11. Climate change and coastal management on Europe's coast

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Abstract

Climate change and sea-level rise due to human emissions of greenhouse gases is expected to accelerate through the 21st Century. Even given substantial reductions in these emissions, sea-level rise will probably be significant through the 21st Century and beyond. This poses a major challenge to long-term coastal management. While Europe has a high adaptive capacity, climate change will produce problems that have not been faced previously, and solutions need to be reconciled with the wider goals of coastal management. A recent European survey of the current response to sea-level rise and climate change shows a few countries engaged in proactive planning, while most are ignoring the issue, or only beginning to recognise its significance. While a proactive response should minimise the actual impacts and need for reactive responses, ignoring sea-level rise and climate change will almost certainly increase vulnerability.

A common theme that emerges is the need for more impact and vulnerability assessment that is relevant to coastal management needs. This should include the consequences of sea-level rise and climate change on coastal areas from the local to the European scale. This will require continued development of broad-scale assessment methods for coastal management. It is also important to assess coastal adaptation and management as a process rather than just focus on the implementation of technical measures. Lastly, the uncertainties of climate change suggest that management should have explicit goals, so that the success or failure of their achievement should be regularly monitored and the management approach adjusted as appropriate.

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Introduction

Climate change is one of the main challenges for environmental management through the 21st Century. Even in areas such as Europe, which has a high adaptive capacity due to relative wealth, access to a strong science base and well-developed management institutions, climate change may produce conditions not previously experienced, and management will need to evolve to cope with this in a variety of ways.

This chapter explores the implications of climate change for coastal management around Europe through the 21st Century and beyond. It builds on a number of earlier reviews and assessments of climate change and Europe's coasts such as Tooley and Jelgersma (1992), Jeftić et al. (1992, 1996), Nicholls and Hoozemans (1996), Nicholls (2000), de la Vega-Leinert et al. (2000), de Groot and Orford (2000), Kundzewicz et al. (2001), Brochier and Ramieri (2001) and Nicholls and de la Vega-Leinert (2004). When assessing long-term coastal management needs, it is fundamental to consider the changing balance of pressures at the coast (e.g. Turner et al. 1998a, 1998b; Turner, this volume). Here the emphasis is on pressures due to climate change and sea-level rise, but this is placed in the broader context of the changing European coast.

The chapter is structured as follows. First, it reviews the uses and trends within the coastal zone of Europe. Then it considers climate change and sea-level rise scenarios for the 21st Century. The potential impacts of these changes in Europe are considered, including both the natural system and socio-economic system changes. Possible responses to these impacts are then considered and placed into the broader context of coastal management. Lastly, some key issues for further investigation are identified and linked to the opportunities and threats for coastal management in Europe. Rochelle-Newall et al. (this volume) explores these key issues in more detail.

The coastal zone in Europe

The coastal zone in Europe is varied with a range of distinct environments in terms of geomorphology and wave/tidal conditions. Five distinct areas are recognised: the Black Sea, the Mediterranean, the Baltic, the North Sea and the Atlantic seaboard (Figure 1). These areas can be subdivided based on natural characteristics into the physical units that will respond to climate change and sea-level rise: coastal cells and sub-cells, estuaries, deltas, etc. These 'natural' divisions are further fragmented by intensive and varying human use, as the coastal zone is a focus for important population and economic centres. Human activities within the coastal zone include industry, urban and residential, tourism and recreation, transport, fisheries/aquaculture and agriculture (Rigg et al. 1997). One third of the European Union (EU) population is estimated to live within 50 km of the coast, with the proportion being 100% in Denmark and 75% in the United Kingdom and the Netherlands. Coastal urban agglomerations are important with a collective population of 120 million people in the EU alone (Papathanassiou et al. 1998).

Even though Europe is already highly urbanised, coastal urbanisation continues due to coastward migration and tourism development, particularly around the Mediterranean. In addition to direct human uses, the coast is an important habitat of international significance with freshwater, brackish and saline marshes and intertidal and shallow subtidal habitats and it supports important fishery resources. Lastly, Europe’s coast is culturally and archaeologically significant as exemplified by Istanbul, Athens, Venice, London, Amsterdam and St. Petersburg, to name a few historic coastal cities.

As populations have grown and economic activity has intensified so a range of pressures have emerged in the coastal zone, including a legacy of significant land claims around estuaries and lagoons (e.g. French 1997, 2001, Papathanassiou et al. 1998). Significant assets and populations are located in floodprone coastal plains subject to erosion, and large lengths of coast are defended (Quelennec et al. 1998). Hard defences generally reduce sediment availability to the coastal system, intensifying erosional pressures and hence increase defence needs. Hard defences also lock the coastal position and hence contribute to a coastal squeeze of intertidal habitats on retreating shorelines (French 1997, Nicholls 2000). Human changes outside the immediate coast have also had adverse consequences on coastal areas, such as deltaic areas that have become threatened because they have been sediment-starved due to changing catchment management, particularly dam construction (e.g. Sanchez-Arcilla et al. 1998).

Given that Europe has a reasonably stable and ageing population, it might be thought that future problems will be minimised. However, present trends suggest coastal pressures will continue and intensify. The different possible pathways of development within Europe will lead to different sets of coastal problems and hence management needs. Turner (this volume) and the group report of Theme 5 (Nunneri et al. this volume) discuss three possible scenarios for Europe’s coasts.

The widespread coastal impacts of human interventions were not foreseen, and only now are their full implications being appreciated. This is driving important changes to more flexible and strategic approaches to coastal management, including more soft engineering, sediment recycling and managed realignment (e.g. Hamm and Stive 2002, Rupp and Nicholls 2003) and long-term analysis of future changes (e.g. DEFRA 2001; the Eurosion Project, http://www.eurosion.org). Environmental designations also protect many coastal areas, and compensation for habitat destruction is now often required, although the long-term success of these policies remains to be assessed.

Climate change and the European coast

Climate change is already a pressure with rising sea levels evident around most of Europe’s coasts, excluding parts of Scandinavia (Figure 2). In the 21st Century this rise is expected to continue and accelerate due to global warming. There are also observed inter-annual and inter-decadal fluctuations in the characteristics of storms during the 20th Century, but with no evidence of long-term trends (e.g. WASA Group 1998). This means that long-term climatic observations are re-

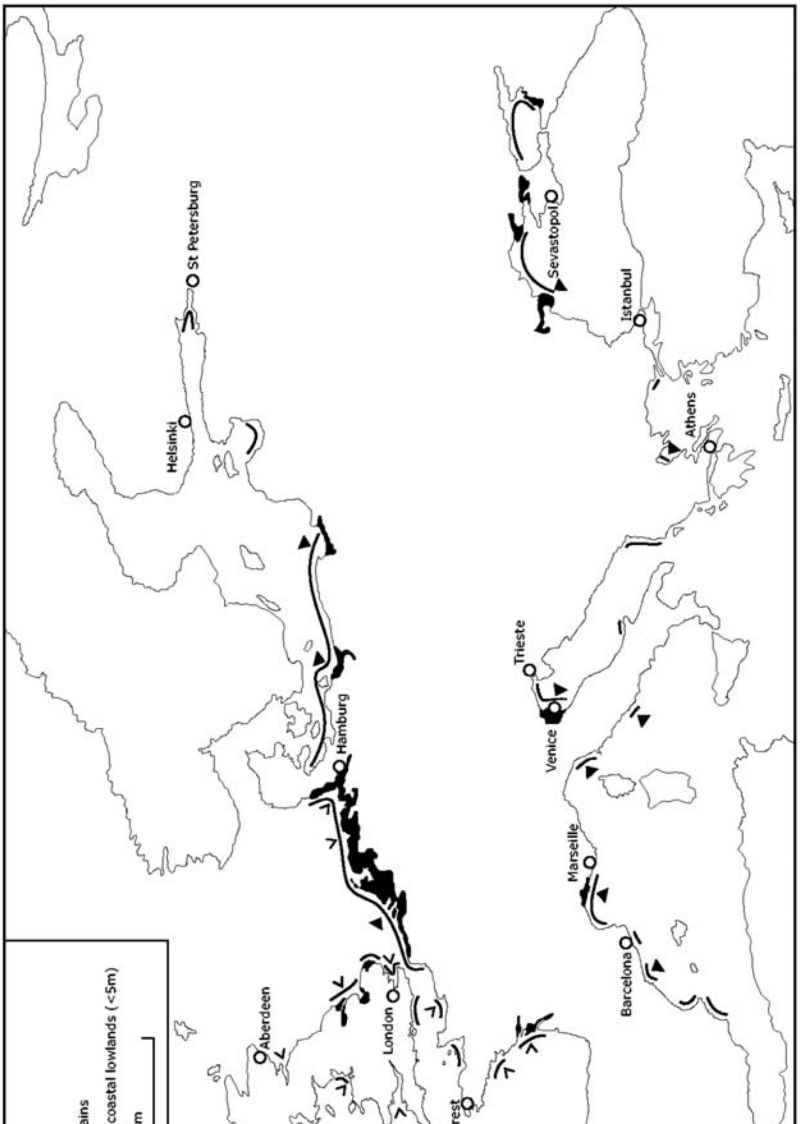

Fig. 1. Major estuaries and deltas, coastal plains and extensive coastal lowlands (<5-m elevation) in Europe, as well as the stations in Figure 2 and selected locations threatened by sea-level rise

quired to accurately estimate storm statistics. A decline in the formation of seasonal sea ice in parts of the Baltic due to rising sea temperatures has been observed, which is now allowing winter storms to cause significant erosion when before the coast was frozen and protected (e.g. Kont et al. 2004). Note that the Caspian Sea has also been impacted by significant sea-level rise (ca 1 m) over the late 20th Century. However, as this is an enclosed sea not linked to the global ocean, these changes are not considered further.

Human-induced climate change is caused by the emission of so-called "greenhouse" gases, which trap long-wave radiation in the upper atmosphere and thus raise atmospheric temperatures. Carbon dioxide is the most important of these gases and its atmospheric concentration has exponentially increased since the beginning of the industrial revolution due to fossil fuel combustion and land-use change. In 1800, the atmospheric concentration of carbon dioxide was about 280 parts per million (ppm); today it is about 350 ppm and rising. Similar increases have been observed for other greenhouse gases such as methane and nitrous oxide (Houghton et al. 2001).

By 2100, carbon cycle models project atmospheric carbon dioxide concentrations of 540 to 970 ppm, with a range of uncertainty of 490 to 1260 ppm (Houghton et al. 2001). Based on these projections and those of other greenhouse gases, the Intergovernmental Panel on Climate Change Third Assessment Report projects an increase in globally averaged surface temperature by 1.4 to 5.8°C over the period 1990 to 2100. It is very likely that nearly all land areas will warm more rapidly than the global average, particularly those at high latitudes in the cold season, including much of Europe (Houghton et al. 2001).

These simulations of global warming have led to a predicted global-mean sea level rise of 9 to 88 cm between 1990 and 2100, due largely to thermal expansion and melting of land-based ice, especially small glaciers. The central estimate of a 48-cm rise represents an average rate of global-mean sea-level rise of 2.2 to 4.4 times the estimated rate of rise over the 20th century. Importantly, even with drastic reductions in greenhouse gas emissions, sea level will continue to rise for centuries beyond 2100 because of the long response time of the deep ocean to reach equilibrium to a surface warming (Wigley and Raper 1993, Church et al. 2001). Thus an ultimate sea-level rise of 2 to 4 metres is possible for atmospheric carbon dioxide concentrations that are twice and four times pre-industrial levels, respectively (Church et al. 2001). Melting of the Greenland ice sheet and instability to the West Antarctic Ice Sheet could contribute significant additional sea-level rise over the coming centuries (Vaughan and Spouge 2002, Woodworth et al. 2004).

For coastal areas, it is not the global-mean sea level that matters but the locally observed, relative sea level, which takes into account regional sea-level variations and vertical movements of the land (Figure 2). A major uncertainty is how sea-level rise will manifest itself at regional scales, such as in the North Atlantic. All the models analysed by Church et al. (2001) and Gregory et al. (2001) show a strongly non-uniform spatial distribution of sea-level rise across the globe. However, the patterns produced by the different models are not similar in detail. This lack of similarity means that confidence in projections of regional sea-level changes is low, and it is possible that sea-level rise on Europe's coast could be ±50% of the global-mean changes already described (Hulme et al. 2002). This uncertainty needs to be taken into account in impact analysis.

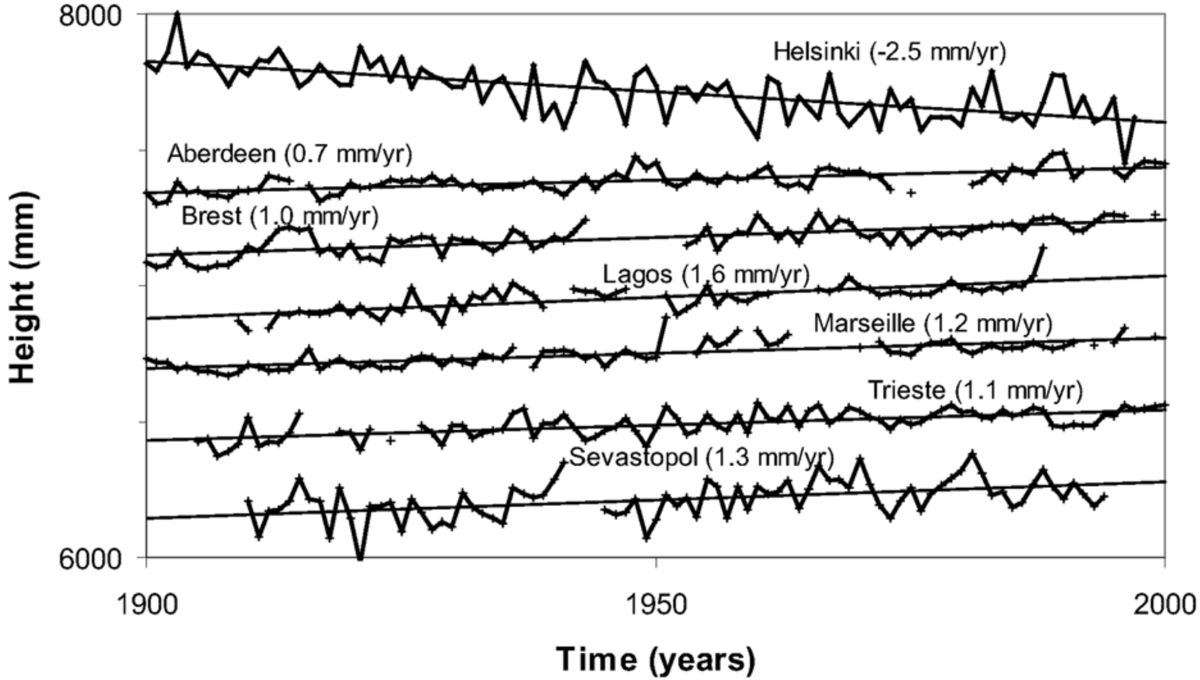

Fig. 2. Sample long-term relative mean sea-level curves from around Europe through the 20th Century, including the linear trend. While sea levels are falling at Helsinki (and some other Scandinavian stations), elsewhere there is a rising trend. Height is arbitrary to allow each record to be seen. Location of stations is shown in Figure 1 (data from the Permanent Service for Sea Level: http://www.pol.ac.uk/psmsl/)

Land uplift and subsidence can also be significant. Parts of Scandinavia experience land uplift due to global-isostatic adjustment at a sufficient rate that projected global-mean sea-level rise may be completely offset and relative sea level may continue to fall, albeit at a lower rate (Johansson et al. 2004). Other areas, such as deltas and coastal lowlands, are characterised by a strong downward movement of the land, which will add to global-mean sea-level rise (Emery and Aubrey 1991, Bird 1993, Suanez and Provansel 1996). This subsidence is often greatly enhanced by land claim and/or sub-surface fluid withdrawals as happened widely in Europe's coastal lowlands, such as around the North Sea. As another example, widespread 20th Century human-induced subsidence in the North Italian coastal plain produced over 2,300 km^2 of land below sea level, which is now protected from inundation by dikes (Bondesan et al. 1995). Thus, many of the areas threatened by sea-level rise are also prone to human-induced subsidence: coastal management needs to recognise this link to avoid this problem being exacerbated during the 21st Century.

Table 1. Possible implications of climate change on coastal zones in Europe, excluding sea-level rise (see Table 2)

Climate factor	Direction of change	Biogeophysical effects	Socio-economic impacts
Air and sea temperature	Increasing	Northerly migration of coastal species	Changes to fisheries, nature conservation implications
		Decreased incidence of sea ice at higher latitudes	Improved navigation, but increased coastal erosion during winter months
			Increased coastal tourism (Mediterranean, Southern North Sea and Baltic)
Water Resources/ Run-off	Drying in south, wetter further north	Changed fluvial sediment supply	Increased erosion (or accretion)
		Changed peak flows	Changed flood risk in coastal lowlands
Coastal storms	Increase in westerlies in northwest Europe (?)	Changed occurrence of storm damage and flooding	Increased risk of flood and storm damage
Atmospheric CO_2	Increasing	Increased productivity in coastal ecosystems	Uncertain

As already noted, sea-level rise is not the only climate-related effect relevant to coastal zones (Table 1). However, confidence in model projections of other manifestations of climate change is generally still low. The North Atlantic Oscillation

(NAO) Index[2] is expected to increase under global warming leading to warmer, wetter and windier winters in northwest Europe (Hulme et al. 2002). This in turn will change the frequency, intensity and spatial patterns of coastal storms, but it is hard to quantify the significance of these changes. A rise in mean sea level will lead to a decrease in the return period of storm surges without any other change, but it remains unclear if changing storms will additionally change the variability of storm surges themselves (e.g. Flather and Williams 2000, Lowe et al. 2001).

Moreover, there could be a weakening of the Gulf Stream due to global warming (Hulme et al. 2002). This would lead to significant cooling of the Northern European landmass. However, given that global warming is also occurring, the net effect is less certain. A cooling event would have such widespread impacts across northern and western Europe, so it is not meaningful to focus on the coast alone for this issue, and it is not shown in Table 1.

Climate change impacts around Europe's coasts

Framework for analysis

Following the uncertainties about other climate change factors, the main focus of most assessments has been the impacts and responses to sea-level rise. A common framework as illustrated in Figure 3 provides a useful basis for interpretation and comparison between studies. In particular, it highlights the varying assumptions and simplifications that are made within all the available studies and hence helps to establish common issues and make limitations more explicit.

Relative sea-level rise, due to whatever cause, has a number of biogeophysical impacts such as erosion and increased flood potential. In turn, these can have direct and indirect socio-economic impacts depending on the human exposure to these changes. There are also important feedbacks as the impacted systems adapt to these changes, including the human exploitation of beneficial changes and adaptation to adverse changes. Hence, the coastal system is best defined in terms of interacting natural and socio-economic systems. Figure 3 has been modified from the original in Klein and Nicholls (1999) to reflect the terms used by Smit et al. (2001), but the basic meanings remain the same. Both systems may be characterised by their *exposure, sensitivity* and *adaptive capacity* to change, both from sea-level rise and related climate change, and these factors may all be modified by other *non-climate stresses*. Sensitivity simply reflects each system's potential to be affected by changes such as sea-level rise, exposure defines the nature and amount to which a system is exposed to climate change, while adaptive capacity describes each system's stability in the face of change. Collectively, sensitivity, exposure and adaptive capacity determine each system's *vulnerability* to sea-level rise and other drivers of change.

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[2] The NAO Index measures the difference in barometric pressure between the Azores and Iceland. It indicates the direction and strength of atmospheric flow across northwest Europe, especially in winter.

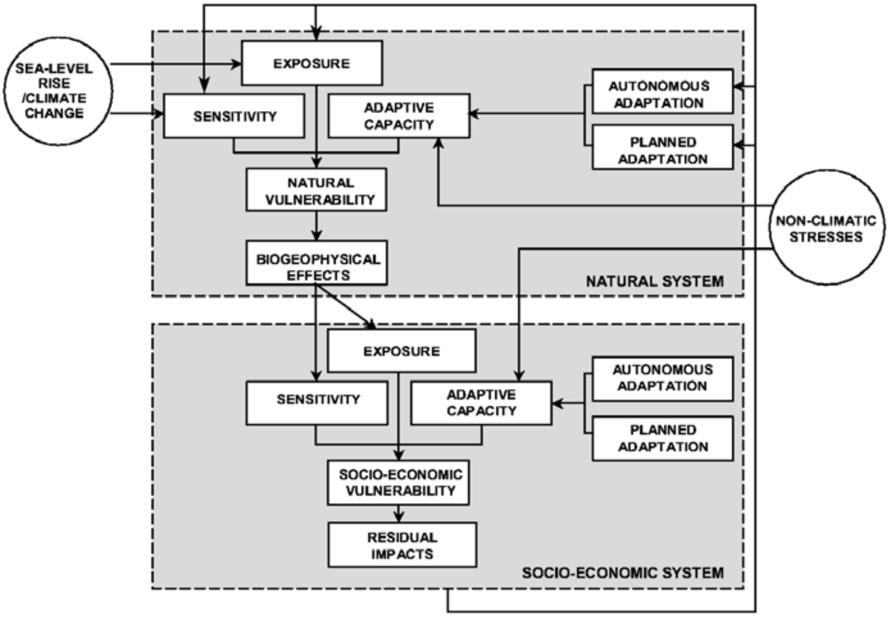

Fig. 3. A conceptual framework for coastal impact and vulnerability assessment of sea-level rise (adapted from Klein and Nicholls 1999)

Both systems are dynamic and adapt to change (e.g. Smit et al. 2001). *Autonomous adaptation* represents the spontaneous adaptive response to sea-level rise (e.g. increased vertical accretion of coastal wetlands within the natural system, or market price adjustments within the socio-economic system). Autonomous processes are often ignored by coastal management, and yet have a significant influence on the magnitude of many impacts. Further, natural autonomous processes may be reduced by human-induced, non-climatic stresses (Bijlsma et al. 1996). *Planned adaptation*, which must emerge from the socio-economic system, can serve to reduce vulnerability by a range of measures, which are discussed in more detail later in this chapter.

Dynamic interaction occurs between the natural and socio-economic systems in the coastal zone, including the natural system impacts on the socio-economic system and planned adaptation by the socio-economic system influencing the natural system. This results in the natural and socio-economic systems interacting in a complex and poorly understood manner, which can only be fully understood via integrated assessment. Importantly, adaptation normally acts to reduce the magnitude of the potential impacts that would occur in its absence[3]. Hence, actual impacts are normally much less than the potential impacts that are estimated in the absence of adaptation. Hence, impact assessments that do not take adaptation into account will generally overestimate impacts (determining *potential* rather than *actual* impacts).

[3] Adaptation that increases potential impacts and vulnerability is termed maladaptation (Smit et al. 2001).

Impacts of sea-level rise

The most significant biogeophysical effects of sea-level rise are summarised in Table 2, including relevant interacting climate and non-climate stresses.

Table 2. The main effects of relative sea-level rise, including relevant interacting factors (adapted from Nicholls (2002). Some factors (e.g. sediment supply) appear twice as they may be influenced both by climate and non-climate factors

Biogeophysical effect		Other relevant factors	
		Climate	Non-climate
Inundation, flood and storm damage	Surge (open coast)	Wave and storm climate, morphological change, sediment supply	Sediment supply, flood management, morphological change, land claim
	Backwater effect (river)	Run-off	Catchment management and land use
Wetland loss (and change)		CO_2 fertilisation Sediment supply	Sediment supply, migration space, direct destruction
Erosion	Direct effect (open coast) Indirect effect (near inlets)	Sediment supply, wave and storm climate	Sediment supply
Saltwater Intrusion	Surface Waters	Run-off	Catchment management and land use
	Ground-water	Rainfall	Land use, aquifer use
Rising water tables/ impeded drainage		Rainfall	Land use, aquifer use

Most of these impacts are broadly linear functions of sea-level rise, although some effects such as wetland loss show a threshold response and are more sensitive to the rate of sea-level rise, rather than the absolute change. Some responses are instantaneous, such as an increase in risk of flooding, while others such as erosion lag behind sea-level rise. Most existing studies have focused on one or more of the first three factors in Table 2: (1) inundation, flood and storm damage, (2) erosion and (3) wetland loss (Nicholls, 1995). Hence, most assessments of the biophysical impacts of sea-level rise are incomplete. These studies often make simple assumptions, such as wetlands being submerged as sea levels rise with no consideration of their possible responses (see Viles and Spencer 1995). Hence the studies are assessing exposure and aspects of sensitivity, and largely ignoring adaptive capacity. In addition, the non-climate stresses identified in Figure 3 and Table 2 are often ignored.

The natural-system effects of sea-level rise in Table 2 have a range of potential socio-economic impacts, including the following identified by McLean et al. (2001):

- Increased loss of property and coastal habitats;
- Increased flood risk and potential loss of life;
- Damage to coastal protection works and other infrastructure;

- Loss of renewable and subsistence resources;
- Loss of tourism, recreation, and transportation functions;
- Loss of non-monetary cultural resources and values;
- Impacts on agriculture and aquaculture through decline in soil and water quality.

The indirect impacts of sea-level rise are more difficult to analyse, but they have the potential to be important in many sectors, such as human health, fisheries, and nature conservation. Europe supports internationally significant numbers of shorebirds, especially in the winter. Shorebird numbers depend on intertidal areas, so sea-level rise could reduce the carrying capacity for these shorebirds. Human migration is another possible consequence of sea-level rise if coastal areas are abandoned or degraded. Forced migration is unlikely in Europe, but sea-level rise could generate migrants to Europe from other parts of the world. Hence, sea-level rise could produce a cascade of impacts through the coastal system, although analysis to date has focussed mainly on the direct impacts.

The impacts of sea-level rise have been investigated in a range of policy-driven sub-national, national and regional/global case studies (e.g. Nicholls and Mimura 1998, de la Vega-Leinert et al. 2000), as well as in more science-orientated studies which examine the biophysical processes of sea-level rise and their linkages (e.g. Cahoon et al. 1999, Capobianco et al. 1999). A range of socio-economic analyses have also been undertaken (e.g. Fankhauser 1995a, Tol 2002a 2002b). While these studies are policy relevant as they discuss issues such as the costs of sea-level rise in monetary terms, they are also experimental in terms of exploring the coupled natural and socio-economic dynamics of the coastal zone (see Figure 3). Most of the policy-driven studies have been relevant to national to international issues, especially reducing greenhouse gas emissions. They are less useful when adaptation and coastal management are considered, due to their broad scale.

Possible impacts of climate change on Europe's coastal areas

In global terms, Europe appears much less threatened by sea-level rise than many developing country regions (e.g. Nicholls 2003). However, coastal ecosystems do appear to be threatened, especially those on the Baltic, Mediterranean and Black Seas. In the worst case, these habitats could be severely reduced or eliminated during the 21st Century. This is due to the low tidal range in these areas, and the limited scope for onshore migration due to the intense human use of the coastal zone.

Most national-scale assessments in Europe comprise semi-quantitative analyses and/or inventories of the potential impacts of sea-level rise, with limited consideration of adaptation (Nicholls and Mimura 1998, Nicholls and de la Vega-Leinert 2004). As one might expect, low-lying coastal areas are most sensitive to sea-level rise, such as the large coastal lowlands bordering the North Sea. Figure 1 indicates the coastal plains and lowlands, estuaries and deltas that are threatened around Europe, as well as selected low-lying cities and areas of historical/cultural significance. The most common scenario has been a 1 m rise imposed on the present socio-economic situation (e.g. Table 3), so results over-emphasise the impacts of sea-level rise over other change factors. However, the results do confirm what has already been stated about the importance of the coastal zone in Europe. Table 3 suggests that >13 million people could be affected by flooding given a rise in sea level, just considering five countries. However, the national results vary between countries, with the Netherlands having the highest potential human impacts, and Poland and Estonia the lowest (Table 3).

Coastal wetlands and intertidal habitats also appear highly threatened in national and sub-national studies (Table 3), although their capacity to respond to sea-level rise requires more assessment as already discussed. Given that increased protection of human activities in coastal areas is a likely response to climate change and variability, these potential impacts combined with coastal squeeze are an important long-term challenge to coastal management in Europe. As discussed later, managed realignment of flood defences and 'depolderisation' is being seriously evaluated, including trials, in parts of Europe (Goeldner 1999, Goeldner-Gianella 2001, Rupp and Nicholls 2003). There are often sufficient sites of land claim to maintain the current stock of saltmarsh and other intertidal habitat, but at the cost of extensive areas of freshwater coastal grazing marsh of significance to nature conservation which have developed on the land claim areas (e.g. Watkinson et al. 2003). Thus, there are again trade-offs to consider with this policy.

In terms of adaptation, these studies have usually made simple assumptions that are consistent with the inventory approach, such as application of a uniform national response (Table 3). These studies show that the poorer countries in Europe face the largest relative burden of adaptation costs: Poland has higher relative adaptation costs than The Netherlands, despite the potential impacts being at least an order of magnitude lower. However, the adaptation process and the capacity of the coastal communities to adapt have not been evaluated. Thus, while we can be confident that Europe can afford significant levels of adaptation, we are much less clear what would be most appropriate. In the UK, an integrated assessment of future flooding concluded that coastal areas will become relatively more threatened by flooding relative to inland areas (Evans, 2003). This reflects the effect of sea-level rise and suggests that in national terms, coastal adaptation will be essential and this will require more resources relative to present management costs. This result will likely be relevant in neighbouring European countries.

One important result of significance to coastal management is the importance of the scale of assessment. Sterr (2004) has investigated the vulnerability of Germany to sea-level rise, at national, state (Schleswig-Holstein) and case studies (within Schleswig-Holstein) levels. As the scale of study increases, so the size of the hazard zones declined due to the use of higher resolution data. However, the potential impacts do not change significantly as the human values remain concentrated in the (smaller) hazard zones. Turner et al. (1995) examined the optimum response to sea-level rise in East Anglia, UK, using cost-benefit analysis. At the regional scale, it was worth protecting the entire coast. In contrast, at the scale of individual flood compartments, 20% of flood compartments should be abandoned, even for the present rates of sea-level rise. This conclusion is consistent with current trends in coastal management policy for this region. This shows that realistic assessment of adaptation options requires quite detailed analysis to capture the potential variation in responses within a region, rather than assuming a uniform adaptation response.

Responding to climate change

Given the potential impacts in Europe identified in the previous sections, some response to climate change is prudent. To date, the European Union's response to climate change has stressed policies to reduce greenhouse gas emissions (usually termed mitigation within the climate change debate). While the authors support this policy, it has become increasingly apparent that it needs to be augmented by adaptation to the inevitable climate change (Parry et al. 1998, Metz et al. 2002). Given the strong commitment to sea-level rise, in coastal areas this need for adaptation is greatest and will continue for centuries (Lowe and Nicholls 2004). This commitment to coastal adaptation needs to be built into long-term coastal management policy. However, while there is consensus on the need for mitigation across the European Union, proactive adaptation across Europe's coasts is much more patchy and variable. The SURVAS Project found that concern about sea-level rise, including the level of preparation varied greatly around Europe, a few northern countries are already preparing for accelerated sea-level rise, while many southern countries are ignoring observed 20th Century rise, let alone preparing for projected accelerated rise (Tol et al. 2004).

Proactive adaptation to climate change is aimed at reducing a system's vulnerability by either minimising risk or maximising adaptive capacity. Five generic objectives of proactive adaptation can be identified (Klein and Tol 1997, Klein 2001), which are relevant to coastal zones:

- *Increasing robustness of infrastructural designs and long-term investments*—for example by extending the range of relevant climatic factors (e.g. still water level) that a system can withstand without failure and/or changing a system's tolerance of loss or failure (e.g. by increasing economic reserves or insurance);
- *Increasing flexibility of vulnerable managed systems*—for example by following adaptive management approaches, which explicitly allow adjustments and learning, and/or reducing economic lifetimes (including increasing depreciation);
- *Enhancing adaptability of vulnerable natural systems*—for example by reducing non-climatic stresses (e.g. reactivating natural sediment supplies) and/or removing barriers to migration (e.g. promoting managed realignment);
- *Reversing maladaptive trends*— for example by introducing zoning regulation in vulnerable areas prone to repeated flood events that prohibits redevelopment after major damage;
- *Improving societal awareness and preparedness*—for example by informing the public of the risks and possible consequences of climate change and/or setting up disaster response and early-warning systems.

For coastal zones another classification of three basic adaptation strategies is often used (IPCC CZMS 1990, Klein et al. 2001):

- *Protect*—to reduce the risk of the event by decreasing the probability of its occurrence;
- *Accommodate*—to increase society's ability to cope with the effects of the event;
- *Retreat*—to reduce the risk of the event by limiting its potential effects.

Table 3. Potential impacts of a 1-m sea-level rise in selected European countries, assuming the 1990s situation and no adaptation, plus adaptation costs to protect the human population (taken from Nicholls and de la Vega-Leinert 2004)

Country	Coastal floodplain population		Population flooded per year		Capital value loss		Land loss		Wetland loss	Adaptation costs	
	no. 10^3	%	no. 10^3	%	10^9 US$	% GNP	Km^2	%	km^2	10^9 US$	% GNP
Netherlands	10,000	67	3,600	24	186	69	2,165	6.7	642	12.3	5.5
Germany	3,120	4	257	0.3	410	30	n.a.	n.a.	2,400	30	2.2
Poland	235	0.6	196	0.5	22.0	24	1,700	0.5	n.a.	4.8	14.5
										+0.4/yr	+1.2/yr
Estonia	47	3	n.a.	n.a.	0.22	3	>580	>1.3	225	n.a.	n.a.
Ireland	<250	<5	<100	<1.8	0.17	0.2	<250	<0.3	<150	<0.42/yr	<0.6/yr

While each of these strategies are designed to protect human use of the coastal zone, if applied appropriately, they have different consequences for coastal ecosystems. Retreat and accommodation avoid coastal squeeze as onshore migration of coastal ecosystems is not hindered. In contrast, protection will lead to a coastal squeeze, although this can be minimised using soft approaches to defence such as beach nourishment and sediment recycling. In terms of timing, accommodate and retreat are best implemented in a proactive manner, while protection can be both proactive or reactive.

The recent shoreline management guidelines used in England and Wales and adapted for use in the Eurosion Project are also useful to consider as they are being applied at a national level (DEFRA 2001, Cooper et al. 2002), and potentially more widely across Europe. They comprise a set of proactive strategies for shoreline management[4]. The original strategies were entirely geometric (MAFF et al. 1995), but based on experience with the first generation of shoreline management plans, five strategies will be considered in the second generation plans, which are just commencing:

- Hold the Line;
- Advance the Line;
- Managed Realignment;
- Limited Intervention;
- No Intervention.

Figure 4 shows the linkages between these three sets of responses. The three coastal adaptation strategies roughly coincide with the first three of the five proactive adaptation objectives.

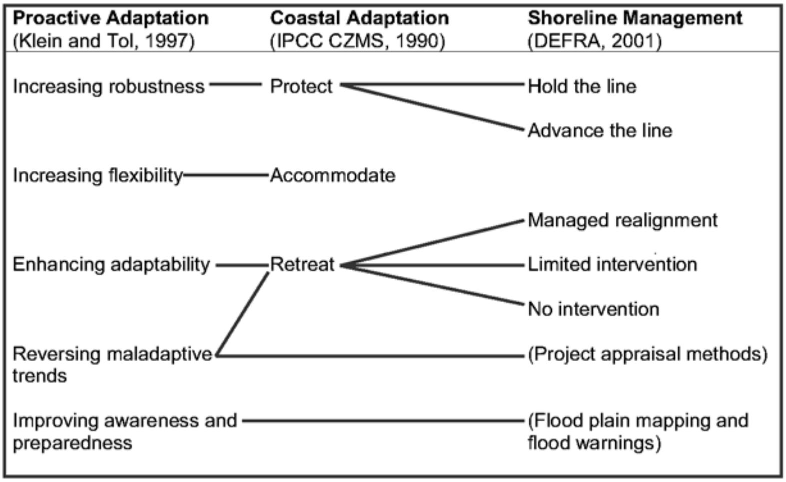

Fig. 4. Linkages between the different adaptation approaches discussed in the text

[4] Strategic management that addresses long-term responses to coastal flood and erosion hazards.

Protecting coastal zones against sea-level rise and other climatic changes would involve increasing the robustness of infrastructural designs and long-term investments such as seawalls and other coastal infrastructure. A strategy to accommodate sea-level rise could include increasing the flexibility of managed systems such as agriculture, tourism and human settlements in coastal zones. A retreat strategy would serve to enhance the adaptability of coastal wetlands, by allowing them space to migrate to higher land as sea level rises. The shoreline management options can also be mapped to these two approaches. Reversing maladaptive trends and improving societal awareness and preparedness are not explicitly addressed in the DEFRA (2001) guidelines. Managed realignment could be seen as reversing maladaptive trends for areas of land claim. It can also be argued that both approaches are addressed in other elements of shoreline management policy: project appraisal is now based on cost-benefit analysis, while flood warning and disaster preparedness are now central elements of flood management in England and Wales (see http://www.defra.gov.uk/environ/fcd/). However, it is striking that while the retreat strategy is now considered, the accommodation option is not considered, except in regard to warning systems. The authors are unaware of accommodation being applied anywhere in Europe, except locally. This contrasts with flood management in the USA, which use accommodation extensively, such as raising coastal buildings above surges and waves on deeply embedded pilings. This suggests that the feasibility of accommodation strategies should be evaluated more explicitly, especially within some of the more innovative approaches being advocated for future coastal development (e.g. Waterman et al. 1998).

Climate change and coastal management

Integrated coastal zone management (ICZM) has been widely recognised and promoted as the most appropriate process to deal with these current and long-term coastal challenges, including climate change and sea-level rise. It is a proactive policy process to address resource-use conflicts, as well as find the balance between short-term economic and longer-term environmental interests. By considering short, medium and long-term interests, ICZM aims to achieve sustainable development by stimulating economic development of coastal areas and resources, whilst reducing the degradation of their natural systems (Cicin-Sain 1993, WCC'93 1994, Ehler et al. 1997, Cicin-Sain and Knecht 1998). Demonstrating that coastal management plans are sustainable is difficult. However, any sustainable plan must address the issue of climate change. Hence the effectiveness of how climate change and sea-level rise are considered in coastal management plans is one useful measure of commitment to integration and sustainability. ICZM has been endorsed as a integrated response to climate change by the Intergovernmental Panel on Climate Change (IPCC CZMS 1992, Bijlsma et al. 1996, McLean et al. 2001). The European Union are exploring ICZM via a demonstration programme (European Commission, 1999a, 1999b) and an EU ICZM Recommendation was ratified in 2002 (see their website:

http://europa.eu.int/comm/environment/iczm/home.htm). National stocktaking is presently being conducted and this may ultimately result in an EU directive on ICZM.

The responses to sea-level rise and climate change discussed in the previous section need to be implemented in this broader context of coastal management, and the responses need to be consistent with the wider objectives of coastal management (Klein et al. 1999, Klein 2003). Current pressures may have adversely affected the coastal ecosystem's integrity and thereby its ability to cope with additional pressures such as climate change and sea-level rise. In Europe given its high level of development, large coastal populations, and high levels of interference with coastal systems this is a particularly significant factor. It can be argued that natural coastal buffers such as dunes and wetlands should be preserved and enhanced, as climate change indicates the value of this buffering capacity. Equally, improving shoreline management for non-climate change reasons will also have benefits in terms of responding to sea-level rise and climate change. This illustrates that when current coastal pressures are not adequately dealt with in the short term, coastal zones will become increasingly more vulnerable to the consequences of climate change and sea-level rise (WCC'93 1994).

Adaptation to climate change in integrated coastal zone management

In an integrated coastal policy that aims to address both climate and non-climate issues, the potential for conflict between development objectives and adaptation needs should be minimised. In view of the fact that coastal zones are usually host to a number of, often competing, sectoral activities, coastal zone management to date has been designed primarily to satisfy sectoral needs. Given the additional challenge of climate change in coastal zones, the purpose and design of coastal management will have to be revisited. In order to do so, it is important that all stakeholders—governments, universities and government-sponsored laboratories, the private sector, non-governmental organisations and local communities—are aware of the need to reduce coastal vulnerability to climate change. In addition, successful coastal management requires that the planning, design and implementation of adaptation technologies be based on the best available information as well as on the regular monitoring and evaluation of their performance.

Accordingly, Klein et al. (1999, 2001) showed that effective and efficient coastal adaptation to climate change is not just a set of technical options. Rather, it can be conceptualised as a multi-stage and iterative process, involving four basic steps, within the wider frame of coastal management (Figure 5):

1. Information development and awareness raising;
2. Planning and design;
3. Implementation;
4. Monitoring and evaluation.

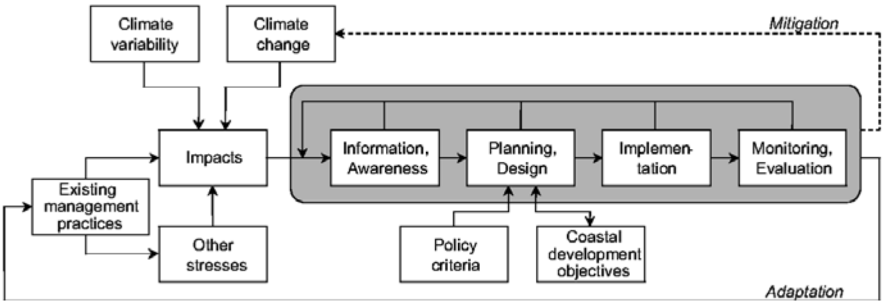

Fig. 5. Conceptual framework showing in the shaded area the iterative steps involved in coastal adaptation to climate variability and change (from Klein et al. 2001)

Climate variability and/or climate change – together with other stresses on the coastal environment brought about by existing management practices – produce actual or potential impacts. These impacts trigger efforts of mitigation to remove the cause of the impacts or adaptation to modify the impacts. The process of adaptation is conditioned by policy criteria and coastal development objectives and interacts with existing management practices.

Figure 5 is a schematic framework based on the long-term coastal management experiences in The Netherlands, the United Kingdom and Japan, with an emphasis on coastal protection. In each of these countries, management approaches have been adjusted over the past decades to reflect new insights and priorities, including concerns about climate variability and, more recently, climate change. It is important to note that Figure 5 represents an idealised decision framework, which does not capture the multitude of actors involved in decision-making, the uncertainty with which these actors are faced, the other interests they have or the institutional and political environments in which they operate.

Given the uncertainty of climate change and the ability of our models to predict its impacts, monitoring and evaluation is fundamental. This will allow an adaptive management approach as we learn more about the problems of climate change, the tools and methods that we use to analyse them, and hence how to effectively management these issues (see National Research Council 1995, Willows and Connell 2003, Tol et al. 2004, Mee this volume).

Improving information on climate change for coastal zone management

Coastal zone management requires more information on the possible impacts of climate change and the choices that are faced in responding to these threats. The variable response to the threats of climate change around Europe's coasts identified by Tol et al. (2004) partly reflects this lack of information, as well as variation in the historical and 20th Century experiences of coastal hazards. This will require further vulnerability assessments with the specific purpose of improving coastal zone management and policy. Earlier assessments were often more focussed on broader needs than coastal management, so their results are of limited value to coastal policy makers. The detailed assessments that have been conducted in the Netherlands (Hekstra 1986, Stive et al. 1990, De Ronde 1993, Baarse et al. 1994, Peerbolte 1994, De Ruig 1998, Jacobs et al. 2000) and shoreline management in the UK (DEFRA 2001, Foresight Project on Flood and Coastal Defence, http://www.foresight.gov.uk) illustrate studies that are helping to improve coastal policy for climate and other long-term changes. Needs include understanding the impacts of sea-level rise and climate change in the context of the non-climate stresses (i.e. an analysis of multiple stresses), defining the options to respond to climate change and identifying when they might be best implemented. Positive benefits of climate change may also occur for some sectors such as coastal tourism (Maddison 2001), and these should be acknowledged and fully exploited.

Some specific issues that might be addressed in future studies were identified at the SURVAS Overview Workshop (Nicholls and de la Vega-Leinert 2001). These reinforce some of the earlier remarks in this chapter. The main recommendations that are pertinent to the future direction of climate change and coastal management in Europe concern the conduct of future vulnerability assessments of coastal areas and are as follows:

- Guided sensitivity analysis of coastal areas to the full plausible range of climate change can usefully proceed in parallel with developments in climate and related science. Scenarios of regional sea-level change and changes in storminess should be developed as promptly as possible (see Beersma et al. 2000);
- It is important to place the impacts/adaptation needs of sea-level rise in a broader context of change and today's coastal problems including consideration of:
  - Other climate change, including extreme events such as storms;
  - Non-climate environmental, land use and socio-economic changes.
- Evaluate the full range of possible impacts, including the natural system and the socio-economic system, and the direct and the indirect impacts (which have often been ignored);
- Consider impacts on the entire coastal zone, including the sub-tidal and intertidal areas (mainly impacts on fisheries and ecosystems);
- Identify 'flagship' impacts on cultural or natural sites (e.g. Venice or the Camargue, France) that are likely to attract widespread public concern and attention;
- Consider adaptation as a process rather than just a set of technical measures or fixes, as there may be important constraints on this process, and once a measure is implemented it requires monitoring;
- Consider the timing of different adaptation measures, particularly identifying those that would be most effective if implemented in the near future;
- Identify the constraints and barriers to adaptation, and how the capacity to adapt could be enhanced.

Conclusions and further work

Some important conclusions concerning climate change and the long-term management of the European coastal zone are as follows:

1. *Climate change and variability are already an issue.* During the 20th Century, sea levels have risen 10 to 20 cm around much of Europe's coast, while storm frequency and track have shown significant interdecadal variability. These climatic factors are already contributing to a range of problems, including increasing flood risk, coastal erosion and coastal squeeze. However, the relative importance of these historic influences on current problems could be better quantified;
2. *Future climate change is expected to be greater than historic experience.* By 2100, global-mean sea levels could be 9 to 88 cm higher than in 1990, while air and sea temperature will have risen significantly. Storm frequency and intensity may increase across northwest Europe and the large interdecadal variability is almost certain to continue;
3. *Potential impacts on human systems are significant.* Of particular concern is increased flood risk and storm damage in low-lying coastal areas. While the North Sea coast presently has the largest exposure, the risk of flooding will increase more around the Mediterranean, Black Sea and the southern Baltic, assuming no human adaptation. Storminess must also be considered;
4. *Intertidal habitats and ecosystems are also threatened.* The Baltic, Mediterranean and Black Sea coasts are most vulnerable to sea-level rise due to their low tidal range and in the worst case, intertidal ecosystems could be largely eliminated in these areas by the 2080s. This is a major challenge for coastal management;
5. *Coastal zones face many other pressures over the 21st Century.* Profound socio-economic and other changes will continue, although future trends are highly uncertain. This will interact with climate change, and exacerbate or ameliorate vulnerability to climate change;
6. *Actual impacts of climate change are highly uncertain.* They will depend on the magnitude of climate and other change and the success of human adaptation to that change. Many of the impacts of sea-level rise and climate change could be avoided or managed effectively given appropriate proactive measures;
7. *There is conflict between sustaining coastal ecosystems and maintaining human coastal activity.* The natural ecosystem response to rising sea levels is onshore migration, but this is stopped by fixed sea defences, producing coastal squeeze. Thus, there is a fundamental conflict between protecting socio-economic activity and sustaining the ecological functioning of the coastal zone in Europe under rising sea levels. This conflict needs to be explicitly acknowledged and resolved by coastal management policy. It suggests a need for more soft protection, managed retreat, and possibly accommodation strategies;
8. *Global sea levels are likely to continue to rise for many centuries irrespective of future greenhouse gas emissions.* Therefore, sea-level rise will remain an important issue for coastal management beyond the 21st Century. Coastal management and land use planning should prepare for these changes, recognising that there is a long-term 'commitment to adapt to sea-level rise'.

Thus, climate change is a major challenge for coastal management through the 21st Century and beyond. The scale of the challenge is significant as most available tools and methods are designed for more immediate local to sub-national problems. Strengthening our capacity for long-term coastal management is fundamental to our response to climate change and sea-level rise. Three issues require further debate and investigation.

First of all, protecting human use and sustaining the natural functioning of the coast: how can we most effectively marry these two often conflicting goals (especially given the long-term commitment to sea-level rise)? While near-universal protection of human activities could probably be provided, it is unlikely that this would be the preferred option. Finding better solutions needs to take account of coastal dynamics, which are often ignored in coastal management. For example, the EU Habitat and Birds Directives (SPAs and SACs) take a rather static view of existing coastal habitats, rather than encouraging a dynamic view of an evolving coastal landscape. Rather than preserving existing coastal sites, the focus could be on preserving and enhancing stocks of habitats, but accepting that their location is not fixed. This suggests the need for European scale assessment of coastal ecosystems.

Secondly, considering the available tools and methods for coastal management, what useful tools and methods exist for climate change issues and what new tools and methods are required to effectively manage the challenges of the 21st Century? While many useful tools and methods already exist, given the long-term implications of climate change, coastal policy and management requires new broad-scale integrated assessment and management tools across a range of scales: local, sub-national (or regional), national and Europe. Assessments at each of these scales will provide useful information to coastal zone management, and if the studies are consistent across the scales, they will allow nesting of the results, maximising their use for policy purposes (e.g. Hall et al. 2003, Polsky et al. 2003). Long-term coastal morphological evolution is an issue that requires particular attention (e.g. Capobianco et al. 1999, De Vriend and Hulscher 2003), as our predictive capability remains quite low, and morphological change influences all other impacts. Dynamic approaches to coastal management also require long-term morphological predictions. It is noteworthy that studies at the European scale are quite limited and often semi-quantitative or qualitative. Possible approaches include combining European-scale assessments such as Eurosion (http://www.eurosion.org) with global-scale integrated assessment models such as DINAS-COAST (http://www.dinas-coast.net), or the more detailed Tyndall Centre Regional Coastal Simulator (http://www.tyndall.ac.uk). However, there are a number of constraints on such integrated model development, including defining the integrated frameworks and appropriate constituent models, as well as identifying the necessary data and scenarios to implement them. Data at broad scales is often rather limited and of variable quality: data on socio-economic and institutional aspects is particularly weak.

Thirdly, what is the appropriate role of proactive versus reactive (wait and see) adaptation policies in long-term management of the coastal zone, and how can proactive approaches be best facilitated? Changing climate and socio-economic conditions presents both opportunities and threats to future coastal developments –

we could develop strategic proactive policies that effectively manage the threats and also fully exploit the opportunities, or conversely, we could ignore the issue which will maximise our vulnerability to climate change and sea-level rise. A recent European survey suggests the latter approach is presently the norm (Tol et al. 2004). The European scale assessments discussed in the previous points could play a role in facilitating debate about coastal adaptation policy, and encourage further investigation via more detailed studies.

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