Chapter 5. Coastal Systems and Low-Lying Areas

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Contents

Executive Summary

Coastal systems and low-lying areas will increasingly experience adverse impacts associated with submergence and extreme sea level flooding due to relative sea level rise (*high confidence*). Large spatial variations in the projected sea level rise, together with local factors such as subsidence suggests that relative sea level rise can be considerably larger than projected GMSL and therefore is an important consideration in impact assessments (*very high confidence*) [5.3.1]. Changes in storms and associated storm surges may further contribute to changes in sea level extremes but the small number of regional storm surge studies, limited spatial coverage and different modelling approaches used means that there is *low confidence* in projections of storm surge [5.3.3.2].

Acidification and warming of coastal waters will continue with significant consequences for coastal ecosystems (*high confidence*). The increase in acidity will be higher in areas where eutrophication is an issue with negative consequences for many calcifying organisms (*high confidence*) [5.4.2.2, 5.4.2.4]. The interaction of acidification and warming exacerbates coral bleaching and mortality (*very high confidence*) [5.4.2.4, Box CC-OA]. Warming will cause a decline of vegetated coastal habitats across the temperate zone [5.4.2.3]. Temperate seagrass and kelp ecosystems will decline with the increased frequency of heat waves and sea temperature extremes as well as through the impact of invasive subtropical species (*high confidence*). The decline of seagrass and kelp habitats will affect food webs, biodiversity and biogeochemical cycling in these ecosystems (*very high confidence)*. In the absence of adaptation, beaches, sand dunes and cliffs currently eroding will continue to do so under increasing sea levels (*high confidence*) [5.4.2.1.-5.4.2.2.]. Increased human-induced drivers have been the primary drivers of change in coastal aquifers, lagoons, estuaries, deltas and wetlands (*very high confidence*). Climate-induced drivers will exacerbate currently existing problems in these natural systems (*very high confidence*) [5.4.2.3-5.4.2.7].

The population and assets exposed to coastal risk as well as human pressures on coastal ecosystems will increase significantly in the coming decades due to population growth, economic development, urbanization and coast-ward migration of people (*high confidence*). Under medium population projections, the population exposed to the 1 in 100 year coastal flood is expected to increase from 271 million in 2010 to 345 million in 2050 due to socio-economic development only [5.4.3.1]. This increase in coastal population is expected to further exacerbate human pressures on coastal systems resulting from excess nutrient input, reduced run-off and sediment delivery (*high confidence*) [5.3.4.3, 5.3.4.4, 5.3.4.5, 5.3.4.6].

The costs of inaction are larger than the sum of adaptation and residual damage costs for the 21st century and at the global scale (*high agreement*). Without adaptation, hundreds of million people will be affected by coastal flooding and be displaced due to land loss through submergence and erosion by 2100; the majority of these affected are from East, Southeast and South Asia (*high confidence*). [5.4.3.1]. Even with very extreme mean sea-level rise of 1.3m by 2100, protection is considered economically rational for most developed coastlines in most countries (*high agreement*) [5.5.3]. Under medium socio-economic development assumption, the expected direct global annual cost of coastal flooding (adaptation and residual damage costs) may reach US$300 billion per year in 2100 without adaptation and US$90 billion per year with adaptation under a 1.26 m sea-level rise scenario [5.5.3]

The impacts of climate change on coasts and the required level of adaptation vary strongly between regions and countries (*high confidence*). While developed countries are expected to be able to adapt to even high levels of sea-level rise, small island states and some low-lying developing countries are expected to face very high impacts and associated annual damage and adaptation costs of several percentage points of GDP (*high agreement*) [5.5.3]. Developing countries and small island states within the tropics relying on coastal tourism, are impacted not only directly by future sea-level rise and associated extremes but also by the impacts of coral bleaching and ocean acidification and reductions in tourist flows from other-regions (*very high confidence*). [5.4.3.4]

Since AR4, the analysis and implementation of coastal adaptation has progressed significantly but much more effort is needed for a transition towards climate resilient and sustainable coasts (*very high confidence*). The analysis of adaptation has progressed towards novel approaches such as robust decision making and adaptation pathways that recognize that the deep uncertainty in projections of drivers does not have to be a barrier to adaptation (*high confidence*) [5.5.2.2]. Adaptation analysis and implementation have also progressed towards considering the institutional context and governance of adaptation, albeit many governance challenges related to vertical and horizontal policy integration, political will and power relations remain (*very high confidence*) [5.5.2.3, 5.5.2.4]. Many countries, sates/provinces, cities and communities are now carrying out adaptation activities including the mainstreaming of coastal adaptation into relevant strategies and management plans (*very high confidence*) [5.5.4].

5.1. Introduction

This chapter presents an updated picture of the impacts, vulnerability and adaptation of coastal systems and low-lying areas to climate change, with emphasis on sea-level rise. Unlike the coastal chapter in the previous assessment

(AR4), some materials pertinent to the oceans are not covered in this chapter but in two new ocean chapters (Chapters 6 and 30).

The topics covered in this chapter follow the outline for sectoral chapters approved by the IPCC. An Executive Summary summarizes the key messages with a line of sight to the supporting sections in the chapter.

This chapter comprises six sections with this first section dealing with progress in knowledge from AR4 to AR5 scope of chapter and new developments. Section 2 defines the coastal systems and climate and non-climate drivers. The coastal systems include both natural systems and human systems and this division is generally followed throughout the chapter. The climate and non-climate drivers are assessed in section 3, followed by the impacts, vulnerabilities and risks in section 4. Section 5 deals with adaptation and managing risks. Information gaps, data gaps and research needs are assessed in section 6. There are 8 boxes on specific topics or examples, including 3 cross-chapter boxes, distributed within the chapter.

In the AR4, the coasts chapter assessed the impact of climate change and global sea-level rise up to 0.6 m to 2100 The coastal systems were deemed be affected mainly by higher sea level, increasing temperature, changes in precipitation, larger storm surges and reduction in ocean pH. Human activities had continued to increase their pressure on the coasts with rapid urbanization in coastal areas and growth of megacities with consequences on the coastal resources. Regionwise, South, Southeast and East Asia, Africa and small islands were identified most vulnerable. The AR4 chapter offered a range of adaptation measures, many under the ICZM (integrated coastal zone management) framework that could be carried out in the developed and developing countries, but recognized that the latter would face more challenges. Various issues on increasing the adaptive capacity or increasing the resilience of coastal communities were discussed. The unavoidability of sea level rise in the long term, even with stringent mitigation was noted, and adaptation would become an urgent issue.

A number of key issues related to the coasts have arisen since the AR4. There is now better understanding of the natural systems, their ecosystem functions, their services and benefits to humanity and how they can be affected by climate change. Their linkages landward to the watersheds and seaward to the seas and oceans need to be considered for a more integrated assessment of climate change impacts. GMSL are projected to be 0.46 to 0.96 cm by 2100 although regional variations in sea level rise may see values vary by up to 20% of GMSL for most countries and as much as 50% for some (WG1 Chapter 13). This may have serious implications for coastal cities, deltas and low-lying states. While higher rates of coastal erosion are generally expected under rising sea levels, the complex inter-relationships between the geomorphological and ecological attributes of the coastal system and the relevant climate and oceanic processes need to be better established at regional and local scales.

Also of concern is ocean acidification and potential impacts of reduced calcification in shellfish and impacts on commercial aquaculture (Barton *et al*., 2012). Together with warming, acidification also causes coral reefs to lose their structural stability with negative implications for reef communities and shore protection (Sheppard *et al*., 2005; Manzello *et al.,* 2008; see also Box CC-OA). A significant number of new findings regarding the impacts of climate change on human settlements, key coastal systems such as rocky coasts, beaches, estuaries, deltas, salt marshes, mangroves, coral reefs and submerged vegetation have become available since the AR4 and are reviewed in this chapter. However, uncertainties regarding projections of potential impacts on coastal systems remain high.

This chapter also provides advances in both vulnerability assessments and the identification of potential adaptation actions, costs, benefits and tradeoffs. A larger number of new studies estimate the cost of inaction versus potential adaptation. Coastal adaptation has become more acceptable and a wider range of approaches and frameworks such as integrated coastal management, ecosystem-based adaptation, community-based adaptation and disaster risk reduction and management are being used.

Climate change will interact differently with the variety of human activities and other drivers of change along coastlines of developed and developing countries. For coastlines of developed countries, changes in weather and climate extremes and sea-level rise may impact for example, demand for housing, recreational facilities and construction of renewable energy infrastructure at the coast (Hadley, 2009). On coasts of developing countries, weather and climate extremes put an additional risk to many of the fastest-growing coastal urban areas, such as in Bangladesh and China (McGranahan *et al.,* 2007; Smith 2011).

5.2. Coastal Systems

Coastal systems and low-lying areas, also referred to as simply coasts in this assessment are areas near to mean sea level. Generally, there is no single definition for the coasts and the coastal zone/area where the latter has an emphasis on area or extent. In relation to exposure to potential sea-level rise, the LECZ (low-elevation coastal zone) has been used in recent years with reference to specific area and population up to 10 m elevation (Vafeidis *et al.*, 2011). This chapter does not consider the polar coasts (chapter 28), small islands (chapter 29), many of which are low-lying, or the region beyond the continental shelf (chapters 6 and 30).

The coastal systems are conceptualized to consist of both natural systems and human systems (Figure 5-1). The natural systems include distinct coastal characterizations and ecosystems such as rocky coasts, beaches, barriers and sand dunes, estuaries and lagoons, deltas, wetlands and coral reefs. These elements help to define the seaward and landward boundaries of the coast. While they provde a wide variety of regulating, provisioning, supporting and cultural services (MEA, 2005) they have been altered and heavily influenced by human activities with climate change constituting only one amongst many pressures these systems are facing. The human systems include the built environment (settlements, infrastructure and transport networks), human activities (e.g., tourism, aquaculture, etc) as well as formal and informal institutions that organize human activities (e.g., policies, laws, customs, norms and culture). Both systems together form a tightly coupled social-ecological system (SES) (Berkes and Folke, 1998; Hopkins *et al.,* 2012).

[INSERT FIGURE 5-1 HERE
Figure 5-1: Schematic diagram indicating the elements of the coastal zone that are considered in this chapter.]

5.3. Drivers

5.3.1. Introduction

In TAR and AR4 changes in climate drivers (any climate-induced factor that directly or indirectly causes a change), including sea level rise, were projected for different SRES emissions scenarios (Nakicenovic and Swart, 2000). Consequently, to date, most of the impacts and vulnerability assessments of climate change in coastal areas are based on SRES A2, A1B, B2 and A1F1 scenarios. Since AR4 a new scenario process has been initiated to replace the SRES scenarios with Representative Concentration Pathways (RCPs) and Shared Socio-economic Pathways (SSPs) (Moss *et al.,* 2010). The RCPs are scenarios specifying concentrations, rather than emissions, thereby avoiding differences in concentrations of Long-Lived Greenhouse Gas and aerosol concentrations for the same emissions scenarios that can arise from the use of different models (van Vuuren *et al.,* 2011). For a comparison between RCP and SRES scenarios see WG1, Chapter 1, Box 1.2. In addition, Extended Concentration Pathways (ECPs) have been introduced for the period 2100-2300 (Meinhausen *et al.* 2009) providing the opportunity to assess the long-term commitment to sea-level rise, which is *very likely* to continue beyond 2500 unless global temperature declines (WG1, Chap.1, 13.5.2).

The SSPs provide representative qualitative story lines (narratives) of world development together with quantitative pathways of key socio-economic variables such as GDP and population (O'Neil *et al.*, 2011). A preliminary list of 5 SSPs have been proposed (Arnell *et al.*, 2011; O'Neil *et al.*, 2011) and will be discussed in 5.3.4.1 and work to further refine these is ongoing (Kriegler *et al.* 2012; Van Vuuren *et al.*, 2012). SSPs do not include assumptions about mitigation policy and are thus independent from RCPs in the sense that the same SSP may lead to different concentration levels and hence rises in sea-level depending on the level of mitigation reached (Arnell *et al.*, 2011; O'Neil *et al.*, 2011).

5.3.2. Relative Sea Level Rise

Relative sea level rise poses a significant threat to coastal systems and low-lying areas around the globe leading to inundation and erosion of coastlines, contamination of freshwater reserves and food crops (Nicholls, 2010). Sea level rise due to thermal expansion as the oceans warm, together with meltwater from glaciers, icecaps and ice sheets of Greenland and Antarctica are the major factors that contribute to relative sea level rise globally. However, the subsidence of coastal land due to sediment compaction, subsurface resource extraction (e.g. groundwater, gas and petroleum; Syvitski *et al*., 2009), glacial isostatic rebound and tectonic movement may also contribute to relative sea level rise locally and therefore requires consideration in coastal impact studies. Sea level impacts are most pronounced during episodes of extreme sea levels and these are discussed in 5.3.3.

5.3.2.1. Global Mean Sea Level

Although sea level change can exhibit large regional variability on different time scales from factors such as climate variability and ocean circulation patterns, it is *very likely* that over the 20th Century, global mean sea level (GMSL) rose at a mean rate between 1.5 to 1.9 mm yr^{-1} and since 1993, at a rate between 2.8 to 3.6 mm yr^{-1}. Ocean thermal expansion and melting of glaciers have been the largest contributors, accounting for over 80% of the MSL rise over the latter period (AR5, Chapter 13). Future contributions to GMSL rise during the 21st century will *very likely* exceed the observed rate for the period 1971–2010 for all RCP scenarios. Sea levels will continue to rise beyond the 21st Century. Projections for sea levels are available for 2200 to 2500 although these are based on fewer and simpler models that include lower resolution coupled climate models for thermal expansion and ice sheet models coupled to climate models to project ice sheet contributions. The basis for the projections are the Extended Concentration Pathways (ECPs) and projections are provided for low, medium and high scenarios which relate to atmospheric GHG concentrations <500 ppm, 500-700 and > 700 ppm respectively (13.5.2). Projections of GMSL for a range of time horizons are summarized in Table 5-1.

[INSERT TABLE 5-1 HERE
Table 5-1: Projections of global mean sea level rise in metres relative to 1986–2005 based on ocean thermal expansion calculated from climate models, the contributions from glaciers, Greenland and Antarctica from surface mass balance calculations using climate model temperature projections, the range of the contribution from Greenland and Antarctica due to dynamical processes, and the terrestrial contribution to sea levels, estimated from available studies. For sea levels up to and including 2100, the central values and the 5-95% range is given whereas for projections from 2200 onwards, the range represents the model spread due to the small number of model projections available (source: WG1, Chapter 13).]

[INSERT TABLE 5-2 HERE
Table 5-2: Main climate-related drivers for coastal systems, their trends due to climate change, and their main physical and ecosystem effects (↑ increase; ↓ decrease; ⊄ no change; ? uncertain; ↔ regional variability).]

5.3.2.2. Regional Sea Level

The impacts of sea level rise will not be uniform in space and time. Natural modes of climate variability influence sea levels in different regions of the globe and this will affect the rate of rise on interdecadal time periods. For example in the equatorial Pacific, sea levels can vary from the global mean by up to 40 cm due to ENSO (e.g. Walsh et al, 2012) and this can strongly influence trends on decadal scales. Regional variations in the rate of sea level rise at the coast can arise from climate and ocean dynamical processes such as changes in winds and air pressure, air-sea heat and freshwater fluxes, ocean currents and their steric properties. Changes in gravitational processes due to the redistribution of water mass and changes in the shape of the sea floor also contribute. Although the vast majority of coastlines are experiencing sea level rise, coastlines near current and former glaciers and ice sheets are experiencing sea level fall. Under RCP4.5 and 8.5, it is *very likely* that about 72% and 77% respectively of the world's coastlines will experience a sea level change that is within ±20% of the GMSL change, although some coastlines may experience a rise of up to 50% above the GMSL (AR5, Chapter 13.6).

5.3.2.3. Local Sea Level

As well as long-term vertical land movements from GIA (glacial isostatic adjustment), relative sea level rise due to subsidence of coastal plains can occur through other natural causes. For example, tectonic movements, both sustained and abrupt, have brought about relative changes of sea level. The Tohoku earthquake in 2011 caused subsidence of up to 1.2 m along ~400 km of the Pacific coast of northeast Japan. The Sumatra-Andaman earthquake in 2004 and subsequent earthquakes in 2005 produced vertical deformation ranging from uplift of 3 m to subsidence of 1 m (Briggs *et al.*, 2006). These movements are especially important in coastal zones located near active plate margins.

Anthropogenic causes of relative sea level rise include sediment consolidation from building loads, reduced sediment delivery to the coast and extraction of subsurface resources such as gas, petroleum and groundwater. Subsidence rates may also be sensitive to the rates of oil and gas removal (e.g. Kolker *et al.*, 2010). Syvitski *et al.*, (2009) estimate that the majority of the world's largest deltas are currently subsiding at rates that are considerably larger than the current rates of sea level rise because of coastal sediment starvation due to substantial dam building over the 20th century or sediment compaction through natural or anthropogenic activities. Many large cities on deltas and delta plains have subsided during the last 100 years, by up to 5 m in eastern Tokyo, 3 m in Shanghai, 2 m in Bangkok, and 3 m in the Po delta (Nicholls, 2011; Teatini *et al.*, 2011). Loads from massive buildings and other large structures can also increase sediment compaction and subsidence (Mazzotti *et al.*, 2009). Relative sea level rise can exceed GMSL rise by an order of magnitude, reaching more than 10 cm/y and it is estimated that the delta surface area vulnerable to flooding could increase by 50% under projected sea-level rise in the twenty-first century (Syvitski et al, 2009).

5.3.2.4. Summary

Observed trends in mean sea level together with projected increases for 2100 and beyond means that coastal systems and low-lying areas will increasingly experience adverse impacts associated with submergence (*high confidence*). Large spatial variations in the projected sea level rise, together with local factors such as subsidence suggests that relative sea level rise can be much larger than projected GMSL and therefore is an important consideration in impact assessments (*very high confidence*).

5.3.3. Climate-related Drivers

Increasing greenhouse gases in the atmosphere produce changes in the climate system on a range of time scales that impact the coastal physical environment. On shorter time scales, physical coastal impacts such as inundation, erosion and coastal flooding arise from severe storm-induced surges, wave overtopping and erosion. On longer time scales, changes in wind and wave climate can cause changes in sediment transport at the coast that may also lead to erosion or accretion. Natural modes of climate variability, which can affect severe storm behaviour and wind and wave climate, may also undergo anthropogenic changes in the future. Ocean temperatures can affect species distribution and lead to declines in some species thereby leading to changes in coastal biodiversity. CO_2 uptake in the ocean increases ocean acidity and reduces the saturation state of carbonate minerals, essential for shell and skeletal formation in many coastal species. Past and future changes to these physical drivers are discussed in this section.

5.3.3.1. Severe Storms

Severe storms lead to strong winds and regions of low pressure which, over coastal seas can generate storm surges and high waves. The severity of these depends also on the storm's track, regional bathymetry and nearshore hydrodynamics. Tropical cyclones pose a significant threat to coastal population (see Box 5-2), mostly due to the associated storm surge, which may combine with fresh water flooding due to extreme rainfall (Rappaport, 2000) and increase the extent of coastal flooding. Extratropical cyclones (ETCs) occur throughout the mid latitudes of both hemispheres and their development is linked to large-scale circulation patterns. Assessment of changes in large-scale climate circulation features indicate that there has been a widening of the tropical belt, poleward shift of storm tracks and jet streams and contraction of the polar vortex leading to the assessment that it is *likely* that, in a zonal mean sense, circulation features have moved poleward (Chapter 2). However, both Seneviratne *et al*. (2012) and AR5 concluded that there is *low confidence* regarding regional changes in intensity of extratropical cyclones. With regards to future changes, models tend to agree on a southward shift in the SH storm track and a global reduction of ETC numbers. However there is *high confidence* that the reduction in the global number of extra-tropical cyclones due to global warming will be small (less than a few percent) and hence small compared to natural interannual variability. There is *high confidence* that a small poleward shift is *likely* in the Southern Hemisphere (AR5 Chapter 14) but changes in the Northern Hemisphere are basin specific and of *lower confidencelower confidence*. There is also *low confidence* in the influence on extreme events of storm track changes.

5.3.3.2. Extreme Sea Levels

Extreme sea levels arise from combinations of factors that include astronomical tides, storm surges, wind and swell waves, sea level variations due to interannual variability and Tsunamis, although the latter are tectonic and therefore not related to climate. The frequency of extreme sea levels will be increased by relative sea level rise. Storm surges, caused by falling atmospheric pressures and surface wind stress associated with storms, may also change if storms are affected by climate change.

Recent global (e.g. Menendez and Woodworth, 2010) and regional studies (e.g. Marcos *et al*., 2009; Haigh *et al*., 2010, Losada *et al*. 2013) have found that observed trends in extreme sea levels are mainly consistent with mean sea level trends (SREX, indicating that the increasing frequency of extreme events observed so far is related to rising MSL and not to changes in the behaviour of severe storms. Observations of present sea level extremes due to variability of tides and storm surges have been combined with projections of MSL and their uncertainties, to estimate a “sea level allowance” (Hunte*r*, 2012; Hunter *et al*., 2012) . Assuming that sea level extremes follow a simple extreme value distribution (i.e. a Gumbel distribution), projected MSL rises of 0.542 m (the projected MSL rise for 1990-2100 under an A1FI scenario) and 1.0 m require an additional allowance of 26% and 44% MSL respectively to preserve the current frequency of flooding events (Figure 5-2). Such an allowance can be factored into adaptive responses to rising sea levels. It should be noted however that extreme sea level distributions may not follow a simple Gumbel distribution (e.g. Tebaldi *et al*. 2012) due to different factors influencing extreme levels.

[INSERT FIGURE 5-2 HERE
Figure 5-2: Results of global analysis, indicated by dot diameter. a Factor by which frequency of flooding events will increase with a rise in sea level of 0.5 metres (key is left-hand column of dots in the bottom left-hand corner). b Sea-level rise allowance (metres) for 1990–2100 which conserves frequency of flooding events for the IPCC A1FI Projection based on A1FI emission scenario and AR4-adjusted TAR projections (normal distribution with Δz=0.542 m and σ=0.168 m); key is central column of dots in the bottom left-hand corner. c Sea-level rise allowance (metres) for 21st century which conserves frequency of flooding events for the 1.0/1.0 m Projection, based on post-AR4 results (raised cosine distribution with Δz=1.0 m and W/2=1.0 m); key is right-hand column of dots in the bottom left-hand corner.]

Several regional studies have assessed future changes to storm surges using hydrodynamic models forced by climate models. Extratropical studies show strong regional variability and sensitivity to the choice GCM or RCM (e.g. Debenard and Roed, 2008; Wang et al, 2008; Sterl et al, 2009 for the northeast Atlantic and Colberg and McInnes; 2012 for the southern Australian coastline. The effect of tropical cyclone changes on storm surges have also been investigated in a number of regions including Australia’s tropical east coast (Harper *et al*.; 2009), Louisiana (Smith *et al*., 2010), Gulf of Mexico, (Mousavi *et al*., 2011), India, (Unnikrishnan *et al*.; 2011) and New York (Lin *et al*., 2012), and methods used and findings vary considerably between the studies. For example Mousavi *et al*., 2011 developed relationships between current climate cyclone intensities and SSTs and used the projected changes in SSTs from climate models to scale the cyclone intensity whereas Lin et al., (2012) use the cyclones simulated in four climate models that were scaled-up to realistic cyclone numbers via a synthetic cyclone approach. Lin *et al*., (2012) found that 2 of their 4 models produced changes in storm surges comparable to the projected sea level rise while changes in the other two models were dominated by sea level rise. Non-linear interactions between the storm surge and increased sea level conditions were also highlighted in some studies (e.g. Smith *et al*., 2010; Mousavi *et al*., 2012).

The small number of regional storm surge studies combined with the different atmospheric forcing factors and modelling approaches means that there is *low confidence* in projections of storm surges. However, there is *high confidence* that extremes will increase with GMSL rise, thereby leading to large increases in the frequency of extreme sea level events by the end of the 21st century (see also Chapter 13).

5.3.3.3. Winds and Waves

In the context of coasts, wind climate determines large-scale wave climate change, which in turn shapes shorelines. Winds influence longshore current regimes and hence upwelling systems (Narayan *et al.,* 2010; Miranda *et al.,* 2012; see also Chapter 6). Energy dissipation via wave breaking contributes to beach erosion, longshore currents, and elevated coastal sea levels through wave set-up and run-up. Changes to wind and wave climate therefore can affect sediment dynamics and shoreline processes (e.g. Aargaard *et al*., 2004; Reguero *et al.,* 2012) while extreme winds and waves associated with storms are a threat to coastal populations. In addition to shorter period wind waves longer period swell, whose energy dominates the wave energy field, poses a significant danger to coastal and offshore structures, (Semedo *et al.,* 2011) and can causes flooding of coastlines with steep shelf margins (Hoeke *et al*. 2013). The coastal impacts of wave climate change are also a function of wave direction and period as well as the coastline itself, which can influence shoaling and refraction.

For observed changes in wind, Seneviratne *et al*., (2012) concluded that there is *low confidence* in trends calculated from measurements of mean and extreme winds and their causes due to the limited length of records and uncertainties associated with different wind measurement techniques. However, WG1 Chapter 3 notes increasing evidence for a strengthening of the wind stress field in the Southern Ocean since the early 1980s from atmospheric reanalyses, satellite observations and island station data. Regional wave climate is strongly related to modes of climate variability (Seneviratne, 2012) and it is *likely* that there have been positive trends in the North Atlantic, North Pacific and Southern Ocean (Chapter 3, see Table 5-1).

Projected changes in mean and extreme winds and waves were assigned *low confidence* (Seneviratne et al, 2012) owing to limited studies. Although there has been an increase in studies addressing wave climate change (Hemer *et al*., 2013), generally *low confidence* remains in projected wave climate change (except for *medium confidence* over the southern ocean) and this is due to uncertainties in future winds, particularly those associated with storms (see also Chapter 13.7).

5.3.3.4. Sea Surface Temperature

Sea surface temperature has significantly warmed during the past 30 years along more than 70% of the world's coastlines, with highly heterogeneous rates of change both spatially and seasonally (Lima and Wethey, 2012). The average rate is 0.18 ± 0.16°C per decade and the average change in seasonal timing was -3.3 ± 4.4 days per decade. These values are larger than in the global ocean where the average of change is about 0.1°C per decade in the upper 75 m of the ocean during the period 1970-2009 (WGI, Chap. 3) and the seasonal shift is -2.3 days per decade (Lima and Wethey, 2012). Extreme events have also been reported. For example, the record high ocean temperatures along the Western Australian coast during the austral summer of 2010/2011, with nearshore temperatures peaking at about 5 °C above average, were unprecedented (Pearce and Feng, 2013). In summary, positive trends in coastal SST's are seen on the majority of coastlines and the rate of rise along coastlines is higher on average than the oceans (*high confidence*, *limited evidence*). Based on projected temperature increases there is *high confidence* that coastal SST's exhibiting positive trends will continue to do so.

5.3.3.5. Ocean Acidification

Anthropogenic ocean acidification refers to the changes in the carbonate chemistry primarily due to the uptake of atmospheric CO2 (Box CC-OA). Seawater pH exhibits a much larger spatial and temporal variability in coastal waters compared to open ocean due to the variable contribution of processes other than CO2 uptake (Duarte *et al.*, 2013) such as upwelling intensity (Feely *et al.*, 2008), deposition of atmospheric nitrogen and sulphur (Doney *et al.*, 2007), carbonate chemistry of riverine waters (Salisbury *et al.*, 2008; Aufdenkampe *et al.*, 2011), as well as inputs of nutrients and organic matter (Borges, 2011; Cai *et al.*, 2011). For example, pH (NBS scale) ranges from 6 to 9 in 24 estuaries (Borges and Abril, 2012) and short-term (hours to weeks) changes of up to 0.5 pH units are not unusual in coastal ecosystems (Hofmann *et al.*, 2011).

Few ocean acidification time series exceed more than 5 years in the coastal ocean (Wootton *et al.*, 2008; Provoost *et al.*, 2010; Waldbusser *et al.*, 2010). Some exhibit considerable differences with the open ocean stations illustrating the fact that anthropogenic ocean acidification can be lessened or enhanced by coastal biogeochemical processes (Borges and Gypens, 2010; Feely *et al.*, 2010).

In more recent years, a phosphorus removal policy limited primary production which led to a decrease in pH much larger than would be expected from the absorption of atmospheric CO_2 alone (-0.016 pH unit yr-1). Under the IS92a CO_2 emission scenario, the global pH (total scale) of coastal waters has been projected decrease from about 8.16 in the year 1850 to 7.83 in 2100 (Lerman *et al.*, 2011) but with considerable spatial variability. For example, using the same CO_2 emission scenario Cai *et al.* (2011) projected that the overall decline in 0.74 pH between pre-industrial time and 2100 in the Northern Gulf of Mexico, a value that is much greater than in the open ocean.

To summarise, seawater pH exhibits considerable temporal and spatial variability in coastal areas compared to open ocean due to additional natural and human influences (*very high confidence*). Coastal acidification is projected to continue but with large and uncertain regional and local variations (*high confidence).*

5.3.3.6. Freshwater Input

Changes in river runoff arise from changes in climate drivers such as precipitation and droughts, complex interactions between changing levels of CO_2, plant physiology and hence evapotranspiration (e.g. Gedney et al, 2006; Betts et al, 2007) and other human drivers such as land-use change, water withdrawal, dam building and other engineered modifications to waterways. Such changes can have multiple effects on coastal systems. Not only are changes in the quantity and quality of runoff relevant but also the temporal distribution. Sudden pulsed discharges of freshwater arising from meltwater or storm-induced runoff into marine systems may impact ecosystems unable to deal with low-salinity water and can affect the efficiency of estuaries to retain or filter material delivered by the rivers. This can result in the delivery of riverine nutrients to coastal sea systems that would otherwise have been processed during transit. Generally higher and more variable river runoff arises from lowered retention due to land clearing (Chapter 4) such as for agricultural purposes and this also associated with increased erosion and sediment yield.

An assessment of run-off trends in 925 of the world's largest ocean-reaching rivers, which account for about 73% of global total runoff, indicates that from 1948–2004 statistically significant trends were present in only one third of gauges and of these two thirds exhibited downward trends and one third upward trends (Dai *et al.,* 2009). Precipitation changes dominate the trends, which for flow discharging into the Pacific, Indian and Atlantic Oceans, is also correlated with ENSO. Positive trends in runoff are more prevalent in the Arctic in winter and spring associated with snow melt. While precipitation change dominates freshwater flows, decreasing trends in river discharge may be further enhanced by human pressures (Dai *et al.*, 2009; Chapter 3.2.3).

Average annual runoff is generally projected to increase at high latitudes and in the wet tropics and projected to decrease in most dry tropical regions (Chapter 3). Shifts to earlier peak flows are also projected in areas affected by snowmelt. However, there are some regions where there is considerable uncertainty in the magnitude and direction of change, specifically south Asia and large parts of South America. Both the patterns of change and the uncertainty is largely driven by projected changes in precipitation.

To summarise, there is *medium confidence (limited evidence)* in a net declining trend in freshwater input globally although large regional variability exists. Trends are dominated by precipitation changes although human pressures on water supply may enhance downward trends (*medium confidence*). Uncertainty in future changes in run-off is linked to precipitation uncertainty. Runoff is generally projected to increase in high latitudes with earlier peak flows and in the wet tropics and decrease in other tropical regions but with large uncertainty (*medium confidence*).

5.3.4. Human Drivers

Coastal systems are subject to a wide range of non climate-related drivers (e.g., Crain *et al*., 2009) the impacts of which can interact with climate-related drivers and confound efforts to attribute causes of changes. Some of the major human drivers, i.e. human-induced factors that directly or indirectly cause changes, are briefly reviewed below.

5.3.4.1. Socioeconomic Development

One of the most important drivers of coastal impacts is socio-economic development (SED). The current understanding of possible future SED pathways is described through a preliminary set of five shared socio-economic pathways (SSPs; Arnell *et al*., 2011; O'Neil *et al*., 2011). The highest GDP and lowest population numbers are attained under SSP1 (called “Sustainability”), which reflects a world progressing towards sustainability with reduced resource intensity and fossil fuel dependency, and SSP 5 (called “Conventional Development”), which reflects a world oriented toward equitable rapid fossil fuel-dominated development. GDP is lowest and population highest under SSP 3 (“Fragmentation”), which reflects a world fragmented into poor regions with low resource intensity and moderately healthy regions with a high fossil fuel dependency. GDP and population under SSP 4 (Inequality) which is a highly unequal world both within and across countries, follows a similar but less extreme trend compared to SSP 3. SSP 2 (Middle of the Road) reflects a world with medium assumptions between the other four SSPs.

There is *very high confidence* that SED has been one of the major drivers of increasing coastal flood damage through increasing exposure (IPCC SREX) and it is expected that this will also be a major driver of climate and sea-level rise impacts during the 21st century (Nicholls and Cazenave, 2010). Currently, the Low Elevation Coastal Zone (LECZ) constitutes 2% of world’s land area but contains 10% of world’s population (600 million) and 13% of world’s urban population (360 million) based on 2000 estimates (McGranahan *et al*., 2007). Although these estimates are subject to uncertainties (see Lichter *et al*., 2011; Mondal and Tatem, 2012), they are indicative of the high exposure of low-lying coastal regions. About 65% of the world’s cities with populations of over 5 million are located in the LECZ, including a large number of small island states and densely populated mega-deltas (McGranahan *et al*., 2007). The top 10 exposed cities in terms of exposed population are Mumbai, Guangzhou, Shanghai, Miami, Ho Chi Minh City, Kolkata, Greater New York, Osaka-Kobe, Alexandria and New Orleans (Hanson *et al*., 2011). In terms of assets exposed, 60% are from the USA, Japan and the Netherlands (Hanson *et al*., 2011). Comparatively, Asia demonstrates the greatest exposure in terms of population, assets and productivity and the largest increases in exposure through socio-economic development is expected in Asia and Africa (Dasgupta, 2009; Hanson *et al*., 2011; Kebede and Nicholls, 2012).

For many locations there is *high confidence* that coastal population and assets exposure is growing faster than the national average trends due to coastward migration, coastal industrialization and urbanization (e.g. McGranahan *et al*., 2007; Smith, 2011; Seto, 2011; WG2 Ch. 8). Coastal net migration has largely taken place in flood- and cyclone-prone areas, which poses a challenge for adaptation (de Sherbinin *et al*., 2012). These processes and associated land use changes are driven by a combination of many social, economic, and institutional factors including taxes, subsidies, insurance schemes, aesthetic and recreational attractiveness of the coast and increased mobility (Bagstadt *et al*., 2007; Palmer *et al*., 2011). In China, the country with the highest exposed population, urbanization and land reclamation are the major drivers of coastal land-use change (Zhu *et al*., 2012). Although coastal migration is expected to continue in the coming decades, it is difficult to capture this process in global scenarios as the drivers of migration and urbanization are complex and variable (Black *et al*. 2011).

Socio-economic development also determines the future capacity to adapt. Poor people living in urban informal settlements, of which there are about 1 billion worldwide, are particularly vulnerable to weather and climate impacts (Handmer *et al*., 2012; de Sherbinin *et al*., 2012). Of the top ten nations classified by population and proportion of population in coastal low-lying areas the majority are in developing countries (Bollman *et al*., 2010). SED and associated land reclamation are also major drivers of the destruction of coastal wetlands, which also makes human settlements more vulnerable since wetlands act as natural buffers reducing wave and storm impacts on the coast (e.g., Crain *et al*., 2009; Shepard *et al*., 2011). Finally, socio-economic development is expected to further exacerbate a number of human pressures on coastal systems related to changes in freshwater input, water-diversion, nutrients and hypoxia, which will be discussed in the following sections.

[INSERT TABLE 5-3 HERE
Table 5-3: Top ten nations with the largest populations and the highest proportions of population in low-lying coastal areas (Countries with fewer than 100,000 inhabitants are not included; 15 SIDs (Small Island Developing States) with total of 423,000 inhabitants are also excluded). Source: Bollman *et al.,* 2010.]

5.3.4.2. Nutrients

Increased nutrient (i.e. nitrogen, phosphorus) loads to coastal systems in many world regions are observed and simulated by regional and global watershed models ((Alexander *et al*., 2008; Howarth *et al*., 1996; Seitzinger *et al*., 2010). River transported anthropogenic nutrients are primarily due to increased fertilizer use for food production and fossil fuel emissions (NOx) (Bouwman *et al*., 2009; Galloway *et al*., 2004).

Anthropogenic global loads of biologically reactive dissolved inorganic N and P (DIN, DIP) are about 2 to 3 times larger than natural sources (Seitzinger *et al*., 2010) resulting in degradation of coastal ecosystems, including hypoxia. Large variations exist between rivers in the magnitude of nutrient loads and their relative sources. Future trends depend on measures to optimize nutrient use in food production and minimize nutrient loss to rivers from agriculture, sewage, and NOx emissions. Using the Millennium Ecosystem Assessment (MEA) scenario with little emphasis on nutrient management, DIN and DIP global discharge increase by about 30% and 55%, respectively, between 2000 and 2050 (Seitzinger *et al*., 2010). In the most ambitious MEA nutrient management scenario, global river DIN loads decrease slightly and DIP increases by 35%. In summary, nutrient loads have increased in many regions of the world (*high confidence*).

5.3.4.3. Hypoxia

The presence of excessive nutrients in coastal waters, which causes eutrophication and the subsequent decomposition of organic matter is the primary cause of decreased oxygen concentration (hypoxia). Upwelling of low oxygen waters (e.g., Grantham *et al*., 2004) and ocean warming, which decreases the solubility of oxygen in seawater (Shaffer *et al*., 2009) are secondary drivers. The oxygen decline rate is greater in the coastal rather than the open ocean (Gilbert *et al*., 2010). Hypoxia poses a serious threat to marine life, which is exacerbated when combined with elevated temperature (Vaquer-Sunyer and Duarte, 2010). The number of so-called “dead zones” has approximately doubled each decade since 1960 (Diaz and Rosenberg, 2008). Fisheries catches from these areas are generally lower than predicted from nutrient loading alone (Breitburg *et al*., 2009). Although non-climate anthropogenic factors are responsible for virtually all hypoxia in estuaries and inner continental shelves, climate drivers such as ocean warming, altered hydrological cycles and coastal currents shifts due to changes in wind patterns may interact with eutrophication in the next decades (Rabalais *et al*., 2010) (*high confidence*).

5.3.4.4. Sediment Delivery

Human activities in drainage basins and coastal plains have impacted the coastal zone by changing sediment delivery to the coast. Sediment trapping behind dams, water diversion for irrigation, and sand and gravel mining in river channels all act to decrease sediment delivery, whereas soil erosion due to land-use changes acts to increase it. In the 1950s, before widespread dam construction, the global discharge of riverine sediment was estimated to have been ~20 Gt yr^{-1} (e.g., Syvitski *et al.*, 2005; Milliman and Farnsworth, 2011), and it has decreased to 12–13 Gt yr^{-1} (Syvitski and Kettner, 2011). Out of 145 major rivers, only 7 showed evidence of an increase in sediment flux while 68 showed significant downward trends (Walling and Fang, 2003). Two stages of drainage basin development have been identified in patterns of sediment delivery: an increase in the early stage due to soil erosion followed by a decrease in later stages due mainly to dam construction (Syvitski, 2008). The number of dams has increased continuously and their distribution has expanded globally. As of early 2011, the world has an estimated 16.7 million reservoirs larger than 0.01 ha with a combined storage capacity of approximately 8070 km^3 (Lehner *et al.*, 2011). Human pressure is the main driver of the observed declining trend in sediment delivery to the coast (*high agreement*). Reduction of sediment delivery to the coast has impacts on river deltas, contributes to shoreline erosion and threatens mangroves and wetlands (Syvitski, 2008) whereas increase delivery due to soil erosion impacts coastal ecosystems.

5.4. Impacts, Vulnerabilities, and Risks

5.4.1. Introduction

The distinction in the meaning of the terms vulnerability and risk is often unclear in current literature (Ch. 1; SREX; WG2 Glossary), with both terms used interchangeably to describe identical methodological approaches (Hinkel, 2010; Wolf, 2011). Therefore in this chapter, literature assessing vulnerability and risk will be treated together. Diverse approaches are applied for assessing impacts, vulnerability and risk. For impacts on natural systems, the key drivers considered are temperature, ocean acidification and sea level and a variety of approaches are applied including field observations of ecosystem features (e.g. biodiversity, reproduction) and functioning (e.g. calcification, primary production), remote sensing (e.g., extent of coral bleaching, surface area of vegetated habitats) and perturbation experiments in the laboratory and in the field. For impacts on human systems, most approaches focus on relative sea-level rise and can be distinguished in terms of the main biophysical impacts they address (Table 5-4).

[INSERT TABLE 5-4 HERE
Table 5-4: Main impacts of relative sea-level rise. Adapted from Nicholls 2002 and Nicholls *et al.* 2010.]

Sea-level rise exposure approaches are applied at all scales to assess values exposed to sea level rise (e.g., people, assets, ecosystems or geomorphological units). *Submergence exposure approaches* assess exposure to permanent inundation under a given level of sea level rise (e.g., Dasgupta *et al.*, 2008; Boateng, 2012) whereas *flood exposure approaches* assess exposure to temporary inundation during a coastal flood event by combining the extreme water level of the flood event with a given level of sea level rise (e.g., Dasgupta *et al.*, 2009; Kebede and Nicholls, 2012).

Indicator-based approaches are also used at all scales to aggregate data on the current state of the coastal systems into vulnerability indices (Hinkel, 2012), based on either biophysical exposure or hazard variables (e.g., Yin *et al.*, 2012; Bosom and Jimenez, 2011), socioeconomic variables representing a social group's capacity to adapt (e.g., Cinner *et al.*, 2012) or both kinds of variables (e.g., Bjarnadottir *et al.*, 2011; Yoo *et al.*, 2012; Li and Li, 2012).

At local scales (10-100 km coastal length), *process-based models* are applied to assess flooding, erosion and wetland impacts. Approaches include assessments of *flood damage* of single extreme water level events using *hydrodynamic/inundation models* (e.g., Xia *et al.*, 2011; Lewis *et al.*, 2011). M*orphodynamic models* are applied to assess impacts of RSLR on coastal erosion *(*Jiménez *et al. 2009;* Ranasinghe *et al. 2012)*. For ecosystem impacts *ecological landscape simulation models* are used to predict habitat change due to sea level rise and other factors (e.g., Costanza *et al.*, 1990, Costanza and Ruth, 1998).

For assessing the impacts of sea level rise at regional to global scales (>1000 km coastal length), heuristic, statistical and economic models together with damage functions are used, as detailed process-based models are not available due to data and computational limits. Global scales assessments have been conducted with the Integrated Assessment Model FUND (Anthoff *et al*., 2010) and the impact model DIVA (Hinkel and Klein, 2009). These models and their results are discussed in 5.4.3.1 and 5.5.3.

In the impacts on, vulnerabilities of and risks to biophysical systems (5.4.2) and for human systems (5.4.3) are covered. For biophysical systems, we start with impacts on smaller scale systems (e.g., beaches, wetlands, etc.) and proceed to larger scale and compound systems (estuaries and deltas). For human systems, we start with impacts on human settlements as a whole followed by impacts on key sectors that support human settlements. Where possible, all subsections address drivers, observed and projected changes.

5.4.2. Natural Systems

Coastal ecosystems are experiencing large cumulative impact of human activities (Halpern *et al*., 2008) arising from both land- and ocean-based anthropogenic drivers. Anthropogenic drivers associated with global climate change are distributed widely and are an important component of cumulative impacts experienced by coastal ecosystems. There are few wetlands, mangroves, estuaries, rocky shores or coral reefs that are not exhibiting some degree of impact. Overexploitation and habitat destruction are often the primary causes of historical changes in coastal systems and eutrophication has largely followed rather than driven observed declines in diversity, structure, and functioning (Lotze *et al*., 2006). Further, extreme climate events generate changes to both the mean and the variance of climatic variables over ecological time scales.

5.4.2.1. Beaches, Barriers, and Sand Dunes

Beaches, barriers and sand dunes constitute about one-third of world’s coasts. These dynamic systems often exhibit distinct diurnal and seasonal changes. Due to their attractive attributes, they are highly valued for their recreational and residential value.

Observed impacts

Globally beaches and dunes have in general undergone net erosion over the past century or longer (e.g. see Bird, 2000 for an overview). This erosion is due to a variety of processes with some climate related: rising sea levels (Ranasinghe and Stive, 2009); increases in the frequency of extreme water levels with sea-level rise (Tebaldi *et al*., 2012); wave propagation caused by sea-level changes realigning shorelines (Tamura *et al*., 2010); sustained changes in the direction of mean wave energy (Reguero *et al*., 2013); increased storm waves (Stutz and Pilkey, 2011) and changes in the loss of natural protective structures such as coral reefs (Grevelle and Mimura, 2008) or mangrove forests (Bongaerts *et al*., 2010). These processes may act at different time scales.

Reasonably accurate maps have been available since about the mid-19th century to compare with more recent maps and imagery to quantify combined climate and non-climate changes. For example, along the U.S. Mid-Atlantic and New England coasts the long-term rate of erosion is 0.5 ± 0.09 m yr^{-1} and 68% showed net erosion based on over 21,000 measurement locations equally spaced along more than 1,000 km of coast (Hapke *et al*., 2011). However, a survey using historical aerial photographs and satellite images of 27 atoll islands in the central Pacific showed that 86% of the islands have remained stable or increased in area over a 19 to 61 year period, contradicting the widespread perception that small islands are eroding with sea-level rise (Webb and Kench, 2010).

Attributing shoreline changes to climate change is still difficult due to the multiple natural and anthropogenic drivers contributing to coastal erosion. For example, rotation of pocket beaches (i.e. where one end of the beach accretes while the other erodes and then the pattern reverses) of Southeast Australia is closely related to interannual changes in swell direction (Harley *et al*., 2010). Additional processes, unrelated to climate change, that contribute to coastal change, include dams capturing fluvial sand (e.g., in Morocco, Chaibi and Sedrati, 2009). Statistically linking sea-level rise to observed magnitudes of beach erosion has been challenging as the coastal sea-level change signal is small relative to other processes (e.g. Sallenger *et al*., 2000; Leatherman *et al*., 2000a; 2000b). A Bayesian network incorporating a variety of factors affecting coastal change including relative sea-level rise, has been successful in hindcasting shoreline change, and, hence, may be useful in forecasting change (Gutierrez *et al*., 2011).

One observed impact of net erosion is clear. Where an eroding shoreline approaches hard, immobile, structures like seawalls or resistant natural cliffs, the beaches will narrow due to coastal squeeze that removes the sands and associated habitats, and potentially steepens the beach slope, impacting the survivability of a variety of organisms (Jackson and McIlvenny, 2011). With coastal squeeze, sand dunes will ultimately be removed as the beach erodes and narrows. Extreme storms can erode and completely remove dunes, degrading land elevations and exposing them to inundation and further change if recovery does not occur before the next storm (Plant *et al*., 2010).

Projected impacts

Projected sea-level rise may approach 1 m or more by 2100, and in the intervening time the resulting inundation and erosion may become detectable and progressively important. The impacts will *likely* be first apparent by sea-level rise adding to storm surge, making extreme water levels higher and more frequent to attack beaches and dunes (Tebaldi *et al.,* 2012).

Some investigators have used the Bruun rule to calculate erosion by sea-level rise (Bruun, 1962), although there is disagreement about whether the Bruun rule is appropriate (Cooper and Pilkey, 2004; Woodroffe and Murray-Wallace 2012). How to calculate the amount of retreat remains controversial (Gutierrez *et al*., 2011; Ranasinghe *et al*., 2012). An increase in storm intensity and ocean swell may accelerate erosion of beaches, barriers and dunes although in places beach response to sea-level rise could be more complex than simple retreat (Irish *et al.,* 2010).

Coastal squeeze will *likely* accelerate with a rising sea level. In many locales, locating sufficient sand to artificially rebuild beaches and dunes will *likely* become increasingly difficult as present supplies near to project sites are depleted. New generation models are emerging to estimate the costs of saving oceanfront homes through beach nourishment relative to the structures cost (McNamara *et al*, 2011). In the absence of adaptation measures, beaches and sand dunes currently affected by erosion will continue to do so under increasing sea levels (*high confidence*).

5.4.2.2. Rocky Shores

According to Davis and FitzGerald (2004) three-quarters of the world’s coasts are rocky. They vary from consolidated sediments (lithified coasts) to unconsolidated sediments (unlithified coasts), with different strengths and typically having an abrasional shore platform at their base. They are characterized by very strong environmental gradients, especially in the intertidal zone where challenges are posed by both aquatic and aerial climatic regimes, such as temperature and desiccation

Observed impacts

Cliffs and platforms are erosional features and any change in the climate system that increases the efficiency of processes to act on them, such as relative sea level rise will lead to increased rates of erosion (Naylor *et al*., 2010). Other significant climate drivers include mid-latitude storminess, wave climate and rainfall regime on cliff dynamics and retreat rates (Brooks and Spencer, 2012). Precipitation and frost appear to have a limited role in cliff retreat (Dornbusch *et al*., 2008).

Cliffs and platforms have reduced resilience to climate change impacts; once platforms are lowered or cliffs retreat, it is difficult to rebuild them (Naylor *et al*., 2010). For cohesive clay coasts, rising sea level will usually result in accelerated rates of bluff recession, especially if the rise is rapid (Trenhaile, 2010).

Changes in the abundance and distribution of rocky shore animals and algae in rocky shores have long been recognized (Hawkins *et al*., 2008) and perturbation experiments provided information about environmental limits, acclimation and adaptation, particularly to changes in temperature (Somero, 2012). The challenge is to distinguish the response that are due to climatic drivers from those due non-climatic drivers, or to natural temporal and spatial fluctuations.

Helmuth *et al*. (2006) reported shifts of range limits of many intertidal species of up to 50 km per decade, much faster than most recorded shifts of terrestrial species. However, the geographical distribution of some species has not changed in recent decades, may be due to weak local warming (Rivadeneira and Fernández, 2005) or overriding effects of variables such as timing of low tide, hydrographic features, lack of suitable substrata, poor larval dispersal, and effects of food supply, predation and competition (Helmuth *et al*., 2002, 2006; Poloczanska *et al*., 2011).

The dramatic decline of biodiversity in mussel beds of the Californian coast, with a 59% loss in species richness between the 1960s and 2002, has been attributed to large-scale processes associated with climate change (*high confidence*; Smith *et al*., 2002). A strong impact of temperature and food availability was shown in mussels on the coast of Oregon, with higher growth during warm than cool events (Menge *et al*., 2008). Warming also reduced predator-free space on rocky shores, which lead to a decrease of the vertical extent of mussel beds by 51% in 52 years in the Salish Sea, and the disappearance of reproductive populations of mussels at several sites, illustrating the alteration of interspecific interactions by climate change (Harley, 2011).

Rocky shores are one of the few ecosystems for which field evidence of the effects of ocean acidification is available. Observational and modeling analysis have shown that the community structure of a rocky shore site of the NE Pacific shifted from a mussel to an algal-barnacledominated community between 2000 and 2008 (Wootton *et al*., 2008), in relation with rapidly declining pH (Wootton and Pfister, 2012).

Projected impacts

Based on contemporary and historic data for shoreline retreat the major driver appears to be sea-level rise (Brooks and Spencer, 2012). Soft-rock recession rates can be estimated by using square root of the relative change in sea-level rise rate while cliff retreat depends not only on total elevation change of sea level but also on the rate of sea-level rise (Ashton *et al*., 2011).

In a modelling study, Trenhaile (2011) found sea-level rise to trigger faster rates of cliff recession, especially in coasts that are already retreating fast. However, results further suggested that coasts currently retreating slowly would experience the largest proportional increases in retreat rates. Increases in storminess appear to have smaller effects on rocky shores (Trenhaile, 2011; Dawson *et al*., 2009). Using existing topographical data and a digital elevation model, the intertidal areas of rocky shore in Scotland are estimated to decrease by 10-27% with a 0.3 sea-level rise (Jackson and MacIlvenny, 2011).

Most projections of the effect of climate change on rocky shore ecosystems have used a climate envelope approach using environmental tolerances obtained in laboratory perturbation experiments and assuming that species will remain in their bioclimatic envelope as climatic stressors change. Few have considered the effects of direct and indirect species interactions (Poloczanska *et al*., 2008; Harley *et al*., 2011) and the effects of multiple stressors (Helmuth *et al*. 2006).

The abundance and distribution of rocky shore species will continue to vary in a warming world (*high confidence*). The likely long-term consequences of ocean warming on mussel beds of the NE Pacific are both positive (increased growth) and negative (increased susceptibility to stress and of exposure to predation)(*medium confidence*; Smith *et* *al*., 2002; Menge *et al*., 2008). Importantly, these projections are conservative as they do not consider hypoxia (Grantham *et al*., 2004) or ocean acidification (Feely *et al*., 2008) which is known to occur in this area.

Despite some shortcomings (Riebesell, 2008), observations performed near natural CO_2 vents in the Mediterranean Sea show that diversity, biomass, and trophic complexity rocky shore communities will decrease at future pH levels (*high confidence*; Barry *et al*., 2011; Kroeker *et al*., 2011). An abundant food supply tolerance appears to enable mussels of the Baltic Sea to tolerate low pH (Thomsen *et al*., 2010, 2012) at the cost of increased energy expenditure. Model projections that assume a linear increase in temperature and ocean acidity, and include the interactive effects of temperature and pH suggests that a local population of a barnacle will become extinct in the English Channel 10 years earlier than would occur if there was only global warming and no concomitant decrease in pH (*medium confidence*; Findlay *et al*., 2010).

Rising sea level is the major driver for rocky shores retreat (*robust evidence*). With coral reefs, rocky shores are the coastal ecosystem for which there is most evidence of the impacts of climate change. The most prominent effects are range shifts of species in response to ocean warming (*high confidence*) and changes in biodiversity (*high confidence*) in relation to ocean warming and acidification.

5.4.2.3. Wetland and Seagrasses Beds

Vegetated coastal habitats, including mangrove forests, salt marshes, seagrass meadows and macroalgal beds occur as a thin vegetation belt fringing the shoreline (Hemminga and Duarte 2000). Coastal wetlands are prominent features and important habitats in the intertidal zone along the coastline, including mangrove forests and tidal marshes. Seagrass meadows and macroalgal beds extend from the intertidal to the subtidal areas in coastal areas.

Observed impacts

Mangrove forests, salt marshes and seagrass meadows are declining globally (Duarte *et al*., 2005), rendering shorelines more vulnerable to erosion due increased sea level rise and increased wave action (e.g., Alongi, 2008) and leading to the loss of carbon stored in sediments. Together, the loss of coastal wetlands and seagrass meadows results in the release of 0.04 to 0.28 Pg C annually from organic deposits (Pendleton *et al*. 2012). Recognition of the important consequences of the loss of mangrove forests, salt marshes and seagrass meadows for coastal protection and carbon burial, has led to large-scale reforestation efforts in some nations (e.g. Thailand, India, Vietnam).

The response of saltmarsh to sea level rise involves landward migration of salt marsh vegetation zones and submergence at lower elevations and drowning of interior marshes. Ocean warming is leading to range shifts in vegetated coastal habitats. The poleward limit of mangrove forests is generally set by the 20 ºC mean winter isotherm (Duke *et al*., 1998). Accordingly, migration of the isotherm with climate change (Burrows *et al*., 2011) should lead to a poleward expansion of mangrove forests, as observed in the Gulf of Mexico (Perry and Mendelssohn, 2009; Comeaux *et al*., 2011, Raabe *et al*. 2012), and New Zealand (Stokes *et al*., 2010), where it leads to increased sediment accretion (*medium confidence*).

Seagrass meadows are already under stress due to climate change (*high confidence*), particularly where maximum temperatures already approach their physiological limit. Heat waves lead to widespread seagrass mortality, as documented for Zostera species in the Atlantic (Reusch *et al*., 2005), and Posidonia meadows in the Mediterranean Sea (Marbà and Duarte, 2010) and Australia (Rasheed and Unsworth, 2011) (*high confidence*). Warming also favours flowering of P. oceanica (Diaz-Almela *et al*., 2007), but the increased recruitment rate is insufficient to compensate for the losses resulting from elevated temperature (Diaz-Almela *et al*., 2009).

Kelp forests have been reported to decline in temperate areas in both hemispheres (Johnson *et al*. 2011, Wernberg *et al*. 2011a,b, Fernández *et al*. 2011), a loss believed to involve climate change (*high confidence*). Decline in kelp populations attributed to ocean warming has been reported in southern Australia (Johnson *et al*. 2011, Wernberg *et* *al*. 2011a,b) and the North Coast of Spain (Fernández *et al*. 2011). The spread of subtropical invasive macroalgal species is believed to be facilitated by climate change, adding to the stresses temperate seagrass meadows experience from ocean warming (*medium evidence, high agreement*).

Projected impacts

Ocean acidification (5.3.34; Box CC-OA) is expected to enhance the production of seagrass (Duarte, 2000, McKee *et al*. 2012) and macroalgae (Wu *et al*., 2008) through the fertilization effect of CO_2. Increased CO_2 concentrations may have already increased seagrass photosynthetic rates by 20% (Hemminga and Duarte, 2000; Hendriks *et al*., 2010) (*limited evidence, high agreement*).

Coupling of downscaled model projections using the A1B scenario in the Western Mediterranean along with empirically-determined relationships between mortality rates and maximum seawater temperature led Jordá *et al*. (2012) to conclude that seagrass, Posidonia oceanica, meadows may become functionally extinct by 2050 to 2060 (*high confidence*). Poleward range shifts in vegetated coastal habitats is expected to continue with climate change (*high confidence*). Reduced ice cover and retreat of coastal glaciers may facilitate the expansion of seagrass meadows and kelp forests along the Arctic (Krause-Jensen *et al*. 2012; *medium confidence*), with cascading effects on the coastal Arctic ecosystem (Krause-Jensen *et al*. 2012).

Elevated CO_2 and ocean acidification are expected to lead to increased productivity of vegetated coastal habitats in the future (Duarte *et al*. 2000) (*high confidence*). However, there is *limited evidence* that elevated CO_2 may increase seagrass survival or resistance to warming (Alexandre *et al*., 2012; Jordá *et al*., 2012).

Coastal wetlands and seagrass meadows experience coastal squeeze in urbanized coastline, with no opportunity to migrate inland with rising sea levels. However, increased CO_2 and warming can stimulate marsh elevation gain, counterbalancing moderate increases in rates of sea-level rise (Langley *et al*., 2009; Kirwan and Mudd, 2012). The net impact of climate change on salt-marsh accretion will be to increase carbon burial rates in the first half of the twenty-first century, with carbon–climate feedbacks diminishing over time (Kirwan and Mudd, 2012) (*medium confidence*).

In summary, climate change will significantly contribute to the continued decline in the extent of seagrass and kelps in the temperate zone (*medium confidence*) and the range of seagrass, mangroves and kelp in the northern hemisphere will expand poleward (*high confidence*). The limited positive impact of warming and increased CO_2 on some vegetated ecosystems will be insufficient to compensate the decline of their extent resulting from other human drivers such as land use change (*very high confidence*).

5.4.2.4. Coral Reefs

Coral reefs are shallow-water structures made of calcium carbonate mostly secreted by reef-building corals and encrusting macroalgae. They are among the most diverse ecosystems and are sources of many benefits through key services provided to humans.

Observed impacts

Coral reefs are susceptible to climate-related and non climated-related processes (see Box CC-CR). Mass coral bleaching has occurred in association with positive temperature anomalies over the past 30 years, sometimes followed by mass mortality (Hoegh-Guldberg, 1999; Kleypas *et al*., 2008; Baker *et al*., 2008). Bleaching events are variable in time and space: 7% of the grid cells comprising reefs exhibited at least one bleaching event in 1985-1994 compared to 38% in the subsequent decade due to intense El Niño events. Recovery from the 1998 global bleaching event was generally slow in the Indian Ocean (about 1% yr^{-1}), absent in the western Atlantic and variable elsewhere (Baker *et al*., 2008).

Warming causes a poleward range expansion of some corals (*high confidence*; Greenstein and Pandolfi, 2008; Yamano *et al*., 2011). The paleontological record suggests that the observed poleward range extension may soon be followed by equatorial range retractions (Kiessling *et al*., 2012). Several reef crises of the last 500 Myr were at least partially governed by ocean acidification and warming (Kiessling and Simpson, 2011). Ocean acidification (5.3.3.5, Box CC-OA) has become a recent source of concern because persistence of coral reefs directly depends on the balance between the production and erosion of calcium carbonate (Andersson and Gledhill, 2013). It generally decreases calcification (Kroeker *et al*., in press) and promotes dissolution of calcium carbonate and bioerosion (Tribollet *et al*., 2009; Wisshak *et al*., 2012), leading to a transition from net accretion to net erosion and to poorly cemented reefs (Manzello *et al*., 2008).

Lower pH decreases calcification in many reef-building corals and coralline algae (Andersson *et al*., 2011) and may have already decreased (e.g., Gattuso *et al*., 1999; Silverman *et al*., 2009) and most (e.g., De'ath *et al*., 2009, Manzello, 2010) retrospective studies show decreased calcification in recent decades. Attribution has proven difficult but warming rather than acidification appears to be the primary driver (*medium confidence*; Cooper *et al*., 2012).

Climate-related drivers other than ocean warming and acidification do not seem to have led to any obvious changes since the industrial revolution (*high confidence*). Coral reef growth is intimately linked to sea level but, within the uncertainties of past sea level rise and coral reef growth, most coral reefs seem to have kept pace with the recent sea-level rise (Buddemeier and Smith, 1988).

Projected impacts

The frequency and magnitude of coral bleaching and mortality will increase in the next few decades (*very high confidence*; Hoegh-Guldberg, 1999; Donner *et al*., 2009; Chapter 30, 30.8.2). Under the A1B CO_2 emission scenario, 99% of the grid cells experience at least one severe bleaching event over 2090-2099 (Figure 5-3; Teneva *et al*., 2011). Half of the coral reefs may avoid high frequency bleaching through 2100 assuming hypothetical acclimation and/or adaptation (*limited evidence, low agreement*; Logan *et al*., sbm).

[INSERT FIGURE 5-3 HERE
Figure 5-3: Percent of reef locations (1°x1° grid cells which have coral reefs) that experience no bleaching, at least one mild bleaching event, or at least one severe bleaching event for each decade. Observed bleaching events are summarized from the ReefBase dataset (Kleypas *et al*. 2008). In the observations, some of the "no bleaching" cells may have experienced bleaching but it was either not observed or not reported. Modeled bleaching events are averages of data from four ensemble runs of the Community Climate System Model version 3 using the SRES A1B CO_2 scenario and the standard degree heating month formula (Teneva *et al*., 2011). The labels of values ≤ 1% are not shown.]

Ocean acidification reduces biodiversity and favours seagrasses and fleshy algae against corals (Fabricius *et al*., 2011). Since the effects of elevated temperature and acidity are synergistic in several reef-builders (Reynaud *et al*., 2003; Anthony *et al*., 2008), their combined impact may be larger than those observed near CO_2 vents today (*high confidence*). Ocean warming and acidification expected under RCP 8.5 will reduce calcification, elevate coral mortality and enhance sediment dissolution (*high confidence*; Manzello *et al*., 2008). Coral reefs may stop growing and start dissolving when atmospheric CO_2 reaches 560 ppm due to the combined effects of both drivers (*medium evidence*; Silverman *et al*., 2009).

The maximum rate of vertical accretion has been variable regionally during the last deglaciation (about 20 mm yr^{-1}; Dullo, 2005; Montaggioni *et al*., 2005) and has not enabled all coral reefs to keep-up with sea level rise. Some reefs kept-up, even when the eustatic sea level rise exceeded 40 mm yr^{-1} (Camoin *et al*., 2012). Therefore, a number of coral reefs could keep up with the maximum rate of sea level rise of 15.1 mm yr^{-1} projected at the end of the century (WGI, Table 13.5; *medium confidence*). A lower net accretion than during the Holocene, as reported for Caribbean reefs (Perry *et al*., 2013) weaken this capability. *high confidence*Reef submergence would increase turbidity leading to increased stress (Storlazzi *et al*., 2011).

In summary, climate-related drivers are the primary cause of mass coral bleaching and mortality (*very high confidence*) and deteriorate the balance between coral reef construction and erosion (*high confidence*). The future magnitude of these effects will depend on the rates of warming and acidification (*very high confidence*), with a moderating role of biological acclimation and adaptation which appears limited (*medium confidence*).

5.4.2.5. Coastal Aquifers

A coastal aquifer is an underground layer of water-bearing permeable rock or unconsolidated materials from which groundwater can be extracted. Consequently, they are of strategic importance for the water supply of highly populated coastal areas, especially in small islands (Chap. 29, 29.3).

Observed impacts

Coastal aquifers are very sensitive to a range of climate and non climate-related drivers. Temperature and evaporation rise, changes in precipitation and extended droughts that affect aquifer recharge are some of the factors that can contribute to displacement of fresh groundwater by more saline water. Rising sea levels and partial or complete overwash from storm waves or storm surge are also relevant drivers, especially in low-lying areas and islands (Terry and Falkland, 2010, White and Falkland, 2010, Post and Abarca, 2010).

Combined with this, excessive groundwater extraction for coastal settlements and agriculture causes intrusion of saline water from the ocean or from deeper, more saline layers below the aquifer. For example, coastal aquifers on the east and west coasts of the US have experienced increased levels of salinity largely due to excessive anthropogenic water extraction (Barlow and Reichard, 2011). The combination of natural with anthropogenic drivers of over-extraction, pollution, mining for building and erosion due to shoreline works compound groundwater supply problems in small tropical islands in the Pacific, Indian and Atlantic Oceans (White *et al*., 2007; White and Falkland, 2010). Detailed information on salinization observations in small islands can be found in Chapter 29.

Attribution of saline intrusion to incremental sea level rise is still not sufficiently supported (Rozell and Wong, 2010; White and Falkland 2010). In small islands, observed saltwater intrusion due to flooding and overwash under storm events cannot be attributed to climate change (Chap. 29). Furthermore, Werner (2010) noted that there are fundamental knowledge gaps that impede assessment of changes in seawater intrusion, which are mostly due to uncertainties in the predictive capabilities of the models, limitations in the assessment of small-scale processes and difficulties in characterizing the marine-groundwater interactions.

Projected impacts

The assessment of climate change impacts that may arise from changes in ground water recharge and sea level rise is still challenging, limiting the work currently available on climate change projected impacts on coastal aquifers. Rozell and Wong, 2010 assessed the impact of rising sea levels on fresh water resources on Shelter Island (USA) for two different combinations of precipitation change and sea level rise. Results show that projected impacts were highly dependent on local conditions. Based on a simplified analytical model Ferguson and Gleeson (2012) concluded that the direct impact of groundwater extraction has been and will be much more significant than the impact of sea level rise under a wide range of hydrogeolic conditions and population densities.

In summary, there is *very high confidence* that increased usage of groundwater resources for agriculture and coastal settlements globally has led to a reduction in groundwater quality, including increased salinization (*high agreement, robust evidence*). Human-induced pressure will continue to be the main driver for aquifer salinization (*high* *agreement*). Climate change through changing patterns of precipitation, increased storminess and sea level rise will exacerbate these problems (*high agreement, limited evidence*).

5.4.2.6. Estuaries and Lagoons

Coastal lagoons are shallow water bodies separated from the ocean by a barrier and connected at least intermittently to the ocean, while estuaries are the primary conduit for water, nutrients and particulates from land to the sea.

Observed impacts

Sediment accumulation in estuaries is generally very high because of riverine particle delivery but heterogeneous and habitat-specific. Changes in sediment accumulation is directly affected by human drivers, such as dredging, and indirectly via habitat loss, changes in sea-level, storminess and sediment supply by rivers (Syvitski *et al.*, 2005). Coastal lagoons are also highly susceptible to alterations of sediment input and erosional processes driven by changes in sea level, precipitation, and storminess (Pickey and Young, 2009). Estuarine water with low tidal range are strongly affected by changes in run-off since the residence time depends on the relative strengths of runoff and tidal forcing and governs many ecosystem processes including nutrient processing, the metabolic balance, carbon dioxide exchange and hypoxia (Howarth *et al.*, 2009; Canuel *et al.*, 2012). River floods and other runoff events have been reported to impact estuarine communities and deliver large quantities of organic matter to coastal systems, controlling the cycling of organic matter and nutrients (Canuel *et al.*, 2012; Statham, 2012).

Enhanced nutrient delivery (5.3.4.3) has resulted in major changes in biogeochemical processes, community structure and ecosystem functions (Howarth *et al.* 2009), including enhanced primary production which has affected coastal fishery yield (Nixon, 1982; Savage *et al.*, 2012). Eutrophication has modified food-web structure (*high confidence*) and led to more intense and longer lasting hypoxia (5.3.4.4), more frequent occurrence of harmful algal blooms (*high confidence*; Breitburg *et al.*, 2009; Howarth *et al.*, 2009) and to enhanced emission of nitrous oxide (*high confidence*; Kroeze *et al.*, 2010; de Bie *et al.*, 2002).

Projected impacts

The increase of atmospheric carbon dioxide levels will reduce the efflux of CO_2 from estuaries (Borges, 2005; Chen and Borges, 2009; *high confidence*). Its impact on the pH of estuarine and lagoon waters will generally be limited because other drivers are generally more important (*high confidence;* 5.3.3.4 and Box CC-OA). For example, recent changes in the freshwater flow in the Scheldt estuary was the main factor controlling pH, either directly via a decreased supply of dissolved inorganic carbon and total alkalinity, and, indirectly, via the decreased input ammonia loadings and lower rates of nitrification (Hofmann *et al.*, 2009).

Sea-level rise will have likely impact sediment redistribution, the partitioning of habitats within estuaries and landward lagoon extension (*high confidence*; Anthony *et al.*, 2009) Lagoons may shrink because landward migration is restricted due to human occupation on the landward side (Pilkey and Young, 2009: Anthony *et al.*, 2010; Stutz and Pilkey, 2011).

Changes in hydrology could affect lagoons and estuaries in multiple ways. The water residence time could either increase or decrease, depending on direction and magnitude of changes in discharge and precipitation-evaporation balance (Anthony *et al.*, 2009) with diverging impacts on primary production, fisheries and aquaculture (Smith *et al.*, 2005b; Webster and Harris, 2004; Canu *et al.*, 2010). Altered riverine discharge may affect estuarine stratification with consequences for ecosystem metabolic balances, intensity and occurrence of biogeochemical processes, organism distribution patterns and frequency and duration of hypoxia (Hong and Shen, 2012; Rabalais *et al.*, 2009). However, stronger winds and droughts may reduce the extent, duration and frequency of estuarine stratification, counteracting the decrease in oxygen concentration (*medium confidence*; Rabalais *et al.*, 2009). Changes in precipitation extremes and freshwater supply may induce dramatic fluctuations in salinity with associated dverse impacts on benthic macrofauna and ecosystem functions (Pollack *et al*., 2011; Levinton *et al*., 2011; Fujii and Raffaelli, 2008; Jeppesen *et al*., 2007).

Warming will lead to enhanced stratification of estuaries and lagoons, increasing hypoxia (*medium confidence*; Diaz and Rosenberg, 2008; Rabalais *et al*., 2009). It will also directly affect most biological processes and the trophic status of coastal ecosystem, and higher carbon dioxide emission (*limited evidence, medium agreement*; Canuel *et al*., 2011). Warming will lengthen the duration of phytoplankton production season (Cloern and Jassby, 2008; *medium confidence*).

Changes in storm events would alter the extent and duration of estuarine stratification (Hong and Shen, 2012), the sediment deposition-erosion balance of lagoons and estuaries (Pilkey and Young, 2009), the structure and functioning of biological communities via the transport of communities and/or of their resources, and the underwater light climate (*medium confidence*; Wetz and Paerl, 2008; Canuel *et al*., 2012).

Finally, any change in the primary production of lagoons will impact fisheries as there is an empirical correlation between primary production and fisheries yield (*limited evidence, medium agreement*; Nixon, 1982). For example, seawater warming and changes in seasonal patterns of precipitations projected in the Venice lagoon using the SRES A2 CO_2 emission scenario for the period 2071-2100, leads to a reduction in plankton production, a decline of habitat suitability for clam growth and aquaculture (Canu *et al*., 2010).

In summary, the primary drivers of change in lagoons and estuaries are human drivers rather than climate change (*very high confidence*). Future changes in climate-related drivers such as warming, acidification, waves, storms, sea level and run-off will have consequences on the functions and services of ecosystems in lagoons and estuaries (*high confidence*) but the impacts cannot be assessed at the global scale as the key drivers operate at a local to regional scale.

5.4.2.7. Deltas

Deltas are low-lying coastal landforms formed by riverine sediments in the areas around river mouths, mostly during the last 6000–7000 years of relatively stable sea level. They are characterized by interplay between rivers, lands, and oceans and are influenced by a combination of river, tidal, and wave processes. Deltas are a coastal complex that combines natural systems in diverse habitats (e.g., tidal flats, salt marshes, mangroves, beaches, estuaries, low-lying wetlands) and human systems (e.g., houses, agriculture, aquaculture, industry, and transport). They have a population density more than 10 times the world average (Ericson *et al*., 2006; Foufoula-Georgiou *et al*., 2011). As low-lying plains, deltas are highly sensitive to changes in sea level. Deltas are subject to climatic impacts from rivers upstream (e.g., freshwater input) and oceans downstream (e.g., sea-level changes, waves) as well as within the deltas themselves. At the same time, they are affected by human activities such as land-use changes, dam construction, irrigation, mining, extraction of subsurface resources, and urbanization (Nicholls *et al*., 2007).

Observed impacts

The combined impact of sediment reduction, relative sea-level rise, land-use changes in deltas, and river management on channels and banks has led to the widespread degradation of deltas (*very high confidence*). Decreased sediment discharge due to dam construction and irrigation creates an imbalance in sediment budget in coastal zones. Degradation of beaches, mangroves, tidal flats, and subaqueous delta front along deltaic coasts has been reported in many deltas (*very high confidence*)(e.g., Nile and Ebro, Sanchez-Arcilla *et al.,* 1998; Po, Simeoni and Corbau, 2009; Krishna-Godavari, Nageswara Rao *et al*., 2010; Changjiang, Yang *et al*., 2011; Huanghe, Chu *et al.,* 1996). Deltaic coasts naturally evolve by seaward migration of the shoreline, forming a delta plain; however, decreasing sediment discharge during the last 50 years has decreased the growth of deltaic land, even reversing it in some locations (e.g., Nile, Godavari, Huanghe). Artificial reinforcement of natural levees also has reduced the interdistributary basin sedimentation in most deltas, resulting in wetland loss.

The major impacts of sea-level rise are changes in coastal wetlands, increased coastal flooding, increased coastal erosion, and saltwater intrusion into estuaries and deltas (Mcleod *et al*., 2010b), which are exacerbated by increased human-induced drivers (*very high confidence*). Ground subsidence amplifies these hazards in farms and cities on deltaic plains through relative sea-level rise (Day and Giosan, 2008; Mazzotti *et al*., 2009). Relative sea-level rise due to subsidence has induced wetland loss and shoreline retreat (*high confidence*)(e.g., the Mississippi delta Morton *et al*., 2005; Chao Phraya delta, Saito *et al*., 2007). Episodic events superimpose their effects on these underlying impacts and accelerate land loss (*high confidence*) (e.g., Hurricanes Katrina and Rita in 2005, Barras *et al*., 2008). To forestall submergence and frequent flooding, many delta cities now depend on a substantial infrastructure for flood defense and water management (Nicholls *et al*., 2010).

Deltas are substantially impacted by river floods and oceanic storm surges and tsunamis (*very high confidence*). Tropical cyclones are noteworthy for their damages to deltas, e.g., the Mississippi delta by Hurricane Katrina in 2005 (Barras *et al*., 2006), the Irrawaddy delta by Cyclone Nargis in 2008, and the Ganges-Brahmaputra delta by Cyclone Gorky in 1991 and Cyclone Sidr in 2007 (Murray *et al*., 2012)(Box CC-TC). A detailed study of 33 deltas around the world found that 85% of the deltas had experienced severe flooding in the past decade, causing the temporary submergence of 260,000 km^2 (Syvitski *et al*., 2009).

Projected impacts

The projected natural impacts on deltas under changing global climate are caused mainly by extreme- precipitation induced floods, sea-level rise, and accompanying changes of waves and storm surges. These will result in increased coastal flooding, decreased wetland areas, increased coastal erosion, and increased salinization of cultivated land and groundwater (*high confidence*) (McLeod *et al*., 2010; Day *et al*., 2011) (Box CC-TC). The surface area of flooding in 33 deltas around the world is projected to increase by 50% under the future sea-level rise projected for 2100 using the IPCC AR4 scenario (Syvitski *et al*., 2009). Non-climatic drivers (e.g., reduction in sediment delivery, subsidence, and land-use changes) more than climatic drives have affected deltas for the last 50 years (*very high confidence*) (Syvitski, 2008). Densely populated deltas are particularly vulnerable due to further population growth together with the above-described impacts. The impacts of further sea-level rise beyond 2100 show a more complex and enhanced flood risk on deltas (e.g., Katsman *et al*., 2011).

In summary, there is *very high confidence* that increased human drivers are the primary cause in changes of deltas (*high agreement, robust evidence*). There is *high agreement* that future climate changes through sea-level rise and increased storminess will exacerbate the problems in deltas with the increase of further human stress.

5.4.3. Human Systems

5.4.3.1. Human Settlements

The most important effects of climate change on coastal settlements include dry land loss due to erosion and submergence, damage of extreme events on built infrastructure (such as wind storms, storm surges, floods, heat extremes and droughts), effects on health, food and water-borne disease, effects on energy use, and effects on water availability and resources (Hunt and Watkiss, 2010). Assessments of climate impacts on settlements have almost exclusively focused on the impacts of sea level rise and coastal flood events. A large number of regional, national and sub-national scale studies have been conducted and Tables 5-4 and 5-5 highlight some of these studies. A comprehensive account of impacts, vulnerabilities and risks in specific regions is given in the Regional Chapters. At the global scale, studies have focused either on exposure to sea-level rise or extreme water levels or on the physical impacts of flooding, submergence and erosion.

[INSERT TABLE 5-5 HERE
Table 5-5: Summary of Coastal Vulnerability Assessments conducted at national or regional scale. Studies that either costed (Adapt$) or considered adaptation options (Adapt) are indicated. In studies that have considered

adaptation: WOA=without adaptation; WA=with adaptation. CVI=Coastal Vulnerability Index; GIS=Geographic Information System, DIVA=Dynamic Interactive Vulnerability Assessment model. RSLR=relative sea level rise.]

Exposure studies confirm the findings of AR4 that coastal vulnerability and risks are strongly influenced by non-climatic drivers. The population exposed to the 1 in 100 year coastal flood is projected to increase from 271 million in 2010 to 345 million in 2050 due to socio-economic development only (UN medium fertility projections) (Jongman *et al.*, 2012). For coastal cities there is *high confidence* that population growth, economic growth and urbanization are the most important drivers of increased exposure (Seto, 2011; Hanson *et al.*, 2011; Chapter 14). For 136 port cities above one million inhabitants the number of people exposed to a 1 in 100 year coastal flood event is expected to increase from 39 million in 2005 to 59 million by 2070 through 0.5 m global mean sea level rise alone and to 148 million if socio-economic development (UN medium population projections) is considered on top of this (Hanson *et al.*, 2011). Asia is expected to continue to have the largest exposed population, North America and Asia the largest economic exposure and North and Sub-Saharan Africa the largest increases in exposure (Dasgupta *et al.*, 2009; Vafeidis *et al.*, 2011; Jongman *et al.*, 2012). As urban population represents increasing proportion of world populations, urban floods will account for an increasing percentage of total flood impact as seen in Pakistan, Australia and Brazil (Jha *et al.*, 2011).

For deltas, another major driver of increases in exposure is relative sea-level rise due to subsidence. 85% of the world's largest deltas have experienced severe flooding in the last decade and the area exposed to flooding could increase by more than 50% by 2100 under current projections of sea-level rise (Syvitski *et al.*, 2009). Under medium UN population projections, human-induced subsidence alone is expected to increase the global economic exposure of 136 major port cities by around 14% although this driver only applies to 36 of the cities (Hanson *et al.*, 2011).

While some literature does not make a clear cut between exposure and impacts (e.g., Dasgupta *et al.*, 2007; Brecht *et al.*, 2012), it is important to distinguish these concepts, as exposure estimates do not consider existing or future adaptation measures that protect the exposed population and assets against coastal risk (Hinkel, 2012). Since AR4, a number of studies, listed in Table 5-5, have provided global assessments of coastal impacts on human settlements including the effects of adaptation. All of these studies also assess monetary costs of impacts and adaptation (5.5.3.). While there is *limited evidence* (few studies and models) three findings emerge.

First, while the global potential impacts of coastal flood damage and land loss on human settlements in the 21st century are substantial, impacts can be reduced substantially through coastal protection (*limited evidence, high agreement*). Nicholls *et al.* (2011) estimated that without protection 72-187 million people would be displaced due to land loss due to submergence and erosion by 2100 assuming sea level increases of 0.5-2.0 m by 2100. Upgrading coastal defenses and nourishing beaches would reduce these impacts roughly by three orders of magnitude. Hinkel *et al.* (2012) estimate the number of people flooded annually in 2100 to reach 170-260 million per year in 2100 without upgrading protection and two orders of magnitude smaller with dike (levee) upgrades, assuming global mean sea-level rises of 0.6-1.3 m by 2100.

Second, despite the delayed response of sea-level rise to global warming levels (WG1, Chapter 3) mitigation may limit 21st century impacts of increased coastal flood damage, dry land loss and wetland loss substantially (*limited evidence, medium agreement*) albeit there is *little agreement* on the exact numbers. Nicholls and Lowe (2004) estimated that stabilizing emission at 550 ppm reduces the annual number of people flooded a factor 50% in 2110 compared to a scenario of unmitigated emissions. Tol (2007) found that stabilizing emissions at 550 ppm reduces global impacts on wetlands and drylands by about 10% in 2100 compared to scenario of unmitigated emissions. Hinkel *et al.* (2012) reported that stabilizing emissions at 450 ppm-CO_2-eq reduces flood risks in 2100 by 23-29%. All three studies only consider the effects of mitigation during the 21st century and due to the thermal expansion component of sea level rise. Mitigation is expected to be more effective when considering impacts beyond 2100 and other components of sea leve rise (WG1 Chapter 13).

Third, studies confirm AR4 findings that there are substantial regional differences in coastal vulnerability and expected impacts (*limited evidence, high agreement*). Most countries in South, South East and East Asia are particularly vulnerable to sea-level rise due to rapid economic growth and coastward migration of people into urban coastal areas together with high rates of anthropogenic subsidence in deltas where many of the densely populated areas are located (Nicholls and Cazenave, 2010). At the same time, economic growth also increases the capacity to adapt and the benefits of adaptation are also highest in these regions (Nicholls *et al*., 2010). On the contrary, while many African countries experience a similar trend in rapid urban coastal growth, the level of economic development is generally lower and hence the capacity to adapt is smaller (Hinkel *et al*., 2011; Kebede and Nicholls, 2012).

Many gaps remain. The available studies have only explored a small fraction of the underlying uncertainty. Only few assessments consider global mean sea-level rise scenarios beyond the range given in AR4, thus excluding the impacts of a possible large contribution of the ice sheets of Greenland and Antarctica to global mean sea-level rise (Sect. 5.3.2, and WG1 Ch. 13). Studies considering regional patterns of climate-induced sea-level rise as well as human-induced subsidence are few. Many studies rely on few or only a single socio-economic scenario. Few studies consider adaptation and those that do generally ignore the wider range of adaptation options beyond hard protection options. Integrated studies assessing multiple hazards, multiple impacts and trade-offs between adaptation options are rare.

_____ START BOX 5-1 HERE _____

Box 5-1. Coastal Megacities

Large coastal urban areas offer both concentrated risk and resources for living with and adapting to the impacts of climate change. When climate related disasters hit megacities costs can be very high: Storm Sandy is estimated to have resulted in more than US$100 billion of damages for New York and its hinterland. When impacts reach these levels, and when strategic infrastructure is damaged, losses in large cities are capable of impacting on regional and global economies through the disruption of globalized flows of goods, resources and capital. Large-scale coastal urbanization is most concentrated in south and southeast Asia. Asia is also a world region with high exposure to climate and weather related hazards and the potential for these to be compounded by geophysical hazards, and those more directly caused by human action such as subsidence.

Of 21 megacities worldwide defined by having populations in excess of 10 million, 14 are in the coastal zone – within 100km and 50m elevation from the coast (Figure 5-4) and it is anticipated that the number of coastal megacities will continue to grow, especially in Africa and Asia. Growth will be largely through planned development but may also feature of unplanned, spontaneous and often illegal development – with implications for the limits and scope of adaptive capacity and management. Growth in neighbouring urban regions offers the prospect of mega-cities or mega-urban-regions, currently the largest is the Hong Kong-Shenhzen-Guangzhou region in China, with a population of 120 million. Many other large coastal cities (e.g., Cairo, London and Sao Paulo) offer important lessons on planning and risk management at scales that indicate the importance of a flexible approach to the study of coastal mega-urbanization.

[INSERT FIGURE 5-4 HERE
Figure 5-4: Mega-urbanisation of on the coast. Source**:** Blackburn S and Marques da Silva C (2013) Mega-urbanisation on the coast: Global context and key trends in the twenty-first century, in Pelling M and Blackburn S (eds) Megacities and the Coast: Risk, Resilience and Transformation, Earthscan: London.]

Contemporary approaches to risk management acknowledge the need for soft risk reduction measures such as education, good governance, and risk communication, being applied in conjunction with hard engineering solutions such as sea walls, groynes and levees and green-engineered equivalents. However applying these principles in megacities is challenging, requiring collaboration between a multitude of stakeholders. These include actors operating at all scales from the international (in the case of large land-owning corporations and supranational donors) to the individual. Good governance is key to risk management, but there is much debate over precisely what this entails and its limitations.

The prospect of dangerous climate change bringing increasing rates of sea-level rise and coastal storminess by mid century asks serious questions of urban planners today. This is especially so in places where these hazard drivers are exacerbated by local conditions, for example of subsidence. Middle-income countries experiencing the most rapid mega-urban expansion also possess an opportunity to plan now for potential risk mid-century and beyond. It is more difficult still to confront the challenge of retrofitting or redesigning cities where current land-use will configure future risk. The next decade is likely to be critical for realigning urban planning, reaching out to informal and regulating market-led developments. Responding to dangerous climate change requires joined-up risk management that can consider transformational adaptation with considerable local impacts on the way cities are imagined, governed and shaped, alongside contemporary, incremental adaptation options.

_____ END BOX 5-1 HERE _____

5.4.3.2. Industry, Infrastructure, Transport, and Network Industries

There is *high confidence* that coastal industries, their supporting infrastructure including transport (ports, roads, rail, airports), power and water supply, storm water and sewerage are sensitive to a range of extreme weather and climate events (Handmer *et al*. 2012) and many of these are projected to change over the coming decades (Seneviratne *et al*., 2012). This is especially relevant considering the fact that most industrial facilities, infrastructure and networks are designed for life cycles extending over several decades, even extending well into the twenty-second horizon such as new nuclear power plants (Wilby *et al*. 2011).

Table 5-6 summarizes potential impacts of sea level rise, coastal floods and storms on critical coastal infrastructure in the communications, energy, transportation and water waste sectors.

[INSERT TABLE 5-6 HERE
Table 5-6: Impacts of sea level rise, coastal floods, and storms on critical coastal infrastructure by sector. Sources: Horton and Rosenzweig (2010), Zimmerman and Faris (2010).]

Severe storms with associated winds, waves, rain, lightning and storm surges are particularly disruptive to transport and power and water supplies. In such network configurations, flooding of even the smallest component of an intermodal system can result in a much larger system disruption. For instance, even though a transportation terminal may not be affected, the access roads to it could be, thus forcing the terminal to cease or reduce operation (CCSP, 2008). Sea transport accounts for more than 80% of global goods trade (by volume) and so disruption to port activities in one location can disrupt supply chains, which can have far reaching consequences (Handmer *et al*., 2012).

Some low-lying railroads, tunnels, ports and roads are already vulnerable to flooding and rising sea levels (5.3.3.2) will exacerbate the situation by causing more frequent and more serious disruption of transportation services under extreme sea levels unless adaptation is enforced. Furthermore, sea-level rise will reduce the extreme flood return periods and will lower the design critical elevations of infrastructure such as airports, tunnels, coastal protections and ship terminals (Jacob *et al*., 2007). Coastal infrastructural instability may result from natural hazards triggered by groundwater-level (GWL) variations resulting from rising sea level. For earthquake-prone coasts, this could be exacerbated by earthquake liquefaction if GWL increases with sea-level rise (Yasuhara *et al*., 2007). Other impacts may arise in coastal industries in high latitudes affected by permafrost thaw causing ground stability and erosion thereby affecting transport safety and the industries that rely on such travel in these regions (e.g., Pearce *et al*., 2010).

There is *high confidence* that climate impacts on coastal industries vary considerably depending on geographical location, associated weather and climate and specific composition of industries within particular coastal regions.

While there is *robust evidence* of the impacts and consequences of extreme events on coastal infrastructure and industrial facilities there are limited assessments on projected impacts. For example, it is estimated that a hypothetical 1 m rise in relative sea level projected for the Gulf Coast region between Alabama and Houston over the next 50-100 years would permanently flood a third of the region's roads as well as putting more than 70% of the regions ports at risk (CCSP, 2008).

Although not completely coastal, the estimated costs of climate change to Alaska's public infrastructure could add US$3.6-6.1 billion (+10% to 20% above normal wear and tear) from now to 2030 and US$5.6-7.6 billion (+10% to 12%) from now to 2080 (Larsen *et al.*, 2008). Higher costs of climate change for coastal infrastructure are expected due to its proximity to the marine environment. Other projected impacts are beneficial for the transportation system. For example, decline of Arctic sea-ice coverage could extend seasonal accessibility to high-latitude shipping routes such as the northwest shipping route that connects the Atlantic to the North Pacific (MCCIP, 2008).

Hanson *et al.* (2011) presents a first estimate of the exposure of the world's large port cities to coastal flooding due to sea-level rise and storm surge in the 2070s. The analysis suggests that the total value of assets exposed in 2005 across all cities considered is estimated to be US$3,000 billion; corresponding to around 5% of global GDP in 2005. By the 2070s, and assuming a homogeneous global sea level rise of 0.5 m, increased extreme water levels up to a 10% and a fixed subsidence rate in susceptible cities with respects today values, asset exposure is estomated to increase to approximately 9% of projected global GDP in this period.

5.4.3.3. Fisheries, Aquaculture, and Agriculture

The coastal zone supports significant fisheries, aquaculture and agricultural activities. Fisheries and aquaculture globally employ 43.5 million people (Daw *et al.*, 2009) and contribute for more than 20% to the dietary animal protein of nearly 1.5 billion people (FAO, 2010). Rice production, the world's number one food crop, is a major crop grown in the low-lying deltaic regions of Asia (Wassman *et al.*, 2009).

Observed impacts

Climate variability and change impact both fishermen livelihoods (Badjeck *et al.*, 2010) and fish production (Barange and Perry, 2009). In the North Sea, ocean warming over the period 1977-2002 led to 8 times more fish species (Hiddink and Hofstede, 2008). In southeastern Australia, Last *et al.* (2011) found an increasing abundance of 45 fish species of warm temperate origin (Ridgeway, 2007), a decline abundance for 9 species, and predicted the potential for longer term detrimental effects for cool temperate species endemic to the region. Impacts of climate change on aquaculture (*Mytilus edulis and Salmo salar*) in the UK and Ireland have been difficult to discern from natural environmental variability (Callaway *et al.*, 2009).

The impact of sea surface temperature changes on fisheries yields over the last 25 years is negative for the Northeast Atlantic large marine ecosystems, and positive for the Indian Ocean (Sherman *et al.*, 2009). In coastal Louisiana, saltwater intrusion was found to reduce the population size of the freshwater western mosquitofish (*Gambusia affinis*) (Purcell *et al.*, 2010). Eutrophication and hypoxia give rise to frequency and intensity of harmful algal blooms (MEA, 2005). A combination of factors renders the Pacific coast and coastal estuaries particularly vulnerable to acidified water (Newton *et al.*, 2010).

The combination of rice yield reduction induced by climate change and inundation of lands by seawater causes an important reduction in production (Chen *et al.*, 2012). Seawater inundation has become a major problem for traditional agriculture in Bangladesh (Rahman *et al.*, 2011), and in low-lying island nations (e.g. Lata and Nunn, 2012).

Projected impacts

Fisheries may be impacted either negatively or positively (Cinner *et al.*, 2012; Meynecke and Lee, 2011; Hare *et al.*, 2010) depending on the latitude, location and climatic factor. Using a partial-equilibrium analysis, Narita *et al.* (2012) estimated that the global economic costs of production loss of mollusks due to ocean acidification by the year 2100 could be over 100 billion USD. Warming ocean temperatures can lead to the migration of the sea urchin (*Centrostephanus rodgersii– Diadematidae*) in Australia (Ling *et al.*, 2009). For aquaculture, negative impacts of rising ocean temperatures will be felt in the temperate regions whereas positive impacts will be felt in the tropical and subtropical regions (De Silva and Soto, 2009).

In summary, there is *medium confidence* that changes have occurred to the distribution of fish species with evidence of poleward expansion of temperate species (*high agreement, limited evidence*). There *is limited evidence* to suggest that tropical and subtropical aquaculture has not been adversely affected by rising ocean temperatures to date. There is also *medium confidence* that coastal agriculture has experienced negative impacts due mainly to increased frequency of submersion of agricultural land by saltwater inundation (*high agreement, limited evidence).*

5.4.3.4. Coastal Tourism and Recreation

Coastal tourism is the largest component of the global tourism industry. More than 60% of Europeans opt for beach holidays and beach tourism provides more than 80% of US tourism receipts (UNEP, 2009). More than 100 countries benefit from the recreational value provided by their coral reefs which contributed US$11.5 billion to global tourism (Burke *et al*., 2011).

Observed impacts

Observed significant impacts on coastal tourism have occurred from changes in extreme events (e.g. flooding, tropical storms, storm surges, heat waves) and climate variability (e.g. drought and prevailing winds accelerating coastal erosion) which can cause damage to infrastructure and tourist attractions (Scott *et al*., 2008; Bender *et al.,* 2010; Knutson *et al*., 2010). Observed climate change impacts on the Great Barrier Reef include the coral bleaching episodes in 1998 and 2002 due to higher summer sea temperatures, more severe storms, rising sea levels and coastal erosion although tourists show a low level of climate change concern with respect to coral bleaching (Zeppel, 2012).

Projected impacts

In order to provide some idea of climate change impacts on coastal destinations, many studies have been made on projecting tourism demand, for example, in Europe (Perch-Nielson *et al*., 2010), East Anglia, UK (Coombes *et al*., 2009), the Baltic region (Haller *et al*., 2011) and beach tourism in the Mediterranean (Moreno and Amelung, 2009a) and in 51 countries worldwide (Perch-Nielson, 2010). The studies provide varying details but it is difficult to draw overarching conclusions on tourism demand for coastal destinations. Less is known about the relationship between the impacts of climate change and specific tourist behaviour, activities or flows to coastal destinations (Moreno and Amelung, 2009b) (see Chapter 10). Usually tourists do not consider climate variability or climate change in their holidays *et al*. although there are a few studies to show on the contrary (Alvarez-Diaz *et al*., 2010; Cambers, 2009).

As for future impacts on coastal tourism, there is *high confidence* in the impacts of extreme events and sea level rise aggravating coastal erosion. A scenario of 1 m sea level rise would be a potential risk to 906 major coastal resort properties in 19 countries in the Caribbean (Scott *et al*., 2012). The presence of coastal tourism infrastructure will continue to exacerbate beach reduction and coastal ecosystems squeeze under rising sea levels, as exemplified in Martinique (Schleupner, 2008). Carbonate reef structures would degrade under a scenario of at least 2ºC by 2050 to 2100 with serious consequences for tourism destinations in Australia, Caribbean and other small island nations (Hoegh-Gulberg *et al*., 2007). Ocean acidification would add its toll to coral reefs (Box CC-CR).

The costs of future climate change impacts on coastal tourism are enormous. For example, in the Caribbean region, a hypothetical 1-m sea-level rise would result in the loss or damage of 21 CARICOM airports, inundation of land surrounding 35 ports, and at least 149 multi-million dollar tourism resorts damaged or lost from erosion to the coastal beach areas.(Simpson *et al*., 2011).

In summary, while coastal tourism can be related to climate change impacts, it is more difficult to relate tourism demand directly to climate change. Coastal tourism continues to be highly vulnerable to weather and climate extremes and rising sea levels with the additional sensitivity to ocean temperature and acidity for the sectors that rely on reef tourism *(high confidence*). Developing countries and small island states within the tropics relying on coastal tourism, are most vulnerable to present and future weather and climate extremes, future sea level rise and the added impacts of coral bleaching and ocean acidification (*very high confidence*).

5.4.3.5. Health

The relationship between health of coastal populations and climate change include direct linkages (e.g. floods, droughts, storm surges and extreme temperatures) and indirect linkages (e.g. changes in the transmission of vector, food and water borne infectious diseases and increased salinisation of coastal land that affects food production and freshwater supply). Coastal settlements, and in particular informal settlements, concentrate the risks of injury and death due to the risk of storm surges and flooding from rainfall and storm surge (Handmer et al, 2012). This section deals with human health in the context of the coastal zone, while Chapter 11 addresses general health issues and Chapter 6 deals with health issues associated with ocean changes. Understanding the relationship between climate and health is often confounded by socio-economic factors that influence coastal settlement patterns and the level and organisation of the response of authorities to health related issues (Baulcomb, 2011).

Mortality risk in coastal areas is related to exposure and vulnerability of coastal populations to climate hazards. Recent modeling of trends in these components highlights that mortality risk is highest in countries with low GDP and weak governance. A regional analysis of changes in exposure, vulnerability and risk indicates that although exposure to flood and cyclone hazards has increased since 1980, the risk of mortality has generally fallen. The reductions reflect strengthening of countries' capacity to respond to disasters (Box 5-1). However, mortality is still rising in the countries with the weakest risk governance capacities (UNISDR, 2011).

Coastal regions face a range of diseases that are sensitive to climate. Increased saline intrusion of coastal land through rising sea levels and changes to river flow is linked to increased incidence of hypertension disease (Vineas et al, 2011). For example, in Bangladesh, higher rates of maternal hypertension disorders have been identified in pregnant women living in coastal regions compared to further inland (Khan et al, 2008). Increasing temperature, humidity and rainfall can increase suitable mosquito habitats, shorten the breeding cycles and reduce the time to infection by vector-borne diseases such as malaria, dengue, leishmaniasis and chikungunya. (Stratten *et al*., 2008; van Kleef *et al*., 2010; Pialoux et al, 2007, Kolivras, 2010) and infectious diseases such as diarrhoea, infectious gastrointestinal disease, rotovirus and salmonella (e.g. Chou *et al*., 2011, Hashizume *et al*., 2007; 2008a Zhang *et al*., 2007, 2010; Onozuka *et al*., 2010). The parasitic disease, Schistosomiasis, is endemic in many tropical and small island coastal regions (Chapter 29) and infection rates have been found to increase linearly with temperature to 30°C but reduce beyond 35°C, because of increased mortality in the snail intermediate host. (Mangal *et al*. 2008).

Cholera outbreaks are also linked to rainfall, patterns and other seasonal climate patterns (e.g. Hashizume et al, 2008b, 2010) and variations in SST (e.g. Koelle et al, 2005). Outbreaks of toxins generated by Harmful Algal Blooms (HABs) such as ciguatera have been linked to SST variability (e.g. Jaykus *et al*., 2008; Erdner *et al*., 2011). However, in general there is *limited evidence* and *low confidence* in how global climate change will impact HABs (Chapter 6). The potential impacts of HABs in human health and different ecosystem services suggests increased monitoring of significant range extensions and associated increases in biotoxins is necessary (Hallegraeff, 2010). Nontoxic blooms that grow to high biomass also can have detrimental effects on biodiversity through oxygen depletion and physical shading of the benthos (Erdner *et al*., 2011) with consequences for ecosystem health, human nutrition and health.

Under future climate conditions, expansion of brackish and saline water bodies in coastal areas under projected sea level rise may increase the incidence of associated vector-borne diseases (Ramasamy and Surendran, 2011) and salinity-related diseases such as diarrhea and hypertension (Vineas et al, 2011). Human responses to climate change also may also influence outcomes on health. However, sparsity of empirical climate-health data increases uncertainties around such projections (Kolstad and Johansson (2011).

Evidence continues to emerge of relationships between many diseases that affect human health in the coastal zone and climate including changes in air and water temperature, rainfall and humidity, coastal salinity and increased salinisation of coastal land. However, the relationships are often complex and vary between diseases and even regionally for the same disease. The interplay between climate and human systems with regards to health impacts is poorly understood and this continues to confound reliable projections of health impacts. (*high agreement, robust evidence*).

5.4.4. Summary: Detection and Attribution

Coastal systems, consisting of natural and human systems, have been heavily influenced by human activities including those associated with climate changes (*high agreement, robust evidence*).

Coastal ecosystems such as rocky shores and coral reefs show the most evidence of the impacts of climate change (5.4.2.2, 5.4.2.4), the most prominent effects being the range shifts of species in response to ocean warming (*high confidence*), changes in biodiversity (*high confidence*) in relation to ocean warming and acidification, and mass coral bleaching and mortality in response to ocean warming (*very high confidence*). Decreased calcification in many reef-building corals and coralline algae is reported widely (*high confidence*), however its attribution to either warming or acidification has proven difficult (*medium confidence*)(5.4.2.4). Ocean warming is also leading to range shifts in mangrove forests and seagrass meadows (*medium confidence*)(5.4.2.3). Seagrass meadows are already under stress due to ocean warming (*high confidence*), and in particular heat waves, which lead to widespread seagrass mortality (*high confidence*). Kelp forests have been reported to decline in temperate areas in both hemispheres, attributed to ocean warming (*high confidence*)(5.4.2.3). The spread of subtropical invasive macroalgal species is believed to be facilitated by climate change, adding to the stresses temperate seagrass meadows experience from ocean warming (*medium evidence, high agreement*)(5.4.2.3). The changes of the distribution of fish species with evidence of poleward expansion of temperate species have occurred (*medium confidence*)(5.4.3.3). There *is limited evidence* to suggest that tropical and subtropical aquaculture has been adversely affected by rising ocean temperatures to date (5.4.3.3).

Though the range shift of mangroves is recognized, mangrove forests and seagrass meadows are declining globally (*very high confidence*) mainly due to land-use changes and coastal erosion (5.4.2.3). Widespread erosion of beaches and dunes has been observed over the past century or more (*robust evidence*) (*very high confidence*). However attributing shoreline changes to climate change is difficult due to the multiple natural and anthropogenic drivers contributing to coastal erosion (*low confidence*) (5.4.2.1). There is *very high confidence* that increased usage of groundwater resources for agriculture and coastal settlements globally has led to a reduction in groundwater quality, including increased salinization (*high agreement, robust evidence*), however, attribution to climate change is *low* (5.4.2.5), human drivers being the primary cause in these changes and degradation of highly-populated deltas and lowlands around estuaries and lagoons (*high agreement, robust evidence*)(5.4.2.7).

Exposure studies confirm the findings of AR4 that coastal vulnerability and risks are strongly influenced by non-climatic drivers. Population of people living in coastal lowlands is increasing and more than 270 million people in 2010 are already exposed to flooding by the 1 in 100 year coastal flood (5.4.3.1)(*very high confidence*). Population growth and land subsidence in coastal lowlands are the major cause and there is *very low attribution* to climate changes. The interplay between climate and human systems with regards to health impacts is poorly understood (*high agreement, robust evidence*)(5.4.3.5).

The coastal systems are affected by both climate-related and human drivers, and complex interactions of both. Though there is *high* attribution to climate changes as coral bleaching and species shift, most of causes in other changes to the coastal system are attributed to mainly human activities (human drivers). Further analysis will be required to more clearly discriminate the relative contributions from human and climate-related drivers.

[INSERT FIGURE 5-5 HERE
Figure 5-5: Summary of detection and attribution in coastal areas.]

5.5. Adaptation and Managing Risks

This section assesses the literature on available on approaches for appraising and implementing coastal adaptation (5.5.1), adaptation options (5.5.2), costs and benefits of coastal adaptation (5.5.3), observed coastal adaptation practice (5.5.4), observed barriers to coastal adaptation (5.5.5), and finally linkages between coastal adaptation and mitigation (5.5.6).

5.5.1. Framing and Approaches

5.5.1.1. Overview of Approaches

Adaptation in general and coastal adaptation in particular are broad concepts referring to a wide range of human activities related to the process of framing the adaptation issue, assessing adaptation (i.e., identifying and analyzing adaptation options), implementing options and monitoring and evaluating these (e.g., UKCIP, 2003; PROVIA, 2013). As a result, a wide variety of approaches are applied (Chapters 2, 15, 16 and 17 for a comprehensive account).

For coastal adaptation, the literature on approaches falls into three categories: decision-analytical approaches, approaches of institutional and governance analysis and practical approaches that cover all stages of the adaptation process.

5.5.1.2. Decision Analysis

Decision-analytical (DA) approaches analyse a particular decision using formal methods in order to identify preferable actions from a set of alternative actions (also called options, alternatives or strategies) given some evaluation criteria. This section highlights some paradigmatic applications of DA methods to coastal adaptation; for a compressive treatment see Chapter 2 (Foundations for decision-making) and Chapter 17 (Economics of Adaptation).

Many standard methods for decision-making under uncertainty use the criterion of optimality (e.g., optimum utility, optimal cost-benefit ratio, etc). These methods cannot be applied for long-term adaptation decisions as they require the computation of expected utility or expected benefits, which is not possible in principle (Lempert and Schlesinger, 2001; Hinkel and Bisaro, 2013). As many coastal decisions involve options with investment time scales of 30 to over 100 years (e.g., land-use planning, flood defenses, construction of housing and transportation infrastructure; see 5.5.2), DA approaches beyond optimization are required (Hallegate, 2009).

Robust decision-making (RDM) refers to a range of alternative approaches that replace the evaluation criterion of optimality with the criterion of robustness. Uncertainty is not represented through a single probability distribution but through a range of alternative scenarios and robust strategies that work well over a wide range of these scenarios are preferred (Lempert and Schlesinger, 2000; Lempert and Collins, 2007). Application of RDM to Port of Los Angeles infrastructure is one of the few applications to coastal adaptation (Lempert *et al.* (2012).

Another set of approaches uses the criterion of flexibility to decide between alternative strategies. Flexible and reversible options are favored over non-flexible and non-reversible ones and decisions are delayed to keep future options open (Hallegate, 2009).

The adaptation pathways approach implements the criterion of flexibility by characterizing alternative strategies in terms of two attributes: i) adaptation tipping points (ATP), which are points beyond which strategies are no longer effective (Kwadijk *et al.*, 2010), and ii) what alternative strategies are available once a tipping point has been reached (Haasnoot *et al.*, 2012). Importantly, the exact time when an ATP is reached does not matter; it is rather the flexibility of having alternative strategies available that is driving the decision. Prominent applications of this approach include the Thames Estuary 2100 Plan (Low *et al*., 2009; Penning-Roswell *et al*. 2011; Box 5-2), the Dutch Delta Programme (Kabat *et al*., 2009; Box 5-3) and the New York City Panel on Climate Change (Rosenzweig *et al*., 2011).

These and other approaches may also be embedded into multi-criteria-analysis (MCA), which considers multiple criteria that may include robustness and flexibility. The application of MCA to coastal decisions is wide spread. Another response to the deep uncertainty characterizing future climate drives is adaptive management, which is the idea of practicing adaptation and evaluating outcomes *ext-post* instead of analyzing decisions *ex-ante*; (e.g. practical approaches in 5.5.2.4).

5.5.1.3. Institutional and Governance Analysis

Institutional and governance analysis (IA) comprise a variety of approaches that aim at describing and explaining the emergence and performance of institutions and governance structures (GS) (Hinkel and Bisaro, 2013). IA is particularly relevant to coastal adaptation, because deciding between options and implementing them is an ongoing process involving complex inter-linkages between public and private decisions at multiple levels of decision making and in the context of other issues, existing policies, conflicting interests and diverse GS (e.g, Few *et al*., 2007; Urwin and Jordan, 2008; Hinkel *et al*., 2009). The non-consideration of this context may hinder or mislead adaptation decisions and implementations (5.5.5). IA strives to understand this context and insights gained may be employed to craft effective institutions and policies for adaptation.

For coastal adaptation, there is *high confidence* that the effectiveness of existing GS is hindered due to a lack of horizontal and vertical integration of organizations and policies. Weak vertical administrative interplay in Sweden (Storbjörk and Hedren (2011)); poor integration in higher-level governance and limited effectiveness of institutional arrangements of Coastal Partnership in UK (Stojanovic and Barker, 2008); difficulty to translate national level recommendations into local level actions in the UK (Few *et al*., 2007); coastal policies with ambigous or contradictory goals (Bagstadt *et al*., 2007) and fragmented economic incentivices in the US (Seto, 2011) or coastal policies not taken into account longer-term climate change in a number of African cases (Bunce *et al*., 2010) are a few examples.

There is *medium evidence* that governance issues are particularly challenging when considering planned retreat. While managed realignment is on the political agenda in Germany and the UK, the political costs of doing so are high as both the existing GS as well as public opinion are geared towards protection, so that short election cycles do not provide incentives for politicians to undertake actions that may produce benefits in the long term (Few *et al*., 2007; Rupp-Armstrong and Nicholls, 2007). Along the coast of South East Queensland, Australia, the option of planned retreat is disappearing because of rapid coastal development favored by liability laws. To prevent this, risks and responsibilities would need to be redistributed from governments to beneficiaries of development (Abel *et al*., 2011).

While there is *high confidence* that many institutional factors are decisive in enabling coastal adaptation, the role of coastal institutions in adaptation is generally under-researched. Contextually differentiated institutional analysis considering both biophysical and social system characteristics (Dietz *et al*., 2003; Ostrom, 2009) as found in the fields of socio-ecological systems (Folke *et al*., 2005; Ostrom 2007, 2009) and new institutional economics (Hagedorn *et al*., 2002; Bougherara *et al*., 2009; Ostrom, 2005, Geels, 2011) are practically non-existent.
Most work focuses on Australia, US, Germany and the UK with little work on developing countries.

5.5.1.4. Approaches to Adaptation Practice

Generally, approaches to adaptation practice build on already existing policy and practice frameworks and cover the whole adaptation processes from framing the issue and analyzing options to implementing adaptation actions and monitoring and evaluation.

Integrated Coastal Zone Management (ICZM) is a long-term, institutionalized and iterative process that promotes the integration of coastal activities of relevant policy makers, practitioners and scientist across coastal sectors, space and organizations with a view to use coastal resources in a sustainable way (Hiledebrand and Norrena, 1992; Sorenses 1993; Sterr *et al.*, 2003; Sales, 2009; Christie *et al.*, 2005; WG2 Glossary). Considering climate change in this framework does not mean radical changes to ICZM, because ICZM already emphasizes the integration of coastal issues across sectors and policy domains as well as the long-term perspective (e.g., Hofstede, 2008; Falaleeva *et al.*, 2011), but there is need to extend decision making horizons (Tobey *et al.* 2010).

So far, however, there is *limited evidence* of the effectiveness of ICZM combined with climate change adaptation. ICZM itself has been applied throughout the world for over 40 years and while demonstrable befits are reported (e.g., Stojanovic and Ballinger, 2009) many obstacles to its successful implementation still remain (*high confidence*). A recent review of ICZM in Europe concluded that the complexity of coastal regulations, demographic deficits, lack of sustainable finance and a failure to involve communities, business and industry hinder its implementation (Shipman and Stojanovic, 2007). Developing countries also struggle to meet the goals of ICZM due to many factors (Box 5-4).

Another prominent framework used for coastal adaptation practice is adaptive management (AM), which has been developed as a response to the deep uncertainty characterizing ecosystem management, where it is often impossible to predict outcomes of management interventions (Holling, 1968; Walters, 1986). There are numerous applications of AM to coastal management (e.g., Walters, 1997; Marchand, 2011, Mulder *et al.*, 2011), but as the majority of these are very recent, there is *limited evidence* of its long-term effectiveness. Limitations of AM are also apparent such as the potential high cost of experimentation and and a range of institutional barriers hindering the delivery of flexible management approaches (e.g. Gunderson *et al.*, 1995, McLain and Lee, 1996; Johnson 1999).

Community-based adaptation (CBA) refers to the generation and implementation of locally-driven adaptation strategies that address both climate change impacts and development deficits for the climate vulnerable poor and strengthen the adaptive capacity of local people to climate and non-climate risk factors (Reid *et al.*, 2009; Nicholls *et al.*, 2007; Ayers and Dodman, 2010; Ayers and Huq, 2013; WG2 AR5 Chapter 14, 14.2.1; Chapter 15, 15.4.3.1; Chapter 24, 24.4.6.5). CBA approaches have been developed through active participatory processes with local stakeholders (Ayers and Forsyth, 2009), and operating on a learning-by-doing, bottom up, empowerment paradigm (Huq and Reid, 2007; Kates, 2000). CBA experiences emphasize that it is import to understand a community's unique perceptions of their adaptive capacities in order to identify useful solutions (Parvin *et al.*, 2008; Paul and Routray, 2010; Badjeck et al, 2009) and that scientific and technical information on anticipated coastal climate impacts needs to be translated into a suitable language and format that allows people to be able to participate in adaptation planning (Saroar and Routray, 2010). Further, effective CBA needs to consider measures that cut across sectors and technological, social and institutional processes; technology by itself is only one component of successful adaptation. (Sovacool *et al.*, 2011; Rawlani and Sovacool, 2011; Pelling, 2011; Gibbs, 2009).

Other important policy and practice frameworks in place in the coastal zone include poverty reduction, development and Disaster Risk Reduction (Romieu *et al.*, 2010; Mercer, 2010; Mitchell *et al.*, 2010; Polack, 2010; Gero *et al.*, 2011; Kirshen *et al.*, 2011; Halpern *et al.*, 2008b)

Across these and other approaches there is *high agreement* on the following three principles. One, information on efficient adaptation options alone (as assessed through DA approaches) may not fully serve managers need and requires to be supplemented by financial and technical assistance as well as boundary organizations which serve as an interface between science and practice (Tribbia and Moser, 2008). Two, the adaptation and decision making processes should be participatory and inclusive, integrating all relevant stakeholders (Dolan and Walker, 2004; O'Riordan and Ward, 1997; Milligan *et al.*, 2009). Three, the adaptation processes must be set up to foster mutual learning, experimentation and deliberation amongst stakeholder and researchers (Fazey *et al.*, 2010; Kenter *et al.*, 2011). Neither scientific climate knowledge alone nor indigenous knowledge alone is sufficient (Sales, 2009; Dodman and Mitland, 2011; Bormann et al, 2012). Coastal adaptation is increasingly acknowledged to be a "wicked problem" (Rittel and Webber, 1973), in the sense that there is often no clear agreement about what exactly the adaptation problem is and there is uncertainty and ambiguity as to how improvements might be made (Moser *et al.*

2012). As coastal systems are complex, diverse and dynamic, their governance needs experimentation and learning by doing (Jentoft, 2006).

While there is *high agreement* on these principles, there is little systematic review and hence *limited evidence* on why a given approach is effective in a given context (and not in another). The need for systematic evaluation and institutional research targeted at a differentiated understanding of these approaches is high. Furthermore, despite experimentation with these approaches, meeting the multiple goals, improving governance, accounting for the most vulnerable populations and sectors and fully integrating consideration of natural ecosystems is still largely aspirational. Meanwhile development in high risk areas grows, coastal ecosystems continue to degrade in many regions, coastal freshwater resources are being overdrawn in many highly populated areas, and vulnerability to coastal disasters grow (e.g., Jentoft, 2009; McFadden, 2008; Mercer, 2010; Shipman and Stojanovic, 2007).

5.5.2. Adaptation Options

Selecting appropriate adaptation options can be challenging considering the ample range of options available. A detailed discussion on general adaptation needs and options can be found in (chapter 16). As a first approximation, adaptation options were classified into: institutional and social options (14.3.2.1), technological and engineered options (14.3.2.2) and ecosystem-based adaptation options (14.3.2.3). In terms of coastal adaptation, most of the existing options can be included within this classification.

The IPCC classification of coastal adaptation strategies consisting of retreat, accommodation and protection (Nicholls *et al*., 2007) is now widely used and applied in both developed and developing countries (Boateng, 2010; Linham and Nicholls, 2012). This trilogy of strategies has also been translated as retreat, defend or attack (Peel, 2010). Protection aims at advancing or holding existing defence lines by different options such as: land claim, beach and dune nourishment, the construction of artificial dunes, hard structures such as sea walls, sea dikes and storm surge barriers or removing invasive and restore native species. Accommodation is achieved, increasing flexibility, by flood proofing, flood agriculture, flood hazard mapping, the implementation of flood warning systems or replacing armoured by living shorelines. Retreat options include allowing wetlands to migrate inland, shoreline setbacks and managed realignment, for example, by breaching coastal defences allowing the creation of an intertidal habitat.

Since AR4 coastal adaptation options have been revised and summarized in several guidebooks (USAID, 2009; EPA, 2009; UNEP, 2010). Especially relevant has been the growth of Community Based Adaptation options. Table 5-7 compiles different examples, of options implemented to address climate change impacts in coastal areas.

[INSERT TABLE 5-7 HERE
Table 5-7: Community-based adaptation options.]

5.5.3. Global Adaptation Costs and Benefits

Since AR4, only a few studies have been published that provide comprehensive and internally consistent estimates of the costs of sea-level rise and adaptation at global scales. These relying either on the FUND (Anthoff *et al*., 2010; Nicholls and Tol, 2009) or the DIVA model (Hinkel and Klein, 2009) and are listed in Table 5-5 and discussed here.

Generally, cost estimates are difficult to compare across studies due to differences in scenarios used, impacts and adaptation options considered, methodologies applied and baseline conditions assumed. No study covers all of the major sea-level rise impacts as reported in Table 5-4. All of these studies use the direct cost method, in which exogenous prices for adaptation options and damages are taken from data of the respective markets. For wetland loss, direct costs are used too but the “prices” are taken from monetary valuation studies for non-market goods and services (Woodward and Wui, 2001; Brander *et al*., 2006; Barbier, 2012). Some studies use computable general equilibrium models and growth models to study the indirect and dynamic costs of climate change, including sea level rise. These studies are reviewed in Chapter 10.

There is *high agreement* that the cost of sea-level rise (sum of adaptation and residual damage cost) are smaller with coastal protection than without for the 21st century and the global scale, when considering the impacts of increased coastal flood damage and land loss due to erosion. (Nicholls and Tol, 2006; Anthoff *et al.*, 2010; Hinkel *et al.*, 2012). *Evidence is low*, however, as only a few studies are available. Considering dryland and wetland loss only, the FUND model shows that under a GMSLR of 20-40cm per century it would be economically justified to protect 80% of the exposed coast in all but 15 countries (Nicholls and Tol, 2006) and even under an extreme GMSLR of 6m per century 50% of today's coastline would still be worth protecting (Nicholls *et al.*, 2008). Considering flood damage only, an application of DIVA shows that for 21st century global mean SEA LEVEL RISE scenarios of 60-126cm, upgraded protection through dikes (levees) may reduce total costs by factors 3 to 5 as compared to no upgrades in protection (Hinkel *et al.*, 2012).

There is also *high agreement* that costs and benefits of sea-level rise impacts and adaptation vary strongly between regions and countries and that some developing countries and Small Island States may reach their limits of adaptive capacity or may not be able to bear the costs of impacts and adaptation without external support (Chapter 29, 29.6.2.1). Even with protection, the cost of land loss due to submergence are projected to be above 1% of national GDP for Micronesia, Palau, the Bahamas and Mozambique under 1m of sea level rise (Anthoff *et al.*, 2010). For coastal flooding, annual damage and protection cost are projected to lie between 5% and 9% of national GDP for Kiribati, the Solomon Islands, Vanuatu and Tuvalu in 2100 under 64 cm of global mean sea-level rise (Hinkel *et al.*, 2012). Further substantial costs arise particularly for developing countries due to their current adaptation deficit (i.e. coastal defenses are not adapted to the current climate variability), which is not well understood and requires further analysis (Parry *et al.*, 2009). For example, the adaption deficit of Africa with regards to coastal flooding is estimated to US $300 billion (1995 prices; Hinkel *et al.*, 2011) and that of Bangladesh with respect to cyclones to US$ 25 billion (2009 prices; World Bank, 2011).

Several methodological issues and gaps remain. As there are so few studies of the costs and befits of sea-leverl rise at a global level, *evidence is low*. Uncertainties are largely unknown and the need for further research is large. Impacts considered and damages and losses valued are incomplete. For example, costs of salinity intrusion, land loss due to increased coastal erosion, the backwater effect and the impact of sea-level rise in combination with other drivers on ecosystems have not been assessed at global scales (see Table 5-4). Generally for sea-level rise impacts, it is difficult to establish a “no adaptation” baseline and the choice of the baseline changes damage costs (Yohe *et al.*, 2011).

Furthermore, assessments have focused on protection via hard structures but many more adaptation options are available including, “soft” protection, retreat and accommodation options (Klein *et al.*, 2001; Sect. 5.1) and future work needs to consider these. While the costs of “soft” protection options are largely unknown (Linham and Nicholls 2010), these may provide additional benefits. For example, ecosystem-based adaptation options, also preserve and restore coastal ecosystems whilst protecting against impacts (Espinosa-Romero *et al.*, 2011; McGinnis and McGinnis, 2011; Pérez *et al.*, 2010; Anthony *et al.*, 2009; Alongi, 2008; Zeitlin *et al.*, 2012; Vignola *et al.*, 2009; IUCN, 2008). Finally, it must be noted that protection also further attracts people and development to the floodplain, which together with protection levels leads to ever increasing residual risks with potential catastrophic consequence in the case of defense failure. This is particularly true for many coastal cities such as London, Tokyo, Shanghai, Hamburg and Rotterdam that already rely heavily on coastal defenses (Nicholls *et al.*, 2007).

[INSERT TABLE 5-8 HERE
Table 5-8: Global assessments of costs of sea-level rise.]

5.5.4. Adaptation Practice

Observed adaptation practice generally refers to the body of commonly used actions and measures for climate change adaptation and differs from approaches (5.5.1) and options (5.5.2).

Much of the observed adaptation practice deals mainly with coastal hazards such as coastal erosion and coastal flooding, although imperfect at times (Hanak and Moreno 2012). In many parts of the world, small island indigenous communities address climate change consequences based on their own traditional knowledge (Percival, 2008; Langton *et al.*, 2012; Nakashima *et al.*, 2012).

Adaptation to sea level rise presents challenges on the ground as past adaptation to hazards may not be ecologically sustainable or economically affordable in light of some high-end sea level rise projections. Long-term adaptation to sea level rise has been confined to few major projects such as the Venice Lagoon project, the Thames Estuary 2100 project, London, and the Delta Works, Netherlands, (Norman, 2009) (Boxes 5-2 and 5-3). In addition, the complex nature of coasts as a socio-ecological system (5.2) makes adaptation practice challenging (Rosenzweig *et al.*, 2011).

_____ START BOX 5-2 HERE _____

Box 5-2. London's Themes Estuary 2100 Plan: Adaptive Management for the Long Term

The Environment Agency in Britain, which has the main responsibility for flood risk management in England and Wales, has recently undertaken the project Themes Estuary 2100 (TE2100) to investigate the future flood threat to London (Environment Agency, 2012). The motivation was a fear that due to accelerated climate change-induced sea-level rise time could already be too short for replacing the Thames Barrier (build in 1982) and other measures that protect London, because such major engineering schemes take 25 to 30 years to plan and implement.

The US$20 million TE2100 project was designed to assess combinations of non-structural and structural engineering measures. Over a period of five years, many disciplines were involved, including engineers, economists, ecologists, geomorphologists and sociologists. The TE2100 Plan was developed in stages, with substantial involvement of the Estuary's stakeholders, using multi-criteria analysis to choose between the many competing options.

The main findings were:

- Anticipated sea-level rise is expected not to outstrip the existing defences in the short term: so there is time to plan future flood risk reduction measures.
- The Thames Barrier has a very high design standard (1 to 5,000 years), higher than had been originally anticipated: such key assets need to be made to last as long as possible.
- The Estuary is geomorphologically stable: a sudden change in its character and hence the risk of flooding is unlikely.
- The area affected contains as high density of with immensely valuable London properties, and developing substantially: risk is rising rapidly.

As a result an adaptive plan that manages risk in an iterative way was adopted, with numerous and diverse kinds of measures spread over the next 50 to 100 years, "pulling down" risk to acceptable levels (Figure 5-6). This plan includes an adaptive approach to managing the existing flood defence 'assets' (walls, barriers, gates) in a carefully planned way over the next 100 years (Penning-Rowsell *et al.*, 2012). During this time they will all need replacing, and could at the same time be enhanced. The plan also includes a strategy to restrict development in the flood risk areas, so that the time available for implementing major new works is not eroded by rapidly increasing risk. Finally, in the longer term (beyond c. 2070) there will be the need to plan for more substantial measures if sea-level rise accelerates. This might include a replacement of the Thames Barrier, with higher protection standards, probably nearer to the sea. In the meantime the adaptive approach requires careful monitoring of the drivers of risk in the Estuary to ensure that flood management authorities are not taken by surprise and forced into emergency measures.

[INSERT FIGURE 5-6 HERE

Figure 5-6: Adaptation measures and pathways considered in the TE2100 project. The boxed show the measures and extend over the range of sea level rise they are effective. The blue arrows link to alternative measures that may be applied once a measure is no longer effective. The red lines show the various sea-level rise scenarios used in the analysis. The fat green line shows a possible future adaptation pathway in the unlikely event of extreme change (>4 m rise).]

_____ END BOX 5-2 HERE _____

To date, certain principles and good practices (methods that have shown consistently better results and could be used as benchmark) can be derived from many observed examples of coastal adaptation. In a broad-scale assessment of climate change threats to Australia's coastal ecosystems, seven principles in adaptation were suggested: clearly defined goals for location, thorough understanding of connectivity within and between ecosystems, consideration of non-climatic drivers, involvement of all relevant stakeholders, easily available and shared data, re-thinking of existing policy and planning constraints and adaptation at local/regional scales (Hawden *et al.,* 2011). Based on Oxfam's adaptation programmes in South Asia that include coastal communities, additional principles include a focus on the poor, vulnerable and marginalized, community or local ownership, flexible and responsive implementation, preparation for future and capacity building at multiple levels (Sterrett, *et al.,* 2011). An assessment of worldwide case studies indicates the importance of knowledge transfer of good practice methods for scaling up adaptation strategies in and between regions and beyond the national scale (Martinez *et al.*, 2011).

For European coastlines facing coastal erosion, flooding and landslide events, more specific practices are given in a good practice guide (McInnes, 2006). In the California adaptation study that includes coasts, the lessons learnt include using best available science, decision on goals and early actions, locating relevant partners, identification and elimination of regulatory barriers and encouragement of introduction of new state mandates and guidelines (Bedsworth and Hanak, 2010). Boateng (2010) presented 15 case studies from 12 countries of best practice in coastal adaptation for surveyors. Bangladesh provides good examples in areas of raising awareness, disaster warning and control, and protective building measures (Martinez *et al.*, 2011)**.** In general, documentation on good adaptation practices for coasts is improving.

The issues for coastal adaptation are not radically different from issues encountered with integrated coastal zone management (ICZM) which offers an enabling environment for adaptation practice (Celliers *et al.*, 2013) (Box 5-4). A guidebook by USAID (2009) indicates the transfer of successful experience in ICZM to coastal adaptation. Detailed descriptions of adaptation measures are available in a number of guides or manuals (Linham and Nicholls, 2010; NOAA, 2010; Engineers Australia, 2012). Eleven types of structural projects have been identified for coastal protection and restoration for Louisiana (CPRA, 2012). The major difference of coastal adaptation from ICZM is coping with the dynamic nature of coastal areas, greater uncertainty, longer time frames in planning (beyond 30 years), and long-term commitments inherent in climate change.

Adaptation practice *is likely* to move forward as climate change adaptation (CCA) converges with disaster risk reduction (DRR) (ISDR, 2009; Setiadi *et al.*, 2010; Tran and Nitivattananon, 2011; Hay, 2012). Adaptation practice *is likely* to expand with two emerging approaches to adaptation in recent years – community-based adaptation (CBA) and ecosystem-based adaptation (EBA). CBA involves all relevant stakeholders especially local communities and is a bottom-up approach instead of the usual top-down (Ayers and Huq, 2009; UNDP, 2010; Riadh *et al.*, 2012) (Table 5-7). EBA includes innovative measures (Clark and Jupiter 2010; Crooks *et al.*, 2011; Girot *et al.*, 2012; Jones *et al.*, 2012; Mercer *et al.*, 2012) especially using mangroves for both CCA and DRR (Lacambra *et al.*, 2008; Spalding *et al.,* 2012).

In summary, adaptation practice in the coastal zone continues to meet challenges of climate change and sea-level rise (*very high confidence*). While more traditional adaptation practices may be revealed there is a myriad of adaptation practices depending on technology, policy, financial and institutional support, supported by documentation on good practices. ICZM with its emphasis on integration *is likely* to remain a major process for coastal adaptation. With a better understanding of coasts as a complex socio-ecological system, the future *is likely* to see a wider net and application of adaptation practices (*very high confidence*).

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Box 5-3. Paradigm Shift in Adaptation to Rising Sea Levels in The Netherlands

Inhabitants in the low-lying coastal area of the Netherlands have been facing coastal and river flooding for centuries. Extreme sea levels together with long-term delta subsidence have been responsible for major catastrophic events causing thousands of fatalities over the last ten centuries. The expansion of habitable land and the increase in the population exposed to catastrophic events have co-existed with technological improvements for coastal protection and large investments resulting in a dramatic decrease in mortality rate (Van Baars and Van Kempen, 2009). Most of the coastal protection has been implemented during the second half of the twentieth century, resulting in the construction of large and numerous structures altering the appearance of an important part of the Dutch coastal area (Kabat *et al.*, 2009).

At present, nine million residents live in coastal areas at an elevation below sea level, where roughly 65% of gross national product is generated (Stive *et al.*, 2011). The anticipation of a changing climate, including sea-level rise, during the twenty-first century, together with an audit carried out in 2007 giving evidence of an aging flood protection system and an increasing vulnerability has renewed the demand for new plans for water and coastal management.

In this context the Dutch Government has set out far-reaching recommendations on how to keep the country flood-proof over the 21st century by considering a paradigm shift, namely addressing coastal protection ‘working with nature’ and providing ‘room for river’ instead of only ‘fighting’ the forces of nature with engineered structures (Figure 5-7). This takes into account a sea-level rise of as high as 0.65-1.3 by 2100. Some of the recommendations include soft and environmentally friendly solutions such as preserving land from development to accommodate increased river inundation; raising the level of lakes to ensure a continuous supply of fresh water; removing existing protection structures to restore natural estuary and tidal regimes; improving the standards of flood protection by a factor of 10 until 2050; maintaining coastal protection by beach nourishment, expanding the coast seaward in the next century and putting in place the necessary political-administrative, legal and financial resources. The estimated total cost of implementing this ambitious plan is €2.5-3.1 billion a year to 2050, representing a 0.5% of the current Dutch annual gross national product (Stive *et al.*, 2011).

[INSERT FIGURE 5-7 HERE
Figure 5-7: Overview of the Delta Committee National Recommendations. Source: Stive et al., 2011.]

Aerts *et al.* (2008) estimated today’s economic damage from flooding based on differentiation according to water depth of all 53 dyke rings as approximately €190 billion covering both direct and indirect damage. The estimated future potential damage would be €400-€800 billion in 2040 and €3700 billion in 2100 in the absence of any measures, given a sea-level rise of 24-60 cm in 2040 and 150 cm in 2100. The factors that govern calculations of estimated future potential damage are economic growth combined with indirect damage. The Delta Committee suggested that, under the umbrella of this paradigm shift in the approach to water and coastal management, climate change offers key challenges that can result in societal and economic growth and evolution, moving the Netherlands into a sustainable country (Kabat *et al.*, 2009).

_____ END BOX 5-3 HERE _____

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Box 5-4. Climate Change Adaptation and Integrated Coastal Zone Management in Developing Countries

Integrated Coastal Zone Management (ICZM) promotes sectoral and spatial integration of various activities in the coastal zone by establishing coordination across various sectors and government institutions with a view to sustainably developing coastal resources and protecting the environment. This makes it feasible for combining climate change adaptation with ICZM as a part of an integrative effort in coastal management.

ICZM in developing countries fostered by international organizations, in particular, struggle to meet the goals of ICZM (Isager, 2008). The drawbacks in the implementation of their ICZM act as constraints in climate change adaptation within ICZM. For example, when initial funding by the external organizations disappears national governments have to step up to finance the cost of ICZM (Ibrahim and Shaw, 2012). Ineffective coastal governance is more visible in cases where the capacity of actors is low, the operation of single agency is dysfunctional, and subsequently, the integration of multiple coastal agencies is beyond the reach of many developing countries (Ibrahim and Shaw, 2012; Martinez *et al*., 2011). Politics are also a strong force because of the involvement of various stakeholders, the hierarchy of government agencies and ministries, and the power of the majority political party or political leaders (Tabet and Fanning, 2012; Isager, 2008). Furthermore, the nature of public participation in developing countries differs from that in developed countries, and different norms and cultures need to be taken into account to assess public participation central to ICZM (Barale and Özhan, 2010). In some cases, there is lack of knowledge regarding the coastal systems (González-Riancho *et al*., 2010).

As legal and institutional capabilities critical to the implementation of ICZM are often not available in developing countries, governments generate climate change adaptation strategies that are part of shoreline management plan, regional development, disaster management, and coastal resource management. Cases of adaptation strategies specific to climate change in practice are few as most are at the planning stage equipped with scenarios. Existing strategies derive from responses to coastal disasters and economic and social change affecting coastal livelihoods, for example, readily accessible and trained volunteers respond well by disseminating cyclone warnings and evacuating and rescuing people (WRI, 2007) and this could be translated into a strategy for climate change adaptation. Other strategies in progress or at the trial stage include forested buffer zones such as wetlands and mangroves (Mustelin *et al*., 2011) and incremental migration. The long-term results and their replicability need to be further assessed.

To anticipate climate change and adapt, a variety of strategies could be used in the future. No or low-regret options provide co-benefits to the goals of sustainable development, livelihood improvement, and human well-being (IPCC, 2012). Combining different strategies are also increasingly under consideration (Cheong, 2011; Cheong *et al*., 2013; Cartwright, 2009) including the blend of ecology and engineering such as mangrove planting, buffer zones and land use, and insurance and structural coastal defence (Yohe *et al*., 2011). Adaptation planning on different geographic scales ranging from international, national, and regional in addition to local is at work. Regional adaptation strategies (Martinez *et al*., 2011) and community-based adaptation (Cutter *et al*., 2012) are both on the rise. Although ICZM can be a valuable policy framework to integrate climate change adaptation and coastal management, no studies of the effectiveness of ICZM combined with climate change adaptation in developing countries exist yet to assess its utility. Furthermore, there is a need for more detailed understanding of the science of coastal change at the local level that can be coupled with existing adaptation strategies of coastal communities.

_____ END BOX 5-4 HERE _____

5.5.5. Adaptation Opportunities, Constraints, and Limits

During the last years the attention on adaptation opportunities, constraints and limits has grown considerably aiming at a better assessment of our knowledge on adaptation strategies. In order to avoid the existing confusion on the contents of these terms, definitions provided in Chapter 16, Box 16-1 are used here.

There is a growing recognition of the potential co-benefits and new opportunities that can be achieved by mainstreaming adaptation with existing local to national goals and priorities (Chapter 14). Disaster Risk Reduction (DRR) and adaptation share the common goals of reducing vulnerability against impacts of extreme events while creating strategies that limit risk from hazards (IPCC, 2012). This is especially true in coastal areas where extreme flooding events due to severe storm surges are one of the main sources of hazard (Box 5-5). Besides, integrating adaptation with national and local planning can also contribute to build resilience in coastal areas. There is a *very high agreement high confidence* that Integrated Coastal Zone Management (IZCM) can make it possible for coastal regions to achieve their diverse goals in their adaptation to climate change (*limited evidence*) (5.5.1.4).

Ecosystems-Based Adaptation (EBA) is considered to be an emerging adaptation opportunity for adaptation (Munroe *et al*. 2011). In coastal area the conservation or restoration of habitats (e.g. mangroves, wetlands and deltas) can provide effective measure against storm surge, saline intrusion and coastal erosion by using biodiversity and the ecosystem services they provide as a mean for adaptation (Jones *et al.*, 2012; Duarte *et al.* 2013, van Wesenbeeck, B.K., 2013, Borsje, *et al.*, 2011).

Since AR4 a variety of studies have been published producing a better understanding of the nature of the constraints and limits to adaptation, both generally (Chapter 16) and more specifically in the coastal sector (e.g., Lata and Nunn, 2011; Mozumber *et al.*, 2011; Storbjörk and Hedrén, 2011; Bedsworth and Hannak, 2010; Frazier *et al.*, 2010; Saroar *et al.*, 2010; Moser *et al.*, 2008; Tribbia and Moser, 2008; Ledoux *et al.*, 2005).

Researchers have categorized constraints in different ways (Chapter 16). The common link among all constraints is that they make adaptation less effective or they can lead to missed opportunities, difficult trade-offs, or higher costs. Several examples of constraints for specific for coastal adaptation can be found in the literature. Among others: polarized views in the community regarding the risk of sea level rise and concerns about fairness about retreat schemes in Australia (Ryan *et al.*, 2011); lack of awareness of sea level rise risks and spiritual beliefs in Fiji (Lata and Nunn 2011); insufficient budget for the development of adaptation policies and other currently pressing issues in the US (Mozumber *et al.*, 2011; Tribia and Moser, 2007 and 2008); distinct preferences for retreat options depending on several social and exposure conditions in Bangladesh (Saroar and Routray, 2010); need to provide compensatory habitats under the Habitats Regulations and lack of local public support in the UK (Ledoux *et al.* 2005).

The wide range of constraints identified in this assessment reflects different coastal management contexts, different foci on levels of governance and actors/decision-makers, as well as different methods used in identifying them. The commonly heard claim that lack of information is the main constraint to coastal adaptation is refuted by the wide range of constraints identified, and many of them are empirically shown to be more important than lack of locally relevant, credible information. (*high agreement, robust evidence*). Different constraints typically do not act in isolation, but come in interacting bundles (*high agreement, robust evidence*). Therefore it is difficult to predict which constraints matter most in any specific context but instead multiple constraints need to be addressed if adaptation is to move successfully through the different stages of the management process (*high agreement, moderate evidence*) (Moser and Ekstrom, 2010; Storbjörk, 2010; Londsdale *et al.*, 2010). Besides, some factors can act as enablers and add capacity to adapt, while acting as constraints at others (*high agreement, moderate evidence*) (Burch, 2010; Storbjörk, 2010).

Finally, a common concern emerging from the literature reviews (Biesbroek *et al.*, 2011; Ekstrom *et al.*, 2011) is that some critical constraints arise from the interactions across policy domains, existing laws and regulations, and long-term impacts of past decisions and policies (*high agreement, low evidence*). A limit is reached when adaptation efforts are unable to provide an acceptable level of security from risks to existing objectives and values and prevent the loss of the key attributes, components or services of ecosystem (Chapter 16, Box 16-1; 16.2, 16.5) and may arise due to most of the constraints described above.

As with regards coastal areas, it is widely recognized that biophysical limitations arise, for example, in small developing island states where adaptation through retreat to increasing impact of sea level rise in conjunction with storm surges and flooding is not an option due to limited high land availability, creating a temporary and eventually permanent human displacement from low-lying areas (Green *et al.* 2009; Pelling and Uitto, 2001),(*high agreement, moderate evidence*). Nicholls *et al.* 2011, show that only a limited number of adaptation options are available for specific coastal areas if sea level exceeds a certain threshold (1 m) at the end of the century.

As with regards to natural (unassisted) adaptation, several researchers have examined particularly biophysical limits, e.g., of coastal marshes (Kirwan *et al.*, 2010a, b; Craft *et al.*, 2009; Langley *et al.*, 2009; Mudd *et al.*, 2009). Kirwan *et al.* (2010a) found that coastal marshes can adapt to conservative rates of sea-level rise (A1B), as long as there is sufficient sediment supply. By contrast, even coastal marshes with high sediment supplies, will *likely* submerge near the end of the 21st century under scenarios of more rapid sea-level rise (e.g., those that include ice sheet melting).

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Box 5-5. Adaptation to Climate Change in the Framework of Coastal Disaster Management in Japan

Coastal disaster management in Japan is implemented through the Seacoast Law which was established in 1956 after the frequent severe natural disasters such as the Tonankai Earthquake Tsunami in 1944, Nankai Earthquake Tsunami in 1946 and Typhoon No. 13 in 1953. The aim of the law was to "protect the country's seacoast from damage due to sea or ground movement including, but not limited to, tsunami, storm surges and high waves". Later, in 1999, the law was amended to include "conservation of the coastal environment" and "promotion of proper use of the coast by public" in view of various functions of the coast. Under these laws the prefectural governors of each of 71 coastal zones covering the whole coastline in Japan shall established a master plan for coastal conservation. If deemed necessary to take management measures against damages the prefectural governor may designate seacoast conservation areas within the coastal zone. By 2010, about 14,200 km out of the total 35,300 km coastline have been designated and about 9,600 km was protected by coastal structures (River Bureau, 2011).

The crown height of coastal protection structures is determined from the height necessary of storm surges and tsunamis with an additional allowance. The sea-level rise at the time of design is taken into consideration by using the latest tide record. After the 2011 Tohoku Earthquake Tsunami, the Central Disaster Management Council (2011) decided to reconstruct protective coastal structures against the relatively frequent tsunamis (with a return period of several tens to one hundred and some years) and to save human lives by evacuation and all other means for the tsunami of the largest class based on scientific knowledge.

On this basis, the Committee on Adaptation Strategy for Global Warming in the Coastal Zone (2011) developed a manual for adaptation. According to the report, the land area below the mean sea level increases by about 50% in the three major bay areas (Tokyo, Nagoya and Osaka) if the sea level rises by 59 cm which is the highest projection in the IPCC (2007) Fourth Assessment Report. In the Tokyo Bay, the inundation area with a sea-level rise of 60 cm was predicted for Typhoon Muroto which landed on the western part of Japan in 1934 and is stronger than the present design typhoon by 40%. The results showed that 265 km^2 of the Tokyo metropolitan area would be inundated.

In order to develop an adaptation strategy, a case study on the criterion for priority was done. Two indicators were selected and calculated for each section of the land area. One indicator is evaluated from the age and earthquake resistance of the coastal structures in the section, reflecting the soundness of the structures and the urgency for improvement. The other reflects the effectiveness of the structural protection which is evaluated from the damage based on the assets in the predicted inundation area. Figure 5-8 shows the diagram for judging priority of adaptation to global warming. In Tokyo Bay, the allowance in the design crown height has absorbed the sea-level rise up to the present. However, adaptation to the future climate change needs to be implemented according to the diagram in parallel to improvement to aging coastal structures and earthquake resistance.

[INSERT FIGURE 5-8 HERE
Figure 5-8: Priority in investment for adaptation to global warming.]

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5.5.6. Synergies and Tradeoffs between Mitigation and Adaptation

Klein *et al.* (2007, p. 749) defined trade-offs between mitigation and adaptation as the "balancing of adaptation and mitigation when it is not possible to carry out both activities fully at the same time (e.g., due to financial or other constraints)". Successful adaptive coastal management of climate risks will involve assessing and minimizing potential trade-offs with other non-climate policy goals (e.g., economic development, enhancement of coastal tourism) and interactions between adaptation and mitigation (e.g. Bunce *et al.*, 2010b; Barbier *et al.*, 2008; Tol 2007; Brown *et al.*, 2002).

A range of studies suggest that adaptation will be the predominant approach to reducing climate risks to coastal communities, populations, resources and activities over the 21st because large increases in sea-level rise cannot be ruled out (WG1, Chapter 13, 13.5.2.) and because of the time lag between emission reductions, temperature changes and impacts on global sea levels (Nicholls *et al*., 2011; Nicholls *et al*., 2007). Systematic assessment of potential synergies and trade-offs between mitigation, adaptation, and other, non-climatic policy goals and efforts to maintain or increase flexibility to enable policy adjustments in the future have been proposed as strategies to recognize, avoid and minimize the risk of negative policy interactions (e.g., Vermaat *et al.* 2005; Nicholls *et al.,* 2011; Chapter 20, 20.3.3.).

Positive synergies and complementarities between mitigation and adaptation in the coastal sector exist. Marine vegetated habitats (seagrasses, saltmarshes, macroalgae or mangroves) contribute to 50% of the total carbon burial in ocean sediments and provide additional functions including the buffering of impacts against storm surges and waves, soil preservation, raising the seafloor and shelter for fish nursery or habitat protection (Duarte *et al.* 2013, Alongi, 2002, Kennedy and Björk, 2009). Consequently, restoration or ecosystem engineering of marine vegetated areas can be considered as a good example of positive synergies between adaptation and mitigation in coastal areas (Duarte *et al.* 2013, Jones, *et al.* 2012, Borsje *et al.* 2011).

Many coastal zone-based activities and various coastal management activities involve emissions of greenhouse gases, the reduction or cessation of some of the may have positive implications for both mitigation and adaptation. The reduction/cessation of offshore oil production will imply a reduction in liquid fuel-related GHG emissions but would also imply a reduced risk of oil spills, a reduction of stresses on the marine/coastal eco-systems and variable socio-economic impacts on human communities and public health (O'Rourke and Connolly, 2003). This may result in reduced vulnerability or increased resilience and consequently a positive for adaptation.

However, some of the coastal adaptation options may have potential negative implications on mitigation. Relocation of infrastructure and development out of the coastal floodplains (retreat) will imply increase in one-time GHG emissions due to rebuilding of structures and possible increase in sprawl and ongoing transportation-related emissions (Biesbroek *et al.* 2009). The building or upgrading of coastal protection structures or ports will also imply an increased energy use and GHG emissions related to construction (cement production) (Boden *et al.* 2011).

Similarly, actions beneficial for mitigation in coastal areas may result in potential negative impacts for adaptation. A more compact coastal urban design, increasing development in floodplains (Giridharan *et al.* 2007) or the development of offshore renewable energy introducing additional drivers on near- and offshore coastal and marine ecosystems and species, are some examples.

5.5.7. Commitment to Adaptation

Recent results (Meehl *et al.* 2012) from global coupled climate model simulations with the new RCPs scenarios to 2300 confirm AR4 (Meehl *et al.* 2007) and indicate that there is a commitment to further sea level rise even if temperatures stabilize due to different levels of mitigation measures. This is mostly due to thermal expansion of seawater and the melting of ice-sheets and glaciers (WG1, Chapter 13).

Table 5-2 summarizes projections from (WG1, Chapter 13) for different extended RCPs for time horizons ranging to 2500 and considering GHG concentrations > 700 ppm. Results show that with aggressive mitigation measures in RCP2.6 limiting global warming, sea level continues to rise after 2100. With more moderate (RCP4.5.) and little (RCP8.5) mitigation, larger ongoing increases in sea level are expected lasting for several centuries.

It can be concluded that since AR4, there is *high agreement* that benefits from mitigation are most immediate for ocean acidification and least immediate for impacts related to sea level rise. A detailed discussion on adaptation efforts mitigation efforts and residual impacts can be found in Chapter 19.

A limited number of studies have estimated impacts due to sea level rise under low or high emission scenarios. Pardaens et al (2011), using projections from two coupled climate models considered the effects on 21st century sea-level rise of mitigation policies, under which the global-mean air temperature stabilizes close to a 2ºC increase, relative to a scenario of business-as-usual (a variant of the A1B scenario). The model-averaged projected sea level rise for 2090–2099 relative to 1980–1999 is 0.29 m–0.51 m and a reduced range under mitigation of 0.17 m–0.34 m, primarily due to reduced thermal expansion. To estimate impacts on coastal populations of the sea level rise projections, the Dynamic Interactive Vulnerability Assessment (DIVA) model was used. Results suggest that by the end of the 21st century and without adaptation around 55% of the 84 million additional people flooded from sea level rise per year globally, under the business-as-usual scenario, could be avoided under such mitigation.

On the other end Nicholls *et al*. (2011) considering an estimate of sea-level rise by 2100, between 0.5 m and 2 m, for a temperature rise of 4°C or more over the same time frame and no mitigation, showed that a real risk of the forced displacement of up to 187 million people over the century (up to 2.4% of global population) exists. By introducing upgrade of protection structures as an adaptation option, it is estimated that the likelihood of protection being successfully implemented varies between regions, and is lowest in small islands, Africa and parts of Asia.

In summary, mitigation plays a role in reducing climate change risk in coastal areas. The intensity and time scale varies depending on the impact considered. Even with aggressive mitigation options future sea-level rise will continue for centuries, but model results show that it can be slowed down, providing more time for long-term strategic adaptation measures to be adopted.

5.6. Information Gaps, Data Gaps, and Research Needs

This chapter has updated knowledge about the impacts of climate change on the coastal systems not in isolation but also from the perspective of overexploitation and degradation that have been responsible for most of the historical changes. There is a better understanding of the varying impacts of weather and climate extremes and long-term sea-level rise on human systems.

That sea levels will rise is a confident projection of climate science but uncertainties around the magnitude of future sea lever rise remain large. It is very likely that GMSL rise during the 21sy century will exceed the observed rate for the period 1971-2100 (Chapter 13, WGI) and that sea level rise will continue to rise for several hundred years even if temperature is stabilized at 2-3ºC above pre-industrial values (Meehl *et al*., 2012). However, many sea level rise assessments are not at spatial or temporal scales most relevant for decision makers who require information on baseline conditions and projections of change (Kettle, 2012) of relative sea level rise (i.e. including local subsidence) for vulnerability assessment and adaptation planning.

Quantitative predictions of future coastal change remain difficult despite the application of improvements in technology, e.g., aerial photographs, satellite imagery, LiDAR (Sesil *et al*., 2009; Revell *et al*., 2011; Pe'eri and Long, 2012) to investigate and characterize large-scale changes in shoreline. There is incomplete understanding of coastal changes over the decade and century timescales (Woodroffe and Murray-Wallace, 2012). Shoreline response is more complex than simple submergence because of factors such as sediment supply, offshore geology, engineering structures, and wave forcing (Ashton *et al*., 2008).

The projection of the future impacts of climate change on natural systems is hampered by the lack of sufficiently detailed data at the required levels of space and time. Observed impacts on beaches, rocky coasts, wetlands, coastal aquifers or deltas area due to the joint effect of multi-drivers of climate and human-induced origin. There is still incomplete understanding of the relative role played by each of these drivers and, especially on their combined effect. Uncertainties are even higher when it comes to the evaluation of projected impacts. For coastal ecosystems virtually all data used to parametrize predictive models have been gathered during perturbation experiments involving only one driver, performed on isolated organisms in the laboratory, and on short periods of time (typically days to weeks). Reliable predictions require information on multifactorial experiments performed on communities (preferably in the field), and on time scale of months to years in order to take into consideration the processes of biological acclimation and adaptation.

Although sea level is projected to rise in future, there are significant gaps in vulnerability assessment of other specific coastal impacts. For example, climate modeling of diseases that could affect coastal areas is based mainly on the mean values of climate. Also, despite tourism as one of most important industries in the coastal areas, not enough is known about tourists' behavioural reactions to projected climatic changes (Moreno and Amelung, 2009).

A wide range of coastal management framework and measures is available and used in coastal adaptation to climate change, and their scope for their integration has increased by combining scenarios of climate change and socio-economic conditions and risk assessment (Kirshen *et al.,* 2012). While various adaptation measures are available, at the local level, there remains insufficient information on assessment of adaptation options. Data and knowledge gaps exist or their reliability is insufficient. Despite the availability of potential useful climate information, a gap exists between what is useful information for scientists and for users in decision-making. The proposed actions to improve usability include varying levels of interaction, customization, value-adding, retailing and wholesaling (Lemos *et al*., 2012) so that data and methods can be more openly-accessable to fellow scientists and public (Kleiner, 2011).

Coastal systems are affected by human and climate drivers and there are also complex interactions between the two. In general, where components of coastal systems are sensitive to temperature change, there is a greater degree of confidence that climate change has played a role. Data are available on the range shift in coastal plant and animal species and the role of higher temperatures on coral bleaching. However, in many cases in the human systems, the detected changes can be largely attributed to human drivers. Reducing our knowledge gaps on the understanding of the processes inducing changes would help to respond to them in an efficient way.

The economics of coastal adaptation is under researched. More comprehensive assessments of adaptation costs and benefits that simultaneously consider both the gradual impact of land loss due to sea level rise and the stochastic impacts of extreme water levels (storm surges, cyclones) are needed, as well as other impacts such as salt water intrusion, wetland loss and change and backwater effects. Assessments should also consider a more comprehensive range of adaptation options and strategies, including “soft” protection, accommodation and retreat options as well as the trade-offs between these.

Governance of coastal adaptation and the role of institutions in the transition towards sustainable coasts are under-researched. While institutional factors are recognized to be decisive in constraining and enabling coastal adaptation, there is little dedicated social science research aiming at understanding which institutional arrangement are effective in which socio-economic and biophysical contexts.

Developing a coastal adaptation knowledge network between scientists, policy makers, stakeholders and the general public could be considered as a priority area for coastal areas of large or regional areas affected by climate change and sea-level rise. This is well developed in the European Union, the Mediterranean and Australia but less so in the developing countries, except in certain regions, e.g. Caribbean islands, Pacific Islands.

Future research needs for coastal adaptation are identified by several developments in climate science. Based on Li *et al.* (2011) survey of the foci of climate research in the 21st century, the implications for coasts would be on biodiversity and flooding. Future technological advances may be significant, e.g., new forms of energy and food production, information and communication technology (ICT) for risk monitoring (Delta Commission, 2008) and these would be useful for flood risks and food production in deltas and coastal systems (aquaculture). With recent adverse climatic and environmental events on coasts, adaptation demands different decision regimes (Kiker *et al.,* 2010) but adaptation, mitigation and avoidance measures still require integrating research that includes natural and social sciences (CCSP, 2009). Although many gaps still remain, there is nevertheless a greater foundation of climate change research on coasts across a wide range of fields (Grieneisen and Zhang, 2011) upon which scientists, policymakers and public may find improved solutions for coastal adaptation.

Frequently Asked Questions

FAQ 5.1: How does climate change affect coastal ecosystems?

The major climate-related drivers affecting coastal ecosystems are sea-level rise, ocean warming and ocean acidification. The impact of sea level is mostly related to the capacity by animals (e.g. corals) and plants (e.g. mangroves) to keep up with the vertical rise of the sea. Ocean warming affects all organisms, increasing their metabolism, causing mass mortality events of those living close their upper thermal limit, and/or affecting their geographical distribution. Ocean acidification negatively impacts many organisms that build shells and skeletons but its effects are poorly known at the ecosystem level.

FAQ 5.2: How is climate change influencing coastal erosion?
Coastal erosion can be caused by winds, waves and currents, especially during storms, as well as sea-level rise and for deltas, river sediment transport and deposition are important factors. Based on the simplest model, a rise in mean sea level usually results in a landward and upward displacement of the cross-shore seabed profile and a retreat of the shoreline. Increasing waves heights can cause the sand bars to move seawards and high storm surges (sea levels) also produce an offshore movement of sand due to non-equilibrium in the profile. Higher waves and surges may increase the probability of sand barrier and dune overwash or breaching. Changes in wave direction may result in increased sediment transport and subsequent erosion.

FAQ 5.3: How can coastal communities adapt to climate change impacts?
Various adaptation strategies are available which range from (managed) retreat, accommodation and protection. Adaptation through structural measures includes hard (e.g. sea walls) and soft (e.g. coastal revegetation) management options. Non-structural measures include land-use planning (e.g. rolling easements that require relocation of vulnerable infrastructure as critical risk thresholds are crossed) and climate-aware policies and plans, including EIA and building codes. Monitoring and compliance are required to ensure implementation of plans. Education is also important for building community resilience. Risk transfer mechanisms (e.g. insurance) address residual risk although where risks are too high, retreat from coastal areas may be the only viable response. A combination of strategies, tailored to suit the particular coastal community, may be required and will need to be reviewed and adjusted as circumstances change in the future.

FAQ 5.4: Does adequate planning for coastal uses contribute to a reduction in climate change risks?
Yes, adequate planning of coastal uses contributes to reduced climate change risks and lessens the chances of reactive responses to the impacts of extreme events. Such planning is normally supported by national legislation and considers both the problems of both climate change and coastal hazards, especially coastal flooding. Regional coastal strategies and plans are established with guidelines for local governments to implement. For measures to be taken, the focus is on precautionary measures irrespective of future climate change. An important paradigm change of planning land uses to reduce climate change is to use the buffer zone as a response to coastal inundation. The strategy is to work with nature rather than against nature, e.g. in the Netherlands. It should be noted that for many developing countries planning at the grass-root level either does not exist or is not yet workable requiring re-evaluation of how to make adaptation more sustainable..

FAQ 5.5: How does ocean acidification affect marine and coastal areas and islands?
PH, a measure of seawater acidity, has numerous implications on biological and geological systems. For example, in coastal systems, it plays a role in primary production which constitutes the base of the food chain, in the deposition of calcium carbonate in shells and skeletons, in the degradation of limestone, as well as in the abundance of certain forms of chemical elements and on their toxicity. Ocean acidification has therefore a lot of ramifications on the biology, ecology, biogeochemistry, and socio-economy of coastal systems. Some of these ramifications are well understood while others such as changes in coastal food-webs and fisheries are poorly known.

Cross-Chapter Boxes

Box CC-CR. Coral Reefs

[Jean-Pierre Gattuso (France), Ove Hoegh-Guldberg (Australia), Hans-Otto Pörtner (Germany)]

Coral reefs are shallow-water structures made of calcium carbonate mostly secreted by reef-building (scleractinian) corals and encrusting macroalgae. They occupy less than 0.1% of the ocean floor yet play multiple important roles throughout the tropics. About 275 million people live within 30 km of a coral reef (Burke et al., 2011) and are likely to derive some benefits from the ecosystem services that coral reefs provide (Hoegh-Guldberg, 2011) including those from provisioning (food, construction material, medicine), regulating (shoreline protection, water quality), supporting services (oxygen supply) and cultural (religion, tourism). This is especially true in small islands (29.3.3.1).

Most human-induced disturbances to coral reefs were local (e.g., coastal development, pollution, nutrient enrichment and overfishing) until the early 1980s when global and climate-related disturbances (ocean warming and acidification) began to occur. Temperature and seawater acidity are two of the most important environmental variables determining the distribution of coral reefs (Kleypas et al., 2001). As corals are centrally important as ecosystem engineers (Wild et al., 2011), the impacts on corals have led to widespread degradation of coral reefs.

A wide range of climatic and non-climatic stressors affect corals and coral reefs and negative impacts are already observed (5.4.2.4, 30.5.3, 30.5.6). Bleaching involves the breakdown and loss of endosymbiotic algae (genus *Symbiodinium*), which live in the coral tissues and play a key role in supplying the coral host with energy and nutrients (Baker et al., 2008) (see 6.2.5 for physiological details and 30.5 for a regional analysis). Mass coral bleaching and mortality, triggered by positive temperature anomalies, is the most widespread and conspicuous impact (Fig. 5X; see Sections, 5.4.2.4, 6.2.5, 25.6.2, 30.5 and 30.8.2). For example, the level of thermal stress at most of the 47 reef sites where bleaching occurred during 1997-98 was unmatched in the period 1903 to 1999 (Lough, 2000). Elevated temperature along with ocean acidification reduces the calcification rate of corals (*high confidence*; 5.4.2.4), and may tip the calcium carbonate balance of reef frameworks towards dissolution (*medium evidence and agreement*; 5.4.2.4). These changes will erode fish habitats with cascading effects reaching fish community structure and associated fisheries (*robust evidence, high agreement*, 30.5).

Around 50% of all coral reefs have experienced medium-high to very high impact of human activities (30-50% to 50-70% degraded; Halpern et al., 2008), which has been a significant stressor for over 50 years in many cases. As a result, the abundance of reef building corals is in rapid decline (1 to 2% per year, 1997-2003) in many Pacific and SE Asian regions (Bruno and Selig, 2007). Similarly, the abundance of reef-building corals has decreased by over 80% on many Caribbean reefs (1977 to 2001; Gardner et al., 2003), with a dramatic phase shift from corals to seaweeds occurring on Jamaican reefs (Hughes, 1994). Tropical cyclones, coral predators and coral bleaching have led to a decline in coral cover on the Great Barrier Reef (about 51% between 1985 and 2012; De'ath et al., 2012).

One third of all coral species exhibit a high risk of extinction, based on recent patterns of decline and other factors such as reproductive strategy (Carpenter et al., 2008). Although less well documented, non-coral benthic invertebrates are also at risk (Przeslawski et al., 2008). Fish biodiversity is threatened by the permanent degradation coral reefs, including in a marine reserve (Jones et al., 2004). While many factors, such as overfishing and local pollution, are involved in the decline of coral reefs, climate change through its pervasive influence on sea temperature, ocean acidity, and storm strength plays a very significant role.

There is *robust evidence* and *high agreement* that coral reefs are one of the most vulnerable marine ecosystems (Chapters 5, 6, 25, and 30). Globally, more than half of the world's reefs are under medium or high risk of degradation (Burke et al., 2011) even in the absence of climatic factors. Future impacts of climate stressors (ocean warming, acidification and sea level rise) will exacerbate the impacts of non-climatic stressors (*high agreement*, *robust evidence*). Even under optimistic assumptions regarding corals being able to rapidly adapt to thermal stress, one-third (9–60%, 68% uncertainty range) of the world's coral reefs are projected to be subject to long-term degradation under the RCP3-PD scenario (Frieler et al., 2013). Under the RCP4.5 scenario, this fraction increases to two-thirds (30–88%, 68% uncertainty range). If present day corals have residual capacity to acclimatize and/or adapt, half of the coral reefs may avoid high frequency bleaching through 2100 (*limited evidence, limited agreement*; Logan et al., sbm). Evidence of corals adapting rapidly, however, to climate change is missing or equivocal (Hoegh-Guldberg, 2012).

Damage to coral reefs has implications for several key regional services:

- *Resources*: Coral reefs produce 10-12% of the fish caught in tropical countries, and 20-25% of the fish caught by developing nations (Garcia & Moreno, 2003). Over half (55%) of the 49 island countries considered by Newton et al. (2012) are already exploiting their coral reef fisheries in an unsustainable way (13.X.X).

- *Tourism*: More than 100 countries benefit from the recreational value provided by their coral reefs (Burke et al., 2011). For example, the Great Barrier Reef Marine Park attracts about 1.9 million visits each year and generates A$ 5.4 billion to the Australian economy and 54,000 jobs (90% in the tourism sector; Biggs, 2011).
- *Coastal* protection: Coral reefs contribute to protecting the shoreline from the destructive action of storm surges and cyclones (Sheppard et al., 2005), sheltering the only habitable land for several island nations, habitats suitable for the establishment and maintenance of mangroves and wetlands, as well as areas for recreational activities. This role is threatened by future sea level rise, the decrease in coral cover, reduced rates of calcification and higher rates of dissolution and bioerosion due to ocean warming and acidification (5.4.2.4, 6.4, 30.5).

Coral reefs make a modest contribution to the global domestic product but their economic importance can be high at the country and regional scales (Pratchett et al., 2008). For example, tourism and fisheries represent on average 5% of the GDP of South Pacific islands (Laurans et al., 2013). At the local scale, these two services provide at least 25% of the annual income of villages in Vanuatu and Fiji (Pascal, 2011; Laurans et al., 2013).

Marine protected areas (MPAs) and fisheries management have the potential to increase ecosystem resilience and increase the recovery of coral reefs after climate change impacts such as mass coral bleaching (McLeod et al., 2009). Although they are key conservation and management tools, they are less effective in reducing coral loss from thermal stress (Selig et al., 2012) suggesting that they need to be complemented with additional and alternative strategies (Rau et al., 2012). Controlling the input of nutrients and sediment from land is an important complementary management strategy because nutrient enrichment can increase the susceptibility of corals to bleaching (Wiedenmann et al., 2012). There is also high confidence that, in the long term, limiting the amount of warming and acidity is central to ensuring the viability of coral reef systems and dependent communities (5.X.X and 30.5).

[INSERT FIGURE CR-1 HERE
Figure CR-1: A and B: the same coral community before and after a bleaching event in February 2002 at 5 m depth, Halfway Island, Great Barrier Reef. Coral cover at the time of bleaching was 95% bleached almost all of it severely bleached, resulting in mortality of 20.9% (Elvidge et al., 2004). Mortality was comparatively low due in part because these communities were able shuffle symbiont types to more thermo-tolerant types (Berkelmans and van Oppen, 2006; Jones et al., 2008). C and D: three CO2 seeps in Milne Bay Province, Papua New Guinea show that prolonged exposure to high CO2 is related to fundamental changes in coral reef structures (Fabricius et al., 2011). Coral communities at three high CO2 (Fig. XB; median pHT 7.7, 7.7 and 8.0), compared with three control sites (Fig. XA; median pHT 8.02), are characterized by significantly reduced coral diversity (-39%), severely reduced structural complexity (-67%), low densities of young corals (-66%) and few crustose coralline algae (-85%). Reef development ceases at pHT values below 7.7. Photo credit: R. Berkelmans (A and B) and K. Fabricius (C and D).]

CC-CR References

Baker A. C., Glynn P. W. & Riegl B., 2008. Climate change and coral reef bleaching: An ecological assessment of long-term impacts, recovery trends and future outlook. Estuarine, Coastal and Shelf Science 80:435-471.

Bruno J. F. & Selig E. R., 2007. Regional decline of coral cover in the Indo-Pacific: timing, extent, and subregional comparisons. PLoS One 2:e711.

Burke L. M., Reytar K., Spalding M. & Perry A., 2011. Reefs at risk revisited. 114 p. Washington, DC: World Resources Institute.

Carpenter K., E., Abrar M., Aeby G., Aronson R., B., Banks S., Bruckner A., Chiriboga A., Cortes J., Delbeek J., Charles, DeVantier L., Edgar G., J., Edwards A., J., Fenner D., Guzman H., M., Hoeksema B., W., Hodgson G., Johan O., Licuanan W., Y., Livingstone S., R., Lovell E., R., Moore J., A., Obura D., O., Ochavillo D., Polidoro B., A., Precht W., F., Quibilan M., C., Reboton C., Richards Z., T., Rogers A., D., Sanciangco J., Sheppard A., Sheppard C., Smith J., Stuart S., Turak E., Veron J., E. N., Wallace C., Weil E. & Wood E., 2008. One-third of reef-building corals face elevated extinction risk from climate change and local impacts. Science 321:560-563.

De'ath G., Fabricius K. E., Sweatman H. & Puotinen M., 2012. The 27-year decline of coral cover on the Great Barrier Reef and its causes. Proceedings of the National Academy of Science U.S.A. 109:17995-17999.

Frieler K., Meinshausen M., Golly A., Mengel M., Lebek K., Donner S. D. & Hoegh-Guldberg O., 2013. Limiting global warming to 2 °C is unlikely to save most coral reefs. Nature Climate Change 3:165-170.

Garcia S. M. & de Leiva Moreno I., 2003. Global overview of marine fisheries. In: Sinclair M. & Valdimarsson G. (Eds.), Responsible fisheries in the marine ecosystem, pp. 1-24. Wallingford: CABI.

Gardner T. A., Cote I. M., Gill J. A., Grant A. & Watkinson A. R., 2003. Long-term region-wide declines in Caribbean corals. Science 301(5635): 958-960.

Hoegh-Guldberg O., 2011. Coral reef ecosystems and anthropogenic climate change. Regional Environmental Change 11:215-227.

Hoegh-Guldberg O., 2012. The adaptation of coral reefs to climate change: is the Red Queen being outpaced? Scientia Marina 76:403-408.

Hughes T. P., 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science 265(5178): 1547-1551.

Jones G. P., McCormick M. I., Srinivasan M. & Eagle J. V., 2004. Coral decline threatens fish biodiversity in marine reserves. Proceedings of the National Academy of Science U.S.A. 101:8251-8253.

Kleypas J. A., Buddemeier R. W. & Gattuso J.-P., 2001. The future of coral reefs in an age of global change. International Journal of Earth Sciences 90:426-437.

Laurans Y., Pascal N., Binet T., Brander L., Clua E., David G., Rojat D. & Seidl A., 2013. Economic valuation of ecosystem services from coral reefs in the South Pacific: taking stock of recent experience. Journal of Environmental Management 116C:135-144.

Lough J. M., 2000. 1997-98: Unprecedented thermal stress to coral reefs? Geophys. Res. Lett. 27(23): 3901-3904.

McLeod E., Salm R., Green A. & Almany J., 2009. Designing marine protected area networks to address the impacts of climate change. Frontiers in Ecology and the Environment 7:362-370.

Newton K., Côté I. M., Pilling G. M., Jennings S. & Dulvy N. K., 2007. Current and future sustainability of island coral reef fisheries. Current Biology 17:655-658.

Pascal N., 2011. Cost-benefit analysis of community-based marine protected areas: 5 case studies in Vanuatu. 107 p. Moorea, French Polynesia: CRISP-CRIOBE.

Pratchett M. S., Munday P. L. & Wilson S. K., 2008. Effects of climate-induced coral bleaching on coral-reef fishes- Ecological and economic consequences. Oceanography and Marine Biology: an Annual Review 46:251-296.

Przeslawski R., Ahyong S., Byrne M., Worheide G. & Hutchings P., 2008. Beyond corals and fish: the effects of climate change on noncoral benthic invertebrates of tropical reefs. Global Change Biology 14:2773-2795.

Rau G. H., McLeod E. L. & Hoegh-Guldberg O., 2012. The need for new ocean conservation strategies in a high-carbon dioxide world. Nature Climate Change 2:720-724.

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

Wiedenmann J., D'Angelo C., Smith E. G., Hunt A. N., Legiret F.-E., Postle A. D. & Achterberg E. P., 2013. Nutrient enrichment can increase the susceptibility of reef corals to bleaching. Nature Climate Change 3:160-164.

Wild C., Hoegh-Guldberg O., Naumann M. S., Florencia Colombo-Pallotta M., Ateweberhan M., Fitt W. K., Iglesias-Prieto R., Palmer C., Bythell J. C., Ortiz J.-C., Loya Y. & van Woesik R., 2011. Climate change impedes scleractinian corals as primary reef ecosystem engineers. Marine and Freshwater Research 62:205-215.

Box CC-OA. Ocean Acidification

[Jean-Pierre Gattuso (France), Peter Brewer (USA), Ove Hoegh-Guldberg (Australia), Joan A. Kleypas (USA), Hans-Otto Pörtner (Germany), Daniela Schmidt (UK)]

Introduction

Anthropogenic ocean acidification and climate change share the same primary cause at the global level, the increase of atmospheric carbon dioxide (WGI, 2.2.1). Eutrophication and upwelling contribute to local ocean acidification (5.3.3.6, 30.5.4). Past and futures changes in chemistry are well known in the surface open ocean (WGI, 3.8.2 and 6.4.4) but are more difficult to project in the more complex coastal systems (5.3.3.6 and 30.5.2).

Chemistry and Projections

The fundamental chemistry of ocean acidification has long been understood: the uptake of CO_2 into mildly alkaline ocean results in an increase in dissolved CO_2 and reductions in pH, dissolved carbonate ion, and the capacity of seawater to buffer changes in its chemistry (*very high confidence*). The changing chemistry of surface seawater can be projected at the global scale with high accuracy from projections of atmospheric CO_2 levels. Time series observations of changing upper ocean CO_2 chemistry support this linkage (WGI Table 3.2 and Figure 3.17; WGII Figure 30.5). Projections of regional changes, especially in coastal waters (5.3.3.6), and at depth are more difficult;

observations and models show with high certainty that fossil fuel CO_2 has penetrated at depths of 1 km and more. Importantly, the natural buffering of increased CO_2 is less in deep than in surface water and thus a greater chemical impact is projected. Additional significant CO_2 increases and pH decreases at mid-depths are expected to result from increases in microbial respiration induced by warming. Projected changes in open ocean, surface water chemistry for year 2100 based on representative concentration pathways (WGII, Figure 6.28) compared to preindustrial values range from a pH change of -0.14 unit with RCP 2.6 (421 ppm CO_2, +1 ºC, 22% reduction of carbonate ion concentration) to a pH change of -0.43 unit with RCP 8.5 (936 ppm CO_2, +3.7 ºC, 56% reduction of carbonate ion concentration).

Biological, Ecological, and Biogeochemical Impacts

The effects of ocean acidification on marine organisms and ecosystems have only recently been investigated. A wide range of sensitivities to projected rates of ocean acidification exists within and across organism groups and phyla with a trend for higher sensitivity in early life stages (*high confidence*; Kroeker et al., in press; 6.2.3-5, 6.3.4). A pattern of impacts, some positive, others negative, emerges for some processes and organisms (*high confidence*; Fig. X.C) but key uncertainties remain from organismal to ecosystem levels (Chap. 5, 6, 30). Responses to ocean acidification are exacerbated at high temperature extremes (*medium confidence*) and can be influenced by other drivers, such as oxygen concentration, nutrients, and light availability (*medium confidence*).

Experimental evidence shows that lower pH decreases the rate of calcification of most, but not all, sea-floor calcifiers such as reef-building corals (Box CC-CR, coralline algae (Raven, in press), bivalves and snails (Gazeau et al., in press) reducing their competitiveness compared to, e.g. seaweeds (Chap. 5, 6, 30). A reduced performance of these ecosystem builders would affect the other components of the ecosystem dependent on the habitats they create.

Growth and primary production are stimulated in seagrass and some phytoplankton (*high confidence*) and harmful algal blooms could become more frequent (*limited evidence, medium agreement*). Ocean acidification may significantly stimulate nitrogen fixation in the oceans (*limited evidence, low agreement*; 6.2.3, 6.3.4). There are few known direct effects on early stages of fish and adult fish remain relatively undisturbed by elevated CO_2. Serious behavioral disturbances were reported, mostly on larval and juvenile coral reef fishes (6.2.4).

Projections of ocean acidification effects at the ecosystem level are limited by the diversity of species-level responses. Natural analogues at CO_2 vents indicate decreased species diversity, biomass and trophic complexity of communities living on the sea-floor. Shifts in community structure have been documented in rocky shore environments (e.g., Wootton et al., 2008), in relation with rapidly declining pH (Wootton and Pfister, 2012). Differential sensitivities and associated shifts in performance and distribution will change predator-prey relationships and competitive interactions (6.2-3), which could impact food webs and higher trophic levels (*limited evidence, high agreement*).

There is *limited evidence* and *medium agreement* that some phytoplankton and mollusks can adapt to ocean acidification, indicating that the long-term responses of these organisms to ocean acidification could be less than responses obtained in short-term experiments. However, mass extinctions during much slower rates of ocean acidification in Earth history (6.1.2) suggest that evolutionary rates are not fast enough for sensitive animals and plants to adapt to the projected rate of change (*high confidence*).

The effect of ocean acidification on global biogeochemical cycles is difficult to predict due to the species-specific responses to ocean acidification, lack of understanding of the effects on trophic interactions, and largely unexplored combined responses to ocean acidification and other climatic and non-climatic drivers, such as temperature, concentrations of oxygen and nutrients, and light availability.

Risks

Climate risk is defined as the probability that climate change will cause specific physical hazards and that those hazards will cause impacts (19.5.2). The risks of ocean acidification to marine organisms, ecosystems, and ultimately to human societies, includes both the probability that ocean acidification will affect key processes, and the magnitude of the resulting impacts. The changes in key processes mentioned above present significant ramifications on ecosystems and ecosystem services (Fig. 19.3). For example, ocean acidification will cause a decrease of calcification of corals, which will cause not only a reduction in the coral's ability to grow its skeleton, but also in its contribution to reef building (*high confidence*; 5.4.2.4). These changes will have consequences for the entire coral reef community and on the ecosystem services that coral reefs provide such as fisheries habitat (*medium confidence*; 19.5.2) and coastal protection (*medium confidence*; Box CC-CR). Ocean acidification poses many other potential risks, but these cannot yet be quantitatively assessed due to the small number of studies available, particularly on the magnitude of the ecological and socioeconomic impacts (19.5.2).

Socioeconomic Impacts and Costs

The biological, ecological and biogeochemical changes driven by ocean acidification will affect several key ecosystem services. The oceans will become less efficient at absorbing CO_2, hence less efficient at moderating climate change, as their CO_2 content will increase (*very high confidence*). The impacts of ocean acidification on coral reefs, together with those of bleaching and sea level rise, will in turn diminish their role of shoreline protection in atolls and small island nations as well as their direct and indirect benefits on the tourism industry (*limited evidence, high agreement*; Box CC-CR).

There is no global estimate of the observed or projected economic costs of ocean acidification. The production of commercially-exploited shelled mollusks may decrease (Barton et al., 2012) resulting in an up to 13% reduction of US production (limited evidence, low agreement; Cooley and Doney, 2009). The global cost of production loss of mollusks could be over 100 billion USD by 2100 (Narita et al., 2012). The largest uncertainty is how the impacts on prey will propagate through the marine food webs and to top predators. Models suggest that ocean acidification will generally reduce fish biomass and catch (*limited evidence, high agreement*) and that complex additive, antagonistic and/or synergistic interactions will occur with other environmental (warming) and human (fisheries management) factors (Branch et al., 2012; Griffith et al., 2012). The annual economic damage of ocean-acidification-induced coral reef loss by 2100 has been estimated, in 2009, to be 870 and 500 billion USD, respectively for A1 and B2 SRES emission scenarios (Brander et al. 2012). Although this number is small compared to global GDP, it represents a large proportion of the GDP of some regions or small island states which rely economically on coral reefs.

Adaptation and Mitigation

The management of ocean acidification comes down to mitigation of the source of the problem and adaptation to the consequences (Rau et al., 2012; Billé et al., sbm). Mitigation of ocean acidification through reduction of atmospheric CO_2 is the most effective and the least risky method to limit ocean acidification and its impacts. Climate geoengineering techniques based on solar radiation management would have no direct effect on ocean acidification because atmospheric CO_2 would continue to rise (6.4.2). Techniques based on carbon dioxide removal could directly address the problem but their effectiveness at the scale required to ameliorate ocean acidification has yet to be demonstrated. Additionally, some ocean-based approaches, such as iron fertilization, would only re-locate ocean acidification from the upper ocean to the ocean interior, with potential ramifications on deep water oxygen levels (Williamson and Turley, 2012; 6.4.2; 30.3.2.3 and 30.5.7). Mitigation of ocean acidification at the local level could involve the reduction of anthropogenic inputs of nutrients and organic matter in the coastal ocean (5.3.4.2). Specific activities, such as aquaculture, could adapt to ocean acidification within limits, for example by altering the production process, selecting less sensitive species or strains, or relocating elsewhere. A low-regret approach is to limit the number and the magnitude of drivers other than CO_2. There is evidence, for example, that reducing a locally determined driver (i.e. nutrient pollution) may substantially reduce its synergistic effects with a globally determined driver such as ocean acidification (Falkenberg et al., 2013).

[INSERT FIGURE OA-1 HERE
Figure OA-1: A: Overview of the chemical, biological, socio-economic impacts of ocean acidification and of policy options (adapted from Turley & Gattuso, 2012). B: Multi-model simulated time series of global mean ocean surface pH (on the total scale) from CMIP5 climate model simulations from 1850 to 2100. Projections are shown for emission scenarios RCP2.6 (blue) and RCP8.5 (red) for the multi-model mean (solid lines) and range across the distribution of individual model simulations (shading). Black (grey shading) is the modelled historical evolution using historical reconstructed forcings. The models that are included are those from CMIP5 that simulate the global carbon cycle while being driven by prescribed atmospheric CO_2 concentrations. The number of CMIP5 models to calculate the multi-model mean is indicated for each time period/scenario (IPCC AR5 WG1 report, Figure 6.28). C: Effect of near future acidification on major response variables estimated using weighted random effects meta-analyses, with the exception of survival which is not weighted (Kroeker et al., in press). The effect size indicates which process is most uniformly affected by ocean acidification but large variability exists between species. Significance is determined when the 95% bootstrapped confidence interval does not cross zero. The number of experiments used in the analyses is shown in parentheses. * denotes a significant effect.]

CC-OA References

Barton A., Hales B., Waldbusser G. G., Langdon C. & Feely R. A., 2012. The Pacific oyster, Crassostrea gigas, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects. Limnology and Oceanography 57:698-710.

Branch T. A., DeJoseph B. M., Ray L. J. & Wagner C. A., in press. Impacts of ocean acidification on marine seafood. Trends in Ecology & Evolution.

Brander L. M., Rehdanz K., Tol R. S. J. & Van Beukering P. J. H., 2012. The economic impact of ocean acidification on coral reefs. Climate Change Economics 3, 1250002. doi:10.1142/S2010007812500029.

Cooley S. R. & Doney S. C., 2009. Anticipating ocean acidification's economic consequences for commercial fisheries. Environmental Research Letters 4:1-8.

Falkenberg L. J., Connell S. D. & Russell B. D., 2013. Disrupting the effects of synergies between stressors: improved water quality dampens the effects of future CO2 on a marine habitat. Journal of Applied Ecology 50:51-58.

Gazeau F., Parker L. M., Comeau S., Gattuso J.-P., O'Connor W., Martin S., Pörtner H.-O. & Ross P., in press. Impacts of ocean acidification on marine shelled molluscs. Marine Biology .

Griffith G. P., Fulton E. A., Gorton R. & Richardson A. J., 2012. Predicting interactions among fishing, ocean warming, and ocean acidification in a marine system with whole-ecosystem models. Conservation Biology 26:1145-1152.

Kroeker K., Kordas R. C., Ryan, Hendriks I., Ramajo L., Singh G., Duarte C. & Gattuso J.-P., in press. Impacts of ocean acidification on marine biota: Quantifying variation in sensitivity among organisms and life stages and at elevated temperature. Global Change Biology.

Narita D., Rehdanz K. & Tol R. S. J., 2012. Economic costs of ocean acidification: a look into the impacts on shellfish production. Climatic Change 113:1049-1063.

Raven J. A., 2011. Effects on marine algae of changed seawater chemistry with increasing CO2. Biology and Environment: Proceedings of the Royal Irish Academy 111B:1-17.

Rau G. H., McLeod E. L. & Hoegh-Guldberg O., 2012. The need for new ocean conservation strategies in a high-carbon dioxide world. Nature Climate Change 2:720-724.

Williamson P. & Turley C., 2012. Ocean acidification in a geoengineering context. Philosophical Transactions of the Royal Society A A370:4317-4342.

Wootton J. T., Pfister C. A. & Forester J. D., 2008. Dynamic patterns and ecological impacts of declining ocean pH in a high-resolution multi-year dataset. Proceedings of the National Academy of Science U.S.A. 105:18848-18853.

Wootton J. T. & Pfister C. A., 2012. Carbon system measurements and potential climatic drivers at a site of rapidly declining ocean pH. PLoS ONE 7, e53396. doi:10.1371/journal.pone.0053396.

Box CC-TC. Case Study Building Long Term Resilience from Tropical Cyclone Disasters

[Yoshiki Saito (Japan), Kathleen McInnes (Australia)]

Tropical cyclones (also referred to as hurricanes and typhoons in some regions) cause powerful winds, torrential rains, high waves and storm surge, all of which can have major impacts on society and ecosystems. For example, Bangladesh and India account for 86% of mortality from tropical cyclones (Murray *et al.*, 2012), which is mainly due to the rarest and most severe storm categories (i.e. Categories 3, 4, and 5).

About 90 tropical cyclones occur globally each year (Seneviratne et al, 2012) although interannual variability is large. Changes in observing techniques particularly after the introduction of satellites in the late 1970s, confounds the assessment of trends in tropical cyclone frequencies and intensities. Therefore, SREX concluded that there is *low confidence* that any observed long-term (i.e. 40 years or more) increases in tropical cyclone activity are robust, after accounting for past changes in observing capability (Seneviratne, *et al.,* 2012; Chapter 2). There is also *low confidence* in the detection and attribution of century scale trends in tropical cyclones. Future changes to tropical cyclones arising from climate change are *likely* to vary by region. This is because there is *medium confidence* that for certain regions, shorter-term forcing by natural and anthropogenic aerosols has had a measurable effect on tropical cyclones. Tropical cyclone frequency is *likely* to decrease or remain unchanged over the 21st century, while intensity (i.e. maximum wind speed and rainfall rates) is *likely* to increase. Regionally specific projections have *lower confidencelower confidence* (see WG1 Box 14.2).

Longer term impacts from tropical cyclones includes salinisation of coastal soils and water supplies and subsequent food and water security issues from the associated storm surge and waves (Terry and Chui, 2012). However, preparation for extreme tropical cyclone events through improved governance and development to reduce their impacts provides an avenue for building resilience to longer term changes associated with climate change.

Densely populated Asian deltas are particularly vulnerable to tropical cyclones due to their large population density in expanding urban areas (Nicholls *et al*., 2007). Extreme cyclones in Asia since 1970 caused over 0.5 million fatalities (Murray *et al*., 2012) e.g., cyclones Bhola in 1970, Gorky in 1991, Thelma in 1998, Gujarat in 1998, Orissa in 1999, Sidr in 2007, and Nargis in 2008. Tropical cyclone Nargis hit Myanmar on 2 May 2008 and caused over 138,000 fatalities. Several-meter high storm surges widely flooded densely populated coastal areas of the Irrawaddy Delta and surrounding areas (Revenga *et al*., 2003; Brakenridge *et al*., 2012). The flooded areas were captured by a NASA MODIS image on 5 May 2008 (Figure TC-1).

[INSERT FIGURE TC-1 HERE
Figure TC-1: The intersection of inland and storm surge flooding. Red shows May 5, 2008 MODIS mapping of the tropical cyclone Nargis storm surge along the Irrawaddy Delta and to the east, Myanmar. The blue areas to the north were flooded by the river in prior years. (From Brakenridge *et al*., 2012).]

Murray *et al*. (2012) compared the response to cyclone Sidr in Bangladesh in 2007 and Nargs in Myanmar in 2008 and demonstrated how disaster risk reduction methods could be successfully applied to climate change adaptation (Murray et al, 2012). Sidr, despite being of similar strength to Nargis, caused far fewer fatalities (3,400 compared to over 138000) and this was attributed to advancement in preparedness and response in Bangladesh through experience in previous cyclones such as Bhola and Gorky. The responses included the construction of multi-storied cyclone shelters, improvement of forecasting and warning capacity, establishing a coastal volunteer network, and coastal reforestation of mangroves. Birkmann and Teichman, (2010) caution that while the combination of risk reduction and climate change adaptation strategies may be desirable, different spatial and temporal scales, norm systems, and knowledge types and sources between the two goals can confound their effective combination.

CC-TC References

Birkman, J. and K. von Teichman 2010: Integrating disaster risk reduction and climate change adaptation: key challenges – scales, knowledge and norms. *Sustainability Science* **5**: 171-184.

Brakenridge, G.R., J.P.M. Syvitski, I. Overeem, S.A. Higgins, A.J. Kettner, J.A. Stewart-Moore, and R. Westerhoff, 2012: Global mapping of storm surges and the assessment of delta vulnerability. *Natural Hazards*, DOI 10.1007/s11069-012-0317-z

Nicholls, R.J. 2007: Adaptation Options for Coastal Areas And Infrastructure: An Analysis For 2030. In Adaptation Options for Coastal Areas And Infrastructure: An Analysis For 2030, 35 pp. Bonn: UNFCCC.

Murray V., G. McBean, M. Bhatt, S. Borsch, T.S. Cheong, W.F. Erian, S. Llosa, F. Nadim, M. Nunez, R. Oyun, and A.G. Suarez, 2012: Case studies. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 487-542.

Revenga, C., Nackoney, J., Hoshino, E., Kura, Y., Maidens, J., 2003: AS 12 Irrawaddy. Watersheds of the World, Water Resources Institute.

Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230

References

Aargaard, T, Nielsen, J. Jensen, S.G. and Friderichsen, J. 2004: Longshore sediment transport and coastal erosion at Skallingen, Denmark. Danish Journal of Geography 104(1) 5-14.

Abel, N., R. Gorddard, B. Harman, A. Leitch, J. Langridge, A. Ryan, and S. Heyenga, 2011: Sea level rise, coastal development and planned retreat: analytical framework, governance principles and an Australian case study. *Environmental Science & Policy,* **14(3)**, 279-288.

Ahammad, R. (2011) Constraints of pro-poor climate change adaptation in Chittagong city. Environment and Urbanization (23): 503.

Ahmed AU (2005) Adaptation options for managing water related extreme events under climate change regime: Bangladesh persectives. Balkema Press, London.

Ahmed, A.U. (ed.), 2010. Reducing Vulnerability to Climate Change: The Pioneering Example of Community Based Adaptation in Bangladesh, Centre for Global Change (CGC) and CARE Bangladesh, Dhaka.

Alexander et al., 2008

Alexandre et al., 2012

Ali, A. (1999) Climate Change Impacts and Adaptation Assessment in Bangladesh, Climate Research (12).

Alongi, D. M., 2002: Present state and future of the world's mangrove forests. *Environmental Conservation* 2**9 (3)**:331-349.

Alongi, D. M., 2008: Mangrove forests: Resilience, protection from tsunamis, and response to global climate change.Estuarine. *Coastal and Shelf Science* **76**: 1-13.

Alvarez-Diaz, M., M.S.O. Giraldez, and M. Gonzalez-Gomez, 2010. Statistical relationships between the North Atlantic Oscillation and international tourism demand in the Balearic Islands, Spain. *Climate Research*, **43**: 207-214.

Andersson & Gledhill, 2013

Andersson, A.J., F.T. Mackenzie, and J. Gattuso, 2011: Effects of ocean acidification on benthic processes, organisms, and ecosystems. In: [Gattuso, J. (ed.)]. Oxford University Press, pp. 122-153.

Anthoff, D., R.J. Nicholls, and R.S.J. Tol, 2010: The economic impact of substantial sea-level rise. **15(4)**, 321-335.

Anthony et al., 2010

Anthony, A., J. Atwood, P. August, C. Byron, S. Cobb, C. Foster, C. Fry, A. Gold, K. Hagos, L. Heffner, D.Q. Kellogg, K. Lellis-Dibble, J.J. Opaluch, C. Oviatt, A. Pfeiffer-Herbert, N. Rohr, L. Smith, T. Smythe, J. Swift, and N. Vinhateiro, 2009: Coastal lagoons and climate change: Ecological and social ramifications in US atlantic and gulf coast ecosystems. *Ecology and Society,* **14(1(8))**.

Anthony, K.R.N., D.L. Kline, G. Diaz-Pulido, S. Dove, and O. Hoegh-Guldberg, 2008: Ocean acidification causes bleaching and productivity loss in coral reef builders. **105(45)**, 17442Ð17446.

Arnell, Nigel, Tom Kram Timothy Carter, Kristie Ebi, Jae Edmonds, Stéphane Hallegatte, Elmar Kriegler, Ritu Mathur, Brian O'Neill, Keywan Riahi, Harald Winkler, Detlef van Vuuren, Timm Zwickel. 2011. A framework for a new generation of socioeconomic scenarios for climate change impact, adaptation, vulnerability, and mitigation research. Draft paper prepared for the Boulder workshop on Socio-Economic Pathways, November 2-4, 2011.

Ashton, A.D., M.J.A. Walkden and M.E. Dickson, 2011. Equilibrium response of cliffed coasts to changes in the rate of sea level rise. *Marine Geology*, **284**: 217-229.

Aufdenkampe, A.K., E. Mayorga, P.A. Raymond, J.M. Melack, S.C. Doney, S.R. Alin, R.E. Aalto, and K. Yoo, 2011: Riverine coupling of biogeochemical cycles between land, oceans, and atmosphere. **9(1)**, 53Ð60.

Aunan, K., and B. Romstad, 2008: Strong coasts and vulnerable communities: Potential implications of accelerated sea-level rise for Norway. *Journal of Coastal Research* **24(2)**, 403-409

Ayers, J and Huq, S. (2009) Supporting adaptation through development: what role for official development assistance? Development Policy Review 27(6), 675-692.

Ayers, J. and Dodman, D. (2010) Climate change adaptation and development: the state of the debate. Progress in Development Studies 10 (2), 161-168.

Ayers, J. and Forsyth, T. (2009) Community-based adaptation to climate change: strengthening resilience through development. Environment 51 (4), 22-31.

Ayers, J. and Huq, S. (2013) 'Adaptation, Development and the Community', Chapter 19 in Climate Adaptation Futures, First Edition. Edited by Jean Palutikof, Sarah L. Boulter, Andrew J. Ash, Mark Stafford Smith, Martin Parry, Marie Waschka and Daniela Guitart. John Wiley & Sons, London.

Azad, Kalam., Jensen, K., Lin, K. (2009) 'Coastal Aquaculture Development in Bangladesh: Unsustainable and Sustainable Experiences,' Environmental Management 44.

Badjeck, M., Allison, E., Halls, A. and Dulvy, N. (2009) Impacts of climate variability and change on fishery-based livelihoods. Marine Policy (34), 375-383.

Bagstad, K.J., K. Stapleton, and J.R. D'Agostino, 2007: Taxes, subsidies, and insurance as drivers of United States coastal development. *Ecological Economics,* **63(2-3)**, 285-298.

Baker, A.C., P.W. Glynn, and B. Riegl, 2008: Climate change and coral reef bleaching: An ecological assessment of long-term impacts, recovery trends and future outlook. *Estuarine, Coastal and Shelf Science,* **80(4)**, 435-471.

Barale, V. and E. Özhan, 2010. Advances in integrated coastal management for the Mediterranean and Black Sea**.** *Journal of Coastal Conservation,* **14**: 249–255.

Barange, M. and R.I. Perry 2009: Physical and ecological impacts of climate change relevant to marine and inland capture fisheries and aquaculture. In *Climate Change Implications for Fisheries and Aquaculture: Overview of Current Scientific Knowledge* [Cochrane, K., C. De Young, D. Soto, and T. Bahri (eds)]. FAO Fisheries and AquacultureTechnical Paper nº **530**. Rome, FAO. pp. 7–106.

Barbier, E. B., E. W. Koch, B. R. Silliman, S. D. Hacker, E. Wolanski, J. Primavera, E. F. Granek, S. Polasky, S. Aswani, L. A. Cramer, D. M. Stoms, C. J. Kennedy, D. Bael, C. V. Kappel, G. M. E. Perillo, and D. J. Reed. 2008. Coastal Ecosystem-Based Management with Nonlinear Ecological Functions and Values. *Science* **319** (5861):321-323.

Barbier, E.B., 2012: Progress and challenges in valuing coastal and marine ecosystem services. *Review of Environmental Economics and Policy* **6(1)**, 1-19.

Baric, A., Grbec, B., Bogner, D. 2008: Potential Implications of Sea-Level Rise for Croatia. *J. Coastal Res*. **24(2)** 299-305.

Barlow, P. And Reichard E. 2010: Saltwater intrusion in coastal regions of North America. Hydrogeol. J. 18, 247-260.

Barras, J.A., J.C. Bernier, and R.A. Morton, 2008, Land area change in coastal Louisiana–A multidecadal perspective (from 1956 to 2006): U.S. Geological Survey Scientific Investigations Map 3019, scale 1:250,000, 14 p. pamphlet.

Barry, J.P., S. Widdicombe, and J. Hall-Spencer, 2011: Effects of ocean acidification on marine biodiversity and ecosystem function. . In: *Ocean Acidification* [J-P. Gattuso and L. Hansson (eds.)], Oxford: Oxford University Press, pp. 192-209.

Barton, A., B. Hales, G.G. Waldbusser, C. Langdon, and R.A. Feely, 2012: The Pacific oyster, Crassostrea gigas, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects. *Limnology and Oceanography,* **57(3)**, 698-710.

Baulcomb, Corinne. 2011: *Review of the Evidence Linking Climate Change to Human Health for Eight Diseases of Tropical Importance*. Land Economy Working Paper Series No **63**. Scottish Agricultural College. Availabe at: http://www.sac.ac.uk/mainrep/pdfs/leergworkingpaper63.pdf

Bedsworth, L.W. and E. Hanak, 2010. Adaptation to climate change. *Journal of the American Planning Association*, **76**: 477-495.

Bender, M.A., T.R. Knutson, R.E. Tuleya, J.J. Sirutis, G.A. Vecchi, S.T. Garner, I.M. Held, 2010. Modeled impact of anthropogenic warming on the frequency of intense Atlantic hurricanes. *Science*, **327**: 454-458.

Berkes, F., and C. Folke, (eds.), 1998. *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. Cambridge University Press, New York.

Bessat, F. and D. Buigues, 2001: Two centuries of variation in coral growth in a massive Porites colony from Moorea (French Polynesia): a response of ocean-atmosphere variability from south central Pacific. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **175(1-4)(1-4)**, 381-392.

Betts et al, 2007

Bhuiyan, MD. J and Dutta, D. (2012) Assessing impacts of sea level rise on river salinity in the Gorai river network, Bangladesh. Estuarine, Coastal and Shelf Science (96), 219-227.

Biesbroek, G.R., R.J. Swart, T.R. Carter, C. Cowan, T. Henrichs, H. Mela, M.D. Morecroft, and D. Rey, 2010: Europe adapts to climate change: Comparing National Adaptation Strategies. *Global Environmental Change-Human and Policy Dimensions,* **20(3)**, 440-450.

Bird, E.C.F., 2000. *Coastal Geomorphology: An Introduction*. John Wiley, Chichester.

Bjarnadottir, S., Y. Li, and M.G. Stewart, 2011: Social vulnerability index for coastal communities at risk to hurricane hazard and a changing climate. *Natural Hazards* **59(2)**, 1055-1075.

Black, R., S.R.G. Bennett, S.M. Thomas, and J.R. Beddington, 2011: Migration as adaptation. *Nature,* **478(7370)**, 447-449.

Black, R., W.N. Adger, N.W. Arnell, S. Dercon, A. Geddes, and D.S.G. Thomas, 2011: Migration and global environmental change. *Global Environmental Change-Human and Policy Dimensions,* **21(1)**, S1-S2.

Black, R., W.N. Adger, N.W. Arnell, S. Dercon, A. Geddes, and D.S.G. Thomas, 2011: The effect of environmental change on human migration. *Global Environmental Change-Human and Policy Dimensions,* **21(1)**, S3-S11.

Boateng, I. 2012a: GIS assessment of coastal vulnerability to climate change and coastal adaption planning in Vietnam. *Journal of Coastal Conservation* **16**: 25–36

Boateng, I. 2012b: An assessment of the physical impacts of sea-level rise and coastal adaptation: a case study of the eastern coast of Ghana. *Climatic Change*.

Boateng, I., 2010. *Spatial Planning in Coastal Regions: Facing the Impact of Climate Change*. International Federation of Surveyors, Copenhagen, Denmark.

Boden, T. G. Marland, and B. Andres, 2011: *Global CO2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751-2008*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN. Emissions data available at: http://cdiac.ornl.gov/ftp/ndp030/global.1751_2008.ems.

Bollmann, M., T. Bosch, F. Colijn, R. Ebinghaus, R. Froese, K. Güssow et al 2010: *World Ocean Review 2010*. Maribus, Hamburg, 232 pp.

Bongaerts, P., T. Ridgeway, E. Sampayo and O. Hoegh-Guldberg, 2010. Assessing the 'deep reef refugia' hypothesis: focus on Caribbean reefs. *Coral Reefs,* 29: 309-327.

Borges A. V. 2005: Do we have enough pieces of the jigsaw to integrate CO2 fluxes in the coastal ocean? *Estuaries* **28**:3–27

Borges and Abril, 2012

Borges, A.V. and G. Abril, 2011: Carbon dioxide and methane dynamics in estuaries. In: [Wolanski, E.M.,D. (ed.)]. Academic Press, pp. 119-161.

Borges, A.V. and N. Gypens, 2010: Carbonate chemistry in the coastal zone responds more strongly to eutrophication than to ocean acidification. *Limnology and Oceanography,* **55(1)**, 346-353.

Bormann, H., Ahlhorn, F. and Klenke, T. (2012) Adaptation of water management to regional climate change in a coastal region – Hydrological change vs. community perception and strategies. Journal of Hydrology (454–455), 64–75.

Borsje, B.W, van Wesenbeeck, B.K., Dekker, F., Paalvast, P., Bouma, T.J., van Katwijk, M.M., de Vries, M. (2011). How ecological engineering can serve in coastal protection. Ecological Engineering, 37, 113-122.

Bosom, E. and J.A. Jimenez, 2011: Probabilistic coastal vulnerability assessment to storms at regional scale - application to Catalan beaches (NW mediterranean). *Natural Hazads and Earth System Sciences,* **11(2)**, 475-484.

Bougherara et al., 2009

Bouwman et al., 2009

Bouwman, A.F., G. Van Drecht, J.M. Knoop, A. Beusen, and C.R. Meinardi, 2005: Exploring changes in river nitrogen export to the world's oceans. *Global Biogeochemical Cycles,* **19(1)**, GB1002.

Brander, L.M., R.J.G.M. Florax, and J.E. Vermaat, 2006: The empirics of wetland valuation: A comprehensive summary and a meta-analysis of the literature. *Environmental and Resource Economics,* **33(2)**, 223-250.

Brecht et al., 2012

Breitburg, D.L., D.W. Hondorp, L.A. Davias, and R.J. Diaz, 2009: Hypoxia, nitrogen, and fisheries: integrating effects across local and global landscapes. **1**, 329-349.

Briggs et al., 2006

Brown K., E. L. Tompkins, and W. N. Adger., 2002: *Making Waves: Integrating Coastal Conservation and Development*. London: Earthscan.

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

Buddemeier, R.W. and S.V. Smith, 1988: Coral reef growth in an era of rapidly rising sea level: predictions and suggestions for long-term research. *Coral Reefs,* **7**, 51-56.

Bunce et al., (2010) Policy misfits, climate change and cross-scale vulnerability in coastal Africa: how development projects undermine resilience. Enviromental Science and Policy (13), 485-497.

Bunce, M., K. Brown, and S. Rosendo, 2010: Policy misfits, climate change and cross-scale vulnerability in coastal Africa: how development projects undermine resilience. *Environmental Science & Policy,* **13(6)**, 485-497.

Burch, S. 2010: Transforming barriers into enablers of action on climate change: Insights from three municipal case studies in British Columbia, Canada. *Global Environmental Change* **20 (2)**:287-297.

Burke, L.M., K. Reytar, M. Spalding, and A. Perry, 2011: *Reefs at risk revisited.* World Resources Institute, Washington, DC, pp. 114.

Burrows et al., 2011

Cai, F., Su, X., Liu, J., Li, B., and Lei, G. 2009: Coastal erosion in China under the condition of global climate change and measures for its prevention, *Progress in Natural Science*, **19**, 415-426.

Cai, W., X. Hu, W. Huang, M.C. Murrell, J.C. Lehrter, S.E. Lohrenz, W. Chou, W. Zhai, J.T. Hollibaugh, Y. Wang, P. Zhao, X. Guo, K. Gundersen, M. Dai, and G. Gong, 2011: Acidification of subsurface coastal waters enhanced by eutrophication. **4**, 766Ð770.

Callaway, R., Shinn, A.P., Grenfell, S.E., Bron, J.E., Burnell, G., Cook,E.J., Crumlish, M., Culloty, S., Davidson, K., Ellis, R.P., Flynn, . J., Fox, C., Green, D. M., Hays, G. C., Hughes, A.D., Johnston, E.,Lowe, C.D., Lupatsch, I., Malham, S., Mendzil, A.F., Nickell, T., Pickerell,T., Rowley, A. F., Stanley, M. S., Tocher, D. R., Turnbull, J. F., Webb,G., Wootton, E., Shields, R. J., 2012. Review of climate change impacts on marine aquaculture in the UK and Ireland Aquatic Conservation: Marine and Freshwater Ecosystems. Aquatic Conservation: Marine and Freshwater Ecosystems. Volume 22, Issue 3, pp: 389–421, May 2012.

Cambers, G, 2009, Caribbean beach changes and climate change adaptation. *Aquatic Ecosystem Health and Management,* **12**: 168-176.

Camoin, G.F., C. Seard, P. Deschamps, J.M. Webster, E. Abbey, J.C. Braga, Y. Iryu, N. Durand, E. Bard, B. Hamelin, Y. Yokoyama, A.L. Thomas, G.M. Henderson, and P. Dussouillez, 2012: Reef response to sea-level and environmental changes during the last deglaciation: integrated Ocean Drilling Program Expedition 310, Tahiti Sea Level. *Geology,* **40(7)**, 643-646.

Canu, D.M., C. Solidoro, G. Cossarini, and F. Giorgi, 2010: Effect of global change on bivalve rearing activity and the need for adaptive management. *Climate Research,* **42(1)**, 13-26.

Canuel, E.A., S.S. Cammer, H.A. McIntosh, and C.R. Pondell, 2012: Climate change impacts on the organic carbon cycle at the land-ocean interface. *Annual Review of Earth and Planetary Sciences,* **40(1)**, 685-711.

Carrington, E., 2002: Seasonal variation in the attachment strength of blue mussels: causes and consequences. *Limnology and Oceanography,* **47(6)**, 1723-1733.

Cartwright, A. 2009. *Coastal Vulnerability in the Context of Climate Change: A South African Perspective*. http://www.90x2030.org.za/oid%5Cdownloads%5CCoastal%20vulnerability%20South%20African%20perspective.pdf

CCSP, 2008: *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Transportation, Washington, DC, USA, 445 pp.

CCSP, 2009

Celliers, L., S. Rosendo, I. Coetzee and G. Daniels, 2013. Pathways of integrated coastal management from national policy to local implementation: Enabling climate change adaptation. *Marine Policy*, **39**: 72-86.

Central Disaster Management Council, 2011. *Report of the Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis Based on the Lessons Learned from the "2011 off the Pacific coast of Tohoku Earthquake*", Government of Japan, 46 p. http://www.bousai.go.jp/jishin/chubou/higashinihon/Report.pdf

Chaibi, M. and M. Sedrati, 2009. Coastal erosion induced by human activities: The case of two embayed beaches on the Moroccan coast. *Journal of Coastal Research*, **Sp. Issue 56**: 1184-1188.

Chen C-TA and Borges AV. 2009 : Reconciling opposing views on carbon cycling in the coastal ocean: continental shelves as sinks and near-shore ecosystems as sources of atmospheric CO2. *Deep-Sea Res. II* **56**:578–90

Chen, C.C., McCarl, B., Chang, C.C. , 2012. Climate change, sea level rise and rice: global market implications. Climatic Change, Volume 110, Issue 3-4, pp 543-560

Cheong, S-M., 2011. Editorial. Guest editor, Special Issue: Coastal Adaptation. *Climatic Change,* **106**: 1-4.

Cheong, S-M., B. Silliman, P.P. Wong, B. van Wesenbeeck, G. Guannel and C-K. Kim, 2013 (forthcoming). Coastal adaptation with ecological engineering. Nature Climate Change,

Chou *et al.*, 2011

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 and Coastal Management* **48 (3-6)**:468-483.

Chu, Z.X., X.G. Sun, S.K. Zhai, and K.H. Xu, 1996: Changing pattern of accretion/erosion of the modern Yellow River (Huanghe) subaerial delta, China: Based on remote sensing images. *Marine Geology*, **227**, 13–30.

Cinner J.E., T.R. Mc Clanahan, N.A.J. Graham, T.M. Daw, J. Maina, S.M. Stead, A. Wamukota, K. Brown, Ö. Bodin. 2012. Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. Global Environmental Change, Volume 22, Issue 1, February 2012, Pages 12–20

Clark, P. and S. Jupiter, 2010. *Principles and Practice of Ecosystem-based Management: A Guide for Conservation Practitioners in the Tropical Western Pacific*. Wildlife Conservation Society, Suva, Fiji.

Cloern, J.E. and A.D. Jassby, 2008: Complex seasonal patterns of primary producers at the land-sea interface. *Ecology Letters,* **11(12)**, 1294-1303.

Colberg and McInnes; 2012

Comeaux et al., 2011

Committee on Adaptation Strategy for Global Warming in the Coastal Zone, 2011. *Manual for Adapting to Global Warming Concurrently with Renewal of Coastal Structures* (interim version), 50 p. (in Japanese)

Coombes, E.G., A.P. Jones and W.J. Sutherland, 2009. The implications of climate change on coastal visitor numbers: a regional analysis. *Journal of Coastal Research*, **25**: 981-990.

Cooper, J.A.G. and O.H. Pilkey, 2004. Sea-level rise and shoreline retreat: Time to abandon the Bruun Rule. *Global and Planetary Change*, **43(3-4)**: 157-171.

Cooper, T.F., R.A. OÕLeary, and J.M. Lough, 2012: Growth of Western Australian corals in the Anthropocene. *Science,* **335(6068)**, 593-596.

Costanza and Ruth, 1998

Costanza et al., 1990

CPRA (Coastal Protection and Restoration Authority of Louisiana), 2012. *Louisiana's Comprehensive* http://www.coastalmasterplan.louisiana.gov/2012-master-plan/final-master-plan/

Craft, C., J. Clough, J. Ehman, S. Joye, R. Park, S. Pennings, H. Guo, and M. Machmuller. 2009. Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services. *Front. Ecol. Environ* **7**:73-78.

Crain C. M., Halpern B. S., Beck M. W. and Kappel C. V., 2009: Understanding and managing human threats to the coastal marine environment. *Year in Ecology and Conservation Biology 2009* **1162**:39-62.

Crain, C.M., B.S. Halpern, M.W. Beck, and C.V. Kappel, 2009: Understanding and Managing Human Threats to the Coastal Marine Environment. In: [Ostfeld, R. and W. Schlesinger(eds.)]. pp. 39-62.

Crooks, S., D. Herr, J. Tamelander, D. Laffoley and J. Vandever, 2011. *Mitigating Climate Change through Restoration and Management of Coastal Wetlands and Near-shore Marine Ecosystems: Challenges and Opportunities*. Environment Department Paper 121, World Bank, Washington, D.C.

Cutter S., B. Osman-Elasha, J. Campbell, S-M. Cheong, S. McCormick, R. Pulwarty, S. Supratid, and G. Ziervogel, 2012: Managing risks from climate extremes at the local level. In : *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change University of Cambridge Press, Cambridge, U.K., p. 291-338.

Dai A., Qian T., Trenberth K. E. and Milliman J. D., 2009: Changes in continental freshwater discharge from 1948 to 2004. *Journal of Climate* **22**:2773-2792.

Dasgupta et al., 2007

Dasgupta *et al.*, 2008

Dasgupta, 2009

Dasgupta, S., B. Laplante, C. Meisner, D. Wheeler, and J. Yan, 2009: The impact of sea level rise on developing countries: a comparative analysis. *Climatic Change* **93(3-4)**, 379-388

Davis, R.A. Jr. and D.M. FitzGerald, 2004. *Beaches and Coasts*. Blackwell Publishing, Oxford.

Daw, T. Adger, W.N. Brown, K. 2009: Climate change and capture fisheries: potential impacts, adaptation and mitigation. In K. Cochrane, C. De Young, D. Soto and T. Bahri (eds). *Climate change implications for fisheries and aquaculture: overview of current scientific knowledge*. FAO Fisheries and Aquaculture Technical Paper No 530. Rome, FAO, pp.107-150.

Dawson, R.J., M.E. Dickson, R.J. Nicholls, J.W. Hall, M.J.A. Walkden, P.K. Stansby, M. Mokrech, J. Richards, J. Zhou, J. Milligan, A. Jordan, S. Pearson, J. Rees, P.D. Bates, S. Koukoulas and A.R. Watkinson, 2009. Integrated analysis of risks of coastal flooding and cliff erosion under scenarios of long term change. *Climatic Change* **95**: 249-288

Day, J.W. and L. Giosan, 2008: Survive or subside? *Nature Geoscience* **1**, 156–157.

Day, J.W., C. Ibáñez, F. Scarton, D. Pont, P. Hensel, J. Day, and R. Lane, 2011: Sustainability of Mediterranean deltaic and lagoon wetlands with sea-level rise: The importance of river input. *Estuaries and Coasts* **34**, 483–493.

De Bie, M. J. M., J.J. Middelburg, M. Starink, and H.J. Laanbroek, 2002: Factors controlling nitrous oxide at the microbial community and estuarine scale. *Marine Ecology Progress Series,* **240**, 1-9.

De la Vega-Leinert, A.C. and R.J. Nicholls 2008 : Potential implications of sea-level rise for Great Britain. *Jour. of Coastal Research* **24**, 342-357.

de Sherbinin et al., 2012

De Silva, S.S. and D. Soto 2009: Climate change and aquaculture: potential impacts, adaptation and mitigation. In *Climate Change Implications for Fisheries and Aquaculture: Overview of Current Scientific Knowledge* [Cochrane, K., C. De Young, D. Soto, and T. Bahri (eds)] FAO Fisheries and Aquaculture Technical Paper No 530. Rome, FAO. pp. 151-212.

De'ath, G., J.M. Lough, and K.E. Fabricius, 2009: Declining coral calcification on the Great Barrier Reef. *Science,* **323(5910)**, 116-119.

De'ath, G., K.E. Fabricius, H. Sweatman, and M. Puotinen, 2012: The 27-year decline of coral cover on the Great Barrier Reef and its causes. *Proceedings of the National Academy of Science U.S.A.* ***109*****(44)**, 17995-17999.

Debenard and Roed, 2008

Delta Commission, 2008: *Working together with water : Summary and conclusions*. 23 pp.

Department of Climate Change, 2009: *Climate Change Risks to Australia's Coast. A First Pass National Assessment*. Report published by the Department of Climate Change, Australian Government, Canberra, Australia, 172 pp.

Dev, P. (2013) Waterlogging through soil-less agriculture as a climate resilient option. In Climate Change Management, Climate Change and Disaster Risk Management, Part 4, Pages 681-692.

Diaz, R.J. and R. Rosenberg, 2008: Spreading dead zones and consequences for marine ecosystems. *Science,* **321(5891)**, 926-929.

Díaz-Almela E, Marbà N and Duarte CM. 2007: Consequences of Mediterranean warming events in seagrass (Posidonia oceanica) flowering records. *Global Change Biology* **13**: 224–235.

Díaz-Almela, E., N. Marbà, R. Martínez, R. Santiago and C. M. Duarte, 2009: Seasonal dynamics of Posidonia oceanica in Magalluf Bay (Mallorca, Spain): temperature effects on seagrass mortality. *Limnology and Oceanography* **54**: 2170–2182

Dietz et al., 2003

Dodman, D. and Mitlin, D. 2011. Challenges to community-based adaptation. Journal of International Development 23 (3).

Dolan and Walker, 2004

Doney, S.C., N. Mahowald, I. Lima, R.A. Feely, F.T. Mackenzie, J. Lamarque, and P.J. Rasch, 2007: Impact of anthropogenic atmospheric nitrogen and sulfur deposition on ocean acidification and the inorganic carbon system. **104(37)**, 14580-14585.

Donner et al., 2009

Duarte, 2000

Duarte, C.M., I.E. Hendriks, T.S. Moore, O. YS, A. Steckbauer, L. Ramajo, J. Carstensen, J.A. Trotter, and M. McCulloch, Is ocean acidification an open-ocean syndrome? Understanding anthropogenic impacts on marine pH.

Duarte, C.M., J.J. Middelburg, and N. Caraco, 2005: Major role of marine vegetation on the oceanic carbon cycle. **2**, 1-8.

Duarte, C.M., Losada, I.J, Hendriks, I., Mazarrasa, I., Marbá, N., 2013. Blue Forests for Climate Change Mitigation and Adaptation. Nature Climate Change (submitted).

Duke et al., 1998

Dullo, W.C., 2005: Coral growth and reef growth: a brief review. **51(1-4)**, 33-48.

Dwarakish, G.S., Vinay, S.A., Natesan, U., Toshiyuki, A., Kakinuma, T., Venkataramana, K., Pai, B.J. and Babita, M.K. 2009: *Ocean and Coastal Management* **52**, 467–478.

Ekstrom et al., 2011

Engineers Australia, 2012. *Climate Change Adaptation Guidelines in Coastal Management and Planning*. EA Books, New South Wales, Australia.

Environment Agency (2012). Managing flood risk through London and the Thames Estuary: TE2100 Plan. London: Environment Agency.

Erdner *et al.*, 2011

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.

Espinosa-Romero, M. J., Chan, K. M. A., McDaniels, T. and Dalmer, D. M. 2011: Structuring decision-making for ecosystem-based management. *Marine Policy* **35(5)**: 575-583.

Fabricius, K.E., C. Langdon, S. Uthicke, C. Humphrey, S. Noonan, G. De'ath, R. Okazaki, N. Muehllehner, M.S. Glas, and J.M. Lough, 2011: Losers and winners in coral reefs acclimatized to elevated carbon dioxide concentrations. **1(3)**, 165-169.

Falaleeva, M., C. O'Mahony, S. Gray, M. Desmond, J. Gault, and V. Cummins, 2011: Towards climate adaptation and coastal governance in Ireland: Integrated architecture for effective management? *Marine Policy,* **35(6)**, 784-793.

FAO. The State of World Fisheries and Aquaculture, 2010. Rome, FAO. 2010. 197p

Faulkner, L. and Ali, I. (2012) Moving towards transformed resilience: Assessing community-based adaptation in Bangladesh. ActionAid Bangladesh/International Centre for Climate Change and Development, Dhaka.

Fazey et al., 2010

Feely, R.A., C.L. Sabine, J. Hernandez-Ayon, D. Ianson, and B. Hales, 2008: Evidence for upwelling of corrosive "acidified" water onto the continental shelf. *Science,* **320(5882)**, 1490-1492.

Feely, R.A., S.R. Alin, J. Newton, C.L. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy, 2010: The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. *Estuarine, Coastal and Shelf Science,* **88**, 442-449.

Fergurson G. and Gleeson T., 2012: Vulnerability of coastal aquifers to groundwater use and climate change. *Nature Climate Change* Vol 2, 342-345

Fernández et al. 2011

Ferreira, O., Dias, J.A. and Taborda, R., 2008: Implications of Sea-Level Rise for Continental Portugal. *J. Coastal Res.* **24(2)** 317-324.

Few, R., K. Brown, and E.L. Tompkins, 2007: Climate change and coastal management decisions: Insights from Christchurch Bay, UK. *Coastal Management,* **35(2-3)**, 255-270.

Findlay, H.S., M.T. Burrows, M.A. Kendall, J.I. Spicer, and S. Widdicombe, 2010: Can ocean acidification affect population dynamics of the barnacle Semibalanus balanoides at its southern range edge? *Ecology,* **91(10)**, 2931-2940.

Folke et al., 2005

Foufoula-Georgiou, E., J. Syvitski, C. Paola, C.T. Hoanh, P. Tuong, C. Vörösmarty, H. Kremer, Brondizio, Y. Saito, R. Twilley, 2011: *International Year of Deltas 2013: A proposal. Eos, Transactions of American Geophysical Union*, 92, 340–341.

Frazier, T. G., N. Wood, and B. Yarnal, 2010: Stakeholder perspectives on land-use strategies for adapting to climate-change-enhanced coastal hazards: Sarasota, Florida. Applied Geography **30(4)**:506-517.

Fujii, T. and D. Raffaelli, 2008: Sea-level rise, expected environmental changes and responses of intertidal benthic macrofauna in the humber estuary, UK. *Marine Ecology - Progress Series,* **371**, 23-35.

Galloway et al., 2004

Gattuso, J., B. Gentili, C.M. Duarte, J.A. Kleypas, J.J. Middelburg, and D. Antoine, 2006: Light availability in the coastal ocean: impact on the distribution of benthic photosynthetic organisms and their contribution to primary production. **3(4)**, 489-513.

Gattuso, J., D. Allemand, and M. Frankignoulle, 1999: Photosynthesis and calcification at cellular, organismal and community levels in coral reefs: a review on interactions and control by carbonate chemistry. *American Zoologist,* **39(1)**, 160-183.

Gedney et al, 2006

Geels, 2011

Gero, A., Meheux, K. and Dominey-Howes, D. 2011: Integrating community based disaster risk reduction and climate change adaptation: examples from the Pacific. *Nat. Hazards Earth Syst*. Sci. **11**: 101-113.

Gibbs, 2009

Gibbs, M., 2011, Resilience: What is it and what does it mean for marine policymakers? Marine Policy (33), 322-331.

Gilbert et al., 2010

Giridharan, R., S. S. Y. Lau, S. Ganesan, and B. Givoni, 2007: Urban design factors influencing heat island intensity in high-rise high-density environments of Hong Kong. *Building and Environment* **42(10)**:3669-3684.

Girot, P., C. Ehrhart and J. Oglethorpe, 2012. *Integrating Community and Ecosystem-Based Approaches in Climate Change Adaptation Responses*. ELAN (Ecosystem and Livelihoods Adaptation Networks). http://elanadapt.net/sites/default/files/siteimages/elan_integratedapproach_15_04_12.pdf

González-Riancho P., Sano M., Medina R., Garcia-Aguilar O., Areizaga J., 2009. A contribution to the implementation of ICZM in the Mediterranean developing countries. Ocean & Coastal Management 52, 545–558

Grantham, B.A., F. Chan, K.J. Nielsen, D.S. Fox, J.A. Barth, A. Huyer, J. Lubchenco, and B.A. Menge, 2004: Upwelling-driven nearshore hypoxia signals ecosystem and oceanographic changes in the northeast Pacific. *Nature,* **429(6993)**, 749-754.

Green et al. 2009

Greenstein, B.J. and J.M. Pandolfi, 2008: Escaping the heat: range shifts of reef coral taxa in coastal Western Australia. *Global Change Biology,* **14(3)**, 513-528.

Grevelle, G. and O. Mimura, 2008. Vulnerability assessment of sea-level rise in Vitu Levu, Fiji Islands. *Sustainability Science*, **3**: 171-180.

Grieneisen and Zhang, 2011

Gunderson et al., 1995

Gutierrez, D., I. Bouloubassi, A. Sifeddine, S. Purca, K. Goubanova, M. Graco, D. Field, L. MŽjanelle, F. Velazco, A. Lorre, R. Salvatteci, D. Quispe, G. Vargas, B. Dewitte, and L. Ortlieb, 2011: Coastal cooling and increased productivity in. *Geophysical Research Letters,* **38(7).** L07603.

Hadley, D. 2009: Land use and the coastal zone. Land Use Policy, **265**: S198-S203.

Hagedorn et al., 2002

Haigh et al., 2010

Hallegatte, S., 2009: Strategies to adapt to an uncertain climate change. *Global Environmental Change-Human and Policy Dimensions,* **19(2)**, 240-247.

Hallegatte, S., Ranger, N., Mestre, O., Dumas, P., Corfee-Morlot, J., Herweijer, C., Muir-Wood, R., 2011: Assessing climate change impacts, sea level rise and storm surge risk in port cities: a case study on Copenhagen . *Climatic Change* **104**:113–137

Hallegraeff, 2010

Haller, I., N. Stybel, S. Schumacher and M. Mossbauer, 2011. Will beaches be enough? Future changes for coastal tourism at the German Baltic Sea. *Journal of Coastal Research*, **Spec. Issue 61**: 70-80.

Halpern, B.S., S. Walbridge, K.A. Selkoe, C.V. Kappel, F. Micheli, C. D'Agrosa, J.F. Bruno, K.S. Casey, C. Ebert, H.E. Fox, R. Fujita, D. Heinemann, H.S. Lenihan, E. Madin, M.T. Perry, E.R. Selig, M. Spalding, R. Steneck, and R. Watson, 2008: A global map of human impact on marine ecosystems. *Science,***319(5865)**, 948-952.

Hanak, E. and G. Moreno, 2012. California coastal management with a changing climate. *Climatic Change*, **111**: 45-73.

Handmer, J., Y. Honda, Z.W. Kundzewicz, N. Arnell, G. Benito, J. Hatfield, I.F. Mohamed, P. Peduzzi, S. Wu, B. Sherstyukov, K. Takahashi, and Z. Yan, 2012: Changes in impacts of climate extremes: human systems and ecosystems. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 231-290.

Hanson, S., Nicholls, R. Ranger, N., Hallegatte, S., Dorfee-Morlot, J., Herweijer, C. and Chateau, J., 2011: A global ranking of port cities with high exposure to climate extremes. *Climatic Change* **104(1)**, 89-111.

Hapke, C., E. Himmelstoss, M. Kratzmann, J. List and E.R. Thierler, 2011. *National Assessment of Shoreline; Historical Shoreline Changes Along the New England and Mid-Atlantic Coasts*. Open-File Report, U.S.G.S, No. 2010-1118. http://pubs.usgs.gov/of/2010/1118/

Haq et al. 2012

Hare, Jonathan A., Michael A. Alexander, Michael J. Fogarty, Erik H. Williams, and James D. Scott. 2010. Forecasting the dynamics of a coastal fishery species using a coupled climate–population model. Ecological Applications 20:452–464. http://dx.doi.org/10.1890/08-1863.1

Hares, A., J. Dickinson and K. Wilkes, 2009. Climate change and the air travel decisions of UK tourists. *Journal of Transport Geography*, **18**: 466-473.

Harley, C.D.G., 2011: Climate change, keystone predation, and biodiversity loss. *Science,* **334(6059)**, 1124-1127.

Harley, C.D.G., K.M. Anderson, K.W. Demes, J.P. Jorve, R.L. Kordas, T.A. Coyle, and M.H. Graham, 2012: Effects of climate change on global seaweed communities. *Journal of Phycology,* **48(5)**, 1064-1078.

Harley, M.D., I.L. Turner, A.D. Short and R. Ranasinghe, 2010. Interannual variability and controls of the Sydney wave climate. *International Journal of Climatology*, **30**: 1322-1335.

Harper et al; 2009

Hashizume, M., A. S. G. Faruque, Y. Wagatsuma, T. Hayashi, and B. Armstrong (2010), Cholera in Bangladesh: Climatic Components of Seasonal Variation, *Epidemiology*, *21*(5), 706-710 710.1097/EDE.1090b1013e3181e1095b1053

Hashizume, M., Armstrong, B., Hajat, S., Wagatsuma, Y., Faruque, A.S.G., Hayashi, T., and Sack, D.A. 2007: Association between climate variability and hospital visits for non-cholera diarrhoea in Bangladesh: effects and vulnerable groups. *International Journal of Epidemiology* **36**:1030–1037

Hashizume, M., B. Armstrong, S. Hajat, Y. Wagatsuma, A. S. G. Faruque, T. Hayashi, and D. A. Sack (2008), The Effect of Rainfall on the Incidence of Cholera in Bangladesh, *Epidemiology*, *19*(1), 103-110 110.1097/EDE.1090b1013e31815c31809ea

Hawden *et al.,* 2011

Hawkins, S.J., P.J. Moore, M.T. Burrows, E. Poloczanska, N. Mieszkowska, R. Herbert, S.R. Jenkins, R.C. Thompson, M.J. Genner, and A.J. Southward, 2008: Complex interactions in a rapidly changing world: responses of rocky shore communities to recent climate change. **37(2-3)**, 123-133.

Hay, J., 2012. *Disaster Risk Reduction and Climate Change Adaptation in the Pacific*. UNISDR, Geneva.

Hellmann, J.J., J.E. Byers, B.G. Bierwagen, and J.S. Dukes, 2008: Five potential consequences of climate change for invasive species. *Conservation Biology,* **22(3)**, 534-543.

Helmle, K.P., R.E. Dodge, P.K. Swart, D.K. Gledhill, and C.M. Eakin, 2011: Growth rates of Florida corals from 1937 to 1996 and their response to climate change. **2**, 215.

Helmuth, B., C. Harley, P.M. Halpin, D. O&apos M, G.E. Hofmann, and C.A. Blanchette, 2002: Climate change and latitudinal patterns of intertidal thermal stress. *Science,* **298(5595)**, 1015-1017.

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.

Hemer, M.A., Y. Fan, N. Mori, A. Semedo and X.L. Wang (2013) Projected future changes in wind-wave climate in a multi-model ensemble. Nature Climate Change. doi: 10.1038/nclimate1791

Hemminga, M.A., and C.M. Duarte 2000: *Seagrass Ecology*. Cambridge Univ. Press, Cambridge.

Hendriks, I. E., C.M. Duarte and M. Álvarez, 2010: Vulnerability of marine biodiversity to ocean acidification: a meta-analysis. *Estuarine, Coastal and Shelf Estuarine Science* **86**: 157–164.

Hiddink J. G. and Hofstede R., 2008: Climate induced increases in species richness of marine fishes. *Global Change Biology* **14**:453-460.

Hiledebrand and Norrena, 1992

Hinkel et al., 2009

Hinkel, 2010

Hinkel, 2012

Hinkel, J. and A. Bisaro, 2013: *A taxonomy of methods for climate change adaptation* .

Hinkel, J. and R.J.T. Klein, 2009: The DINAS-COAST project: Developing a tool for the dynamic and interactive assessment of coastal vulnerability. *Global Environmental Change,* **19(3)**, 384-395.

Hinkel, J. Nicholls, R.J., Vafeidis, A.T., Tol, S.J. and Avagianou, T. 2010: Assessing risk of and adaptation to sea-level rise in the European Union: an application of DIVA. *Mitigation and Adaptation Strategies for Global Change,* **5(7)**, 1-17.

Hinkel, J., Brown, S., Exner, L., Nicholls, R.J., Vafeidis, A.T. and Kebede, A.S. 2011: Sea-level rise impacts on Africa and the effects of mitigation and adaptation: an application of DIVA. *Regional Environmental Change,* **12**, 207-224.

Hinkel, J., D.P.v. Vuuren, R.J. Nicholls, and R.J.T. Klein, 2012: *The effects of mitigation and adaptation on coastal impacts in the 21st century*.

Hoegh-Guldberg, O., 1999: Climate change, coral bleaching, and the future of the world's coral reefs.

Hoegh-Guldberg, O., 2012: The adaptation of coral reefs to climate change: is the Red Queen being outpaced? Scientia Marina **76(2)**, 403-408.

Hoegh-Guldberg, O., P.J. Mumby, A.J. Hooten, R.S. Steneck, P. Greenfield, E. Gomez, C.D. Harvell, P.F. Sale, A.J. Edwards, K. Caldeira, N. Knowlton, C.M. Eakin, R. Iglesias-Prieto, N. Muthiga, R.H. Bradbury, A. Dubi, and M.E. Hatziolos, 2007: Coral reefs under rapid climate change and ocean acidification. *Science,* **318(5857)**, 1737-1742.

Hoeke, R.K., McInnes, K.L., Kruger, J., McNaught, R., Hunter, J., and Smithers, S. 2012: Widespread inundation of Pacific islands by distant-source wind-waves (Global and Planetary Change, submitted)

Hoeke, R.K., P.L. Jokiel, R.W. Buddemeier, and R.E. Brainard, 2011: Projected changes to growth and mortality of Hawaiian corals over the next 100 years. **6(3)**, e18038.

Hofmann G. E., Smith J. E., Johnson K. S., Send U., Levin L. A., Micheli F., Paytan A., Price N. N., Peterson B., Takeshita Y., Matson P. G., Crook E. D., Kroeker K. J., Gambi M. C., Rivest E. B., Frieder C. A., Yu P. C. and Martz T. R., 2011: *High-frequency dynamics of ocean pH: a multi-ecosystem comparison*. PLoS ONE 6:e28983.

Hofmann, A.F., J.J. Middelburg, K. Soetaert, and F. Meysman, 2009: pH modelling in aquatic systems with time-variable acid-base dissociation constants applied to the turbid, tidal Scheldt estuary. **6**, 1539-1561.

Hofstede, 2008

Holling, 1968

Hong, B. and J. Shen, 2012: Responses of estuarine salinity and transport processes to potential future sea-level rise in the Chesapeake Bay. *Estuarine, Coastal and Shelf Science,* **104-105 02727714**, 33-45.

Hopkins et al., 2012

Horton, R., Rosenzweig, C., Gornitz, V., Bader, D., O'Grady, M. (2010) Climate risk information: climate change scenarios and implications for NYC infrastructure. New York City Panel on Climate Change. Annals of the New York Academy of Sciences, 1196 (1), pp. 147-228.

Howarth et al, 2009

Howarth et al., 1996

Hunt and Watkiss, 2010

Hunter, J. (2012), A simple technique for estimating an allowance for uncertain sea-level rise, *Climatic Change*, *113*(2), 239-252

Hunter, J. R., J. A. Church, N. J. White, and X. Zhang 2012, Towards a global regionally varying allowance for sea-level rise, *Ocean Engineering (0)*

Huq, S. and Reid, H. (2007) Community Based Adaptation. International Institute for Environment and Development, London.

Ibrahim H.S. and D. Shaw, 2012. Assessing progress toward integrated coastal zone management: Some lessons from Egypt. *Ocean and Coastal Management*, **58**: 26-35.

IPCC, 2007. Climate Change 2007: *The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2012: Summary for policymakers. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.

Irish, J.L, A.E. Frey, J.D. Rosati, F. Olivera, L.M. Dunkin, J.M. Kaihatu, C.M. Ferreira and B.L. Edge, 2010. Potential implications of global warming and barrier island degradation on future hurricane inundation, property damages, and population impacted. *Ocean and Coastal Management*, **53**: 645-657.

Isager, L., 2008. *Coastal Zone Management in Developing Countries with Kenya as a Particular Example*. Geocenter, Denmark. http://geocenter.dk/projekter/2008_coastal_zone/index.html

ISDR (International Strategy for Disaster Reduction), 2010. *Adaptation to Climate Change by Reducing Disaster Risks: Country Practices and Lessons*. Briefing Note 02. http://www.unisdr.org/files/11775_UNISDRBriefingAdaptationtoClimateCh.pdf

IUCN 2008: Ecosystem-based adaptation: An approach for building resilience and reducing risk for local communities and ecosystems. A submission by IUCN to the Chair of the AWG-LCA with respect to the Shared Vision and Enhanced Action on Adaptation, on behalf of: IUCN, The Nature Conservancy, WWF, Conservation International, BirdLife International, Indigenous Peoples of Africa Co-ordinating Committee, Practical Action, WILD Foundation, Wildlife Conservation Society, Fauna and Flora International and Wetlands International. Gland, Switzerland: IUNC.

Jackson, A.C. and J. MacIlvenny, 2011. Coastal squeeze on rocky shores in northern Scotland and some possible ecological impacts. *Journal of Experimental Marine Biology and Ecology*, **400**: 314-321.

Jacob KH, Gornitz V, Rosenzweig C (2007) Vulnerability of the New York City metropolitan area to coastal hazards, including sea-level rise: inferences for urban coastal risk management and adaptation policies. In: McFadden L, Nicholls RJ, Penning-Roswell E (eds) Managing coastal vulnerability, Amsterdam, Elsevier, pp 61–88

Jaykus, L.-A., Woolridge, M., Frank, J.M., Miraglia, M., McQuatters-Gollop, A., Tirado, C. Clarke, R. and Friel, M. 2008: Food and Agrigulture Organization of the United Nations (FAO) paper 49pp.

Jentoft, 2006

Jentoft, S. 2009. "Future Challenges in Environmental Policy Relative to Integrated Coastal Zone Management." Integrated Coastal Zone Management pp. 155-169: Wiley-Blackwell.

Jeppesen E., Sondergaard M., Pedersen A. R., Jurgens K., Strzelczak A., Lauridsen T. L. and Johansson L. S., 2007. Salinity induced regime shift in shallow brackish lagoons. Ecosystems 10:47-57.

Jha, A., J. Lamond, R. Bloch, N. Bhattacharya, A. Lopez, N. Papachristodoulou, A. Bird, D. Proverbs, J. Davies, and R. Barker 2011: Five Feet High and Rising – Cities and Flooding in the 21st Century. Policy Research Working Paper 5648, The World Bank, 62 pp.

J*iménez et al. 2009*

Johnson 1999

Johnson et al. 2011

Johnson, V.R., B.D. Russell, K.E. Fabricius, C. Brownlee, and J. Hall-Spencer, 2012: Temperate and tropical brown macroalgae thrive, despite decalcification, along natural CO2 gradients. *Global Change Biology,* **18(9)**, 2792Ð2803.

Jones, G.P., M.I. McCormick, M. Srinivasan, and J.V. Eagle, 2004: Coral decline threatens fish biodiversity in marine reserves. Proceedings of the National Academy of Science U.S.A. **101(21)**, 8251-8253.

Jones, H.P., D.G. Hole and E.S. Zavaleta, 2012. Harnessing nature to help people adapt to climate change. *Nature Climate Change*, **2**: 504-509.

Jongman et al., 2012

Jordá et al., 2012

Kabat, P., L.O. Fresco, M.J.C. Stive, M.J.C., C.P. Veerman, J.S.L.J. van Alphen, B.W.A.H. Parmet, W. Hazeleger, and C.A. Katsman, C.A. 2009. Dutch coasts in transition. Nature Geoscience, Vol. 2, July, pp. 450-452.

Kapos, V., J. Scharlemann, P. Bubb, A. Campbell, A. Chenery, N. Doswald and B. Dickson 2009. Impacts of climate change on biodiversity – A review of the recent scientific literature. In : Review of the Literature on the Links between Biodiversity and Climate Change: Impacts, Adaptation and Mitigation [Campbell, A., V. Kapos, J.P.W. Scharlemann, P. Bubb, A. Chenery, L. Coad, B. Dickson, N. Doswald, M.S.I. Khan, F. Kershaw and M. Rashid, eds.], Secretariat of the Convention on Biological Diversity, Montreal. Technical Series No. 42, p. 7-47.

Karaca, M. and Nicholls, R. J. 2008: Potential Implications of Accelerated Sea-Level Rise for Turkey. Journal of Coastal Research, 24(2), 288-298.

Karim, M and Mimura, N. (2008) Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh. Global Environmental Change (18), 490– 500.

Kates, R.W. (200) Cautionary Tales: Adaptation and the Global Poor. Climatic Change (45).

Katsman et al., 2011

Kay, R. and J. Adler, 2005. *Coastal Planning and Management*. 2nd edition, Taylor and Francis, London.

Kebede, A.S. and Nicholls R.J. 2012: Exposure and vulnerability to climate extremes: population and asset exposure to coastal flooding in Dar es Salaam, Tanzania. Regional Environmental Change 12:81–94

Kennedy H. and Björk M., 2009: Seagrass meadows. In: Laffoley D. & Grimsditch G. (Eds.). The management of natural coastal carbon sinks, pp. 23-29. Gland, Switzerland: IUCN.

Kenter et al., 2011

Kettle N.P. 2012. Exposing compounding uncertainties in sea level rise assessments. Journal of Coastal Research, 28: 161-173.

Khan et al, 2008

Khan, A. S., Ramachandran, A., Usha, N., Punitha, S. and Selvam, V. (2012) Predicted impact of the sea-level rise at Vellar–Coleroon estuarine region of Tamil Nadu coast in India: Mainstreaming adaptation as a coastal zone management option. Ocean & Coastal Management (69).

Kiessling et al., 2012

Kiessling, W. and C. Simpson, 2011: On the potential for ocean acidification to be a general cause of ancient reef crises. *Global Change Biology,* **17**, 56-67.

Kiker *et al.,* 2010

Kirshen *et al.,* 2012

Kirshen P., S. Merrill, P. Slovinsky and N. Richardson. 2011. Simplified method for scenario-based risk assessment adaptation planning in the coastal zone. Climatic Change, pp: 1-13. Doi: 10.1007/s10584-011-0379-z.

Kirwan and Mudd, 2012

Kirwan M. L. and G. R. Guntenspergen, 2010: The influence of tidal range on the stability of coastal marshland, J. Geophys. Res., 115, F02009, doi:10.1029/2009JF001400.

Kirwan M. L., G. R. Guntenspergen, A. D'Alpaos, J. T. Morris, S. M. Mudd, and S. Temmerman. 2010: Limits on the adaptability of coastal marshes to rising sea level. Geophysical Research Letters. 37(23):L23401.

Klein *et al.* 2007

Klein et al., 2001

Kleiner, 2011

Kleypas, J.A., G. Danabasoglu, and J.M. Lough, 2008: Potential role of the ocean thermostat in determining regional differences in coral reef bleaching events. *Geophysical Research Letters,* **35(3)**, ARTN L03613.

Knutson, T.R., J.L. McBride, J. Chan, K. Emanuel, G. Holland, C. Landsea, I. Held, J.P. Kossin, A.K. Srivastava and M. Sugi, 2010. Tropical cyclones and climate change. *Nature Geoscience*, **3**: 157-163.

Koelle, K., X. Rodo, M. Pascual, M. Yunus, and G. Mostafa (2005), Refractory periods and climate forcing in cholera dynamics, *Nature*, *436*(7051), 696-700

Kolivras K.N. 2010: Changes in dengue risk potential in Hawaii, USA, due to climate variability and change. Climate Research, 42, 1-11.

Kolker et al, 2010

Kolstad, E.W. and K.A. Johansson 2011: Uncertainties associated with quantifying climate change impacts on human health : a case study for diarrhea. Environmental Health Perspectives, 119, 299-305.

Kont, A., J. Jaagus, R. Aunap, U. Ratas, and R. Rivis, 2008: Implications of sea-level rise for Estonia. Journal of Coastal Research, 24(2), 423-431

Krause-Jensen et al. 2012

Kriegler, E., B.C. O'Neill, S. Hallegatte, T. Kram, R.J. Lempert, R.H. Moss, and T. Wilbanks, 2012: The need for and use of socio-economic scenarios for climate change analysis: A new approach based on shared socio-economic pathways. *Global Environmental Change-Human and Policy Dimensions,* **22(4)**, 807-822.

Kroeker, K., R.C. Kordas Ryan, I. Hendriks, L. Ramajo, G. Singh, C. Duarte, and J. Gattuso, in press: Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. *Global Change Biology,* .

Kroeker, K.J., F. Michell, M.C. Gambi and T.R. Martz, 2011. Divergent ecosystem responses within a benthic marine community to ocean acidification. *Proceedings of the National Academy of Sciences of the United States of America,* **108**:14515-14520.

Kroeze, C., E. Dumont, and S. Seitzinger, 2010: Future trends in emissions of N2O from rivers and estuaries. **7 1943-815X**, 71-78.

Kwadijk, J.C.J., M. Haasnoot, J.P.M. Mulder, M.M.C. Hoogvliet, A.B.M. Jeuken, d.K. van, van Oostrom, Niels G. C., H.A. Schelfhout, E.H. van Velzen, H. van Waveren, and de Wit, Marcel J. M., 2010: Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. *Wiley Interdisciplinary Reviews-Climate Change,* **1(5)**, 729-740.

Lacambra, C., T. Spencer and I. Moeller, 2008. Literature review: tropical coastal ecosystems as coastal defences. *The Role of Environmental Management and Eco-Engineering in Disaster Risk Reduction and Climate Change Adaptation*. ProAct Network. http://www.proactnetwork.org/proactwebsite/media/download/CCA_DRR_reports/casestudies/em.report.case_1.pdf

Langley, J.A., K.L. McKee, D.R. Cahoon, J.A. Cherry, and J.P. Megonigal, 2009: Elevated CO2 stimulates marsh elevation gain, counterbalancing sea-level rise. *Proceedings of the National Academy of Sciences of the United States of America,* **106(15)**, 6182-6186.

Langton, M., M. Parsons, S. Leonard, K. Auty, D. Bell, P. Burgess, S. Edwards, R. Howitt, S. Jackson, V. McGrath and J. Morrison, 2012: *National Climate Change Adaptation Research Plan for Indigenous Communities*, National Climate Change Adaptation Research Facility, Gold Coast, Australia.

Larsen, P.H., S. Goldsmith, O. Smith, M.L. Wilson, K. Strzepek, P. Chinowsky, and B. Saylor 2008: Estimating future costs for Alaska public infrastructure at risk from climate change. Global Environment Change, 18, 442-457.

Last, P.R., White, W.T., Gledhill, D. C., Hobday, A.J., Brown, R., Edgar, G.J. and Pecl, G. 2011: Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. Global Ecol. Biogeogr. 20, 58–72.

Lata S., and P. Nunn. 2011. Misperceptions of climate-change risk as barriers to climate-change adaptation: a case study from the Rewa Delta, Fiji. Climatic Change online first. DOI 10.1007/s10584-011-0062-4

Leatherman, S., K. Zang, and B. Douglas, 2000a. Sea level rise shown to drive coastal erosion. *EOS Transactions of the American Geophysical Union* , **81**(6): 55-57.

Leatherman, S., K. Zang, and B. Douglas, 2000b. Sea level rise shown to drive coastal erosion: a reply. *EOS Transactions of the American Geophysical Union*, **81** (38): 437-441.

Ledoux L., S. Cornell, T. O'Riordan, R. Harvey, and L. Banyard. 2005. Towards sustainable flood and coastal management: identifying drivers of, and obstacles to, managed realignment. Land Use Policy 22 (2):129-144.

Lehner, B., C.R. Liermann, C. Revenga, C. Vorosmarty, B. Fekete, P. Crouzet, P. Doll, M. Endejan, K. Frenken, J. Magome, C. Nilsson, J.C. Robertson, R. Rodel, N. Sindorf, and D. Wisser, 2011: High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. Frontiers in Ecology and the Environment, 9, 494–502.

Lemos *et al.*, 2012

Lempert and Collins, 2007

Lempert et al. (2012)

Lempert, R. and M.E. Schlesinger, 2001: Climate-change strategy needs to be robust. *Nature,* **412(6845)**, 375.

Lempert, R.J. and M.E. Schlesinger, 2000: Robust strategies for abating climate change - An editorial essay. *Climatic Change,* **45(3-4)**, 387-401.

Lerman, A., M. Guidry, A.J. Andersson, and F.T. Mackenzie, 2011: Coastal ocean last glacial maximum to 2100 CO2-carbonic acid-carbonate system: a modeling approach. *Aquatic Geochemistry,* **17**, 749-773.

Levinton, J., M. Doall, D. Ralston, A. Starke, and B. Allam, 2011: Climate change, precipitation and impacts on an estuarine refuge from disease. *Plos One,* **6(4)**.

Lewis *et al.*, 2011

Li and Li, 2012

Li, J., M.H. Wang and Y.S. Ho 2011. Trends in research on global climate change: A Science Citation Index Expanded-based analysis. Global and Planetary Change, 77: 13-20.

Lichter et al., 2011

Lima, F.P. and D.S. Wethey, 2012: Three decades of high-resolution coastal sea surface temperatures reveal more than warming. **3**, 1-13.

Lin, N., K. Emanuel, M. Oppenheimer, and E. Vanmarcke (2012), Physically based assessment of hurricane surge threat under climate change, *Nature Clim. Change*, *2*(6), 462-467

Ling S. D., Johnson C. R., Frusher S. D. and Ridgway K. R., 2009. Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. Proceedings of the National Academy of Science U.S.A. 106:22341-22345.

Linham, M.M. and R.J. Nicholls, 2010. *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding*. UNEP Risø Centre on Energy, Climate and Sustainable Development, Roskilde, Denmark.

Linham, M.M. and R.J. Nicholls, 2012. Adaptation technologies for coastal erosion and flooding: a review. *Proceedings of the Institute of Civil Engineers – Maritime Engineering,* **165**: 95-111.

Logan et al., sbm

Lonsdale, K. G., M. J. Gawith, K. Johnstone, R. B. Street, C. C. West, and A. D. Brown. 2010. Attributes of Well-Adapting Organisations. A report prepared by UK Climate Impacts Programme for the Adaptation Sub-Committee: UK Climate Impacts Programme.

Losada, I.J, Reguero, B.G., Mendez F.J, Castanedo, S., Abascal, A.J., Minguez, R., 2013: Long-term Changes in Sea-level Components in Latin America and the Caribbean. Global and Planetary Change (in press).

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

Low et al., 2009

Mangal, T.D., Paterson, S., and Fenton, A. 2008: Predicting the Impact of Long-Term Temperature Changes on the Epidemiology and Control of Schistosomiasis: A Mechanistic Model. PLoS one, 1438(1) 1-9.

Manzello, D.P., 2010: Coral growth with thermal stress and ocean acidification: lessons from the eastern tropical Pacific. *Coral Reefs,* **29(3)**, 749-758.

Manzello, D.P., J.A. Kleypas, D.A. Budd, C.M. Eakin, P.W. Glynn, and C. Langdon, 2008: Poorly cemented coral reefs of the eastern tropical Pacific: Possible insights into reef development in a high-CO_2 world. **105(30)**, 10450-10455.

Marbà, N. and C.M. Duarte. 2010. Mediterranean warming triggers seagrass (Posidonia oceanica) shoot mortality. Global Change Biology 16: 2366-2375.

Marchand, 2011

Marcos et al., 2009

Martinez, G., L. Bizikova, D. Blobel and R. Swart, 2011. Emerging Climate Change Coastal Adaptation Strategies and Case Studies Around the World. *Global Change and Baltic Coastal Zones Coastal Research Library*, **1**: 249-273.

Martinich et al, 2012

Mazzotti S., A. Lambert, M. Van der Kooij, and A. Mainville, 2009: Impact of anthropogenic subsidence on relative sea-level rise in the Fraser River delta. Geology, 37, 771–774.

MCCIP, 2008:Marine Climate Change Impacts parnertship. Climate change: impacts on our vision for commercially productive seas. Annual Report Card.

McFadden L. 2008. "Exploring the challenges of integrated coastal zone management and reflecting on contributions to 'integration' from geographical thought." Geographical Journal 174(4): 299-314.

McGinnis M. V. and McGinnis, C. E. 2011: "Adapting to Climate Impacts in California: The Importance of Civic Science in Local Coastal Planning." Coastal Management 39(3): 225 - 241.

McGranahan G., D. Balk, and B. Anderson 2007: The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environment and Urbanization, 19, 17-37.

McInnes K.L., Macadam, I., Hubbert, G.D. and O'Grady, J.G. 2011: An assessment of current and future vulnerability to coastal inundation due to sea level extremes in Victoria, southeast Australia Int. J. Clim. DOI: 10.1002/joc.3405

McInnes, K.L., Macadam, I., Hubbert, G.D. and O'Grady, J.G. 2013: An assessment of current and future vulnerability to coastal inundation due to sea level extremes in Victoria, southeast Australia Int. J. Clim. 33: 33-47. DOI: 10.1002/joc.3405

McInnes, R., 2006. *Risks from Climate Change in Coastal Zones - a Good Practice Guide*. Centre for the Coastal Environment, Isle of Wight Council, UK.

McKee, K., K. Rogers, and N. Saintilan, 2012: Response of salt marsh and mangrove wetlands to changes in atmospheric CO2, climate, and sea level. In: [Middleton, B.A. (ed.)]. Springer, pp. 63-96.

McLain and Lee, 1996

McLeod E., B. Poulter, J. Hinkel, E. Reyes, and R. Salm, 2010b: Sea-level rise impact models and environmental conservation: A review of models and their applications. **53(9)**, 507-517.

McNamara, D.E., A.B. Murray and M.D. Smith, 2011. Coastal sustainability depends on how economic and coastline responses to climate change affect each other. *Geophysical Research Letters*, **38**: L07401.

MEA (Millennium Ecosystem Assessment), 2005. *Ecosystems and Human Well-Being: Synthesis*. Island Press, Washington, D.C.

Meehl G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C. Zhao, 2007: Global Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, pp. 747-846.

Meehl, G.A. A. Hu, C. Tebaldi, J.M. Arblaster, W.M. Washington, H. Teng, B. Sanderson, T. Ault, W.G. Strand and J.B. White III, 2012: Relative outcomes of climate change mitigation related to global temperature versus sea level rise, Nature Climate Change, 2, 576-580, doi:10.1038/nclimate1529

Meinshausen, M., S.J. Smith, K. Calvin, J.S. Daniel, M.L.T. Kainuma, J. Lamarque, K. Matsumoto, S.A. Montzka, S.C.B. Raper, K. Riahi, A. Thomson, and G.J.M. Velders, 2011: The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. *Climatic Change,* **109**, 213-241.

Menendez M. and P.L. Woodworth, 2010: Changes in extreme high water levels based on a quasi-global tide-gauge dataset. *Journal of Geophysical Research*, **115**, C10011.

Menge, B.A., F. Chan, and J. Lubchenco, 2008: Response of a rocky intertidal ecosystem engineer and community dominant to climate change. *Ecology Letters,* **11(2)**, 151-162.

Mercer J. 2010. "Disaster risk reduction or climate change adaptation: Are we reinventing the wheel?" Journal of International Development 22(2): 247-264.

Mercer, J., I. Kelman, B. Alfthan and T. Kurvits, 2012. Ecosystem-based adaptation to climate change in Caribbean small island developing states: integrating local and external knowledge. *Sustainability*, **4**: 1908-1932.

Meynecke, J.O. and Yip Lee S., 2011. Climate-coastal fisheries relationships and their spatial variation in Queensland, Australia. Fisheries Research, Volume 110, Issue 2, pp. 365-376.

Milligan J., T. O'Riordan, S.A. Nicholson-Cole and A.R. Watkinson. 2009. Nature conservation for future sustainable shorelines: Lessons from seeking to involve the public. Land Use Policy 26: 203-213.

Milliman J.D., and K.L. Farnsworth, 2011: River Discharge to the Coastal Ocean. A Global Synthesis. Cambridge University Press, 384pp.

Miranda et al, 2012

Mirza, M. (2002) Global warming and changes in the probability of occurrence of floods in Bangladesh and implications. Global Environmental Change (12), 127–138.

Mitchell T., M. van Aalst and P.S. Vllanueva 2010. Assessing progress on integrating disaster risk reduction and climate change adaptation in development processes. Strengthening Climate Resilience Discussion Paper 2, Institute of Development Studies, Brighton, 28 pp.

Mondal and Tatem, 2012

Montaggioni, L.F., 2005: History of Indo-Pacific coral reef systems since the last glaciation: development patterns and controlling factors. *Earth-Science Reviews,* **71(1-2)**, 1-75.

Moreno, A. and B. Amelung, 2009a. How hot is too hot? A survey on climate (change) and tourism. *Proceedings of CMT2009, the 6th International Congress on Coastal and Marine Tourism*, 237-241.

Moreno, A. and B. Amelung, 2009b. Climate change and coastal and marine tourism: review and analysis. *Journal of Coastal Research*, **Spec. Issue 56**: 1140-1144.

Morton , R.A., J.C. Bernier , J.A. Barras, and N.F., Ferina, 2005: Rapid subsidence and historical wetland loss in the Mississippi delta plain: Likely causes and future implications. Open-file report 2005-1216, U.S. Department of Interior, U.S. Geological Survey, 116p.

Moser et al. 2012

Moser S. C., and J. A. Ekstrom. 2010. A Framework to Diagnose Barriers to Climate Change Adaptation. Proc Natl Acad Sci 107 (51):22026-22031.

Moser S. C., R. E. Kasperson, G. Yohe, and J. Agyeman, 2008: Adaptation to climate change in the Northeast United States: Opportunities, processes, constraints. Mitigation and Adaptation Strategies for Global Change 13 (5-6):643-659.

Moss, R.H., J.A. Edmonds, K.A. Hibbard, M.R. Manning, S.K. Rose, D.P. van Vuuren, T.R. Carter, S. Emori, M. Kainuma, T. Kram, G.A. Meehl, J.F.B. Mitchell, N. Nakicenovic, K. Riahi, S.J. Smith, R.J. Stouffer, A.M. Thomson, J.P. Weyant, and T.J. Wilbanks, 2010: The next generation of scenarios for climate change research and assessment. *Nature,* **463(7282)**, 747-756.

Mousavi et al, 2011

Mousavi et al, 2012

Mozumder P., E. Flugman, and T. Randhir, 2011: Adaptation behavior in the face of global climate change: Survey responses from experts and decision makers serving the Florida Keys. Ocean and Coastal Management 54 (1):37-44.

Mudd S. M., S. M. Howell, and J. T. Morris, 2009: Impact of dynamic feedbacks between sedimentation, sea-level rise, and biomass production on near-surface marsh stratigraphy and carbon accumulation, Estuarine Coastal Shelf Sci., 82, 377–389, doi:10.1016/j.ecss.2009.01.028.

Mulder et al., 2011

Munroe et al. 2011

Murray V., G. McBean, M. Bhatt, S. Borsch, T.S. Cheong, W.F. Erian, S. Llosa, F. Nadim, M. Nunez, R. Oyun, and A.G. Suarez, 2012: Case studies. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 487-542.

Mustelin J., R.G. Klein, B. Assaid, T. Sitari, M. Khamis, A. Mzee and T. Haji, 2010. Understanding current and future vulnerability in coastal settings: community perceptions and preferences for adaptation in Zanzibar, Tanzania. *Population and Environment*, **31**: 371-398.

Nageswara Rao, K, P. Subraelu, K.Ch.V. Naga Kumar, G. Demudu, B. Hema Malini, A.S. Rajawat and Ajai, 2010: Impacts of sediment retention by dams on delta shoreline recession: evidences from the Krishna and Godavari deltas, India. Earth Surface Processes and Landforms, 35, 817–827.

Nakashima, D.J., K. Galloway McLean, H.D. Thulstrup. A. Ramos Castillo and R.T. Rubis, 2012. *Weathering Uncertainty: Traditional Knowledge for Climate Change Assessment and Adaptation*. UNESCO, Paris and UNU, Darwin, Australia.

Nakicenovic and Swart, 2000

Narayan, N., A. Paul, S. Mulitza, and M. Schulz, 2010: Trends in coastal upwelling intensity during the late 20th century. **6(3)**, 815-823.

Narita, D., K. Rehdanz, and R. Tol, 2012: Economic costs of ocean acidification: a look into the impacts on shellfish production. *Climatic Change,* **113(3-4)**, 1049-1063.

Neumann et al., 2010

Newton K., Côté I. M., Pilling G. M., Jennings S. & Dulvy N. K., 2007: Current and future sustainability of island coral reef fisheries. *Current Biology* **17(7):**655-658.

Newton, J.; Martin, D.; Mayorga, E.; Devol, A.; Feely, R.; Alin, S.; Dewey, B.; Eudeline, B.; Barton, A.; Suhrbier, A.; , "NANOOS partnerships for assessing ocean acidification in the Pacific Northwest," Oceans, 2012 , vol., no., pp:1-4, 14-19 Oct. 201, doi: 10.1109/OCEANS.2012.6405086

Nicholls and Lowe (2004)

Nicholls and Tol, 2009

Nicholls, 2002

Nicholls, R. J., N. Marinova, J. A. Lowe, S. Brown, P. Vellinga, D. De Gusmão, J. Hinkel and R. S. J. Tol, 2011: Sea-level rise and its possible impacts given a ‘beyond 4°c world’ in the twenty-first century. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 369 (1934), 161-181.

Nicholls, R., S. Brown, S. Hanson, and J. Hinkel, 2010: Economics of Coastal Zone Adaptation to Climate Change (Not Formally Peer-Reviewed), The World Bank.

Nicholls, R.J. 2010: Impacts of and responses to sea-level rise. Chap. 2. In: Understanding Sea-level rise and variability. Wiley-Blackwell. ISBN 978-4443-3451-7, 17-43.

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. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,* **364(1841)**, 1073-1095.

Nicholls, R.J., and A. Cazenave, 2010: Sea-level rise and its impact on coastal zones. Science, 328(5985), 1517–1520.

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.

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.

Nicholls, R.J., S. Hanson, C. Herweijer, N. Patmore, S. Hallegatte, J. Corfee-Morlot, J. Château, and R. Muir-Wood 2008: Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes. OECD Environment Working Papers No. 1, OECD Publishing, 62 pp.

Nixon S. W., 1982. Nutrient dynamics, primary production and fisheries yields of lagoons. Oceanologica acta N° SP:357-371.

NOAA (National Oceanic and Atmospheric Administration), 2010. *Adapting to Climate Change: A Planning Guide for State Coastal Managers*. NOAA Office of Ocean and Coastal Resource Management. http://coastalmanagement.noaa.gov/climate/docs/adaptationguide.pdf.

Norman, B., 2009. *Planning for Coastal Climate Change: An Insight into International and National Approaches*. Victorian Government Department of Planning and Community Development and Department of Sustainability and Environment, Melbourne. http://www.climatechange.vic.gov.au/__data/assets/pdf_file/0017/73250/Planningforcoastalclimatechangev1.pdf

O'Neill, B.C., Carter, T.R., Ebi, K.L., Edmonds, J., Hallegatte, S., Kemp-Benedict, E., Kriegler,E., Mearns, L., Moss, R., Riahi, K., van Ruijven, B., van Vuuren, D. 2012. Meeting Report of theWorkshop on The Nature and Use of New Socioeconomic Pathways for Climate Change Research, Boulder, CO, November 2-4, 2011. Available at: http://www.isp.ucar.edu/socio-economic-pathways.

O'Riordan and Ward, 1997

O'Rourke, D., and S. Connolly. 2003. Just oil? The distribution of environmental and social impacts of oil production and consumption. Annual Review of Environment and Resources 28 (1):587-617.

Palmer, B.J., T.R. Hill, G.K. Mcgregor, and A.W. Paterson, 2011: An Assessment of Coastal Development and Land Use Change Using the DPSIR Framework: Case Studies from the Eastern Cape, South Africa. *Coastal Management,* **39(2)**, 158-174.

Pardaens, A.K., Lowe, J.A., Brown, S., Nicholls, R.J., De Gusmão, D. (2011) Sea-level rise and impacts projections under a future scenario with large greenhouse gas emission reductions. Geophysical Research Letters, 38 (12), art. no. L12604.

Parry, M., N. Arnell, P. Berry, D. Dodman, S. Fankhauser, C. Hope, S. Kovats, R. Nicholls, D. Satterthwaite, R. Tiffin, and T. Wheeler, 2009: Assessing the costs of adaptation to climate change: A review of the UNFCCC and other recent estimates. *International Institute for Environment and Development and Grantham Institute for Climate Change, London, U*.K.

Parvin, G., Takahashi, F and Shaw, R. (2008) Coastal hazards and community-coping methods in Bangladesh. Journal of Coastal Conservation (12): 4.

Paul, S and Routray, J. (2010) Household response to cyclone and induced surge in coastal Bangladesh: coping strategies and explanatory variables. Natural Hazards (57): 2, 477-499.

Pe'eri and Long, 2012

Pearce, A.F. and M. Feng, 2013: The rise and fall of the "marine heat wave" off Western Australia during the summer of 2010/11. *Journal of Marine Systems,* **111-112 09247963**, 139Ð156.

Pearce, T., Smit, B., Duerden, F., Ford, J.D., Goose, A., Kataoyak, F., 2010: Inuit vulnerability and adaptive capacity to climate change in Ulukhaktok, Northwest Territories, Canada. Polar Record 46 (237): 157–177.

Peel, C., 2010. Facing Up to Rising Sea-Levels: Retreat? Defend? Attack? Institution of Civil Engineers, London. http://www.ice.org.uk/getattachment/25ea1cf5-83b4-494c-a536-574ca9b8a4e6/Facing-up-to-rising-sea-levels.aspx

Pelling, M, and S. Blackburn (eds) 2013. *Megacities and the Coast: Risk, Resilience and Transformation*, Earthscan, London.

Pelling, M. (2011) Adaptation to Climate Change: From Resilience to Transformation. Oxfordshire: Routledge.

Pelling, M. and Uitto, J.I. (2001); Small island developing states: natural disaster vulnerability and global change. Environmental Hazards, 3, 49-62.

Pendleton et al. 2012

Penning-Rowsell, E.C., Haigh, N., Lavery, S., and McFadden L. (2012) A threatened world city: The benefits of protecting London from the sea. Natural Hazards DOI: 10.1007/s11069-011-0075-3

Perch-Nielson, S.L., B. Amelung and R. Knutti, 2010. Future climatic resources for tourism in Europe based on the daily Tourism Climatic Index. *Climatic Change*, **103**: 363-381.

Percival, G.S., 2008. *An Assessment of Indigenous Environmental Knowledge (IEK) in the Pacific Region to Improve Resilience Environmental Change*. Climate Change Research Centre, University of New South Wales, Australia.

Pérez, Á.A., B.H. Fernández and R.C. Gatti, eds., 2010: Building resilience to climate change: Ecosystem-based adaptation and lessons from the field. IUCN, Gland, Ecosystem Management Series No. 9, pp. 160-165.

Perry and Mendelssohn, 2009

Perry, C.T., G.N. Murphy, P.S. Kench, S.G. Smithers, E.N. Edinger, R.S. Steneck, and P.J. Mumby, 2013: Caribbean-wide decline in carbonate production threatens coral reef growth. **4**, 1402.

Pialoux, G., B.-A. Gaüzère, S. Jauréguiberry, and M. Strobel (2007), Chikungunya, an epidemic arbovirosis, *The Lancet Infectious Diseases*, *7*(5), 319-327

Pickey and Young, 2009

Plant, N., H. Stockdon, A. Sallenger, M. Turco, J. East, A. Taylor and W. Shaffer, 2010. Forecasting hurricane impact on coastal topography. *EOS, Transactions of the American Geophysical Union,* **91(7):** 65-72.

Polack, E. 2010: Integrating climate change into regional disaster risk management at the Mekong River Commission. Strengthening Climate Resilience Discussion Paper 4, Institute of Development Studies, Brighton, 36 pp.

Pollack, J.B., T.A. Palmer, and P.A. Montagna, 2011: Long-term trends in the response of benthic macrofauna to climate variability in the lavaca-colorado estuary, texas. *Marine Ecology-Progress Series,* **436**, 67-80.

Poloczanska, E.S., S. Smith, L. Fauconnet, J. Healy, I.R. Tibbetts, M.T. Burrows, and A.J. Richardson, 2011: Little change in the distribution of rocky shore faunal communities on the Australian east coast after 50 years of rapid warming. *Journal of Experimental Marine Biology and Ecology,* **400(1-2)**, 145-154.

Poloczanska, E.S., S.J. Hawkins, A.J. Southward, and M.T. Burrows, 2008: Modeling the response of populations of competing species to climate change. *Ecology,* **89(11)**, 3138-3149.

Pomeroy, R.S., Ratner, B.D., Hall, S.J., Pimoljinda, J., Vivekanandan, V., 2006. Coping with disaster: rehabilitating coastal livelihoods and communities. Marine Policy 30 (6).

Post, V. and Abarca, E. (2010), Preface: Salwater and freshwater interactions in coastal aquifers. Hydrogeology Journal 18: 1-4.

Pouliotte, J., Smit, B. and Westerhoff, L. (2009) Adaptation and development: Livelihoods and climate change in Subarnabad, Bangladesh. Climate and Development (1), Issue 1.

PROVIA, 2013

Provoost, P., S. van Heuven, K. Soetaert, R. Laane, and J.J. Middelburg, 2010: Seasonal and long-term changes in pH in the Dutch coastal zone. **7(11)**, 3869-3878.

Pruszak, Z., and E. Zawadzka, 2008: Potential implications of sea-level rise for Poland. Journal of Coastal Research, 24(2), 410-422

Purcell, K.M., P.L. Klerks and P.L. Leberg 2010: Adaptation to sea level rise: does local adaptation influence the demography of coastal fish populations. Jour of Fish Biology, 77 : 1209-1218.

Raabe et al. 2012

Rabalais, N. N., Turner, R. E., Dıaz, R. J., and Justic, D., 2009: Climate change and eutrophication of coastal waters, ICES J. Mar. Sci., 1528-1537.

Rabalais, N.N., R.J. Diaz, L.A. Levin, R.E. Turner, D. Gilbert, and J. Zhang, 2010: Dynamics and distribution of natural and human-caused hypoxia. **7(2)**, 585-619.

Rabbani, M. G., Rahman, S.H., Faulkner, L. (2013) Climate Change Impacts on Small Wetland Ecosystems (Ponds) along the Coast of Bangladesh: Associated Impacts and Potential Adaptation Mechanisms for the Climate

Vulnerable Poor. A paper (revised version) submitted to MDPI for a special journal issue "Adaptation or Extinction."

Rabbani, M.G., Rahman, A.A., Islam, N. (2010), Climate Change and Sea Level Rise: Issues and Challenges for Coastal Communities in The Indian Ocean Region. In Michael, D., Pandya, A.(eds) Coastal Zones and Climate Change. The Henry L. Stimson Centre, Washington, USA.

Rahman, K. M. M., Ensor, J. and, Berger, R. (2009) River erosion and flooding in northern Bangladesh. In: Ensor, J. and Berger, R. (eds.), Understanding Climate Change Adaptation: Lessons from Community -- Based Approaches. Practical Action Publishing, Rugby, pp. 39-54.

Raihan, S., Huq, M., Gerstrøm Alsted, N., Andreasen, M. (2010) Understanding climate change from below, addressing barriers from above: Practical experience and learning from a community-based adaptation project in Bangladesh. ActionAid Bangladesh, Dhaka.

Ramasamy, R. and S.N. Surendran 2011: Possible impact of rising sea levels on vector-borne infectious diseases. BMC Infectious Diseases, 11:18. doi:10.1186/1471-2334-11-18.

Ranasinghe, R. and M. Stive, 2009. Rising seas and retreating coastlines. *Climatic Change,* **97**: 465-468.

Ranasinghe, R., D. Callaghan and M. Stive, 2012. Estimating coastal recession due to sea level rise: beyond the Bruun rule. *Climatic Change*, **110**: 561-574.

Rasheed M. A. and Unsworth R. K. F., 2011: Long-term climate-associated dynamics of a tropical seagrass meadow: implications for the future. Marine Ecology Progress Series 422:93-103.

Rawlani and Sovacool, 2011

Rawlani, A and Sovacool, B. (2011) Building responsiveness to climate change through community based adaptation in Bangladesh. Mitigation and Adaptation Strategies for Global Change (16) 8, 845-863.

Reguero, B. G., F. J. Méndez, and I. J. Losada (2013), Variability of multivariate wave climate in Latin America and the Caribbean, *Global and Planetary Change*, *100*(0), 70-84

Reguero, B., F.J. Méndez and I.J. Losada 2013. Variability of multivariate wave climate in Latin America and the Caribbean. *Global and Planetary Change*, **100**: 70-84.

Reid, H., Cannon, T., Berger, R., Alam, M., and Milligan, A. (eds.) (2009) Community Based Adaptation to Climate Change. International Institute for Environment and Development, London.

Reusch, T.B.H., A. Ehlers, A. Hämmerli, and B. Worm, 2005: Ecosystem recovery after climatic extremes enhanced by genotypic diversity. Proceedings of the National Academy of Sciences 102: 2826-2831.

Revell, D.L., R. Battalio, B. Spear, P. Ruggiero, and J. Vandever, 2011: A methodology for predicting future coastal hazards due to sea-level rise on the california coast. *Climatic Change,* **109(SUPPL. 1)**, 251-276.

Reynaud, S., N. Leclercq, S. Romaine-Lioud, C. Ferrier-PagÈs, J. Jaubert, and J. Gattuso, 2003: Interacting effects of CO2 partial pressure and temperature on photosynthesis and calcification in a scleractinian coral. *Global Change Biology,* **9(11)**, 1660-1668.

Riadh, S.M., R.M. Chowdhury and A. Ishtiaque, 2012. *Community-based Climate Change Adaptation: Planning through Nishorgo Network*. USAID's Integrated Protected Area Co-Management Project, Dhaka, Bangladesh. http://www.nishorgo.org/admin/upload/pdf/0.47011000%201354654473_Community%20Based%20Climate%20Change%20Adaptaion%20Plan.pdf

Ridgeway, K.R. 2007: Long-term trend and decadal variability of the southward penetration of the East Australian Current. Geophys. Res. Lett. 34, L13613, doi:10.1029/2007GL030393

Riebesell, U., 2008: Acid test for marine biodiversity. *Nature,* **454**, 46-47.

Rittel and Webber, 1973

Rivadeneira, M.M. and M. Fern‡ndez, 2005: Shifts in southern endpoints of distribution in rocky intertidal species along the south-eastern Pacific coast. *Journal of Biogeography,* **32(2)**, 203-209.

River Bureau, Ministry of Land, Infrastructure, Transport and Tourism, 2011. *Statistics of Coasts, 2011 Fiscal Year Version* (in Japanese).

Romieu, E., Welle, T., Schneiderbauer, S., Pelling, M. and Vinchon, C. 2010: "Vulnerability assessment within climate change and natural hazard contexts: revealing gaps and synergies through coastal applications." Sustainability Science 5(2): 159-170.

Rosenzweig, C., W.D. Solecki, R. Blake, M. Bowman, C. Faris, V. Gornitz, R. Horton, K. Jacob, A. LeBlanc, R. Leichenko, M. Linkin, D. Major, M. O'Grady, L. Patrick, E. Sussman, G. Yohe, and R. Zimmerman, 2011. Developing coastal adaptation to climate change in the New York City infrastructure-shed: Process, approach, tools, and strategies. *Climatic Change*, **106**, 93-127.

Rozell, D.J. and Wong, T.F. (2010) Effects of climate change on groundwater resources at Shelter Island (New York State, USA). Hydrogeology Journal, 18: 1657-1665.

Rupp-Armstrong and Nicholls, 2007

Ryan et al., 2011

Saito, Y., N. Chaimanee, T. Jarupongsakul, and J.P.M. Syvitski, 2007: Shrinking megadeltas in Asia: Sea-level rise and sediment reduction impacts from case study of the Chao Phraya Delta. *LOICZ INPRINT*, no. 2007/2, 3–9.

Sales, R. F. M. (2009) Vulnerability and adaptation of coastal communities to climate variability and sea-level rise: Their implications for integrated coastal management in Cavite City, Philippines. Ocean & Coastal Management (52) Issue 7.

Salisbury, J., M. Green, C. Hunt, and J. Campbell, 2008: Coastal acidification by rivers: a new threat to shellfish? *EOS, Transactions, American Geophysical Union,* **89(50)**, 513.

Sallenger, A., R. Morton, C. Fletcher, E.R. Thierler and P. Howd, 2000. Discussion of 'Sea level rise shown to drive coastal erosion' by Leatherman et al. (2000*). EOS, Transactions of the American Geophysical Union*, **81(38):** 436.

Sanchez-Arcilla, A., J.A. Jimenez, H.I. Valdemoro, and V. Gracia, 1998: Implications of climatic change on Spanish Mediterranean low-lying coasts: The Ebro Delta case. Journal of Coastal Research, 24, 306–316.

Sano, M., J.A. Jimenez, R. Medina, A. Stanica, A. Sanchez-Arcilla, and I. Trumbic, 2011: The role of coastal setbacks in the context of coastal erosion and climate change. *Ocean & Coastal Management,* **54(12)**, 943-950.

Saroar, M and Routray, J. (2010) Adaptation in situ or retreat? A multivariate approach to explore the factors that guide the peoples' preference against the impacts of sea level rise in coastal Bangladesh. Local Environment: The International Journal of Justice and Sustainability (15):7, 663-686.

Savage, C., S.F. Thrush, A.M. Lohrer, and J.E. Hewitt, 2012: Ecosystem services transcend boundaries: estuaries provide resource subsidies and influence functional diversity in coastal benthic communities. **7(8)**, e42708.

Schleupner, C., 2008. Evaluation of coastal squeeze and its consequences for the Caribbean island Martinique. *Ocean and Coastal Management*, **51**: 383-390.

Scott, D., B. Amelung, S. Becken, J-P Ceron, G. Dubois, S. Gössling, P. Peeters and M.C. Simpson, 2008. *Climate Change and Tourism – Responding to Global Challenges*. UNWTO, Madrid, Spain.

Scott, D., M.C. Simpson, and R. Sim, 2012. The vulnerability of Caribbean coastal tourism to scenarios of climate change related to sea level rise. *Journal of Sustainable Tourism*, 20: 883-898.

Seitzinger, S.P., E. Mayorga, A.F. Bouwman, C. Kroeze, A.H.W. Beusen, G. Billen, D. Van G., E. Dumont, B.M. Fekete, J. Garnier, and J.A. Harrison, 2010: Global river nutrient export: a scenario analysis of past and future trends. *Global Biogeochemical Cycles,* **24 0886-6236**, GB0A08.

Semedo, A., K. Sušelj, A. Rutgersson, and A. Sterl (2011), A global view on the wind sea and swell climate and variability from ERA-40, *Journal of Climate*, *24*(5), 1461-1479

Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. In: [Field, C. (ed.)]. Cambridge University Press, pp. 109-230.

Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.

Sesil *et al*., 2009

Setiadi, N., J. Birkmann and P. Buckle, 2010, (eds.). *Disaster Risk Reduction and Climate Change Adaptation: Case Studies from South and Southeast Asia*. United Nations Institute for Environment and Human Security (UNU-EHS), Bonn, Germany, Publication No. 14/2010.

Seto, K.C., 2011: Exploring the dynamics of migration to mega-delta cities in Asia and Africa: Contemporary drivers and future scenarios. *Global Environmental Change-Human and Policy Dimensions,* **21(1)**, S94-S107.

Shaffer, G., S.M. Olsen, and J.O.P. Pedersen, 2009: Long-term ocean oxygen depletion in response to carbon dioxide emissions from fossil fuels. **2(2)**, 105-109.

Shepard, C.C., C.M. Crain, and M.W. Beck, 2011: The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis. *Plos One,* **6(11)**.

Sheppard, 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. *Estuarine, Coastal and Shelf Science,* **64(2-3)**, 223-234.

Shermann K., I. M. Belkin, K. D. Friedland, J. O'Reilly and K. Hyde, 2009. Accelerated Warming and Emergent Trends in Fisheries Biomass Yields of the World's Large Marine Ecosystems. Ambio Vol. 38 (4), June 2009 – pp: 215-224

Shipman B. and Stojanovic, T. 2007: "Facts, Fictions, and Failures of Integrated Coastal Zone Management in Europe." Coastal Management 35(2): 375 - 398.

Silverman, J., B. Lazar, L. Cao, K. Caldeira, and J. Erez, 2009: Coral reefs may start dissolving when atmospheric CO2 doubles. *Geophysical Research Letters,* **36**, L05606.

Simeoni, U. and C. Corbau, 2009: A review of the Delta Po evolution (Italy) related to climatic changes and human impacts. Geomorphology, 107, 64–71.

Simpson, M.C., D. Scott, M. Harrison, N. Silver, E. O'Keeffe, R. Sim, S. Harrison, M. Taylor, G. Lizcano, M. Rutty, H. Stager, J. Oldham, M. Wilson, M. New, J. Clarke, O.J. Day, N. Fields, J. Georges, R. Waithe and P. McSharry, 2010. *Quantification and Magnitude of Losses and Damages Resulting from the Impacts of Climate Change: Modelling the Transformational Impacts and Costs of Sea Level Rise in the Caribbean (Summary Document).* United Nations Development Programme (UNDP), Barbados, West Indies.

Smith et al, 2010

Smith S. V., 2005a: Length of the global coastal zone. In: Crossland C. J., Kremer H. H., Lindeboom H. J., Marshall Crossland J. I. and Le Tissier M. D. A. (Eds.), Coastal fluxes in the anthropocene, pp. 3. Berlin: Springer-Verlag.

Smith S., Buddemeier R., Wulff F., Swaney D., Camacho-Ibar V., David L., Dupra V., Kleypas J., San D.-M., Maria, McLaughlin C. and Sandhei P., 2005b. C, N, P fluxes in the coastal zone. In: Crossland C. J., Kremer H. H., Lindeboom H. J., Marshall Crossland J. I. and Le Tissier M. D. A. (Eds.), Coastal fluxes in the anthropocene, pp. 95-143. Berlin: Springer-Verlag.

Smith, K., 2011: We are seven billion. *Nature Climate Change,* **1(7)**, 331-335.

Somero, G.N., 2012: The physiology of global change: linking patterns to mechanism. **4**, 39-61.

Sorenses 1993

Sovacool, B., D'Agostino, A., Meenawat, H. and Rawlani, A. (2011) Expert views of climate change adaptation in least developed Asia. Journal of Environmental Management (97), 78-88.

Sovacool, B., D'Agostino, A., Rawlani, A. and Meenawat, H. (2012) Improving Climate change adaptation in least developed Asia. Environmental Science and Policy (21), 112-125.

Spalding, M. S. Ruffo, C. Lacambra, I. Meliane, L.Z. Hale, C. Shepard and M. Beck (in press). The role of ecosystems in coastal protection: adapting to climate change and coastal hazards. *Journal of Marine Research/Ocean and Coastal Management??* (to be updated)

Statham, P.J., 2012: Nutrients in estuaries--an overview and the potential impacts of climate change. *The Science of the Total Environment,* **434**, 213-227.

Sterl et al, 2009

Sterr et al., 2003

Sterr, H., 2008: Assessment of vulnerability and adaptation to sea-level rise for the coastal zone of Germany. Journal of Coastal Research, 24(2), 380-393

Sterrett, C., 2011. *Review of Climate Change Adaptation Practices in South Asia.* Oxfam Research Report. Oxford, UK.

Stive, M.J.C., L.O. Fresco, P. Kabat, B.W.A.H. Parmet, and C.P. Veerman 2011: How the Dutch plan to stay dry over the next century. Proceedings of Institution of Civil Engineers. 164, pp. 114-121.

Stojanovic and Barker, 2008

Stojanovic, T.A. and R.C. Ballinger, 2009: Integrated Coastal Management: A comparative analysis of four UK initiatives. *Applied Geography,* **29(1)**, 49-62.

Stokes et al., 2010

Storbjörk, S. 2010: "It Takes More to Get a Ship to Change Course": Barriers for Organizational Learning and Local Climate Adaptation in Sweden. Journal of Environmental Policy and Planning 12 (3):235 - 254.

Storbjork, S. and J. Hedren, 2011: Institutional capacity-building for targeting sea-level rise in the climate adaptation of Swedish coastal zone management. Lessons from Coastby. *Ocean & Coastal Management,* **54(3)**, 265-273.

Storlazzi, C.D., E. Elias, M.E. Field, and M.K. Presto, 2011: Numerical modeling of the impact of sea-level rise on fringing coral reef hydrodynamics and sediment transport. *Coral Reefs,* **30**, 83-96.

Stratten, L., O'Neill, M.S., Kruk, M.E., Bell, M. L. 2008: The persistent problem of malaria: Addressing the fundamental causes of a global killer. Social Science and Medicine 67 (2008) 854–862.

Stutz, M.L. and O.H. Pilkey, 2011: Open-ocean barrier islands: global influence of climatic, oceanographic, and depositional settings. *Journal of Coastal Research,* **272 0749-0208**, 207-222.

Syvitski, J.P.M. and A. Kettner, 2011: Sediment flux and the Anthropocene. Philosophical Transactions of Royal Society A, 369, 957-975

Syvitski, J.P.M., 2008: Deltas at risk. Sustainability Science, 3, 23–32.

Syvitski, J.P.M., A.J. Kettner, I. Overeem, E.W.H. Hutton, M.T. Hannon, G.R. Brakenridge, J. Day, C. Vörösmarty, Y. Saito, L. Giosan, and R.J. Nicholls, 2009: Sinking deltas due to human activities. Nature Geoscience, 2, 681–686.

Syvitski, J.P.M., C.J. Vorosmarty, 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.

Tabet, L. and L. Fanning, 2012: Integrated coastal zone management under authoritarian rule: An evaluation framework of coastal governance in Egypt. *Ocean and Coastal Management*, **61**: 1-9.

Tamura, T., K. Horaguchi, Y. Saito, L.N. Van, M. Tateishi, K.O.T. Thi, F. Nanayama and K. Watanabe, 2010. Monsoon-influenced variations in morphology and sediment of mesotidal beach on the Mekong River delta coast. *Geomorphology*, **116**: 11-23.

Teatini et al., 2011

Tebaldi, C., B.H. Strauss and C.E. Zervas, 2012. Modelling sea level rise impacts on storm surges along US coasts. *Environmental Research Letters*, **7**: 014032.

Teneva, L., M. Karnauskas, C.A. Logan, L. Bianucci, J.C. Currie, and J.A. Kleypas, 2011: Predicting coral bleaching hotspots: the role of regional variability in thermal stress and potential adaptation rates. *Coral Reefs,* **31(1)**, 1-12.

Terry, J.P. and A.C. Falkland 2010: Responses of atoll freshwater lenses to storm-surge overwash in the Northern Cook Islands. Hydrology Journal, 18, 749-759

Thomsen, J., F. Melzner, J.T. Wootton, C.A. Pfister, and J.D. Forester, 2008: Moderate seawater acidification does not elicit long-term metabolic depression in the blue mussel Mytilus edulis; Dynamic patterns and ecological impacts of declining ocean pH in a high-resolution multi-year dataset. *Marine Biology,* **157 0025-3162; 105(48)**, 2667; 18848-2676; 18853.

Thomsen, J., M.A. Gutowska, J. Saphšrster, A. Heinemann, K. TrŸbenbach, J. Fietzke, C. Hiebenthal, A. Eisenhauer, A. Kšrtzinger, M. Wahl, and F. Melzner, 2010: Calcifying invertebrates succeed in a naturally CO2 enriched coastal habitat but are threatened by high levels of future acidification. **7(11)**, 3879-3891.

Tobey, J., P. Rubinoff, D. Robadue Jr., G. Ricci, R. Volk, J. Furlow and G. Anderson, 2010. Practicing coastal adaptation to climate change: lessons from integrated coastal management. *Coastal Management*, **38**: 317-335.

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(5)**, 741-753.

Tompkins, E., W.N. Adger, and K. Brown, 2002: Institutional networks for inclusive coastal management in Trinidad and Tobago. *Environment and Planning A,* **34(6)**, 1095-1111.

Tran, T.T. and V. Nitivattananon, 2010. Adaptation to flood risks in Ho Chi Minh City, Vietnam. *International Journal of Climate Change Strategies and Management,* **3**: 61-73.

Trenhaile, A.S., 2010. Modeling cohesive clay coast evolution and response to climate change. *Marine Geology*, **277**: 11-20.

Trenhaile, A.S., 2011. Predicting the response of hard and soft rock coasts to changes in sea level and wave height. *Climatic Change*, **109**: 599-615.

Tribbia, J. and S.C. Moser, 2008: More than information: What coastal managers need to plan for climate change. *Environmental Science and Policy* **11(4)**, 315-328.

Tribia and Moser, 2007

Tribollet, A., C. Godinot, M. Atkinson, and C. Langdon, 2009: Effects of elevated pCO2 on dissolution of coral carbonates by microbial euendoliths. *Global Biogeochemical Cycles,* **23**, GB3008.

U.S. EPA (2009). Synthesis of Adaptation Options for Coastal Areas. Washington, DC, U.S. Environmental Protection Agency. Climate Ready Estuaries Program. EPA 430-F-08-024, January, 2009.

UKCIP, 2003

UNDP, 2010. *Community-based Adaptation to Climate Change Brochure*.

UNEP 2010, Tecnhologies for Climate Change Adaptation: Coastal Erosion and Flooding. TNA Guidebook Series, UNEP Risø Centre on Energy, Climate and Sustainable Development, Roskilde, Denmark, 150 pp

UNEP, 2009. *Sustainable Coastal Tourism: An Integrated Planning and Management Approach*. UNEP, Paris, France.

UNISDR, 2011: Global Assessment Report on Disaster Risk Reduction: Revealing Risk, Redefining Development. United Nations International Strategy for Disaster Reduction Secretariat, Geneva, Switzerland, Information Press, Oxford, UK, 178 pp.

Unnikrishnan et al; 2011

Urwin and Jordan, 2008

USAID, 2009. *Adaptation to Coastal Climate Change – A Guidebook for Development Planners*. USAID, Washington, D.C.

Vafeidis, A., B. Neumann, J. Zimmermann, and R.J. Nicholls, 201 1: *MR9: Analysis of land area and population in the low-elevation coastal zone (LECZ). Review in commission of the Foresight Project ``Migration and Global Environmental Change*''.

Van Baars, S. and I.M. Van Kempen, 2009: The Causes and Mechanisms of Historical Dike Failures in the Netherlands. E-Water Official Publication of the European Water Association, Hennef, Germany, 14 pp.

Van Kleef, E., H. Bambrick, and S. Hales 2010: The geographic distribution of dengue fever and the potential influence of global climate change. TropIKA.net http://journal.tropika.net.

Van Vuuren, D.,P., J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G.C. Hurtt, T. Kram, V. Krey, J. Lamarque, and others, 2011: The representative concentration pathways: an overview. *Climatic Change,* **109(1)**, 5-31.

van Vuuren, D.,P., K. Riahi, R. Moss, J. Edmonds, A. Thomson, N. Nakicenovic, T. Kram, F. Berkhout, R. Swart, A. Janetos, and others, 2012: A proposal for a new scenario framework to support research and assessment in different climate research communities. *Global Environmental Change,* **22**, 21-35.

Vaquer-Sunyer, R. and C.M. Duarte, 2011: Temperature effects on oxygen thresholds for hypoxia in marine benthic organisms. *Global Change Biology,* **17(5)**, 1788-1797.

Vermaat J., W. Salomons, L. Bouwer, K. Turner, R. Nicholls, and R. Klein, 2005: Climate change and coastal management on Europe's coast. In *Managing European Coasts*, Eds. R. Allan, U. Förstner and W. Salomons 199-226: Springer Berlin Heidelberg.

Vignola, R., B. Locatelli, C. Martinez, and P. Imbach. 2009. Ecosystem-based adaptation to climate change: what role for policy-makers, society and scientists? Mitigation and Adaptation Strategies for Global Change 14 (8):691-696.

Vinchon, C., S. Aubie, Y. Balouin, L. Closset, M. Garcin, D. Idier, and C. Mallet, 2009: Anticipate response of climate change on coastal risks at regional scale in Aquitaine and Languedoc Roussillon (France). Ocean and Coastal Management, 52(1), 47-56

Vineis, P., Chan, Q., Khan, A. 2011: Climate change impacts on water salinity and health Journal of Epidemiology and Global Health 1(1),5-10

Waldbusser, G.G., H. Bergschneider, and M.A. Green, 2010: Size-dependent pH effect on calcification in post-larval hard clam Mercenaria spp. *Marine Ecology Progress Series,* **417**, 171-182.

Walling, D.E. and D. Fang, 2003: Recent trends in the suspended sediment loads of the world's rivers. Global and Planetary Change, 39, 111–126.

Walsh et al, 2012

Walters, 1986

Walters, 1997

Wang et al, 2008

Webb, A.P. and P.S. Kench, 2010. The dynamic response of reef islands to sea-level rise: Evidence from multi-decadal analysis of island change in the Central Pacific. *Global and Planetary Change*, **72**: 234-246.

Webster I. T. and Harris G. P., 2004: Anthropogenic impacts on the ecosystems of coastal lagoons: modelling fundamental biogeochemical processes and management implications. Marine and Freshwater Research 55:67-78.

Weiss et al., 2011

Wernberg et al. 2011a,b

Werner, A.D and Simmons, C.T. 2009: Impact of sea-level rise on sea water intrusion in coastal aquifers. Ground Wat. 47, 197-204.

Werner, A.D. 2010: A review of seawater intrusion and its management in Australia. Hydrogeology Journal 18: 281–285

Wetz, M.S. and H.W. Paerl, 2008: Estuarine Phytoplankton Responses to Hurricanes and Tropical Storms with Different Characteristics (Trajectory, Rainfall, Winds). **31(2)**, 419-429.

White, I. and Falkland, T, 2010: Management of freshwater lenses on small Pacific islands Hydrogeology Journal 18: 227–246

White, I., T. Falkland, P. Perez, A. Dray, T. Metutera, E. Metia, and M. Overmars 2007: Challenges in freshwater management in low coral atolls. Jour of Cleaner Production, 15, 1522-1528.

Wilby, R.L., Nicholls, R.J., Warren, R., Wheater, H.S., Clarke, D., Dawson, R.J. (2011).Keeping nuclear and other coastal sites safe from climate change. Proceedings of ICE. Civil Engineering, 164: 129-136.

Wisshak, M., C. Schšnberg, A. Form, and A. Freiwald, 2012: Ocean acidification accelerates reef bioerosion. **7(9)**, e45124.

Wolf, 2011

Wolf, S., 2012: Vulnerability and Risk -- Comparing Assessment Approaches. *Natural Hazards,* **61(3)**.

Woodroffe, C.D. and C.V. Murray-Wallace, 2012. Sea-level rise and coastal change: the past as a guide to the future. *Quaternary Science Reviews*, **54**: 4-11.

Woodward, R.T. and Y. Wui, 2001: The economic value of wetland services: A meta-analysis. *Ecological Economics,* **37(2)**, 257-270.

Wootton, J.T. and C.A. Pfister, 2012: Carbon system measurements and potential climatic drivers at a site of rapidly declining ocean pH. PLoS ONE **7(12)**, e53396.

Wootton, J.T., C. A. Pfister and J.D. Forester. 2008. Dynamic patterns and ecological impacts of declining ocean pH in a high-resolution multi-year dataset. *Proceedings of the National Academy of Sciences of the United States of America,* **105**: 18848-18853.

World Bank, 2011

WRI (World Resource Institute), 2007. *Bangladesh: Cyclone Preparedness Program.* http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=37

Wu, H.Y., Zou, D.H., Gao, K.S.. 2008. Impacts of increased atmospheric CO2 concentration on photosynthesis and growth of micro- and macro-algae. Science in China Series C: Life Sciences. 51: 1144-1150

Xia, J., R.A. Falconer, B. Lin, and G. Tan, 2011: Estimation of future coastal flood risk in the severn estuary due to a barrage. *Journal of Flood Risk Management,* **4(3)**, 247-259..

Yamano, H., K. Sugihara, and K. Nomura, 2011: Rapid poleward range expansion of tropical reef corals in response to rising sea surface temperatures. *Geophysical Research Letters,* **38(4)**, L04501.

Yang, S.L., J.D. Milliman, P. Li, and K. Xu, 2011: 50,000 dams later: Erosion of the Yangtze River and its delta. Global and Planetary Change, 75, 14-20.

Yasuhara, K., S. Murakami, N. Mimura, H. Komine, and J. Recio 2007: Influence of global warning on coastal infrastructural instability. Sustainability Science, 2, 13-25.

Yin, J, Yin, Z, Wang, J, Xu S. 2012: National assessment of coastal vulnerability to sea-level rise for the Chinese coast. Journal Coastal Conservation 16(1):123–133

Yohe, G., K. Knee, and P. Kirshen, 2011: On the economics of coastal adaptation solutions in an uncertain world. *Climatic Change,* **106(1)**, 71-92.

Yoo *et al.*, 2012

Zeitlin H.L., I. Meliane, S. Davidson, T. Sandwith and J. Hoekstra 2012: Ecosystem-based adaptation in marine and coastal ecosystems. Environmental Sciences, 25: 1-10.

Zeppel, H., 2012. Climate change and tourism in the Great Barrier Reef Marine Park. *Current Issues in Tourism*, **15**: 287-292.

Zhang et al, 2011

Zhang, 2011

Zhang, J., D. Gilbert, A.J. Gooday, L. Levin, S.W.A. Naqvi, J.J. Middelburg, M. Scranton, W. Ekau, A. Pe–a, B. Dewitte, T. Oguz, P.M.S. Monteiro, E. Urban, N.N. Rabalais, V. Ittekkot, W.M. Kemp, O. Ulloa, R. Elmgren, E. Escobar-Briones, and d.P. Van, 2010: Natural and human-induced hypoxia and consequences for coastal areas: synthesis and future development. **7(5)**, 1443-1467.

Zhu, G., X. Xu, Z. Ma, L. Xu, and J.H. Porter, 2012: Spatial Dynamics and Zoning of Coastal Land-Use Change along Bohai Bay, China, during 1979-2008. *Journal of Coastal Research,* **28(5)**, 1186-1196.

Zimmerman, R. and Faris, C., 2010: Infrastructure impacts and adaptation challenges. In: Rosenzweig, C., Solecki, W. (Eds) *New York City Panel on Climate Change, 2010: Climate change adaptation in new your city: building a risk management response*. Prepared for use by the New York City Climate Change Adaptation Task Force. Annuals of the New York Academy of Science 2010. New York, NY, pp 63-85.

Table 5-1: Projections of global mean sea level rise in metres relative to 1986–2005 based on ocean thermal expansion calculated from climate models, the contributions from glaciers, Greenland and Antarctica from surface mass balance calculations using climate model temperature projections, the range of the contribution from Greenland and Antarctica due to dynamical processes, and the terrestrial contribution to sea levels, estimated from available studies. For sea levels up to and including 2100, the central values and the 5-95% range is given whereas for projections from 2200 onwards, the range represents the model spread due to the small number of model projections available (source: WG1, Chapter 13).

	RCP	2080-2100	2100	2200	2300	2400	2500
Low	2.6	0.42 [0.29 to 0.55]	0.46 [0.32 to .61]	0.47–0.60	0.59–0.67	0.67–0.79	0.77–0.91
Medium	4.5	0.49 [0.36 to 0.63]	0.56 [0.41 to .71]	0.25–0.90	0.31–1.12	0.30–1.38	0.27–1.67
High	6.0	0.50 [0.37 to 0.64]	0.58 [0.42 to .74]	0.67–1.92	1.10–3.21	1.44–4.55	1.80–5.76
	8.5	0.64 [0.48 to 0.82]	0.76 [0.56 to .96]				

Table 5-2: Main climate-related drivers for coastal systems, their trends due to climate change, and their main physical and ecosystem effects (↑ increase; ↓ decrease; ⊄ no change; ? uncertain; ↔ regional variability).

Climate Driver	Physical effects	Trends	Projections	Progress since AR4
Sea Level	Submergence, flood damage, erosion; saltwater intrusion; rising water tables/impeded drainage; wetland loss (and change).	GMSL *very likely* ☐ (5.3.2.2, WG1 Ch. 13)	GMSL *very likely* ☐ (see Table 5.1, WG1 Ch. 13) « (5.3.2.2, WG1 Ch. 13)	Improved confidence in contributions to observed sea level. More information on regional and local SLR.
Storms (Tropical cyclones (TC's), extratropical cyclones (ETC's)	Storm surges and storm waves, coastal flooding, erosion; saltwater intrusion; rising water tables/impeded drainage; wetland loss (and change). Coastal infrastructure damage and flood defence failure.	TC's (Box 5.1, WG1 2.6.3) *Low confidence* in trends in frequency and intensity due to limitations in observations « ETC's (5.3.3.1 WG1 2.6.4) *Likely* poleward movement of circulation features but *low confidence* in intensity changes.	TC's (Box 5.1) *Likely* ¯ - Ë in frequency; *Likely* ↑ in the most intense TC's ETC's (5.3.3.1) *High confidence* that reduction of ETC's will be small globally. *Low confidence* in changes in intensity.	Lowering of confidence of observed trends in TC's and ETC's since AR4. More basin-specific information on storm track changes.
Winds	Wind waves, storm surges, coastal currents, coastal infrastructure damage.	*Low confidence* in trends in mean and extreme wind speeds (5.3.3.2, SREX, WG1 Ch 2).	*Low confidence* in projected mean wind speeds. *Likely* increase in TC extreme wind speeds (5.3.3.2, SREX).	Winds not specifically addressed in AR4.

Waves	Coastal erosion, overtopping and coastal flooding.	*Likely* positive trends in high latitudes (5.3.3.2, WG1, Ch 3).	*Low confidence* for projections overall but *medium confidence* for southern ocean increases (5.3.3.2).	Large increase in number of wave projection studies since AR4.
Extreme Sea Levels	Coastal flooding erosion, saltwater intrusion	*High confidence* of increase due to GSLR (5.3.3.3, WG1 Chapter 13).	*High confidence* of increase due to GSLR, *low confidence* of changes due to storm changes (5.3.3.3, WG1 Chapter 13) «	Local subsidence is an important contribution to RSLR in many locations.
Sea Surface Temperature	Changes to stratification and circulation; reduced incidence of sea ice at higher latitudes; increased coral bleaching and mortality, poleward species migration; increased algal blooms.	*High confidence* that coastal SST increase is higher than global SST increase « (5.3.3.4, WG1 Ch. 3).	*High confidence* that coastal SSTs will increase with projected temperature increase (5.3.3.4).	Emerging information on coastal changes in SSTs.
Freshwater Input	Altered flood risk in coastal lowlands; altered water quality/salinity; altered fluvial sediment supply; altered circulation and nutrient supply.	*Mmedium confidence (limited evidence)* in a net declining trend in freshwater input.	*Medium confidence* for general increase in high latitudes and wet tropics and decrease in other tropical regions «.	Emerging information on freshwater input.
Ocean Acidity	Increased CO2 fertilisation; decreased seawater pH and carbonate ion concentration (or 'ocean acidification') [this is not a "Physical effect"]	*High confidence* of overall increase, with high local and regional variability (5.3.3.5).	*High confidence* of increase at unprecedented rates but with local and regional variability (Box CC-OA).	OA not specifically addressed in AR4. Considerable progress made in chemical projections and biological impacts.

Table 5-3: Top ten nations with the largest populations and the highest proportions of population in low-lying coastal areas (Countries with fewer than 100,000 inhabitants are not included; 15 SIDs (Small Island Developing States) with total of 423,000 inhabitants are also excluded). Source: Bollman *et al.,* 2010.

Top ten nations classified by population in low-lying coastal regions			Top ten nations classified by proportion of population in low-lying coastal regions		
Nation	Population in low-lying coastal regions (10^3)	% of population in low-lying coastal regions	Nations	Population in low-lying coastal regions (10^3)	% of population in low-lying coastal regions
1. China	127,038	10 %	1. Maldives	291	100 %
2. India	63,341	6 %	2. Bahamas	267	88 %
3. Bangladesh	53,111	39 %	3. Bahrain	501	78 %
4. Indonesia	41,807	20 %	4. Suriname	325	78 %
5. Vietnam	41,439	53 %	5. Netherlands	9590	60 %
6. Japan	30,827	24 %	6. Macao	264	59 %
7. Egypt	24,411	36 %	7. Guyana	419	55 %
8. USA	23,279	8 %	8. Vietnam	41,439	53 %
9. Thailand	15,689	25 %	9. Djibouti	250	40 %
10. Philippines	15,122	20 %	10. Bangladesh	53,111	39 %

Table 5-4: Main impacts of relative sea-level rise. Adapted from Nicholls 2002 and Nicholls *et al*. 2010.

Biophysical impacts of relative sea-level rise	**Other climate drivers**	**Other human drivers**
Dryland loss due to submergence	Wave and storm climate, morphological change, sediment supply	Sediment supply, flood management, morphological change, land claim
Flood damage (due to surges, tropical cyclones)	Wave and storm climate, morphological change, sediment supply	Sediment supply, flood management, morphological change, land claim
Backwater effect (river)	Runoff	Catchment management and land use
Wetland loss (and change)	Sediment supply, CO_2 fertilization,	Sediment supply, migration space, direct destruction
Dryland loss due to erosion	Sediment supply, wave and storm climate	Sediment supply
Saltwater intrusion into surface waters	Runoff	Catchment management and land use
Saltwater intrusion into ground waters	Precipitation	Land use, aquifer use
Rising water tables/ impeded drainage	Precipitation	Land use, aquifer use

Table 5-5: Summary of Coastal Vulnerability Assessments conducted at national or regional scale. Studies that either costed (Adapt$) or considered adaptation options (Adapt) are indicated. In studies that have considered adaptation: WOA=without adaptation; WA=with adaptation. CVI=Coastal Vulnerability Index; GIS=Geographic Information System, DIVA=Dynamic Interactive Vulnerability Assessment model. RSLR=relative sea level rise.

Location	Physical impacts considered	SLR scenario	Socio-economic scenario	Physical and ecosystem vulnerability	Human system vulnerability	Method and tools	Reference
Africa							
Africa	Erosion, flooding	0.64-1.26 m SLR by 2100, plus local subsidence/ uplift	IMAGE model scenario		WOA: 16–27 million people flooded and US$5-9 billion annual damage costs WA: Adaptation cuts people flooded by two orders of magnitude and damage costs by half, adaptation deficit US$300 billion and annual costs US$2-6 billion	DIVA (Adapt$)	Hinkel *et al.*, 2011
Ghana (east coast)	Erosion, submergence	1-5m SLR		Possible erosion of existing coastal buffer zones that separate open coast from coastal lagoons and inundation of coastal plains		GIS	Boateng, 2012b
Tanzania (Dar-es-Salaam)	Flood exposure	0.13-0.66 m by 2070, plus local subsidence/ uplift, plus to 1-in-100 event	A1 with rapid urbanization		210,000 people and US$10 billion exposed to 100-year coastal flood by 2070	GIS	Kebede and Nicholls, 2012
Asia							
China				Sediment supply to major delta regions has reduced by 50% since early 1980's and is driving coastal erosion			Cai *et al.*, 2009
China	Flooding, erosion	Current rate of RSLR (average 6mm/yr)		Vulnerability to flooding and erosion of the 18,000 km coastline, is ranked very high-3%; high-29%; moderate- 58% and low-10%.		CVI	Yin *et al.*, 2012
East Timor	Flooding, erosion wetland loss, salt water intrusion	0.31-0.54 m by 2100, plus local subsidence / uplift	A2 and B1	Wetland area reduction under 0.54m SLR is greatest for the Solomon Islands (68%), the Philippines (51%) and East Timor (50%). Composition of wetland areas in 2100 change to include more mangroves and less unvegetated wetland areas in 2100 compared to 2010. Increased salinity intrusion up major rivers 14-27% under A2	Expected number of people flooded annually relative national population (pop): WOA 0.54% pop A2; WA 0.01% pop A2	DIVA (Adapt$)	McLeod *et al.*, 2010
Indonesia					WOA 1.19% pop A2; WA 0.00% pop A2		
Malaysia					WOA 0.46% pop A2; WA 0.00% pop A2		
Papua New Guinea					WOA 0.07% pop A2; WA 0.01% pop A2		
Philippines					WOA 0.80% pop A2; WA 0.00% pop A2		
Solomon Islands					WOA 0.27% pop A2; WA 0.00% pop A2		

				Increased salinity intrusion into land areas 7-12% under A2			
India (Udupi coast)	Erosion, submergence	1-10m SLR		Erosion risk: of the 95 km of coastline, 59% assessed as very high; 7%high, 4% moderate, 30% low erosion risk. 372-42 km^2 exposed to submergence from 1m SLR	Qualitative assessment of affected areas include residential and recreational areas, agricultural land and the natural ecosystem	CVI	Dwarakish *et al.*, 2009
Vietnam	Submergence exposure	1-5m			Exposure is largest in Red River and Mekong deltas. Options identified to prolong the use of these areas into the future	GIS	Boateng, 2012a
Australasia							
Australia	Flood exposure, Erosion	1.1 m, combined with either 1-in-100 year flood event or mean high tide level		Exposure to tropical cyclone related hazards across northern half of continent, health of Great Barrier Reef will affect coastal resilience in NE. Southern coastline with extensive cliffs, large bays, estuaries, gulfs and flats vulnerable to SLR inundation and cliff instability if wave climate changes. Greater erosion along populous eastern coast due to SLR and storm changes.	Potential inundation of, 157,000–247,600 of the 711,000 existing residential buildings close to water. Nearly 39,000 buildings at risk from erosion due to SLR. Indigenous communities, including island based deemed particularly vulnerable due to their remoteness and location on low elevation land.	GIS coastal geomorphology model and Bruun Rule GIS DEM infrastructure database	Department of Climate Change, 2009
Australia (Victoria)	Flood exposure	0.8-1.4 m SLR by 2100, plus 1-in-100 year flood event		Across 9 coastal settlements considered, area exposed to 1-in-100 flood ranges from 153 to 408 km^2 for 0-1.4 m SLR	Across 9 coastal settlements considered, land parcels exposed to 1-in-100 flood ranges from 2,362 to 47,102 for 0 to1.4 m SLR	Hydrodynamic modelling, GIS	McInnes *et al.*, 2011
Europe							
Croatia	Submergence exposure	0.2-0.86 m SLR		A long narrow steep coastline with one major reclaimed alluvial plain will become increasingly vulnerable to inundation particularly for larger SLR projections. Erosion of pocket beaches will increase.	Sewage systems, agriculture and maritime transport and tourism affected by greater flood frequency of low-lying land and berths and piers.	Qualitative assessment	Baric *et al.*, 2008
Denmark-Copenhagen	Flood exposure	0.0-1.25 m SLR			Copenhagen not highly vulnerable to coastal flooding due to existing flood protection. WOA: direct costs of 1-in-100 year event increase from €3-4.8 billion with 0.5m SLR	GIS (Adapt)	Hallegatte *et al.*, 2011
Estonia	Submergence exposure	1 m SLR adjusted for regional uplift (i.e.		Observed beach erosion has resulted from increased storminess in the eastern Baltic Sea, combined with decline in winter sea-ice cover. Future	Possible productivity benefit from longer growing season. Major towns are not threatened due to location inland and mitigating effects of uplift. Sandy beaches and emerging coastal	Qualitative assessmen	Kont *et al.*, 2008

		69–73 cm RSLR)		land loss will impact major bird breeding grounds	tourism at risk.	t	
France	Flood exposure, erosion	0.88 m SLR + 5.8m surge (Atlantic) and 2.7 m surge (Mediterranean)		Atlantic coast with extensive dune systems is assessed as more resilient to rising sea levels over the coming century compared with Mediterranean coast where narrow dune systems are highly urbanized		GIS	Vinchon *et al.*, 2009
Germany	Submergence exposure	1 m SLR		There is a high level of reliance on hard coastal protection against extreme sea level hazards which will increase ecological vulnerability over time	300,000 people exposed in the coastal cities and communities. Erosion and flooding risks US$300 billion (based on 1995 values) of assets	GIS DEM, land-use, socio economic data	Sterr, 2008
Great Britain	Erosion, submergence	0.8 – 1m SLR		Large parts of the coasts are presently sediment starved and eroding and this will continue	At the national scale, economic losses due to erosion are expected to remain considerably smaller than flood losses	Qualitative assessment	de la Vega-Leinert and Nicholls, 2008
Norway	Submergence	0.5 - 1m SLR		Nationally, low susceptibility to accelerated sea-level rise due to mainly steep and resistant coastlines	Extensive infrastructure on northern and western coastlines likely to be negatively affected by sea-level rise, and adaptation costs could be significant	Qualitative assessment	Aunan and Romstad, 2008
Poland	Submergence	0.3 – 1m SLR		Lagoons, river deltas and estuaries in the far east and west were considered most vulnerable		Qualitative assessment	Pruszak and Zawadzka, 2008
Portugal	Submergence	0.14-0.57 m by 2100 SLR		Estuaries and coastal lagoons are assessed as most vulnerable and already sediment starved coastal beaches will continue to erode		Qualitative assessment	Ferreira *et al.*, 2008
Turkey	Submergence	1 m SLR			Without adaptation, impacts could cost 6% of current GNP. Adaptation/protection could cost 10% of current GNP.	Qualitative (Adapt)	Karaca and Nicholls, 2008
European Union	Erosion, flooding, salinity intrusion	0.35-0.45 m by 2100 SLR	A2 and B1		WOA: 0.2-0.8 million people flooded and US$17 billion annual damage costs WA: adaptation cuts exposure by a factor of 100 and annual damage costs by a factor of 10.	DIVA (Adapt$)	Hinkel *et al.*, 2010
N. America							
US	Submergence exposure	Land below 6 m above			20 municipalities with populations greater than 300,000 and 160 municipalities	GIS	Weiss *et al.*, 2011

		MHHW			with populations between 50,000 and 300,000 have land area with elevations at or below 6 m and connectivity to the sea,		
US	Land loss due to submergence	0.19-1.26 m SLR by 2100	2% annual GDP growth		WA: Total cost (adaptation plus residual damage) of US$ 50-75 billion (discounted at 3%)	GIS, CBA of protection vs. retreat (Adapt$)	Neumann *et al.*, 2010
US South Florida	Land loss due to submergence	0.5, 1.0, 1.5 m SLR by 2100 combined with MHHW		Submergence affects areas of ~1300 km^2, ~1700km^2, ~ 3000 km^2 respectively for SLR scenarios considered	~68000, ~210000, ~750000 population exposed population to SLR scenarios respectively $8 billion, $47 billion, $144 billion exposed to SLR scenarios respectively	GIS	Zhang, 2011
US Florida Keys	Land loss due to submergence	0.3, 0.6, 0.9, 1.2, 1.5, 1.8m SLR by 2100 combined with MHHW		Submergence affects areas of ~82 km^2, ~95km^2, ~ 107 km^2, ~119 km^2, ~127km^2, ~ 133 km^2 respectively for SLR scenarios	2663, 6403, 11,026, 15933, 19802, 21768 population exposed population to SLR scenarios respectively ~$56 million, ~$367 million, ~$2 billion, ~$6 billion, ~$9 billion, ~$12 billion exposed to SLR scenarios respectively	GIS	Zhang et al, 2011
US	Land loss due to submergence	0.67 m by 2100			Under the mid-SLR scenario (), approximately 1,630,000 people are potentially affected by SLR. Of these, 332,000 (~20%) are among the most socially vulnerable.	GIS & Social Vulnerability Index (SoVI)	Martinich et al, 2012
NW territories (Canada)	Shoreline stability and population exposure	Temperature, wind patterns		Loss of sea ice and shorter winter season and more variable weather patterns lead to changes in coastal sea ice coverage. Effects on species health and numbers.	More hazardous travel conditions for traditional hunting practices. Loss of traditional knowledge, skills and values.	Qualitative (Adapt)	Pearce *et al.*, 2010

Table 5-6: Impacts of sea level rise, coastal floods, and storms on critical coastal infrastructure by sector. Sources: Horton and Rosenzweig (2010), Zimmerman and Faris (2010).

Communications	Energy	Transportation	Water and waste
Higher average sea level			
• Increased salt water encroachment and damage to low-lying communications infrastructure not built to withstand saltwater exposure • Increased rates of coastal erosion and/or permanent inundation of low-lying areas, causing increased maintenance cost and shortened replacement cycles • Tower destruction or loss of function	• Increased rates of coastal erosion and/or permanent inundation of low-lying areas, threatening coastal power plants and refineries • Increased equipment damage from corrosive effects of salt water encroachment resulting in higher maintenance costs and shorter replacement cycles	• Increased salt water encroachment and damage to infrastructure not built to withstand saltwater exposure • Increased rates of coastal erosion and/or permanent inundation of low-lying areas, resulting in increased maintenance cost and shorter replacement cycles • Decreased clearance levels under bridges	• Increased salt water encroachment and damage to water and waste infrastructure not built to withstand saltwater exposure • Increased release of pollution and contaminant runoff from sewer systems, treatment plants, brownfields and waste-storage facilities • Permanent inundation of low-lying areas, wetlands, piers, and marine transfer stations • Increased salt water infriltration into distribution systems transfer stations
More frequent and intense coastal flooding			
• Increased need for emergency management actions with high demand on communications infrastructure • Increase damage to communications equipment and infrastructure in low-lying areas	• Increased need for emergency management actions • Exacerbated flooding of low-lying power plants and equipment, as well as structural damage to infrastructure due to wave action • Increased use of energy to control floodwaters • Increased number and duration of local outages due to flooded and corroded equipment	• Increased need for emergency management actions • Exacerbated flooding of streets, subways, tunnel and bridge entrances, as well as structural damage to • Decreased levels of service from infrastructure due to wave action flooded roadways; increased hours of delay from congestion during street-flooding episodes • Increased energy use for pumping	• Increased need for emergency management actions • Exacerbated street, basemend and sewer flooding, leading to structural damage to infraesctructure • Episodic inundation of low-lying areas, wetlands, piers, and marine transfer stations

Table 5-7: Community-based adaptation options.

Impact	**Type of option**	**Option**	**Brief description**	**References**
Salinity	New and diversified livelihoods	Saline-tolerant crop cultivation	Farmer production of saline-tolerant multi-vegetable varieties and non-rice crops.	Rabbani *et al*. 2013; Ahmed 2010
	New and diversified livelihoods	Keora nursery	Mangrove fruit production to develop local female entrepreneurship.	Ahmed 2010
	New and diversified livelihoods	Crab fattening	Collection, rearing and feeding of crabs for 15 days to increase local market value.	Pouliotte *et al*. 2009
	Structural	Homestead protection	Houses constructed on raised foundations to mitigate salinity ingress.	Ayers and Forsyth 2009
Flooding /Waterlogging	Socio-technical	Disaster management committees	Multi-community stakeholder committees established to discuss disaster preparedness and response on a monthly basis.	Ahammad 2011
	Socio-technical	Early flood warning systems	Established systems converted into a language and format understood by local communities; warning dissemination through community radio services.	Ahmed 2005; Saroar and Routray 2010
	New and diversified livelihoods	Aquaculture: cage and integrated approaches	Small-scale fish culture in cages on submerged agriculture land; aquaculture integrated with other livelihood practices.	Pouliotte *et al*. 2009; Khan *et al*. 2012; Pomeroy *et al*. 2006
	New and diversified livelihoods	Embankment cropping	Growing different vegetable varieties around heightened shrimp enclosures/coastal polders for productive use of fallow land.	Ahmed 2010
	New and diversified livelihoods	Hydroponics	Cultivating vegetables and other crops on floating gardens.	Dev 2013; Ahmed 2010; Ayers and Forsyth 2009
Cyclones / storm surges	Structural/hard	Homestead reinforcement	Low-cost retrofitting to strengthen existing household structures especially roofs; strict implementation of building codes.	Ahmed 2010; Sales 2009
	Structural/soft	Homestead ecosystem protection	Plantation of specific fruit trees around homestead area.	Haq *et al*. 2012
	Structural/hard	Underground bunker construction	Underground bunker established providing protected storage space for valuable community assets.	Raihan *et al*. 2010
Sea-level rise (SLR)	Institutional	Risk insurance mechanisms	Farmers educated on comprehensive risk insurance focusing on sea-level rise and coastal agriculture.	Khan *et al*. 2012
Multi-coastal impacts	Institutional	Integrating climate change into education	Formal and informal teacher training and curriculum development on climate change, vulnerability and risk management.	Ahmed 2010
	Institutional	Integrated coastal zone management plan (ICZM)	ICZM plan development at local institutional level including land and sea use zoning for ecosystem conservation.	Sales 2009
	Structural / soft	Restoration, regeneration and management of coastal habitats	Community-led reforestation and afforestation of mangrove plantations including integration of aquaculture and farming to increase household income levels.	Sovacool *et al*. 2012; Rawlani *et al*. 2011

	Institutional	Community participation in local government decision-making	Active female participation in local government planning and budgeting processes to facilitate delivery of priority coastal adaptation needs.	Faulkner and Ali 2012
	Institutional /socio-technical	Improved research and knowledge management	Establishment of research centres; community-based monitoring of changes in coastal areas.	Rawlani *et al*. 2011; Sales 2009

Table 5-8: Global assessments of costs of sea-level rise.

Reference	Physical impacts	SLR scenario	Socio-economic scenario	Impact indicators	Without adaptation	With adaptation
Anthoff *et al*., 2010	Submergence, wetland loss	0.5-2.0m SLR by 2100	A1, A2, B1, B2	Net present value of total cost for 2005-2100 (pure rate of time preference 1%)	US$ 800-3300 billion in 2100	US$200-2200 billion in 2100
Nicholls *et al*., 2011	Submergence, erosion	0.5-2.0 m SLR by 2100	A1FI	Cumulative number of people displaced due to land loss to submergence and erosion	72-187 million people during 21st century	0.04-0.3 million people during 21st century
				Annual adaptation cost	N/a	US$ 25-270 billion/yr
Hinkel *et al*., 2012	Flooding	0.6-1.3m by 2100	UN medium fertility	Annual expected number of people flooded	170-260 million people/yr in 2100	Two orders of magnitude smaller than w/o adaptation
				Annual total cost (including dike upgrade, dike maintenance and residual damage cost)	US$ 160-300 billion/yr in 2100	US$ 30-90 billion/yr in 2100
				Annual total cost relative to GDP	0.05% -0.09% of global GDP in 2100	0.01%-0.03% of global GDP in 2100

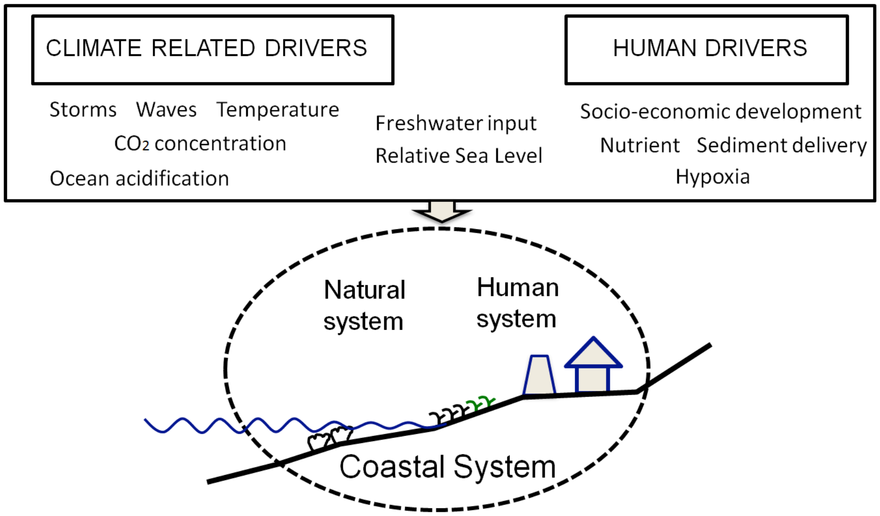

Figure 5-1: Schematic diagram indicating the elements of the coastal zone that are considered in this chapter.

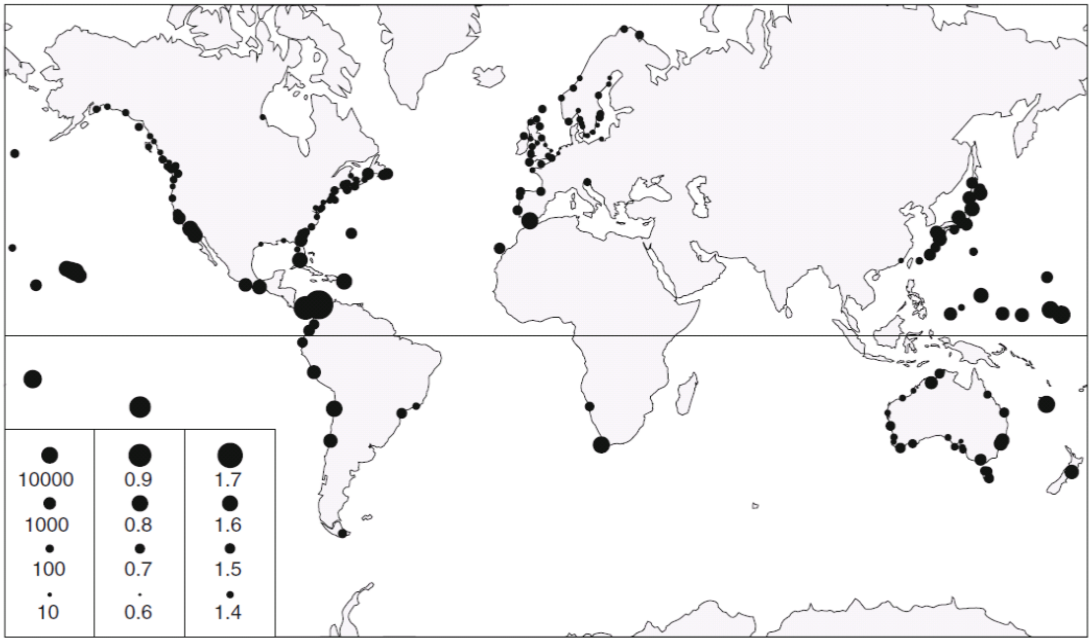

Figure 5-2: Results of global analysis, indicated by dot diameter. a Factor by which frequency of flooding events will increase with a rise in sea level of 0.5 metres (key is left-hand column of dots in the bottom left-hand corner). b Sea-level rise allowance (metres) for 1990–2100 which conserves frequency of flooding events for the IPCC A1FI Projection based on A1FI emission scenario and AR4-adjusted TAR projections (normal distribution with Δz=0.542 m and σ=0.168 m); key is central column of dots in the bottom left-hand corner. c Sea-level rise allowance (metres) for 21st century which conserves frequency of flooding events for the 1.0/1.0 m Projection, based on post-AR4 results (raised cosine distribution with Δz=1.0 m and W/2=1.0 m); key is right-hand column of dots in the bottom left-hand corner.

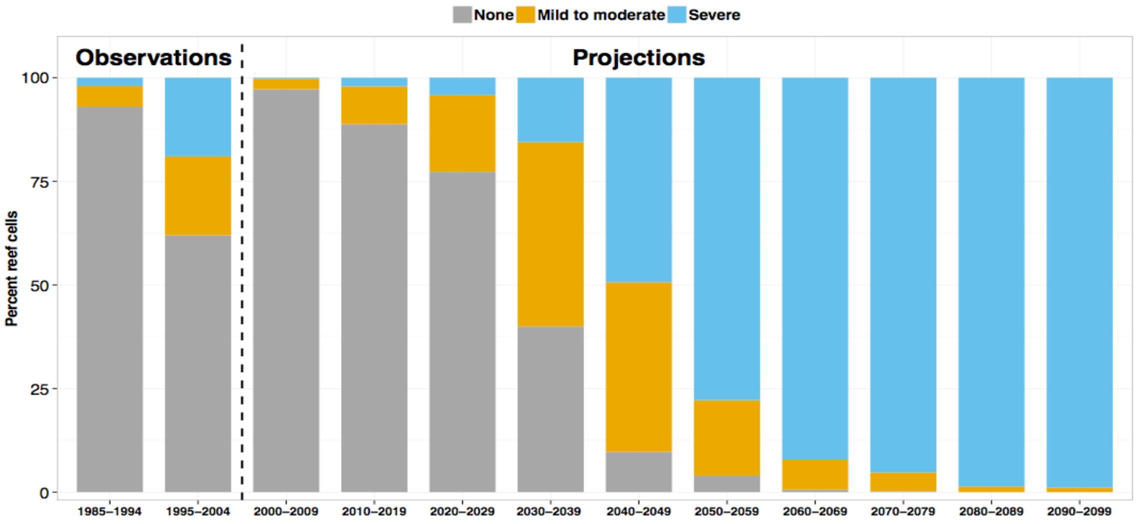

Figure 5-3: Percent of reef locations (1°x1° grid cells which have coral reefs) that experience no bleaching (green), at least one mild bleaching event (reddish-brown), or at least one severe bleaching event (purple) for each decade. Observed bleaching events are summarized from the ReefBase dataset (Kleypas *et al*. 2008). In the observations, some of the "no bleaching" cells may have experienced bleaching but it was either not observed or not reported. Modeled bleaching events are averages of data from four ensemble runs of the Community Climate System Model version 3 using the SRES A1B CO_2 scenario and the standard degree heating month formula (Teneva *et al*., 2011). The labels of values ≤ 1% are not shown.]

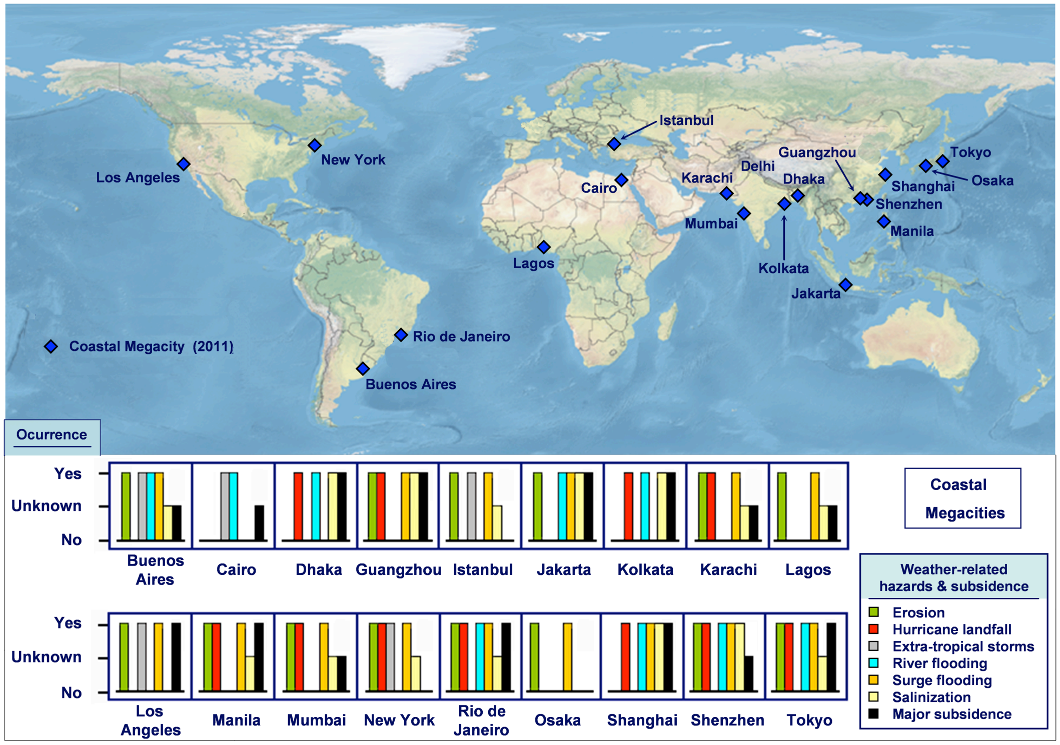

Figure 5-4: Mega-urbanisation on the coast. Source:Blackburn S and Marques da Silva C (2013) Mega-urbanisation on the coast: Global context and key trends in the twenty-first century, in Pelling M and Blackburn S (eds) Megacities and the Coast: Risk, Resilience and Transformation, Earthscan: London.

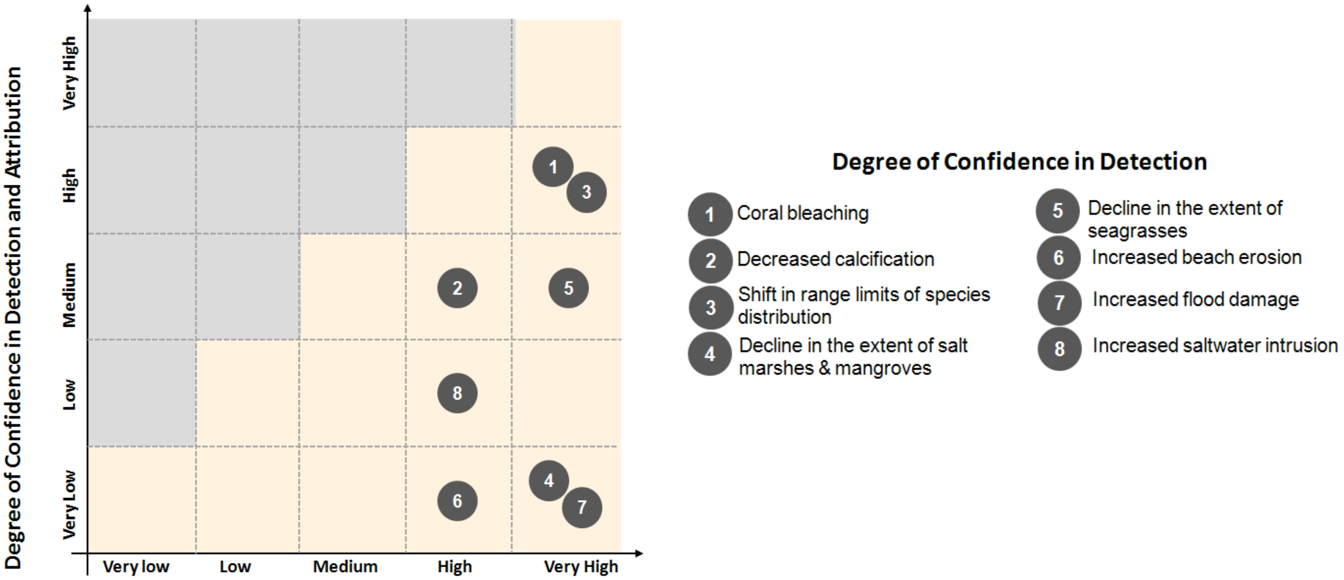

Figure 5-5: Summary on detection and attribution in this chapter.

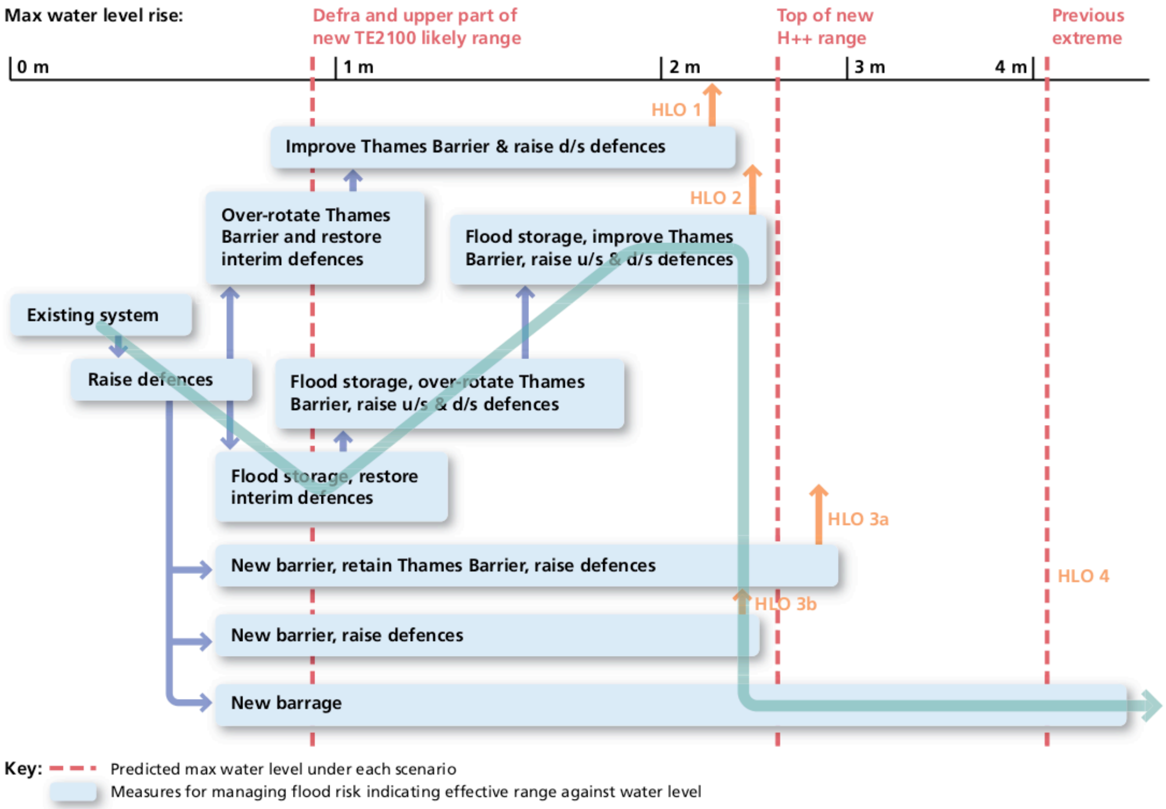

Figure 5-6: Adaptation measures and pathways considered in the TE2100 project. The boxed show the measures and extend over the range of sea level rise they are effective. The blue arrows link to alternative measures that may be applied once a measures is no longer effective. The red lines show the various sea-level rise scenarios used in the analysis. The fat green line shows a possible future adaptation pathway in the unlikely event of extreme change (>4 m rise).

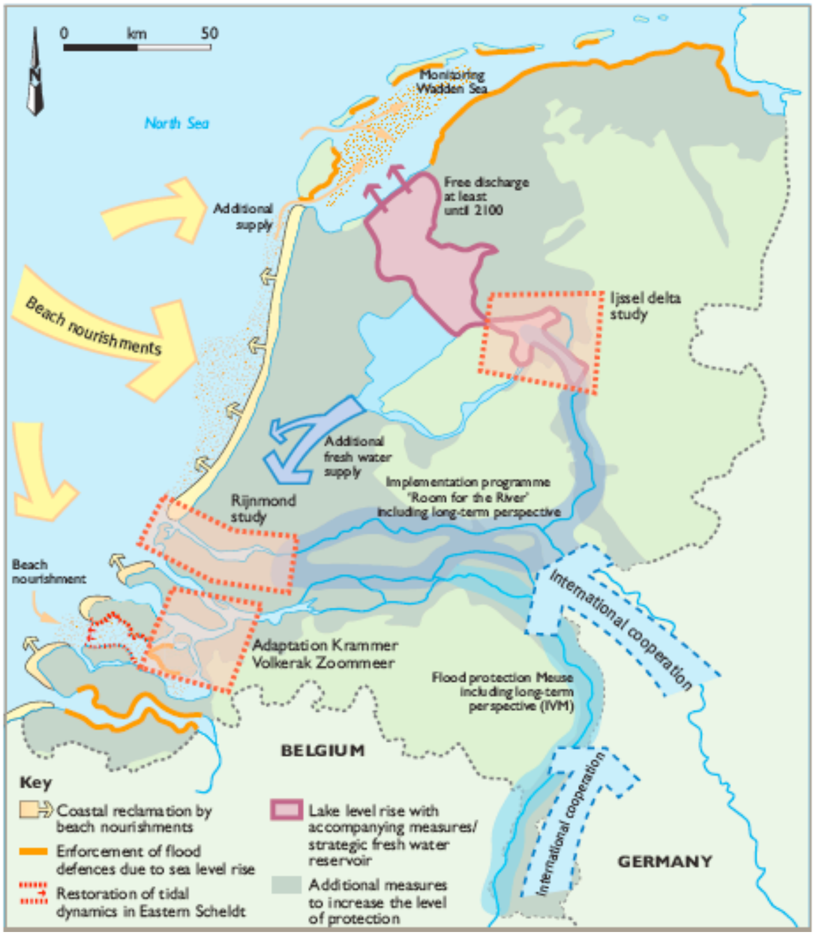

Figure 5-7: Overview of the Delta Committee National Recommendations. Source: Stive *et al.*, 2011.

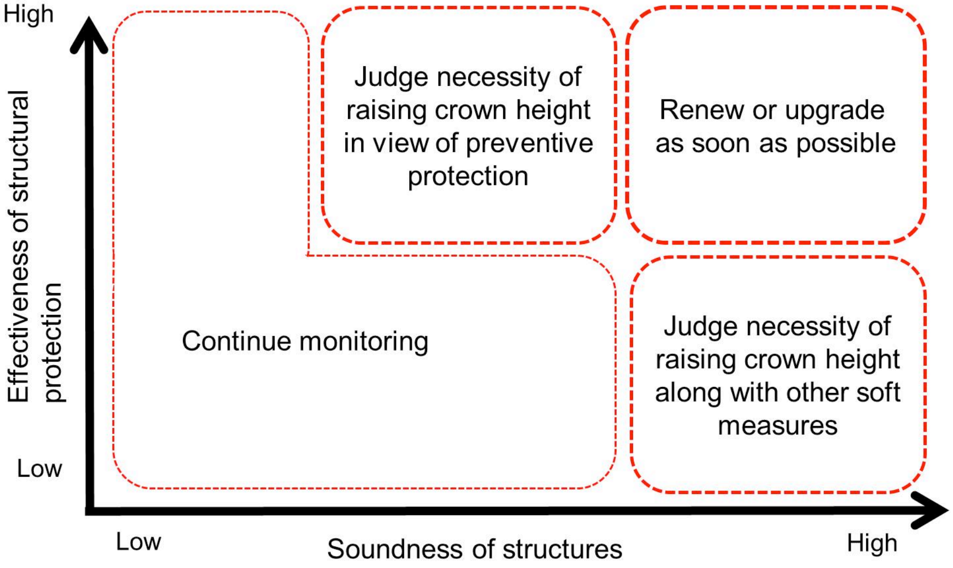

Figure 5-8: Priority in investment for adaptation to global warming.

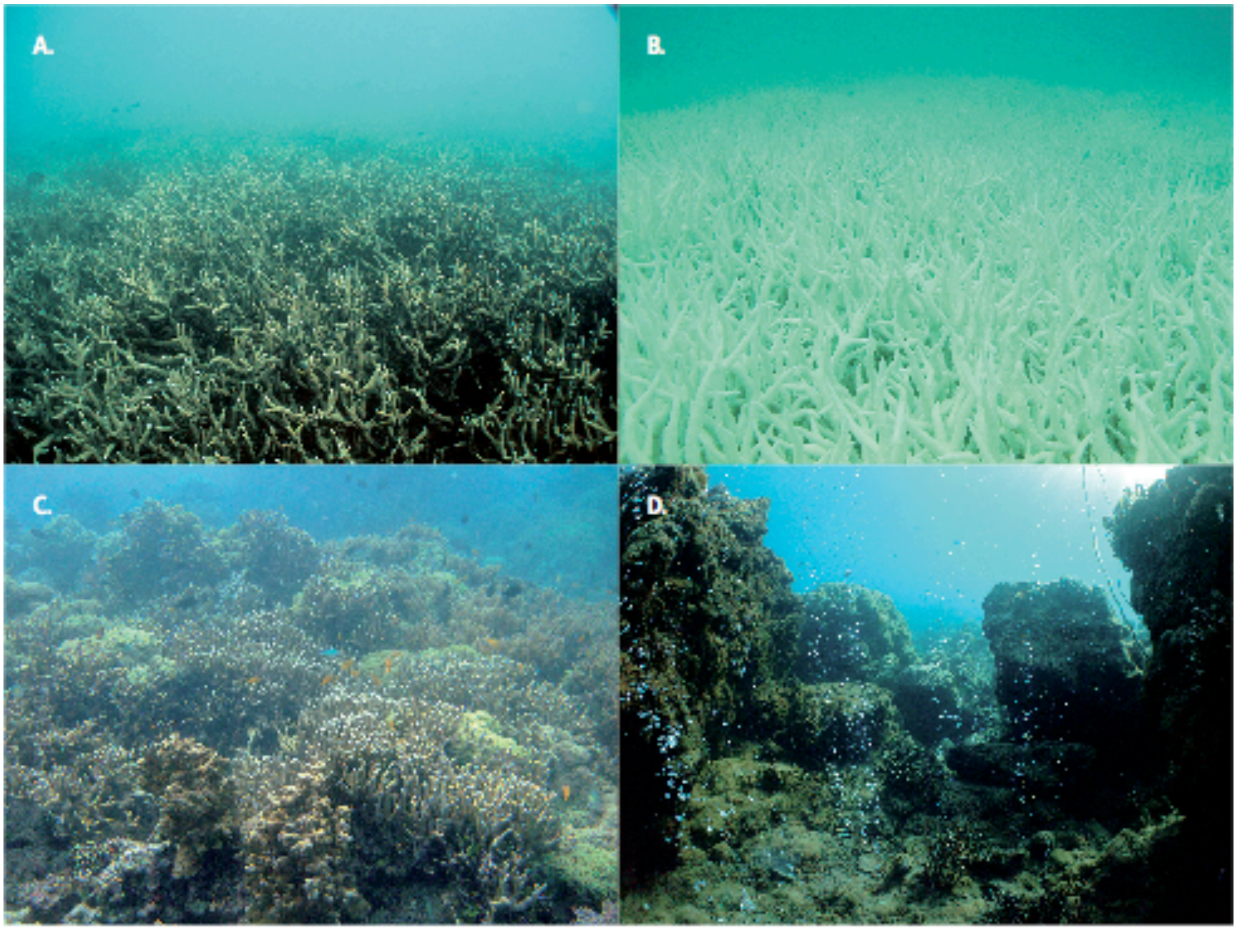

Figure CR-1: A and B: the same coral community before and after a bleaching event in February 2002 at 5 m depth, Halfway Island, Great Barrier Reef. Coral cover at the time of bleaching was 95% bleached almost all of it severely bleached, resulting in mortality of 20.9% (Elvidge et al., 2004). Mortality was comparatively low due in part because these communities were able shuffle symbiont types to more thermo-tolerant types (Berkelmans and van Oppen, 2006; Jones et al., 2008). C and D: three CO2 seeps in Milne Bay Province, Papua New Guinea show that prolonged exposure to high CO2 is related to fundamental changes in coral reef structures (Fabricius et al., 2011). Coral communities at three high CO2 (Fig. XB; median pHT 7.7, 7.7 and 8.0), compared with three control sites (Fig. XA; median pHT 8.02), are characterized by significantly reduced coral diversity (-39%), severely reduced structural complexity (-67%), low densities of young corals (-66%) and few crustose coralline algae (-85%). Reef development ceases at pHT values below 7.7. Photo credit: R. Berkelmans (A and B) and K. Fabricius (C and D).

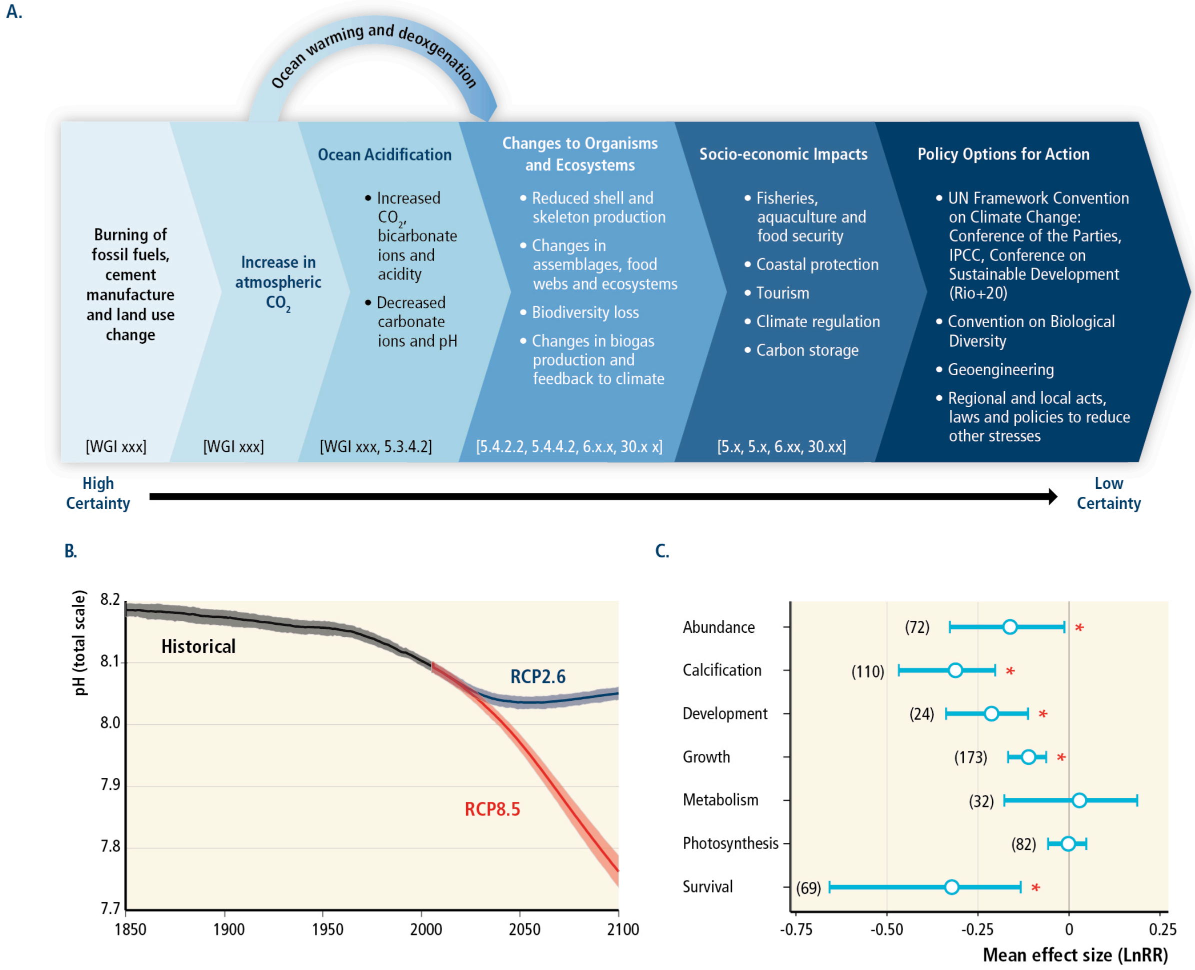

Figure OA-1: A: Overview of the chemical, biological, socio-economic impacts of ocean acidification and of policy options (adapted from Turley & Gattuso, 2012). B: Multi-model simulated time series of global mean ocean surface pH (on the total scale) from CMIP5 climate model simulations from 1850 to 2100. Projections are shown for emission scenarios RCP2.6 (blue) and RCP8.5 (red) for the multi-model mean (solid lines) and range across the distribution of individual model simulations (shading). Black (grey shading) is the modelled historical evolution using historical reconstructed forcings. The models that are included are those from CMIP5 that simulate the global carbon cycle while being driven by prescribed atmospheric CO_2 concentrations. The number of CMIP5 models to calculate the multi-model mean is indicated for each time period/scenario (IPCC AR5 WG1 report, Figure 6.28). C: Effect of near future acidification on major response variables estimated using weighted random effects meta-analyses, with the exception of survival which is not weighted (Kroeker et al., in press). The effect size indicates which process is most uniformly affected by ocean acidification but large variability exists between species. Significance is determined when the 95% bootstrapped confidence interval does not cross zero. The number of experiments used in the analyses is shown in parentheses. * denotes a significant effect.

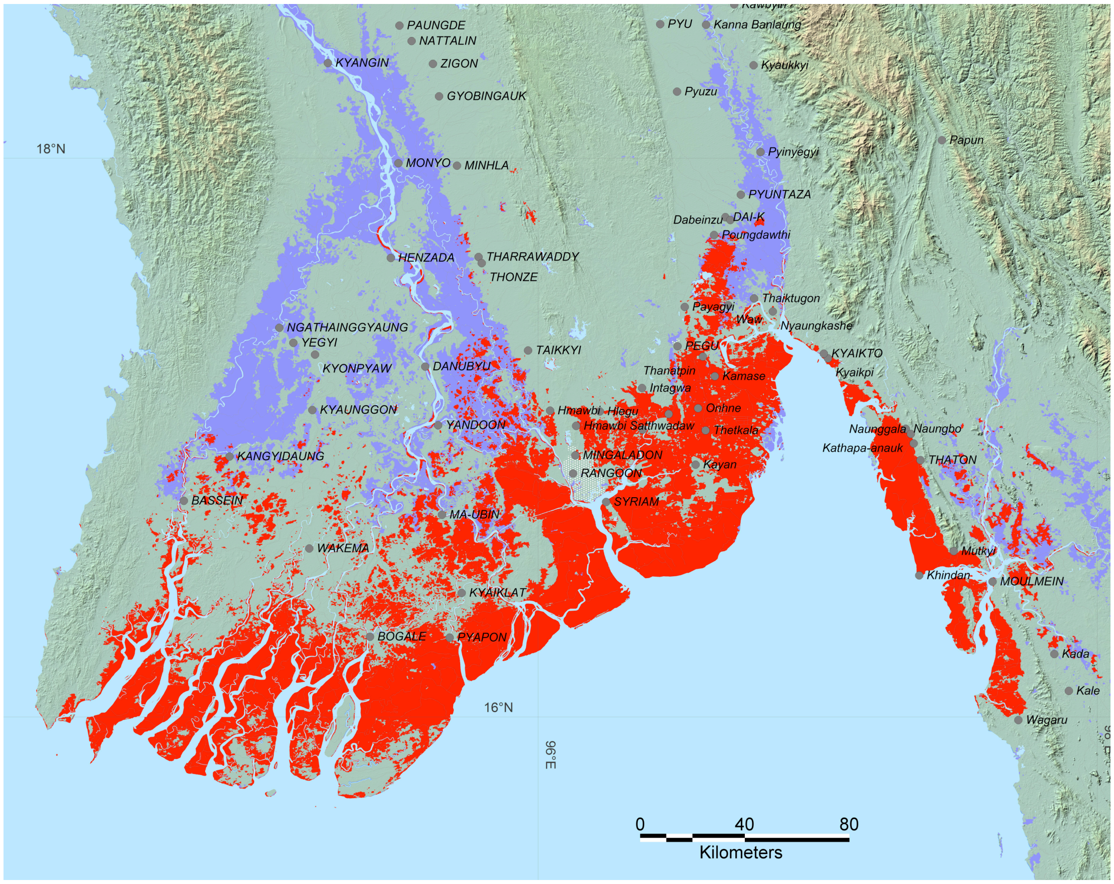

Figure TC-1: The intersection of inland and storm surge flooding. Red shows May 5, 2008 MODIS mapping of the tropical cyclone Nargis storm surge along the Irrawaddy Delta and to the east, Myanmar. The blue areas to the north were flooded by the river in prior years. (From Brakenridge *et al.*, 2012).