‘The Vulnerability and Adaptive Capacity of Coastal Settlements’

LIFE Environment Project 2003-2006 ‘RESPONSE’: LIFE 03 ENV/UK/000611

Contents

1. Scope of the report

This report forms part of RESPONSE Task 3: Coastal Study Area Investigations, which aims to "develop and test an effective, transferable methodology for coastal evolution studies and risk mapping that can be applied across the EU to allow local authorities and Regions to assess and prepare for the impacts of climate change along their coastline". The objective of this report is to gather data on the vulnerability and adaptive capacity of coastal settlements to climate change.

The Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) describes vulnerability as "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity." (IPCC, 2001).

Adaptive capacity is defined by the IPCC (2001) as, "The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences". In simple terms, adaptive capacity is the ability of a system to modify its characteristics so as to cope better with existing or anticipated external stresses.

2. Introduction

Human populations have always tended to favour settlement in the coastal zone. "In spite of coastal erosion problems and the increasing impacts of 'coastal squeeze' on the ability of the coast to sustain human use, development pressures on the coast have not abated" (EUROSION, 2004). The increasing value of the land and property in these areas has led to the consolidation and extension of the structures built to defend them. Structures such as sea walls and groyne fields have not only helped to sustain these lands from erosion and flooding, but also provided the impetus for more coastal land to be developed. This has in turn resulted in a sometimes-dramatic loss of habitats and with them a reduction in their natural dynamic characteristics. (EUROSION, 2004).

The EUROSION project was commissioned by the Directorate General Environment of the European Commission, which aimed to produce policy recommendations on how to manage coastal erosion in Europe in the most sustainable way. The project, which concluded in May 2004, found that the prospect of further sea level rise due to climate change and the heritage of mismanagement in the past imply that coastal erosion will be a growing concern in the future.

Coastal communities are more vulnerable to climate change than inland communities because, in addition to meteorological parameters, they are also affected by changes in oceanic parameters, especially increases in sea level and wave heights. Both direct effects (for example changes in coastal erosion, storm surges and water temperature) and indirect effects (like reductions in fish stocks) will have physical and socio-economic impacts on coastal communities (Tsimplis, 2004).

In many areas in Europe, population, economic activity, and arable land are concentrated in coastal zones, which has led to a decrease in their resilience and adaptability to variability and change. Some coastal areas-such as much of The Netherlands, the fens in eastern England, and the Po River plain (Italy)-already are beneath mean sea level; many more areas are vulnerable to flooding from storm surges. Fixed, rigid flood defences and sea-level rise already are causing "coastal squeeze" (i.e., a decline in intertidal coastal habitats) (IPCC Special Report on the Regional Impacts of Climate Change An Assessment of Vulnerability). EUROSION established that whilst coastal protection is possible, long-term trends and knock-on effects from the structures themselves can result in negative effects on the resilience of much larger coastal units. It is anticipated that this situation will be aggravated by rising sea levels and a more unpredictable and extreme storm climate associated with climate change. This will result in a long-term threat to the safety of people, the sustainability of many coastal activities, coastal biodiversity and the ability of the coast to provide a 'natural' coastal defence.

The impacts of a changing climate will differ significantly across geographical regions. Natural systems can be especially vulnerable to climate change because of limited adaptive capacity, and some of these systems may undergo significant and irreversible damage. The vulnerability of human systems in the coastal zone varies with geographical location, time and social, economic, and environmental conditions. (IPCC, 2001). Urban centres will be affected by changing patterns of customer demand and disruption to transport links, while sea level rise and changing conditions at the coast may transform coastal landscapes. Marginal habitats are particularly vulnerable and the changes could potentially be irreversible.

The IPCC Special Report on the Regional Impacts of Climate Change An Assessment of Vulnerability recognises the following potential impacts of climate change in the coastal zone:

- Sea-level rise will place additional stress on coastal zones already stressed by other factors (urbanization, coastal developments, pollution, etc.).
- The level of impact will depend on the adaptation capacity (e.g., the ability of systems to move inland) and policies of individual countries (e.g., trade-offs between lands that are not considered important and those that need to be protected).
- Sensitive zones include areas already close to or below mean sea level (such as the Dutch and German North Sea coastlines, the Po River delta, and the Ukrainian Black Sea coast), areas with low intertidal variation (such as the coastal zones of the Baltic Sea and the Mediterranean), and coastal wetlands.
- Changes in the nature and frequency of storm surges, particularly in the North Sea, are likely to be of considerable importance for low-lying coastal areas.

Climate change could affect the social, economic and environmental well being of communities. "Local authorities have a key role to play as community leaders to ensure that buildings and infrastructure are sustainable in a changing climate, that services can continue to be provided at reasonable costs and that communities are able to adapt to change" (UKCIP, 2003). The RESPONSE project aims to demonstrate a methodology of assessing and prioritising coastal risks, with the objective of minimising the vulnerability and increasing the adaptive capacity of coastal settlements to the impacts of climate change.

3. Adaptation and climate change opportunities in the coastal zone

Adaptation can be defined as “Action to minimise the adverse impacts of climate change and to take advantage of opportunities it might present” (UKCIP, 2003). Adaptation is essential if we want to minimise the impacts and take advantage of the opportunities that arise. So far, adaptation has not been sufficiently recognised within national and international policies. This is in stark contrast to mitigation, where international policies like the Kyoto Protocol have brought to attention the need to reduce greenhouse gases on a global scale (ESPACE, 2004).

Without adaptation, a rise in sea level would inundate and displace wetlands and lowlands, erode shorelines, exacerbate coastal storm flooding, increase the salinity of estuaries, threaten freshwater aquifers, and otherwise impact water quality. The impacts would vary from place to place and would depend on coastal type and relative topography. Areas most at risk would be tidal deltas, low-lying coastal plains, beaches, islands (including barrier islands), coastal wetlands, and estuaries. Tidal range also is a key factor: In general, the smaller the tidal range, the greater the response to a given rise in sea level. This pattern suggests that the Mediterranean and Baltic coasts, with their low tidal range, may be more vulnerable to sea-level rise than the open ocean coasts (IPCC Special Report on the Regional Impacts of Climate Change An Assessment of Vulnerability)..

Examples of susceptible coasts include the Rhone (in the Languedoc-Roussillon RESPONSE Coastal Study Area), Po (in the Italian RESPONSE coastal study area), and Ebro deltas. These areas already are subsiding because of natural and sometimes human factors, and they are sediment-starved as a result of changes in catchment management. Many of Europe's largest cities-such as London, Hamburg, St. Petersburg, Thessaloniki, and Venice-are built on estuaries and lagoons. Such locations are exposed to storm surges, and climatic change is an important factor to consider for long-term development. In Venice, a 30-cm rise in relative sea level this century has greatly exacerbated flooding and damage to this unique medieval city; permanent solutions to this problem are still being investigated. Beaches tend to erode given sea-level rise, which destroys a valuable resource and exposes human activities landward of the beach to increased wave and flood action. Intense recreational use of beaches in many coastal areas, particularly around the Mediterranean, makes this erosion a particular problem; some response to such changes often is essential (IPCC Special Report on the Regional Impacts of Climate Change An Assessment of Vulnerability).

Whilst it is important to recognise the vulnerability of coastal settlements to the impacts of climate change and to assess the adaptive capacity of these settlements, it should also be noted that a changing climate offers opportunities as well as risks. It is important that we respond now to realise the potential opportunities presented by a warmer climate. Local authorities need to integrate climate change into sustainable development, land use planning and reinforce positive initiatives to manage the natural environment (Yorkshire Futures, 2002). Some of the possible opportunities offered by a warmer climate include:

- Possible increase in tourism.

- Greater winter rainfall will recharge aquifers and benefit reservoirs (though greater winter rainfall would increase landslide risk).
- Species migration may lead to an increase in biodiversity in certain areas.

4. Vulnerability definitions

Vulnerability can be defined as the potential to suffer harm, loss or detriment from a human perspective. There is, however, a number of ways in which this simple concept has been adopted, depending on the context, including:

- Variation in level or chance of impact; the impact of an event (e.g. flood or landslide) on the exposed population or assets can vary between total loss (e.g. write-off of all properties or death) to partial loss, where only a proportion of the population or assets are killed or destroyed. This variation in impact is generally expressed in terms of the vulnerability of the assets, population or activity (e.g. Leone et al 1996). In many risk assessments, therefore, vulnerability is defined as the level of potential damage, or degree of loss, of a particular asset (expressed on a scale of 0 to 1) subjected to a hazard event of a given intensity (e.g. UNDRO 1982; Lee and Jones 2004). This can also be expressed as the chance (0 to 1) of a particular level of damage, given the hazard event (e.g. the chance of a seawall breaching given a 1 in 100 year storm or the chance of a pedestrian being killed by a vehicle travelling at 30mph).

- Sensitivity to impacts; the degree to which a system (e.g. coastal societies) is susceptible to, or unable to cope with particular events such as the adverse effects of climate change (IPCC 2001). Vulnerability is a function of the sensitivity of a system to changes (e.g. the degree to which a system will respond to a given change in climate, including beneficial and harmful effects), adaptive capacity (the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate), and the degree of exposure of the system to hazards. A highly vulnerable system is very sensitive to modest changes in climate or sea level.

  In this context vulnerability can be defined as "the degree of incapability to cope with the consequences of climate change and accelerated sea-level rise" (Bijlsma et al., 1996).

At a strategic level, knowledge of the sensitivity of a coastline to climate change enables decision-makers to anticipate impacts that could emerge over future decades and prioritise management efforts that need to be undertaken to minimise the risks or to mitigate possible consequences. To this end a number of methodologies have been developed and implemented in order to provide a consistent framework for identifying the types and magnitude of problems that different coastal areas may have to face, as well as identify possible solutions. These methods have been termed "vulnerability assessment" and are described in the following sections.

5. Vulnerability assessment

5.1 Introduction

Vulnerability assessment involves the analysis of the scope and severity of the potential biogeophysical effects of climate change and sea-level rise, including:

- Increasing probability of flood events of a particular magnitude;
- Erosion;
- Gradual inundation of low-lying areas and wetlands;
- Rising water tables;
- Saltwater intrusion;
- Biological effects.

The Common Methodology for Assessing the Vulnerability of Coastal Areas to Sea-Level Rise was proposed by the Coastal Zone Management Subgroup of the IPCC (IPCC CZMS 1992). The aim was to assist countries in making first-order assessments of potential coastal impacts of and adaptations to sea level rise. The method defines vulnerability as a nation's ability to cope with the consequences of accelerated sea-level rise and other coastal impacts of climate change.

The method comprises 7 analytical stages, from delineating case study areas and assessing the physical responses and vulnerability, to identification of needs and actions. The assessment considers the potential impact of global sea level rises of 0.3m and 1m by 2100 on population, economic, ecological and social assets and on agricultural production. It also considers national or local development by extrapolating 30 years from the present situation, along with a full range of adaptive responses, from total protection to retreat.

The IPCC have also developed Technical Guidelines for Assessing Climate Change Impacts and Adaptations to provide a framework for any natural or socio-economic system (Carter et al., 1994). The Technical Guidelines also comprise 7 analytical steps for vulnerability assessment; however, they are not identical to the stages in the Common Methodology (Figure 5.1; Klein and Nicholls 1999).

The United Nations Environment Programme elaborated the Technical Guidelines into a form appropriate for coastal regions (Feenstra et al 1998; Klein and Nicholls, 1998). This approach distinguishes between natural vulnerability (i.e. the coastal landforms, materials and processes) and socio-economic vulnerability; analysis of socio-economic vulnerability needs to be based on an understanding of natural vulnerability.

A coastal system's natural vulnerability is described in terms of a number of parameters (Klein and Nicholls 1998, 1999):

- Natural susceptibility; the coastal system's potential to be affected by sea-level rise, (e.g. the contrasting susceptibility between a subsiding delta, a soft cliff on a transgressive coast and an emerging fjord coast).
- Resilience; the speed with which a systems returns to its original state after disturbance (i.e. perturbation);
- Resistance; the ability of the system to avoid disturbance in the first place
- Autonomous adaptation; the coastal system's spontaneous adaptive response to sea level rise. The system's resilience and resistance determine this.

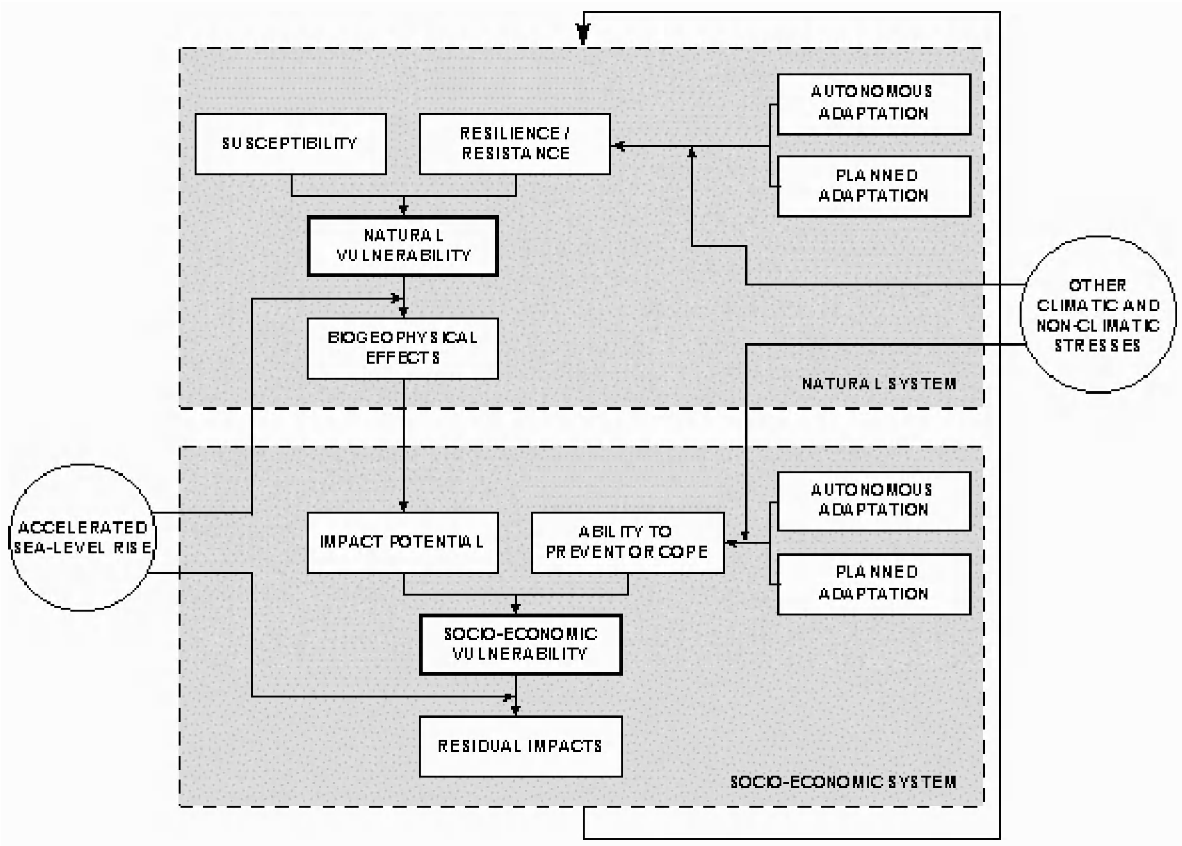

Figure 5.1 Framework for coastal vulnerability assessment (from Klein and Nicholls, 1998; 1999).

Resilience and resistance are often affected by human activities. The effect of human activity needs not only be negative: planned adaptation (e.g. establishing set back lines) can serve to reduce natural vulnerability by enhancing the system's resilience and resistance and thereby adding to the effectiveness of autonomous adaptation (Klein and Nicholls, 1999).

Socio-economic vulnerability is a function of:

- The impact potential; this is the socio-economic equivalent of the natural susceptibility, but is inevitably dependant on human influences
- The ability to cope; the equivalent of natural resilience and resistance, and is also largely influenced by both autonomous and planned adaptations.

Adaptation is recognized as a crucial response to climate change and sea-level rise. Studies that neglect adaptive potential are likely to overestimate the costs of climatic impacts (e.g., Reilly et al., 1996).

Vulnerability assessment can be an iterative process, involving at least 3 levels of increasingly complex assessment:

- Screening assessment (SA); this focuses on susceptibility. The results can be used to define the need for and scope of a vulnerability assessment;
- Vulnerability assessment (VA); including explicit assessment of biogeophysical effects, socio-economic impacts and adaptation.

- Planning assessment (PA); PA involves analysis at an integrated level suitable for detailed coastal planning and would take place in the wider context of coastal management.

5.2 Assessment of socio-economic impacts

The socio-economic implications of changing flood and erosion hazards can be evaluated in terms of 3 categories (Klein and Nicholls 1998, 1999):

- Human population; The population at risk is defined as the number of people experiencing flooding or threatened by erosion in a typical year (Hoozemans et al., 1993; Baarse, 1995). For flood hazards, this number is estimated by multiplying the total number of people living in an area potentially affected by flooding by the probability of flooding in any year, as determined for each risk zone. For example, if 3 million people were exposed to a flood-frequency probability of 1/10 years, the population at risk would be 300,000 people per year.
- Marketed goods and services; if the risk zone's contribution to a country's gross national product (GNP), is known, the GNP at risk from sea-level rise can be estimated. For example, Turner et al. (1995) assessed GNP at risk assuming an equal annual incremental rise in sea level between 1990 and 2050, of which impacts are a linear function. Since a time horizon of 60 years is used, 1/60th of the total capital value and activity would be at risk after one year, 2/60ths after two years, and so on.
- Estimates of potential losses in capital assets such as land, property and infrastructure can be based on the accelerated depreciation cost of the capital assets, and, particularly in the case of land, their opportunity costs. Once an inventory has been made of the capital value in the risk zone, a similar analysis can be conducted as for population at risk. Thus, capital value at increased risk over time can be assessed.
- Non-marketed goods and services; non-marketed goods and services include recreational values, cultural and subsistence values (e.g., community structures), and natural values (e.g., a wetland's capacity to buffer wave energy and assimilate waste). Methods available for the valuation of non-marketed coastal goods and services can be found in Turner and Adger (1996).

5.3 Outputs: vulnerability indicators and profiles

The Common Methodology and similar approaches have been applied in about 30 national assessments and one global assessment (Nicholls 1995; Bijlsma et al., 1996). Most studies focused on a single socio-economic scenario based on today's situation (i.e. the 1990s) and a 1-m rise in sea level on the present situation (IPCC CZMS, 1992; WCC'93, 1994; Nicholls, 1995; Bijlsma et al., 1996).

The results from the Common Methodology can be expressed in terms of a number of vulnerability indicators:

- People affected;
- People at risk;
- Capital value loss;
- Land area loss;
- Protection / adaptation costs;

- Wetland loss.

5.4 The SURVAS Project

The SURVAS (Synthesis and Upscaling of sea-level Rise Vulnerability Assessment Studies) Project has been launched by a global network of coastal researchers with the aim of developing regional and global perspectives on the impacts of sea-level rise. It is part of a mutually supportive process of bottom-up and top-down assessment processes that can inform a range of policy makers from national coastal management policy to the UNFCCC and global greenhouse gas emissions. It is based on Access and includes quantitative vulnerability indicators and supplemental information.

For more details see: www.survas.mdx.ac.uk

5.5 Discussion: vulnerability assessment, risk and the RESPONSE methodology

Despite the name, vulnerability assessment can be regarded as a form of risk assessment, in that it considers both the hazards (i.e. the biogeophysical effects of climate change) and adverse consequences (i.e. the vulnerability indicators). The approach does not generate an “expectation value” for the level of risk (i.e. the product of the probability of the hazard and consequences); rather it provides a semi-quantitative measure of the level of consequences associated with particular hazard scenarios (e.g. 1m sea-level rise by 2100). By normalising the indicator values – either as a proportion of the total population/ area, or the GNP – comparisons can be made between different countries or regions. System vulnerability is assumed to increase with vulnerability class (see Table 1) i.e. with increasing consequence. Used in this way, vulnerability assessment is essentially a relative risk assessment method.

The key elements of vulnerability assessment are:

- Development of climate change and sea-level rise scenarios;
- Modelling the coastal landform/system response to these scenarios;
- Estimating the outcomes generated by the landform/system responses i.e. the expected consequences.

The same elements are central to the RESPONSE approach. The concepts of susceptibility, resilience and resistance that are used to define natural vulnerability are measures of system response to changing environmental controls.

The RESPONSE methodology does not generate a measure of risk or vulnerability, rather an indication as to whether current risks can be expected to increase. However, consideration could be given to incorporating aspects of the vulnerability assessment approach e.g. the vulnerability classes and indicators.

6. Central-south coast of England, UK

The coastal study area of southern central England covers almost 400km of coastline, from Lyme Regis in Dorset in the west to Shoreham-by-Sea in East Sussex to the east and includes the Isle of Wight. The coastal region is highly valuable, in terms of both economic and natural coastal assets. The coastal zone is densely populated and includes the major coastal cities of Southampton, Portsmouth and Bournemouth. Environmentally, the area is highly protected by local, national and international designations.

The rapid growth of the coastal population in the region started in the mid nineteenth century with the development of resort towns, and has continued until the present day with the influx of migrants from many parts of the UK seeking retirement homes and (more recently) employment opportunities. Much of this development has been absorbed by the eastern part of the region. The West Sussex coast is almost continuously developed and forms part of what has been called the South Coast Conurbation. Growth, initially centred on the old-established cities of Southampton and Portsmouth, has converted the littoral zone of the northeast Solent into one of the most urbanised sections of the British coast. In other areas, urban growth has been more modest, with the cores of many medieval towns surviving such as Weymouth and Chichester. In the summer months the resident population almost doubles due to the influx of tourists to coastal areas. This considerable increase in the summer population puts more people at risk, thus increasing the scale of hazards and vulnerability.

Plate 6.1 Densely developed shoreline at Portsmouth, Hampshire.

Along the coastline of central southern England the variety of landforms and developments results in a wide variety of coastal risks. These risks are largely related to the probability of landsliding, erosion and flooding events affecting coastal assets. A large proportion of this length of coastline has the potential to experience significantly increasing risks under climate change as a result of either failure of defences or increased activity on the 'natural' coast.

More than 50% of the coastline of southern central England east of Poole Harbour has been at least partially stabilised by defence and protection structures. In some areas, the spatial pattern of hard defences is a legacy from late Victorian concepts of shoreline management. The western part of the region and the Isle of Wight have a much lower proportion of defended and protected coastal frontage. This is due to the geological and geomorphological character of the coast and the relatively low population density in some parts of the coastal zone.

Coastal defence measures may reduce hazards dramatically in the short term only for them to increase in the longer term due to their potential adverse or unsustainable effects upon processes and natural landform elements acting in combination with the progressive impacts of climate change. Where hard structural engineering solutions are implemented or a dynamic shoreline is held in a fixed position the integrity of naturally sustaining processes and landforms is likely to reduce over time so that an increasingly heavy dependence will develop on the management solution. In view of the anticipated impacts of climate change, including rising sea levels and an increased frequency of storm events, it will become more difficult and less economically viable to maintain current levels of protection afforded by coastal defence structures. If defence structures are not maintained adequately or improved according to the implications of climate change, it is likely that coastal hazards will increase and larger populations will become vulnerable to coastal risks.

Plate 6.2 Coastal defences, Worthing, West Sussex.

Dramatic increases in hazards and the exposure of vulnerable coastal communities are likely to result from reactivation of presently relic cliffs and resumption of recession wherever defences are abandoned. These situations are likely to involve initial periods of foreshore decline and toe erosion before relic landslides are reactivated. This is potentially a major risk where relic landslides have been developed, e.g. around Lyme Regis, Dorset, and within the Undercliff and on the north coast of the Isle of Wight.

Evidence of landslide reactivation was observed in the exceptionally wet winter of 2000/01, which resulted in intensification of reactivations at some locations and is an indication of the conditions that might be expected to occur more frequently in the future. The A3055 was completely severed over a 100m section by a major landslide within the Isle of Wight Undercliff during the Spring 2001. The landslide appears to have occurred due to prolonged high groundwater levels following heavy rainfall in autumn 2000. The slope would have been "prepared" or reduced in stability by persistent marine erosion at the toe in Binnel Bay and Puckaster Cove, but was triggered by rising groundwater levels. The landslide represents a reactivation and major seaward and downward movement of an ancient landslide that already existed within the Undercliff. It produced a new scarp some 10m to 20m in height that severed this important coastal route.

Plate 6.3 Undercliff Drive, Isle of Wight 2001.

Marine erosion of the Liassic Clay and limestone sea-cliffs at Lyme Regis is reactivating a series of ancient mudslides and translational slides, creating a scarp and bench topography that is retrogressing inland. Reactivation has accelerated in recent decades such that fresh landslides are beginning to be triggered within the Upper Greensand strata of Timber Hill (the wooded scarp leading up to the hill crest). Westward extension of these reactivations could in future threaten the A 3052 road leading into Lyme Regis from the East.

Plate 6.4 Lyme Regis, Dorset: The Spittles and Timber Hill, 2001.

7. North-east coast of England (North Yorkshire), UK

The study area covers 91km of coastline, of which approximately 15km are currently protected, 32km lies within the North Yorkshire Moors National Park and 41 km is designated Heritage Coast. There are also several Sites of Special Scientific Interest (SSSIs) extending 34km along the coast together with 15km of Sensitive Marine Areas.

The coastline is generally unspoilt with major population centres at Whitby, Scarborough and Filey. 75% of the 108,000 residents live within the coastal settlements of Staithes, Runswick Bay, Sandsend, Whitby, Robin Hoods Bay, Scarborough and Filey. The towns are protected from the North Sea by a variety of coastal defence structures. The estimated value of these structures is believed to exceed £150,000,000 and the value of the assets they protect much greater.

The coastline has generally not been subject to excessive hard engineering. Most of the coastal towns and villages are defended, some with locally extensive seawalls and slope stability works. The majority of the coast is, however, undefended with the rate of erosion generally determined by geology, aspect and the presence or absence of protective rock platforms. Consequently a key feature of the sustainable management of the coast is an appreciation of the complex problems associated with marine erosion and landslip activity at particularly vulnerable localities in the study area.

High cliffs front much of the coastline with relatively few areas subject to localised flooding. Cliff recession and coastal landsliding have historically been a problem along the coast, particularly where Quaternary "soft" Boulder Clay deposits dominate the geology.

The type and extent of the solid and superficial geological formations and their structural relationship are the major controls on the magnitude and rate of cliff erosion. Glacial till forms the main superficial formation and is invariably a stiff fissured clay forming unstable cliff slopes. In addition the predominant slope aspect and exposure to weathering, and the prevailing wave and tidal regime all impact on the foreshore instability on the North Yorkshire Coast.

Major landslide events are a feature of the till cliffs. In 1682, the village of Runswick Bay, North Yorkshire was destroyed by a sudden cliff failure (Lee and Jones 1994). The most recent example occurred in Scarborough during 1993, when guests at the Holbeck Hall Hotel awoke to discover that a major landslide had occurred on the 70m high coastal cliffs in front of the hotel. Over 60m of cliff frontage was lost overnight.

The hamlet of Flatcliffs is built upon a series of low till cliffs and landslides. These are predominantly locally active, with erosion of sea cliffs and small mudslides. The community is at risk from potential instability caused by erosion of the sea cliffs and high groundwater levels. There are 36 properties and 1900 caravans potentially at risk in the area.

Plate 7.1 Hamlet of Flatcliffs, North Yorkshire, developed on a relic landslide with only one access road backed by an extensive holiday caravan site.

The public highway between Whitby and Sandsend is cantilevered over the seawall along the Sandsend frontage. Any erosion at this location could result in the loss of the road. Overtopping of the seawall also occurs occasionally. The road is the major transport link between Sandsend and Whitby.

Plate 7.2 Sandsend to Whitby, North Yorkshire, showing recent regrading works following the landslide.

Filey, the southerly terminus of the nationally important Cleveland Way long distance coastal path, which runs along the entire length of the study area and is used by an estimated 300,000 visitors per year adds £1 million to the local economy. The coastal path is under constant threat from erosion and landslides. A major instability study is pending for Filey, to investigate instability issues along the town's coastal frontage.

Plate 7.3 Filey, North Yorkshire.

8. Central-east coast of Italy (Regione Marche)

The coastal zone of the Marche Region is highly valuable, both economically and environmentally. During the last century the area was intensely developed to support residential expansion, tourism pressures, industrial and commercial growth and new infrastructure. This rapid development in the coastal zone was insensitive to the natural environment and took no account of coastal hazards such as coastal erosion, fluvial flooding, landslides and seismicity.

Plate 8.1 Pesaro Beach before and after the violent sea-storm of the end of December 1978 (by Franco Marabini).

Coastal erosion from storm waves presents a significant issue, in terms of economic stability, tourism and major infrastructure.

In the past, sediment supply to beaches have come from fluvial yield and material derived from coastal landslides. The sediment is transported by longshore drift from the south to the north. In the XIX century the coastline was advancing due to the southerly longshore drift, rich in sediment yield. However, since the beginning of the XX century widespread regression began to dominate, reaching a critical stage after the Second World War, sometimes with irreversible effects. This reversal, to a regressive trend was caused by several factors:

- The urbanisation of extensive parts of the coastal zone, for tourism without regard for the natural environment;
- The decrease in material from the cliffs, caused by the construction of seawalls to protect the railway from storm waves;
- The continued excavation of sand and gravel along the eastward flowing rivers beds, which contribute to the sediment budget. This has drastically lowered the supply of sediments to the shore;
- The longshore currents deprivation of sandy materials, and the consequent decrease of their input to the coastal regime; meanwhile the onshore – offshore transport mechanisms carry beach sands toward the open sea;
- The seabed profile is increasing near the shoreline and, consequently, storm waves are much more effective and destructive in spite of defence works;

Approximately 100km (58%) of the coastline is protected by defence structures, constructed to minimise the effect of erosion. This figure represents almost 70% (90 km) of the beach type coastline. However, coastal defence structures do not permanently protect all coastal settlements along this stretch of coast.

The coastal cliffs, comprising the Gabicce - Pesaro and Mt. Conero promontories, are characterised by periodic landslides (rock-falls) with cliff regression. Landslide material is then transported by longshore drift along the narrow backshore at the foot of the cliffs. Locally, large complex landslides are present in Ancona (reactivated in 1982) and Sirolo, where a slow seaward movement affects the village. Landslides occurring in the Ancona area could seriously damage coastal assets as well as major national infrastructure (the main east coast railway line and motorways connecting northern and southern Italy along the Adriatic coast).

Plate 8.2 Rebuilding of the coastal road in Pesaro after sea-storm of the end of December 1978 (by Franco Marabini)

In the south, the coastal slope is 100-120 metres high and formed by Plio-Pleistocene sandy conglomerate deposits superimposed on the clayey bedrock. It is affected by several roto-translational dormant slides with many landslide terraces sloping towards the sea. This zone is densely populated and crossed by important communication routes. The reactivation of deep-seated movements, with regression of the landslide crown, are historically documented along the coastline north of Grottammare (1843, 1928). In the Colle delle Quaglie landslide (9th May 1928) the landslide material hit a passenger train and caused many casualties.

Plate 8.3 The Grottammare coastal zone affected by several dormant landslides (by Maceo-Giovanni Angeli & Fabrizio Pontoni).

Coastal protection measures do not preclude the reactivation of the slope movements. These may occur as a consequence of changes of hydraulic conditions within the landslides bodies. In this context the role of climate change can be considered critical for the landslide's reactivation.

Along the coast of Marche Region a number of the rivers flowing into the Adriatic Sea have flat, highly urbanised alluvial plains; these rivers are typically gravel-bed streams draining the eastern margin of the Appennine Mountains. Fluvial flooding occurs frequently and is accentuated by river channel engineering works.

Typical examples are the recurrent floods of the Tronto River in the south of the study area (San Benedetto del Tronto). In 1992 an urban and industrial area of approximately 19 km^2 was inundated, causing significant damage. The buildings hindered the flow of water and the flood took four days to recede through new temporary outlets, which formed north of the natural mouth in the town of Porto d'Ascoli.

The whole coastal zone of the Marche Region is exposed to seismicity, of a medium strength in the North as far as to Conero promontory, and lower in the Southern zone. The most recent large earthquakes along the coastal zone occurred in Senigallia (1930) and in Ancona (1972). In the Senigallia earthquake severe damage to the buildings and infrastructure was caused by liquefaction of the sands.

In addition to damages to human assets, the effects of seismic events could be significant to landslides' bodies, as quakes could alter both their inner physical structure and hydrogeological balances, triggering new movements, which may occur weeks or months later.

9. French coastal study areas

9.1 Languedoc-Roussillon Coast

During the past decade, the Languedoc-Roussillon coastal zone has experienced the greatest level of development in France, with the exception of Marseille to Menton. The coastal zone of Languedoc-Roussillon has been greatly modified by human intervention. The Rhone River has been engineered and as a result there has been a 90% reduction in the amount of sediment reaching the coast (Regional Environmental Management, 2000). Groynes, which were constructed to maintain beach levels, have reduced sediment input to beaches downstream. This in turn has led to a destabilisation of the dune system behind the depleted beaches. Erosion of the dune systems and the landward migration of lagoon barriers are likely to become more rapid in the future with the predicted impacts of climate change. In the short-term at least, artificial beach nourishment appears to be the most appropriate solution to mitigate these impacts of climate change, which is threatening tourism in the area.

The Languedoc Coastline can be divided into two major sections of coast:

1. The Northern part: the sandy coast between the Rhône delta and Colioure
The sandy coast is very flat and characterised by the Lido configuration, with often-narrow beaches, low levels dunes (up to a few metres in height) that are protecting low-lying land where large pounds of brackish water often collect. The 5 m elevation line is usually found quite a distance inland (an average distance of 5 kilometres and up to almost 10 kilometre in the vicinity of Leucate and Port Barcares).

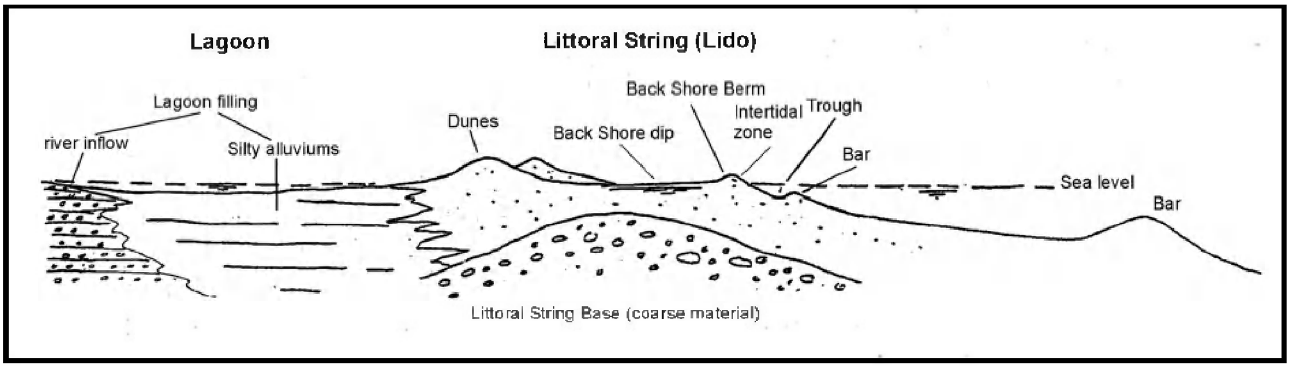

Figure 9.1 Typical profile of the Languedoc-Roussillon coastline.

The principal human assets are located almost continuously along the coast and around the brackish water pound (oysters and mussels culture) and was developed during the second half of the last century. Urban areas, including settlements and major transport links, have been constructed within the coastal dune system.

Along most of this section of coastline the beaches are retreating slowly and are protected by intense coastal defence structures (groynes, brakewaters) or artificial beach nourishment.

The vulnerability of the Languedoc Coastline to climate change is related to the potential evolution of the dune systems (increasing marine erosion), which protects the brackish water pound from massive marine intrusion and the flood hazard due to the potential sea level rise and rainfall increase, which threatens human assets.

2. The Southern part: the Rocky Coast between Colioure and the Spanish border
The few kilometres of the rocky coast between Colioure and the Spanish border is characterised by fractured hard rock cliffs. This area is relatively stable under current climatic conditions, but problems of instability could increase due to the impacts of climate change such as increased winter rainfall.

9.2 Aquitaine Coast

The Aquitaine Coastline can be divided into three major sections of coast:

1. The sandy coast between the Gironde estuary and the city of Bayonne

The sandy coast (also called the Landes Coastline) is characterised by long beaches, high dunes (generally between 15 to 30 metres but up to a hundred metres in height) and pines forests at the inland dune toes. The principal human assets are seaside resorts, which developed along the coast during the second half of the last century. In some locations, urban settlements have reached the top of the dune systems.

The vulnerability to anticipated climate change is related to the potential evolution of the dune systems. Under the combined effect of increasing water levels, the potential increase of wave and current energy and the eroding effect of storms, erosion of the dunes is likely to increase.

2. The Arcachon Bassin

The Arcachon basin area is less intensely developed. However, current sediment transport trends suggest that there is a high probability that the channel may become closed to the sea. This result of this possible situation would be an increased risk of flooding along the shore of the intensely developed basin. On top of the increased flooding hazard, the impact on the local ecosystem due to the channel closure may endanger oyster production, which provides a major source if income of the area.

3. The Basque Coast from Biarritz to St-Jean-de-Luz

The Basque Coastline is characterised by a succession of cliffs and bays. Sandy beaches are present at the toe of the cliffs and within the bays. In the central part of this coastal strip (Biarritz to Guethary) high value urban development is located close to the cliff edge where there exists a risk of landslide events. Where buildings have been constructed adjacent to eroding areas of sand dune, coastal defence structures have been constructed. The Aquitaine coastline is heavily protected by hard engineering structures in order to stabilise the cliffs and coastal slopes.

The vulnerability of the Aquitaine coast to climate change relates to the potential rise in sea levels (which may increase the toe erosion of the cliffs), and the potential increased in precipitation (which through the rise of the water table may increase the frequency of landslides).

10. Conclusions

The potential impacts of climate change and sea level rise present a significant challenge to future coastal management. It is anticipated that there will be increasing levels of risk to many coastal communities and assets. It is possible that attitudes towards acceptable risks and suitable standards of protection will change. It follows that there may be a need to improve the standards of protection in high-risk urban areas to reflect these trends. This would lead to the increased polarisation of risk exposure to individuals in built up and rural areas. However, the disadvantages of building hard, inflexible protection structures have been demonstrated many times. One way of avoiding problems caused by hard engineering defences is to adopt more flexible; 'soft' approaches to coastal engineering. They basically simulate or manipulate natural processes by adjusting their forms to natural processes, whilst still providing a level of protection.

Population settlements in coastal areas have risen dramatically in recent decades and are likely to continue to expand for the foreseeable future. The size of vulnerable communities at the coast will, therefore, continue to increase and the hazards being faced by these communities are expected to escalate with the predicted impacts of climate change. In addition to local populations, all of the RESPONSE coastal study areas are popular tourist destinations so tend to experience massively increasing populations in the summer months. This puts added pressure on the coast thus increasing risk exposure and vulnerability.

The RESPONSE coastal study areas are particularly vulnerable to hazards such as landslides, erosion and flooding. Examples of these types of events have been described in the report and it is likely that the frequency and intensity of extreme events of this kind are likely to increase with climate change. In order to minimise the vulnerability and increase the adaptive capacity of coastal settlements, and to optimise the opportunities presented by climate change, it is essential that we respond now to the likely impacts of a changing climate.

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