Stable: no genuine change. The asterisk identifies EU Annex I priority sites.

[**Note:** *Table 5B was populated using results provided in NPWS (2013ii). There were a number of errors in the transfer of data between the 2007 and 2013 reports. The Assessment Summary table for Habitat 2140 for 2007 has two errors: Structure and Functions is listed as Red (should be green) and Overall status is listed as Red (should be amber); the Assessment Summary table for Habitat 2150 has two errors: Structure and Functions is listed as Red (should be green) and Overall status is listed as Red (should be amber); the Assessment Summary table for Habitat 2170 has one error: Area is listed as Green (should be amber). The Assessment Summary tables are switched for Habitats 2110 and 2120.*]

Habitat Code	Habitat Name	Range	Area	Structure and Functions	Future Prospects	Overall
1210	Annual vegetation of drift lines		↓	↓	=	↓
1220	Perennial vegetation of stony banks		=	=	=	=
2110	Embryonic shifting dunes			=	=	=
2120	Shifting dunes along shoreline with Ammophila arenaria		=	=	=	=
*2130**	Fixed coastal dunes with herbaceous vegetation			=	=	=
2140*	Decalcified fixed dunes with Empetrum nigrum			=	=	=
2150*	Atlantic decalcified fixed dunes			=	=	=
2170	Dunes with Salix repens ssp argentea			=	=	=
2190	Humid dune slacks	↓	↑	=	↓	↓
21A0*	Machairs		=	=	=	=

Sand dune habitat monitoring and assessment II: SDM

The Annex I sand dune habitat survey subsequent to CMP is subsumed within the NPWS (2013) reports '*The Status of EU Protected Habitats and Species in Ireland – Volumes 1-3*'. The SDM dune habitat survey (referred to as the Sand Dune Monitoring project) was conducted by Botanical, Environmental and Conservation (BEC) Consultants from 2011-2013 on behalf of NPWS and published in Delaney *et al.,* 2013. Only forty sites

were strategically selected (i.e., sites covered a substantial proportion of total national resource for each habitat) for monitoring and assessment. The NPWS (2013) report is the basis for the second Irish Article 17 report to the EU. Similar to CMP, the SDM assessed habitats on the basis of four parameters: Range, Area, Structure and Function, and Future Prospects and each received a score of '*Favourable*' (green), '*Unfavourable-Inadequate*' (amber), or '*Unfavourable-Bad*' (red) (Table 5B). The evaluation matrix is described in Table 1.1 (p4) in Delaney *et al.* (2013) and is partly based on changes from the previous CMP survey. Overall, direct comparison with the 2007 assessments was approached with caution, as some 2013 results show an apparent change which is due to either improved knowledge (more detailed surveys lead to improved understanding of distributions and ecology of habitats) or changes in assessment methods (e.g., new guidelines and lists of pressures and threats). There is no overall change in dune health. The change in 'Shifting dunes along shoreline with *Ammophila arenaria*' (2120) from Red to Amber is due to changes in the assessment techniques and '*does not represent genuine change on the ground* (p26)'. These dune areas are still listed as being under pressure from recreation and coastal defences. Similarly, the overall status of dune slacks has changed from '*Unfavourable-Bad*' to '*Inadequate and declining*' due to the on-going losses and pressures from interference in the local hydrology, recreation and agriculture. The amalgamated pressures/threats reported in 2013 for coastal dunes in Ireland are similar in themes to the CMP: agriculture (unsuitable grazing and fertilisation), mining, urbanisation, human intrusion and disturbances, pollution, invasive and problematic species, natural system modifications, natural biotic and abiotic processes, natural catastrophes, and climate change (NPWS, 2013).

Methods

The Coastal Monitoring Project Report – including GIS maps of the dune areas reported in Ireland for 2004-2006 – was downloaded (free resource) from the NPWS online resource (NPWS, 2018) and information portal: https://www.npws.ie/maps-and-data/habitat-and-species-data [Accessed 15/08/2018]. The full dataset incorporates multiple land uses and land types (including dunes) of the Irish coastline. The dataset was imported into a GIS where a filter query was applied to, firstly, identify the dune area extent in each county and, secondly, to isolate the three major dune categories (Fixed, Embryonic and Mobile) within each mapped 'unit'. The GIS calculated the total dune area for fixed, embryonic and mobile dunes within each unit. The polygon features for each dune category (a total of 179 polygons) were assessed a 'shoreline orientation' based on the cardinal and ordinal wind directions (N, NE, E, SE, S, SW, W, NW). The data are presented in mapped and tabular formats. The major contribution of this research is to categorise dune locations and extents on a county by county basis in Ireland using secondary data sourced from the comprehensive national dune geodatabase freely available from NPWS (referenced previously).

Results

The mapped and tabular data of dune locations and dune characteristics (dune type, area, and orientation) for each county are provided in Appendices (separate available via the Irish Geography website, xxxx), for the for the thirteen coastal counties (Appendix 1-13) in Ireland identified as containing dune habitats. These results provide a small scale map for visual reference of dune locations in each county and unit descriptions (location, area, type, orientation). The aggregated data are discussed in the next sections. For larger scale maps it is recommended to access the NPWS database and download the CMP report and associated GIS files.

Dune Area

The total dune area coverage for the Republic of Ireland is c.7,627,5508m^2 (76.2km^2). The results show that Donegal has the largest extent (27,499,318m^2) of dunes which comprises 36% of the total dune area in the country (Table 6). Counties Mayo (18,161,930m^2) and Kerry (10,577,528m^2) have the second and third largest areas of dunes comprising 24% and 14% of the total dune area, respectively. These three counties have 74% of the total dune area in Ireland. Counties Wexford (6,058,873m^2; 8%) and Sligo (5,063,087m^2; 7%) are the next largest areas. These top five counties contain 89% of the fixed, embryonic, and mobile dunes in Ireland. There is a substantial decrease in dune area observed for Dublin (1,569,438m^2; 2%), Wicklow (1,419,409m^2; 2%), Clare (1,362,302m^2; 2%), Galway (1,305,984m^2; 2%), Cork (1,278,860m^2; 2%), Waterford (810,575m^2; 1%), Louth (418,103m^2; 1%) and Meath (404,217m^2; 1%). Fixed dunes comprise 93% of the total dune area of interest in this study; mobile (5%) and embryonic (2%) dunes have a much smaller areal extent.

Table 6: A list of dune area extent in each county; dune areas are subdivided into three categories (Fixed, Embryonic, and Mobile Dunes). Further details are available in Appendix 1.

	Total Area	Fixed	Embryonic	Mobile	Area	Fixed	Embryonic	Mobile
	m^2	m^2	m^2	m^2	%	%	%	%
Donegal	27,499,318	25,736,622	524,277	1,238,419	36	36	31	31
Mayo	18,161,930	17,347,752	67,764	746,414	24	25	4	18
Kerry	10,577,528	9,735,038	222,045	620,444	14	14	13	15
Wexford	6,058,873	5,204,682	208,154	646,036	8	7	12	16
Sligo	5,063,087	4,497,736	345,204	220,147	7	6	20	5
Dublin	1,569,438	1,285,196	82,553	201,689	2	2	5	5
Wicklow	1,419,409	1,304,170	43,014	72,225	2	2	3	2
Clare	1,362,302	1,319,063	14,661	28,579	2	2	1	1

	Total Area	Fixed	Embryonic	Mobile	Area	Fixed	Embryonic	Mobile
Galway	1,305,984	1,184,044	65,705	56,235	2	2	4	1
Cork	1,278,860	1,198,247	41,101	39,511	2	2	2	1
Waterford	810,575	713,729	43,580	53,267	1	1	3	1
Meath	404,217	346,247	15,565	42,405	1	0	1	1
Louth	763,988	657,610	32,740	73,638	1	1	2	2
Total	76,275,509	70,530,136	1,706,363	4,039,009				
Total %		93	2	5	100	100	100	100

Fixed dunes

Not surprisingly, the total area of fixed dunes shows a similar pattern to the total area coverage. Donegal contains the greatest proportion (36%) of fixed dunes with an area 25,736,622m^2, followed by Mayo (17,347,752m^2; 25%) and Kerry (9,735,038m^2; 14%). Wexford (5,204,682m^2; 7%) and Sligo (4,497,736m^2; 6%) have smaller, but not insignificant, fixed dune distributions with rapid decrease in fixed dune areas for counties Clare, Wicklow, Dublin, Cork, Galway and Waterford. The lowest fixed dune coverages are observed in Counties Louth and Meath (see Table 6).

Embryonic dunes

Donegal has the largest distribution of embryonic dunes (524,277m^2; 31%). Sligo has the second largest distribution (345,204m^2; 20%). Kerry (13%) and Wexford (12%) have similar extents with 222,045m^2 and 208,154m^2 of embryonic dunes, respectively. The areal coverage of embryonic dunes rapidly decreases for counties Dublin, Mayo, Galway, Waterford, Wicklow, and Cork. The smallest proportions of embryonic dunes occur in Louth, Meath and Clare (see Table 6).

Mobile dunes

The total area of mobile dunes is greatest in Donegal (1,238,419m^2; 31%). Counties Mayo (18%), Wexford (16%), and Kerry (15%) have extents ranging between 600,000m^2 and 800,000m^2. Cumulatively, these four counties comprise 80% of all mobile dunes in Ireland (see Table 6). Sligo (220,147m^2) and Dublin (201,689m^2) contribute 5% each to the mobile dune area. Counties Louth, Wicklow, Galway, Waterford, Cork, Clare, and Meath have much smaller mobile dune coverage (1-2% range for each).

Dune orientation

The distribution of dune orientations is dominated by west (W), southwest (SW), and northwest (NW) facing dune habitats. Cumulatively, these three directions comprise

72% of fixed dunes, 65% of embryonic dunes, and 57% of mobile dunes. Not surprisingly, these results mimic the dune area analyses as counties lying along the western seaboard are dominated with W, SW, NW dune orientations. A full description of the different dune orientations are listed in Appendix 1 for each county. Tables 7A and 7B list the aggregated dune orientation data for Ireland and *per* county.

Table 7A: Aggregated dune orientation data for Total, Fixed, Embryonic, and Mobile Dunes. Further details are available in Appendix 1.

Orientation	N	NE	E	SE	S	W	SW	NW
Total Area (%)	6	6	7	6	4	32	17	22
Fixed (%)	6	6	6	6	3	33	17	22
Embryonic (%)	4	6	9	11	4	40	16	9
Mobile (%)	8	9	9	12	4	21	20	16
Fixed (m^2)	4,557,111	4,127,915	4,495,025	4,054,858	2,458,901	23,118,789	12,050,155	15,667,382
Embryonic (m^2)	73,144	100,830	158,769	182,874	74,912	687,900	266,412	161,521
Mobile (m^2)	327,183	359,307	382,568	502,911	147,460	862,917	816,144	640,519
Total Area	**4,957,438**	**4,588,053**	**5,036,362**	**4,740,643**	**2,681,272**	**24,669,606**	**13,132,711**	**16,469,422**

Table 7B: Aggregated dune orientation data *per* county. Further details are available in Appendix 1.

County	Orientation	%
Donegal	NW	44
Mayo	W	48
Kerry	W	42
Wexford	SW	40
Sligo	NW	48
Dublin	SE	91
Wicklow	SE	58
Clare	W	83
Galway	NE	52
Cork	S	44
Waterford	SW	83
Meath	E	81
Louth	E	100

Observed and Projected Climate Extremes

There are still high levels of uncertainty in projections of storm track positions in the NE Atlantic and these can only be partly reconciled by paleoclimate studies. Until then, the degree of confidence in assessing any directional shift in storms remains moderate or low. There is evidence in several model simulations that investigate the future evolution of the NAO that the Icelandic Low will shift eastwards associated with an eastwards extension of the Polar Front Jet (PFJ) over Europe (Feser *et al.,* 2014; Jung *et al.,* 2003; Pinto and Raible, 2012; Pinto *et al.,* 2009; Raible *et al.,* 2006; Ulbrich and Christoph, 1999). It is noteworthy that Ireland's closer vicinity to the Icelandic Low has been recorded in the palaeoclimate records during the last thermal maximum when there was a significant shift in the boundary between the warmer ocean water and cooler Irish coastal waters. This shift eastwards of the warmer ocean waters reduces the extent of cooler coastal waters and the west coast is more susceptible to wind stresses from the west and northwest. These conditions will mean an equivalent gradual shift in the dominant storm direction from southwesterly to westerly and northwesterly. Such a shift will increase dune vulnerability in Counties Clare (83% of dunes oriented W), Mayo (48% W), Sligo (48% NW), Donegal (44% NW), and Kerry (42% W) (Table 7B).

In Ireland, extreme winds are generally (but not always) associated with the positive phase of the North Atlantic Oscillation (NAO), which influences storm generation, pathways and magnitude in the North Atlantic region (Pinto and Raible, 2012; Wanner *et al.,* 2001). The NAO describes inter-annual variability of sea level pressure differences between the Azores High and Icelandic Low, with high (low) index phases representing strong (weak) pressure differences (Hurrell, 1995). The reason why the NAO has an influence on Ireland's winter weather is because of its association with the Polar Front Jet (PFJ) Stream. The location of the PFJ determines where the largest temperature and pressure gradients are, which are then the preferred travel path for mid-latitude cyclones and thereby link the PFJ with storm trajectories at the ground (Ambaum *et al.,* 2001). During times of positive NAO (+), increased pressure gradient results in a higher potential for storms crossing over the NE Atlantic (Feser *et al.,* 2014). The impacts of this for Ireland are observed in an increased intensity of winter storm tracks coming from the southwest. Loureiro and Cooper (2018) examined the variability in frequency and sequencing of winter storm conditions in NW Ireland and determined from two independent wave reanalyses (ERA-Interim and WAVEWATCH III) that high energetic and stormy winters occur in clusters during positive phases of the NAO. During the negative NAO (-), the pressure gradient is reduced, which moves the Jet Stream position further south and is manifested in a meander type configuration of the PFJ (Feser *et al.,* 2014). The impact of this for Ireland's west coast is observed through fewer storms crossing the Irish coast as the Jet Stream moves down towards the south of Europe. Storms that reach the coast of Ireland during these periods are more likely to come from a northwest or northerly direction due to the PFJ meander (Stewart *et al.,* 2017). However, the relationship between storm frequency/intensity and the NAO is far from perfect (Morley and Rosenthal, 2014). Indeed, only a third of winter storm variability is linked to the NAO

(Feser *et al.,* 2014) with a stronger correlation in recent decades (Alexander *et al.,* 2005) and weaker correlations when considering longer historical timescales (Alexandersson *et al.,* 1998). It is also critical to note that the PFJ refers to upper atmospheric conditions and storms are driven by wind stress closer to the ocean surface.

This research is not focussed on reviewing ocean climate projections (see references herein), rather to provide the benchmark data of dune habitats in each county to assess dune vulnerability as ocean climate model projections become better constrained. What we do recognise is that the severity of the impacts from storms depends not only on the character (size, duration, direction) of the extremes, but also on the exposure and vulnerability of coastal ecosystems and communities to these extremes.

Discussion

Longitudinal dune surveys such as the CMP and SDM described previously are invaluable to provide snapshots in time (every six years) of the state of dune habitat health in Ireland, but these surveys do not provide any insight into (i) the processes (natural and/or human impacts) that are causing short- and long-term changes; nor (ii) the spatial and temporal characteristics of the changes *via* system thresholds and feedbacks manifested through patterns of response and recovery over large (small) and long (short) spatial and temporal scales (Farrell and Bourke, 2018). Local Authorities need to coordinate their efforts with physical and social scientists to undertake a comprehensive set of case study activities that will result in a greater understanding of the drivers that enhance and/or reduce resilience of all these natural environments for the communities that host them and identify measures that will increase current levels of resilience.

The development of coastal dune management strategies needs to be considered in the context of increased usage of coastal zones for social and economic purposes (Cooper and McKenna, 2008). This is due to the fact that natural and human disturbances have varying influences for the distribution of sediment to and from the dunes (Jackson and Nordstrom, 2011) and these sediment exchange processes are critical for healthy dune systems. Human-induced pressures include grazing (including overgrazing and undergrazing), recreation (sports and leisure structures and activities), urbanisation, sand and gravel mining, pollution, invasive species, erosion, and trampling. Mitigating these pressures requires attention and effective planning when designing, implementing, and enforcing coastal management plans (and bye laws) for beaches and connecting dune areas. For example, Delaney *et al.* (2013, 105) highlights how the drainage of wetlands or the erection of sea walls disturbs the natural processes which underpin dune ecosystems and argues that '*interrupting the natural transitions between sand dunes and other habitats also reduces the ecological value of sand dunes as fauna from the wider landscape is no longer able to access the dunes*'. Ryle *et al.* (2009) noted that the overall assessment of sand dunes under Annex I indicate that the condition and future prospects are such that none are achieving favourable conservation status. It is suggested that a comprehensive combination of research and information pertaining to dune management

and conservation is required to develop the most appropriate responses and preventative measures. If implemented, these should '*minimise the damage of potential impacts/threats and halt the decline in the status of the Irish sand dune systems and their habitats*' (Ryle *et al.,* 2009, 115).

Notwithstanding current issues of dune habitat degradation and loss, the future is bleak when we also consider changing ocean climates. Future predicted rising sea levels, which are a consequence of climate change, combined with potentially increased intensity of NE Atlantic storms crossing through the Irish coastline, could have the effect of increasing storm surges and wave run up (Desmond *et al.,* 2017). Loureiro and Cooper (2018) found that winters in Ireland are becoming more energetic and stormier in the northwest of Ireland and this has potential implications for the erosion and recovery of coastal beach-dune systems. The orientation of the shoreline with respect to the direction of the storm influences the susceptibility to erosion in each coastal cell *via* wave run-up processes (Castelle *et al.,* 2015). As stated in the IPCC (2012, 2) report, '*the character and severity of impacts from climate extremes depends not only on the extremes themselves, but also on the exposure and vulnerability to these extremes'*. Therefore, investigating the long-term vulnerability of Irish dune systems needs to be done in the context of their physiographic and regional setting (Cooper and McKenna, 2008; Jackson and Nordstrom, 2011).

Addressing these immediate challenges will only be successful if coastal communities are an integral part of the management process from identifying risks to designing short- and long-term solutions. Existing evidence suggests that a number of communities are already engaged with the transition towards climate resilience *via* local coastal management interventions with varying degrees of success. Some valuable lessons and insights are emerging. For example, recent work in The Maharees, Co. Kerry (OPW and Kerry County Council funded) by the first author and colleagues in NUIG highlight both enablers and barriers to effective community led responses to climate adaptation. Enablers include: availability of scientific expertise; good governance arrangements; and policy coherence. Barriers include: competing values and priorities; lack of guidance on problem identification; visioning, and actions; policy overload; lack of recognition or support at government level; and also perceived lack of expertise within local authorities tasked with making decisions and driving the implementation of adaptation (Farrell *et al.,* 2018). It was found that there are many benefits to be derived in empowering coastal communities. Involving them in decision making (bottom-up) results in policy and legislation that is more likely to be acceptable. Likewise, the survival of rural coastal communities depends on empowering people to make change locally and providing them with tools to adapt to climate change impacts.

Conclusions

Five counties contain 89% of the fixed, embryonic, and mobile dunes in Ireland. Local Authorities in Donegal (36%), Mayo (24%), Kerry (14%), Wexford (8%), and Sligo (7%) especially need to have well designed, fit-for-purpose coastal management, conservation, and protections strategies (which are not mutually exclusive) that explicitly target increasing the resilience of their coastal dune habitats. Other counties have equally important but smaller dune locations and should not be ignored.

The distribution of dune orientations is dominated by west (W), southwest (SW), and northwest (NW) facing coasts in Ireland. Cumulatively, these three directions comprise 72% of fixed dunes, 65% of embryonic dunes, and 57% of mobile dunes. Not surprisingly, these results mimic the dune area analyses as counties lying along the western seaboard are dominated with W, SW, NW dune orientations and are most vulnerable to current and future storms.

Longitudinal dune surveys such as the Coastal Monitoring Project (2004-2006) and the Sand Dune Monitoring project (2013) are carried out to fulfil our legal obligations under Articles 11 and 17 of the EU Habitats Directive. These surveys are invaluable to provide snapshots in time (every six years) of the state of habitat health in Ireland but they do not provide any insight into the processes that are causing short- and long-term changes. Resolving the spatial and temporal characteristics of coastal changes *via* system thresholds and feedbacks manifested through patterns of response and recovery over large (small) and long (short) scales is rudimentary to understanding how our sensitive coastal systems will respond to climate change projections.

Future coastal management strategies and plans will only be successful if coastal communities are an integral part of the process from identifying risks to designing short- and long-term solutions. There are many benefits to be derived from empowering coastal communities and involving them in decision making (bottom-up) that results in policy and Local Plans that are more likely to be acceptable

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Note: Copies of all individual county listings are available as Appendices from the Irish Geography website.

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Appendices

Appendix 1. County Donegal

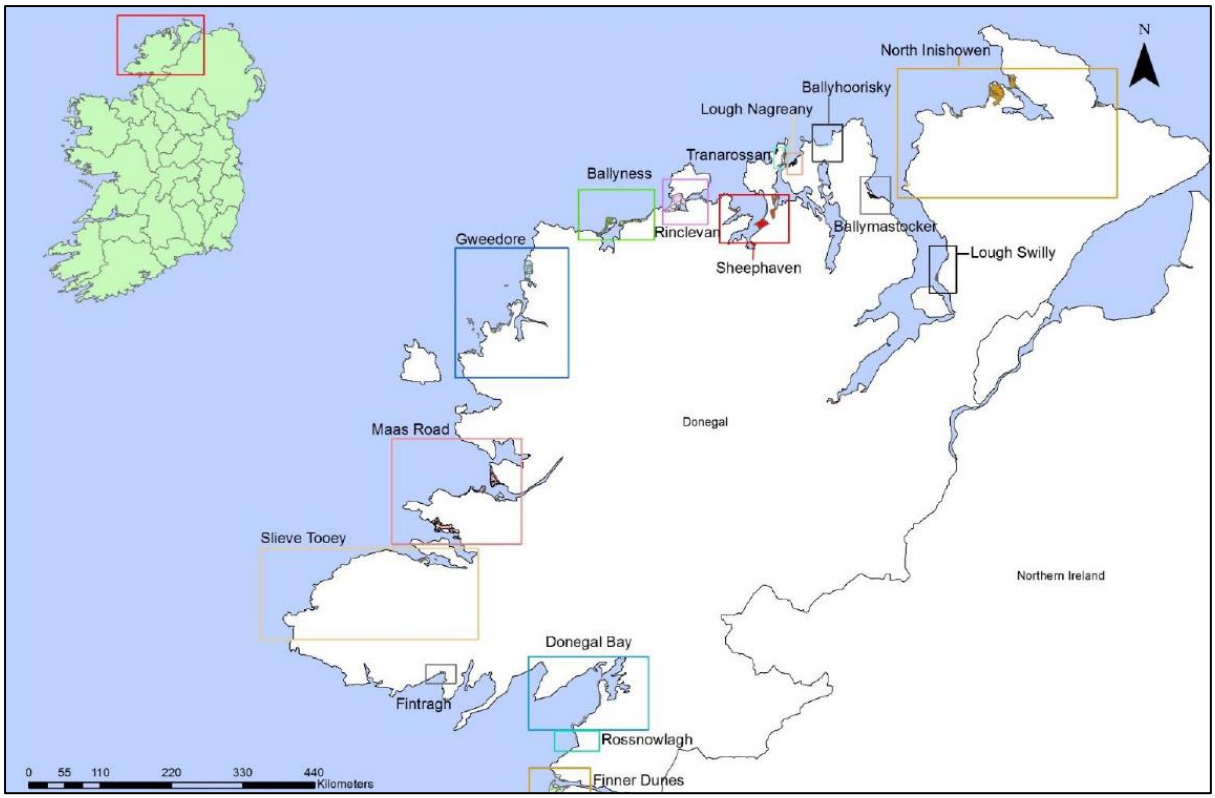

Table 8A. NPWS isolated coastal dune sites including total dune area, fixed, embryonic, mobile dune type areas and orientation for each identified area within County Donegal (Data source: NPWS Coastal Monitoring Project).

Donegal NPWS Site Name	CMP Site Name	County	Total Area m^2	Fixed m^2	Embryonic m^2	Mobile m^2	Orientation
Ballyness	Ballyness	Donegal	1074844	910742	22576	141526	N
Ballyness2	Dooey	Donegal	1101317	948263	48012	105042	NW
Gweedore	Lunniagh	Donegal	1904089	1867248	0	36841	W
Gweedore2	Derrybeg	Donegal	115466	53669	14513	47285	W
Gweedore3	Carnboy	Donegal	254420	246324	3547	4548	N
Gweedore4	Gola Island	Donegal	39179	33767	0	5412	N
Rinclevan	Rinclevan	Donegal	3037742	2985584	0	52158	NW
Gweedore5	Carnboy2	Donegal	391193	361306	10351	19535	NW
Gweedore6	Kincaslough	Donegal	634801	626221	563	8016	NW
Gweedore7a	Cruit_Lower	Donegal	221872	211607	4348	5917	SW
Gweedore7b	Cruit_Lower	Donegal	62255	62255	0	0	NE
Gweedore8	Cruit_Lower	Donegal	59371	37034	8538	13799	NW
Gweedore9a	Keadew	Donegal	89681	82393	3151	4138	N
Gweedore9b	Keadew	Donegal	78899	74446	1276	3177	NW
Maas_Road	Lettermacaward	Donegal	1378236	1285114	19614	73508	W
Maas_Road2	Clooney	Donegal	447521	408579	18871	20071	N

Mass_Road3	Clooney	Donegal	45835	20041	10834	14961	NW
Mass_Road4	Sheskinmore	Donegal	2722785	2451339	90419	181027	W
Slieve_Tooey	Maghera	Donegal	323617	243055	8602	71961	NW
Slieve_Tooey2	Glen Bay	Donegal	142756	132701	1263	8791	W
Fintragh	Fintragh	Donegal	84097	70222	12188	1687	SW
Inver	Inver	Donegal	10780	7833	2947	0	SW
Donegal Bay	Mount Charles	Donegal	85305	78208	4102	2995	SW
Donegal Bay 2	Mullansole	Donegal	38194	38194	0	0	NW
Donegal Bay 3	Mullansole 2	Donegal	223691	163334	39342	21015	W
Rossnowlagh	Durnesh Lake	Donegal	124552	117173	1530	5849	NW
Rossnowlagh 2	Durnesh Lake	Donegal	23658	23658	0	0	NW
Rossnowlagh 3	Durnesh Lake	Donegal	140456	132377	7505	574	W
Finner Dunes	Finner	Donegal	2558510	2378978	107862	71670	W
NorthInishowen	Lag_Doagh Isle	Donegal	4367693	4337660	2002	28031	NW
NorthInishowen 2	Tullagh	Donegal	351893	308429	2200	41264	NE
NorthInishowen 3	Lenankeel	Donegal	117837	114250	0	3588	SW
NorthInishowen 4	Crummies Bay	Donegal	144016	138495	947	4573	NW
NorthInishowen 5	White Strand	Donegal	23486	23486	0	0	NW
NorthInishowen 6	Culdaff	Donegal	192231	181031	864	10336	NE
Ballymastocker	Ballymastocker	Donegal	275153	241781	9651	23721	NE
Ballyhoorisky Point	Maherdrumman	Donegal	34897	29264	0	5633	E
Ballyhoorisky Point 2	Maherdrumman	Donegal	532986	518170	315	14502	N
Lough Nagreany	Gortnatraw_Doaghmore	Donegal	371687	339655	7661	24371	NW
Sheephaven	Rossnapena	Donegal	1138754	1138754	0	0	E
Tranarossan	Melmore_Tranarossan	Donegal	159546	137741	0	21805	NE
Tranarossan 2	Melmore	Donegal	139080	137941	0	1138	SE
Tranarossan 3	Melmore	Donegal	43676	39848	982	2846	E
Tranarossan 4	Melmore	Donegal	81691	52650	0	29041	NW
Sheephaven 2	Rossapenna	Donegal	1142027	1080801	27126	34100	NW
Sheephaven 3	Ards	Donegal	126600	120734	1080	4787	NE
Sheephaven 4	Marble Hill	Donegal	322735	310661	1979	10095	NE
Sheephaven 5	Rossapenna	Donegal	23445	0	0	23445	NW
Lough Swilly	Fahan	Donegal	156533	129876	15061	11596	NE
Rinclevan 2	Dunfanaghy	Donegal	338228	303730	12455	22043	E
	Total	**Donegal**	**27499318**	**25736622**	**524277**	**1238419**	

Table 8B. Orientation, Total Area, Fixed, Embryonic, Mobile and % Area Orientation for County Donegal (Data source: NPWS Coastal Monitoring Project 2004-2006).

Orientation	Total Area	Fixed	Embryonic	Mobile	%
E	1555555	1511596	13437	30522	6
N	2438632	2199975	48460	190197	9
NE	1646947	1492508	30836	123603	6
NW	12013223	11447721	127441	438061	44
S	0	0	0	0	0
SE	139080	137941	0	1138	1
SW	519891	482119	23586	14186	2
W	9185990	8464761	280517	440711	33

Appendix 2. County Sligo

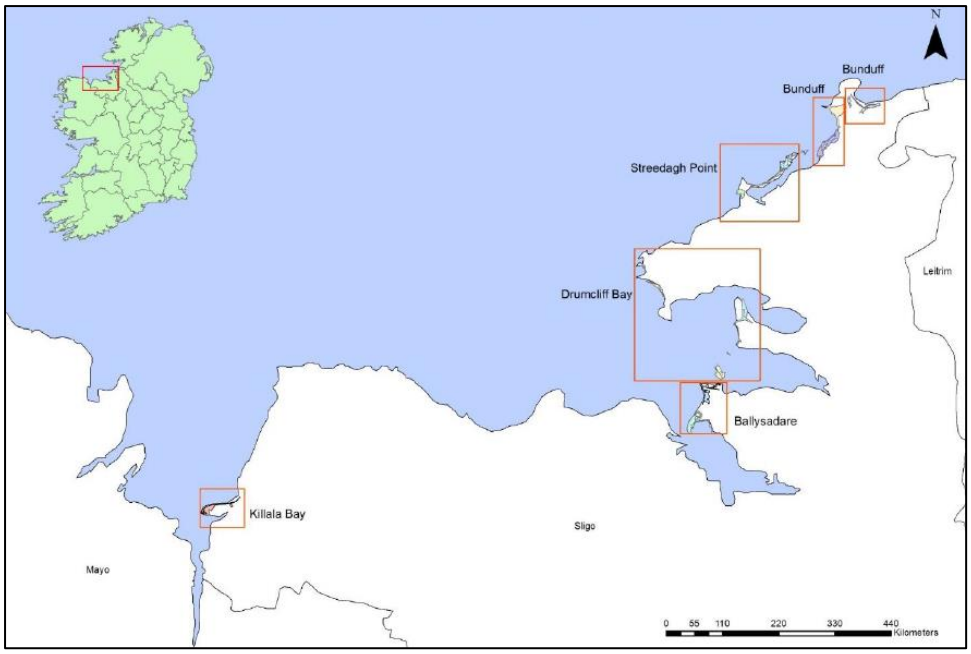

Table 9A. NPWS isolated coastal dune sites including total dune area, fixed, embryonic, mobile dune type areas and orientation for each identified area within County Sligo (Data source: NPWS Coastal Monitoring Project).

Sligo NPWS Site Name	CMP Site Name	County	Total Area m^2	Fixed m^2	Embryonic m^2	Mobile m^2	Orientation
Bunduff Lough	Bunduff	Sligo	447769	396773	0	50996	NE
Bunduff Lough 2	Mullaghmore	Sligo	708648	708648	0	0	W
Bunduff Lough 3	Trawlua	Sligo	802521	751802	436	50282	NW
Streedagh Point Dunes	Streedagh Point	Sligo	39069	34022	2126	2921	N
Streedagh Point Dunes 2	Streedagh Point	Sligo	368739	357340	1378	10021	NW
Streedagh Point Dunes 3	Streedagh Point	Sligo	243541	234892	728	7920	NW
Streedagh Point Dunes 4	Streedagh Point	Sligo	203862	203553	0	309	SW
Drumcliff Bay	Yellowstrand	Sligo	4940	4940	0	0	S
Drumcliff Bay 2	Yellowstrand	Sligo	228687	215651	8362	4674	SW
Drumcliff Bay 3	Rosses Point	Sligo	546305	221815	322747	1744	W
Drumcliff Bay 4	Coney Island	Sligo	8408	8408	0	0	NE
Ballysadare	Strandhill	Sligo	418548	411423	1810	5315	NW
Ballysadare 2	Strandhill	Sligo	601321	544268	7616	49437	NW
Killala Bay	Inishcrone	Sligo	440730	404201	0	36529	N
	Total	**Sligo**	**5063087**	**4497736**	**345204**	**220147**	

Table 9B. Orientation, Total Area, Fixed, Embryonic, Mobile and % Area Orientation for County Sligo (Data source: NPWS Coastal Monitoring Project 2004-2006).

Orientation	Total Area	Fixed	Embryonic	Mobile	%
N	479799	438224	2126	39449	10
NE	456177	405181	0	50996	9
NW	2434669	2299725	11969	122975	48
S	4940	4940	0	0	0.1
SW	432549	419204	8362	4983	9
W	1254953	930463	322747	1744	25
E	0	0	0	0	0
SE	0	0	0	0	0

Appendix 3. County Mayo

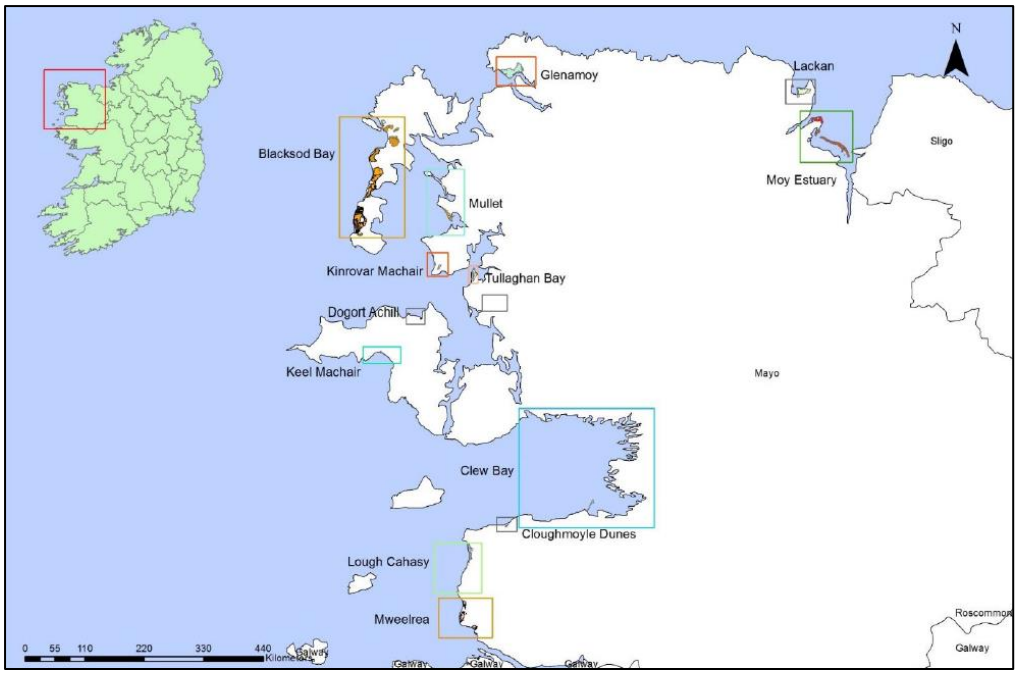

Table 10A. NPWS isolated coastal dune sites including total dune area, fixed, embryonic, mobile dune type areas and orientation for each identified area within County Mayo (Data source: NPWS Coastal Monitoring Project).

Mayo NPWS Site Name	CMP Site Name	County	Total Area m^2	Fixed m^2	Embryonic m^2	Mobile m^2	Orientation
Moy Estuary	Bartragh Island	Mayo	1284814	1202141	7484	75189	NE
Moy Estuary 2	Ross	Mayo	251793	248887	1450	1457	SE
Moy Estuary 3	Ross	Mayo	806835	785870	6619	14347	N
Lackan	Lackan	Mayo	1062510	1033596	662	28251	N
Glenamoy	Garter Hill	Mayo	2377012	2246999	0	130013	SW
Glenamoy2	Garter Hill	Mayo	85651	81872	0	3779	NW
Blacksod Bay	Termoncaragh Lough	Mayo	253237	240653	3378	9206	W
Blacksod Bay 2	Termoncaragh Lough	Mayo	13933	0	4531	9402	NW
Blacksod Bay 3	Termoncaragh Lough	Mayo	659912	653023	0	6889	S
Blacksod Bay 4	Termoncaragh Lough	Mayo	1417534	1412117	5144	273	W
Blacksod Bay 5	Termoncaragh Lough	Mayo	969669	943081	526	26063	NW
Blacksod Bay 6	Agleam_Leam Lough	Mayo	5907398	5829209	3312	74877	W
Mullet	Doo Lough_Dooyork	Mayo	826588	735237	4661	86690	SW
Kinrovar Machair	Kinrovar	Mayo	144808	135295	0	9513	W
Tullaghan Bay	Trawboy	Mayo	506239	472882	0	33357	SW
Dogort Achill	LoughDoo	Mayo	10690	0	0	10690	NW
Keel Machair	Keel Lough	Mayo	18734	0	0	18734	SW
Clew Bay	Bartraw	Mayo	128254	126188	225	1841	NW
Clew Bay 2	Rossmurrevagh	Mayo	17420	0	13787	3633	SW
Cloghmoyle Dunes	Cloghmoyle	Mayo	46772	40318	304	6149	NW
Lough Cahasy	Lough Cahasy	Mayo	424031	404780	10274	8977	W
Mweelrea	Dooaghrty	Mayo	201889	157376	0	44513	SW
Mweelrea 2	Dooaghrty	Mayo	492036	397144	5164	89729	W
Mweelrea 3	Dooaghrty	Mayo	254170	201085	243	52842	SW
		Total	**18161930**	**17347752**	**67764**	**746414**	

Table 10B. Orientation, Total Area, Fixed, Embryonic, Mobile and % Area Orientation for County Mayo (Data source: NPWS Coastal Monitoring Project 2004-2006).

Orientation	Total Area	Fixed	Embryonic	Mobile	%
N	1869345	1819466	7281	42598	10
NE	1284814	1202141	7484	75189	7
NW	1254969	1191459	5586	57924	7
S	659912	653023	0	6889	4
SE	251794	248887	14450	1457	1
SW	4202052	3813578	18691	369783	23
W	8639044	8419197	27272	192575	48
E	0	0	0	0	0

Appendix 4. County Galway

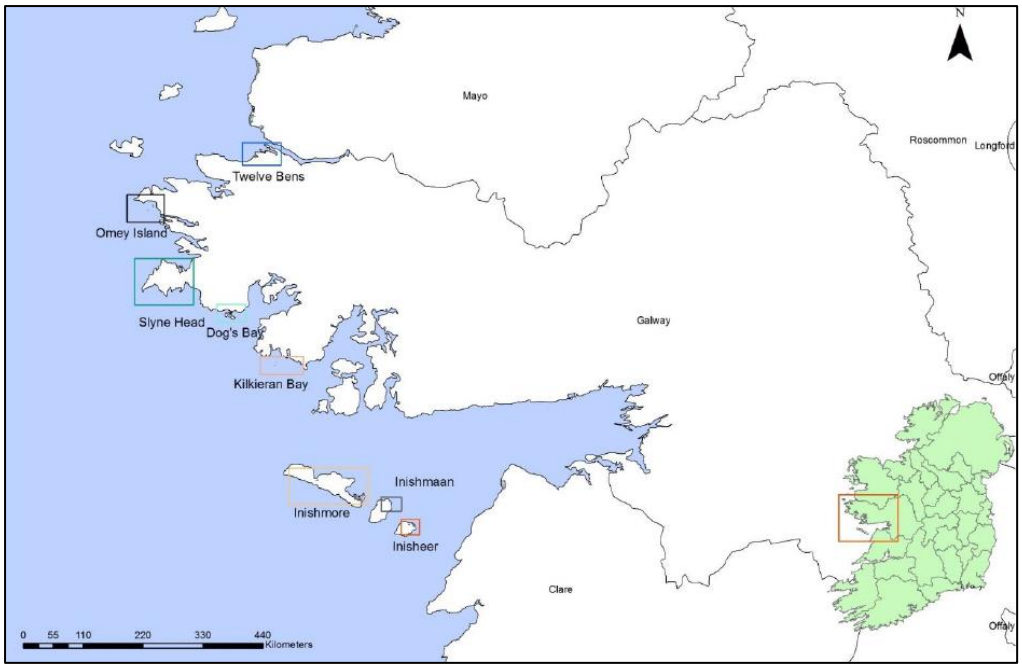

Table 11A. NPWS isolated coastal dune sites including total dune area, fixed, embryonic, mobile dune type areas and orientation for each identified area within County Galway (Data source: NPWS Coastal Monitoring Project).

Galway NPWS Site Name	CMP Site Name	County	Total Area m^2	Fixed m^2	Embryonic m^2	Mobile m^2	Orientation
Augrusbeg Machair	Augrusbeg	Galway	2909	0	2909	0	W
Omey Island Machair	Omey Island	Galway	2824	0	2824	0	W
Omey Island Machair 2	Omey Island	Galway	2464	0	2464	0	E
Kilkieran Bay	Mason Island	Galway	1728	0	1728	0	E
Kilkieran Bay 2	Mweenish Island	Galway	470	0	470	0	S
Kilkieran Bay 3	Mweenish Island	Galway	682	0	682	0	NE
Kilkieran Bay 4	Finish Island	Galway	1427	0	1427	0	SW
Twelve Bens	Gowlaun	Galway	51499	41784	2231	7484	N
Twelve Bens 2	Gowlaun	Galway	64505	55500	0	9005	NW
Dogs Bay	Dogs Bay	Galway	95951	92901	1405	1644	NW
Dogs Bay 2	Dogs Bay	Galway	105949	100331	2702	2916	SE
Dogs Bay 3	Dogs Bay	Galway	237997	236808	1189	0	S
Dogs Bay 4	Dogs Bay	Galway	16518	16518	0	0	SW
Inishmore	Eararna	Galway	598506	581049	1006	16451	NE
Inishmaan	Inishmaan	Galway	31739	0	15625	16114	NE
Inisheer	Inisheer	Galway	50476	45962	2578	1936	NE
Slyne Head	Mannin Bay	Galway	805	0	805	0	NE
Slyne Head 2	Mannin Bay	Galway	2908	0	2908	0	N
Slyne Head 3	Mannin Bay	Galway	764	0	764	0	NE
Slyne Head 4	Mannin Bay	Galway	9076	0	9076	0	N
Slyne Head 5	Doonloughan	Galway	6157	0	6157	0	W
Slyne Head 6	Aillebrack	Galway	2527	0	1843	683	S
Slyne Head 7	Aillebrack	Galway	13191	13191	0	0	SE
Slyne Head 8	Aillebrack	Galway	4912	0	4912	0	SW
		Total	**1305984**	**1184044**	**65705**	**56235**	

Table 11B. Orientation, Total Area, Fixed, Embryonic, Mobile and % Area Orientation for County Galway (Data source: NPWS Coastal Monitoring Project 2004-2006).

Orientation	Total Area	Fixed	Embryonic	Mobile	%
E	4191	0	4191	0	0.3
N	11983.9	41784	14215	7484	4.9
NE	682972	627011	21460	34502	52.3
NW	160456	148401	1405	10649	12.3
S	240994	236808	3503	683	18.5
SE	119140	113522	2702	2916	9.1
SW	22857	16518	6339	0	1.8
W	11890	0	11890	0	0.9

Appendix 5. County Clare

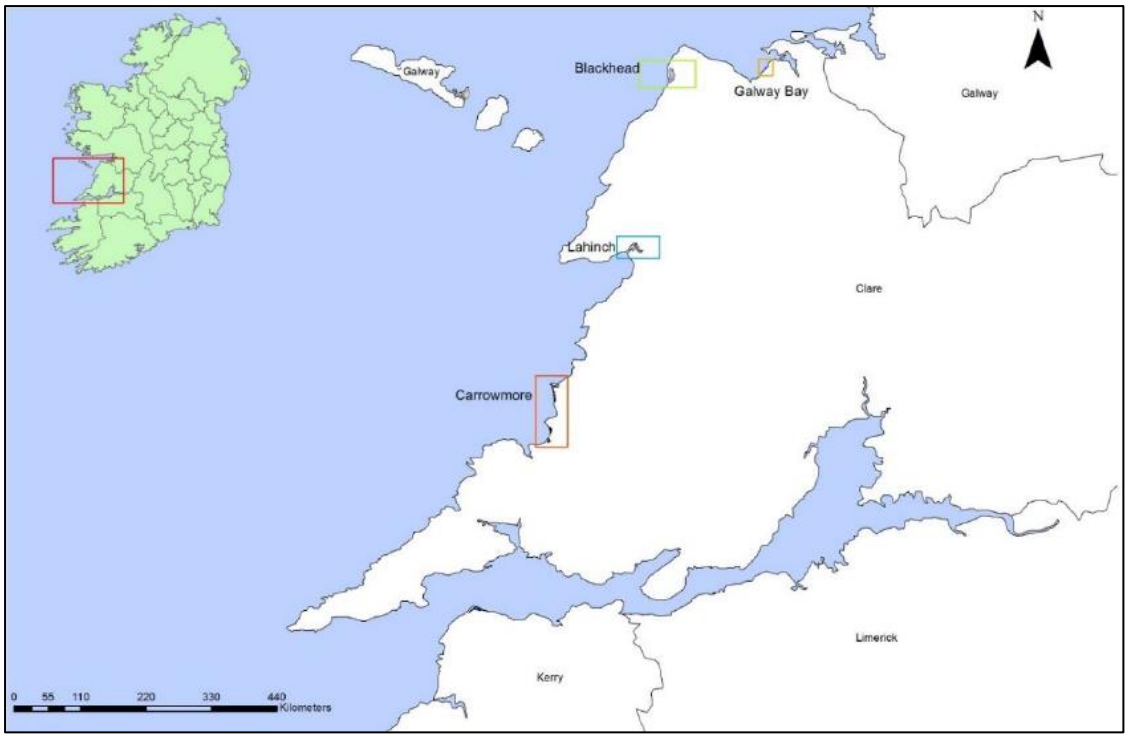

Table 12A. NPWS isolated coastal dune sites including total dune area, fixed, embryonic, mobile dune type areas and orientation for each identified area within County Clare (Data source: NPWS Coastal Monitoring Project).

Clare NPWS Site Name	CMP Site Name	County	Total Area m^2	Fixed m^2	Embryonic m^2	Mobile m^2	Orientation
GalwayBay	Bishopsquarter	Clare	50266	48496	335	1435	NW
Blackhead	Fanore	Clare	625361	618749	2827	3785	W
Lahinch	Inagh River Estuary	Clare	180541	176648	2512	1381	SW
Carrowmore 3	Spanish Point White Strand	Clare	506135	475170	8987	21978	W
		Total	**1362302**	**1319063**	**14661**	**28579**	

Table 12B. Orientation, Total Area, Fixed, Embryonic, Mobile and % Area Orientation for County Clare (Data source: NPWS Coastal Monitoring Project 2004-2006).

Orientation	Total Area	Fixed	Embryonic	Mobile	%
N	0	0	0	0	0
NE	0	0	0	0	0
NW	50266	48496	335	1435	4
S	0	0	0	0	0
SE	0	0	0	0	0
SW	180541	176648	2512	1381	13
W	1131496	1093919	11814	25763	83
E	0	0	0	0	0

Appendix 6. County Kerry

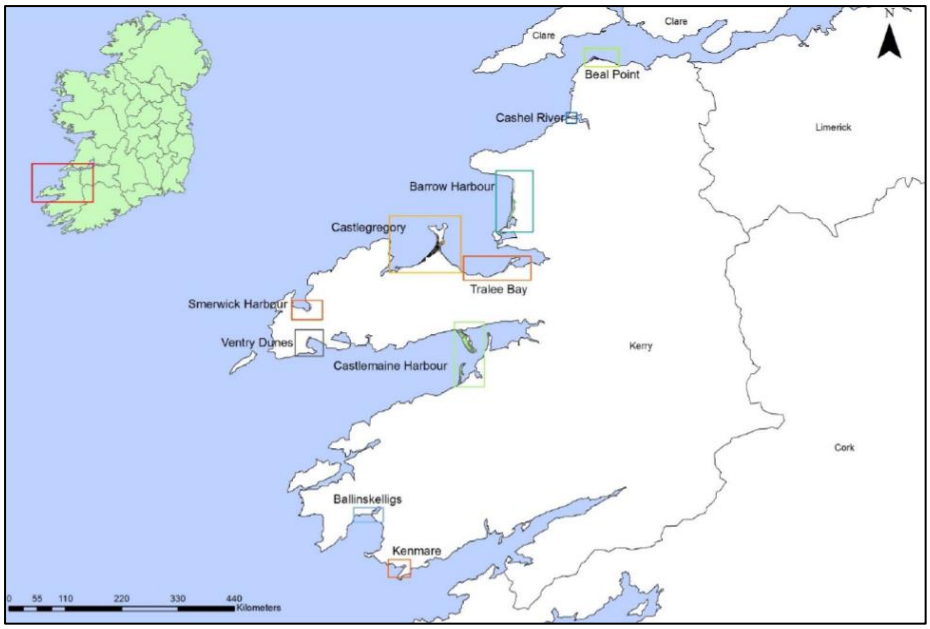

Table 13A. NPWS isolated coastal dune sites including total dune area, fixed, embryonic, mobile dune type areas and orientation for each identified area within County Kerry (Data source: NPWS Coastal Monitoring Project).

Kerry NPWS Site Name	CMP Site Name	County	Total Area m^2	Fixed m^2	Embryonic m^2	Mobile m^2	Orientation
BealPoint	Beal Point	Kerry	299136	281429	12571	5136	NW
CashelRiver	Ballybunion	Kerry	37788	20416	1227	16146	SW
BarrowHarbour	Ballyheigue_BannaStrand	Kerry	1959620	1862939	22670	74012	W
TraleeBay	Derrymore_Castlegregory	Kerry	106179	57663	1062	47454	N
TraleeBay 2	Castlegregory	Kerry	214847	189430	8799	16618	NE
CastlegregoryWest	Castlegregory	Kerry	1383807	1356815	3069	23923	W
CastlegregoryEast	Castlegregory	Kerry	657800	656336	0	1464	E
TraleeBay3	Fermoyle	Kerry	134258	99966	1732	32560	NE
Smerwick Harbour	Ballydavid	Kerry	256703	250150	2214	4339	NW
Ventry Dunes	Ventry	Kerry	135926	122376	1158	12392	SW
Castlemaine	Inch	Kerry	3924425	3522364	144078	257983	SW
Castlemaine 2	Rossbehy	Kerry	1102805	990695	7922	104188	W
Ballinskelligs	Waterville	Kerry	133412	120377	5472	7563	S
Kenmare	Derryane	Kerry	210068	183330	10071	16667	SW
Kenmare 2	Derrynane	Kerry	20752	20752	0	0	E
		Total	**10577528**	**9735038**	**222045**	**620444**	

Table 13B. Orientation, Total Area, Fixed, Embryonic, Mobile and % Area Orientation for County Kerry (Data source: NPWS Coastal Monitoring Project 2004-2006).

Orientation	Total Area	Fixed	Embryonic	Mobile	%
E	678552	677088	0	1464	6
N	106179	57663	1062	47454	1
NE	349105	289396	10531	49178	3
NW	555839	531579	14786	9475	5
S	133412	120377	5472	7563	1
SW	4308207	3848486	156532	303187	41
W	4446233	0	33660	202124	42
SE	0	0	0	0	0

Appendix 7. County Cork

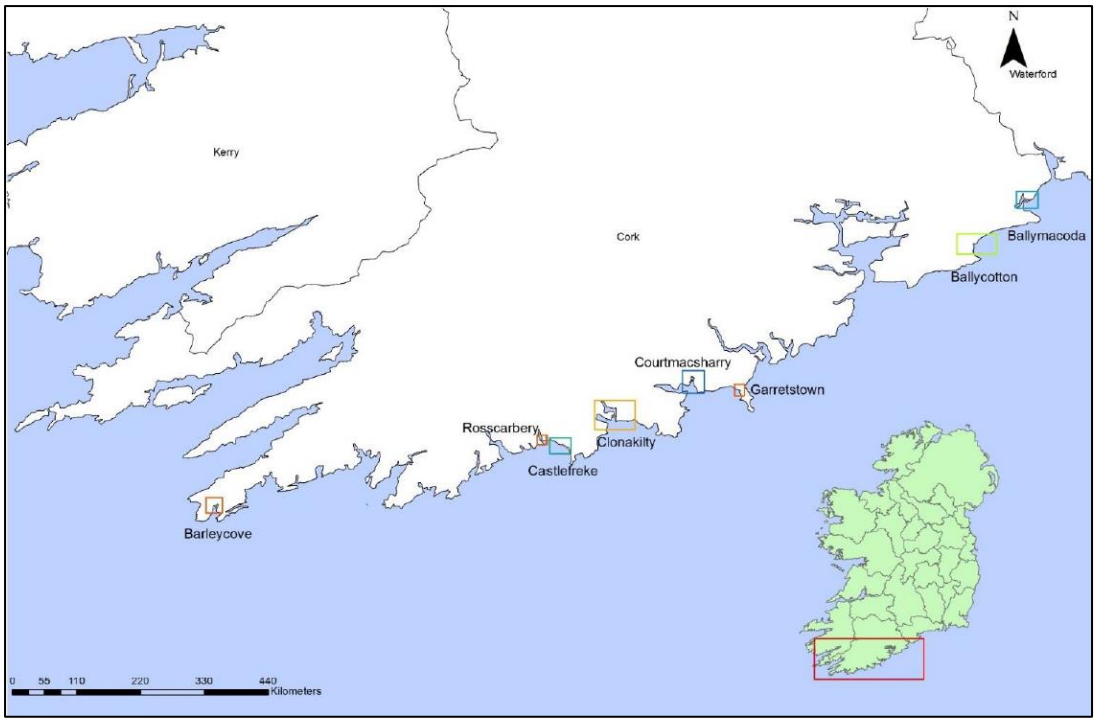

Table 14A. NPWS isolated coastal dune sites including total dune area, fixed, embryonic, mobile dune type areas and orientation for each identified area within County Cork (Data source: NPWS Coastal Monitoring Project).

CORK NPWS Site Name	CMP Site Name	County	Total Area m^2	Fixed m^2	Embryonic m^2	Mobile m^2	Orientation
Barleycove	Barleycove	Cork	320739	314079	508	6152	S
Castlefreke	Owenahincha_Castlefreke	Cork	339073	313687	6448	18938	SW
Rosscarbery	Warren	Cork	63501	56624	4228	2649	SE
Clonakilty	Inchydoney	Cork	182841	178127	513	4200	S
Courtmacsharry	Harbour	Cork	56145	45525	6487	4132	S
Garretstown	Garretstown	Cork	18308	18197	13	98	SW
Ballycotton	Shanagarry	Cork	71509	56776	14733	0	SE
Ballymacoda	Ballymacoda	Cork	226744	215231	8171	3343	SE
		Total	**1278860**	**1198247**	**41101**	**39511**	

Table 14B. Orientation, Total Area, Fixed, Embryonic, Mobile and % Area Orientation for County Cork (Data source: NPWS Coastal Monitoring Project 2004-2006).

Orientation	Total Area	Fixed	Embryonic	Mobile	%
S	559725	537732	7509	14485	44
SE	361754	328631	27131	5992	28
SW	357381	331885	6461	19035	28
N	0	0	0	0	0
NE	0	0	0	0	0
E	0	0	0	0	0
W	0	0	0	0	0
NW	0	0	0	0	0

Appendix 8. County Waterford

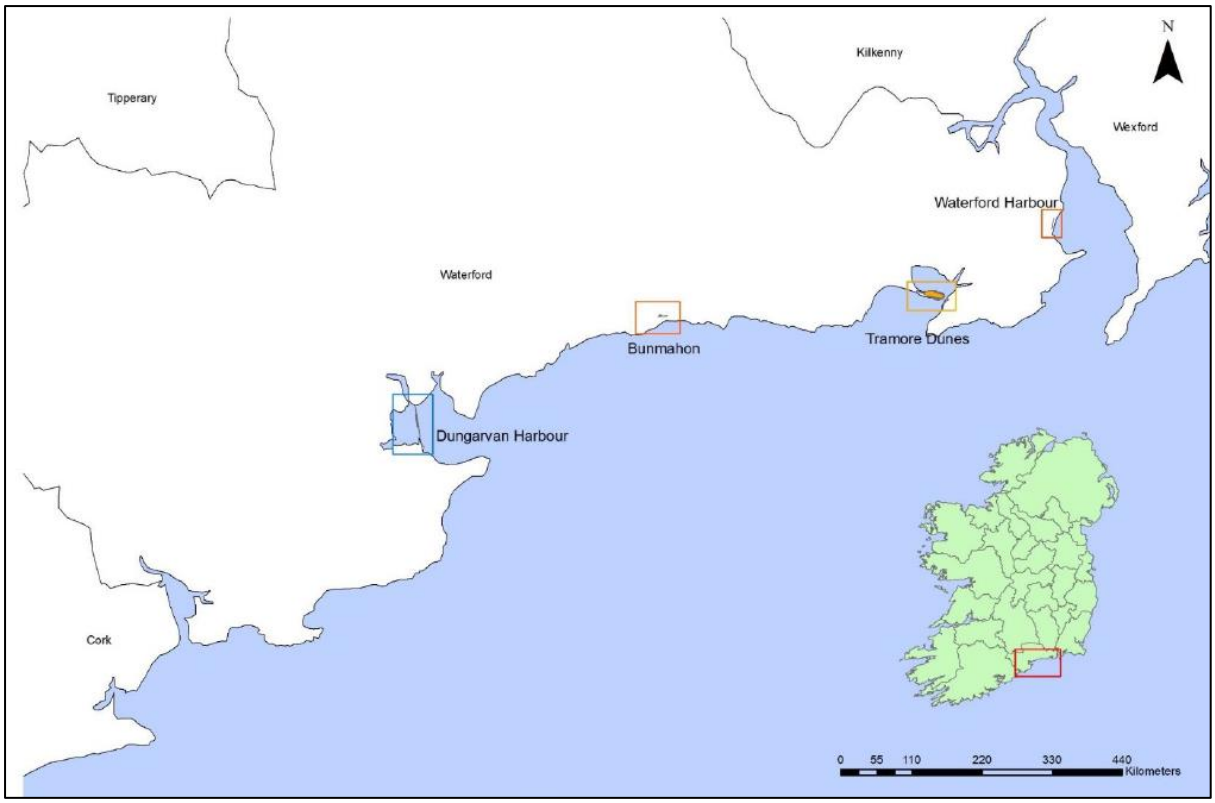

Table 15A. NPWS isolated coastal dune sites including total dune area, fixed, embryonic, mobile dune type areas and orientation for each identified area within County Waterford (Data source: NPWS Coastal Monitoring Project).

Waterford NPWS Site Name	CMP Site Name	County	Total Area m^2	Fixed m^2	Embryonic m^2	Mobile m^2	Orientation
Dungarvan Harbour	Cunnigar Point	Waterford	107066	101696	0	5370	SE
Bunmahon	Bunmahon	Waterford	30016	23130	205	6681	S
Waterford Harbour	Woodstown	Waterford	13962	13601	361	0	E
Tramore	Tramore	Waterford	659531	575301	43013	41216	SW
		Total	**810575**	**713729**	**43580**	**53267**	

Table 15B. Orientation, Total Area, Fixed, Embryonic, Mobile and % Area Orientation for County Waterford (Data source: NPWS Coastal Monitoring Project 2004-2006).

Orientation	Area	Fixed	Embryonic	Mobile	%
SE	107066	101696	0	5370	13
S	30016	23130	205	6681	4
SW	659531	575301	43013	41216	83
N	0	0	0	0	0
NE	0	0	0	0	0
E	13962	13601	361	0	0
W	0	0	0	0	0
NW	0	0	0	0	0

Appendix 9. County Wexford

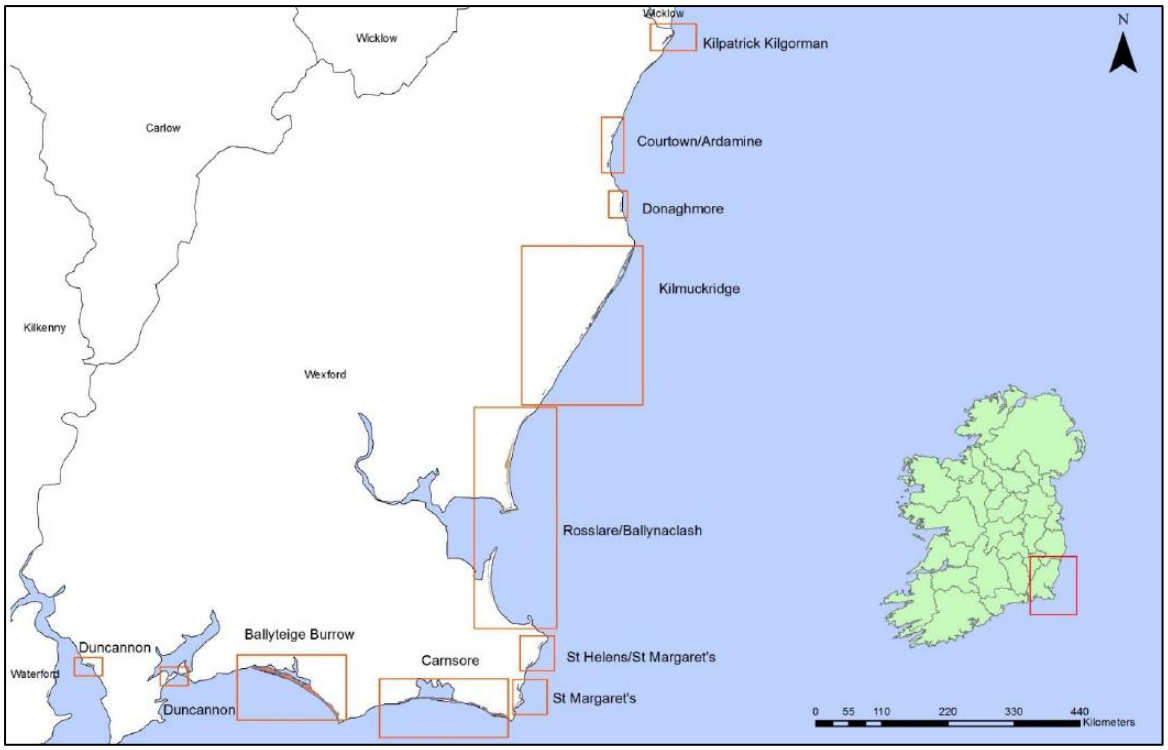

Table 16A. NPWS isolated coastal dune sites including total dune area, fixed, embryonic, mobile dune type areas and orientation for each identified area within County Wexford (Data source: NPWS Coastal Monitoring Project).

Wexford NPWS Site Name	CMP Site Name	County	Total Area m^2	Fixed m^2	Embryonic m^2	Mobile m^2	Orientation
Ballyteige Burrow	Ballyteige Burrow	Wexford	2449703	2386416	914	62373	SW
Carnsore	Carnsore_Tucumshin	Wexford	998738	838459	55987	104292	S
Rosslare Ballynaclash	Curraclo/Raven/Ballynaclash	Wexford	842698	622251	51008	169439	E
Kilmuckridge	Cahore Point_Ballynamona	Wexford	1418038	1077233	55265	285540	SE
Donaghmore	Donaghmore	Wexford	4103	560	2162	1382	E
Courtown1	Courtown_Ardamine	Wexford	32339	30600	666	1072	E
Bannow Bay	Grange	Wexford	29329	8446	143859	6497	E
Bannow Bay 2	Bannow Island	Wexford	33378	32327	0	1050	S
Duncannon Sandhills	Duncannon	Wexford	20158	12106	2236	5817	S
St. Margaret's	St. Margaret's	Wexford	44836	36720	8116	0	E
St Helen's/St. Margaret's	St Helen's/St. Margaret's	Wexford	34182	26379	7803	0	SE
Kilpatrick_Kilgorman	Kilpatrick_Kilgorman	Wexford	151370	133185	9612	8573	SE
		Total	**6058873**	**5204682**	**208154**	**646036**	

Table 16B. Orientation, Total Area, Fixed, Embryonic, Mobile and % Area Orientation for County Wexford (Data source: NPWS Coastal Monitoring Project 2004-2006).

Orientation	Total Area	Fixed	Embryonic	Mobile	%
E	953306	698578	76337	178390	16
S	1052274	882892	58223	111159	17
SE	1603590	1236797	72680	294113	27
SW	2449703	2386416	914	62373	40
N	0	0	0	0	0
NE	0	0	0	0	0
W	0	0	0	0	0
NW	0	0	0	0	0

Appendix 10. County Wicklow

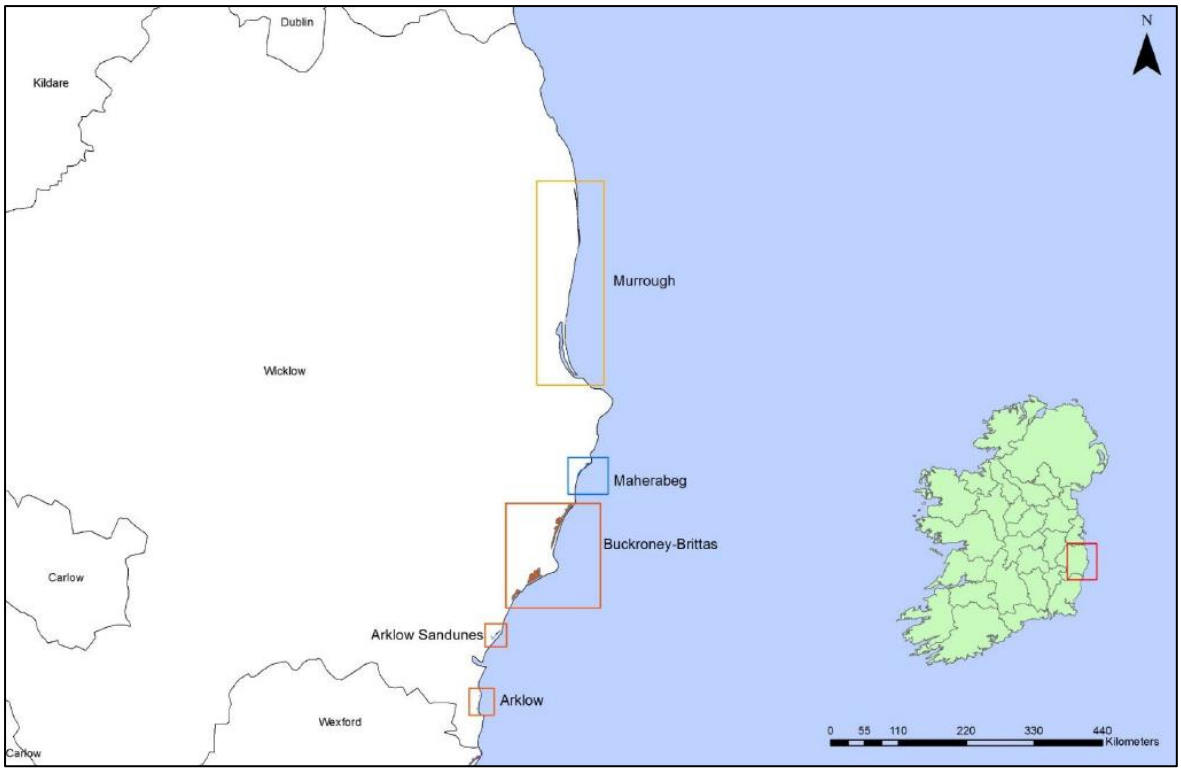

Table 17A. NPWS isolated coastal dune sites including total dune area, fixed, embryonic, mobile dune type areas and orientation for each identified area within County Wicklow (Data source: NPWS Coastal Monitoring Project).

Wicklow NPWS Site Name	CMP Site Name	County	Total Area m^2	Fixed m^2	Embryonic m^2	Mobile m^2	Orientation
Arklow	Askintinny	Wicklow	1031	0	1031	0	E
ArklowSandDunes	ArklowNorth_South	Wicklow	28298	20006	5182	3111	SE
BuckroneyBrittas	Mizen Head	Wicklow	577649	547035	12622	17992	SE
BuckroneyBrittas 2	Brittas Dunes	Wicklow	536734	497178	6466	33090	E
Magherabeg	Magherabeg Dunes	Wicklow	114442	79290	17119	18032	SE
Murrough	Ballybla	Wicklow	106219	105625	594	0	SE
Murrough 2	Kilcoole	Wicklow	55037	55037	0	0	E
		Total	**1419409**	**1304170**	**43014**	**72225**	

Table 17B. Orientation, Total Area, Fixed, Embryonic, Mobile and % Area Orientation for County Wicklow (Data source: NPWS Coastal Monitoring Project 2004-2006).

Orientation	Total Area	Fixed	Embryonic	Mobile	%
E	592802	552215	7497	33090	42
SE	826608	751956	35517	39135	58
N	0	0	0	0	0
NE	0	0	0	0	0
SW	0	0	0	0	0
W	0	0	0	0	0
NW	0	0	0	0	0

Appendix 11. County Dublin

Table 18A. NPWS isolated coastal dune sites including total dune area, fixed, embryonic, mobile dune type areas and orientation for each identified area within County Dublin (Data source: NPWS Coastal Monitoring Project).

Dublin NPWS Site Name	CMP Site Name	County	Total Area m^2	Fixed m^2	Embryonic m^2	Mobile m^2	Orientation
Killiney Hill	Killiney	Dublin	6433	3952	1797	684	E
NorthDublinBay	South_North Bull	Dublin	1034081	883385	29289	121407	SE
Baldoyle 2	Portmarnock	Dublin	44939	44001	0	938	E
Rogerstown	Portrane	Dublin	89827	55735	21605	12487	NE
Rogerstown 2	Rush Sandhills	Dublin	60690	35937	11337	13416	SE
Malahide	Malahide Island	Dublin	236841	216106	2769	17966	SE
Baldoyle	Portmarnock	Dublin	96627	46081	15757	34789	E
		Total	**1569438**	**1285196**	**82553**	**201689**	

Table 18B. Orientation, Total Area, Fixed, Embryonic, Mobile and % Area Orientation for County Dublin (Data source: NPWS Coastal Monitoring Project 2004-2006).

Orientation	Total Area	Fixed	Embryonic	Mobile	%
E	147999	94033	17553	36412	9
NE	89827	55735	21605	12487	6
SE	1331612	1135428	43394	152790	85
N	0	0	0	0	0
S	0	0	0	0	0
SW	0	0	0	0	0
W	0	0	0	0	0
NW	0	0	0	0	0

Appendix 12. County Meath

Table 19A. NPWS isolated coastal dune sites including total dune area, fixed, embryonic, mobile dune type areas and orientation for each identified area within County Meath (Data source: NPWS Coastal Monitoring Project).

Meath NPWS Site Name	CMP Site Name	County	Total Area m^2	Fixed m^2	Embryonic m^2	Mobile m^2	Orientation
Laytown Dunes	Laytown	Meath	78210	55943	8914	13353	NE
Boyne Coast and Estuary	Mornington	Meath	326007	290304	6651	29052	E
		Total	**404217**	**346247**	**15565**	**42405**	

Table 19B. Orientation, Total Area, Fixed, Embryonic, Mobile and % Area Orientation for County Meath (Data source: NPWS Coastal Monitoring Project 2004-2006).

Orientation	Total Area	Fixed	Embryonic	Mobile	%
NE	78210	55943	8914	13353	19
N	0	0	0	0	0
E	326007	290304	6651	29052	81
SE	0	0	0	0	0
S	0	0	0	0	0
SW	0	0	0	0	0
W	0	0	0	0	0
NW	0	0	0	0	0

Appendix 13. County Louth

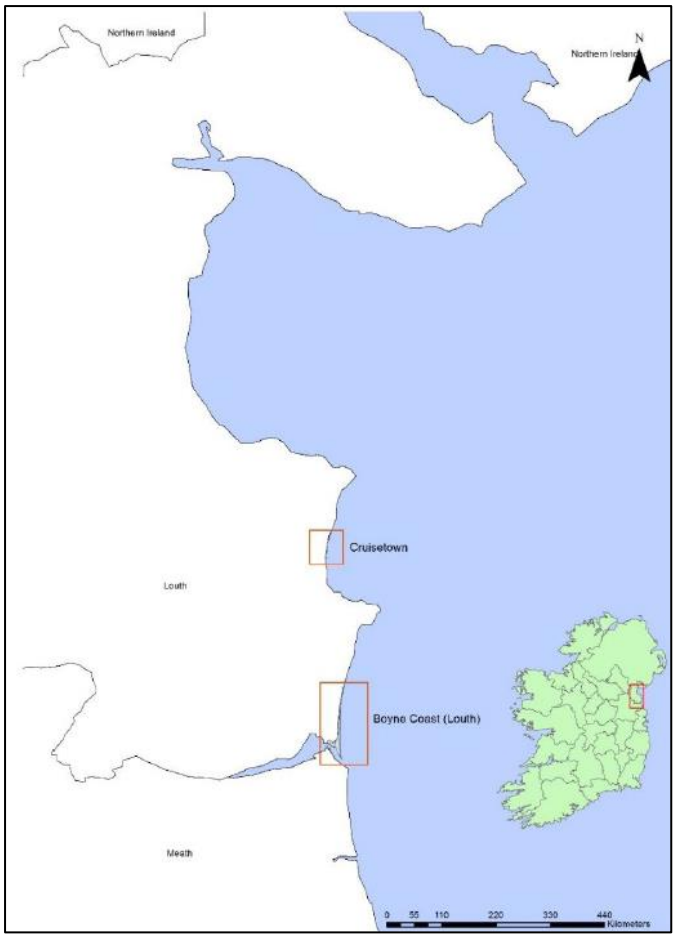

Table 20A. NPWS isolated coastal dune sites including total dune area, fixed, embryonic, mobile dune type areas and orientation for each identified area within County Louth (Data source: NPWS Coastal Monitoring Project).

Louth NPWS Site Name	CMP Site Name	County	Total Area m^2	Fixed m^2	Embryonic m^2	Mobile m^2	Orientation
Boyne Coast (Louth)	Baltray	Louth	400185	330486	26079	43620	E
Cruisetown	Cruisetown	Louth	17918	17847	0	71	E
	Total	**Louth**	**418103**	**348333**	**26080**	**43691**	

Table 20B. Orientation, Total Area, Fixed, Embryonic, Mobile and % Area Orientation for County Louth (Data source: NPWS Coastal Monitoring Project 2004-2006).

Orientation	Total Area	Fixed	Embryonic	Mobile	%
E	418103	17847	0	71	100
N	0	0	0	0	0
NE	0	0	0	0	0
SE	0	0	0	0	0
S	0	0	0	0	0
SW	0	0	0	0	0
W	0	0	0	0	0
NW	0	0	0	0	0