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Coastal Vulnerability and the Implications of Sea-Level Rise for Ireland

Robert J.N. Devoy

Department of Geography and the Coastal and Marine Resources Centre
University College Cork (National University of Ireland, Cork)
College Road
Cork, Ireland
r.devoy@ucc.ie

ABSTRACT

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Ireland, as an island, has a long (>7000 km), crenellate, and cliffed coastline. More than 50% of its population (*ca.* 5.4 million in 1998) live within 15 km of the coastline. But most of these people are concentrated in a few major urban centres. Effectively, large areas of the coast have a low-density population. These factors mean that Ireland is seen as having an overall low vulnerability to the impacts of sea-level rise. Even so, about 30% of its coastal wetlands could be lost given a 1-m sea-level-rise scenario. People's valuation and awareness of the coastal environment in Ireland has been limited for much of the 20th century by factors of history and emigration. Many coastal areas have remained relatively undeveloped since the 18th and 19th centuries. In the late 20th century, an island-wide awakening to the resource potential of coastal and marine environments began to change this former neglect. In the Republic of Ireland, the Department of the Marine and Natural Resources was set up in 1988, and a separate Marine Institute was added in 1991. These developments established the coastal zone as an important element in future national strategic planning. This article examines the physical components of coastal vulnerability throughout Ireland under sea-level rise and climate change, coupled with the influences of people at the coast. These factors are placed in the context of the development of coastal zone management in Ireland and its links to reducing vulnerability.

ADDITIONAL INDEX WORDS: *Coastal zone management, coastal sediments, erosion, storminess, modelling, climate change, wave energy, shoreline defence, population and socio-economic changes, resources, consensus planning, government policy.*

INTRODUCTION

Analyses of Europe's coastal vulnerability to sea-level rise (SLR) place Ireland in a relatively low risk category (ROTMANS, HULME, and DOWNING, 1994). Ireland has predominantly cliffed coasts (Figures 1 and 2), together with meso- to macrotidal coastal regimes. These, and other biogeophysical features, determine that Ireland's coastal environments should be able to absorb much of the expected SLR occurring under future climate warming. However, Ireland's position in the centre of north-west Europe's coastal margin (between 52° and 55° N) gives it a wider significance for European and international coastal studies than for vulnerability alone (ORFORD, COOPER, and SMITH, 1997). This may be seen in terms of the related issues of (1) storm impacts on coastal systems; (2) the value of Ireland for coastal baseline studies because of the occurrence of relatively pristine coastal environments (MARINE INSTITUTE STAFF, 2000), although human impacts are important; and (3) human responses to and cultural views of environmental management and associated legislation (DEVOY, 1992).

An extensive literature has been established since the 1980s concerning coastal vulnerability and its links to issues of coastal zone management (CZM) (*e.g.,* see NICHOLLS, HOOZEMANS, and MARCHAND, 1999; NICHOLLS and MIMURA, 1998; PARRY, 2000). This work details the issues, concepts, and methodologies involved in CZM under climate-warming scenarios (HOUGHTON *et al.,* 1996; INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE STAFF, 2001; PARRY *et al.*, 2007). A conclusion from this work, however, is that a significant deficiency exists in the establishment of local- to national-scale studies of coastal management and functioning. Coastal research, of all types, is frequently directed more towards the generic questions involved in helping the understanding of coastal functioning and evolution and in the development of coastal management concepts (CARTER and WOODROFFE, 1994; DE GROOT and ORFORD, 1999; DEVOY *et al.,* 1996, 2000a). Yet it is at local spatial levels that the outcomes of generic coastal studies have to be applied. There is a need, therefore, at the beginning of the 21st century, with the awareness that climate warming and its effects are real (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE STAFF, 2001; RAPER, 2000; PARRY *et al.*, 2007), to develop more local- to national-scaled work.

The purpose of this study is to present the key concerns for coastal vulnerability and management in Ireland involved at these scales, particularly under the impacts of SLR and climate changes. The study will set out the nature of Ireland's

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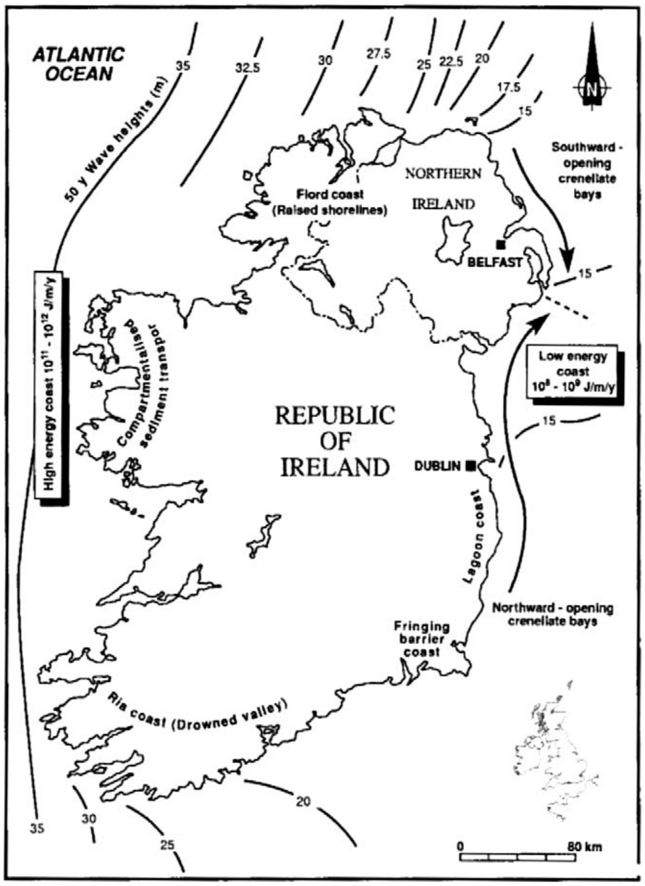

Figure 1. Ireland's coastal configuration and spatial changes in wave climate (Carter, 1991a; Orford, 1989).

Figure 2. Ireland's rocky and cliffed coast: (a) the cliffs of Moher, County Clare; (b) localised dunes and sand-beach coast, Lough Swilly area, County Donegal; (c) cliffs developed in glacigenic sediments, forming a common coast type for southern and eastern coasts (NCEC, 1992).

biogeophysical coastal environments; the potential vulnerability to SLR; the work undertaken in assessing these issues and in establishing Ireland's CZM approaches (both in the Republic of Ireland and in Northern Ireland); and the future needs for CZM.

COASTAL ENVIRONMENTAL CHARACTERISTICS

Physical Setting

In relation to its overall area (*ca.* 81,500 km^2), Ireland has a long coastline, approximately 7400 km ± 5% (Marine Institute Staff, 1996). Upland areas on the island occur mainly in coastal regions, reaching maximum heights of about 1000 m (Ireland's "upland rim". The uplands define a low elevation and poorly drained interior. Topography, together with linked geological controls, has resulted in extensive (>3000 km) rock-dominated coasts (Figure 2a). This is particularly so for the south-western–western and northern regions of Ireland. In contrast, the eastern and south-eastern regions are composed of unconsolidated Quaternary glacigenic sediments and fewer rock exposures (Figures 2b and 2c). Glacial and fluvial actions have also created major sedimentary areas on the western coasts in the form of large bays and estuaries. The resulting coastline of Ireland is highly irregular and crenellate in form (Figure 1), characterised by a bay-headland-type configuration and conditioned by a high wave energy regime.

High-energy, exposed coasts constitute about 2900 km of the coastline, and sheltered coasts make up approximately 3700 km. Within the different coastal settings, significant

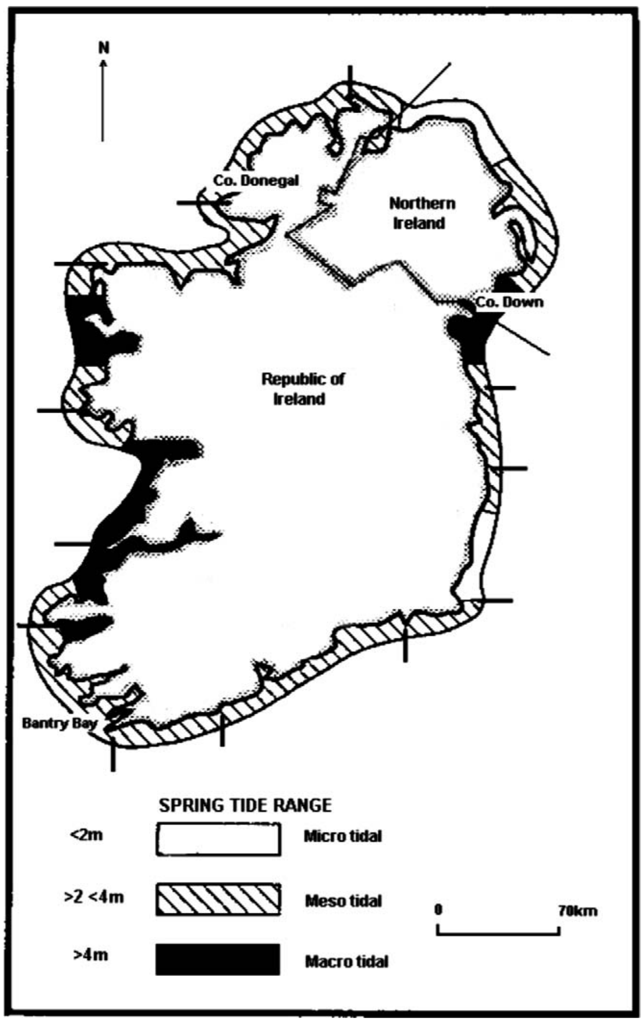

Figure 3. Variation in spring tidal ranges around the Irish coastline (Carter, 1991a). At the coast, the heavy horizontal/vertical black lines define the lateral boundaries of coastal cells for the Republic of Ireland, recommended as the basis for coastal planning units (Brady Shipman Martin, 1997).

coastal systems include those of cliffs, beaches, and barriers (sand and gravel types); lagoons; dunes and machair (sand "plains"); and salt marshes, mudflats and other wetlands (Carter, 1991b; Curtis, 1991; Davies and Stephens, 1978; Sinnott and Devoy, 1992).

The impact of Holocene relative sea-level changes has been important in the development of these biogeophysical systems (Devoy *et al.,* 1996). Variation in the late Quaternary ice loading of Ireland has led to a north-to-south gradient in isostatic crustal movements, resulting in predominantly emergent coasts in northern areas and changing southwards to coastal environments that are submergent to "apparently stable". Relative sea level for Ireland is rising 1 mm/y on average, although there are significant regional variations (Carter, Devoy, and Shaw, 1989; Devoy, 1990, 1995, 2000a; Pugh, 1982). At present, there are no apparent effects

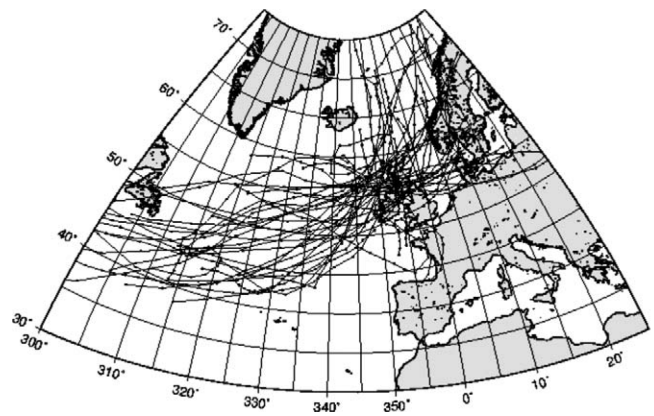

Figure 4. The focus and paths of cyclones (minimum wind speed > 15.3 m/s) affecting Ireland and coastal Northwest Europe (record taken for the period 1973–1975) (Devoy, 2000b; Lozano *et al.*, 2002).

of climate warming on SLR and coastal changes (Devoy, 2000a, 2000b).

The dynamic controls (*e.g.,* storms surges, waves, tides, currents, and fluvial discharges) affecting the different coastal environments also vary significantly in scale around Ireland. Tidal regimes are primarily meso- to macrotidal (spring tidal range is 2 m to more than 4 m) but also include microtidal areas (spring tidal range is below 2 m) for south-east and central northern coasts (Figure 3). This varied tidal background is further influenced in height by major storm activity. Coasts, particularly those of western Ireland, are exposed to the full effects of eastwards-moving cyclones and swell wave energy from the North Atlantic (Figure 4). Studies of the coastal processes operating on these coasts show the importance of wave and storm energy gradients in driving coastal systems' functioning: operating from high-energy, open-coast situations to inner-bay, lower-energy areas (Duffy and Devoy, 1999; Wheeler, Orford, and Dardis, 1999). Consequently, the predicted changes in North Atlantic storminess as part of climate warming (Flather and Smith, 1998; Ulbrich and Christoph, 1999; WASA Group, 1998) are likely to cause Ireland's coastal wetlands and other soft-sedimentary systems to be among the first in Europe to respond to storm-led SLR.

Wave heights and energy around Ireland reach maximum values along western coasts, with significant deep-water wave heights (H_{sig}) of 15–20 m (Figure 1). These values reduce eastwards into the Irish Sea region (H_{sig} modal values of *ca.* 1.6–2 m) (Carter *et al.,* 1993; Orford, 1989). Although coasts here remain storm influenced, they receive only about 20% of the wave energy levels occurring on open Atlantic coasts. Coastal erosion rates upon "soft" (sediment-dominated) coasts (*e.g.,* sandy systems and glacial sediments) reach average values of 0.2–0.5 m/y, commonly rising to 1–2 m/y on southern and eastern coasts (Carter and Bartlett, 1990; National Coastal Erosion Committee Staff, 1992). Retreat rates for rocky shorelines are not well known (McKenna, Carter, and Bartlett, 1992). Long stretches of shorelines raised during the Quaternary period (>200,000 years old) still exist along southern and western coasts, indicating relatively slow retreat rates and a resistance of these rocky coasts to change. Rates may be as low as 0.01 m per century, although retreat commonly occurs through sudden cliff failures and catastrophic point-process operation. Current total rates of land loss for Ireland from erosion and flooding have been estimated to be approximately 1.6 km^2/y, concentrated in about 300 sites (CARTER, 1991a).

Population and Socio-economic Setting

The population of Ireland is about 5.4 million people (Republic of Ireland about 3.7 million and Northern Ireland about 1.7 million in 1998). It should be noted that the population in the last 150–200 years has been as high as approximately 9 million, with many people in the 19th century living in rural coastal areas. This past population pressure has had significant repercussions upon coastal land uses, sedimentary system changes, reclamation, coastal shape, and the built environment. Although population has declined in the 20th century, coastal systems are still responding to the earlier (18th- and 19th-century) human impacts (*e.g.,* DUFFY and DEVOY, 1999; MULRENNAN, 1993).

Since the 1980s, the coastal population has been on the increase through factors such as urban expansion, retirement and second homes, and the tourism industry. The coastal population (*i.e.,* living within <5 km of the coast) comprises about 34% of the total (Republic of Ireland about 1.25 million and Northern Ireland about 0.6 million). If the population of the major coastal urban centres is included (*i.e.,* living <15 km from the coast), then Ireland's coastal population would be more than 50% of the total. The major cities in Ireland (*e.g.,* Dublin, Belfast, Cork, and Londonderry each with more than 200,000 people and Limerick and Galway each with more than 50,000) are all at the coast. For some of these urban and adjacent coastal areas (*e.g.,* involving parts of Dublin, Belfast, Cork, Galway, and Limerick immediate to the coast), population values have shown major increases since 1971 (as high as three- to fourfold every decade) (CARTER, 1991a; EUROPEAN COMMISSION STAFF, 1999a). Many other small coastal towns and villages (250–2000 people) also exist. Otherwise, most coastal districts remain with low and dispersed rural populations (<25 people/km^2).

Major industry, although predominantly urban based, is not intimately linked to the coast apart from the links to port activities. Traditional-style, heavy-manufacturing industries in Ireland (*e.g.,* steel, shipbuilding, and automotive manufacture) were linked to coastal and dockland sites (*e.g.,* Cork, Belfast, Dublin, and Arklow), but these have either been closed or are of much reduced significance. New chemical and pharmaceutical industries, however, have often chosen coastal locations (*e.g.,* Cork Harbour and the Limerick and Shannon regions). These developments and the trend towards the rejuvenation of former docklands (*e.g.,* Belfast, Dublin, Cork, and Dungarvan) (MOORE, 1999) may pose problems for coastal vulnerability.

Ireland, however, has many harbours and landing points (>900), with their accompanying environmental impacts upon the coastal zone. Most of these harbours are small and have little infrastructure. The main ports, however, provide oil and petrochemical facilities, power production, and bulk cargo handling and roll-on, roll-off terminals (BRUNT, 2000). For some harbours and linked local coastal economies, fishing remains an important industry, employing 15,470 in the Republic of Ireland (in 1995) (BRADY SHIPMAN MARTIN, 1997). For many coastal communities, however, the economic importance of fishing is declining under actions of the EU Common Fisheries Policy. The physical impacts of European international fishing on Ireland's offshore areas continue to grow (CONNOLLY and HEGARTY, 1999). Some communities have responded to this decline by diversifying into related areas of aquaculture (employment in aquaculture reaching 2946 in the Republic of Ireland in 1995). The physical environmental and visual impacts of these activities for the coastal zone are also of increasing importance (CORK COUNTY COUNCIL STAFF, 2001).

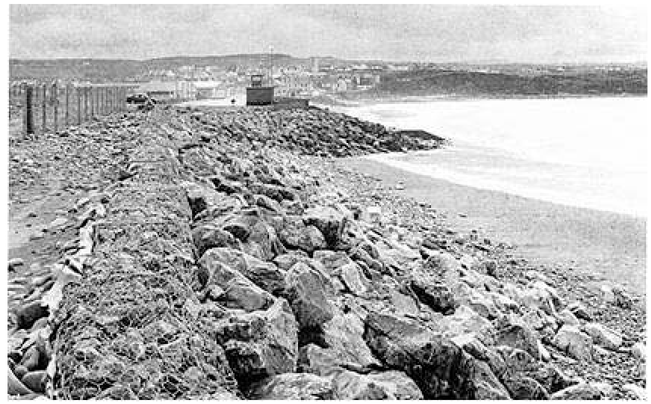

Figure 5. Shoreline defences at Waterville, County Kerry, composed of gabion and riprap structures; typical of shoreline protection works commonly found at coastal sites in Ireland (NCEC, 1992).

Factors of culture and history have been important in conditioning Ireland's contemporary uses of coastal environments (DEVOY, 1992; ORFORD, COOPER, and SMITH, 1997). There is a deep-rooted attachment to land ownership in Ireland. In coastal communities, this is reflected in a determination to prevent land losses to the sea, almost irrespective of cost. Many examples of small-scale coastal defence actions in response to local erosion problems exist around the coastline (NATIONAL COASTAL EROSION COMMITTEE STAFF, 1992) (Figure 5).

VULNERABILITY AND RESILIENCE FACTORS IN SLR IMPACTS

The concepts underpinning the complexities of coastal vulnerability and its assessment have been established (BIJLSMA *et al.,* 1992; CARTER *et al.,* 1994; FEENSTRA *et al.,* 1998; PEERBOLTE *et al.,* 1991; WATSON, ZINYOWERA, and MOSS, 1996). The roles of natural (biogeophysical) susceptibility and resilience factors to SLR and coastal changes, linked to human socio-economic controls, have been used to provide a basis for the quantitative measurement of coastal vulnerability

Table 1. *Vulnerability components for Ireland, assuming a scenario of 1-m relative SLR to 2100 and assuming the existing socio-economic situation.*

Impact Categories*	Component	Proportion/Factor Scale	Vulnerability Class *Low–Critical*
People affected (by coastal impacts) [(people/total population) × 100%]	<250,000	<4.6%	Medium (1–10%)
People at risk (by *e.g.,* SLR-induced flooding) [(people × flood probability)/1000]	<100,000 (from 1:100 yr flood)	1–8 people/1000	Low (<10 people/1000)
Capital value loss [(total loss/GNP) × 100%]	c. US$170M (at agricultural land values)	c. 0.2% GNP	Low (<1%)
Dry Land loss [(area/total area) × 100%]	<230 km²	<0.3% Total area	Low (<3%)
Wetland loss [(area/total area) × 100%]	c. 800 km²	c. 30% Wetland total	High (10–30%) [IPCC critical values: >30%]
Protection/adaptation costs† (for Republic of Ireland only) [(annual cost/GNP) × 100%]	*Potential*-US$ c. 420M/yr	c. 0.6% GNP	High (0.25–1.0%)
	Envisaged-US$ <10M/yr	c. 0.02% GNP	Low (<0.05%)

* The Impact Categories and outcome statistics shown are based on the recommended IPCC (WATSON, ZINYOWERA, and MOSS, 1996) methodology for the quantification of coastal vulnerability, † <4% of Ireland's coast is protected by built shore structures.

(see Fig. 3 in KLEIN and NICHOLLS, 1999). This formalisation of terms and concepts has been valuable in identifying vulnerability issues and assessing risks. A potential drawback, however, of this formalised definition lies in its emphasis upon the distinction and diagnosis of the individual components of vulnerability, such as those of susceptibility, resilience, resistance, and adaptation. These definitions may underplay the important feedbacks that can exist among components (KLEIN *et al.,* 1998) (*e.g.,* a coast's apparent susceptibility to SLR, as from the erosion of soft sediments, later becomes an element in its resilience—now from new sediment supply as rates of SLR increase).

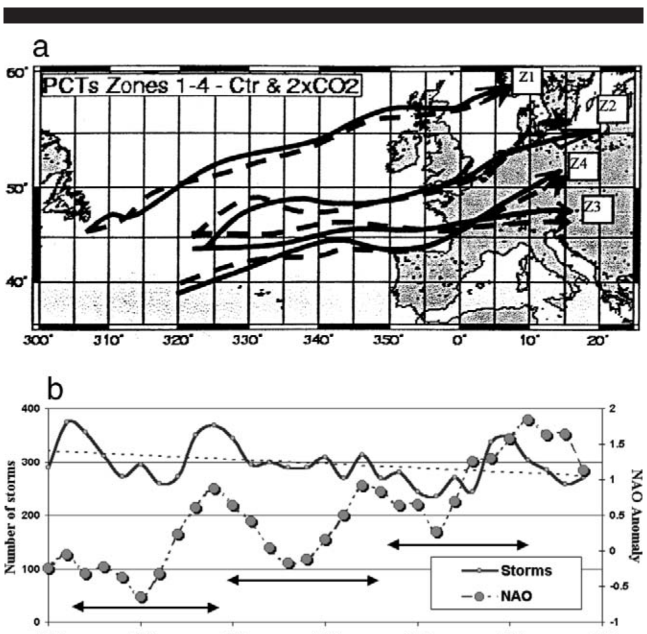

Figure 6. (a) Principal storm tracks (Z1–Z4) affecting Northwest European coastal zones. Solid lines show the present storm tracks; dashed lines show changed positions with climate warming by 2060 (CO_2 x2 coupled GCM experiment) (Devoy, 2000b; Lozano *et al.*, 2002). (b) Comparison of storminess in the Northeast Atlantic and NAO. The thick line shows the frequency of storms in the Northeast Atlantic during the period 1965–1995, the dashed line shows a trend in storms during the period 1965–1995, circles with a dotted line represent the NAO December–March anomaly, and arrows represent periods of 8.5 years (Devoy *et al.,* 2000b; Lozano *et al.,* 2002).

Studies of SLR impacts and associated vulnerability for Ireland have been undertaken (CARTER, 1991a; ENVIRONMENT SERVICE OF NORTHERN IRELAND STAFF, 1995; NATIONAL COASTAL EROSION COMMITTEE STAFF, 1992; SWEENEY, 1997) but have not adopted the formal assessment methodologies and technical language defined by the Intergovernmental Panel on Climate Change (IPCC) and others. An overview assessment of Ireland's vulnerability to SLR, based upon the IPCC's common methodology (BIJLSMA *et al.,* 1992; NICHOLLS and MIMURA, 1998) is given in Table 1. These data support Ireland's relatively low vulnerability to SLR, as consistent with much of north-west Europe (PARRY, 2000). At local scales, the situation is necessarily more complex, driven by the operation of the specific environmental controls in a particular area. An appraisal of the main susceptibility–resilience factors to SLR in Ireland is now given.

Factors of Susceptibility, Resilience or Resistance, and Adaptation

Five "natural" influence factors and four human influence factors can be identified and are discussed in turn.

"Natural" Influences

Changes and Exposure to High Wave Energy. Ireland lies in the path of the major northerly North Atlantic storm tracks (Figure 6a). These storms affect all of Ireland's coasts to some extent (SWEENEY, 2000). Its western and southern coasts are particularly susceptible to flooding and erosion under storm conditions as linked to morphodynamic processes (factor iii) (DEVOY *et al.,* 1996; DEVOY, DUFFY, and DELANEY, 1996; ORFORD *et al.,* 1996). Results from regionally scaled general circulation model (GCM) of storminess for the North Atlantic margin (ECHAM4-AO GCM and other models) (LOZANO *et al.,* 2002), show meso- (10^1 y) to long-term (10^2 y) patterns of variability in storm frequency for Atlantic European coasts (DEVOY *et al.,* 2000b; SWEENEY, 2000). Pronounced cyclical changes in frequency have occurred since the 1940s at a quasi-decadal (*ca.* 8.5 years) level (LOZANO and DEVOY, 2000). These variations appear to be linked to the behaviour of the North Atlantic Oscillation (NAO) (Figure 6b). Under CO_2 x2 climate warming to 2090, the modelling predictions show changes in the focus and an increase in the magnitude of storms affecting Ireland's coasts. Upon combining background SLR to these events, such storms are likely to locally record further enhanced coastal impacts. Incremental SLR under climate warming may result in the reduced periodicity of such extreme events (CARTER, 1991a), thereby effectively *increasing* the return frequency of high-magnitude storms with associated increased coastal flooding and erosion.

The prediction of interannual and regional variability in storminess is also marked for Ireland. Modelling shows increased winter storms into the 21st century, especially for north-west to northern coasts, and calmer summers. Analyses of wind variations for south-east and eastern coasts may also suggest an increased occurrence of easterly winds and associated storminess in these regions, again with implications for coastal erosion.

Climate Changes and Coastal Links to Freshwater Flooding. Many major settlements in Ireland (>50,000 people) are situated on estuaries. The effects of river floods during storms, particularly where these are coupled with marine surges, create notable flood events in these coastal settlements, as in the case of Cork (DEVOY, 2000b; HICKEY, 1990). Results of GCMs of wider climate changes for CO_2 x2 scenarios again show distinct regional and seasonal variations for Ireland (SWEENEY, 1997). Under climate warming to 2050, increases in winter rainfall of more than 15% are predicted for western areas, with summer reductions in all areas of 5–15%. These winter rainfall changes are linked to likely increased river discharges and flooding (SWEENEY, 1997). Some river catchments may record both a reduction in the return period for "design" floods and a concomitant increase of summer low-flow conditions of about 50% (CUNNANE and REGAN, 1994), as coupled to changes in evapotranspiration and groundwater parameters.

These predicted rainfall and associated climatic changes for Ireland would have wider coastal repercussions. Coastal aquifers may be affected by these changes. These aquifers are generally small and restricted in size by steep land-to-shore gradients of the groundwater table (CARTER, 1991a). However, saltwater intrusion of groundwater will probably become more frequent during the summer under conditions of both reduced freshwater discharge and SLR. Coastal aquifer water quality (pollution) will also suffer, especially with any increases in annual temperature and contamination by waste. Salinisation of these aquifers is unlikely to extend more than 200 m further inland, and at present coastal aquifers are of little economic importance, reducing this impact of environmental change. But a continued expansion in coastal populations and industrial pressures on freshwater resources, as well as changing agricultural land uses at the coast (Table 1), may create negative feedbacks to coastal resilience. Such changes will increase the susceptibility of coastal river catchments to flooding and to water contamination problems (MCWILLIAMS, 1991). Strict planning controls, in the context of an integrated land management–environmental policy, will be required to reduce the impacts of these climate-warming effects.

Increased temperature (air and seawater) and rainfall under climate warming may add to the productivity of biotic systems (vascular and algal plants and carbonates). Rises in biological productivity from eutrophication and sedimentary changes have already been noted from many coastal sites in Ireland. For coastal sedimentary accumulation (see factors iii and iv), these may be seen as positive trends. The growth of coastal plant communities and the productivity of marine carbonates provide positive feedbacks to sedimentary accumulation at the coast. The supply of carbonates is an important component of beach sands for western and southern areas of Ireland (GUILCHER and KING, 1961).

Morphodynamics. Many of Ireland's soft coasts are low, at mean sea level (msl) of less than +10 m to +12 m, and are susceptible to surge and storm activity. Deep water storm waves at the coast may exceed levels of +11-m to +20-m ordnance datum (Belfast), with resultant barrier overwashing, changes in sediment distribution, barrier erosion, and breakdown (CARTER, 1983; CARTER *et al.,* 1987; DELANEY and DEVOY, 1995; DEVOY *et al.,* 1996; ORFORD and CARTER, 1984). Large areas of low, embayed, and estuary-type coasts also exist (Figure 1). These contain fine sediments in marsh and mudflat systems, which are tuned to changes in hydroperiodicity and exposure to wave energy at micro- to mesotemporal and spatial scales. Studies of these environments show that sediment transfers during storm action, linked to the annual accretion of sediments in these systems, may provide some resilience or resistance to SLR changes through marsh buildup. Many sites on southern and western coasts show current accretion rates of 4–8 mm/y (DUFFY and DEVOY, 1999; WHEELER, OLDFIELD, and ORFORD, 1999; WHEELER, ORFORD, and DARDIS, 1999). This compares with longer-term background accretion levels of less than 2 mm/y, where mechanisms of geological averaging have finally led to the removal of sediments from systems (DEVOY *et al.,* 1996; DEVOY, DUFFY, AND DELANEY, 1996). At the open coast, sediment accretion rates in sand-dominated barrier systems are very variable but can exceed 60 mm/y. Storms are again important here in producing sediment buildup. However, local site conditions, storm cyclicity, and threshold-response mechanisms in sediment transport are critical in determining a system's behaviour. Under climate warming and changing storminess, a continued positive supply of sediments to these systems will be essential in maintaining current coastal positions.

A wide, shallow-water inshore zone (water depths < 50 m) and continental shelf—coupled to wide dissipative beach systems, rock platforms, and abrasion surfaces—are also characteristic of Ireland's coastline. These features lead towards maximising wave energy absorption and reducing wave-surge impacts; providing a measure of resistance to the erosion of coastal areas. Any increased acceleration in coastal retreat under SLR would result in an amplification of this Holocene pattern of coastal morphological development, tending to slow any initially enhanced erosion rates. The operation of this Bruun Rule–type feedback, particularly for sand- and soft-sediment-dominated coasts, would link to other areas of coastal resilience in providing materials for transport into zones of sediment deficit. For the southern and eastern coasts especially, there is an abundance of glacigenic materials (wide–coarse to fine size ranges), which would become a ready source of new sediment supply with SLR.

These and other elements in coastal resilience derive from coastal biogeophysical systems developed under conditions of environmental extremes (*e.g.,* dominant meso- to macrotides and high storm activity and rainfall). Predictions for Ireland based upon modelling (*e.g.,* to 2050–2100) indicate significant changes to some of these boundary controls (*e.g.,* winds, storm magnitude, and rainfall). However, the existing tuning of coastal systems to natural extremes may provide further capacity for coasts to absorb some of these expected climate-induced changes in boundary controls.

"Coastal Squeeze" and Sedimentary Changes. Sediment deficit and "coastal squeeze" (PETHICK, 1993; PYE and ALLEN, 2000) are noticeable on Ireland's coasts. The transfer of "new" sediments to most coasts from offshore–shelf sources has almost ceased (CARTER *et al.,* 1987; CARTER and WILSON, 1993). In the late Holocene, coastal barriers became stranded against the uplands and landwards-rising hard-rock surfaces. Consequently, beach-barrier sediments are being lost through reworking alongshore and diffused into other coastal environments. This leaves a regionally to locally varied and often-limited capacity for the further onshore movement and adjustment of soft-sedimentary coasts to SLR impacts. A distinct negative impact upon beach systems is also the continued removal by people of sand and gravel as a resource, despite prohibition (CURTIS, 1991; QUINN, 1977). These materials are highly attractive for industrial uses (*e.g.,* as building aggregates and in agriculture) (SUTTON and WHEELER, 2001). These sediment sources require strict management if they are not to continue to be lost from the coastal systems.

The natural adaptation of coastal environments may be further reduced by other human controls, as trapped by defence works (Figure 5) and coastal infrastructures (*e.g.,* road, rail, and settlements) (CARTER and BARTLETT, 1990). In rural areas in Ireland, coastal roads are common (CARTER, 1991a) and there are often strong local pressures to maintain their position, in spite of there often being room to move inland (DOLLARD, 2000; LEWIS, 1992). These roads frequently come under threat from coastal changes (*e.g.,* from marine flooding and landslides). However, in some instances of major communications (*e.g.,* east coast railway at Greystones, County Wicklow), a more enlightened CZM policy has been practised. Here, a major rail link has been moved and build up of the coastal sand systems has been encouraged as defence buffers (Figure 7) (NATIONAL COASTAL EROSION COMMITTEE STAFF, 1992).

These physical and human limitations to onshore coastal movements and sediment budgets will create a greater stressing of system boundaries and thresholds under SLR (WOLFF, DIJKEMA, and ENS, 1993), leading to significant future changes in the organisation of coastal system domains. Where steep land surfaces prevent the onshore movement and spatial adjustment of coastal sedimentary systems, there is a high potential for the loss of these systems.

Marsh Systems. The biogeophysical functioning of coastal marshes and mudflats, coupled with factors i–iv, will lead to varied susceptibility–resilience responses of these systems under SLR. Coastal marshes in Ireland are often organic dominated with distinctive low, across-marsh height ranges (CURTIS and SHEEHY SKEFFINGTON, 1998; SHEEHY SKEFFINGTON and WYMER, 1991). Associated plant communities are commonly species poor, often lacking a clear halophytic zonation. Mild climate and high annual rainfall, especially over western coasts, are probably important factors in conditioning these marsh characteristics, causing increases in plant productivity and competitiveness in marshes of freshwater and euryhaline species (DUFFY and DEVOY, 1999; WHEELER, ORFORD, and DARDIS, 1999). Under earlier conditions in the mid-Holocene, the rapid growth rates of many western coastal wetlands, as linked to reed swamps and freshwater bogs, outstripped SLR and limited marine inundation and onshore movement of clastic sediments (CARTER, DEVOY, and SHAW, 1989; DEVOY *et al.,* 1996). Accelerated SLR, together with renewed human pressures on coastal land use, may reduce this former natural resilience or resistance of marshes to inundation, with these environments becoming increasingly more sensitive to biogeophysical changes (Table 1). At present, these coasts contain extensive areas of integrated wetland systems in good condition (EUROPEAN COMMISSION STAFF, 1999a).

Figure 7. Coastal squeeze and buffering. Realignment inland of the railway at Greystones, County Wicklow, showing the old and new track positions (NCEC, 1992).

Human Influences

Population Impacts. As coupled to the natural influence factors, the current human impact potential on coastal wetlands and dune systems is high (CARTER, 1988; QUIGLEY, 1991; WILSON and BRALEY, 1997). From at least the 18th century, the reclamation and reconstruction of marsh and other coastal areas was common (estimated order of land reclaimed by 1900 was *ca.* 90–150 km^2). Changes in sedimentation patterns through built coastal structures, reclamation, and agriculture have taken place, exemplified at Rosslare (ORFORD, 1988), Castlemaine (DUFFY and DEVOY, 1999), Portmarnock and Dublin Bay (MULRENNAN, 1993), and many other coastal sites (CARTER and ORFORD, 1988). The growth of *Spartina* spp. (*Spartina alterniflora* introduced from the 1880s into Ireland) (BOYLE and KAVANAGH, 1961) has come to dominate large areas of coastal wetlands. The sediment accretion and subsequent dieback and sediment release issues associated with *Spartina* have caused significant siltation problems in some coastal areas (*e.g.,* Cork Harbour and Strangford Lough).

Emigration and rural decline by the 1920s had lessened the human pressures on the coast, together with the effects of earlier coastal reclamation. Reclaimed land was often "let go" (*e.g.,* Dungarvan, County Waterford, and Rossbehy, County Kerry), and a recovery of biogeophysical systems is allowed to happen (an unplanned but early example of managed retreat). In the late 20th century, coastal areas were suffering renewed threat (BRADY SHIPMAN MARTIN, 1997; BRADY SHIPMAN MARTIN and HYDE, 1973; COASTWATCH, 1994; ECOPRO, 1996; NATIONAL COASTAL EROSION COMMITTEE STAFF, 1992).

Degradation of coastal dune and other biogeophysical systems is apparent, with pollution and reduction in biodiversity (DOWNEY and NÍ UID, 1978). In the 1990s, direct urban expansion apart, there has been a rise in the number and range of new coastal building developments. Increased stresses on coastal systems, potentially reducing their sustainability, are represented by many activities: marinas (*e.g.,* Dingle Harbour, County Kerry, and Kinsale, County Cork), dune-based golf courses (*e.g.,* Inch and Ballyheige, County Kerry), leisure centres and residential complexes, extensive aquaculture development of bay and shallow water sites (MARINE INSTITUTE STAFF, 1996, 1998), littoral sand and gravel extraction (Irish Sea), and the renewed reclamation of intertidal-bay areas (*e.g.,* Lough Foyle, County Derry, and Clonakilty Bay, County Cork). In the Republic of Ireland, coastal lands are seen as a national resource to be used if possible: "Ireland is 90% undiscovered, undeveloped and underwater" (MARINE INSTITUTE STAFF, 1996, 1998). While environmental legislation through national and EU initiatives (CONNOLLY and HEGARTY, 1999) provides some protection to this trend towards development, the declared national aim of achieving resource use with environmental sustainability is going to be difficult in practice.

Under SLR, a positive element in the ability of Ireland's coasts to cope with these human pressures is that large areas are not heavily populated. People are concentrated in relatively few coastal locations. Outside of the main urban areas, the coastal population (living less than 5 km from the coast) is only about 10% of the total. The potential for planned adaptation exists through the development of both accommodation- and retreat-type strategies (PARRY, 2000; SMIT *et al.,* 1999), including those of coastal setback or even of shoreline realignment and managed retreat (PETHICK, 1993). However, cultural attitudes and historically important land holding rights may offset this potential advantage of apparently long, "unfixed" shorelines. Furthermore, coastal environments, despite late 20th century increases in development pressures, remain relatively clean, extensive, and in apparently good condition (EUROPEAN COMMISSION STAFF, 1999a). Visible evidence of the earlier heavy population and use of the coasts (*e.g.,* 18th and 19th centuries) is difficult to find, indicating the coast's high natural potential for absorption of stresses and recovery from change.

Administrative Divisions. Government throughout Ireland has encouraged a reduced adaptive capacity for dealing with coastal change issues and the impacts of SLR. This can be seen in the development at local to national levels of overlapping and inefficient administrative structures for the coast (CARTER *et al.,* 1993; DEVOY, 1992; MARINE INSTITUTE STAFF, 1996; O'KEEFFE, 1992; ORFORD, 1993). Different approaches to coastal use (*e.g.,* by scientists, engineers, planners, government, and the public) have led to an uneven application of CZM measures among coastal authorities (BRADY SHIPMAN MARTIN, 1997; ORFORD, 1993). With some exceptions, best practice is rarely adopted. This, together with inadequacies in legislation, availability of coastal data, and awareness of international coastal control measures, maintained until the 1990s a fragmented national approach in CZM (CONNOLLY and HEGARTY, 1999). At present, great potential for social and administrative inertia exists in responding to coastal needs.

People's Awareness of SLR and Coastal Changes. A lack of awareness and education about coastal vulnerability under different environmental scenarios (KLEIN and NICHOLLS, 1999) remains a constraint upon society's ability in Ireland to cope with the impacts of SLR. Coastal users (private, commercial, and public) still tend to operate in isolation and on the basis of self-interest (although some national and regional differences may exist, *e.g.,* Northern Ireland). Incidences of independent action (sometimes illegal) are widespread—for example, in the breaching of coastal barriers to encourage land drainage in the face of environmental opposition (ORFORD and CARTER, 1982), in the dumping of debris as quasi-shoreline defences, or in the removal of beach materials (CARTER, 1988).

Great pressure on coastal authorities exists to provide site-specific control measures to deal with erosion or related problems of coastal dynamics (*e.g.,* Rosscarbery, County Cork). Attitudes focused upon coastal defence are still common. Small site schemes of riprap, gabions, seawall construction and sand-fixing, or beach nourishment measures occur widely. The costs of these schemes are upwards of €60,000 and may reach into the millions independent of subsequent maintenance costs. Competing coastal-use interests among landowners, aquaculture, tourism–recreation–environment, housing, and regional–local industrial development are increasing

Table 2. *Sequence of events and key actions in developing coastal zone management (CZM) for the Repbulic of Ireland, 1988–2001.*

Date	Event and Action
1987/1988	(i) Major political party (Fianna Fail) policy document on the marine environment.
1988	(ii) The Department of the Marine and Natural Resources (Dublin) was set up to administer and promote a national policy for coastal and marine environments. The consolidation, under the department and together with Forbairt (now Enterprise Ireland), of the limited public technical services dealing with coastal infrastructures and shoreline protection measures was also accomplished at this time.
1989–1990	(iii) The Department of the Environment (Dublin) commissioned a major report to examine the impact on Ireland of major changes in mean sea level (Carter, 1991b). This gave a comprehensive review of coastal environmental issues linked to sea-level changes, including approaches to coastal vulnerability and resilience, coastal data, and coastal management (policy and structures). This review consolidated the work of many independent coastal research groups and policy studies undertaken by universities, professional institutes (*e.g.*, engineering and planning), and public interest groups (*e.g.*, Coastwatch). The work of these different sector interests has continued and grown in scale.
1991	(iv) The set up of a national Marine Institute to deal with the acquisition and handling of marine and coastal data, the promotion of research, and related commercial activities.
1992	(v) Report and national policy proposals of the National Coastal Erosion Committee; further consolidating research work and other elements of item i.
1992*	(vi) In the United Kingdom, the report of the House of Commons Environment Committee on the organisation of coastal planning and management recommendations. This began the subsequent devolution of CZM organisation in the constituent parts of the United Kingdom (Scotland, England, Wales, and Northern Ireland) and set the overall pattern of approach to CZM.
1992/1993	(vii) Some rationalisation and improvements in coastal legislation under the Local Government (Planning and Development) Act (1993) and the Environmental Protection Agency Act (1992).
1995*	(viii) In Northern Ireland, the Environmental Service of Northern Ireland (ESNI) report, *Delivering Coastal Zone Mangement in Northern Ireland*. Official government response to earlier NGO and other environmental pressure group documents treating the needs for SLR and CZM in Northern Ireland.
1995/1996	(ix) The initiation (1995) through the Marine Institute of a public debate (consultative process) to help determine marine policy for Ireland—initially through a series of public seminars held around Ireland, focusing on key coastal and marine issues. Report on country-wide seminars and consultation published 1996 (Marine Institute Staff, 1996).
1997	(x) The completion of a government *Draft Policy for Ireland of Coastal Zone Management* (Brady Shipman Martin, 1997). This document continued the work of the earlier Department of the Environment review and of independent studies at the start of the 1990s. It contains an update of coastal data for Ireland and links possible approaches in coastal management to wider international views on ICZM. Part of the purpose of the *Draft Policy* document has been to continue and to develop public debate on coastal issues and subsequently debate through European Union, expert, and other forums on CZM policy.
1997/1998	(xi) The implementation of elements of a National Coastal Survey, including digital aerial photographic coverage of the coastline (ongoing). This has involved a variety of research and commercial groups (including the Marine Insitute and Enterprise Ireland).
	At local-regional scales, the local government authorities (as the on-the-ground administrators of the coasts), university and technical institutes, and other groups have continued many independent studies of coastal issues through EU and national research funding. These projects have been involved particularly in gathering data and setting up of database systems; applying a GIS or MIS to coastal issues; doing fundamental research on coastal process operations, the impacts of relative sea level, and linked climate changes on coasts; investigating ICZM approaches relevant to Ireland; coastal erosion measurement and mitigation; investigations of wave energy.
2000	(xii) Approval of a national Coastal Protection Programme and the implementation of limited funding (May 2000).
2000/2001	(xiii) Implementation of a CZM policy review (Brady Shipman Martin, 1997), stages 1 and 2 (ongoing).

GIS = geographic information system, ENSI = Environment and Heritage Service, ICZM = integrated coastal zone management, MIS = management information system, NGO = nongovernmental organisation, SLR = sea-level rise.
* For Northern Ireland, the timing of the main CZM policy decisions during this period is asterisked.

(Cork County Council Staff, 2001). The outcome of these ingredients of environmental awareness and society's responses to coastal changes is currently weighted towards a potentially wasteful use of resources and inertia in meeting the needs of environmental sustainability. The role of the media in this has tended in the past to emphasise catastrophe and the possible destructive impacts of climate warming, rather than to provide informed environmental information.

Funding and Resourcing. A significant economic problem in dealing with coastal issues has been an endemic lack of public resourcing of infrastructural development. Coastal defences and other infrastructure are often old, and less than 4% of the coastline is protected by shoreline defences (Carter, 1991a). In many rural areas, structures now serving as defences were originally built as property or agricultural boundaries (*e.g.,* walls and dikes). Existing structures frequently have their origin in the 19th century and have been modified subsequently on a piecemeal, needs-must basis. These structures are unlikely to be able to cope with future SLR and linked changes. The cost of essential repairs alone to coastal defences was estimated in 1991 to be about €159 million (National Coastal Erosion Committee Staff, 1992). The first-time provision of national funding of €44.4 million over 5 years to primarily coastal authorities to help meet these infrastructural needs was made only in May 2000 (Table 2). The record of past and planned funding indicates that this environmental sector is significantly underresourced. In national policy, the emphasis remains on the provision of finance from commercial and other funding sources (European Union, local) to meet coastal needs.

A FIRST-ORDER ESTIMATE OF POTENTIAL IMPACTS ON IRELAND

Table 1 shows a first-order assessment of coastal vulnerability responses assuming a 1-m relative SLR by 2100. It is based upon the IPCC's common methodology (Bijlsma *et al.,* 1992, Appendix C; Klein and Nicholls, 1999). Existing statistics, including trends of demographic changes, economic, and spatial environmental patterns for Ireland, were used (*e.g.,* CARTER, 1991a; MARINE INSTITUTE STAFF, 1996). Coastal changes were assessed from an overlay of the 1-m SLR scenario upon coastal land surfaces (irrespective of existing defence structures, which currently protect less than 4% of Ireland's coast). Available Ordnance Survey map data were used; map contour spacing generally has a less than 5-m resolution. Modelled predictions for environmental changes involving climate variations (*e.g.,* return flooding and groundwater and sedimentary responses) were included in estimates. No predictive economic or population models were applied. Allowance was made for inflation costs (*e.g.,* in coastal defence costs), leading to estimation of the potential costs for expenditure for the protection of coasts most at risk (*ca.* 1500 km). This value is contrasted with the envisaged annual government expenditure (Republic of Ireland). Economic models involving GNP, land values, inflation, population movements and housing trends are notoriously speculative (BRUCE, LEE, and HAITES, 1996). Similarly, major assumptions about wetland system functioning are involved in the IPCC calculation of wetland losses (WATSON, ZINYOWERA, and MOSS, 1996). Possibly 25–50% of these wetlands will be lost under SLR, but the amount is debatable (CARTER, 1988; WATSON, ZINYOWERA, and MOSS, 1996). The resilient properties of Ireland's wetlands and the probable lags in the rates of SLR and wetland responses suggest that losses are more likely to be below the IPCC's critical level (*i.e.,* values > 30% loss).

DISCUSSION

CZM Policy and Assessment of SLR Impacts

In spite of the human problems (socio-economic issues) that continue to contribute to Ireland's coastal vulnerability, Ireland at the beginning of the 21st century is moving towards a transformation in its treatment of the coastal zone. Throughout Ireland, people have awakened relatively recently (post-1980s) to the resource values, uses, and environmental importance of both coastal and marine offshore areas. This is seen most clearly in the Republic of Ireland, which administers about 70% of Ireland's coasts (Figure 3). Here there have been significant positive moves towards favouring coastal and marine environments; these are reflected in the attitudes of political parties, in new government policy measures and research and development funding, in people's awareness of coastal issues, and in the involvement of educational and professional institutions. The practical outcomes of this institutional and policy activity are summarised in Table 2.

At present, there are no specific national (or islandwide) policies in place to manage the effects of SLR under global warming. The studies that have been done (WATSON, ZINYOWERA, and MOSS, 1996), while detailing the implications of SLR for Ireland under climate warming, have necessarily stressed the need for urgent action upon other linked coastal matters. In particular, the immediate pragmatic issues of coastal administration, efficient decision making, resourcing, and more recently, the coast as part of river catchment management and the needs for environmental sustainability.

Policy studies have reflected a move towards developing an integrated coastal zone management (ICZM) approach in both the Republic of Ireland and Northern Ireland. In both, the adoption of a cell-based shoreline planning (Figure 3) has been advocated as the basis for coastal management organisation (BRADY SHIPMAN MARTIN, 1997; CARTER, 1991a; ENVIRONMENT SERVICE OF NORTHERN IRELAND STAFF, 1995; NATIONAL COASTAL EROSION COMMITTEE STAFF, 1992). However, the absence of coordinated CZM (islandwide) means that responses to the increasing pressures to develop coastal sites (*e.g.,* in Cork, Dublin, Belfast, and Galway) falls upon the limited coastal expertise of the local authorities and upon generalised environmental legislation from the 1990s. Some major coastal local authorities (*e.g.,* Wicklow, Clare, Cork, Down, Donegal, and Antrim) have undertaken proactive approaches to dune conservation and coastal setback and have linked both built and passive techniques of shoreline protection (BRADY SHIPMAN MARTIN, 1997). But the implementation of these approaches at present is more a matter of serendipity than national policy.

Awareness of climate-warming issues and flood risk has led many local authorities and the Environmental Protection Agency in the Republic of Ireland (responsible for implementing environmental impact assessments, or EIAs) to prohibit developments in the coastal zone below +3-m msl and close to vulnerable dune and eroding coastal areas. EIAs for large-scale coastal developments are now required. However, politics and money "speak", and planning guidelines are increasingly becoming infringed in the absence of clear ICZM policy and linked legislation. Interestingly, the awareness of engineers and planners in Ireland of the need to involve SLR in the design of coastal protective measures dates from the late 1970s (ECOPRO, 1996).

Until the late-1980s urban expansion, Ireland had managed to largely avoid areas known to be high flood or erosion risk, occasional isolated houses and developments apart (*e.g.,* at Douglas, Cork; Ballybunion; and Rosslare). A region with particular problems, however, is that of Dublin Bay. Strong pressures exist here from the growth of Dublin to extend developments into environmentally sensitive coastal wetlands (*e.g.,* north County Dublin) and onto the extensive low-lying, soft coasts of the region (DEVOY and O'MAHONY, 1992). There's a persistent pressure from the public for the provision of greater shoreline protection. However, the city of Dublin itself, away from the immediate waterfront areas, and the region as a whole are not inherently more susceptible to SLR than other soft coastlines in Ireland. The important issue here for vulnerability is the concentration of the economic, industrial, and population exposure to coastal change.

Coastal Administration

The awakening in the 1990s of interest in CZM throughout Ireland reflected a range of internal and external stimuli. These included the effects of a real growth in the economic value and resource potential of Ireland's coastal zone (BRADY SHIPMAN MARTIN, 1997), a positive response to international concern upon environmental degradation (*e.g.,* ENVIRONMENT SERVICE OF NORTHERN IRELAND STAFF, 1995; MArine Institute Staff, 1996, 2000), and a cautious willingness (*e.g.,* in the Republic of Ireland) to accept EU policy and directives on environmental management (*e.g.,* Bijlsma, Ehler, and Mimura, 1994; Commission of the European Communities Staff, 1992; United Nations Conference on Environment and Development Staff, 1993). The role of the climate change and relative SLR debate (*e.g.,* Houghton *et al.,* 1996) has also been an important catalyst in developing this awareness. In the Republic of Ireland, measures dealing with the sustainability of resource use and the limitation of environmental impacts began to be incorporated into national legislation during the 1990s (Connolly and Hegarty, 1999). Environmental issues now form cornerstones in CZM policy formulation (O'Sullivan, 1993). In Northern Ireland, similar coastal issues exist and have been pursued by the Northern Ireland Department of the Environment, by the Northern Ireland local government authorities, and through the wider U.K. coastal administrative structures (Scannell, 1995).

The coastal administration of the island is politically separated (Environment Service of Northern Ireland Staff, 1995; House of Commons Environment Committee Staff, 1992). However, the approaches taken (in both the Republic of Ireland and Northern Ireland) come from common attitudes and philosophies towards the practice of government (Carter *et al.,* 1993; Devoy, 1992). Reviews detailing the environmental background, administration, problems, and approaches for CZM in Ireland (as a whole) are given in Devoy and O'Mahony (1992), Orford (1993), National Coastal Erosion Committee Staff (1992), Environment Service of Northern Ireland Staff (1995), Brady Shipman Martin (1997), and Connolly and Hegarty (1999).

The current organisation of CZM in Ireland (overall) reflects the multiple sectoral interests of government. These include those of local and national government, semistate bodies, and linked commercial groups (*e.g.,* research and environmental agencies and marine, port, and harbour authorities) and of nongovernmental organisations (NGOs) (*e.g.,* those concerned with the environment, such as The National Trust, Northern Ireland, and An Taisce, the Republic of Ireland). In the Republic of Ireland, primary control is split among four main agencies:

Department of the Environment and Local Government (for landwards planning)
Department of the Marine and Natural Resources (for seawards planning)
Department of Arts, Heritage, Gaeltacht and the Islands (for nature conservation)
Environmental Protection Agency (for environmental management)

In Northern Ireland, administration remains more concentrated: in the hands of the Department of the Environment and the National Trust. The role of the National Trust in administering coastal lands lies deep in the United Kingdom's long-term encouragement of NGO involvement in heritage and coastal management. This traditional U.K. *laissez-faire* approach to CZM (Carter, 1988) is well exemplified in Northern Ireland. The National Trust is a major coastal landowner here, is involved in the implementation of everyday management activities, and consequently is an important contributor to policy development.

These strong sectoral interests have provided a rigid top-down hierarchy for coastal administration, often with competing interests for responsibility (Carter, 1988). An awareness of these deficiencies (Carter *et al.,* 1993; Connolly and Hegarty, 1999; Orford, 1993) has led to the reappraisal of CZM needs in both the Republic of Ireland (National Coastal Erosion Committee Staff, 1992; Brady Shipman Martin, 1997) and Northern Ireland (Environmental Service of Northern Ireland Staff, 1995). The subsequent policy recommendations for change have adopted similar approaches. These may be characterised as an approach of "evolution", to develop a more integrated administration and policies of ICZM, rather than "revolution," through the construction of a single autonomous authority responsible for all coastal issues. Coastal users' calls for a National Coasts Authority–type structure (*e.g.,* Devoy and ~~O'Mahoney,~~ 1992; MacCann, 1994; National Coastal Erosion Committee Staff, 1992; Environmental Service of Northern Ireland, 1995) have effectively been rejected in the policy reviews (*e.g.*, Brady Shipman Martin, 1997).

This may be the expected response of existing administrators, although significant and open public discussion of the issues involved has occurred and the process of reform is moving ahead (Table 2). The response, however, does support fears that there will be continued administrative inertia in response time and decision making for ICZM, effectively increasing coastal vulnerability in both Ireland and Britain. The issue of a single-island ICZM authority has been set aside; the political peace process in Northern Ireland has to be resolved before pragmatic environmental concerns about coasts can be addressed at an island scale. The harmonisation of coastal policies and approaches remains at levels of interdepartmental cooperation and as part of the development of cross-border political discussions.

EU Initiatives

The role of the European Union and of wider international interests (Brady Shipman Martin, 1997) may encourage more radical changes earlier to the existing hierarchical approach to CZM in Ireland. The Commission of European Communities moves towards ICZM in the European Union, for example, on issues of sustainability (*e.g.,* World Bank Staff, 1993) and Strategic Environmental Assessment (Connolly and Hegarty, 1999), provide a continuing stimulus for administrative changes at national levels.

In the European Union, the internationally agreed-upon needs for greater grassroots public participation in coastal decision making, as in Agenda 21 (Commission of the European Communities Staff, 1992; European Commission Staff, 1999a, 1999b) and the Strategic Environmental Assessment to aid goals of environmental sustainability, are being spearheaded by EU project initiatives and funding. Three high-profile EU demonstration coastal projects (United Nations Conference on Environment and Devel-

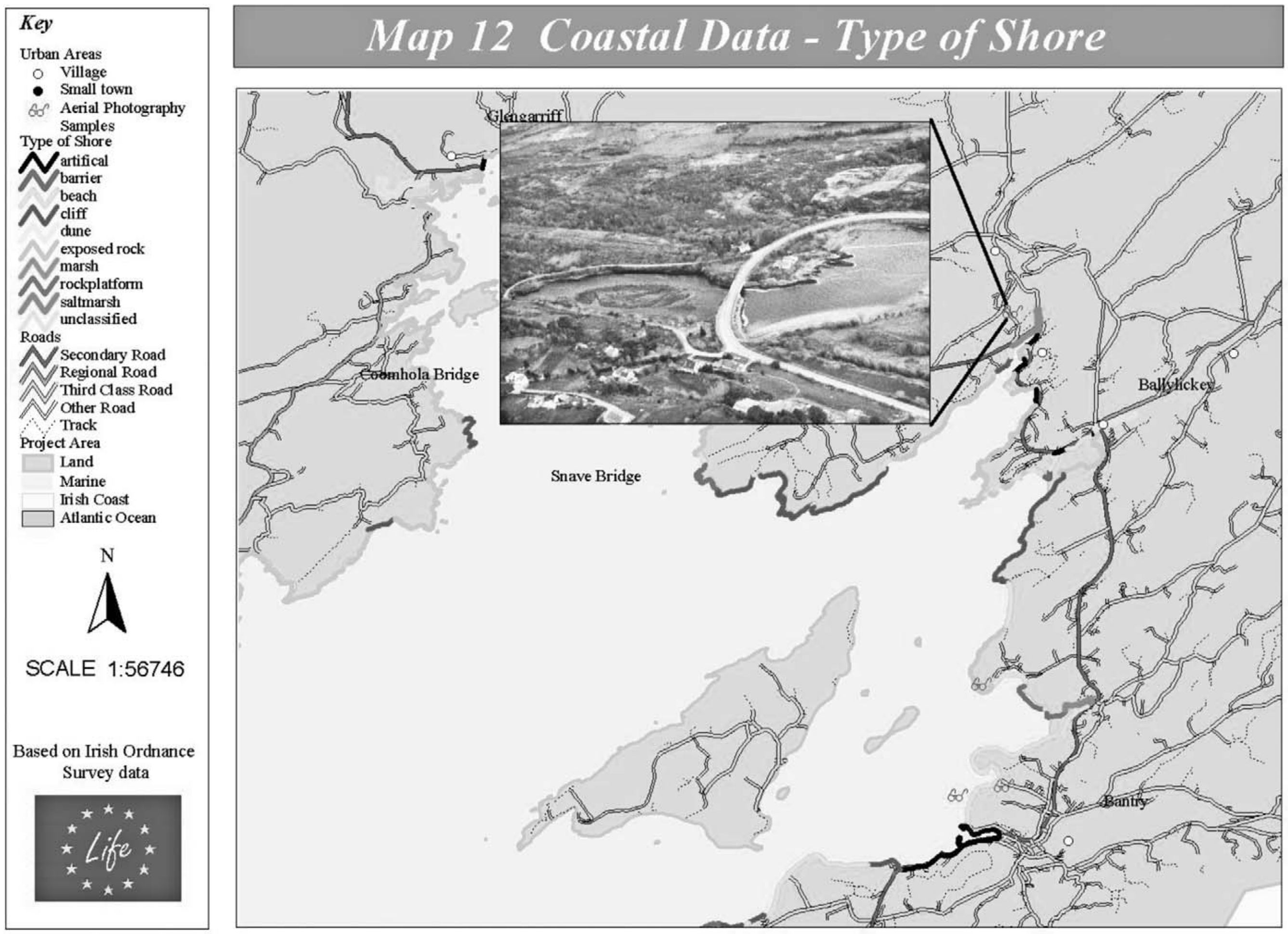

Figure 8. Coastal data output from the GIS established for the Bantry Bay Charter project (Cork County Council, 2001). Coastal zone data here form the basis for the subsequent assessment and mapping of coastal sensitivity–vulnerability. **For a color version of this figure, see page 443**.

OPMENT STAFF, 1992) are based in Ireland in County Down, County Donegal, and County Cork (Figure 3). The projects are concerned with developing ICZM approaches and with data integration and use in Ireland. Project themes include those of coastal erosion and management (Irish Beaches, Donegal), coastal heritage–recreation–landscape maintenance and biodiversity (Down), and socio-economic consensus-based planning, aquaculture, and resources (Bantry Bay, County Cork). All of these themes are of key importance in assessing the scale of climate change impacts for SLR and coastal vulnerability. Many other studies involving coastal and marine vulnerability also exist (*e.g.,* under national funding schemes, the IGBP's International Geosphere–Biosphere Programme's Land–Ocean Interactions in the Coastal Zone core programmes, and the European Union's INTERREG and Frameworks 4 and 5 environment and climate research programmes).

Practical ICZM: The Bantry Bay Project. Potentially one of the most radical of the demonstration projects for ICZM is the Bantry Bay Charter (EUROPEAN COMMISSION STAFF, 1999a, 1999b). Work in Bantry Bay, County Cork, has focused upon developing people's participation in addressing local coastal zone needs and in solving specific environmental issues (*e.g.,* aquaculture–mussel farming, port use and pollution, coastal erosion, land use pressure, and second homes) (CORK COUNTY COUNCIL STAFF, 2001). Here, the use of the stakeholder concept and consensus planning in the community, and in partnership with government, is being tested at the local level under the coordination of the local coastal authority (Cork County Council). The Bantry Bay area was chosen because it displayed many of the contemporary management issues affecting Ireland's coasts, within a characteristic biogeophysical setting for Ireland.

The project has provided a review of CZM methodologies at national and international scales, together with the establishment of a geographic information system (GIS) for all area and regional coastal data (Figure 8). This and earlier work in Ireland on the applications of coastal GIS (MANSERAGH, 1993) has enhanced the development of coastal vulnerability and sensitivity mapping for Bantry, as well as for many other locations around Ireland (Figure 8) (BARTLETT *et al.,* 1997; MCCALL and DEVOY, 1995). The GIS and database in Bantry are on open access to the community. Together they provide an information source and focus for public feedback in the process of consensus planning. In this process, working groups involving all potential coastal stakeholders (*e.g.,* local user–government and semistate–commercial interests) are set up to develop policy issues and an agenda for action for the coast. These groups meet (roundtable conferencing) to agree on policy decisions and to establish a coastal charter (the Bantry Bay Charter), which should form the basic coastal planning document at a local level (*e.g.,* MARINE INSTITUTE STAFF, 2000).

This approach is experimental. It is hoped that lessons learnt here will provide a basis for introducing effective bottom-up ICZM methods to other coastal authorities in Ireland and in which centralised government and "expert" opinion are more partners than controllers in decision making. A significant problem in the process has been accommodating the many interest groups that exist (for the Bantry area, this is more than 60 groups). Consensus building techniques developed in the United States and Canada (CONNOLLY and HEGARTY, 1999) have generally dealt with fewer groups (*ca.* 15–16 groups), and techniques had to be evolved to meet the Irish conditions. In the Bantry Bay project, 66 organisations have now come together to agree on a coastal charter. The approach is seen both by the European Union and under Agenda 21 as the ideal in developing the grassroots involvement of coastal users in building sustainable management of the coastal zone. A practical planning and sustainability issue highlighted by the project is the need for greater linkage between coast and river catchment management in Ireland. At present, no specific environmental catchment control legislation exists. Under climate-warming impacts, this will become essential.

Problems in Developing ICZM and in the Assessment of Vulnerability

Four key areas of concern exist arising from the established management and approaches to living in the coastal zone.

Resource Availability and Allocation. Ireland has a small population, and other national priorities have meant that relatively little money has been available in the past to help examine coastal issues. Yet the area of Ireland's potential marine and coastal resources, at 900,000 km^2, is large. In planning the distribution of Ireland's approximately €51 billion of EU "structural" and other funding in the National Development Plan (2000–2006), only €63.5 million was allocated to the marine and coastal sector for research, technology, and development initiatives (CORK COUNTY COUNCIL STAFF, 2001). The size of the coast and a formerly poor economy have effectively deterred national-scale work and have made the job of implementing coastal action (*e.g.,* shoreline protection) even worse.

Coastal Data Gathering and Research. Data gathering and research have been undertaken on a *laissez-faire* and fragmented basis. Data sets are often old, inadequate (especially for the Republic of Ireland), and stored in a variety of competing systems (traditional archive to information technology–based) and in different locations. Competition for grant awards remains a primary means of funding data collection; the many different competitor groups eventually involved compounding this fragmentation. The development of the Marine Institute (Table 2) set out to help consolidate data archiving and dissemination but has subsequently been sidetracked in this by a lack of adequate resourcing and competing institutional goals (MARINE INSTITUTE STAFF, 1998).

There is a need to develop a high-quality tide gauge network for Ireland for the monitoring of relative sea level, together with the provision of regular wave–hydrographic–bathymetric data and other marine surveys. These are fundamental data sets for the assessment of SLR and wave energy impacts at the coast. Such data gathering should now be linked to information technology systems (incorporating satellite imagery) to provide a comprehensive view of coastal zone conditions (*e.g.,* suspended sediment flux, vegetation–wetland changes, and wave climate).

Policymaking. Clear policymaking and linked administrative structures for ICZM have been slow in formulation and are still not in place. This results in slow response times on critical coastal issues, such as planning for aquaculture development (MARINE INSTITUTE STAFF, 1998) and shoreline management issues. However, implementation of Phases 1 and 2 of the BRADY SHIPMAN MARTIN report (1997) in the Republic of Ireland and of the ENVIRONMENTAL SERVICE OF NORTHERN IRELAND report (1995) report in Northern Ireland are in progress. Still, most coastal authorities are not geared towards developing or coping with public debate and feedback on CZM matters. These local authorities are underresourced to deal with the many different and complex coastal problems that arise now, and especially in the future, under climate warming and accelerated SLR.

The Coast as a Resource. At many public and individual levels, the image of the coast remains stereotyped and dated. Concerns about SLR, or other environmental impacts, devolve rapidly to factors of self-interest, fear, ignorance, and media hype. For many, the coast is not a major priority unless it is being eroded or polluted. Issues of environmental sustainability are much used in environmental discussions, official publications, and legislation in Ireland. However, the view that human expansion and environmental conservation are *incompatible* is not a popular one. The desire at national and local levels to increase the use of coastal and marine resources is strong (MARINE INSTITUTE STAFF, 1996, 1998). Given these resource use aims, balancing the needs of sustainable coastal management, especially under increased SLR stressing, is going to be tough. There is need for change in people's understanding of *acceptable* coastal use.

CONCLUSIONS AND NEXT STEPS

The issues of SLR and coastal vulnerability are inextricably linked. Practical (local–regional scale) problems of coastal flooding, sediment removal, erosion, and related SLR exist now, need tackling, and are only likely to worsen under the effects of climate warming. In terms of shoreline defence, off-the-shelf technologies (built techniques and the information technology–based monitoring of changes) and appropriate methods to help deal with individual biogeophysical changes in coastal situations are well established (MARINE INSTITUTE STAFF, 1996, 1998). However, it would be valuable to link these prescriptive approaches to a quantitative and regular environmental audit of Ireland's coasts, incorporating scenario building to allow for the possible effects of climate warming and SLR on these coasts. Such an approach has already become part of the environmental planning process in other countries (*e.g.,* the United States and The Netherlands). This audit should become a part of the coastal local government authorities' required 5-year review of structured environmental planning. Coastal trouble spots should be identified and planning and remedial approaches should be devised, with resourcing strategies implemented to meet the needs. Some of these recommendations are implicit in recent policy studies (ECOPRO, 1996) but not clearly formulated.

However, the way forward in addressing longer-term coastal vulnerability and issues of SLR lies with engaging in developing people's responses to the organisation and management of the coast. For Ireland, many of us in ICZM work see the following actions as particularly necessary:

(i) Policy and management: Recommendations for a more integrated coastal zone authority structure (possibly an islandwide coastal authority crossing political divides) should be implemented. The establishment of a dedicated and fully resourced authority able to deal rapidly and practically with coastal environmental problems as they start to arise through the 21st century might be desirable. The practicability of this proposal, and of the links such an authority might have with existing government departments and power structures, is still being debated.

(ii) Empowering stakeholder involvement: ICZM policy recommendations (defined in Ireland through the 1990s) should be implemented to establish sustainable and best-practice approaches to ICZM at local to regional levels, ensuring efficient and consistent responses to problems. In the area of administration, we should move from authoritarian top-down structures towards wider community-based participation (the principle of coastal users as stakeholders). In essence, the development of flexible and culturally appropriate bottom-up approaches to the solution of practical coastal-use problems and the generation of local–regional scale policy planning is ideal. From experience, this approach is not easy or cheap, either for the local communities involved or for the central authorities charged with overall responsibility and coordinating a coherent national approach to coastal resource management.

(iii) Data and research: Adequate resources, systems, and structures should be provided for the collection of high-quality information about the coastal zone and for its continued monitoring. The linking of these activities to the process of management would facilitate informed decision making and planning. In coastal research, problem-solving groups should be established.

(iv) Education and adaptability: Approaches should encourage people's awareness and knowledge about coastal issues—a sense of responsibility for use of coastal environments. Incentives and deterrents (*e.g.,* economic and stakeholder involvement) should be provided to encourage a more open and flexible response to coasts by coastal users. These activities are going to be necessary for Ireland. In the context of Ireland's emphasis upon tourism in its economy (north and south), greater attention should be paid to the economic contribution that might be drawn from this sector, and from coastal dwellers themselves, to the maintenance of the coastal zone. Such a policy of bias and user-paid "penalties" in economic approach is unpopular but worth examining (*e.g.,* BRADY SHIPMAN MARTIN, 1997; ENVIRONMENTAL SERVICE OF NORTHERN IRELAND, 1995; TITUS, 1991).

In essence, Ireland's coastal vulnerability lies more with the attitudes of the people towards ICZM than in any physical susceptibility of the coast for response to climate changes.

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