6

Coastal systems and low-lying areas

Coordinating Lead Authors:

Robert J. Nicholls (UK), Poh Poh Wong (Singapore)

Lead Authors:

Virginia Burkett (USA), Jorge Codignotto (Argentina), John Hay (New Zealand), Roger McLean (Australia), Sachooda Ragoonaden (Mauritius), Colin D. Woodroffe (Australia)

Contributing Authors:

Pamela Abuodha (Kenya), Julie Arblaster (USA/Australia), Barbara Brown (UK), Don Forbes (Canada), Jim Hall (UK), Sari Kovats (UK), Jason Lowe (UK), Kathy McInnes (Australia), Susanne Moser (USA), Susanne Rupp-Armstrong (UK), Yoshiki Saito (Japan), Richard S.J. Tol (Ireland)

Review Editors:

Job Dronkers (The Netherlands), Geoff Love (Australia), Jin-Eong Ong (Malaysia)

This chapter should be cited as:

Nicholls, R.J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden and C.D. Woodroffe, 2007: Coastal systems and low-lying areas. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 315-356.

Table of Contents

Executive Summary

Since the IPCC Third Assessment Report (TAR), our understanding of the implications of climate change for coastal systems and low-lying areas (henceforth referred to as 'coasts') has increased substantially and six important policy-relevant messages have emerged.

Coasts are experiencing the adverse consequences of hazards related to climate and sea level (very high confidence).
Coasts are highly vulnerable to extreme events, such as storms, which impose substantial costs on coastal societies [6.2.1, 6.2.2, 6.5.2]. Annually, about 120 million people are exposed to tropical cyclone hazards, which killed 250,000 people from 1980 to 2000 [6.5.2]. Through the 20th century, global rise of sea level contributed to increased coastal inundation, erosion and ecosystem losses, but with considerable local and regional variation due to other factors [6.2.5, 6.4.1]. Late 20th century effects of rising temperature include loss of sea ice, thawing of permafrost and associated coastal retreat, and more frequent coral bleaching and mortality [6.2.5].

Coasts will be exposed to increasing risks, including coastal erosion, over coming decades due to climate change and sea-level rise (very high confidence).
Anticipated climate-related changes include: an accelerated rise in sea level of up to 0.6 m or more by 2100; a further rise in sea surface temperatures by up to 3°C; an intensification of tropical and extra-tropical cyclones; larger extreme waves and storm surges; altered precipitation/run-off; and ocean acidification [6.3.2]. These phenomena will vary considerably at regional and local scales, but the impacts are virtually certain to be overwhelmingly negative [6.4, 6.5.3].

Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1 to 3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatisation by corals [Box 6.1, 6.4].

Coastal wetland ecosystems, such as saltmarshes and mangroves, are especially threatened where they are sediment-starved or constrained on their landward margin [6.4.1]. Degradation of coastal ecosystems, especially wetlands and coral reefs, has serious implications for the well-being of societies dependent on the coastal ecosystems for goods and services [6.4.2, 6.5.3]. Increased flooding and the degradation of freshwater, fisheries and other resources could impact hundreds of millions of people, and socio-economic costs on coasts will escalate as a result of climate change [6.4.2, 6.5.3].

The impact of climate change on coasts is exacerbated by increasing human-induced pressures (very high confidence).
Utilisation of the coast increased dramatically during the 20th century and this trend is virtually certain to continue through the 21st century. Under the SRES scenarios, the coastal population could grow from 1.2 billion people (in 1990) to 1.8 to 5.2 billion people by the 2080s, depending on assumptions about migration [6.3.1]. Increasing numbers of people and assets at risk at the coast are subject to additional stresses due to land-use and hydrological changes in catchments, including dams that reduce sediment supply to the coast [6.3.2]. Populated deltas (especially Asian megadeltas), low-lying coastal urban areas and atolls are key societal hotspots of coastal vulnerability, occurring where the stresses on natural systems coincide with low human adaptive capacity and high exposure [6.4.3]. Regionally, South, South-east and East Asia, Africa and small islands are most vulnerable [6.4.2]. Climate change therefore reinforces the desirability of managing coasts in an integrated manner [6.6.1.3].

Adaptation for the coasts of developing countries will be more challenging than for coasts of developed countries, due to constraints on adaptive capacity (high confidence).
While physical exposure can significantly influence vulnerability for both human populations and natural systems, a lack of adaptive capacity is often the most important factor that creates a hotspot of human vulnerability. Adaptive capacity is largely dependent upon development status. Developing nations may have the political or societal will to protect or relocate people who live in low-lying coastal zones, but without the necessary financial and other resources/capacities, their vulnerability is much greater than that of a developed nation in an identical coastal setting. Vulnerability will also vary between developing countries, while developed countries are not insulated from the adverse consequences of extreme events [6.4.3, 6.5.2].

Adaptation costs for vulnerable coasts are much less than the costs of inaction (high confidence).
Adaptation costs for climate change are much lower than damage costs without adaptation for most developed coasts, even considering only property losses and human deaths [6.6.2, 6.6.3]. As post-event impacts on coastal businesses, people, housing, public and private social institutions, natural resources, and the environment generally go unrecognised in disaster cost accounting, the full benefits of adaptation are even larger [6.5.2, 6.6.2]. Without adaptation, the high-end sea-level rise scenarios, combined with other climate changes (e.g., increased storm intensity), are as likely as not to render some islands and low-lying areas unviable by 2100, so effective adaptation is urgently required [6.6.3].

The unavoidability of sea-level rise, even in the longer-term, frequently conflicts with present-day human development patterns and trends (high confidence).
Sea-level rise has substantial inertia and will continue beyond 2100 for many centuries. Irreversible breakdown of the West Antarctica and/or Greenland ice sheets, if triggered by rising temperatures, would make this long-term rise significantly larger, ultimately questioning the viability of many coastal settlements across the globe. The issue is reinforced by the increasing human use of the coastal zone. Settlement patterns also have substantial inertia, and this issue presents a challenge for long-term coastal spatial planning. Stabilisation of climate could reduce the risks of ice sheet breakdown, and reduce but

not stop sea-level rise due to thermal expansion [Box 6.6]. Hence, it is now more apparent than it was in the TAR that the most appropriate response to sea-level rise for coastal areas is a combination of *adaptation* to deal with the inevitable rise, and *mitigation* to limit the long-term rise to a manageable level [6.6.5, 6.7].

6.1 Introduction: scope, summary of Third Assessment Report conclusions and key issues

This chapter presents a global perspective on the impacts of climate change and sea-level rise on coastal and adjoining low-lying areas, with an emphasis on post-2000 insights. Here, coastal systems are considered as the interacting low-lying areas and shallow coastal waters, including their human components (Figure 6.1). This includes adjoining coastal lowlands, which have often developed through sedimentation during the Holocene (past 10,000 years), but excludes the continental shelf and ocean margins (for marine ecosystems see Chapter 4). Inland seas are not covered, except as analogues. In addition to local drivers and interactions, coasts are subject to external events that pose a hazard to human activities and may compromise the natural functioning of coastal systems (Figure 6.1). Terrestrial-sourced hazards include river floods and inputs of sediment or pollutants; marine-sourced hazards include storm surges, energetic swell and tsunamis.

In this chapter, we reinforce the findings of the Third Assessment Report (TAR; IPCC, 2001) concerning the potential importance of the full range of climate change drivers on coastal systems and the complexity of their potential effects. The TAR also noted growing interest in adaptation to climate change in coastal areas, a trend which continues to gather momentum, as shown in this assessment. Whereas some coastal countries and communities have the adaptive capacity to minimise the impacts of climate change, others have fewer options and hence are much more vulnerable to climate change. This is compounded as human population growth in many coastal regions is both increasing socio-economic vulnerability and decreasing the resilience of coastal systems. Integrated assessment and management of coastal systems, together with a better understanding of their interaction with socio-economic and cultural development, were presented in the TAR as important components of successful adaptation to climate change.

This chapter builds on and develops these insights in the TAR by considering the emerging knowledge concerning impacts and adaptation to climate change in coastal areas across a wider spectrum of climate change drivers and from local to global scales. Nonetheless, the issue of sea-level rise still dominates the literature on coastal areas and climate change. This chapter includes an assessment of current sensitivity and vulnerability, the key changes that coastal systems may undergo in response to climate and sea-level change, including costs and other socio-economic aspects, the potential for adaptation, and the implications for sustainable development. Given that there are strong interactions both within and between the natural and human sub-systems in the coastal system (Figure 6.1), this chapter takes an integrated perspective of the coastal zone and its management, insofar as the published literature permits.

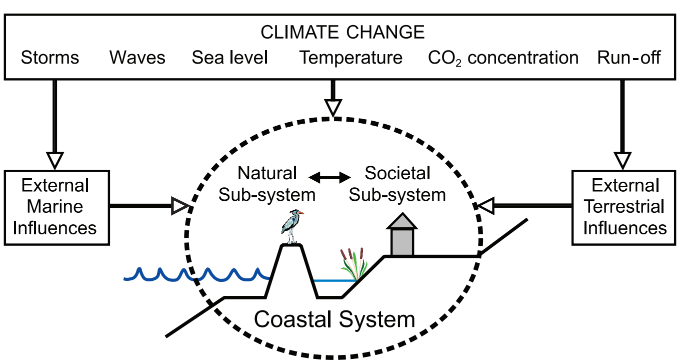

Figure 6.1. *Climate change and the coastal system showing the major climate change factors, including external marine and terrestrial influences.*

6.2 Current sensitivity/vulnerability

This section provides key insights into the ways in which coastal systems are presently changing, as context for assessing the impacts of, and early effects attributable to, climate change.

6.2.1 Natural coastal systems

Coasts are dynamic systems, undergoing adjustments of form and process (termed morphodynamics) at different time and space scales in response to geomorphological and oceanographical factors (Cowell et al., 2003a,b). Human activity exerts additional pressures that may dominate over natural processes. Often models of coastal behaviour are based on palaeoenvironmental reconstructions at millennial scales and/or process studies at sub-annual scales (Rodriguez et al., 2001; Storms et al., 2002; Stolper et al., 2005). Adapting to global climate change, however, requires insight into processes at decadal to century scales, at which understanding is least developed (de Groot, 1999; Donnelly et al., 2004).

Coastal landforms, affected by short-term perturbations such as storms, generally return to their pre-disturbance morphology, implying a simple, morphodynamic equilibrium. Many coasts undergo continual adjustment towards a dynamic equilibrium, often adopting different 'states' in response to varying wave energy and sediment supply (Woodroffe, 2003). Coasts respond to altered conditions external to the system, such as storm events, or changes triggered by internal thresholds that cannot be predicted on the basis of external stimuli. This natural variability of coasts can make it difficult to identify the impacts of climate change. For example, most beaches worldwide show evidence of recent erosion but sea-level rise is not necessarily the primary driver. Erosion can result from other factors, such as altered wind patterns (Pirazzoli et al., 2004; Regnauld et al., 2004), offshore bathymetric changes (Cooper and Navas, 2004), or reduced fluvial sediment input (Sections 6.2.4 and 6.4.1.1). A major challenge is determining whether observed changes have resulted from alteration in external factors (such as climate change), exceeding an internal threshold (such as a delta distributary switching to a new location), or short-term disturbance within natural climate variability (such as a storm).

Climate-related ocean-atmosphere oscillations can lead to coastal changes (Viles and Goudie, 2003). One of the most prominent is the El Niño-Southern Oscillation (ENSO) phenomenon, an interaction between pronounced temperature anomalies and sea-level pressure gradients in the equatorial Pacific Ocean, with an average periodicity of 2 to 7 years. Recent research has shown that dominant wind patterns and storminess associated with ENSO may perturb coastal dynamics, influencing (1) beach morphodynamics in eastern Australia (Ranasinghe et al., 2004; Short and Trembanis, 2004), mid-Pacific (Solomon and Forbes, 1999) and Oregon (Allan et al., 2003); (2) cliff retreat in California (Storlazzi and Griggs, 2000); and (3) groundwater levels in mangrove ecosystems in Micronesia (Drexler, 2001) and Australia (Rogers et al., 2005). Coral bleaching and mortality appear related to the frequency and intensity of ENSO events in the Indo-Pacific region, which may alter as a component of climate change (Box 6.1), becoming more widespread because of global warming (Stone et al., 1999). It is likely that coasts also respond to longer term variations; for instance, a relationship with the Pacific Decadal Oscillation (PDO) is indicated by monitoring of a south-east Australian beach for more than 30 years (McLean and Shen, 2006). Correlations between the North Atlantic Oscillation (NAO) and storm frequency imply similar periodic influences on Atlantic coasts (Tsimplis et al., 2005, 2006), and the Indian Ocean Dipole (IOD) may drive similar periodic fluctuations on coasts around the Indian Ocean (Saji et al., 1999).

6.2.2 Increasing human utilisation of the coastal zone

Few of the world's coastlines are now beyond the influence of human pressures, although not all coasts are inhabited (Buddemeier et al., 2002). Utilisation of the coast increased dramatically during the 20th century, a trend that seems certain to continue through the 21st century (Section 6.3.1). Coastal population growth in many of the world's deltas, barrier islands and estuaries has led to widespread conversion of natural coastal landscapes to agriculture, aquaculture, silviculture, as well as industrial and residential uses (Valiela, 2006). It has been estimated that 23% of the world's population lives both within 100 km distance of the coast and <100 m above sea level, and population densities in coastal regions are about three times higher than the global average (Small and Nicholls, 2003) (see also Box 6.6). The attractiveness of the coast has resulted in disproportionately rapid expansion of economic activity, settlements, urban centres and tourist resorts. Migration of people to coastal regions is common in both developed and developing nations. Sixty percent of the world's 39 metropolises with a population of over 5 million are located within 100 km of the coast, including 12 of the world's 16 cities with populations greater than 10 million. Rapid urbanisation has many consequences: for example, enlargement of natural coastal inlets and dredging of waterways for navigation, port facilities, and pipelines exacerbate saltwater intrusion into surface and ground waters. Increasing shoreline retreat and risk of flooding of coastal cities in Thailand (Durongdej, 2001; Saito, 2001), India (Mohanti, 2000), Vietnam (Thanh et al., 2004) and the United States (Scavia et al., 2002) have been attributed to degradation of coastal ecosystems by human activities, illustrating a widespread trend.

The direct impacts of human activities on the coastal zone have been more significant over the past century than impacts that can be directly attributed to observed climate change (Scavia et al., 2002; Lotze et al., 2006). The major direct impacts include drainage of coastal wetlands, deforestation and reclamation, and discharge of sewage, fertilisers and contaminants into coastal waters. Extractive activities include sand mining and hydrocarbon production, harvests of fisheries and other living resources, introductions of invasive species and construction of seawalls and other structures. Engineering structures, such as damming, channelisation and diversions of coastal waterways, harden the coast, change circulation patterns and alter freshwater, sediment and nutrient delivery. Natural systems are often directly or indirectly altered, even by soft engineering solutions, such as beach nourishment and foredune construction (Nordstrom, 2000; Hamm and Stive, 2002). Ecosystem services on the coast are often disrupted by human activities. For example, tropical and subtropical mangrove forests and temperate saltmarshes provide goods and services (they accumulate and transform nutrients, attenuate waves and storms, bind sediments and support rich ecological communities), which are reduced by large-scale ecosystem conversion for agriculture, industrial and urban development, and aquaculture (Section 6.4.2).

6.2.3 External terrestrial and marine influences

External terrestrial influences have led to substantial environmental stresses on coastal and nearshore marine habitats (Sahagian, 2000; Saito, 2001; NRC, 2004; Crossland et al., 2005). As a consequence of activities outside the coastal zone, natural ecosystems (particularly within the catchments draining to the coast) have been fragmented and the downstream flow of water, sediment and nutrients has been disrupted (Nilsson et al., 2005; Section 6.4.1.3). Land-use change, particularly deforestation, and hydrological modifications have had downstream impacts, in addition to localised development on the coast. Erosion in the catchment has increased river sediment load; for example, suspended loads in the Huanghe (Yellow) River have increased 2 to 10 times over the past 2000 years (Jiongxin, 2003). In contrast, damming and channelisation have greatly reduced the supply of sediments to the coast on other rivers through retention of sediment in dams (Syvitski et al., 2005). This effect will likely dominate during the 21st century (Section 6.4.1).

Coasts can be affected by external marine influences (Figure 6.1). Waves generated by storms over the oceans reach the coast as swell; there are also more extreme, but infrequent, high-energy swells generated remotely (Vassie et al., 2004). Tsunamis are still rarer, but can be particularly devastating (Bryant, 2001). Ocean currents modify coastal environments through their influence on heat transfer, with both ecological and geomorphological consequences. Sea ice has physical impacts, and its presence or absence influences whether or not waves reach the coast (Jaagus, 2006). Other external influences include atmospheric inputs, such as dust (Shinn et al., 2000), and invasive species.

6.2.4 Thresholds in the behaviour of coastal systems

Dynamic coastal systems often show complex, non-linear morphological responses to change (Dronkers, 2005). Erosion, transport and deposition of sediment often involve significant time-lags (Brunsden, 2001), and the morphological evolution of sedimentary coasts is the outcome of counteracting transport processes of sediment supply versus removal. A shoreline may adopt an equilibrium, in profile or plan form, where these processes are in balance. However, external factors, such as storms, often induce morphodynamic change away from an equilibrium state. Climate change and sea-level rise affect sediment transport in complex ways and abrupt, non-linear changes may occur as thresholds are crossed (Alley et al., 2003). If sea level rises slowly, the balance between sediment supply and morphological adjustment can be maintained if a saltmarsh accretes, or a lagoon infills, at the same rate. An acceleration in the rate of sea-level rise may mean that morphology cannot keep up, particularly where the supply of sediment is limited, as for example when coastal floodplains are inundated after natural levees or artificial embankments are overtopped. Exceeding the critical sea-level thresholds can initiate an irreversible process of drowning, and other geomorphological and ecological responses follow abrupt changes of inundation and salinity (Williams et al., 1999; Doyle et al., 2003; Burkett et al., 2005). Widespread submergence is expected in the case of the coast of the Wadden Sea if the rate of relative sea-level rise exceeds 10 mm/yr (van Goor et al., 2003). For each coastal system the critical threshold will have a specific value, depending on hydrodynamic and sedimentary characteristics. Abrupt and persistent flooding occurs in coastal Argentina when landward winds (sudestadas) and/or heavy rainfall coincide with storm surges (Canziani and Gimenez, 2002; Codignotto, 2004a), further emphasising non-linearities between several interacting factors. Better understanding of thresholds in, and non-linear behaviour of, coastal systems will enhance the ability of managers and engineers to plan more effective coastal protection strategies, including the placement of coastal buildings, infrastructure and defences.

6.2.5 Observed effects of climate change on coastal systems

Trenberth et al. (2007) and Bindoff et al. (2007) observed a number of important climate change-related effects relevant to coastal zones. Rising CO_2 concentrations have lowered ocean surface pH by 0.1 unit since 1750, although to date no significant impacts on coastal ecosystems have been identified. Recent trend analyses indicate that tropical cyclones have increased in intensity (see Section 6.3.2). Global sea levels rose at 1.7 ± 0.5 mm/yr through the 20th century, while global mean sea surface temperatures have risen about 0.6°C since 1950, with associated atmospheric warming in coastal areas (Bindoff et al., 2007).

Many coasts are experiencing erosion and ecosystem losses (Sections 6.2.1 and 6.4.1), but few studies have unambiguously quantified the relationships between observed coastal land loss and the rate of sea-level rise (Zhang et al., 2004; Gibbons and Nicholls, 2006). Coastal erosion is observed on many shorelines around the world, but it usually remains unclear to what extent these losses are associated with relative sea-level rise due to subsidence, and other human drivers of land loss, and to what extent they result from global warming (Hansom, 2001; Jackson et al., 2002; Burkett et al., 2005; Wolters et al., 2005) (see Chapter 1, Section 1.3.3). Long-term ecological studies of rocky shore communities indicate adjustments apparently coinciding with climatic trends (Hawkins et al., 2003). However, for mid-latitudinal coastal systems it is often difficult to discriminate the extent to which such changes are a part of natural variability; and the clearest evidence of the impact of climate change on coasts over the past few decades comes from high and low latitudes, particularly polar coasts and tropical reefs.

There is evidence for a series of adverse impacts on polar coasts, although warmer conditions in high latitudes can have positive effects, such as longer tourist seasons and improved navigability (see Chapter 15, Section 15.4.3.2). Traditional knowledge also points to widespread coastal change across the North American Arctic from the Northwest Territories, Yukon and Alaska in the west to Nunavut in the east (Fox, 2003). Reduced sea-ice cover means a greater potential for wave generation where the coast is exposed (Johannessen et al., 2002; Forbes, 2005; Kont et al., 2007). Moreover, relative sea-level rise on low-relief, easily eroded, shores leads to rapid retreat, accentuated by melting of permafrost that binds coastal sediments, warmer ground temperatures, enhanced thaw, and subsidence associated with the melting of massive ground ice, as recorded at sites in Arctic Canada (Forbes et al., 2004b; Manson et al., 2006), northern USA (Smith, 2002b; Lestak et al., 2004) and northern Russia (Koreysha et al., 2002; Nikiforov et al., 2003; Ogorodov, 2003). Mid-latitude coasts with seasonal sea ice may also respond to reduced ice cover; ice extent has diminished over recent decades in the Bering and Baltic Seas (ARAG, 1999; Jevrejeva et al., 2004) and possibly in the Gulf of St. Lawrence (Forbes et al., 2002).

Global warming poses a threat to coral reefs, particularly any increase in sea surface temperature (SST). The synergistic effects of various other pressures, particularly human impacts such as over-fishing, appear to be exacerbating the thermal stresses on reef systems and, at least on a local scale, exceeding the thresholds beyond which coral is replaced by other organisms (Buddemeier et al., 2004). These impacts and their likely consequences are considered in Box 6.1, the threat posed by ocean acidification is examined in Chapter 4, Section 4.4.9, the impact of multiple stresses is examined in Box 16.2, and the example of the Great Barrier Reef, where decreases in coral cover could have major negative impacts on tourism, is described in Chapter 11, Section 11.6.

Box 6.1. Environmental thresholds and observed coral bleaching

Coral bleaching, due to the loss of symbiotic algae and/or their pigments, has been observed on many reefs since the early 1980s. It may have previously occurred, but gone unrecorded. Slight paling occurs naturally in response to seasonal increases in sea surface temperature (SST) and solar radiation. Corals bleach white in response to anomalously high SST (~1°C above average seasonal maxima, often combined with high solar radiation). Whereas some corals recover their natural colour when environmental conditions ameliorate, their growth rate and reproductive ability may be significantly reduced for a substantial period. If bleaching is prolonged, or if SST exceeds 2°C above average seasonal maxima, corals die. Branching species appear more susceptible than massive corals (Douglas, 2003).

Major bleaching events were observed in 1982-83, 1987-88 and 1994-95 (Hoegh-Guldberg, 1999). Particularly severe bleaching occurred in 1998 (Figure 6.2), associated with pronounced El Niño events in one of the hottest years on record (Lough, 2000; Bruno et al., 2001). Since 1998 there have been several extensive bleaching events. For example, in 2002 bleaching occurred on much of the Great Barrier Reef (Berkelmans et al., 2004; see Chapter 11, Section 11.6) and elsewhere. Reefs in the eastern Caribbean experienced a massive bleaching event in late 2005, another of the hottest years on record. On many Caribbean reefs, bleaching exceeded that of 1998 in both extent and mortality (Figure 6.2), and reefs are in decline as a result of the synergistic effects of multiple stresses (Gardner et al., 2005; McWilliams et al., 2005; see Box 16.2). There is considerable variability in coral susceptibility and recovery to elevated SST in both time and space, and in the incidence of mortality (Webster et al., 1999; Wilkinson, 2002; Obura, 2005).

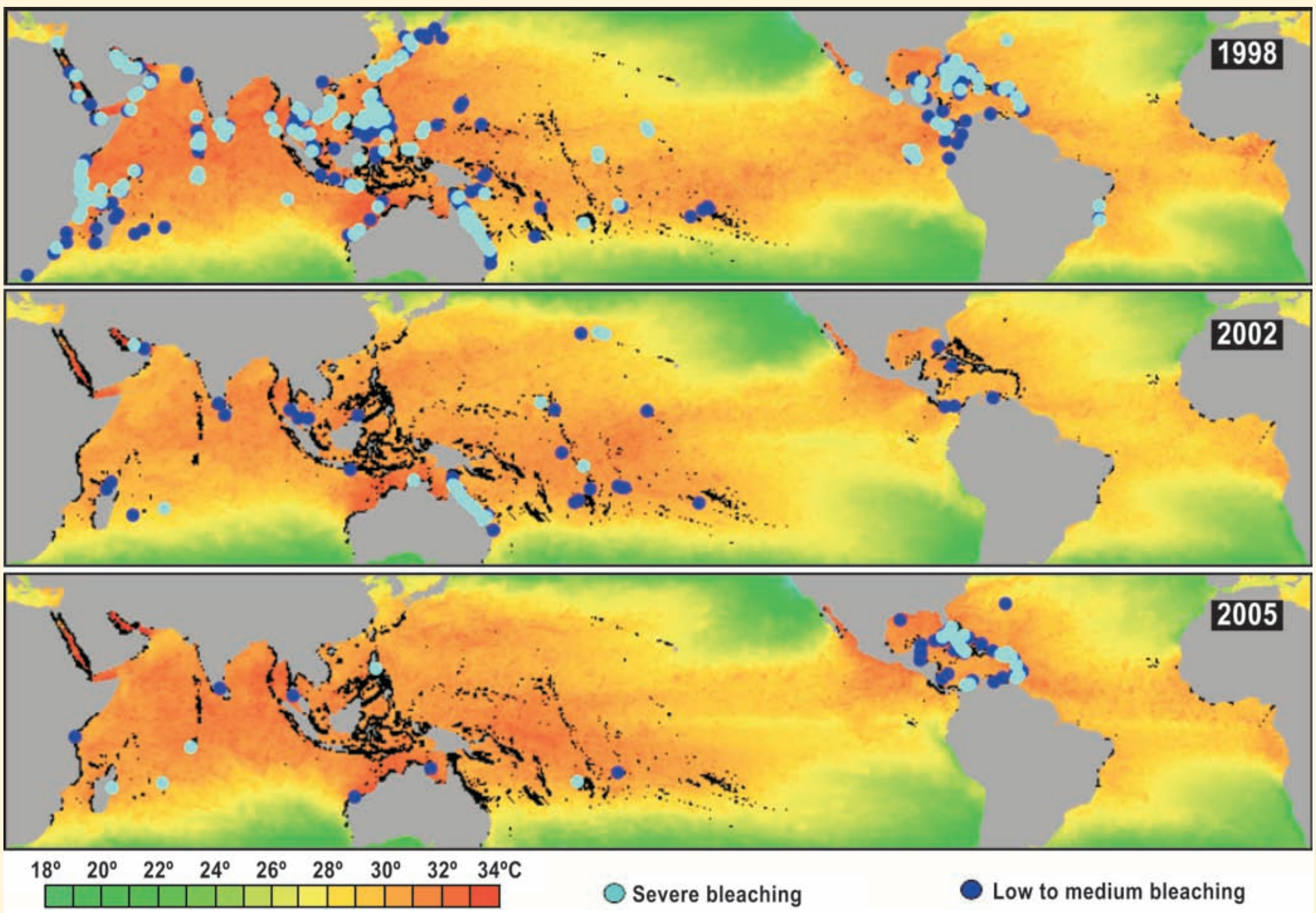

Figure 6.2. *Maximum monthly mean sea surface temperature for 1998, 2002 and 2005, and locations of reported coral bleaching (data source, NOAA Coral Reef Watch (coralreefwatch.noaa.gov) and Reefbase (www.reefbase.org)).*

Global climate model results imply that thermal thresholds will be exceeded more frequently with the consequence that bleaching will recur more often than reefs can sustain (Hoegh-Guldberg, 1999, 2004; Donner et al., 2005), perhaps almost annually on some reefs in the next few decades (Sheppard, 2003; Hoegh-Guldberg, 2005). If the threshold remains unchanged, more frequent bleaching and mortality seems inevitable (see Figure 6.3a), but with local variations due to different susceptibilities to factors such as water depth. Recent preliminary studies lend some support to the adaptive bleaching hypothesis, indicating that the coral host may be able to adapt or acclimatise as a result of expelling one clade[1] of symbiotic algae but recovering with a new one (termed shuffling, see Box 4.4), creating 'new' ecospecies with different temperature tolerances (Coles and Brown, 2003; Buddemeier et al., 2004; Little et al., 2004; Obura, 2005; Rowan, 2004). Adaptation or acclimatisation might result in an increase in the threshold temperature at which bleaching occurs (Figure 6.3b). The extent to which the thermal threshold could increase with warming of more than a couple of degrees remains very uncertain, as are the effects of additional stresses, such as reduced carbonate supersaturation in surface waters (see Box 4.4) and non-climate stresses (see Box 16.2). Corals and other calcifying organisms (e.g., molluscs, foraminifers) remain extremely susceptible to increases in SST. Bleaching events reported in recent years have already impacted many reefs, and their more frequent recurrence is very likely to further reduce both coral cover and diversity on reefs over the next few decades.

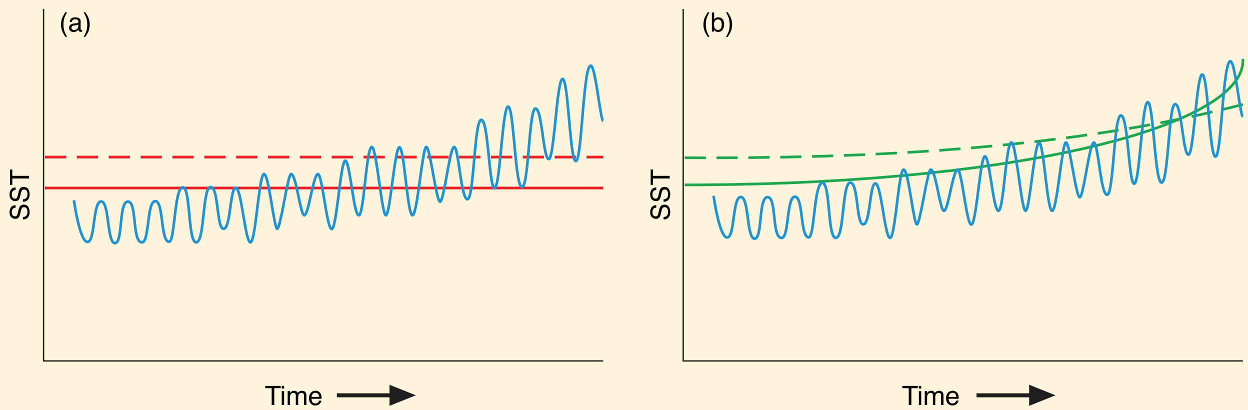

Figure 6.3. *Alternative hypotheses concerning the threshold SST at which coral bleaching occurs; a) invariant threshold for coral bleaching (red line) which occurs when SST exceeds usual seasonal maximum threshold (by ~1°C) and mortality (dashed red line, threshold of 2°C), with local variation due to different species or water depth; b) elevated threshold for bleaching (green line) and mortality (dashed green line) where corals adapt or acclimatise to increased SST (based on Hughes et al., 2003).*

6.3 Assumptions about future trends for coastal systems and low-lying areas

This section builds on Chapter 2 and Section 6.2 to develop relevant environmental, socio-economic, and climate change scenarios for coastal areas through the 21st century. The IPCC Special Report on Emissions Scenarios (SRES; Nakićenović and Swart, 2000) provides one suitable framework (Arnell et al., 2004; Chapter 2, Section 2.4).

National coastal socio-economic scenarios have also been developed for policy analysis, including links to appropriate climate change scenarios. Examples include the UK Foresight Flood and Coastal Defence analysis (Evans et al., 2004a,b; Thorne et al., 2006), and the US National Assessment (NAST, 2000), while model-based methods have been applied to socio-economic futures in the Ebro delta, Spain (Otter, 2000; Otter et al., 2001). However, socio-economic scenarios of coastal areas are underdeveloped relative to climate and sea-level scenarios.

6.3.1 Environmental and socio-economic trends

In the SRES, four families of socio-economic scenarios (A1, A2, B1 and B2) represent different world futures in two distinct dimensions: a focus on economic versus environmental concerns, and global versus regional development patterns. In all four cases, global gross domestic product (GDP) increases substantially and there is economic convergence at differing rates. Global population also increases to 2050 but, in the A1/B1 futures, the population subsequently declines, while in A2/B2 it continues to grow throughout the 21st century (see Chapter 2, Box 2.2). Relevant trends for coastal areas under the SRES scenarios are described in Table 6.1.

6.3.2 Climate and sea-level scenarios

In terms of climate change, the SRES scenarios in Section 6.3.1 translate into six greenhouse-gas emission 'marker' scenarios: one each for the A2, B1 and B2 worlds, and three scenarios for the A1 world – A1T (non-fossil fuel sources), A1B (balanced fuel sources) and A1FI (fossil-intensive fuel sources) (Nakićenović and Swart, 2000). B1 produces the lowest emissions and A1FI produces the highest emissions (see Chapter 2).

Table 6.2 summarises the range of potential drivers of climate change impacts in coastal areas, including the results from Meehl et al. (2007) and Christensen et al. (2007). In most cases

[1] A clade of algae is a group of closely related, but nevertheless different, types.

there will be significant regional variations in the changes, and any impacts will be the result of the interaction between these climate change drivers and other drivers of change, leading to diverse effects and vulnerabilities (Sections 6.2 and 6.4).

Understanding of the relevant climate-change drivers for coastal areas has improved since the TAR. Projected global mean changes under the SRES scenarios are summarised in Table 6.3. As atmospheric CO_2 levels increase, more CO_2 is absorbed by surface waters, decreasing seawater pH and carbonate saturation (Andersson et al., 2003; Royal Society, 2005; Turley et al., 2006). A significant increase in atmospheric CO_2 concentration appears virtually certain (Table 6.3). Sea surface temperatures are also virtually certain to rise significantly (Table 6.3), although less than the global mean temperature rise. The rise will not be spatially uniform, with possible intensification of ENSO and time variability which suggests greater change in extremes with important implications for coral reefs (Box 6.1).

Table 6.1. *Selected global non-climatic environmental and socio-economic trends relevant to coastal areas for the SRES storylines. Regional and local deviations are expected.*

Environmental and socio-economic factors	Non-climatic changes and trends for coastal and low-lying areas (by SRES Future)			
	'A1 World'	'A2 World'	'B1 World'	'B2 World'
Population (2080s) (billions)[a]	1.8 to 2.4	3.2 to 5.2	1.8 to 2.4	2.3 to 3.4
Coastward migration	Most likely	Less likely	More likely	Least likely
Human-induced subsidence[b]	More likely		Less likely	
Terrestrial freshwater/sediment supply (due to catchment management)	Greatest reduction	Large reduction	Smallest reduction	Smaller reduction
Aquaculture growth	Large increase		Smaller increase	
Infrastructure growth	Largest	Large	Smaller	Smallest
Extractive industries	Larger		Smaller	
Adaptation response	More reactive		More proactive	
Hazard risk management	Lower priority		Higher priority	
Habitat conservation	Low priority		High priority	
Tourism growth	Highest	High	High	Lowest

[a] Population living both below 100 m elevation above sea level and within 100 km distance of the coast – uncertainty depends on assumptions about coastward migration (Nicholls, 2004).
[b] Subsidence due to sub-surface fluid withdrawal and drainage of organic soils in susceptible coastal lowlands.

Table 6.2. *Main climate drivers for coastal systems (Figure 6.1), their trends due to climate change, and their main physical and ecosystem effects. (Trend: ↑ increase; ? uncertain; R regional variability).*

Climate driver (trend)	Main physical and ecosystem effects on coastal systems (discussed in Section 6.4.1)
CO_2 concentration (↑)	Increased CO_2 fertilisation; decreased seawater pH (or 'ocean acidification') negatively impacting coral reefs and other pH sensitive organisms.
Sea surface temperature (↑, R)	Increased stratification/changed circulation; reduced incidence of sea ice at higher latitudes; increased coral bleaching and mortality (see Box 6.1); poleward species migration; increased algal blooms
Sea level (↑, R)	Inundation, flood and storm damage (see Box 6.2); erosion; saltwater intrusion; rising water tables/impeded drainage; wetland loss (and change).
Storm intensity (↑, R)	Increased extreme water levels and wave heights; increased episodic erosion, storm damage, risk of flooding and defence failure (see Box 6.2).
Storm frequency (?, R) Storm track (?, R)	Altered surges and storm waves and hence risk of storm damage and flooding (see Box 6.2).
Wave climate (?, R)	Altered wave conditions, including swell; altered patterns of erosion and accretion; re-orientation of beach plan form.
Run-off (R)	Altered flood risk in coastal lowlands; altered water quality/salinity; altered fluvial sediment supply; altered circulation and nutrient supply.

Table 6.3. *Projected global mean climate parameters relevant to coastal areas at the end of the 21st century for the six SRES marker scenarios (from Meehl et al., 2007).*

Climate driver			B1	B2	A1B	A1T	A2	A1FI
Surface ocean pH (baseline today: 8.1)			8.0	7.9	7.9	7.9	7.8	7.7
SST rise (°C) (relative to 1980-1999)			1.5	-	2.2	-	2.6	-
Sea-level rise (relative to 1980-1999)	Best estimate (m)		0.28	0.32	0.35	0.33	0.37	0.43
	Range (m)	5%	0.19	0.21	0.23	0.22	0.25	0.28
		95%	0.37	0.42	0.47	0.44	0.50	0.58

The global mean sea-level rise scenarios (Table 6.3) are based on thermal expansion and ice melt; the best estimate shows an acceleration of up to 2.4 times compared to the 20th century. These projections are smaller than those of Church et al. (2001), reflecting improved understanding, especially of estimates of ocean heat uptake. If recently observed increases in ice discharge rates from the Greenland and Antarctic ice sheets were to increase linearly with global mean temperature change, this would add a 0.05 to 0.11 m rise for the A1FI scenario over the 21st century (Meehl et al., 2007). (Large and long-term sea-level rise beyond 2100 is considered in Box 6.6.)

Importantly, local (or relative) changes in sea level depart from the global mean trend due to regional variations in oceanic level change and geological uplift/subsidence; it is relative sea-level change that drives impacts and is of concern to coastal managers (Nicholls and Klein, 2005; Harvey, 2006a). Meehl et al. (2007) found that regional sea-level change will depart significantly from the global mean trends in Table 6.3: for the A1B scenario the spatial standard deviation by the 2080s is 0.08 m, with a larger rise than average in the Arctic. While there is currently insufficient understanding to develop detailed scenarios, Hulme et al. (2002) suggested that impact analysis should explore additional sea-level rise scenarios of +50% the amount of global mean rise, plus uplift/subsidence, to assess the full range of possible change. Although this approach has been followed in the UK (Pearson et al., 2005; Thorne et al., 2006), its application elsewhere is limited to date.

Furthermore, coasts subsiding due to natural or human-induced causes will experience larger relative rises in sea level (Bird, 2000). In some locations, such as deltas and coastal cities, this effect can be significant (Dixon et al., 2006; Ericson et al., 2006).

Increases of extreme sea levels due to rises in mean sea level and/or changes in storm characteristics (Table 6.2) are of widespread concern (Box 6.2). Meehl et al. (2007) found that models suggest both tropical and extra-tropical storm intensity will increase. This implies additional coastal impacts than attributable to sea-level rise alone, especially for tropical and mid-latitude coastal systems. Increases in tropical cyclone intensity over the past three decades are consistent with the observed changes in SST (Emanuel, 2005; Webster et al., 2005). Changes in other storm characteristics are less certain and the number of tropical and extra-tropical storms might even reduce (Meehl et al., 2007). Similarly, future wave climate is uncertain, although extreme wave heights will likely increase with more intense storms (Meehl et al., 2007). Changes in runoff driven by changes to the hydrological cycle appear likely, but the uncertainties are large. Milly et al. (2005) showed increased discharges to coastal waters in the Arctic, in northern Argentina and southern Brazil, parts of the Indian sub-continent, China and Australia, while reduced discharges to coastal waters are suggested in southern Argentina and Chile, Western and Southern Africa, and in the Mediterranean Basin. The additional effects of catchment management also need to be considered (Table 6.1).

6.4 Key future impacts and vulnerabilities

The following sections characterise the coastal ecosystem impacts that are anticipated to result from the climate change summarised in Figures 6.1 and Table 6.2. The summary of impacts on natural coastal systems and implications for human society (including ecosystem services) leads to the recognition of key vulnerabilities and hotspots.

6.4.1 Natural system responses to climate change drivers

6.4.1.1 Beaches, rocky shorelines and cliffed coasts

Most of the world's sandy shorelines retreated during the past century (Bird, 1985; NRC, 1990; Leatherman, 2001; Eurosion, 2004) and sea-level rise is one underlying cause (see Section 6.2.5 and Chapter 1, Section 1.3.3). One half or more of the Mississippi and Texas shorelines have eroded at average rates of 3.1 to 2.6 m/yr since the 1970s, while 90% of the Louisiana shoreline eroded at a rate of 12.0 m/yr (Morton et al., 2004). In Nigeria, retreat rates up to 30 m/yr are reported (Okude and Ademiluyi, 2006). Coastal squeeze and steepening are also widespread as illustrated along the eastern coast of the United Kingdom where 67% of the coastline experienced a landward retreat of the low-water mark over the past century (Taylor et al., 2004).

An acceleration in sea-level rise will widely exacerbate beach erosion around the globe (Brown and McLachlan, 2002), although the local response will depend on the total sediment budget (Stive et al., 2002; Cowell et al., 2003a,b). The widely cited Bruun (1962) model suggests that shoreline recession is in the range 50 to 200 times the rise in relative sea level. While supported by field data in ideal circumstances (Zhang et al., 2004), wider application of the Bruun model remains controversial (Komar, 1998; Cooper and Pilkey, 2004; Davidson-Arnott, 2005). An indirect, less-frequently examined influence of sea-level rise on the beach sediment budget is due to the infilling of coastal embayments. As sea-level rises, estuaries and lagoons attempt to maintain equilibrium by raising their bed elevation in tandem, and hence potentially act as a major sink of sand which is often derived from the open coast (van Goor et al., 2001; van Goor et al., 2003; Stive, 2004). This process can potentially cause erosion an order of magnitude or more greater than that predicted by the Bruun model (Woodworth et al., 2004), implying the potential for major coastal instability due to sea-level rise in the vicinity of tidal inlets. Several recent studies indicate that beach protection strategies and changes in the behaviour or frequency of storms can be more important than the projected acceleration of sea-level rise in determining future beach erosion rates (Ahrendt, 2001; Leont'yev, 2003). Thus there is not a simple relationship between sea-level rise and horizontal movement of the shoreline, and sediment budget approaches are most useful to assess beach response to climate change (Cowell et al., 2006).

The combined effects of beach erosion and storms can lead to the erosion or inundation of other coastal systems. For example, an increase in wave heights in coastal bays is a secondary effect of sandy barrier island erosion in Louisiana, and increased wave

Box 6.2. Examples of extreme water level simulations for impact studies

Although inundation by increases in mean sea level over the 21st century and beyond will be a problem for unprotected low-lying areas, the most devastating impacts are likely to be associated with changes in extreme sea levels resulting from the passage of storms (e.g., Gornitz et al., 2002), especially as more intense tropical and extra-tropical storms are expected (Meehl et al., 2007). Simulations show that future changes are likely to be spatially variable, and a high level of detail can be modelled (see also Box 11.5 in Christensen et al. (2007).

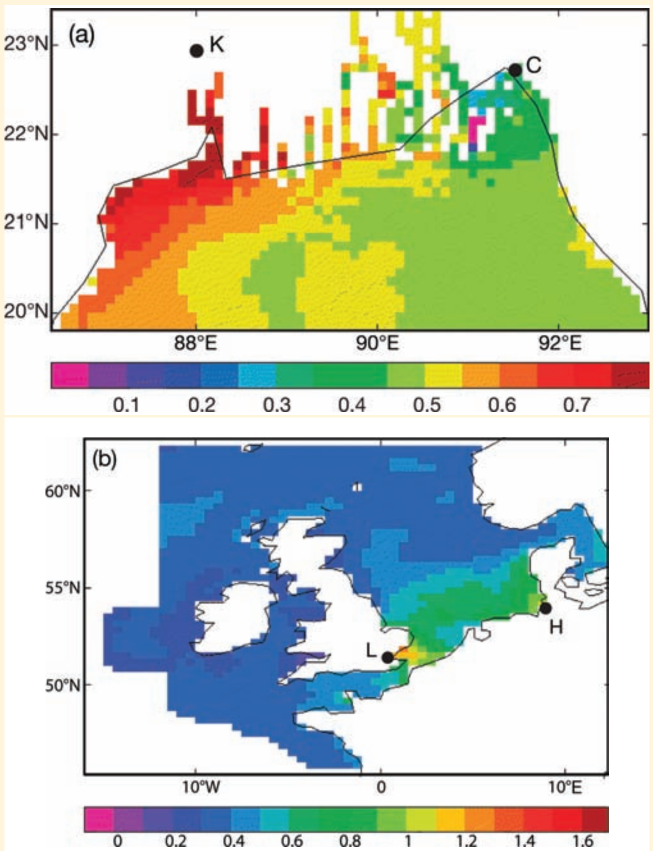

Figure 6.4. *Increases in the height (m) of the 50-year extreme water level. (a) In the northern Bay of Bengal under the IS92a climate scenario in 2040-2060 (K – Kolkata (Calcutta), C – Chittagong) (adapted from Mitchell et al., 2006). (b) Around the UK for the A2 scenario in the 2080s (L – London; H – Hamburg) (adapted from Lowe and Gregory, 2005).*

Figures 6.4 and 6.5 are based on barotropic surge models driven by climate change projections for two flood-prone regions. In the northern Bay of Bengal, simulated changes in storminess cause changes in extreme water levels. When added to consistent relative sea-level rise scenarios, these result in increases in extreme water levels across the Bay, especially near Kolkata (Figure 6.4a). Around the UK, extreme high sea levels also occur. The largest change near London has important implications for flood defence (Figure 6.4b; Dawson et al., 2005; Lavery and Donovan, 2005). Figure 6.5 shows the change in flooding due to climate change for Cairns (Australia). It is based on a combination of stochastic sampling and dynamic modelling. This assumes a 10% increase in tropical cyclone intensity, implying more flooding than sea-level rise alone would suggest. However, detailed patterns and magnitudes of changes in extreme water levels remain uncertain (e.g., Lowe and Gregory, 2005); better quantification of this uncertainty and further field validation would support wider application of such scenarios.

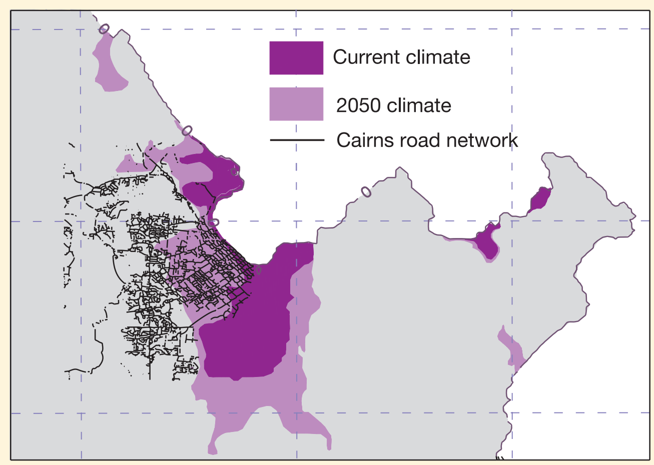

Figure 6.5. *Flooding around Cairns, Australia during the >100 year return-period event under current and 2050 climate conditions based on a 2xCO2 scenario. The road network is shown in black (based on McInnes et al., 2003).*

heights have enhanced erosion rates of bay shorelines, tidal creeks and adjacent wetlands (Stone and McBride, 1998; Stone et al., 2003). The impacts of accelerated sea-level rise on gravel beaches have received less attention than sandy beaches. These systems are threatened by sea-level rise (Orford et al., 2001, 2003; Chadwick et al., 2005), even under high accretion rates (Codignotto et al., 2001). The persistence of gravel and cobble-boulder beaches will also be influenced by storms, tectonic events and other factors that build and reshape these highly dynamic shorelines (Orford et al., 2001).

Since the TAR, monitoring, modelling and process-oriented research have revealed some important differences in cliff vulnerability and the mechanics by which groundwater, wave climate and other climate factors influence cliff erosion patterns and rates. Hard rock cliffs have a relatively high resistance to erosion, while cliffs formed in softer lithologies are likely to retreat more rapidly in the future due to increased toe erosion resulting from sea-level rise (Cooper and Jay, 2002). Cliff failure and retreat may be amplified in many areas by increased precipitation and higher groundwater levels: examples include UK, Argentina and France (Hosking and McInnes, 2002; Codignotto, 2004b; Pierre and Lahousse, 2006). Relationships between cliff retreat, freeze-thaw cycles and air temperature records have also been described (Hutchinson, 1998). Hence, four physical features of climate change – temperature, precipitation, sea level and wave climate – can affect the stability of soft rock cliffs.

Soft rock cliff retreat is usually episodic with many metres of cliff top retreat occurring locally in a single event, followed by relative quiescence for significant periods (Brunsden, 2001; Eurosion, 2004). Considerable progress has been made in the long-term prediction of cliff-top, shore profile and plan-shape evolution of soft rock coastlines by simulating the relevant physical processes and their interactions (Hall et al., 2002; Trenhaile, 2002, 2004). An application of the SCAPE (Soft Cliff and Platform Erosion) model (Dickson et al., 2005; Walkden and Hall, 2005) to part of Norfolk, UK has indicated that rates of cliff retreat are sensitive to sea-level rise, changes in wave conditions and sediment supply via longshore transport. For soft cliff areas with limited beach development, there appears to be a simple relationship between long-term cliff retreat and the rate of sea-level rise (Walkden and Dickson, 2006), allowing useful predictions for planning purposes.

6.4.1.2 Deltas

Deltaic landforms are naturally shaped by a combination of river, wave and tide processes. River-dominated deltas receiving fluvial sediment input show prominent levees and channels that meander or avulse[2], leaving abandoned channels on the coastal plains. Wave-dominated deltas are characterised by shore-parallel sand ridges, often coalescing into beach-ridge plains. Tide domination is indicated by exponentially tapering channels, with funnel-shaped mouths. Delta plains contain a diverse range of landforms but, at any time, only part of a delta is active, and this is usually river-dominated, whereas the abandoned delta plain receives little river flow and is progressively dominated by marine processes (Woodroffe, 2003).

Human development patterns also influence the differential vulnerability of deltas to the effects of climate change. Sediment starvation due to dams, alterations in tidal flow patterns, navigation and flood control works are common consequences of human activity (Table 6.1). Changes in surface water runoff and sediment loads can greatly affect the ability of a delta to cope with the physical impacts of climatic change. For example, in the subsiding Mississippi River deltaic plain of south-east Louisiana, sediment starvation and increases in the salinity and water levels of coastal marshes due to human development occurred so rapidly that 1565 km^2 of intertidal coastal marshes and adjacent lands were converted to open water between 1978 and 2000 (Barras et al., 2003). By 2050 about 1300 km^2 of additional coastal land loss is projected if current global, regional and local processes continue; the projected acceleration of sea level and increase in tropical storm intensity (Section 6.3.2) would exacerbate these losses (Barras et al., 2003). Much of this land loss is episodic, as demonstrated during the landfall of Hurricane Katrina (Box 6.4).

Deltas have long been recognised as highly sensitive to sea-level rise (Ericson et al., 2006; Woodroffe et al., 2006) (Box 6.3). Rates of relative sea-level rise can greatly exceed the global average in many heavily populated deltaic areas due to subsidence, including the Chao Phraya delta (Saito, 2001), Mississippi River delta (Burkett et al., 2003) and the Changjiang River delta (Liu, 2002; Waltham, 2002), because of human activities. Natural subsidence due to autocompaction of sediment under its own weight is enhanced by sub-surface fluid withdrawals and drainage (Table 6.1). This increases the potential for inundation, especially for the most populated cities on these deltaic plains (i.e., Bangkok, New Orleans and Shanghai). Most of the land area of Bangladesh consists of the deltaic plains of the Ganges, Brahmaputra and Meghna rivers. Accelerated global sea-level rise and higher extreme water levels (Box 6.2) may have acute effects on human populations of Bangladesh (and parts of West Bengal, India) because of the complex relationships between observed trends in SST over the Bay of Bengal and monsoon rains (Singh, 2001), subsidence and human activity that has converted natural coastal defences (mangroves) to aquaculture (Woodroffe et al., 2006).

Whereas present rates of sea-level rise are contributing to the gradual diminution of many of the world's deltas, most recent losses of deltaic wetlands are attributed to human development. An analysis of satellite images of fourteen of the world's major deltas (Danube, Ganges-Brahmaputra, Indus, Mahanadi, Mangoky, McKenzie, Mississippi, Niger, Nile, Shatt el Arab, Volga, Huanghe, Yukon and Zambezi) indicated a total loss of 15,845 km^2 of deltaic wetlands over the past 14 years (Coleman et al., 2005). Every delta showed land loss, but at varying rates, and human development activities accounted for over half of the losses. In Asia, for example, where human activities have led to increased sediment loads of major rivers in the past, the construction of upstream dams is now seriously depleting the supply of sediments to many deltas with increased coastal erosion a widespread consequence (see Chapter 10, Section 10.4.3.2). As an example, large reservoirs constructed on the Huanghe River in China have reduced the annual sediment delivered to its delta from 1.1 billion metric tons to 0.4 billion metric tons (Li et al., 2004). Human influence is likely to continue to increase throughout Asia and globally (Section 6.2.2; Table 6.1).

Sea-level rise poses a particular threat to deltaic environments, especially with the synergistic effects of other climate and human pressures (e.g., Sánchez-Arcilla et al., 2007). These issues are especially noteworthy in many of the largest deltas with an indicative area $>10^4$ km^2 (henceforth megadeltas) due to their often large populations and important environmental services. The problems of climate change in megadeltas are reflected throughout this report, with a number of chapters considering these issues from complementary perspectives. Box 6.3 considers the vulnerability of delta systems across the globe, and concludes that the large populated Asian megadeltas are especially vulnerable to climate change. Chapter 10, Section 10.6.1 builds on this global

[2] Avulse: when a river changes its course from one channel to another as a result of a flood.

Box 6.3. Deltas and megadeltas: hotspots for vulnerability

Deltas, some of the largest sedimentary deposits in the world, are widely recognised as highly vulnerable to the impacts of climate change, particularly sea-level rise and changes in runoff, as well as being subject to stresses imposed by human modification of catchment and delta plain land use. Most deltas are already undergoing natural subsidence that results in accelerated rates of relative sea-level rise above the global average. Many are impacted by the effects of water extraction and diversion, as well as declining sediment input as a consequence of entrapment in dams. Delta plains, particularly those in Asia (Chapter 10, Section 10.6.1), are densely populated and large numbers of people are often impacted as a result of external terrestrial influences (river floods, sediment starvation) and/or external marine influences (storm surges, erosion) (see Figure 6.1).

Ericson et al. (2006) estimated that nearly 300 million people inhabit a sample of 40 deltas globally, including all the large megadeltas. Average population density is 500 people/km^2 with the largest population in the Ganges-Brahmaputra delta, and the highest density in the Nile delta. Many of these deltas and megadeltas are associated with significant and expanding urban areas. Ericson et al. (2006) used a generalised modelling approach to approximate the effective rate of sea-level rise under present conditions, basing estimates of sediment trapping and flow diversion on a global dam database, and modifying estimates of natural subsidence to incorporate accelerated human-induced subsidence. This analysis showed that much of the population of these 40 deltas is at risk through coastal erosion and land loss, primarily as a result of decreased sediment delivery by the rivers, but also through accentuated rates of sea-level rise. They estimate, using a coarse digital terrain model and global population distribution data, that more than 1 million people will be directly affected by 2050 in three megadeltas: the Ganges-Brahmaputra delta in Bangladesh, the Mekong delta in Vietnam and the Nile delta in Egypt. More than 50,000 people are likely to be directly impacted in each of a further 9 deltas, and more than 5,000 in each of a further 12 deltas (Figure 6.6). This generalised modelling approach indicates that 75% of the population affected live on Asian megadeltas and deltas, and a large proportion of the remainder are on deltas in Africa. These impacts would be exacerbated by accelerated sea-level rise and enhanced human pressures (e.g., Chapter 10, Section 10.6.1). Within the Asian megadeltas, the surface topography is complex as a result of the geomorphological development of the deltas, and the population distribution shows considerable spatial variability, reflecting the intensive land use and the growth of some of the world's largest megacities (Woodroffe et al., 2006). Many people in these and other deltas worldwide are already subject to flooding from both storm surges and seasonal river floods, and therefore it is necessary to develop further methods to assess individual delta vulnerability (e.g., Sánchez-Arcilla et al., 2006).

Figure 6.6. *Relative vulnerability of coastal deltas as shown by the indicative population potentially displaced by current sea-level trends to 2050 (Extreme = >1 million; High = 1 million to 50,000; Medium = 50,000 to 5,000; following Ericson et al., 2006).*

view and examines the Asian megadeltas in more detail. Chapter 5, Box 5.3 considers the threats to fisheries in the lower Mekong and associated delta due to climate change. Hurricane Katrina made landfall on the Mississippi delta in Louisiana, and Box 6.4 and Chapter 7, Box 7.4 consider different aspects of this important event, which gives an indication of the likely impacts if tropical storm intensity continues to increase. Lastly, Section 15.6.2 considers the specific problems of Arctic megadeltas.

6.4.1.3 Estuaries and lagoons

Global mean sea-level rise will generally lead to higher relative coastal water levels and increasing salinity in estuarine systems, thereby tending to displace existing coastal plant and animal communities inland. Estuarine plant and animal communities may persist as sea level rises if migration is not blocked and if the rate of change does not exceed the capacity of natural communities to adapt or migrate. Climate change impacts on one or more 'leverage species', however, can result in sweeping community level changes (Harley et al., 2006).

Some of the greatest potential impacts of climate change on estuaries may result from changes in physical mixing characteristics caused by changes in freshwater runoff (Scavia et al., 2002). A globally intensified hydrologic cycle and regional changes in runoff all portend changes in coastal water quality (Section 6.3.2). Freshwater inflows into estuaries influence water residence time, nutrient delivery, vertical stratification, salinity and control of phytoplankton growth rates. Increased freshwater inflows decrease water residence time and increase vertical stratification, and vice versa (Moore et al., 1997). The effects of altered residence times can have significant effects on phytoplankton populations, which have the potential to increase fourfold per day. Consequently, in estuaries with very short water residence times, phytoplankton are generally flushed from the system as fast as they can grow, reducing the estuary's susceptibility to eutrophication[3] and harmful algal blooms (HABs) (Section 6.4.2.4). Changes in the timing of freshwater delivery to estuaries could lead to a decoupling of the juvenile phases of many estuarine and marine fishery species from the available nursery habitat. In some hypersaline lagoonal systems, such as the Laguna Madre of Mexico and Texas, sea-level rise will increase water depths, leading to increased tidal exchange and hence reduced salinity (cf. Quammen and Onuf, 1993).

Increased water temperature could also affect algal production and the availability of light, oxygen and carbon for other estuarine species (Short and Neckles, 1999). The propensity for HABs is further enhanced by the fertilisation effect of increasing dissolved CO_2 levels. Increased water temperature also affects important microbial processes such as nitrogen fixation and denitrification in estuaries (Lomas et al., 2002). Water temperature regulates oxygen and carbonate solubility, viral pestilence, pH and conductivity, and photosynthesis and respiration rates of estuarine macrophytes[4]. While temperature is important in regulating physiological processes in estuaries (Lomas et al., 2002), predicting the ecological outcome is complicated by the feedbacks and interactions among temperature change and independent physical and biogeochemical processes such as eutrophication (cf. Section 6.2.4).

Decreased seawater pH and carbonate saturation (Mackenzie et al., 2001; Caldeira and Wickett, 2005) has at least two important consequences: the potential for reducing the ability of carbonate flora and fauna to calcify; and the potential for enhanced dissolution of nutrients and carbonate minerals in sediments (Andersson et al., 2003; Royal Society, 2005; Turley et al., 2006). As these potential impacts could be significant, it is important to improve understanding of them.

The landward transgression of natural estuarine shorelines as sea level rises has been summarised by Pethick (2001), who adopted a mass balance approach based on an equilibrium assumption resulting in landward retreat of the entire estuarine system. In this view, sea level rise of 6 mm causes 10 m of retreat of the Blackwater estuary, UK, and only 8 m of retreat for the Humber estuary, UK, due to the steeper gradient of the latter. The Humber estuary will also likely experience a deepening of the main channel, changes in tidal regime and larger waves that will promote further erosion around the margins (Winn et al., 2003). In Venice Lagoon, Italy, the combination of sea-level rise, altered sediment dynamics, and geological land subsidence has lowered the lagoon floor, widened tidal inlets, submerged tidal flats and islands, and caused the shoreline to retreat around the lagoon circumference (Fletcher and Spencer, 2005). In situations where the area of intertidal environments has been reduced by embanking or reclamation, the initial response will be a lowering of remaining tidal flats and infilling of tidal channels. Depending on tidal characteristics, the availability of marine sediment, and the rate of sea-level rise, the remaining tidal flats may either be further drowned, or their relative level in the tidal frame may be maintained, as shown by several tidal basins in the Dutch Wadden Sea (Dronkers, 2005).

A projected increase in the intensity of tropical cyclones and other coastal storms (Section 6.3.2) could alter bottom sediment dynamics, organic matter inputs, phytoplankton and fisheries populations, salinity and oxygen levels, and biogeochemical processes in estuaries (Paerl et al., 2001). The role of powerful storms in structuring estuarine sediments and biodiversity is illustrated in the stratigraphic record of massive, episodic estuary infilling of Bohai Bay, China during the Holocene, with alternating oyster reefs and thick mud deposits (Wang and Fan, 2005).

6.4.1.4 Mangroves, saltmarshes and sea grasses

Coastal vegetated wetlands are sensitive to climate change and long-term sea-level change as their location is intimately linked to sea level. Modelling of all coastal wetlands (but excluding sea grasses) by McFadden et al. (2007a) suggests global losses from 2000 to 2080 of 33% and 44% given a 36 cm and 72 cm rise in sea level, respectively. Regionally, losses would be most severe on the Atlantic and Gulf of Mexico coasts of North and Central America, the Caribbean, the Mediterranean, the Baltic and most small island regions due to

[3] Eutrophication: over-enrichment of a water body with nutrients, resulting in excessive growth of organisms and depletion of oxygen concentration.
[4] Macrophytes: aquatic plants large enough to be visible to the naked eye.

their low tidal range (Nicholls, 2004). However, wetland processes are complex, and Cahoon et al. (2006) developed a broad regional to global geographical model relating wetland accretion, elevation, and shallow subsidence in different plate tectonic, climatic and geomorphic settings for both temperate saltmarshes and tropical mangrove forests. Changes in storm intensity can also affect vegetated coastal wetlands. Cahoon et al. (2003) analysed the elevation responses from a variety of hurricane-influenced coastal settings and found that a storm can simultaneously influence both surface and subsurface soil processes, but with much variability.

Saltmarshes (halophytic grasses, sedges, rushes and succulents) are common features of temperate depositional coastlines. Hydrology and energy regimes are two key factors that influence the coastal zonation of the plant species which typically grade inland from salt, to brackish, to freshwater species. Climate change will likely have its most pronounced effects on brackish and freshwater marshes in the coastal zone through alteration of hydrological regimes (Burkett and Kusler, 2000; Baldwin et al., 2001; Sun et al., 2002), specifically, the nature and variability of hydroperiod and the number and severity of extreme events. Other variables – altered biogeochemistry, altered amounts and pattern of suspended sediments loading, fire, oxidation of organic sediments, and the physical effects of wave energy – may also play important roles in determining regional and local impacts.

Sea-level rise does not necessarily lead to loss of saltmarsh areas, especially where there are significant tides, because these marshes accrete vertically and maintain their elevation relative to sea level where the supply of sediment is sufficient (Hughes, 2004; Cahoon et al., 2006). The threshold at which wetlands drown varies widely depending upon local morphodynamic processes. Saltmarshes of some mesotidal and high tide range estuaries (e.g., Tagus estuary, Portugal) are susceptible to sea-level rise only in a worst-case scenario. Similarly, wetlands with high sediment inputs in the south-east United States would remain stable relative to sea level unless the rate of sea-level rise accelerates to nearly four times its current rate (Morris et al., 2002). Yet, even sediment inputs from frequently recurring hurricanes cannot compensate for subsidence effects combined with predicted accelerations in sea-level rise in rapidly subsiding marshes of the Mississippi River delta (Rybczyk and Cahoon, 2002).

Mangrove forests dominate intertidal subtropical and tropical coastlines between 25ºN and 25ºS latitude. Mangrove communities are likely to show a blend of positive responses to climate change, such as enhanced growth resulting from higher levels of CO_2 and temperature, as well as negative impacts, such as increased saline intrusion and erosion, largely depending on site-specific factors (Saenger, 2002). The response of coastal forested wetlands to climate change has not received the detailed research and modelling that has been directed towards the saltmarsh coasts of North America (Morris et al., 2002; Reed, 2002; Rybczyk and Cahoon, 2002) and north-west Europe (Allen, 2000, 2003). Nevertheless, it seems highly likely that similar principles are in operation and that the sedimentary response of the shoreline is a function of both the availability of sediment (Walsh and Nittrouer, 2004) and the ability of the organic production by mangroves themselves to fill accommodation space provided by sea-level rise (Simas et al., 2001). Mangroves are able to produce root material that builds up the substrate beneath them (Middleton and McKee, 2001; Jennerjahn and Ittekkot, 2002), but collapse of peat occurs rapidly in the absence of new root growth, as observed after Hurricane Mitch (Cahoon et al., 2003) and after lightning strikes (Sherman et al., 2000). Groundwater levels play an important role in the elevation of mangrove soils by processes affecting soil shrink and swell. Hence, the influence of hydrology should be considered when evaluating the effect of disturbances, sea-level rise and water management decisions on mangrove systems (Whelan et al., 2005). A global assessment of mangrove accretion rates by Saenger (2002) indicates that vertical accretion is variable but commonly approaches 5 mm/yr. However, many mangrove shorelines are subsiding and thus experiencing a more rapid relative sea-level rise (Cahoon et al., 2003).

A landward migration of mangroves into adjacent wetland communities has been recorded in the Florida Everglades during the past 50 years (Ross et al., 2000), apparently responding to sea-level rise over that period. Mangroves have extended landward into saltmarsh over the past five decades throughout south-east Australia, but the influence of sea-level rise in this region is considered minor compared to that of human disturbance (Saintilan and Williams, 1999) and land surface subsidence (Rogers et al., 2005, 2006). Rapid expansion of tidal creeks has been observed in northern Australia (Finlayson and Eliot, 2001; Hughes, 2003). Sea-level rise and salt water intrusion have been identified as a causal factor in the decline of coastal bald cypress (Taxodium disticum) forests in Louisiana (Krauss et al., 2000; Melillo et al., 2000) and die off of cabbage palm (Sabal palmetto) forests in coastal Florida (Williams et al., 1999, 2003).

On balance, coastal wetlands will decline with rising sea levels and other climate and human pressures (reduced sediment inputs, coastal squeeze constraints on landward migration, etc.) will tend to exacerbate these losses. However, the processes shaping these environments are complex and while our understanding has improved significantly over the last 10 years, it remains far from complete. Continued work on the basic science and its application to future prognosis at local, regional and global scales remains a priority (Cahoon et al., 2006; McFadden et al., 2007a).

Sea grasses appear to be declining around many coasts due to human impacts, and this is expected to accelerate if climate change alters environmental conditions in coastal waters (Duarte, 2002). Changes in salinity and temperature and increased sea level, atmospheric CO_2, storm activity and ultraviolet irradiance alter sea grass distribution, productivity and community composition (Short and Neckles, 1999). Increases in the amount of dissolved CO_2 and, for some species, HCO_3 present in aquatic environments, will lead to higher rates of photosynthesis in submerged aquatic vegetation, similar to the effects of CO_2 enrichment on most terrestrial plants, if nutrient availability or other limiting factors do not offset the potential for enhanced productivity. Increases in growth and biomass with elevated CO_2 have been observed for the sea grass *Z. marina* (Zimmerman et al., 1997). Algae growth in lagoons and estuaries may also respond positively to elevated dissolved inorganic carbon (DIC), though marine macroalgae do not appear to be limited by DIC levels (Beer and Koch, 1996). An increase in epiphytic or suspended algae would decrease light available to submerged aquatic vegetation in estuarine and lagoonal systems.

6.4.1.5 Coral reefs

Reef-building corals are under stress on many coastlines (see Chapter 1, Section 1.3.4.1). Reefs have deteriorated as a result of a combination of anthropogenic impacts such as overfishing and pollution from adjacent land masses (Pandolfi et al., 2003; Graham et al., 2006), together with an increased frequency and severity of bleaching associated with climate change (Box 6.1). The relative significance of these stresses varies from site to site. Coral mortality on Caribbean reefs is generally related to recent disease outbreaks, variations in herbivory[5], and hurricanes (Gardner et al., 2003; McWilliams et al., 2005), whereas Pacific reefs have been particularly impacted by episodes of coral bleaching caused by thermal stress anomalies especially during recent El Niño events (Hughes et al., 2003), as well as non-climate stresses.

Mass coral bleaching events are clearly correlated with rises of SST of short duration above summer maxima (Douglas, 2003; Lesser, 2004; McWilliams et al., 2005). Particularly extensive bleaching was recorded across the Indian Ocean region associated with extreme El Niño conditions in 1998 (Box 6.1 and Chapter 11, Section 11.6: Climate change and the Great Barrier Reef case study). Many reefs appear to have experienced similar SST conditions earlier in the 20th century and it is unclear how extensive bleaching was before widespread reporting post-1980 (Barton and Casey, 2005). There is limited ecological and genetic evidence for adaptation of corals to warmer conditions (Boxes 4.4 and 6.1). It is very likely that projected future increases in SST of about 1 to 3°C (Section 6.3.2) will result in more frequent bleaching events and widespread mortality, if there is not thermal adaptation or acclimatisation by corals and their symbionts (Sheppard, 2003; Hoegh-Guldberg, 2004). The ability of coral reef ecosystems to withstand the impacts of climate change will depend on the extent of degradation from other anthropogenic pressures and the frequency of future bleaching events (Donner et al., 2005).

In addition to coral bleaching, there are other threats to reefs associated with climate change (Kleypas and Langdon, 2002). Increased concentrations of CO_2 in seawater will lead to ocean acidification (Section 6.3.2), affecting aragonite saturation state (Meehl et al., 2007) and reducing calcification rates of calcifying organisms such as corals (LeClerq et al., 2002; Guinotte et al., 2003; Chapter 4, Box 4.4). Cores from long-lived massive corals indicate past minor variations in calcification (Lough and Barnes, 2000), but disintegration of degraded reefs following bleaching or reduced calcification may result in increased wave energy across reef flats with potential for shoreline erosion (Sheppard et al., 2005). Relative sea-level rise appears unlikely to threaten reefs in the next few decades; coral reefs have been shown to keep pace with rapid postglacial sea-level rise when not subjected to environmental or anthropogenic stresses (Hallock, 2005). A slight rise in sea level is likely to result in submergence of some Indo-Pacific reef flats and recolonisation by corals, as these intertidal surfaces, presently emerged at low tide, become suitable for coral growth (Buddemeier et al., 2004).

Many reefs are affected by tropical cyclones (hurricanes, typhoons); impacts range from minor breakage of fragile corals to destruction of the majority of corals on a reef and deposition of debris as coarse storm ridges. Such storms represent major perturbations, affecting species composition and abundance, from which reef ecosystems require time to recover. The sequence of ridges deposited on the reef top can provide a record of past storm history (Hayne and Chappell, 2001); for the northern Great Barrier Reef no change in frequency of extremely large cyclones has been detected over the past 5000 years (Nott and Hayne, 2001). An intensification of tropical storms (Section 6.3.2) could have devastating consequences on the reefs themselves, as well as for the inhabitants of many low-lying islands (Sections 6.4.2 and 16.3.1.3). There is limited evidence that global warming may result in an increase of coral range; for example, extension of branching Acropora poleward has been recorded in Florida, despite an almost Caribbean-wide trend for reef deterioration (Precht and Aronson, 2004), but there are several constraints, including low genetic diversity and the limited suitable substrate at the latitudinal limits to reef growth (Riegl, 2003; Ayre and Hughes, 2004; Woodroffe et al., 2005).

The fate of the small reef islands on the rim of atolls is of special concern. Small reef islands in the Indo-Pacific formed over recent millennia during a period when regional sea level fell (Woodroffe and Morrison, 2001; Dickinson, 2004). However, the response of these islands to future sea-level rise remains uncertain, and is addressed in greater detail in Chapter 16, Section 16.4.2. It will be important to identify critical thresholds of change beyond which there may be collapse of ecological and social systems on atolls. There are limited data, little local expertise to assess the dangers, and a low level of economic activity to cover the costs of adaptation for atolls in countries such as the Maldives, Kiribati and Tuvalu (Barnett and Adger, 2003; Chapter 16, Box 16.6).

6.4.2 Consequences for human society

Since the TAR, global and regional studies on the impacts of climate change are increasingly available, but few distinguish the socio-economic implications for the coastal zone (see also Section 6.5). Within these limits, Table 6.4 provides a qualitative overview of climate-related changes on the various socio-economic sectors of the coastal zone discussed in this section.

The socio-economic impacts in Table 6.4 are generally a product of the physical changes outlined in Table 6.2. For instance, extensive low-lying (often deltaic) areas, e.g., the Netherlands, Guyana and Bangladesh (Box 6.3), and oceanic islands are especially threatened by a rising sea level and all its resulting impacts, whereas coral reef systems and polar regions are already affected by rising temperatures (Sections 6.2.5 and 6.4.1). Socio-economic impacts are also influenced by the magnitude and frequency of existing processes and extreme events, e.g., the densely populated coasts of East, South and South-east Asia are already exposed to frequent cyclones, and

[5] Herbivory: the consumption of plants by animals.

Table 6.4. *Summary of climate-related impacts on socio-economic sectors in coastal zones.*

Coastal socio-economic sector	Climate-related impacts (and their climate drivers in Figure 6.1) Temperature rise (air and seawater)	Extreme events (storms, waves)	Floods (sea level, runoff)	Rising water tables (sea level)	Erosion (sea level, storms, waves)	Salt water intrusion (sea level, runoff)	Biological effects (all climate drivers)
Freshwater resources	**X**	**X**	**X**	**X**	–	**X**	x
Agriculture and forestry	**X**	**X**	**X**	**X**	–	**X**	x
Fisheries and aquaculture	**X**	**X**	x	–	x	**X**	**X**
Health	**X**	**X**	**X**	x	–	**X**	**X**
Recreation and tourism	**X**	**X**	x	–	**X**	–	**X**
Biodiversity	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Settlements/ infrastructure	**X**	**X**	**X**	**X**	**X**	**X**	–

X = strong; x= weak; – = negligible or not established.

this will compound the impacts of other climate changes (see Chapter 10). Coastal ecosystems are particularly at risk from climate change (CBD, 2003; Section 6.4.1), with serious implications for the services that they provide to human society (see Section 6.2.2; Box 6.4 and Chapter 4, Section 4.4.9).

Since the TAR, some important observations on the impacts and consequences of climate change on human society at coasts have emerged. First, significant regional differences in climate change and local variability of the coast, including human development patterns, result in variable impacts and adjustments along the coast, with implications for adaptation responses (Section 6.6). Second, human vulnerability to sea-level rise and climate change is strongly influenced by the characteristics of socio-economic development (Section 6.6.3). There are large differences in coastal impacts when comparing the different SRES worlds which cannot be attributed solely to the magnitude of climate change (Nicholls and Lowe, 2006; Nicholls and Tol, 2006). Third, although the future magnitude of sea-level rise will be reduced by mitigation, the long timescales of ocean response (Box 6.6) mean that it is unclear what coastal impacts are avoided and what impacts are simply delayed by the stabilisation of greenhouse gas concentration in the atmosphere (Nicholls and Lowe, 2006). Fourth, vulnerability to the impacts of climate change, including the higher socio-economic burden imposed by present climate-related hazards and disasters, is very likely to be greater on coastal communities of developing countries than in developed countries due to inequalities in adaptive capacity (Defra, 2004; Section 6.5). For example, one quarter of Africa's population is located in resource-rich coastal zones and a high proportion of GDP is exposed to climate-influenced coastal risks (Nyong and Niang-Diop, 2006; Chapter 9). In Guyana, 90% of its population and important economic activities are located within the coastal zone and are threatened by sea-level rise and climate change (Khan, 2001). Low-lying densely populated areas in India, China and Bangladesh (see Chapter 10) and other deltaic areas are highly exposed, as are the economies of small islands (see Chapter 16).

6.4.2.1 Freshwater resources

The direct influences of sea-level rise on freshwater resources come principally from seawater intrusion into surface waters and coastal aquifers, further encroachment of saltwater into estuaries and coastal river systems, more extensive coastal inundation and higher levels of sea flooding, increases in the landward reach of sea waves and storm surges, and new or accelerated coastal erosion (Hay and Mimura, 2005). Although the coast contains a substantial proportion of the world's population, it has a much smaller proportion of the global renewable water supply, and the coastal population is growing faster than elsewhere, exacerbating this imbalance (see Section 6.2.2 and Chapter 3, Section 3.2).

Many coastal aquifers, especially shallow ones, experience saltwater intrusion caused by natural and human-induced factors, and this is exacerbated by sea-level rise (Essink, 2001). The scale of saltwater intrusion is dependent on aquifer dimensions, geological factors, groundwater withdrawals, surface water recharge, submarine groundwater discharges and precipitation. Therefore, coastal areas experiencing increases in precipitation and run-off due to climate change (Section 6.3.2), including floods, may benefit from groundwater recharge, especially on some arid coasts (Khiyami et al., 2005). Salinisation of surface waters in estuaries is also promoted by a rising sea level, e.g., Bay of Bengal (Allison et al., 2003).

Globally, freshwater supply problems due to climate change are most likely in developing countries with a high proportion of coastal lowland, arid and semi-arid coasts, coastal megacities particularly in the Asia-Pacific region, and small island states, reflecting both natural and socio-economic factors that enhance the levels of risks (Alcamo and Henrichs, 2002; Ragab and Prudhomme, 2002). Identifying future coastal areas with stressed freshwater resources is difficult, particularly where there are strong seasonal demands, poor or no metering, and theft of water (Hall, 2003). Overall efficiency of water use is an important consideration, particularly where agriculture is a large consumer, e.g., the Nile delta (see Chapter 9, Box 9.2) and Asian megadeltas.

Based on the SRES emissions scenarios, it is estimated that the increase in water stress would have a significant impact by the 2050s, when the different SRES population scenarios have a clear effect (Arnell, 2004). But, regardless of the scenarios applied, critical regions with a higher sensitivity to water stresses, arising from either increases in water withdrawal or decreases in water available, have been identified in coastal regions that include parts of the western coasts of Latin America and the Algerian coast (Alcamo and Henrichs, 2002).

Box 6.4. Hurricane Katrina and coastal ecosystem services in the Mississippi delta

Whereas an individual hurricane event cannot be attributed to climate change, it can serve to illustrate the consequences for ecosystem services if the intensity and/or frequency of such events were to increase in the future. One result of Hurricane Katrina, which made landfall in coastal Louisiana on 29th August 2005, was the loss of 388 km^2 of coastal wetlands, levees and islands that flank New Orleans in the Mississippi River deltaic plain (Barras, 2006) (Figure 6.7). (Hurricane Rita, which struck in September 2005, had relatively minor effects on this part of the Louisiana coast which are included in this estimate.) The Chandeleur Islands, which lie south-east of the city, were reduced to roughly half of their former extent as a direct result of Hurricane Katrina. Collectively, these natural systems serve as the first line of defence against storm surge in this highly populated region. While some habitat recovery is expected, it is likely to be minimal compared to the scale of the losses. The Chandeleur Islands serve as an important wintering ground for migratory waterfowl and neo-tropical birds; a large population of North American redhead ducks, for example, feed on the rhizomes of sheltered sea grasses leeward of the Chandeleur Islands (Michot, 2000). Historically the region has ranked second only to Alaska in U.S. commercial fisheries production, and this high productivity has been attributed to the extent of coastal marshes and sheltered estuaries of the Mississippi River delta. Over 1800 people lost their lives (Graumann et al., 2005) during Hurricane Katrina and the economic losses totalled more than US$100 billion (NOAA, 2007). Roughly 300,000 homes and over 1,000 historical and cultural sites were destroyed along the Louisiana and Mississippi coasts (the loss of oil production and refinery capacity helped to raise global oil prices in the short term). Post-Katrina, some major changes to the delta's management are being advocated, most notably abandonment of the "bird-foot delta" where artificial levees channel valuable sediments into deep water (EFGC, 2006; NRC, 2006). The aim is to restore large-scale delta building processes and hence sustain the ecosystem services in the long term. Hurricane Katrina is further discussed in Box 7.4 (Chapter 7) and Chapter 14.

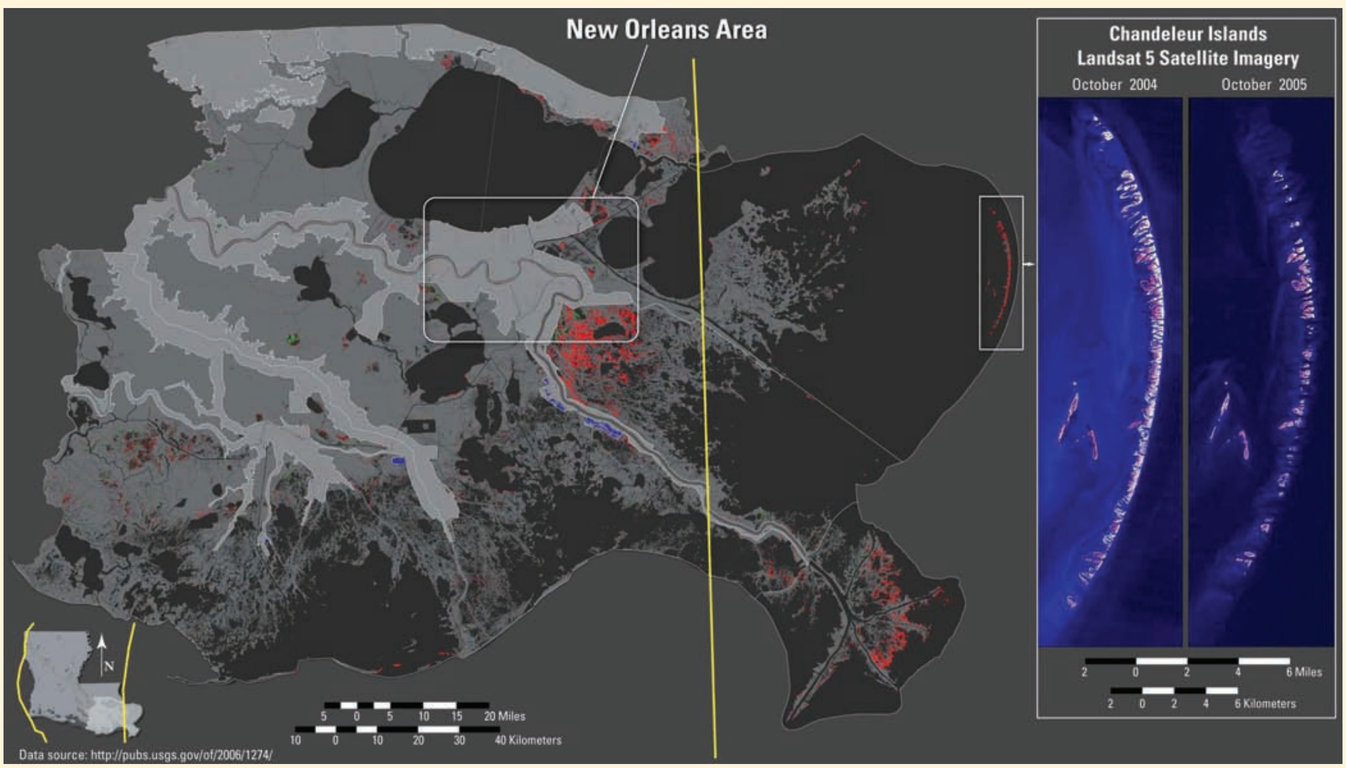

Figure 6.7. *The Mississippi delta, including the Chandeleur Islands. Areas in red were converted to open water during the hurricane. Yellow lines on index map of Louisiana show tracks of Hurricane Katrina on right and Hurricane Rita on left. (Figure source: U.S. Geological Survey, modified from Barras, 2006.)*

6.4.2.2 *Agriculture, forestry and fisheries*

Climate change is expected to have impacts on agriculture and, to a lesser extent, on forestry, although non-climatic factors, such as technological development and management practices can be more significant (Easterling, 2003). Climate variability and change also impacts fisheries in coastal and estuarine waters (Daufresne et al., 2003; Genner et al., 2004), although non-climatic factors, such as overfishing and habitat loss and degradation, are already responsible for reducing fish stocks. Globally an increased agricultural production potential due to climate change and CO_2 fertilisation should in principle add to food security, but the impacts on the coastal areas may differ regionally and locally. For example, in Europe, climate-related increases in crop yields are expected in the north, while the largest reductions are expected in the Mediterranean, the south-west Balkans and southern Russia (Maracchi et al., 2005).

Temperature increases can shorten growing cycles, e.g., those of cotton and mango on the north coast of Peru during the El Niño (see Chapter 13, Section 13.2.2). More frequent extreme climate events during specific crop development stages, together with higher rainfall intensity and longer dry spells, may impact negatively on crop yields (Olesen et al., 2006). Cyclone landfalls causing floods and destruction have negative impacts on coastal areas, e.g., on coconuts in India (see Chapter 5, Section 5.4.4), or on sugar cane and bananas in Queensland (Cyclone Larry in March 2006). Rising sea level has negative impacts on coastal agriculture. Detailed modelling of inundation implies significant changes to the number of rice crops possible in the Mekong delta under 20-40 cm of relative sea-level rise (Wassmann et al., 2004). Rising sea level potentially threatens inundation and soil salinisation of palm oil and coconuts in Benin and Côte d'Ivoire (see Chapter 9, Section 9.4.6) and mangoes, cashew nuts and coconuts in Kenya (Republic of Kenya, 2002).

Coastal forestry is little studied, but forests are easily affected by climatic perturbations, and severe storms can cause extensive losses, e.g., Hurricane Katrina. Plantation forests (mainly *P. radiata*) on the east coast of North Island, New Zealand, are likely to experience growth reductions under projected rainfall decreases (Ministry for the Environment, 2001). Increasing salinity and greater frequency of flooding due to sea-level rise reduces the ability of trees to generate, including mangroves which will also experience other changes (Section 6.4.1.4) (IUCN, 2003).

Future climate change impacts will be greater on coastal than on pelagic species, and for temperate endemics than for tropical species (see Chapter 11, Section 11.4.6). For Europe, regional climate warming has influenced northerly migration of fish species, e.g., sardines and anchovies in the North Sea (Brander et al., 2003a). The biotic communities and productivity of coastal lagoons may experience a variety of changes, depending on the changes in wetland area, freshwater flows and salt intrusion which affect the species. Intensification of ENSO events and increases in SST, wind stress, hypoxia (shortage of oxygen) and the deepening of the thermocline will reduce spawning areas and catches of anchovy off Peru (see Chapter 13, Table 13.7). There is also concern that climate change may affect the abundance and distribution of pathogens and HABs, with implications for aquatic organisms and human health (Section 6.4.2.4). The linkage between temperature changes and HABs is still not robust, and the extent to which coastal eutrophication will be affected by future climate variability will vary with local physical environmental conditions and current eutrophication status (Justic et al., 2005). Ocean acidification is a concern, but impacts are uncertain (Royal Society, 2005). Climate change also has implications for mariculture but again these are not well understood.

6.4.2.3 *Human settlements, infrastructure and migration*

Climate change and sea-level rise affect coastal settlements and infrastructure in several ways (Table 6.4). Sea-level rise raises extreme water levels with possible increases in storm intensity portending additional climate impacts on many coastal areas (Box 6.2), while saltwater intrusion may threaten water supplies. The degradation of natural coastal systems due to climate change, such as wetlands, beaches and barrier islands (Section 6.4.1.1), removes the natural defences of coastal communities against extreme water levels during storms (Box 6.5). Rapid population growth, urban sprawl, growing demand for waterfront properties, and coastal resort development have additional deleterious effects on protective coastal ecosystems.

Much of the coast of many European and East Asian countries have defences against flooding and erosion, e.g., the Netherlands (Jonkman et al., 2005) and Japan (Chapter 10, Section 10.5.3), reflecting a strong tradition of coastal defence. In particular, many coastal cities are heavily dependent upon artificial coastal defences, e.g., Tokyo, Shanghai, Hamburg, Rotterdam and London. These urban systems are vulnerable to low-probability extreme events above defence standards and to systemic failures (domino effects), e.g., the ports, roads and railways along the US Gulf and Atlantic coasts are especially vulnerable to coastal flooding (see Chapter 14, Section 14.2.6). Where these cities are subsiding, there are additional risks of extreme water levels overtopping flood defences, e.g., New Orleans during Hurricane Katrina (Box 6.4). Climate change and sea-level rise will exacerbate flood risk. Hence, many coastal cities require upgraded design criteria for flood embankments and barrages (e.g., the Thames barrier in London, the Delta works in the Netherlands, Shanghai's defences, and planned protection for Venice) (Fletcher and Spencer, 2005) (see Box 6.2 and Section 6.6).

There is now a better understanding of flooding as a natural hazard, and how climate change and other factors are likely to influence coastal flooding in the future (Hunt, 2002). However, the prediction of precise locations for increased flood risk resulting from climate change is difficult, as flood risk dynamics have multiple social, technical and environmental drivers (Few et al., 2004b). The population exposed to flooding by storm surges will increase over the 21st century (Table 6.5). Asia dominates the global exposure with its large coastal population: Bangladesh, China, Japan, Vietnam and Thailand having serious coastal flooding problems (see Section 6.6.2; Chapter 10, Section 10.4.3.1; Mimura, 2001). Africa is also likely to see a substantially increased exposure, with East Africa (e.g., Mozambique) having particular problems due to the combination of tropical storm landfalls and large projected population growth in addition to sea-level rise (Nicholls, 2006).

Table 6.5. *Estimates of the population (in millions) of the coastal flood plain* in 1990 and the 2080s (following Nicholls, 2004). Assumes uniform population growth; net coastward migration could substantially increase these numbers.*

Region	1990 (baseline)	SRES scenarios (and sea-level rise scenario in metres)			
		A1FI (0.34)	A2 (0.28)	B1 (0.22)	B2 (0.25)
Australia	1	1	2	1	1
Europe	25	30	35	29	27
Asia	132	185	376	180	247
North America	12	23	28	22	18
Latin America	9	17	35	16	20
Africa	19	58	86	56	86
Global	197	313	561	304	399

** Area below the 1 in 1,000 year flood level.*

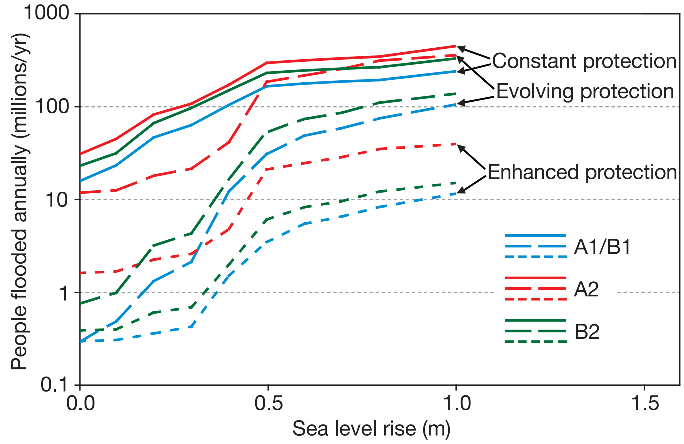

Figure 6.8. *Estimates of people flooded in coastal areas due to sea-level rise, SRES socio-economic scenario and protection response in the 2080s (following Nicholls and Lowe, 2006; Nicholls and Tol, 2006)*

Table 6.6 shows estimates of coastal flooding due to storm surge, taking into account one adaptation assumption. Asia and Africa experience the largest impacts: without sea-level rise, coastal flooding is projected to diminish as a problem under the SRES scenarios while, with sea-level rise, the coastal flood problem is growing by the 2080s, most especially under the A2 scenario. Increased storm intensity would exacerbate these impacts, as would larger rises in sea level, including due to human-induced subsidence (Nicholls, 2004). Figure 6.8 shows the numbers of people flooded in the 2080s as a function of sea-level rise, and variable assumptions on adaptation. Flood impacts vary with sea-level rise scenario, socio-economic situation and adaptation assumptions. Assuming that there will be no defence upgrade has a dramatic impact on the result, with more than 100 million people flooded per year above a 40 cm rise for all SRES scenarios. Upgraded defences reduce the impacts substantially: the greater the upgrade the lower the impacts. This stresses the importance of understanding the effectiveness and timing of adaptation (Section 6.6).

6.4.2.4 Human health

Coastal communities, particularly in low income countries, are vulnerable to a range of health effects due to climate variability and long-term climate change, particularly extreme weather and climate events (such as cyclones, floods and droughts) as summarised in Table 6.7.

The potential impacts of climate change on populations in coastal regions will be determined by the future health status of the population, its capacity to cope with climate hazards and control infectious diseases, and other public health measures. Coastal communities that rely on marine resources for food, in terms of both supply and maintaining food quality (food safety), are vulnerable to climate-related impacts, in both health and economic terms. Marine ecological processes linked to temperature changes also play a role in determining human health risks, such as from cholera, and other enteric pathogens (*Vibrio parahaemolyticus*), HABs, and shellfish and reef fish

Table 6.6. *Estimates of the average annual number of coastal flood victims (in millions) due to sea-level rise (following Nicholls, 2004). Assumes no change in storm intensity and evolving protection**. Range reflects population growth as reported in Table 6.1. Base= baseline without sea-level rise; aSLR = additional impacts due to sea-level rise.*

Region	Case	Timelines, SRES socio-economic (and sea-level rise scenarios in metres)											
		2020s				2050s				2080s			
		A1FI (0.05)	A2 (0.05)	B1 (0.05)	B2 (0.06)	A1FI (0.16)	A2 (0.14)	B1 (0.13)	B2 (0.14)	A1FI (0.34)	A2 (0.28)	B1 (0.22)	B2 (0.25)
Australia	Base	0	0	0	0	0	0	0	0	0	0	0	0
	aSLR	0	0	0	0	0	0	0	0	0	0	0	0
Europe	Base	0	0	0	0	0	0	0	0	0	0	0	0
	aSLR	0	0	0	0	0	0	0	0	2	0	0	0
Asia	Base	9/12	14/20	12/17	9/13	0	15/24	2	1/2	0	11/18	0	0/1
	aSLR	0	0	0	0	0	1/2	0	0	1	4/7	0	0/1
North America	Base	0	0	0	0	0	0	0	0	0	0	0	0
	aSLR	0	0	0	0	0	0	0	0	0	0	0	0
Latin America	Base	0	0	0	0	0	0	0	0	0	0	0	0
	aSLR	0	0	0	0	0	0	0	0	1	0/1	0	0
Africa	Base	1	2/4	1	3/4	0	1/2	0	1/2	0	0/1	0	0
	aSLR	0	0	0	0	0	1	0	0/1	2/5	4/7	1	2/4
Global Total	Base	10/14	17/24	13/18	12/17	0/1	16/26	2	3/4	0	11/19	0	1
	aSLR	0	0	0	0	0	2/3	0	0/1	6/10	9/15	2/3	3/5

*** Protection standards improve as GDP per capita increases, but there is no additional adaptation for sea-level rise.*

Table 6.7. *Health effects of climate change and sea-level rise in coastal areas.*

Exposure/hazard	Health outcome	Sources
(Catastrophic) flooding	Deaths (drowning, other causes), injuries, infectious disease (respiratory, intestinal, skin), mental health disorders, impacts from interruption of health services and population displacement.	Sections 6.4.2, 6.5.2 and 8.2.2; Box 6.4 (Few and Matthies, 2006)
Impairment of food quality and/or food supplies (loss of crop land, decreased fisheries productivity). Climate change effects on HABs.	Food safety: marine bacteria proliferation, shellfish poisoning, ciguatera. Malnutrition and micro-nutrient deficiencies.	Sections 6.4.1.3 6.4.2.2 and 8.2.4
Reduced water quality and/or access to potable water supplies due to salinisation, flooding or drought.	Diarrhoeal diseases (giardia, cholera), and hepatitis, enteric fevers. Water-washed infections.	Sections 6.4.2.1, 7.5 and 8.2.5
Change in transmission intensity or distribution of vector-borne disease. Changes in vector abundance.	Changes in malaria, and other mosquito-borne infections (some *Anopheles* vectors breed in brackish water).	Sections 8.2.8 and 16.4.5
Effects on livelihoods, population movement, and potential "environmental refugees".	Health effects are less well described. Large-scale rapid population movement would have severe health implications.	Section 6.4.2.3 and limited health literature.

poisoning (Pascual et al., 2002; Hunter, 2003; Lipp et al., 2004; Peperzak, 2005; McLaughlin et al., 2006).

Convincing evidence of the impacts of observed climate change on coastal disease patterns is absent (Kovats and Haines, 2005). There is an association between ENSO and cholera risk in Bangladesh (Pascual et al., 2002). Rainfall changes associated with ENSO are known to increase the risk of malaria epidemics in coastal regions of Venezuela and Colombia (Kovats et al., 2003). The projection of health impacts of climate change is still difficult and uncertain (Ebi and Gamble, 2005; Kovats et al., 2005), and socio-economic factors may be more critical than climate. There are also complex relationships between ecosystems and human well-being, and the future coastal ecosystem changes discussed in Section 6.4.1 may affect human health (cf. Butler et al., 2005).

6.4.2.5 Biodiversity

The distribution, production, and many other aspects of species and biodiversity in coastal ecosystems are highly sensitive to variations in weather and climate (Section 6.4.1), affecting the distribution and abundance of the plant and animal species that depend on each coastal system type. Human development patterns also have an important influence on biodiversity among coastal system types. Mangroves, for example, support rich ecological communities of fish and crustaceans, are a source of energy for coastal food chains, and export carbon in the form of plant and animal detritus, stimulating estuarine and nearshore productivity (Jennerjahn and Ittekkot, 2002). Large-scale conversions of coastal mangrove forests to shrimp aquaculture have occurred during the past three decades along the coastlines of Vietnam (Binh et al., 1997), Bangladesh and India (Zweig, 1998), Hong Kong (Tam and Wong, 2002), the Philippines (Spalding et al., 1997), Mexico (Contreras-Espinosa and Warner, 2004), Thailand (Furakawa and Baba, 2001) and Malaysia (Ong, 2001). The additional stressors associated with climate change could lead to further declines in mangroves forests and their biodiversity.

Several recent studies have revealed that climate change is already impacting biodiversity in some coastal systems. Long-term monitoring of the occurrence and distribution of a series of intertidal and shallow water organisms in south-west Britain has shown several patterns of change, particularly in the case of barnacles, which correlate broadly with changes in temperature over the several decades of record (Hawkins et al., 2003; Mieszkowska et al., 2006). It is clear that responses of intertidal and shallow marine organisms to climate change are more complex than simply latitudinal shifts related to temperature increase, with complex biotic interactions superimposed on the abiotic (Harley et al., 2006; Helmuth et al., 2006). Examples include the northward range extension of a marine snail in California (Zacherl et al., 2003) and the reappearance of the blue mussel in Svalbard (Berge et al., 2005).

Patterns of overwintering of migratory birds on the British coast appear to have changed in response to temperature rise (Rehfisch et al., 2004), and it has been suggested that changes in invertebrate distribution might subsequently influence the distribution of ducks and wading birds (Kendall et al., 2004). However, as detailed studies of redshank have shown, the factors controlling distribution are complex and in many cases are influenced by human activities (Norris et al., 2004). Piersma and Lindstrom (2004) review changes in bird distribution but conclude that none can be convincingly attributed to climate change. Loss of birds from some estuaries appears to be the result of coastal squeeze and relative sea-level rise (Hughes, 2004; Knogge et al., 2004). A report by the United Nations Framework Convention on Biodiversity (CBD, 2006) presents guidance for incorporating biodiversity considerations in climate change adaptation strategies, with examples from several coastal regions.

6.4.2.6 Recreation and tourism

Climate change has major potential impacts on coastal tourism, which is strongly dependent on 'sun, sea and sand'. Globally, travel to sunny and warm coastal destinations is the major factor for tourists travelling from Northern Europe to the Mediterranean (16% of world's tourists) and from North America to the Caribbean (1% of world's tourists) (WTO, 2003). By 2020, the total number of international tourists is expected to exceed 1.5 billion (WTO, undated).

Climate change may influence tourism directly via the decision-making process by influencing tourists to choose different destinations; and indirectly as a result of sea-level rise and resulting coastal erosion (Agnew and Viner, 2001). The preferences for climates at tourist destinations also differ among age and income groups (Lise and Tol, 2002), suggesting differential responses. Increased awareness of interactions between ozone depletion and climate change and the subsequent impact on the exposure of human skin to ultraviolet light is another factor influencing tourists' travel choice (Diffey, 2004). In general, air temperature rise is most important to tourism, except where factors such as sea-level rise promote beach degradation and viable adaptation options (e.g., nourishment or recycling) are not available (Bigano et al., 2005). Other likely impacts of climate change on coastal tourism are due to coral reef degradation (Box 6.1; Section 6.4.1.5) (Hoegh-Guldberg et al., 2000). Temperature and rainfall pattern changes may impact water quality in coastal areas and this may lead to more beach closures.

Climate change is likely to affect international tourist flows prior to travel, en route, and at the destination (Becken and Hay, undated). As tourism is still a growth industry, the changes in tourist numbers induced by climate change are likely to be much smaller than those resulting from population and economic growth (Bigano et al., 2005; Hamilton et al., 2005; Table 6.2). Higher temperatures are likely to change summer destination preferences, especially for Europe: summer heatwaves in the Mediterranean may lead to a shift in tourism to spring and autumn (Madisson, 2001) with growth in summer tourism around the Baltic and North Seas (see Chapter 12, Section 12.4.9). Although new climate niches are emerging, the empirical data do not suggest reduced competitiveness of the sun, sea and sand destinations, as they are able to restructure to meet tourists' demands (Aguiló et al., 2005). Within the Caribbean, the rapidly growing cruise industry is not vulnerable to sea-level rise, unlike coastal resorts. On high-risk (e.g., hurricane-prone) coasts, insurance costs for tourism could increase substantially or insurance may no longer be available. This exacerbates the impacts of extreme events or restricts new tourism in high-risk regions (Scott et al., 2005), e.g., four hurricanes in 2004 dealt a heavy toll in infrastructure damage and lost business in Florida's tourism industry (see Chapter 14, Section 14.2.7).

6.4.3 Key vulnerabilities and hotspots

A comprehensive assessment of the potential impacts of climate change must consider at least three components of vulnerability: exposure, sensitivity and adaptive capacity (Section 6.6). Significant regional differences in present climate and expected climate change give rise to different exposure among human populations and natural systems to climate stimuli (IPCC, 2001). The previous sections of this chapter broadly characterise the sensitivity and natural adaptive capacity (or resilience) of several major classes of coastal environments to changes in climate and sea-level rise. Differences in geological, oceanographic and biological processes can also lead to substantially different impacts on a single coastal system at different locations. Some global patterns and hotspots of vulnerability are evident, however, and deltas/estuaries (especially populated megadeltas), coral reefs (especially atolls), and ice-dominated coasts appear most vulnerable to either climate change or associated sea-level rise and changes. Low-lying coastal wetlands, small islands, sand and gravel beaches and soft rock cliffs may also experience significant changes.

An acceleration of sea-level rise would directly increase the vulnerability of all of the above systems, but sea-level rise will not occur uniformly around the world (Section 6.3.2). Variability of storms and waves, as well as sediment supply and the ability to migrate landward, also influence the vulnerability of many of these coastal system types. Hence, there is an important element of local to regional variation among coastal system types that must be considered when conducting site-specific vulnerability assessments.

Our understanding of human adaptive capacity is less developed than our understanding of responses by natural systems, which limits the degree to which we can quantify societal vulnerability in the world's coastal regions. Nonetheless, several key aspects of human vulnerability have emerged. It is also apparent that multiple and concomitant non-climate stresses will exacerbate the impacts of climate change on most natural coastal systems, leading to much larger and detrimental changes in the 21st century than those of the 20th century. Table 6.8 summarises some of the key hotspots of vulnerability that often arise from the combination of natural and societal factors. Note that some examples such as atolls and small islands and deltas/megadeltas recur, stressing their high vulnerability.

While physical exposure is an important aspect of the vulnerability for both human populations and natural systems to both present and future climate variability and change, a lack of adaptive capacity is often the most important factor that creates a hotspot of human vulnerability. Societal vulnerability is largely dependent upon development status (Yohe and Tol, 2002). Developing nations may have the societal will to relocate people who live in low-lying coastal zones but, without the necessary financial resources, their vulnerability is much greater than that of a developed nation in an identical coastal setting. Looking to the scenarios, the A2 SRES world often appears most vulnerable to climate change in coastal areas, again reflecting socio-economic controls in addition to the magnitude of climate change (Nicholls, 2004; Nicholls and Tol, 2006). Hence, development is not only a key consideration in evaluating greenhouse gas emissions and climate change, but is also fundamental in assessing adaptive capacity because greater access to wealth and technology generally increases adaptive capacity, while poverty limits adaptation options (Yohe and Tol, 2002). A lack of risk awareness or institutional capacity can also have an important influence on human vulnerability, as experienced in the United States during Hurricane Katrina.

6.5 Costs and other socio-economic aspects

The costs, benefits and other socio-economic consequences of climate variability and change for coastal and low-lying areas have been determined for many aspects, including heat stress and changes in plant and animal metabolism (see Chapter 4, Section 4.2 and Box 4.4), disease (see Chapter 8, Section 8.5),

Table 6.8. *Key hotspots of societal vulnerability in coastal zones.*

Controlling factors	Examples from this Chapter
Coastal areas where there are substantial barriers to adaptation (economic, institutional, environmental, technical, etc.)	Venice, Asian megadeltas, atolls and small islands, New Orleans
Coastal areas subject to multiple natural and human-induced stresses, such as subsidence or declining natural defences	Mississippi, Nile and Asian megadeltas, the Netherlands, Mediterranean, Maldives
Coastal areas already experiencing adverse effects of temperature rise	Coral reefs, Arctic coasts (USA, Canada, Russia), Antarctic peninsula
Coastal areas with significant flood-plain populations that are exposed to significant storm surge hazards	Bay of Bengal, Gulf of Mexico/Caribbean, Rio de la Plata/Parana delta, North Sea
Coastal areas where freshwater resources are likely to be reduced by climate change	W. Africa, W. Australia, atolls and small islands
Coastal areas with tourist-based economies where major adverse effects on tourism are likely	Caribbean, Mediterranean, Florida, Thailand, Maldives
Highly sensitive coastal systems where the scope for inland migration is limited	Many developed estuarine coasts, low small islands, Bangladesh

water supply (see Chapter 3, Section 3.5), and coastal forests, agriculture and aquaculture (see Chapter 5, Section 5.6). The following section focuses on evaluating the socio-economic consequences of sea-level rise, storm damage and coastal erosion.

6.5.1 Methods and tools for characterising socio-economic consequences

Since the TAR there has been further progress in moving from classical cost-benefit analysis to assessments that integrate monetary, social and natural science criteria. For example, Hughes et al. (2005) report the emergence of a complex systems approach for sustaining and repairing marine ecosystems. This links ecological resilience to governance structures, economics and society. Such developments are in response to the growing recognition of the intricate linkages between physical coastal processes, the diverse coastal ecosystems, and resources at risk from climate change, the many ecological functions they serve and services they provide, and the variety of human amenities and activities that depend on them. Thus a more complete picture of climate change impacts emerges if assessments take into account the locally embedded realities and constraints that affect individual decision makers and community responses to climate change (Moser, 2000, 2005). Increasingly, Integrated Assessment provides an analytical framework, and an interdisciplinary learning and engagement process for experts, decision makers and stakeholders (Turner, 2001). Evaluations of societal and other consequences combine impact-benefit/cost-effectiveness analytical methods with scenario analysis. For example, a recent analysis of managed realignment schemes (Coombes et al., 2004) took into account social, environmental and economic consequences when evaluating direct and indirect benefits.

Direct cost estimates are common across the climate change impact literature as they are relatively simple to conduct and easy to explain. Such estimates are also becoming increasingly elaborate. For example, several studies of sea-level rise considered land and wetland loss, population displacement and coastal protection via dike construction (e.g., Tol, 2007). Socio-economic variables, such as income and population density, are important in estimating wetland value but are often omitted when making such estimations (Brander et al., 2003b). But direct cost estimates ignore such effects as changes in land use and food prices if land is lost. One way to estimate these additional effects is to use a computable general equilibrium (CGE) model to consider markets for all goods and services simultaneously, taking international trade and investment into account (e.g., Bosello et al., 2004). However, the major economic effects of climate change may well be associated with out-of-equilibrium phenomena (Moser, 2006). Also, few CGE models include adequate representations of physical processes and constraints.

Given the recent and anticipated increases in damages from extreme events, the insurance industry and others are making greater use of catastrophe models. These cover event generation (e.g., storm magnitude and frequency), hazard simulation (wind stresses and surge heights), damage modelling (extent of structural damage), and financial modelling (costs) (Muir-Wood et al., 2005). Stochastic modelling is used to generate thousands of simulated events and develop probabilistic approaches to quantifying the risks (Aliff, 2006; Chapter 2).

Methodologically, many challenges remain. Work to date has insufficiently crossed disciplinary boundaries (Visser, 2004). Although valuation techniques are continually being improved, and are now better linked to risk-based decision making, they remain imperfect, and in some instances controversial. This requires a transdisciplinary response from the social and natural sciences.

6.5.2 Socio-economic consequences under current climate conditions

Under current climate conditions, developing countries bear the main human burden of climate-related extreme events (Munich Re Group, 2004; CRED, 2005; UN Secretary General, 2006a). But it is equally evident that developed countries are not insulated from disastrous consequences (Boxes 6.4 and Chapter 7, Box 7.4). The societal costs of coastal disasters are typically quantified in terms of property losses and human deaths. For example, Figure 6.9 shows a significant threshold in real estate damage costs related to flood levels. Post-event impacts on coastal businesses, families and neighbourhoods, public and private social institutions, natural resources, and the environment generally go unrecognised in disaster cost accounting (Heinz Center, 2000; Baxter, 2005). Finding an accurate way to document these unreported or hidden costs is a challenging problem that has received increasing attention in recent years. For example, Heinz Center (2000) showed that family roles and responsibilities after a disastrous coastal storm undergo profound changes associated with household and employment disruption, economic hardship, poor living conditions, and the disruption of pubic services such as education and preventive health care. Indirect costs imposed by health problems (Section 6.4.2.4) result from damaged homes and utilities, extreme temperatures, contaminated food, polluted water, debris- and mud-borne bacteria, and mildew and mould. Within the family, relationships after a disastrous climate-related event can become so stressful that family desertion and divorce may increase. Hence, accounting for the full range of costs is difficult, though essential to the accurate assessment of climate-related coastal hazards.

Tropical cyclones have major economic, social and environmental consequences for coastal areas (Box 6.4). Up to 119 million people are on average exposed every year to tropical cyclone hazard (UNDP, 2004). Worldwide, from 1980 to 2000, a total of more than 250,000 deaths were associated with tropical cyclones, of which 60% occurred in Bangladesh (this is less than the 300,000 killed in Bangladesh in 1970 by a single cyclone). The death toll has been reduced in the past decade due largely to improvements in warnings and preparedness, wider public awareness and a stronger sense of community responsibility (ISDR, 2004). The most-exposed countries have densely populated coastal areas, often comprising deltas and megadeltas (China, India, the Philippines, Japan, Bangladesh) (UNDP, 2004). In Cairns (Australia), cyclone experience and education may have contributed synergistically to a change in risk perceptions and a reduction in the vulnerability of residents to tropical cyclone and storm surge hazards (Anderson-Berry, 2003). In Japan, the annual number of tropical cyclones and typhoons making landfall showed no significant trend from 1950 to 2004, but the number of port-related disasters decreased. This is attributed to increased protection against such disasters. However, annual average restoration expenditures over the period still amount to over US$250 million (Hay and Mimura, 2006).

Between 1980 and 2005, the United States sustained 67 weather-related disasters, each with an overall damage cost of at least US$1 billion. Coastal states in the south-east US experienced the greatest number of such disasters. The total costs including both insured and uninsured losses for the period, adjusted to 2002, were over US$500 billion (NOAA, 2007). There are differing views as to whether climatic factors have contributed to the increasing frequency of major weather-related disasters along the Atlantic and Gulf coasts of the USA (Pielke Jr et al., 2005; Pielke and Landsea, 1998). But the most recent reviews by Trenberth et al. (2007) and Meehl et al. (2007) support the view that storm intensity has increased and this will continue with global warming. Whichever view is correct, the damage costs associated with these events are undisputedly high, and will increase into the future.

Erosion of coasts (Section 6.4.1.1) is a costly problem under present climatic conditions. About 20% of the European Union's coastline suffered serious erosion impacts in 2004, with the area lost or seriously impacted estimated at 15 km^2/yr. In 2001, annual expenditure on coastline protection in Europe was an estimated US$4 billion, up from US$3 billion in 1986 (Eurosion, 2004). The high rates of erosion experienced by beach communities on Delaware's Atlantic coast (USA) are already requiring publicly funded beach nourishment projects in order to sustain the area's attractiveness as a summer resort (Daniel, 2001). Along the east coast of the United States and Canada, sea-level rise over the last century has reduced the return period of extreme water levels, exacerbating the damage to fixed structures from modern storms compared to the same events a century ago (Zhang et al., 2000; Forbes et al., 2004a). These and other studies have raised major questions, including: (i) the feasibility, implications and acceptability of shoreline retreat; (ii) the appropriate type of shoreline protection (e.g., beach nourishment, hard protection or other typically expensive responses) in situations where rates of shoreline retreat are increasing; (iii) doubts as to the longer-term sustainability of such interventions; and (iv) whether insurance provided by the public and private sectors encourages people to build, and rebuild, in vulnerable areas.

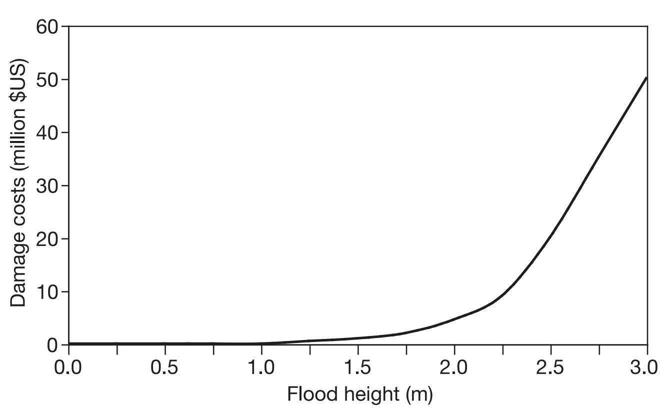

Figure 6.9. *Real estate damage costs related to flood levels for the Rio de la Plata, Argentina (Barros et al., 2006).*

6.5.3 Socio-economic consequences of climate change

Substantial progress has been made in evaluating the socio-economic consequences of climate change, including changes in variability and extremes. In general, the results show that socio-economic costs will likely escalate as a result of climate change, as already shown for the broader impacts (Section 6.4). Most immediately, this will reflect increases in variability and extreme events and only in the longer term will costs (in the widest sense) be dominated by trends in average conditions, such as mean sea-level rise (van Aalst, 2006). The impacts of such changes in climate and sea level are overwhelmingly adverse. But benefits have also been identified, including reduced cold-water mortalities of many valuable fish and shellfish species (see Chapter 15, Section 15.4.3.2), opportunities for increased use of fishing vessels and coastal shipping facilities (see Chapter 15, Section 15.4.3.3), expansion of areas suitable for aquaculture (see Chapter 5, Section 5.4.6.1), reduced hull strengthening and icebreaking costs, and the opening of new ocean routes due to reduced sea ice. Countries with large land areas generally benefit from competitive advantage effects (Bosello et al., 2004).

In the absence of an improvement to protection, coastal flooding could grow tenfold or more by the 2080s, to affect more than 100 million people/yr, due to sea-level rise alone (Figure 6.8). Figure 6.10 shows the consequences and total costs of a rise in sea level for developing and developed countries, and globally. This analysis assumes protection is implemented based on benefit-cost analysis, so the impacts are more consistent with enhanced protection in Figure 6.8, and investment is required for the protection. The consequences of sea-level rise will be far greater for developing countries, and protection costs will be higher, relative to those for developed countries.

Such global assessments are complemented by numerous regional, national and more detailed studies. The number of people in Europe subject to coastal erosion or flood risk in 2020 may exceed 158,000, while half of Europe's coastal wetlands are expected to disappear as a result of sea-level rise (Eurosion, 2004). In Thailand, loss of land due to a sea-level rise of 50 cm and 100 cm could decrease national GDP by 0.36% and 0.69% (US$300 to 600 million) per year, respectively; due to location and other factors, the manufacturing sector in Bangkok could suffer the greatest damage, amounting to about 61% and 38% of the total damage, respectively (Ohno, 2001). The annual cost of protecting Singapore's coast is estimated to be between US$0.3 and 5.7 million by 2050 and between US$0.9 and 16.8 million by 2100 (Ng and Mendelsohn, 2005). In the cities of Alexandria, Rosetta and Port Said on the Nile delta coast of Egypt, a sea-level rise of 50 cm could result in over 2 million people abandoning their homes, the loss of 214,000 jobs and the loss of land valued at over US$35 billion (El-Raey, 1997).

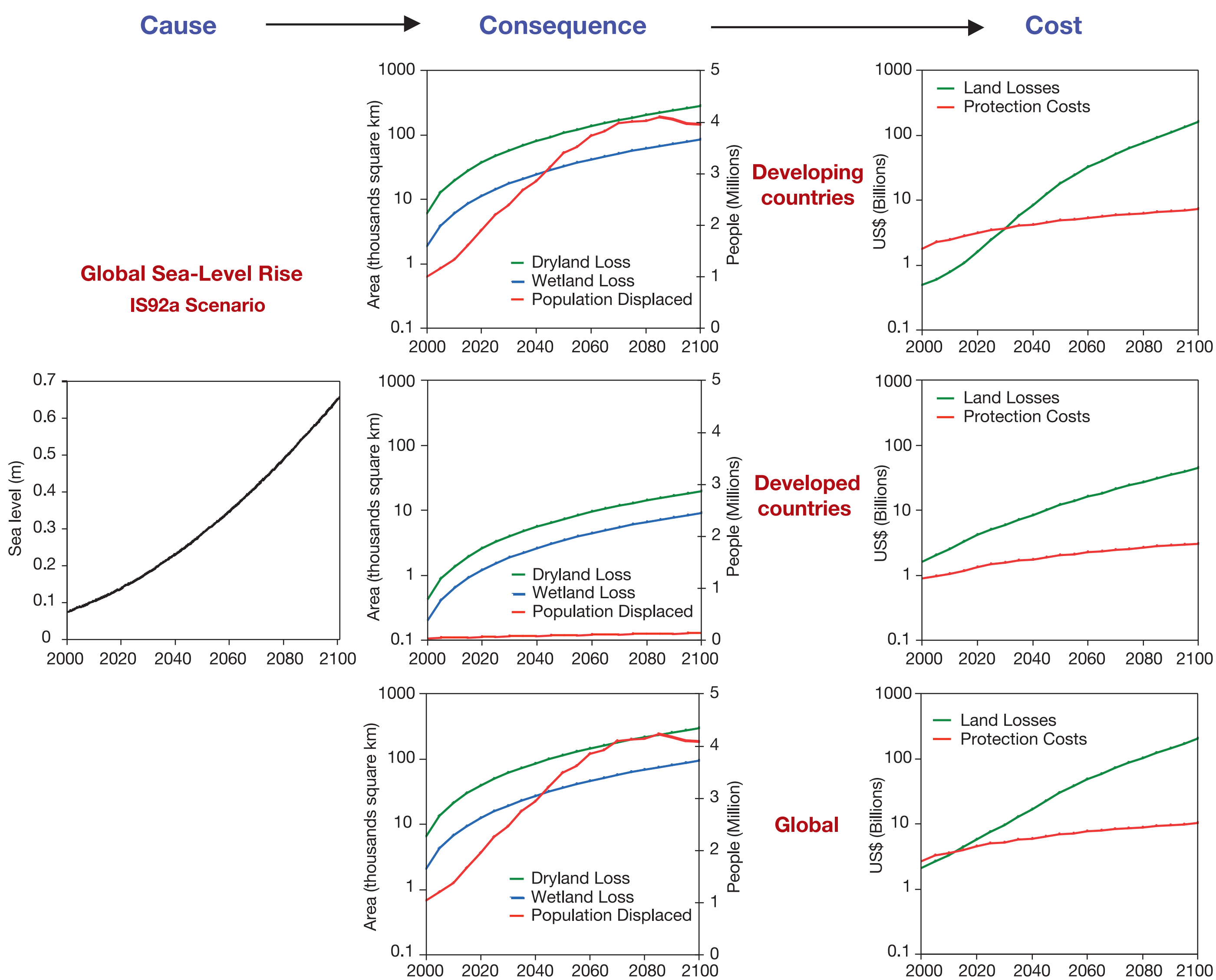

Figure 6.10. *Causes, selected consequences (dryland and wetland loss, people displaced) and the total costs of an assumed sea-level rise, for developing and developed countries, and as a global total. (based on Tol, 2007).*

6.6 Adaptation: practices, options and constraints

This section first highlights issues that arise with interventions designed to reduce risks to natural and human coastal systems as a consequence of climate change. As recognised in earlier IPCC assessments (Bijlsma et al., 1996; McLean et al., 2001), a key conclusion is that reactive and standalone efforts to reduce climate-related risks to coastal systems are less effective than responses which are part of integrated coastal zone management (ICZM), including long-term national and community planning (see also Kay and Adler, 2005). Within this context, subsequent sections describe the tools relevant to adaptation in coastal areas, options for adaptation of coastal systems, and current and planned adaptation initiatives. Examples of the costs of, and limits to, coastal adaptation are described, as are the trade-offs. Constraints on, limitations to, and strategies for strengthening adaptive capacity are also described. Finally, the links between coastal adaptation and efforts to mitigate climate change are discussed.

6.6.1 Adaptation to changes in climate and sea level

6.6.1.1 Issues and challenges

Recent extreme events (Box 6.5), whether climate-related or not, have highlighted many of the challenges inherent in adapting to changes in climate and sea level. One constraint on successful management of climate-related risks to coastal systems is the limited ability to characterise in appropriate detail how these systems, and their constituent parts, will respond to climate change drivers and to adaptation initiatives (Sections 6.2.4 and 6.4; Finkl, 2002). Of particular importance is understanding the extent to which natural coastal systems can adapt and therefore continue to provide essential life-supporting services to society. The lack of understanding of the coastal system, including the highly interactive nature and non-linear behaviour (Sections 6.2 and 6.4), means that failure to take an integrated approach to characterising climate-related risks increases the likelihood that the effectiveness of adaptation will be reduced, and perhaps even negated. Despite the growing emphasis on beach nourishment (Hanson et al., 2002), the long-term effectiveness and feasibility of such adaptive measures remains uncertain, especially with the multiple goals explicit within ICZM (Section 6.6.1.2). The question of who pays and who benefits from adaptation is another issue of concern. Public acceptance of the need for adaptation, and of specific measures, also needs to be increased (Neumann et al., 2000). The significant and diverse challenges are summarised in Table 6.9 and discussed further in the identified sections.

6.6.1.2 Integrated coastal zone management (ICZM)

ICZM provides a major opportunity to address the many issues and challenges identified above. Since it offers advantages over purely sectoral approaches, ICZM is widely recognised and promoted as the most appropriate process to deal with climate change, sea-level rise and other current and long-term coastal challenges (Isobe, 2001; Nicholls and Klein, 2005; Harvey, 2006b). Enhancing adaptive capacity is an important part of ICZM. The extent to which climate change and sea-level rise are considered in coastal management plans is one useful measure of commitment to integration and sustainability. Responses to sea-level rise and climate change need to be implemented in the broader context and the wider objectives of coastal planning and management (Kennish, 2002; Moser, 2005). ICZM focuses on integrating and balancing multiple objectives in the planning process (Christie et al., 2005). Generation of equitably distributed social and environmental benefits is a key factor in ICZM process sustainability, but is difficult to achieve. Attention is also paid to legal and institutional frameworks that support integrative planning on local and national scales. Different social groups have contrasting, and often conflicting views on the relative priorities

Box 6.5. Recent extreme events – lessons for coastal adaptation to climate change

Recent extreme events, both climate and non-climate related, that had major consequences for coastal systems, provide important messages for adaptation to climate change. Scientific literature and government reports emanating from hurricane and cyclone impacts (e.g., Cook Islands (Ingram, 2005); Katrina (US Government, 2006); Australia (Williams et al., 2007), flood impacts (e.g., Mumbai (Wisner, 2006)) and the Boxing Day Sumatran tsunami (UNEP, 2005; UNOCHA, 2005) include the following.

- An effective early warning communication and response system can reduce death and destruction;
- Hazard awareness education and personal hazard experience are important contributors to reducing community vulnerability;
- Many factors reduce the ability or willingness of people to flee an impending disaster, including the warning time, access and egress routes, and their perceived need to protect property, pets and possessions;
- Coastal landforms (coral reefs, barrier islands) and wetland ecosystems (mangroves, marshes) provide a natural first line of protection from storm surges and flooding, despite divergent views about the extent to which they reduce destruction;
- Recurrent events reduce the resilience of natural and artificial defences;
- In the aftermath of extreme events, additional trauma occurs in terms of dispossession and mental health;
- Uncoordinated and poorly regulated construction has accentuated vulnerability;
- Effective disaster prevention and response rely on strong governance and institutions, as well as adequate public preparedness.

Table 6.9. *Major impediments to the success of adaptation in the coastal zone.*

Impediment	Example Reference	Section
Lack of dynamic predictions of landform migration	Pethick, 2001	6.6.1.2
Insufficient or inappropriate shoreline protection measures	Finkl, 2002	6.6.1.4
Data exchange and integration hampered by divergent information management systems	Hale et al., 2003	6.6.1.3
Lack of definition of key indicators and thresholds relevant to coastal managers	Rice, 2003	6.6.1.2
Inadequate knowledge of coastal conditions and appropriate management measures	Kay and Adler, 2005	6.6.1.3
Lack of long-term data for key coastal descriptors	Hall, 2002	6.6.1.2
Fragmented and ineffective institutional arrangements, and weak governance	Moser, 2000	6.6.1.3
Societal resistance to change	Tompkins et al., 2005a	6.6.3

to be given to development, the environment and social considerations, as well as short and long-term perspectives (Visser, 2004).

6.6.1.3 Tools for assessing adaptation needs and options

Since the TAR, many more tools have become available to support assessments of the need for adaptation and to identify appropriate interventions (Table 6.10).

6.6.1.4 Adaptation options

Figure 6.11 illustrates the evolution of thinking with respect to planned adaptation practices in the coastal zone. It also provides examples of current adaptation interventions. The capacity of coastal systems to regenerate after disasters, and to continue to produce resources and services for human livelihoods and well-being, is being tested with increasing frequency. This is highlighting the need to consider the resilience of coastal systems at broader scales and for their adaptive capacity to be actively managed and nurtured.

Those involved in managing coastal systems have many practical options for simultaneously reducing risks related to current climate extremes and variability as well as adapting to climate change (Yohe, 2000; Daniel, 2001; Queensland Government, 2001; Townend and Pethick, 2002). This reflects the fact that many disaster and climate change response strategies are the same as those which contribute positively to present-day efforts to implement sustainable development, including enhancement of social equity, sound environmental management and wise resource use (Helmer and Hilhorst, 2006). This will help harmonise coastal planning and climate change adaptation and, in turn, strengthen the anticipatory response capacity of institutions (Few et al., 2004a). The timeframes for development are typically shorter than those for natural changes in the coastal region, though management is starting to address this issue. Examples include restoration and management of the Mississippi River and delta plain (Box 6.4) and management of coastal erosion in Europe (Eurosion, 2004; Defra, 2006; MESSINA, 2006). Identifying and selecting adaptation options can be guided by experience and best practice for reducing the adverse impacts of analogous, though causally unrelated, phenomena such as subsidence (natural and/or human-induced) and tsunami (Olsen et al., 2005). Based on this experience, it is highly advantageous to integrate and mainstream disaster management and adaptation to climate variability and change into wider coastal management, especially given relevant lessons from recent disasters (Box 6.5).

Table 6.10. *Selected tools that support coastal adaptation assessments and interventions.*

Description	Selected examples
Indices of vulnerability to sea-level rise	Thieler and Hammar-Klose, 2000; Kokot et al., 2004
Integrated models and frameworks for knowledge management and adaptation assessment	Warrick et al., 2005; Dinas-Coast Consortium, 2006; Schmidt-Thomé, 2006
Geographic information systems for decision support	Green and King, 2002; Bartlett and Smith, 2005
Scenarios – a tool to facilitate thinking and deciding about the future	DTI, 2002; Ledoux and Turner, 2002
Community vulnerability assessment tool	NOAA Coastal Services Center, 1999; Flak et al., 2002
Flood simulator for flood and coastal defences and other responses	Discovery Software, 2006; Box 6.2
Estimating the socio-economic and environmental effects of disasters	ECLAC, 2003
ICZM process sustainability – a score card	Milne et al., 2003
Monetary economic valuation of the environment	Ledoux et al., 2001; Ohno, 2001
Evaluating and mapping return periods of extreme events	Bernier et al., 2007
Methods and tools to evaluate vulnerability and adaptation	UNFCCC, 2005

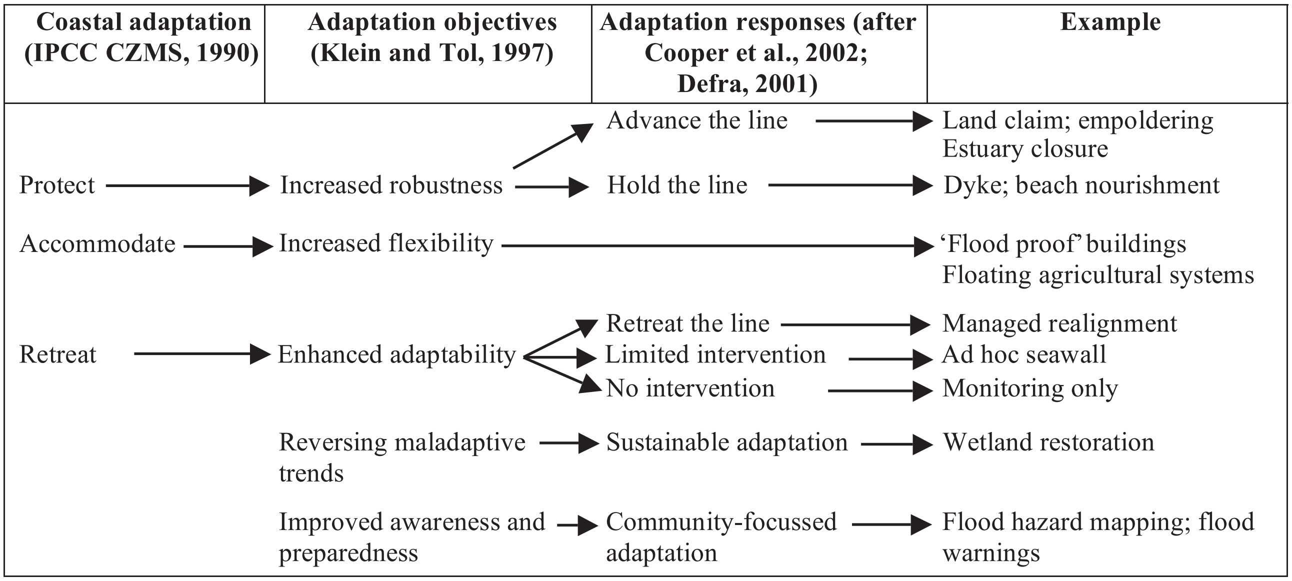

Figure 6.11. *Evolution of planned coastal adaptation practices.*

Klein et al. (2001) describe three trends: (i) growing recognition of the benefits of 'soft' protection and of 'retreat and accommodate' strategies; (ii) an increasing reliance on technologies to develop and manage information; and (iii) an enhanced awareness of the need for coastal adaptation to reflect local natural and socio-economic conditions. The decision as to which adaptation option is chosen is likely to be largely influenced by local socio-economic considerations (Knogge et al., 2004; Persson et al., 2006). It is also important to consider adaptation measures that reduce the direct threats to the survival of coastal ecosystems. These include marine protected areas and 'no take' reserves. Moser (2000) identified several factors that prompted local communities to act against coastal erosion. These included: (i) threats of or actual litigation; (ii) frustration among local officials regarding lack of clarity in local regulations, resulting in confusion as well as exposure to litigation; and (iii) concern over soaring numbers of applications for shoreline-hardening structures, since these are perceived to have negative, often external, environmental impacts. The particular adaptation strategy adopted depends on many factors, including the value of the land or infrastructure under threat, the available financial and economic resources, political and cultural values, the local application of coastal management policies, and the ability to understand and implement adaptation options (Yohe, 2000).

6.6.2 Costs and benefits of adaptation

The body of information on costs of adaptation has increased dramatically since the TAR, covering the range from specific interventions to global aggregations. Most analyses quantify the costs of responses to the more certain and specific effects of sea-level rise. Selected indicative and comparative costs of coastal adaptation measures are presented in Table 6.11. They reveal a wide range in adaptation costs. But in most populated areas such interventions have costs lower than damage costs, even when just considering property losses (Tol, 2002, 2007). Climate change affects the structural stability and performance of coastal defence structures and hence significantly raises the costs of building new structures (Burgess and Townend, 2004) or upgrading existing structures (Townend and Burgess, 2004). Financial cost is not the only criterion on which adaptation should be judged – local conditions and circumstances might result in a more expensive option being favoured, especially where multiple benefits result.

6.6.3 Limits and trade-offs in adaptation

Recent studies suggest that there are limits to the extent to which natural and human coastal systems can adapt even to the more immediate changes in climate variability and extreme events, including in more developed countries (Moser, 2005; Box 6.6). For example, without either adaptation or mitigation, the impacts of sea-level rise and other climate change such as more intense storms (Section 6.3.2) will be substantial, suggesting that some coastal low-lying areas, including atolls, may become unviable by 2100 (Barnett and Adger, 2003; Nicholls, 2004), with widespread impacts in many other areas. This may be reinforced by risk perception and disinvestment from these vulnerable areas. Adaptation could reduce impacts by a factor of 10 to 100 (Hall et al., 2006; Tol, 2007) and, apart from some small island nations, this appears to come at a minor cost compared to the damage avoided (Nicholls and Tol, 2006). However, the analysis is idealised, and while adaptation is likely to be widespread, it remains less clear if coastal societies can fully realise this potential for adaptation (see Box 6.6).

Adaptation for present climate risks is often inadequate and the ability to manage further increases in climate-related risks is frequently lacking. Moreover, increases in coastal development and population will magnify the risks of coastal flooding and other hazards (Section 6.2.2; Pielke Jr et al., 2005). Most measures to compensate and control the salinisation of coastal aquifers are expensive and laborious (Essink, 2001). Frequent floods impose enormous constraints on development. For example, Bangladesh has struggled to put sizeable

Table 6.11. *Selected information on costs and benefits of adaptation.*

Optimal (benefit-cost) coastal protection costs and remaining number of people displaced given a 1 m rise in sea level (Tol, 2002) (see also Figure 6.11).			
Region	**Protection Costs (10^9 US$)**	**Number of People Displaced (10^6)**	
Africa	92	2.74	
OECD Europe	136	0.22	
World	955	8.61	
Construction costs for coastal defence in England and Wales (average total cost in US$/km) (Evans et al., 2004a)			
Earth embankment	970,000	Culverts	3.5 million
Protected embankment	4.7 million	Sea wall	4.7 million
Dunes (excl. replenishment)	93,000	Groynes, breakwater (shingle beach)	9 million
Costs (US$/km) to protect against 1 m in rise in sea level for the USA (Neumann et al., 2000)			
Dike or levee	450,000 – 2.4 million	Sea wall; bulkhead construction	450,000 – 12 million
Capital costs (US$/km) for selected coastal management options in New Zealand (Jenks et al., 2005)			
Sand dune replanting, with community input (maintenance costs minimal)			6,000 – 24,000
Dune restoration, including education programmes (maintenance costs minimal)			15,000 – 35,000
Dune reshaping and replanting (maintenance costs minimal)			50,000 – 300,000
Sea walls and revetments (maintenance costs high – full rebuild every 20 – 40 years)			900,000 – 1.3 million
Direct losses, costs and benefits of adaptation to 65 cm sea-level rise in Pearl Delta, China (Hay and Mimura, 2005)			
Tidal level	Loss (US$ billion)	Cost (US$ billion)	Benefit (US$ billion)
Highest recorded	5.2	0.4	4.8
100 year high water	4.8	0.4	4.4

infrastructure in place to prevent flooding, but with limited success (Ahmad and Ahmed, 2003). Vietnam's transition from state central planning to a more market-oriented economy has had negative impacts on social vulnerability, with a decrease in institutional adaptation to environmental risks associated with flooding and typhoon impacts in the coastal environment (Adger, 2000). In a practical sense adaptation options for coral reefs are limited (Buddemeier, 2001) as is the case for most ecosystems. The continuing observed degradation of many coastal ecosystems (Section 6.2.2), despite the considerable efforts to reverse the trend, suggests that it will also be difficult to alleviate the added stresses resulting from climate change.

Knowledge and skill gaps are important impediments to understanding potential impacts, and thus to developing appropriate adaptation strategies for coastal systems (Crimp et al., 2004). The public often has conflicting views on the issues of sustainability, hard and soft defences, economics, the environment and consultation. Identifying the information needs of local residents, and facilitating access to information, are integral components in the process of public understanding and behavioural change (Myatt et al., 2003; Moser, 2005, 2006; Luers and Moser, 2006).

There are also important trade-offs in adaptation. For instance, while hard protection can greatly reduce the impacts of sea level and climate change on socio-economic systems, this is to the detriment of associated natural ecosystems due to coastal squeeze (Knogge et al., 2004; Rochelle-Newall et al., 2005). Managed retreat is an alternative response, but at what cost to socio-economic systems? General principles that can guide decision making in this regard are only beginning to be developed (Eurosion, 2004; Defra, 2006). Stakeholders will be faced with difficult choices, including questions as to whether traditional uses should be retained, whether invasive alien species or native species increasing in abundance should be controlled, whether planned retreat is an appropriate response to rising relative sea level or whether measures can be taken to reduce erosion. Decisions will need to take into account social and economic as well as ecological concerns (Adam, 2002). Considering these factors, the US Environmental Protection Agency is preparing sea-level rise planning maps that assign all shores along its Atlantic Coast to categories indicating whether shore protection is certain, likely, unlikely, or precluded by existing conservation policies (Titus, 2004). In the Humber estuary (UK) sea-level rise is reducing the standard of protection, and increasing erosion. Adaptation initiatives include creation of new intertidal habitat, which may promote more cost-effective defences and also helps to offset the loss of protected sites, including losses due to coastal squeeze (Winn et al., 2003).

Effective policies for developments that relate to the coast are sensitive to resource use conflicts, resource depletion and to pollution or resource degradation. Absence of an integrated holistic approach to policy-making, and a failure to link the process of policy-making with the substance of policy, results in outcomes that some would consider inferior when viewed within a sustainability framework (Noronha, 2004). Proponents of managed retreat argue that provision of long-term sustainable coastal defences must start with the premise that "coasts need space" (Rochelle-Newall et al., 2005). Some argue that governments must work to increase public awareness, scientific knowledge, and political will to facilitate such a retreat from the "sacrosanct" existing shoreline (Pethick, 2002). Others argue that the highest priority should be the transfer of property rights in lesser developed areas, to allow for changing setbacks in anticipation of an encroaching ocean. This makes inland migration of wetlands and beaches an expectation well before the existing shoreline becomes sacrosanct (Titus, 2001). Property rights and land use often make it difficult to achieve such goals, as shown by the post-Katrina recovery of New Orleans. Economic, social, ecological, legal and political lines of thinking have to be combined in order to achieve meaningful policies for the sustainable development of groundwater reserves and for the protection of subsurface ecosystems (Danielopol et al., 2003). Socio-economic and cultural conditions frequently present barriers to choosing and implementing the most appropriate adaptation to sea-level rise. Many such barriers can often be resolved by way of education at all levels, including local seminars and workshops for relevant stakeholders (Kobayashi, 2004; Tompkins et al., 2005a). Institutional strengthening and other interventions are also of importance (Bettencourt et al., 2005).

6.6.4 Adaptive capacity

Adaptive capacity is the ability of a system to evolve in order to accommodate climate changes or to expand the range of variability with which it can cope (see Chapter 17 for further explanation). The adaptive capacity of coastal communities to cope with the effects of severe climate impacts declines if there is a lack of physical, economic and institutional capacities to reduce climate-related risks and hence the vulnerability of high-risk communities and groups. But even a high adaptive capacity may not translate into effective adaptation if there is no commitment to sustained action (Luers and Moser, 2006).

Current pressures are likely to adversely affect the integrity of coastal ecosystems and thereby their ability to cope with additional pressures, including climate change and sea-level rise. This is a particularly significant factor in areas where there is a high level of development, large coastal populations and high levels of interference with coastal systems. Natural coastal habitats, such as dunes and wetlands, have a buffering capacity which can help reduce the adverse impacts of climate change. Equally, improving shoreline management for non-climate change reasons will also have benefits in terms of responding to sea-level rise and climate change (Nicholls and Klein, 2005). Adopting a static policy approach towards sea-level rise conflicts with sustaining a dynamic coastal system that responds to perturbations via sediment movement and long-term evolution (Crooks, 2004). In the case of coastal megacities, maintaining and enhancing both resilience and adaptive capacity for weather-related hazards are critically important policy and management goals. The dual approach brings benefits in terms of linking analysis of present and future hazardous conditions. It also enhances the capacity for disaster prevention and preparedness, disaster recovery and for adaptation to climate change (Klein et al., 2003).

6.6.4.1 Constraints and limitations

Yohe and Tol (2002) assessed the potential contributions of various adaptation options to improving systems' coping capacities. They suggest focusing attention directly on the underlying determinants of adaptive capacity (see Section 17.3.1). The future status of coastal wetlands appears highly sensitive to societal attitudes to the environment (Table 6.1), and this could be a more important control of their future status than sea-level rise (Nicholls, 2004). This highlights the importance of the socio-economic conditions (e.g., institutional capabilities; informed and engaged public) as a fundamental control of impacts with and without climate change (Tompkins et al., 2005b). Hazard awareness education and personal hazard experience are significant and important contributors to reducing community vulnerability. But despite such experience and education, some unnecessary and avoidable losses associated with tropical cyclone and storm surge hazards are still highly likely to occur (Anderson-Berry, 2003). These losses will differ across socio-economic groups, as has been highlighted recently by Hurricane Katrina. The constraints and limitations on adaptation by coastal systems, both natural and human, highlight the benefits for deeper public discourse on climate risk management, adaptation needs, challenges and allocation and use of resources.

6.6.4.2 Capacity-strengthening strategies

Policies that enhance social and economic equity, reduce poverty, increase consumption efficiencies, decrease the discharge of wastes, improve environmental management, and increase the quality of life of vulnerable and other marginal coastal groups can collectively advance sustainable development, and hence strengthen adaptive capacity and coping mechanisms. Many proposals to strengthen adaptive capacity have been made including: mainstreaming the building of resilience and reduction of vulnerability (Agrawala and van Aalst, 2005; McFadden et al., 2007b); full and open data exchange (Hall, 2002); scenarios as a tool for communities to explore future adaptation policies and practices (Poumadère et al., 2005); public participation, co-ordination among oceans-related agencies (West, 2003); research on responses of ecological and socio-economic systems, including the interactions between ecological, socio-economic and climate systems (Parson et al., 2003); research on linkages between upstream and downstream process to underpin comprehensive coastal management plans (Contreras-Espinosa and Warner, 2004); research to generate useful, usable and actionable information that helps close the science-policy gap (Hay and Mimura, 2006); strengthening institutions and enhancing regional co-operation and co-ordination (Bettencourt et al., 2005); and short-term training for practitioners at all levels of management (Smith, 2002a).

6.6.5 The links between adaptation and mitigation in coastal and low-lying areas

Adaptation (e.g., coastal planning and management) and mitigation (reducing greenhouse gas emissions) are responses to climate change, which can be considered together (King,

2004) (see Chapter 18). The response of sea-level rise to mitigation of greenhouse gas emissions is slower than for other climate factors (Meehl et al., 2007) and mitigation alone will not stop growth in potential impacts (Nicholls and Lowe, 2006). However, mitigation decreases the rate of future rise and the ultimate rise, limiting and slowing the need for adaptation as shown by Hall et al. (2005). Hence Nicholls and Lowe (2006) and Tol (2007) argue that adaptation and mitigation need to be considered together when addressing the consequences of climate change for coastal areas. Collectively these interventions can provide a more robust response to human-induced climate change than consideration of each policy alone.

Adaptation will provide immediate and longer-term reductions in risk in the specific area that is adapting. On the other hand, mitigation reduces future risks in the longer term and at the global scale. Identifying the optimal mix is problematic as it requires consensus on many issues, including definitions, indicators and the significance of thresholds. Importantly, mitigation removes resources from adaptation, and benefits are not immediate, so investment in adaptation may appear preferable, especially in developing countries (Goklany, 2005). The opposite view of the need for urgent mitigation has recently been argued (Stern, 2007). Importantly, the limits to adaptation may mean that the costs of climate change are underestimated (Section 6.6.3), especially in the long term. These findings highlight the need to consider impacts beyond 2100, in order to assess the full implications of different mitigation and adaptation policy mixes (Box 6.6).

6.7 Conclusions: implications for sustainable development

The main conclusions are reported in the Executive Summary and are reviewed here in the context of sustainable development. Coastal ecosystems are dynamic, spatially constrained, and attractive for development. This leads to increasing multiple stresses under current conditions (Section 6.2.2), often resulting in significant degradation and losses, especially to economies highly dependent on coastal resources, such as small islands. Trends in human development along coasts amplify their vulnerability, even if climate does not change. For example, in China 100 million people moved from inland to the coast in the last twenty years (Dang, 2003), providing significant benefits to the national economy, but presenting major challenges for coastal management. This qualitative trend is mirrored in most populated coastal areas and raises the conflict between conservation and development (Green and Penning-Rowsell, 1999). Equally the pattern of development can have tremendous inertia (Klein et al., 2002) and decisions made today may have implications centuries into the future (Box 6.6).

Climate change and sea-level rise increase the challenge of achieving sustainable development in coastal areas, with the most serious impediments in developing countries, in part due to their lower adaptive capacity. It will make achieving the Millennium Development Goals (UN Secretary General, 2006b) more difficult, especially the Goal of Ensuring Environmental Sustainability (reversing loss of environmental resources, and improving lives of slum dwellers, many of whom are coastal). Adapting effectively to climate change and sea-level rise will involve substantial investment, with resources diverted from other productive uses. Even with the large investment possible in developed countries, residual risk remains, as shown by Hurricane Katrina in New Orleans (Box 6.4), requiring a portfolio of responses that addresses human safety across all events (protection, warnings, evacuation, etc.) and also can address multiple goals (e.g., protection of the environment as well as adaptation to climate change) (Evans et al., 2004a; Jonkman et al., 2005). Long-term sea-level rise projections mean that risks will grow for many generations unless there is a substantial and ongoing investment in adaptation (Box 6.6). Hence, sustainability for coastal areas appears to depend upon a combination of adaptation and mitigation (Sections 6.3.2 and 6.6.5).

There will be substantial benefits if plans are developed and implemented in order to address coastal changes due to climate and other factors, such as those processes that also contribute to relative sea-level rise (Rodolfo and Siringan, 2006). This requires increased effort to move from reactive to more proactive responses in coastal management. Strengthening integrated multidisciplinary and participatory approaches will also help improve the prospects for sustaining coastal resources and communities. There is also much to be learnt from experience and retrospective analyses of coastal disasters (McRobie et al., 2005). Technological developments are likely to assist this process, most especially in softer technologies associated with monitoring (Bradbury et al., 2005), predictive modelling and broad-scale assessment (Burgess et al., 2003; Cowell et al., 2003a; Boruff et al., 2005) and assessment of coastal management actions, both present and past (Klein et al., 2001). Traditional practices can be an important component of the coastal management toolkit.

6.8 Key uncertainties, research gaps and priorities

This assessment shows that the level of knowledge is not consistent with the potential severity of the problem of climate change and coastal zones. While knowledge is not adequate in any aspect, uncertainty increases as we move from the natural sub-system to the human sub-system, with the largest uncertainties concerning their interaction (Figure 6.1). An understanding of this interaction is critical to a comprehensive understanding of human vulnerability in coastal and low-lying areas and should include the role of institutional adaptation and public participation (Section 6.4.3). While research is required at all scales, improved understanding at the physiographic unit scale (e.g., coastal cells, deltas or estuaries) would have particular benefits, and support adaptation to climate change and wider coastal management. There also remains a strong focus on sea-level rise, which needs to be broadened to include all the climate drivers in the coastal zone (Table 6.2). Finally, any response to climate change has to address the other non-

Box 6.6. Long-term sea-level rise impacts (beyond 2100)

The timescales of ocean warming are much longer than those of surface air temperature rise. As a result, sea-level rise due to thermal expansion is expected to continue at a significant rate for centuries, even if climate forcing is stabilised (Meehl et al., 2005; Wigley, 2005). Deglaciation of small land-based glaciers, and possibly the Greenland and the West Antarctic ice sheets, may contribute large additional rises, with irreversible melting of Greenland occurring for a sustained global temperature rise of 1.1 to 3.8°C above today's global average temperature: this is likely to happen by 2100 under the A1B scenario, for instance (Meehl et al., 2007). More than 10 m of sea-level rise is possible, albeit over very long time spans (centuries or longer), and this has been termed 'the commitment to sea-level rise'. The potential exposure to these changes, just based on today's socio-economic conditions, is significant both regionally and globally (Table 6.12) and growing (Section 6.3.1). Thus there is a conflict between long-term sea-level rise and present-day human development patterns and migration to the coast (Nicholls et al., 2006).

The rate of sea-level rise is uncertain and a large rise (>0.6 m to 0.7 m/century) remains a low probability/high impact risk (Meehl et al., 2007). Some analyses suggest that protection would be an economically optimum response in most developed locations, even for an arbitrary 2 m/century scenario (Anthoff et al., 2006). However, sea-level rise will accumulate beyond 2100, increasing impact potential (Nicholls and Lowe, 2006). Further, there are several potential constraints to adaptation which are poorly understood (Section 6.4.3; Nicholls and Tol, 2006; Tol et al., 2006). This raises long-term questions about the implications of 'hold the line' versus 'retreat the line' adaptation policies and, more generally, how best to approach coastal spatial planning. While shoreline management is starting to address such issues for the 21st century (Eurosion, 2004; Defra, 2006), the long timescales of sea-level rise suggest that coastal management, including spatial planning, needs to take a long-term view on adaptation to sea-level rise and climate change, especially with long-life infrastructure such as nuclear power stations.

Table 6.12. *Indicative estimates of regional exposure as a function of elevation and baseline (1995) socio-economics. MER – market exchange rates (after Anthoff et al., 2006).*

Region	Exposure by factor and elevation above mean high water								
	Land area (km^2)			Population (millions)			GDP MER (US$ billions)		
	1m	5m	10m	1m	5m	10m	1m	5m	10m
Africa	118	183	271	8	14	22	6	11	19
Asia	875	1548	2342	108	200	294	453	843	1185
Australia	135	198	267	2	3	4	38	51	67
Europe	139	230	331	14	21	30	305	470	635
Latin America	317	509	676	10	17	25	39	71	103
North America	640	1000	1335	4	14	22	103	358	561
Global (Total)	2223	3667	5223	145	268	397	944	1802	2570

climate drivers of coastal change in terms of understanding potential impacts and responses, as they will interact with climate change. As recognised in earlier IPCC assessments and the Millennium Ecosystem and LOICZ Assessments (Agardy et al., 2005; Crossland et al., 2005), these other drivers generally exacerbate the impacts of climate change.

The following research initiatives would substantially reduce these uncertainties and increase the effectiveness and science base of long-term coastal planning and policy development.

Establishing better baselines of actual coastal changes, including local factors and sea-level rise, and the climate and non-climate drivers, through additional observations and expanded monitoring. This would help to better establish the causal links between climate and coastal change which tend to remain inferred rather than observed (Section 6.2.5), and support model development.

- Improving predictive capacity for future coastal change due to climate and other drivers, through field observations, experiments and model development. A particular challenge will be understanding thresholds under multiple drivers of change (Sections 6.2.4; 6.4.1).
- Developing a better understanding of the adaptation of the human systems in the coastal zone. At the simplest this could be an inventory of assets at risk, but much more could be done in terms of deepening our understanding of the qualitative trends suggested in Table 6.1 (see also Section 6.4.2) and issues of adaptive capacity.

- Improving impact and vulnerability assessments within an integrated assessment framework that includes natural-human sub-system interactions. This requires a strong inter-disciplinary approach and the targeting of the most vulnerable areas, such as populated megadeltas and deltas, small islands and coastal cities (Section 6.4.3). Improving systems of coastal planning and zoning and institutions that can enforce regulations for clearer coastal governance is required in many countries.
- Developing methods for identification and prioritisation of coastal adaptation options. The effectiveness and efficiency of adaptation interventions need to be considered, including immediate benefits and the longer term goal of sustainable development (Sections 6.6; 6.7).
- Developing and expanding networks to share knowledge and experience on climate change and coastal management among coastal scientists and practitioners.

These issues need to be explored across the range of spatial scales: from local to global scale assessments and, given the long timescales of sea-level rise, implications beyond the 21st century should not be ignored. Thus this research agenda needs to be taken forward across a broad range of activities from the needs of coastal management and adaptation to global integrated assessments and the benefits of mitigation. While some existing global research efforts are pushing in the direction that is recommended, e.g., the IGBP/IHDP LOICZ Science Plan (Kremer et al., 2004), much more effort is required to achieve these goals, especially those referring to the human, integrated assessment and adaptation goals, and at local to regional scales (Few et al., 2004a).

References

Adam, P., 2002: Saltmarshes in a time of change. *Environ. Conserv.*, **29**, 39-61.

Adger, W.N., 2000: Institutional adaptation to environmental risk under the transition in Vietnam. *Ann. Assoc. Am. Geogr.*, **90**, 738-758.

Agardy, T., J. Alder, P. Dayton, S. Curran, A. Kitchingman, M. Wilson, A. Catenazzi, J. Restrepo and Co-authors, 2005: Coastal systems. *Millennium Ecosystem Assessment: Ecosystems & Human Well-Being, Volume 1: Current State and Trends*, W. Reid, Ed., Island Press, 513-549.

Agnew, M.D., and D. Viner, 2001: Potential impacts of climate change on international tourism. *Tourism and Hospitality Research*, **3**, 37-60.

Agrawala, S., and M. van Aalst, 2005: Bridging the gap between climate change and development. *Bridge over Troubled Waters: Linking Climate Change and Development*, S. Agrawala, Ed., Organisation for Economic Co-operation and Development (OECD). 153pp.

Aguiló, E., J. Alegre and M. Sard, 2005: The persistence of the sun and sand tourism model. *Tourism Manage.*, **26**, 219-231.

Ahmad, Q.K. and A.U. Ahmed, 2003: Regional cooperation in flood management in the Ganges-Brahmaputra-Meghna region: Bangladesh perspective. *Nat. Hazards*, **28**, 181-198.

Ahrendt, K., 2001: Expected effects of climate change on Sylt Island; results from a multidisciplinary German project. *Climate Res.*, **18**, 141-146.

Alcamo, J., and T. Henrichs, 2002: Critical regions: a model-based estimation of world water resources sensitive to global changes. *Aquat. Sci.*, **64**, 352-362.

Aliff, G., 2006: Have hurricanes changed everything? Or is a soft market ahead? *Risk Manage.*, **53**, 12-19.

Allan, J., P. Komar and G. Priest, 2003: Shoreline variability on the high-energy Oregon coast and its usefulness in erosion-hazard assessments. *J. Coastal Res.*, **S38**, 83-105.

Allen, J.R.L., 2000: Morphodynamics of Holocene saltmarshes: a review sketch from the Atlantic and Southern North Sea coasts of Europe. *Quaternary Sci. Rev.*, **19**, 1155-1231.

Allen, J.R.L.,, 2003: An eclectic morphostratigraphic model for the sedimentary response to Holocene sea-level rise in northwest Europe. *Sediment. Geol.*, **161**, 31-54.

Alley, R.B., J. Marotzke, W.D. Nordhaus, J.T. Overpeck, D.M. Peteet, R.A. Pielke, R.T. Pierrehumbert, R.T. Rhines and Co-authors, 2003: Abrupt climate change. *Science*, **299**, 2005-2010.

Allison, M.A., S.R. Khan, S.L. Goodbred Jr. and S.A. Kuehl, 2003: Stratigraphic evolution of the late Holocene Ganges-Brahmaputra lower delta plain. *Sediment. Geol.*, **155**, 317-342.

Anderson-Berry, L.J., 2003: Community vulnerability to tropical cyclones: Cairns, 1996-2000. *Nat. Hazards*, **30**, 209-232.

Andersson, A.J., F.T. Mackenzie and L.M. Ver, 2003: Solution of shallow-water carbonates: an insignificant buffer against rising atmospheric CO_2. *Geology*, **31**, 513-516.

Anthoff, D., R.J. Nicholls, R.S.J. Tol and A.T. Vafeidis, 2006: *Global and Regional Exposure to Large Rises in Sea Level: A Sensitivity Analysis*. Working Paper 96. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, Norfolk, 31pp.

ARAG, 1999: *The potential consequences of climate variability and change: Alaska. Preparing for a changing climate*. Alaska Regional Assessment Group (ARAG). Center for Global Change and Arctic System Research, University of Alaska, 39 pp.

Arnell, N.W., 2004: Climate change and global water resources: SRES scenarios and socio-economic scenarios. *Glob. Environ. Chang.*, **14**, 31-52.

Arnell, N.W., M.J.L. Livermore, S. Kovats, P.E. Levy, R. Nicholls, M.L. Parry and S.R. Gaffin, 2004: Climate and socio-economic scenarios for global-scale climate change impacts assessments: Characterising the SRES storylines. *Glob. Environ. Chang.*, **14**, 3-20.

Ayre, D.J., and T.P. Hughes, 2004: Climate change, genotypic diversity and gene flow in reef-building corals. *Ecol. Lett.*, **7**, 273-278.

Baldwin, A.H., M.S. Egnotovich and E. Clarke, 2001: Hydrologic change and vegetation of tidal freshwater marshes: Field, greenhouse and seed-bank experiments. *Wetlands*, **21**, 519-531.

Barnett, J., and W.N. Adger, 2003: Climate dangers and atoll countries. *Climatic Change*, **61**, 321-337.

Barras, J. A., cited 2006: Land area change in coastal Louisiana after the 2005 hurricanes - a series of three maps. U.S. Geological Survey Open-File Report 2006-1274. [Accessed 29.03.07: http://pubs.usgs.gov/of/2006/1274/]

Barras, J., S. Beville, D. Britsch, S. Hartley, S. Hawes, J. Johnston, P. Kemp, Q. Kinler and Co-authors, 2003: Historical and projected coastal Louisiana land changes: 1978-2050. Open File Report 03-334. U.S. Geological Survey, 39 pp.

Barros, V., A. Menéndez, C. Natenzon, R.R. Kokot, J.O. Codignotto, M. Re, P. Bronstein, I. Camilloni and Co-authors, 2006: *Vulnerability to floods in the metropolitan region of Buenos Aires under future climate change*. Working Paper 26. Assessments of Impacts and Adaptations to Climate Change (AIACC), 36 pp.

Bartlett, D., and J.L. Smith, Eds., 2005: *GIS for Coastal Zone Management*. CRC Press, 310 pp.

Barton, A.D., and K.S. Casey, 2005: Climatological context for large-scale coral bleaching. *Coral Reefs*, **24**, 536-554.

Baxter, P.J., 2005: The east coast Big Flood, 31 January-1 February 1953: a summary of the human disaster. *Philos. T. Roy. Soc. A*, **363**, 1293-1312.

Becken, S., and J. Hay, undated: *Tourism and Climate Change – Risk and opportunities*. Landcare Research, 292 pp.

Beer, S., and E. Koch, 1996: Photosynthesis of marine macroalgae and seagrass in globally changing CO_2 environments. *Mar. Ecol-Prog. Ser.*, **141**, 199-204.

Berge, J., G. Johnsen, F. Nilsen, B. Gulliksen and D. Slagstad, 2005: Ocean temperature oscillations enable reappearance of blue mussels *Mytilus edulis* in Svalbard after a 1000 year absence. *Mar. Ecol-Prog. Ser.*, **303**, 167-175.

Berkelmans, R., G. De'ath, S. Kininmouth and W.J. Skirving, 2004: A comparison of the 1998 and 2002 coral bleaching events on the Great Barrier Reef: spatial correlation, patterns and predictions. *Coral Reefs*, **23**, 74-83.

Bernier, N.B., K.R. Thompson, J. Ou and H. Ritchie, 2007: Mapping the return periods of extreme sea levels: Allowing for short sea level records, seasonality and climate change. *Global Planet Change*. doi:10.1016/j.gloplacha.2006.11.027.

Bettencourt, S., R. Croad, P. Freeman, J.E. Hay, R. Jones, P. King, P. Lal, A. Mearns and Co-authors, 2005: *Not if but when: Adapting to natural hazards in the Pacific Islands region*. A policy note. Pacific Islands Country Management Unit, East Asia and Pacific Region, World Bank, 46 pp.

Bigano, A., J.M. Hamilton and R.S.J. Tol, 2005: *The Impact of Climate Change on Domestic and International Tourism: A Simulation Study.* Working paper FNU-58, 23 pp.

Bijlsma, L., C.N. Ehler, R.J.T. Klein, S.M. Kulshrestha, R.F. McLean, N. Mimura, R.J. Nicholls, L.A. Nurse and Co-authors, 1996: Coastal zones and small islands. *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, R.T. Watson, M.C. Zinyowera and R.H. Moss, Eds., Cambridge University Press, Cambridge, 289-324.

Bindoff, N., J. Willebrand, V. Artale, A. Cazenave, J. Gregory, S. Gulev, K. Hanawa, C. Le Quéré and Co-authors, 2007: Observations: Oceanic climate change and sea level. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Eds., Cambridge University Press, Cambridge 385-432.

Binh, C.T., M.J. Phillips and H. Demaine, 1997: Integrated shrimp-mangrove farming systems in the Mekong Delta of Vietnam. *Agr. Res*., **28**, 599-610.

Bird, E.C.F., 1985: *Coastline Changes: A Global Review.* John Wiley and Sons, Chichester, 219 pp.

Bird, E.C.F.,, 2000: *Coastal Geomorphology: An Introduction*. Wiley and Sons, Chichester. 340 pp.

Boruff, B.J., C. Emrich and S.L. Cutter, 2005: Erosion hazard vulnerability of US coastal counties. *J. Coastal Res*., **21**, 932-942.

Bosello, F., R. Lazzarin and R.S.J. Tol, 2004: *Economy-wide Estimates of the Implications of Climate Change: Sea Level Rise*. Working Paper FNU-38. Research Unit Sustainability and Global Change, Centre for Marina and Climate Research, Hamburg University. 22pp.

Bradbury, A., S. Cope and H. Dalton, 2005: Integration of large-scale regional measurement, data management and analysis programmes, for coastal processes, geomorphology and ecology. *Proceeding of CoastGIS '05*, 21-23 July, Aberdeen, Scotland. 14 pp.

Brander, K., G. Blom, M.F. Borges, K. Erzini, G. Henderson, B.R. MacKenzie, H. Mendes, A.M.P. Santos and P. Toresen, 2003a: Changes in fish distribution in the eastern North Atlantic: are we seeing a coherent response to changing temperature? *ICES Marine Science Symposia*, **219**, 260-273.

Brander, L.M., R.J.G.M. Florax and J.E. Vermaat, 2003b: *The Empirics of Wetland Valuation: A Comprehensive Summary and a Meta-analysis of the Literature*. Report No.W-03/30. Institute for Environmental Studies (IVM), Vrije Universiteit, Amsterdam, 33 pp.

Brown, A.C., and A. McLachlan, 2002: Sandy shore ecosystems and the threats facing them: some predictions for the year 2025. *Environ. Conserv*., **29**, 62-77.

Bruno, J.F., C.E. Siddon, J.D. Witman, P.L. Colin and M.A. Toscano, 2001: El Niño related coral bleaching in Palau, Western Caroline Islands. *Coral Reefs*, **20**, 127-136.

Brunsden, D., 2001: A critical assessment of the sensitivity concept in geomorphology. *Catena*, **42**, 99-123.

Bruun, P., 1962: Sea-level rise as a cause of shore erosion. *Journal of the Waterways and Harbors Division*, **88**, 117-130.

Bryant, E., 2001: *Tsunami: The Underrated Hazard*. Cambridge University Press, Cambridge, 320 pp.

Buddemeier, R.W., 2001: Is it time to give up? *B. Mar. Sci*., **69**, 317-326.

Buddemeier, R.W., S.V. Smith, D.P. Swaaney and C.J. Crossland, 2002: *The Role of the Coastal Ocean in the Disturbed and Undisturbed Nutrient and Carbon Cycles*. LOICZ Reports and Studies Series No. 24. 84 pp.

Buddemeier, R.W., J.A. Kleypas and B. Aronson, 2004: *Coral Reefs and Global Climate Change: Potential Contributions of Climate Change to Stresses on Coral Reef Ecosystems*. Report prepared for the Pew Centre of Climate Change, Arlington, Virginia, 56 pp.

Burgess, K., and I. Townend, 2004: The impact of climate change upon coastal defence structures. *39th DEFRA Flood and Coastal Management Conference*, 29 June - 1 July, York UK, Department of Environment, Food and Rural Affairs (Defra), 11.12.11-11.12.12.

Burgess, K., J.D. Orford, K. Dyer, I. Townend and P. Balson, 2003: FUTURECOAST — The integration of knowledge to assess future coastal evolution at a national scale. *Proceedings of the 28th International Conference on Coastal Engineering*, **3**, 3221-3233.

Burkett, V.R., and J. Kusler, 2000: Climate change: potential impacts and interactions in wetlands of the United States. *J. Am. Water Resour. As*., **36**, 313-320.

Burkett, V.R., D.B. Zilkoski and D.A. Hart, 2003: Sea-level rise and subsidence: Implication for flooding in New Orleans. *U.S. Geological Survey Subsidence Interest Group Conference, proceedings of the technical meeting. Water Resources Division (Open File Report 03-308)*, 27th - 29th November 2001. Galveston, Texas, U.S. Geological Survey, 63-70.

Burkett, V.R., D.A. Wilcox, R. Stottlemeyer, W. Barrow, D. Fagre, J. Baron, J. Price, J. Nielsen and Co-authors, 2005: Nonlinear dynamics in ecosystem response to climate change: Case studies and policy implications. *Ecological Complexity*, **2**, 357-394.

Butler, C.D., C.F. Corvalan and H.S. Koren, 2005: Human health, well-being, and global ecological scenarios. *Ecosystems*, **8**, 153-162.

Cahoon, D.R., P. Hensel, J. Rybczyk, K. McKee, C.E. Proffitt and B. Perez, 2003: Mass tree mortality leads to mangrove peat collapse at Bay Islands, Honduras after Hurricane Mitch. *J. Ecol*., **91**, 1093-1105.

Cahoon, D.R., P.F. Hensel, T. Spencer, D.J. Reed, K.L. McKee and N. Saintilan, 2006: Coastal wetland vulnerability to relative sea-level rise: wetland elevation trends and process controls. *Wetlands as a Natural Resource, Vol. 1: Wetlands and Natural Resource Management*, J. Verhoeven, D. Whigham, R. Bobbink and B. Beltman, Eds., Springer Ecological Studies series, Chapter 12. 271-292.

Caldeira, K., and M.E. Wickett, 2005: Anthropogenic carbon and ocean pH. *Nature*, **425**, 365.

Canziani, O.F., and J.C. Gimenez, 2002: *Hydrometeorological Aspects of the Impact of Climate Change on the Argentina's Pampas*. EPA Report. United States Environmental Protection Agency.

CBD, 2003: *Interlinkages Between Biological Diversity and Climate Change*. CBD Technical report 10. Secretariat of the Convention on Biological Diversity, 142 pp.

CBD, 2006: *Guidance for Promoting Synergy Among Activities Addressing Biological Diversity, Desertification, Land Degradation and Climate Change*. CBD Technical Series 25. Secretariat of the Convention on Biological Diversity, iv + 43 pp.

Chadwick, A.J., H. Karunarathna, W.R. Gehrels, A.C. Massey, D. O'Brien and D. Dales, 2005: A new analysis of the Slapton barrier beach system, UK. *Proc. Inst. Civ. Eng. Water Maritime Engng*, **158**, 147-161.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, W.-T. Kwon and Co-authors, 2007: Regional climate projections. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Eds., Cambridge University Press, Cambridge, 847-940.

Christie, P., K. Lowry, A.T. White, E.G. Oracion, L. Sievanen, R.S. Pomeroy, R.B. Pollnac, J.M. Patlis and R.L.V. Eisma, 2005: Key findings from a multidisciplinary examination of integrated coastal management process sustainability. *Ocean Coast. Manage*., **48**, 468-483.

Church, J.A., J.M. Gregory, P. Huybrechts, M. Kuhn, K. Lambeck, M.T. Nhuan, D. Qin and P.L. Woodworth, 2001: Changes in sea level. *Climate Change 2001. The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden and D. Xiaosu, Eds., Cambridge University Press, Cambridge, 639-693.

Codignotto, J.O., 2004a: Sea-level rise and coastal de La Plata River. *Report for the second AIACC "It's raining, it's pouring, ... I''s time to be adapting"; Regional Workshop for Latin America and the Caribbean* 24-27th August 2004, Buenos Aires. 4-18pp.

Codignotto, J.O., 2004b: Diagnóstico del estado actual de las áreas costeras de Argentina. Report for Programa de las Naciones Unidas para el Desarrollo (Argentina) PNUD/ARG 3, 43 pp.

Codignotto, J.O., R.R. Kokot and A.J.A. Monti, 2001: Cambios rápidos en la Costa de Caleta Valdés, Chubut. *Asociación Geológica Argentina*, **56**, 67-72.

Coleman, J.M., O.K. Huh, D.H. Braud, Jr. and H.H. Roberts, 2005: Major World Delta Variability and Wetland Loss. *Gulf Coast Association of Geological Societies (GCAGS) Transactions*, **55**, 102-131

Coles, S.L., and B.E. Brown, 2003: Coral bleaching - capacity for acclimatization and adaptation. *Adv. Mar. Biol*., **46**, 183-224.

Contreras-Espinosa, F., and B.G. Warner, 2004: Ecosystem characteristics and management considerations for coastal wetlands in Mexico. *Hydrobiologia*, **511**, 233-245.

Coombes, E., D. Burgess, N. Jackson, K. Turner and S. Cornell, 2004: Case study: Climate change and coastal management in practice - A cost-benefit assessment in the Humber, UK. 56 pp. [Accessed 30.05.07: http://www.eloisegroup.org/themes/climatechange/contents.htm]

Cooper, J.A.G., and O.H. Pilkey, 2004: Sea-level rise and shoreline retreat: time to abandon the Bruun Rule. *Global Planet Change*, **43**, 157-171.

Cooper, J.A.G., and F. Navas, 2004: Natural bathymetric change as a control on century-scale shoreline behaviour. *Geology*, **32**, 513-516.

Cooper, N., and H. Jay, 2002: Predictions of large-scale coastal tendency: development and application of a qualitative behaviour-based methodology. *J. Coastal Res.*, **S 36**, 173-181.

Cooper, N., P.C. Barber, M.C. Bray and D.J. Carter, 2002: Shoreline management plans: a national review and an engineering perspective. *Proc. Inst. Civ. Eng. Water Maritime Engng.*, **154**, 221-228.

Cowell, P.J., M.J.F. Stive, A.W. Niedoroda, H.J. De Vriend, D.J.P. Swift, G.M. Kaminsky and M. Capobianco, 2003a: The coastal tract. Part 1: A conceptual approach to aggregated modelling of low-order coastal change. *J. Coastal Res.*, **19**, 812-827.

Cowell, P.J., M.J.F. Stive, A.W. Niedoroda, D.J.P. Swift, H.J. De Vriend, M.C. Buijsman, R.J. Nicholls, P.S. Roy and Co-authors, 2003b: The coastal tract. Part 2: Applications of aggregated modelling of lower-order coastal change. *J. Coastal Res.*, **19**, 828-848.

Cowell, P.J., B.G. Thom, R.A. Jones, C.H. Everts and D. Simanovic, 2006: Management of uncertainty in predicting climate-change impacts on beaches. *J. Coastal Res.*, **22**, 232.

CRED, 2005: *CRED Crunch*. Centre for Research on the Epidemiology of Disasters (CRED), Université catholique de Louvain, Louvain-la-Neuve, 2 pp.

Crimp, S., J. Balston, A.J. Ash, L. Anderson-Berry, T. Done, R. Greiner, D. Hilbert, M. Howden and Co-authors, 2004: *Climate Change in the Cairns and Great Barrier Reef region: Scope and Focus for an Integrated Assessment*. Australian Greenhouse Office, Canberra, 100 pp.

Crooks, S., 2004: The effect of sea-level rise on coastal geomorphology. *Ibis*, **146**, 18-20.

Crossland, C.J., H.H. Kremer, H.J. Lindeboom, J.I. Marshall Crossland and M.D.A. Le Tissier, 2005: *Coastal Fluxes in the Anthropocene*. The Land-Ocean Interactions in the Coastal Zone Project of the International Geosphere-Biosphere Programme Series: Global Change - The IGBP Series, 232 pp.

Dang, N.A., 2003: Internal migration policies in the ESCAP region. *Asia-Pacific Population Journal*, **18**, 27-40.

Daniel, H., 2001: Replenishment versus retreat: the cost of maintaining Delaware's beaches. *Ocean Coast. Manage.*, **44**, 87-104.

Danielopol, D.L., C. Griebler, A. Gunatilaka and J. Notenboom, 2003: Present state and future prospects for groundwater ecosystems. *Environ. Conserv.*, **30**, 104-130.

Daufresne, M., M.C. Roger, H. Capra and N. Lamouroux, 2003: Long-term changes within the invertebrate and fish communities of the Upper Rhône River: effects of climatic factors. *Glob. Change Biol.*, **10**, 124-140.

Davidson-Arnott, R.G.D., 2005: Conceptual model of the effects of sea-level rise on sandy coasts. *J. Coastal Res.*, **21**, 1173-1177.

Dawson, R.J., J.W. Hall, P.D. Bates and R.J. Nicholls, 2005: Quantified analysis of the probability of flooding in the Thames Estuary under imaginable worst case sea-level rise scenarios. *Int. J. Water. Resour. D.*, **21**, 577-591.

de Groot, T.A.M., 1999: Climate shifts and coastal changes in a geological perspective. A contribution to integrated coastal zone management. *Geol. Mijnbouw*, **77**, 351-361.

Defra, 2001: *Shoreline Management Plans: A Guide for Coastal Defence Authorities*. Department for Environment, Food and Rural Affairs (Defra), London, 77pp.

Defra, 2004: *Scientific and Technical Aspects of Climate Change, including Impacts and Adaptation and Associated Costs*. Department for Environment, Food and Rural Affairs (Defra), London, 19 pp.

Defra, 2006: *Shoreline Management Plan Guidance*. Volume 1: Aims and requirements. Department for Environment, Farming and Rural Affairs (Defra), London, 54 pp.

Dickinson, W.R., 2004: Impacts of eustasy and hydro-isostasy on the evolution and landforms of Pacific atolls. *Palaeogeogr., Palaeoclimatol., Palaeoecol.,* **213**, 251-269.

Dickson, M.E., M.J.A. Walkden, J.W. Hall, S.G. Pearson and J. Rees, 2005: Numerical modelling of potential climate change impacts on rates of soft cliff recession, northeast Norfolk, UK. *Proceedings of the International Conference on Coastal Dynamics*, 4-8th April; Barcelona, Spain, American Society of Civil Engineers (ASCE).

Diffey, B., 2004: Climate change, ozone depletion and the impact on ultraviolet exposure of human skin. *Phys. Med. Biol.*, **49**, R1-R11.

Dinas-Coast Consortium, 2006: Dynamic Interactive Vulnerability Assessment (DIVA), Potsdam Institute for Climate Impact Research, Potsdam.

Discovery Software, cited 2006: Software solutions for a dynamic world including STEMgis, FloodRanger, SimCoast and NineNil. [Accessed 10.04.07: www.discoverysoftware.co.uk]

Dixon, T.H., F. Amelung, A. Ferretti, F. Novali, F. Rocca, R. Dokka, G. Sella, S.-W. Kim and Co-authors, 2006: Subsidence and flooding in New Orleans. *Nature*, **441**, 587-588.

Donnelly, J.P., P. Cleary, P. Newby and R. Ettinger, 2004: Coupling instrumental and geological records of sea level change: Evidence from southern New England of an increase in the rate of sea-level rise in the late 19th century. *Geophys. Res. Lett.*, **31**, article no. L05203.

Donner, S.D., W.J. Skirving, C.M. Little, M. Oppenheimer and O. Hoegh-Guldberg, 2005: Global assessment of coral bleaching and required rates of adaptation under climate change. *Glob. Change Biol.*, **11**, 2251-2265.

Douglas, A.E., 2003: Coral bleaching - how and why? *Mar. Pollut. Bull.*, **46**, 385-392.

Doyle, T.W., R.H. Day and J.M. Biagas, 2003: Predicting coastal retreat in the Florida Big Bend region of the Gulf Coast under climate change induced sea-level rise. *Integrated Assessment of the Climate Change Impacts on the Gulf Coast region. Foundation Document*, Z.H. Ning, R.E. Turner, T. Doyle, and K. Abdollahi, Eds., Louisiana State University Press, Baton Rouge, 201-209.

Drexler, J.E., 2001: Effect of the 1997-1998 ENSO-related drought on hydrology and salinity in a Micronesian wetland complex. *Estuaries*, **24**, 343-358.

Dronkers, J., 2005: *Dynamics of Coastal Systems*. Advanced Series on Ocean Engineering. 25. World Scientific Publishing Company, Hackensack, 519 pp.

DTI, 2002: *Foresight Futures 2020. Revised Scenarios and Guidance*. Department of Trade and Industry (DTI), London. 36 pp.

Duarte, C.M., 2002: The future of seagrass meadows. *Environ. Conserv.*, **9**, 192-206.

Durongdej, S., 2001: Land use changes in coastal areas of Thailand. *Proceedings of the APN/SURVAS/LOICZ Joint Conference on Coastal Impacts of Climate Change and Adaptation in the Asia – Pacific Region*, 14-16th November 2000, Kobe, Japan, Asia Pacific Network for Global Change Research, 113-117.

Easterling, W.E., 2003: Observed impacts of climate change in agriculture and forestry. *IPCC Workshop on the Detection and Attribution of the Effects of Climate Change*, June 17-19, New York City, USA.

Ebi, K.L., and J.L. Gamble, 2005: Summary of a workshop on the future of health models and scenarios: strategies for the future. *Environ. Health Persp.*, **113**, 335.

ECLAC, 2003: *Handbook for Estimating the Socio-Economic and Environmental Effects*. LC/MEX/G.5. Economic Commission for Latin America and the Caribbean (ECLAC). 357 pp.

EFGC, 2006: *Envisioning the Future of the Gulf Coast*. Final report and findings. D. Reed, Ed. America's Wetland: Campaign to Save Coastal Louisiana, 11 pp.

El-Raey, M., 1997: Vulnerability assessment of the coastal zone of the Nile delta of Egypt, to the impacts of sea-level rise. *Ocean Coast. Manage.*, **37**, 29-40.

Emanuel, K., 2005: Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, **436**, 686-688.

Ericson, J.P., C.J. Vorosmarty, S.L. Dingman, L.G. Ward and M. Meybeck, 2006: Effective sea-level rise and deltas: causes of change and human dimension implications. *Global Planet Change*, **50**, 63-82.

Essink, G., 2001: Improving fresh groundwater supply - problems and solutions. *Ocean Coast. Manage.*, **44**, 429-449.

Eurosion, 2004: *Living with Coastal Erosion in Europe: Sediment and Space for Sustainability. Part-1 Major Findings and Policy Recommendations of the EUROSION Project*. Guidelines for implementing local information systems dedicated to coastal erosion management. Service contract B4-3301/2001/329175/MAR/B3 "Coastal erosion – Evaluation of the need for action". Directorate General Environment, European Commission, 54 pp.

Evans, E.P., R.M. Ashley, J. Hall, E. Penning-Rowsell, P. Sayers, C. Thorne and A. Watkinson, 2004a: *Foresight; Future Flooding. Scientific Summary*. Volume II: Managing future risks. Office of Science and Technology, London.

Evans, E.P., R.M. Ashley, J. Hall, E. Penning-Rowsell, A. Saul, P. Sayers, C. Thorne and A. Watkinson, 2004b: *Foresight; Future Flooding. Scientific Summary*. Volume I: Future risks and their drivers. Office of Science and Technology, London.

Few, R., and F. Matthies, 2006: Responses to the health risks from flooding. *Flood Hazards and Health: Responding to present and future risks*, R. Few, and F. Matthies, Eds., Earthscan, London.

Few, R., K. Brown and E.L. Tompkins, 2004a: *Scaling Adaptation: Climate Change Response and Coastal Management in the UK*. Working paper 60. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, Norfolk, 24 pp.

Few, R., M. Ahern, F. Matthies and S. Kovats, 2004b: *Floods, Health and Climate Change: A Strategic Review*. Working Paper 63. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, Norfolk, 138 pp.

Finkl, C.W., 2002: Long-term analysis of trends in shore protection based on papers appearing in the Journal of Coastal Research, 1984-2000. *J. Coastal Res*., **18**, 211-224.

Finlayson, C.M., and I. Eliot, 2001: Ecological assessment and monitoring of coastal wetlands in Australia's wet-dry tropics: a paradigm for elsewhere? *Coast. Manage*., **29**, 105-115.

Flak, L.K., R.W. Jackson and D.N. Stearn, 2002: Community vulnerability assessment tool methodology. *Natural Hazards Review*, **3**, 163-176.

Fletcher, C.A., and T. Spencer, Eds., 2005: *Flooding and Environmental Challenges for Venice and its Lagoon: State of Knowledge*. Cambridge University Press, Cambridge, 691 pp.

Forbes, D.L., 2005: Coastal erosion. *Encyclopedia of the Arctic*, M. Nutall, Ed., Routledge, 391-393.

Forbes, D.L., G.K. Manson, R. Chagnon, S.M. Solomon, J.J. van der Sanden and T.L. Lynds, 2002: Nearshore ice and climate change in the southern Gulf of St. Lawrence. *Ice in the Environment Proceedings of the 16th International Association of Hydraulic Engineering and Research International Symposium on Ice*, Dunedin, New Zealand, 344-351.

Forbes, D.L., G.S. Parkes, G.K. Manson and L.A. Ketch, 2004a: Storms and shoreline erosion in the southern Gulf of St. Lawrence. *Mar. Geol*., **210**, 169-204.

Forbes, D.L., M. Craymer, G.K. Manson and S.M. Solomon, 2004b: Defining limits of submergence and potential for rapid coastal change in the Canadian Arctic. *Ber. Polar- Meeresforsch*., **482**, 196-202.

Fox, S., 2003: *When the Weather is uggianaqtuq: Inuit Observations of Environmental Change*. Cooperative Institute for Research in Environmental Sciences. CD-ROM. University of Colorado, Boulder.

Furakawa, K., and S. Baba, 2001: Effects of sea-level rise on Asian mangrove forests. *Proceedings of the APN/SURVAS/LOICZ Joint Conference on Coastal Impacts of Climate Change and Adaptation in the Asia – Pacific Region*, 14-16th November 2000, Kobe, Japan, Asia Pacific Network for Global Change Research, 219-224.

Gardner, T.A., I.M. Côté, J.A. Gill, A. Grant and A.R. Watkinson, 2003: Long-term region-wide declines in Caribbean corals. *Science*, **301**, 958-960.

Gardner, T.A., I.M. Côté, J.A. Gill, A. Grant and A.R. Watkinson , 2005: Hurricanes and Caribbean coral reefs: impacts, recovery patterns, and role in long-term decline. *Ecology*, **86**, 174-184.

Genner, M.J., D.W. Sims, V.J. Wearmouth, E.J. Southall, A.J. Southward, P.A. Henderson and S.J. Hawkins, 2004: Regional climatic warming drives long-term community changes of British marine fish. *P. Roy. Soc. Lond. B Bio*., **271**, 655-661.

Gibbons, S.J.A., and R.J. Nicholls, 2006: Island abandonment and sea-level rise: An historical analog from the Chesapeake Bay, USA. *Glob. Environ. Chang*., **16**, 40-47.

Goklany, I.M., 2005: A climate policy for the short and medium term: Stabilization or adaptation? *Energy Environ*., **16**, 667-680.

Gornitz, V., S. Couch and E.K. Hartig, 2002: Impacts of sea-level rise in the New York City metropolitan area. *Global Planet Change*, **32**, 61-88.

Graham, N.A.J., S.K. Wilson, S. Jennings, N.V.C. Polunin, J.P. Bijoux and J. Robinson, 2006: Dynamic fragility of oceanic coral reef ecosystems. *Proc. Natl. Acad. Sci. U. S. A*., **103**, 8425-8429.

Graumann, A.,T. Houston, J. Lawrimore, D. Levinson, N. Lott, S. McCown, S. Stephens and D.Wuertz, 2005: Hurricane Katrina - a climatological perpective. October 2005, updated August 2006. Technical Report 2005-01. 28 p. NOAA National Climate Data Center, available at: http://www.ncdc.noaa.gov /oa/reports/tech-report-200501z.pdf

Green, C., and E. Penning-Rowsell, 1999: Inherent conflicts at the coast. *J. Coast. Conserv*., **5**, 153-162.

Green, D.R., and S.D. King, 2002: *Coastal and Marine Geo-Information Systems: Applying the Technology to the Environment*. Kluwer, 596 pp.

Guinotte, J.M., R.W. Buddemeier and J.A. Kleypas, 2003: Future coral reef habitat marginality: temporal and spatial effects of climate change in the Pacific basin. *Coral Reefs*, **22**, 551-558.

Hale, S.S., A.H. Miglarese, M.P. Bradley, T.J. Belton, L.D. Cooper, M.T. Frame, C.A. Friel, L.M. Harwell and Co-authors, 2003: Managing troubled data: Coastal data partnerships smooth data integration. *Environ. Monit. Assess*., **81**, 133-148.

Hall, J.W., R.. Dawson, S. Lavery, R. Nicholls, J. Wicks and D. Parker, 2005: Tidal Flood Risk in London Under Stabilisation Scenarios, *Symposium on Avoiding Dangerous Climate Change*, 1-3 February, Exeter. Poster session paper, extended abstract, 4 pp. [Accessed 12.04.07: *http://www.stabilisation2005.com/posters/Hall_Jim.pdf*]

Hall, J.W., I.C. Meadowcroft, E.M. Lee and P.H.A.J.M. van Gelder, 2002: Stochastic simulation of episodic soft coastal cliff recession. *Coast. Eng*., **46**, 159-174.

Hall, J.W., P.B. Sayers, M.J.A. Walkden and M. Panzeri, 2006: Impacts of climate change on coastal flood risk in England and Wales: 2030-2100. *Philos. T. Roy. Soc. A*, **364**, 1027-1050.

Hall, M.J., 2003: Global warming and the demand for water. *J. Chart. Inst. Water E*., **17**, 157-161.

Hall, S.J., 2002: The continental shelf benthic ecosystem: current status, agents for change and future prospects. *Environ. Conserv*., **29**, 350-374.

Hallock, P., 2005: Global change and modern coral reefs: new opportunities to understand shallow-water carbonate depositional processes. *Sediment. Geol*., **175**, 19-33.

Hamilton, J.M., D.R. Maddison and R.S.J. Tol, 2005: Climate change and international tourism: a simulation study. *Glob. Environ. Chang*., **15**, 253-266.

Hamm, L., and M.J.F. Stive, Eds., 2002: Shore nourishment in Europe. *Coast. Eng*., **47**, 79-263.

Hansom, J.D., 2001: Coastal sensitivity to environmental change: a view from the beach. *Catena*, **42**, 291-305.

Hanson, H., A. Brampton, M. Capobianco, H.H. Dette, L. Hamm, C. Laustrup, A. Lechuga and R. Spanhoff, 2002: Beach nourishment projects, practices, and objectives - a European overview. *Coast. Eng*., **47**, 81-111.

Harley, C.D.G., A.R. Hughes, K.M. Hultgren, B.G. Miner, C.J.B. Sorte, C.S. Thornber, L.F. Rodriguez, L. Tomanek and S.L. Williams, 2006: The impacts of climate change in coastal marine systems. *Ecol. Lett*., **9**, 228-241.

Harvey, N., 2006a: Rates and impacts of global sea level change. *New Frontiers in Environmental Research*, M.P. Glazer, Ed., Nova Science Publishers, Hauppage, New York

Harvey, N., Ed., 2006b: *Global Change and Integrated Coastal Management. The Asia-Pacific Region*. Coastal Systems and Continental Margins. 10. Springer, New York. 340 pp.

Hawkins, S.J., A.J. Southward and M.J. Genner, 2003: Detection of environmental change in a marine ecosystem - evidence from the western English Channel. *Sci. Total Environ*., **310**, 245-256.

Hay, J.E., and N. Mimura, 2005: Sea-level rise: Implications for water resources management. *Mitigation and Adaptation Strategies for Global Change*, **10**, 717-737.

Hay, J.E., and N. Mimura , 2006: Supporting climate change vulnerability and adaptation assessments in the Asia-Pacific Region – An example of sustainability science. *Sustainability Science*, **1**, DOI 10.1007/s11625-11006-10011-11628.

Hayne, M., and J. Chappell, 2001: Cyclone frequency during the last 5000 years at Curacao Island, north Queensland, Australia. *Palaeogeogr., Palaeoclimatol., Palaeoecol.,* **168**, 207-219.

Heinz Center, 2000: *The Hidden Costs of Coastal Hazards: Implications for Risk Assessment and Mitigation*. A multisector collaborative project of the H. John Heinz Center for Science, Economics, and the Environment. Island Press, 220 pp.

Helmer, M., and D. Hilhorst, 2006: Natural disasters and climate change. *Disasters*, **30**, 1-4.

Helmuth, B., N. Mieszkowska, P. Moore and S.J. Hawkins, 2006: Living on the edge of two changing worlds: Forecasting the responses of rocky intertidal ecosystems to climate change. *Annual Review of Ecology Evolution and Systematics*, **37**, 373-404.

Hoegh-Guldberg, O., 1999: Climate change, coral bleaching and the future of the world's coral reefs. *Mar. Freshwater Res*.., **50**, 839-866.

Hoegh-Guldberg, O., 2004: Coral reefs in a century of rapid environmental change.

Symbiosis, **37**, 1-31.
Hoegh-Guldberg, O., 2005: Low coral cover in a high-CO_2 world. *J. Geophys. Res., [Oceans]*, **110**, C09S06.
Hoegh-Guldberg, O., H. Hoegh-Guldberg, H. Cesar and A. Timmerman, 2000: *Pacific in peril: biological, economic and social impacts of climate change on Pacific coral reefs*. Greenpeace, 72 pp.
Hosking, A., and R. McInnes, 2002: Preparing for the impacts of climate change on the Central Southeast of England: A framework for future risk management. *J. Coastal Res.*, **S36**, 381-389.
Hughes, L., 2003: Climatic change and Australia: Trends, projections and impacts. *Austral. Ecol.*, **28**, 423-443.
Hughes, R.J., 2004: Climate change and loss of saltmarshes: Consequences for birds. *Ibis*, **146**, 21-28.
Hughes, T.P., D.R. Bellwood, C. Folke, R.S. Steneck and J. Wilson, 2005: New paradigms for supporting the resilience of marine ecosystems. *Trends Ecol. Evol.*, **20**, 380-386.
Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg and Co-authors, 2003: Climate change, human impacts, and the resilience of coral reefs. *Science*, **301**, 929-933.
Hulme, M., G.J. Jenkins, X. Lu, J.R. Turnpenny, T.D. Mitchell, R.G. Jones, J. Lowe, J.M. Murphy and Co-authors, 2002: *Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report*. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, Norfolk, 120 pp.
Hunt, J.C.R., 2002: Floods in a changing climate: a review. *Philos. T. Roy. Soc. A*, **360**, 1531-1543.
Hunter, P.R., 2003: Climate change and waterborne and vectorborne disease. *J. Appl. Microbiol.*, **94**, 37-46.
Hutchinson, J.N., 1998: A small-scale field check on the Fisher-Lehmann and Bakker-Le Heux cliff degradation models. *Earth Surf. Proc. Land.*, **23**, 913-926.
Ingram, I., 2005: Adaptation behaviour before to the 2004/05 tropical cyclone season in the Cook Islands. Island Climate Update 58. National Climate Center. [Accessed 22.01.07: http://www.niwascience.co.nz/ncc/icu/2005-07/article]
IPCC, 2001: *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White, Eds., Cambridge University Press, Cambridge, 1032 pp.
IPCC CZMS, 1990: *Strategies for Adaptation to Sea-level rise*. Report of the Coastal Zone Management Subgroup, Response Strategies Working Group of the Intergovernmental Panel on Climate Change. Ministry of Transport, Public Works and Water Management (the Netherlands), x + 122 pp.
ISDR, 2004: *Living With Risk: a Global Review of Disaster Reduction Initiatives*. International Strategy for Disaster Reduction (ISDR).
Isobe, M., 2001: A Theory of Integrated Coastal Zone Management in Japan. Department of Civil Engineering, University of Tokyo, Tokyo, 17 pp.
IUCN, 2003: *Indus Delta, Pakistan: Economic Costs of Reduction in Freshwater Flows*. Case studies in Wetland Valuation 5. The World Conservation Union, Pakistan Country Office, Karachi, 6 pp.
Jaagus, J., 2006: Trends in sea ice conditions in the Baltic Sea near the Estonian coast during the period 1949/1950-2003/2004 and their relationships to large-scale atmospheric circulation. *Boreal Environ. Res.*, **11**, 169-183.
Jackson, N.L., K.F. Nordstrom, I. Eliot and G. Masselink, 2002: 'Low energy' sandy beaches in marine and estuarine environments: a review. *Geomorphology*, **48**, 147-162.
Jenks, G., J. Dah and D. Bergin, 2005: Changing paradigms in coastal protection ideology: The role of dune management. *Presentation to NZ Coastal Society Annual Conference*, 12-14 October, Tutukaka, Northland New Zealand, 27pp.
Jennerjahn, T.C., and V. Ittekkot, 2002: Relevance of mangroves for the production and deposition of organic matter along tropical continental margins. *Naturwissenschaften*, **89**, 23-30.
Jevrejeva, S., V.V. Drabkin, J. Kostjukov, A.A. Lebedev, M. Lepparanta, Y.U. Mironov, N. Schmelzer and M. Sztobryn, 2004: Baltic Sea ice seasons in the twentieth century. *Climate Res.*, **25**, 217-227.
Jiongxin, X., 2003: Sediment flux to the sea as influenced by changing human activities and precipitation: example of the Yellow River, China. *Environ. Manage*, **31**, 328-341.
Johannessen, O.M., L. Bengtsson, M.W. Miles, S.I. Kuzmina, V.A. Semenov, G.V. Aleekseev, A.P. Nagurnyi, V.F. Zakharov and Co-authors, 2002: *Arctic climate change - Observed and modeled temperature and sea ice variability*. Technical Report 218. Nansen Environmental and Remote Sensing Centre, Bergen.
Jonkman, S.N., M.J. Stive and J.K. Vrijling, 2005: New Orleans is a lesson for the Dutch. *J. Coastal Res.*, **21**, xi-xii.
Justic, D., N.N. Rabalais and R.E. Turner, 2005: Coupling between climate variability and coastal eutrophication: evidence and outlook for the northern Gulf of Mexico. *J. Sea Res.*, **54**, 25-35.
Kay, R., and J. Adler, 2005: *Coastal Planning and Management*. 2nd edition. Routeledge. 380 pp.
Kendall, M.A., M.T. Burrows, A.J. Southward and S.J. Hawkins, 2004: Predicting the effects of marine climate change on the invertebrate prey of the birds of rocky shores. *Ibis*, **146**, 40-47.
Kennish, M.J., 2002: Environmental threats and environmental future of estuaries. *Environ. Conserv.*, **29**, 78-107.
Khan, M., 2001: *National Climate Change Adaptation Policy and Implementation Plan for Guyana*. Caribbean: Planning for Adaptation to Global Climate Change, CPACC Component 4. National Ozone Action Unit of Guyana/Hydrometeorological Service, 18 Brickdam, Georgetown, Guyana, 74 pp.
Khiyami, H.A., Z. Şen, S.C. Al-Harthy, F.A. Al-Ammawi, A.B. Al-Balkhi, M.I. Al-Zahrani and H.M. Al-Hawsawy, 2005: *Flood Hazard Evaluation in Wadi Hali and Wadi Yibah*. Technical Report. Saudi Geological Survey, Jeddah, Saudi Arabia, 138 pp.
King, D.A., 2004: Climate change science: adapt, mitigate, or ignore? *Science*, **303**, 176-177.
Klein, R.J.T., and R.S.J. Tol, 1997: *Adaptation to Climate Change: Options and Technologies - An Overview Paper.* Technical Paper FCCC/TP/1997/3. UNFCC Secretariat. 37 pp.
Klein, R.J.T., R.J. Nicholls, S. Ragoonaden, M. Capobianco, J. Aston and E.N. Buckley, 2001: Technological options for adaptation to climate change in coastal zones. *J. Coastal Res.*, **17**, 531-543.
Klein, R.J.T., R.J. Nicholls and F. Thomalla, 2002: The resilience of coastal megacities to weather-related hazards: A review. *Proceedings of The Future of Disaster Risk: Building Safer Cities*, A. Kreimer, M. Arnold and A. Carlin, Eds., World Bank Group, Washington, District of Columbia, 111-137.
Klein, R.J.T., R.J. Nicholls and F. Thomalla , 2003: Resilience to natural hazards: How useful is this concept? *Environmental Hazards*, **5**, 35-45.
Kleypas, J.A., and C. Langdon, 2002: Overview of CO_2-induced changes in seawater chemistry. *Proceedings of the 9th International Coral Reef Symposium*, 23-27th October 2000, Bali, Indonesia, 1085-1089.
Knogge, T., M. Schirmer and B. Schuchardt, 2004: Landscape-scale socio-economics of sea-level rise. *Ibis*, **146**, 11-17.
Kobayashi, H., 2004: Impact evaluation of sea-level rise on Indonesian coastal cities - Micro approach through field survey and macro approach through satellite image analysis. *Journal of Global Environment Engineering*, **10**, 77-91.
Kokot, R.R., J.O. Codignotto and M. Elisondo, 2004: Vulnerabilidad al ascenso del nivel del mar en la costa de la provincia de Río Negro. *Asociación Geológica Argentina Rev*, **59**, 477-487.
Komar, P.D., 1998: *Beach and Nearshore Sedimentation*. Second Edition. Prentice Hall.
Kont, A., J. Jaagus, R. Aunap, U. Ratasa and R. Rivis, 2007: Implications of sea-level rise for Estonia. *J. Coastal Res.*, in press.
Koreysha, M.M., F.M. Rivkin and N.V. Ivanova, 2002: The classification of Russian Arctic coasts for their engineering protection. *Extreme Phenomena in Cryosphere: Basic and Applied Aspects*, Russian Academy of Sciences, 65-66 (in Russian).
Kovats, R.S., and A. Haines, 2005: Global climate change and health: recent findings and future steps. *Can. Med. Assoc. J.*, **172**, 501-502.
Kovats, R.S., M.J. Bouma, S. Hajat, E. Worrall and A. Haines, 2003: El Niño and health. *Lancet*, **362**, 1481-1489.
Kovats, R.S., D. Campbell-Lendrum and F. Matthies, 2005: Climate change and human health: estimating avoidable deaths and disease. *Risk Anal.*, **25**, 1409-1418.
Krauss, K.W., J.L. Chambers, J.A. Allen, D.M. Soileau Jr. and A.S. DeBosier, 2000: Growth and nutrition of baldcypress families planted under varying salinity regimes in Louisiana, USA. *J. Coastal Res.*, **16**, 153-163.
Kremer, H.H., M.D.A. Le Tisser, P.R. Burbridge, L. Talaue-McManus, N.N. Rabalais, J. Parslow, C.J. Crossland and W. Young, 2004: *Land-Ocean Interactions in the Coastal Zone: Science Plan and Implementation Strategy.* IGBP Report 51/IHDP Report 18. IGBP Secretariat, 60 pp.
Lavery, S., and B. Donovan, 2005: Flood risk management in the Thames Estuary:

looking ahead 100 years. *Philos. T. Roy. Soc. A*, **363**, 1455-1474.

Leatherman, S.P., 2001: Social and economic costs of sea-level rise. *Sea-level rise, History and Consequences*, B.C. Douglas, M.S. Kearney, and S.P. Leatherman, Eds., Academic Press, 181-223.

LeClerq, N., J.-P. Gattuso, and J. Jaubert, 2002: Primary production, respiration, and calcification of a coral reef mesocosm under increased CO_2 pressure. *Limnol. Oceanogr.*, **47**, 558-564.

Ledoux, L., and R.K. Turner, 2002: Valuing ocean and coastal resources: a review of practical examples and issues for further action. *Ocean Coast. Manage.*, **45**, 583-616.

Ledoux, L., R.K. Turner, L. Mathieu, and S. Crooks, 2001: Valuing ocean and coastal resources: Practical examples and issues for further action. *Paper presented at the Global Conference on Oceans and Coasts at Rio+10: Assessing Progress, Addressing Continuing and New Challenges,* Paris, UNESCO, 37.

Leont'yev, I.O., 2003: Modelling erosion of sedimentary coasts in the Western Russian Arctic. *Coast. Eng.*, **47**, 413-429.

Lesser, M.P., 2004: Experimental biology of coral reef ecosystems. *J. Exp. Mar. Biol. Ecol.*, **300**, 217-252.

Lestak, L.R., W.F. Manley, and J.A. Maslanik, 2004: Photogrammetric analysis of coastal erosion along the Chukchi coast at Barrow, Alaska. *Ber. Polar- Meeresforsch.*, **482**, 38-40.

Li, C.X., D.D. Fan, B. Deng, and V. Korotaev, 2004: The coasts of China and issues of sea-level rise. *J. Coastal Res.*, **43**, 36-47.

Lipp, E.K., A. Huq, and R.R. Colwell, 2004: Health climate and infectious disease: a global perspective. *Clin. Microbiol. Rev.*, **15**, 757-770.

Lise, W., and R.S.J. Tol, 2002: Impact of climate on tourist demand. *Climatic Change*, **55**, 429-449.

Little, A.F., M.J.H. van Oppen and B. L. Willis, 2004: Flexibility in algal endosymbioses shapes growth in reef corals. *Science*, **304**, 1492-1494.

Liu, Y., 2002: A strategy of ground-water distribution exploitation to mitigate the magnitude of subsidence. *Abstracts from the Denver Annual Meeting*, Denver, The Geological Society of America, Paper no. 116-8. [Accessed 13.04.07: http://gsa.confex.com/gsa/2002AM/finalprogram/abstract_40369.htm]

Lomas, M.W., P.M. Glibert, F. Shiah and E.M. Smith, 2002: Microbial process and temperature in Chesapeake Bay: Current relationships and potential impacts of regional warming. *Glob. Change Biol.*, **8**, 51-70.

Lotze, H.K., H.S. Lenihan, B.J. Bourque, R.H. Bradbury, R.G. Cooke, M.C. Kay, S.M. Kidwell, M.X. Kirby, C.H. Peterson and J.B.C. Jackson, 2006: Depletion, degradation and recovery potential of estuaries and coastal seas. *Science*, **312**, 1806-1809.

Lough, J.M., 2000: 1997-98: unprecedented thermal stress to coral reefs? *Geophys. Res. Lett.*, **27**, 3901-3904.

Lough, J.M., and D.J. Barnes, 2000: Environmental controls on growth of the massive coral porites. *J. Exp. Mar. Biol. Ecol.*, **245**, 225-243.

Lowe, J.A., and J.M. Gregory, 2005: The effects of climate change on storm surges around the United Kingdom. *Philos. T. Roy. Soc. A*, **363**, 1313-1328.

Luers, A.L., and S.C. Moser, 2006: Preparing for the impacts of climate change in California: Opportunities and constraints for adaptation. Report CEC-500-2005-198-SF. California Climate Change Center. 47 pp.

Mackenzie, F.T., A. Lerman and L.M. Ver, 2001: Recent past and future of the global carbon cycle. *Geological Perspectives of Global Climate Change*, L.C. Gerhard, W.E. Harrison and M.M. Hanson, Eds., American Association of Petroleum Geologists (AAPG), 51-82.

Madisson, D., 2001: In search of warmer climates? The impact of climate change on flows of British tourists. *Climatic Change*, **49**, 193-208.

Manson, G.K., S.M. Solomon, D.L. Forbes, D.E. Atkinson and M. Craymer, 2006: Spatial variability of factors influencing coastal change in the western Canadian Arctic. *Geo-Mar. Lett.*, **25**, 138-145.

Maracchi, G., O. Sirotenko and M. Bindi, 2005: Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. *Climatic Change*, **70**, 117-135.

McFadden, L., T. Spencer and R.J. Nicholls, 2007a: Broad-scale modelling of coastal wetlands: What is required? *Hydrobiologia*, **577**, 5-15.

McFadden, L., R.J. Nicholls and E. Penning-Rowsell, Eds., 2007b: *Managing Coastal Vulnerability*, Elsevier, Oxford, 282pp.

McInnes, K.L., K.J.E. Walsh, G.D. Hubbert and T. Beer, 2003: Impact of sea-level rise and storm surges on a coastal community. *Nat. Hazards*, **30**, 187-207.

McLaughlin, J., A. DePaola, C.A. Bopp, K.A. Martinek, N.P. Napolilli, C.G. Allison, S.L. Murray, E.C. Thompson, M.M. Bird and M.D. Middaugh, 2006: Outbreak of *Vibrio parahaemolyticus* gastroenteritis associated with Alaskan oysters. *N. Engl. J. Med.*, **353**, 1463-1470.

McLean, R., A. Tsyban, V. Burkett, J.O. Codignotto, D.L. Forbes, N. Mimura, R.J. Beamish and V. Ittekkot, 2001: Coastal zone and marine ecosystems. *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White, Eds., Cambridge University Press, Cambridge, 343-380.

McLean, R.F., and J.-S. Shen, 2006: From foreshore to foredune: Foredune development over the last 30 years at Moruya Beach, New South Wales, Australia. *J. Coastal Res.*, **22**, 28-36.

McRobie, A., T. Spencer and H. Gerritsen, 2005: The Big Flood: North Sea storm surge. *Philos. T. Roy. Soc. A*, **363**, 1261-1491.

McWilliams, J.P., I.M. Côté, J.A. Gill, W.J. Sutherland and A.R. Watkinson, 2005: Accelerating impacts of temperature-induced coral bleaching in the Caribbean. *Ecology*, **86**, 2055.

Meehl, G.A., W.M. Washington, W.D. Collins, J.M. Arblaster, A. Hu, L.E. Buja, W.G. Strand and H. Teng, 2005: How much more global warming and sea-level rise? *Science*, **307**, 1769-1772.

Meehl, G.A., T.F. Stocker, W. Collins, P. Friedlingstein, A. Gaye, J. Gregory, A. Kitoh, R. Knutti and Co-authors, 2007: Global climate projections. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Eds., Cambridge University Press, Cambridge, 747-846.

Melillo, J.M., A.C. Janetos, T.R. Karl, R.C. Corell, E.J. Barron, V. Burkett, T.F. Cecich, K. Jacobs and Co-authors, Eds., 2000: *Climate Change Impacts on the United States: The potential consequences of climate variability and change, Overview*. Cambridge University Press, Cambridge, 154 pp.

MESSINA, cited 2006: Integrating the shoreline into spatial policies. Managing European Shoreline and Sharing Information on Nearshore Areas (MESSINA). 191 pp. [Accessed 13.04.07: http://www.interreg-messina.org/documents/Coastal-Toolkit/Zipped/MESSINA%20-%20Practical%20Guide%20-%20Integrating%20the%20Shoreline.zip]

Michot, T.C., 2000: Comparison of wintering redhead populations in four Gulf of Mexico seagrass beds. *Limnology and Aquatic Birds: Monitoring, Modelling and Management*, F.A. Comin, J.A. Herrera and J. Ramirez, Eds., Universidad Autónoma de Yucatán, Merida, 243-260.

Middleton, B.A., and K.L. McKee, 2001: Degradation of mangrove tissues and implications for peat formation in Belizean island forests. *J. Ecol.*, **89**, 818-828.

Mieszkowska, N., M.A. Kendall, S.J. Hawkins, R. Leaper, P. Williamson, N.J. Hardman-Mountford and A.J. Southward, 2006: Changes in the range of some common rocky shore species in Britain - a response to climate change? *Hydrobiologia*, **555**, 241-251.

Milly, P.C.D., K.A. Dunne and A.V. Vecchia, 2005: Global pattern of trends in streamflow and water availability in a changing climate. *Nature*, **438** 347-350.

Milne, N., P. Christie, R. Oram, R.L. Eisma and A.T. White, 2003: *Integrated Coastal Management Process Sustainability Reference Book*. University of Washington School of Marine Affairs, Silliman University and the Coastal Resource Management Project of the Department of Environment and Natural Resources, Cebu City, 50 pp.

Mimura, N., 2001: Distribution of vulnerability and adaptation in the Asia and Pacific Region. *Global Change and Asia Pacific Coasts. Proceedings of the APN/SURVAS/LOICZ Joint Conference on Coastal Impacts of Climate Change and Adaptation in the Asia – Pacific Region*, 14-16th November 2000, Kobe, Japan, Asia Pacific Network for Global Change Research, 21-25.

Ministry for the Environment, 2001: Climate change impacts on New Zealand. Report prepared by the Ministry for the Environment as part of the New Zealand Climate Change Programme. Ministry for the Environment, 39 pp.

Mitchell, J.F.B., J. Lowe, R.A. Wood and M. Vellinga, 2006: Extreme events due to human-induced climate change. *Philos. T. Roy. Soc. A*, **364**, 2117-2133.

Mohanti, M., 2000: Unprecedented supercyclone in the Orissa Coast of the Bay of Bengal, India. *Cogeoenvironment Newsletter. Commission on Geological Sciences for Environmental Planning of the International Union on Geological Sciences*, **16**, 11-13.

Moore, M.V., M.L. Pace, J.R. Mather, P.S. Murdoch, R.W. Howarth, C.L. Folt, C.Y. Chen, H.F. Hemond, P.A. Flebbe and C.T. Driscoll, 1997: Potential effects of climate change on freshwater ecosystems of the New England/mid-Atlantic region.

Hydrol. Process., **11**, 925-947.

Morris, J.T., P.V. Sundareshwar, C.T. Nietch, B. Kjerfve and D.R. Cahoon, 2002: Responses of coastal wetlands to rising sea level. *Ecology*, **83**, 2869-2877.

Morton, R.A., T.L. Miller and L.J. Moore, 2004: National assessment of shoreline change: Part 1 Historical shoreline changes and associated coastal land loss along the U.S.Gulf Of Mexico. Open File Report 2004-1043. U.S. Geological Survey, 44 pp.

Moser, S., 2000: Community responses to coastal erosion: Implications of potential policy changes to the National Flood Insurance Program. *Evaluation of Erosion Hazards: A Project of The H. John Heinz II Center for Science Economics and the Environment*. Prepared for the Federal Emergency Management Agency. 99 pp.

Moser, S., 2005: Impacts assessments and policy responses to sea-level rise in three U.S. States: An exploration of human dimension uncertainties. *Glob. Environ. Chang.*, **15**, 353-369.

Moser, S., 2006: Climate scenarios and projections: The known, the unknown, and the unknowable as applied to California. *Synthesis Report of a Workshop held at the Aspen Global Change Institute*, Aspen Global Change Institute, Aspen, Colorado, 7 pp.

Muir-Wood, R., M. Drayton, A. Berger, P. Burgess and T. Wright, 2005: Catastrophe loss modelling of storm-surge flood risk in eastern England. *Philos. T. Roy. Soc. A*, **363**, 1407-1422.

Munich Re Group, 2004: *Annual Review Natural Catastrophes in 2003*. Topics Geo. Munich Re Group, Munich, 56 pp.

Myatt, L.B., M.D. Scrimshaw and J.N. Lester, 2003: Public perceptions and attitudes towards a current managed realignment scheme: Brancaster West Marsh, North Norfolk, U.K. *J. Coastal Res.*, **19**, 278-286.

Nakićenović, N., and R. Swart, Eds., 2000: *Emissions Scenarios. Special Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, 599 pp.

NAST, 2000: *Climate Change Impacts in the United States, Overview.* Report for the U.S. Global Change Research Program. National Assessment Synthesis Team Members (NAST), 154 pp.

Neumann, J.E., G. Yohe, R.J. Nicholls and M. Manion, 2000: *Sea Level Rise and Global Climate Change: A Review of Impacts to U.S. Coasts*. Pew Center on Global Climate Change, Arlington, Virginia43 pp.

Ng, W.S., and R. Mendelsohn, 2005: The impact of sea-level rise on Singapore. *Environ. Dev Econ.*, **10**, 201-215.

Nicholls, R.J., 2004: Coastal flooding and wetland loss in the 21st century: changes under the SRES climate and socio-economic scenarios. *Glob. Environ. Chang.*, **14**, 69-86.

Nicholls, R.J., 2006: Storm surges in coastal areas. *Natural Disaster Hotspots: Case Studies. Disaster Risk Management 6*, M. Arnold, R.S. Chen, U. Deichmann, M. Dilley, A.L. Lerner-Lam, R.E. Pullen and Z. Trohanis, Eds., The World Bank, Washington, District of Columbia, 79-108.

Nicholls, R.J., and R.J.T. Klein, 2005: Climate change and coastal management on Europe's coast. *Managing European Coasts: Past, Present and Future*, J.E. Vermaat, L. Bouwer, K. Turner and W. Salomons, Eds., Springer, Environmental Science Monograph Series. 199-226.

Nicholls, R.J., and J.A. Lowe, 2006: Climate stabilisation and impacts of sea-level rise. *Avoiding Dangerous Climate Change*, H.J. Schellnhuber, W. Cramer, N. Nakićenović, T.M.L. Wigley and G. Yohe, Eds., Cambridge University Press, Cambridge, 195-202.

Nicholls, R.J., and R.S.J. Tol, 2006: Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century. *Philos. T. Roy. Soc. A*, **364**, 1073-1095.

Nicholls, R.J., S.E. Hanson, J. Lowe, D.A. Vaughan, T. Lenton, A. Ganopolski, R.S.J. Tol and A.T. Vafeidis, 2006: *Metrics for Assessing the Economic Benefits of Climate Change Policies: Sea Level Rise*. Report to the OECD. ENV/EPOC/GSP(2006)3/FINAL. Organisation for Economic Co-operation and Development (OECD). 128 pp.

Nikiforov, S.L., N.N. Dunaev, S.A. Ogorodov and A.B. Artemyev, 2003: Physical geographic characteristics. *The Pechora Sea: Integrated Research*, E.A. Romankevich, A.P. Lisitzin and M.E. Vinogradov, Eds., MOPE, (in Russian).

Nilsson, C., C.A. Reidy, M. Dynesius and C. Revenga, 2005: Fragmentation and flow regulation of the world's large river systems. *Science*, **308**, 405-408.

NOAA, 2007: Billion dollar U.S. weather disasters, 1980-2006. http://www.ncdc.noaa.gov/oa/reports/billionz.html [Accessed 13.04.07]

NOAA Coastal Services Center, 1999: Community Vulnerability Assessment Tool. CD-ROM Available from NOAA Coastal Services Center, Charleston, South Carolina http://www.csc.noaa.gov/products/nchaz/startup.htm. [Accessed 13.04.07]

Nordstrom, K.F., 2000: *Beaches and Dunes of Developed Coasts*. Cambridge University Press, 338 pp.

Noronha, L., 2004: Coastal management policy: observations from an Indian case. *Ocean Coast. Manage.*, **47**, 63-77.

Norris, K., P.W. Atkinson and J.A. Gill, 2004: Climate change and coastal waterbird populations - past declines and future impacts. *Ibis*, **149**, 82-89.

Nott, J., and M. Hayne, 2001: High frequency of 'super-cyclones' along the Great Barrier Reef over the past 5,000 years. *Nature*, **413**, 508-512.

NRC, 1990: *Managing Coastal Erosion*. National Research Council. National Academy Press, Washington, District of Columbia, 204 pp.

NRC , 2004: *River Basins and Coastal Systems Planning within the U.S. Army Corps of Engineers*. National Research Council. National Academy Press, Washington, District of Columbia,167 pp.

NRC , 2006: *Drawing Louisiana's New Map; Addressing Land Loss in Coastal Louisiana*. National Research Council, National Academy Press, Washington, District of Columbia, 204 pp.

Nyong, A., and I. Niang-Diop, 2006: Impacts of climate change in the tropics: the African experience. *Avoiding Dangerous Climate Change*, H.J. Schellnhuber, W. Cramer, N. Nakićenović, T.M.L. Wigley and G. Yohe, Eds., Cambridge University Press, Cambridge, 235-241.

Obura, D.O., 2005: Resilience and climate change: lessons from coral reefs and bleaching in the western Indian Ocean. *Estuar. Coast Shelf Sci.*, **63**, 353-372.

Ogorodov, S.A., 2003: Coastal dynamics in the Pechora Sea under technogenic impact. *Ber. Polar- Meeresforsch*, **443**, 74-80.

Ohno, E., 2001: Economic evaluation of impact of land loss due to sea-level rise in Thailand. *Proceedings of the APN/SURVAS/LOICZ Joint Conference on Coastal Impacts of Climate Change and Adaptation in the Asia – Pacific Region*, 14-16th November 2000, Kobe, Japan, Asia Pacific Network for Global Change Research, 231-235.

Okude, A.S., and I.A. Ademiluyi, 2006: Coastal erosion phenomenon in Nigeria: Causes, control and implications. *World Applied Sciences Journal*, **1**, 44-51.

Olesen, J.E., T.R. Carter, C.H. Díaz-Ambrona, S. Fronzek, T. Heidmann, T. Hickler, T. Holt, M.I. Minguez and Co-authors, 2006: Uncertainties in projected impacts of climate change on European agriculture and terrestrial ecosystems based on scenarios from regional climate models. *Climatic Change*, doi: 10.1007/s10584-006-9216-1.

Olsen, S.B., W. Matuszeski, T.V. Padma and H.J.M. Wickremeratne, 2005: Rebuilding after the tsunami: Getting it right. *Ambio*, **34**, 611-614.

Ong, J.E., 2001: Vulnerability of Malaysia to sea level change. *Proceedings of the APN/SURVAS/LOICZ Joint Conference on Coastal Impacts of Climate Change and Adaptation in the Asia – Pacific Region*, 14-16th November 2000, Kobe, Japan, Asia Pacific Network for Global Change Research, 89-93.

Orford, J.D., S.C. Jennings and D.L. Forbes, 2001: Origin, development, reworking and breakdown of gravel-dominated coastal barriers in Atlantic Canada: future scenarios for the British coast. *Ecology and Geomorphology of Coastal Shingle*, J.R. Packham, R.E. Randall, R.S.K. Barnes and A. Neal, Eds., Westbury Academic and Scientific Publishing, Otley, West Yorkshire.

Orford, J.D., S.C. Jennings and J. Pethick, 2003: Extreme storm effect on gravel-dominated barriers. *Proceedings of the International Conference on Coastal Sediments 2003*, R.A. Davis, Ed., World Scientific Publishing Corporation and East Meets West Productions, Corpus Christi, Texas, CD-ROM.

Otter, H.S., 2000: *Complex Adaptive Land Use Systems: An Interdisciplinary Approach with Agent-based Models*. Unpublished PhD thesis, University of Twente, Enschede, the Netherlands, 245 pp.

Otter, H.S., A. van der Veen and H.J. de Vriend, 2001: Spatial patterns and location behaviour: ABLOOM: An explanation based on agent based modelling. *JASSS*, **4**, 1460-7425.

Paerl, H.W., J.D. Bales, L.W. Ausley, C.P. Buzzelli, L.B. Crowder, L.A. Eby, J.M. Fear, M. Go and Co-authors, 2001: Ecosystem impacts of three sequential hurricanes (Dennis, Floyd, and Irene) on the United States' largest lagoonal estuary, Pamlico Sound, NC. *Proc. Natl. Acad. Sci. U.S.A.*, **98**, 5655-5660.

Pandolfi, J.M., R.H. Bradbury, E. Sala, T.P. Hughes, K.A. Bjorndal, R.G. Cooke, D. McArdle, L. McClenachan and Co-authors, 2003: Global trajectories of the long-term decline of coral reef ecosystems. *Science*, **301**, 955-958.

Parson, E.A., R.W. Corell, E.J. Barron, V. Burkett, A. Janetos, L. Joyce, T.R. Karl, M.C. MacCracken and Co-authors, 2003: Understanding climatic impacts, vulnerabilities, and adaptation in the United States: Building a capacity for assessment. *Climatic Change*, **57**, 9-42.

Pascual, M., M.J. Bouma and A.P. Dobson, 2002: Cholera and climate: revisiting the quantitative evidence. *Microbes Infect*., **4**, 237-246.

Pearson, S., J. Rees, C. Poulton, M. Dickson, M. Walkden, J. Hall, R. Nicholls, M. Mokrech and Co-authors, 2005: *Towards an Integrated Coastal Sediment Dynamics and Shoreline Response Simulator.* Technical report 38. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, Norfolk, 53 pp.

Peperzak, L., 2005: Future increase in harmful algal blooms in the North Sea due to climate change. *Water Sci. Technol*., **51**, 31-36.

Persson, M., K. Rydell, B. Rankka and E. Uytewaal, cited 2006: Valuing the shoreline: Guideline for socio - economic analyses. Managing European Shoreline and Sharing Information on Nearshore Areas (MESSINA). 72 pp. [Accessed 13.04.07: http://www.interreg-messina.org/documents/CoastalToolkit/Zipped/MESSINA%20-%20Practical%20Guide%20-%20Valuing%20the %20Shoreline.zip]

Pethick, J., 2001: Coastal management and sea-level rise. *Catena*, **42**, 307-322.

Pethick, J 2002: Estuarine and tidal wetland restoration in the United Kingdom: Policy versus practice. *Restor. Ecol*., **10**, 431-437.

Pielke Jr, R.A., C. Landsea, M. Mayfield, J. Laver and R. Pasch, 2005: Hurricanes and global warming. *B. Am. Meteorol. Soc*., **86**, 1571-1575.

Pielke, R.A., and C.W. Landsea, 1998: Normalized hurricane damages in the United States: 1925-95. *Weather Forecast*., **13**, 621-631.

Pierre, G., and P. Lahousse, 2006: The role of groundwater in cliff instability: an example at Cape Blanc-Nez (Pas-de-Calais, France). *Earth Surf. Proc. Land*., **31**, 31-45.

Piersma, T., and A. Lindstrom, 2004: Migrating shorebirds as integrative sentinels of global environmental change. *Ibis*, **146**, 61-69.

Pirazzoli, P.A., H. Regnauld and L. Lemasson, 2004: Changes in storminess and surges in western France during the last century. *Mar. Geol*., **210**, 307-323.

Poumadère, M., C. Mays, G. Pfeifle and A.T. Vafeidis, 2005: *Worst Case Scenario and Stakeholder Group Decision: A 5-6 Meter Sea Level Rise in the Rhone Delta, France*. Working paper FNU-76. Hamburg University and Centre for Marine and Atmospheric Science, Hamburg, 30 pp.

Precht, W.F., and R.B. Aronson, 2004: Climate flickers and range shifts of coral reefs. *Frontiers in Ecology and the Environment*, **2**, 307-314.

Quammen, M.L., and C.P. Onuf, 1993: Laguna Madre - seagrass changes continue decades after salinity reduction. *Estuaries*, **16**, 302-310.

Queensland Government, 2001: *State Coastal Management Plan*. Environmental Protection Agency/Queensland Parks and Wildlife Service, Brisbane, Queensland, 90 pp.

Ragab, R., and C. Prudhomme, 2002: Climate change and water resources management in arid and semi-arid regions: prospective and challenges for the 21st century. *Biosystems Engineering*, **81**, 3-34.

Ranasinghe, R., R. McLoughlin, A.D. Short and G. Symonds, 2004: The Southern Oscillation Index, wave climate, and beach rotation. *Mar. Geol*., **204**, 273-287.

Reed, D.J., 2002: Sea-level rise and coastal marsh sustainability: geological and ecological factors in the Mississippi delta plain. *Geomorphology*, **48**, 233-243.

Regnauld, H., P.A. Pirazzoli, G. Morvan and M. Ruz, 2004: Impact of storms and evolution of the coastline in western France. *Mar. Geol*., **210**, 325-337.

Rehfisch, M.M., G.E. Austin, S.N. Freeman, M.J.S. Armitage and N.H.K. Burton, 2004: The possible impact of climate change on the future distributions and numbers of waders on Britain's non-estuarine coast. *Ibis*, **146**, 70-81.

Republic of Kenya, 2002: *First National Communication of Kenya to the Conference of Parties to the United Nations Framework Convention on Climate Change*. Ministry of Environment and Natural Resources, Nairobi, 155 pp.

Rice, J., 2003: Environmental health indicators. *Ocean Coast. Manage*., **46**, 235-259.

Riegl, B., 2003: Climate change and coral reefs: different effects in two high-latitude areas (Arabian Gulf, South Africa). *Coral Reefs*, **22**, 433-446.

Rochelle-Newall, E., R.J.T. Klein, R.J. Nicholls, K. Barrett, H. Behrendt, T.N.H. Bresser, A. Cieslak, E.F.L.M. de Bruin and Co-authors, 2005: Global change and the European coast – climate change and economic development. *Managing European Coasts: Past, Present and Future*, J.E. Vermaat, L. Ledoux, K. Turner and W. Salomons, Eds., Springer (Environmental Science Monograph Series), New York, New York, 239-254.

Rodolfo, K.S., and F.P. Siringan, 2006: Global sea-level rise is recognised, but flooding from anthropogenic land subsidence is ignored around northern Manila Bay, Philippines. *Disaster Manage*., **30**, 118-139.

Rodriguez, A.B., M.L. Fassell and J.B. Anderson, 2001: Variations in shoreface progradation and ravinement along the Texas coast, Gulf of Mexico. *Sedimentology*, **48**, 837-853.

Rogers, K., N. Saintilan and H. Heinjis, 2005: Mangrove encroachment of salt marsh in Western Port Bay, Victoria: the role of sedimentation, subsidence, and sea-level rise. *Estuaries*, **28**, 551-559.

Rogers, K., K.M. Wilton and N. Saintilan, 2006: Vegetation change and surface elevation dynamics in estuarine wetlands of southeast Australia. *Estuar. Coast Shelf S*., **66**, 559-569.

Ross, M.S., J.F. Meeder, J.P. Sah, P.L. Ruiz and G.J. Telesnicki, 2000: The southeast saline Everglades revisited: 50 years of coastal vegetation change. *J. Veg. Sci*., **11**, 101-112.

Rowan, R., 2004: Coral bleaching - Thermal adaptation in reef coral symbionts. *Nature*, **430**, 742.

Royal Society, 2005: *Ocean Acidification due to Increasing Atmospheric Carbon Dioxide*. The Royal Society, London, 60 pp.

Rybczyk, J.M., and D.R. Cahoon, 2002: Estimating the potential for submergence for two subsiding wetlands in the Mississippi River delta. *Estuaries*, **25**, 985-998.

Saenger, P., 2002: *Mangrove Ecology, Silviculture and Conservation*. Kluwer, 360 pp.

Sahagian, D., 2000: Global physical effects of anthropogenic hydrological alterations: sea level and water redistribution. *Global Planet Change*, **25**, 29-38.

Saintilan, N., and R.J. Williams, 1999: Mangrove transgression into saltmarsh environments in south-east Australia. *Global Ecol. Biogeogr*., **8**, 117-124.

Saito, Y., 2001: Deltas in Southeast and East Asia: their evolution and current problems. *Proceedings of the APN/SURVAS/LOICZ Joint Conference on Coastal Impacts of Climate Change and Adaptation in the Asia – Pacific Region*, 14-16th November 2000, Kobe, Japan, Asia Pacific Network for Global Change Research, 185-191.

Saji, N.H., B.N. Goswami, P.N. Vinayachandran and T. Yamagata, 1999: A dipole mode in the tropical Indian Ocean. *Nature*, **401**, 360-363.

Sánchez-Arcilla, A., J.A. Jiménez and H.I. Valdemoro, 2006: A note on the vulnerability of deltaic coasts. Application to the Ebro delta. *Managing Coastal Vulnerability: An Integrated Approach*, L. McFadden, R.J. Nicholls and E. Penning-Rowsell, Eds., Elsevier Science, Amsterdam, 282 pp.

Sánchez-Arcilla, A., J.A. Jiménez, H.I. Valdemoro and V. Gracia, 2007: Implications of climatic change on Spanish Mediterranean low-lying coasts: The Ebro delta case. *J. Coastal Res*., in press.

Scavia, D., J.C. Field, D.F. Boesch, R. Buddemeier, D.R. Cayan, V. Burkett, M. Fogarty, M. Harwell and Co-authors, 2002: Climate change impacts on U.S. coastal and marine ecosystems. *Estuaries*, **25**, 149-164.

Schmidt-Thorné, P, Ed., 2006: *Sea Level Change Affecting the Spatial Development in the Baltic Sea Region*. Geological Survey of Finland, Special Paper 41, Geological Survey of Finland, Espoo, 154 pp.

Scott, D., G. Wall and G. McBoyle, 2005: Climate change and tourism and recreation in north America: exploring regional risks and opportunities. *Tourism, Recreation and Climate Change*, C.M. Hall and J. Higham, Eds., Channel View, Clevedon, 115-129.

Sheppard, C.R.C., 2003: Predicted recurrences of mass coral mortality in the Indian Ocean. *Nature*, **425**, 294-297.

Sheppard, C.R.C., D.J. Dixon, M. Gourlay, A. Sheppard and R. Payet, 2005: Coral mortality increases wave energy reaching shores protected by reef flats: examples from the Seychelles. *Estuar. Coast Shelf S*., **64**, 223-234.

Sherman, R.E., T.J. Fahey and J.J. Battles, 2000: Small-scale disturbance and regeneration dynamics in a neotropical mangrove forest. *J. Ecol*., **88**, 165-178.

Shinn, E.A., G.W. Smith, J.M. Prospero, P. Betzer, M.L. Hayes, V. Garrison and R.T. Barber, 2000: African dust and the demise of Caribbean coral reefs. *Geophys. Res. Lett*., **27**, 3029-3032.

Short, A.D., and A.C. Trembanis, 2004: Decadal scale patterns in beach oscillation and rotation, Narrabeen Beach, Australia - time series, PCA and wavelet analysis. *J. Coastal Res*., **20**, 523-532.

Short, F.T., and H.A. Neckles, 1999: The effects of global change on seagrasses. *Aquat. Bot*., **63**, 169-196.

Simas, T., J.P. Nunes and J.G. Ferreira, 2001: Effects of global change on coastal salt marshes. *Ecol. Model*., **139**, 1-15.

Singh, O.P., 2001: Cause-effect relationships between sea surface temperature, precipitation and sea level along the Bangladesh cost. *Theor. Appl. Climatol*., **68**, 233-243.

Small, C., and R.J. Nicholls, 2003: A global analysis of human settlement in coastal zones. *J. Coastal Res*., **19**, 584-599.

Smith, H.D., 2002a: The role of the social sciences in capacity building in ocean and coastal management. *Ocean Coast. Manage.*, **45**, 573-582.

Smith, O.P., 2002b: Coastal erosion in Alaska. *Ber. Polar- Meeresforsch.*, **413**, 65-68.

Solomon, S.M., and D.L. Forbes, 1999: Coastal hazards, and associated management issues on South Pacific islands. *Ocean Coast. Manage.*, **42**, 523-554.

Spalding, M., F. Blasco and C. Field, 1997: *World Mangrove Atlas*. The International Society for Mangrove Ecosystems, 178 pp.

Stern, N., 2007: *The Economics of Climate Change: The Stern Review*. Cambridge University Press, Cambridge, 692 pp.

Stive, M.J.F., 2004: How important is global warming for coastal erosion? An editorial comment. *Climatic Change*, **64**, 27-39.

Stive, M.J.F., S.J.C. Aarninkoff, L. Hamm, H. Hanson, M. Larson, K. Wijnberg, R.J. Nicholls and M. Capbianco, 2002: Variability of shore and shoreline evolution. *Coast. Eng.*, **47**, 211-235.

Stolper, D., J.H. List and E.R. Thieler, 2005: Simulating the evolution of coastal morphology and stratigraphy with a new morphological-behaviour model (GEOMBEST). *Mar. Geol.*, **218**, 17-36.

Stone, G.W., and R.A. McBride, 1998: Louisiana barrier islands and their importance in wetland protection: Forecasting shoreline change and subsequent response of wave climate. *J. Coastal Res.*, **14**, 900-916.

Stone, G.W., J.P. Morgan, A. Sheremet and X. Zhang, 2003: *Coastal Land Loss and Wave-surge Predictions During Hurricanes in Coastal Louisiana: Implications for the Oil and Gas Industry.* Coastal Studies Institute, Louisiana State University, Baton Rouge, Louisiana, 67 pp.

Stone, L., A. Huppert, B. Rajagopalan, H. Bhasin and Y. Loya, 1999: Mass coral bleaching: a recent outcome of increased El Niño activity? *Ecol. Lett.*, **2**, 325-330.

Storlazzi, C.D., and G.B. Griggs, 2000: Influence of El Niño-Southern Oscillation (ENSO) events on the evolution of central California's shoreline. *Geol. Soc. Am. Bull.*, **112**, 236-249.

Storms, J.E.A., G.J. Weltje, J.J. van Dijke, C.R. Geel and S.B. Kroonenberg, 2002: Process-response modeling of wave-dominated coastal systems: simulating evolution and stratigraphy on geological timescales. *J. Sediment Res.*, **72**, 226-239.

Sun, G., S.G. McNulty, D.M. Amatya, R.W. Skaggs, L.W. Swift, P. Shepard and H. Riekerk, 2002: A comparison of watershed hydrology of coastal forested wetlands and the mountainous uplands in the Southern US. *J. Hydrol.*, **263**, 92-104.

Syvitski, J.P.M., C.J. Vörösmarty, A.J. Kettner and P. Green, 2005: Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *Science*, **308**, 376-380.

Tam, N.Y.Y., and Y.S. Wong, 2002: Conservation and sustainable exploitation of mangroves in Hong Kong. *Trees*, **16**, 224-229.

Taylor, J.A., A.P. Murdock and N.I. Pontee, 2004: A macroscale analysis of coastal steepening around the coast of England and Wales. *Geogr. J.*, **170**, 179-188.

Thanh, T.D., Y. Saito, D.V. Huy, V.L. Nguyen, T.K.O. Oanh and M. Tateishi, 2004: Regimes of human and climate impacts on coastal changes in Vietnam. *Regional Environmental Change*, **4**, 49-62.

Thieler, E.R., and E.S. Hammar-Klose, 2000: *National Assessment of Coastal Vulnerability to Sea Level Rise: Preliminary Results for the U.S. Pacific Coast*. U.S. Geological Survey Open-File Report 00-178. [Accessed 13.04.07: http://pubs.usgs.gov/of/2000/of00-178/pages/toc.html]

Thorne, C., E. Evans and E. Penning-Rowsell, Eds., 2006: *Future Flooding and Coastal Erosion Risks*. Thomas Telford, London, 350 pp.

Titus, J.G., 2001: Does the U.S. Government realize that the sea is rising? How to restructure Federal programs so that wetland and beaches survive. *Golden Gate University Law Review*, **30**, 717-778.

Titus, J.G., 2004: Maps that depict the business-as-usual response to sea-level rise in the decentralized United States of America. *Global Forum on Sustainable Development: Development and Climate Change. 11-12 November, Paris*, Organisation for Economic Co-operation and Development (OECD). 22 pp.

Tol, R.S.J., 2002: Estimates of the damage costs of climate change. Part II: Dynamic estimates. *Environ. Resour. Econ.*, **21**, 135-160.

Tol, R.S.J., 2007: The double trade-off between adaptation and mitigation for sea-level rise: An application of FUND. *Mitigation and Adaptation Strategies for Global Change*, **12**, 741-753.

Tol, R.S.J., M. Bohn, T.E. Downing, M.L. Guillerminet, E. Hizsnyik, R. Kasperson, K. Lonsdale, C. Mays and Co-authors, 2006: Adaptation to five metres of sea-level rise. *J. Risk Res.*, **9**, 467-482.

Tompkins, E., S. Nicholson-Cole, L. Hurlston, E. Boyd, G. Brooks Hodge, J. Clarke, G. Gray, N. Trotz and L. Varlack, 2005a: *Surviving Climate Change in Small Islands - A guidebook*. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, Norfolk, 132 pp.

Tompkins, E.L., E. Boyd, S. Nicholson-Cole, K. Weatherhead, N.W. Arnell and W.N. Adger, 2005b: *Linking Adaptation Research and Practice*. Report to DEFRA Climate Change Impacts and Adaptation Cross-Regional Research Programme. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, Norfolk, 120pp.

Townend, I., and J. Pethick, 2002: Estuarine flooding and managed retreat. *Philos. T. Roy. Soc. A*, **360**, 1477-1495.

Townend, I., and K. Burgess, 2004: Methodology for assessing the impact of climate change upon coastal defence structures. *Proceedings of the 29th International Conference on Coastal Engineering 2004*,19-24 September; Lisbon, Portugal, World Scientific Publishing, 3593-3965.

Trenberth, K.E., P.D. Jones, P.G. Ambenje, R. Bojariu, D.R. Easterling, A.M.G. Klein Tank, D.E. Parker, J.A. Renwick and Co-authors, 2007: Surface and atmospheric climate change. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Eds., Cambridge University Press, Cambridge, 235-336.

Trenhaile, A.S., 2002: Rock coasts, with particular emphasis on shore platforms. *Geomorphology*, **48**, 7-22.

Trenhaile, A.S., 2004: Modeling the accumulation and dynamics of beaches on shore platforms. *Mar. Geol.*, **206**, 55-72.

Tsimplis, M.N., D.K. Woolf, T.J. Osborn, S. Wakelin, J. Wolf, R.A. Flather, A.G.P. Shaw, P.H. Woodworth, P.G. Challenor, D. Blackman, F. Pert, Z. Yan and S. Jevrejeva, 2005: Towards a vulnerability assessment of the UK and northern European coasts: the role of regional climate variability. *Philos. T. Roy. Soc. A*, **363**, 1329-1358.

Tsimplis, M.N., A.G.P. Shaw, R.A. Flather and D.K. Woolf, 2006: The influence of the North Atlantic Oscillation on the sea level around the northern European coasts reconsidered: the thermosteric effects. *Philos. T. Roy. Soc. A*, **364**, 845-856.

Turley, C., J.C. Blackford, S. Widdicombe, D. Lowe, P.D. Nightingale and A.P. Rees, 2006: Reviewing the impact of increased atmospheric CO_2 on oceanic pH and the marine ecosystem. *Avoiding Dangerous Climate Change*, H.J. Schellnhuber, W. Cramer, N. Nakićenović, T.M.L. Wigley, and G. Yohe, Eds., Cambridge University Press, Cambridge, 65-70.

Turner, R.K., 2001: *Concepts and Methods for Integrated Coastal Management*. Marine Biodiversity and Climate Change. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, Norfolk, 10 pp.

UN Secretary General, cited 2006a: International co-operation on humanitarian assistance in the field of natural disasters, from relief to development; Strengthening of the coordination of emergency assistance of the United Nations. United Nations General Assembly Sixty-first Session. Sessions A/61. [Accessed 13.04.07: http://www.un.org/ga/61/issues/ha.shtml]

UN Secretary General, cited 2006b: United Nations Millennium Declaration (18th September 2000). United Nations General Assembly Fifty-fifth Session. Agenda item 60(b). 9 pp. [Accessed 13.04.07: http://www.un.org/millennium/declaration/ares552e.pdf]

UNDP, 2004: Reducing disaster risk: A challenge for development, Disaster Reduction Unit, Bureau for Crisis Prevention and Recovery, 161 pp.

UNEP, 2005: *After the Tsunami; Rapid Environmental Assessment*. United Nations Environment Programme (UNEP), 141 pp.

UNFCCC, 2005: *Compendium on Methods and Tools to Evaluate Impacts of, and Vulnerability and Adaptation to, Climate Change*. UNFCC Secretariat, 155 pp.

UNOCHA, 2005: *Regional Workshop on Lessons Learned and Best Practices of Disasters*. United Nations, Economic Commission for Latin America and the Caribbean (ECLAC), 111 pp.

US Government, cited 2006: The Federal response to Hurricane Katrina: Lessons learned. 228 pp. [Accessed 13.04.07: http://www.whitehouse.gov/reports/katrina-lessons-learned.pdf]

Valiela, I., 2006: *Global Coastal Change*. Blackwell, Oxford, 368 pp.

van Aalst, M.K., 2006: The impacts of climate change on the risk of natural disasters. *Disasters*, **30**, 5-18.

van Goor, M.A., M.J. Stive, Z.B. Wang and T.J. Zitman, 2001: Influence of relative sea-level rise on coastal inlets and tidal basins. *Coastal Dynamics 2001. Proceedings of the Fourth Conference on Coastal Dynamics held June 11-15, 2001* *in Lund, Sweden*, H. Hanson, Ed., American Society of Civil Engineers (ASCE), Reston, Virginia, 242-251.

van Goor, M.A., T.J. Zitman, Z.B. Wang and M.J. Stive, 2003: Impact of sea-level rise on the morphological equilibrium state of tidal inlets. *Mar. Geol*., **202**, 211-227.

Vassie, J.M., P.L. Woodworth and M.W. Holt, 2004: An example of North Atlantic deep-ocean swell impacting Ascension and St. Helena Islands in the Central South Atlantic. *J. Atmos. Ocean. Tech*., **21**, 1095-1103.

Viles, H.A., and A.S. Goudie, 2003: Interannual decadal and multidecadal scale climatic variability and geomorphology. *Earth-Sci. Rev*., **61**, 105-131.

Visser, L.E., 2004: *Challenging Coasts: Transdisciplinary Excursions into Integrated Coastal Zone Development*. Amsterdam University Press, Amsterdam, 248 pp.

Walkden, M.J., and J.W. Hall, 2005: A predictive mesoscale model of the erosion and profile development of soft rock shores. *Coast. Eng*., **52**, 535-563.

Walkden, M.J.A., and M.E. Dickson, 2006: *The Response of Soft Rock Shore Profiles to Increased Sea Level Rise*. Working Paper 105. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, Norfolk, 13 pp.

Walsh, J.P., and C.A. Nittrouer, 2004: Mangrove-bank sedimentation in a mesotidal environment with large sediment supply, Gulf of Papua. *Mar. Geol*., **208**, 225-248.

Waltham, T., 2002: Sinking cities. *Geology Today*, **18**, 95-100.

Wang, H., and C.F. Fan, 2005: The C14 database (II) on the Circum-Bohai Sea coast. *Quaternary Sciences (in Chinese)*, **25**, 144-155.

Warrick, R., W. Ye, P. Kouwenhoven, J.E. Hay and C. Cheatham, 2005: New developments of the SimCLIM model for simulating adaptation to risks arising from climate variability and change. *MODSIM 2005 International Congress on Modelling and Simulation*, A. Zerger, and R.M. Argent, Eds., Modelling and Simulation Society of Australia and New Zealand, 170-176.

Wassmann, R., X.H. Nguyen, T.H. Chu and P.T. To, 2004: Sea-level rise affecting the Vietnamese Mekong Delta: water elevation in the flood season and implications for rice production. *Climatic Change*, **66**, 89-107.

Webster, P.J., A.M. Moore, J.P. Loschnigg and R.R. Leben, 1999: Coupled ocean-temperature dynamics in the Indian Ocean during 1997-98. *Nature*, **401**, 356-360.

Webster, P.J., G.J. Holland, J.A. Curry and H.-R. Chang, 2005: Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science*, **309**, 1844-1846.

West, M.B., 2003: Improving science applications to coastal management. *Mar. Policy*, **27**, 291-293.

Whelan, K.T., T.J. Smith, D.R. Cahoon, J.C. Lynch and G.H. Anderson, 2005: Groundwater control of mangrove surface elevation: Shrink and swell varies with soil depth. *Estuaries*, **28**, 833-843.

Wigley, T.M.L., 2005: The climate change commitment. *Science*, **307**, 1766-1769.

Wilkinson, C.R., 2002: *Status of Coral Reefs of the World*. Australian Institute of Marine Sciences. 388 pp.

Williams, K., M. MacDonald and L.D.L. Sternberg, 2003: Interactions of storm, drought, and sea-level rise on coastal forest: a case study. *J. Coastal Res*., **19**, 1116-1121.

Williams, K.L., K.C. Ewel, R.P. Stumpf, F.E. Putz and T.W. Workman, 1999: Sea-level rise and coastal forest retreat on the west coast of Florida. *Ecology*, **80**, 2045-2063.

Williams, M.J., R. Coles, and J.H. Primavera, 2007: A lesson from cyclone Larry: An untold story of the success of good coastal planning. *Estuar. Coast Shelf S*., **71**, 364-367.

Winn, P.J.S., R.M. Young and A.M.C. Edwards, 2003: Planning for the rising tides: the Humber Estuary Shoreline Management Plan. *Sci. Total Environ*., **314**, 13-30.

Wisner, B., cited 2006: Monsoon, market, and miscalculation: The political ecology of Mumbai's July 2005 floods. 6 pp. [Accessed 13.04.07: http://www.radixonline.org/resources/wisner-mumbaifloods2005_22-jan2006.doc]

Wolters, M., J.P. Bakker, M.D. Bertness, R.L. Jefferies and I. Möller, 2005: Saltmarsh erosion and restoration in south-east England: squeezing the evidence requires realignment. *J. Appl. Ecol*., **42**, 844-851.

Woodroffe, C.D., 2003: *Coasts: Form, Process and Evolution*. Cambridge University Press, 623 pp.

Woodroffe, C.D., and R.J. Morrison, 2001: Reef-island accretion and soil development, Makin Island, Kiribati, central Pacific. *Catena*, **44**, 245-261.

Woodroffe, C.D., M. Dickson, B.P. Brooke and D.M. Kennedy, 2005: Episodes of reef growth at Lord Howe Island, the southernmost reef in the southwest Pacific. *Global Planet Change*, **49**, 222-237.

Woodroffe, C.D., R.J. Nicholls, Y. Saito, Z. Chen and S.L. Goodbred, 2006: Landscape variability and the response of Asian megadeltas to environmental change. *Global Change and Integrated Coastal Management: The Asia-Pacific Region*, N. Harvey, Ed., Springer, New York, New York, 277-314.

Woodworth, P.H., J. Gregory and R.J. Nicholls, 2004: Long term sea level changes and their impacts. *The Sea*, vol. 12/13, A. Robinson and K. Brink, Eds., Harvard University Press, Cambridge, Massachusetts.

WTO, 2003: Climate change and tourism. *Proceedings of the 1st International Conference on Climate Change and Tourism*, 9-11th April, Djerba, Tunisia, World Tourism Organization. 55 pp.

WTO, undated: *Long-Term Prospects: Tourism 2020 Vision. [*Accessed 13.04.07: http://www.world-tourism.org/market_research/facts/market_trends.htm]

Yohe, G., 2000: Assessing the role of adaptation in evaluating vulnerability to climate change. *Climatic Change*, **46**, 371-390.

Yohe, G., and R.S.J. Tol, 2002: Indicators for social and economic coping capacity - moving toward a working definition of adaptive capacity. *Glob. Environ. Chang*., **12**, 25-40.

Zacherl, D., S.D. Gaines and S.I. Lonhart, 2003: The limits to biogeographical distributions: insights from the northward range extension of the marine snail, *Kelletia kelletii* (Forbes, 1852). *J. Biogeogr*., **30**, 913-924.

Zhang, K.Q., B.C. Douglas and S.P. Leatherman, 2000: Twentieth-century storm activity along the US east coast. *J. Clim*., **13**, 1748-1761.

Zhang, K.Q., B.C. Douglas and S.P. Leatherman, 2004: Global warming and coastal erosion. *Climatic Change*, **64**, 41-58.

Zimmerman, R.C., D.G. Kohrs, D.L. Steller and R.S. Alberte, 1997: Impacts of CO2 enrichment on productivity and light requirements of eelgrass. *Plant. Physiol*., **115**, 599-607.

Zweig, R., 1998: *Sustainable Aquaculture: Seizing Opportunities to Meet Global Demand*. Agriculture Technology Notes 22. World Bank, Washington, District of Columbia.