Impacts of Climate Change in Coastal Areas: Lessons Learned and Experiences

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Abstract This conclusions paper summarises some of the main development and trends related to climate change in coastal areas and outlines future research needs.

Introduction

Sixty percent of the world's cities with a population of over 5 million are located within 100 km of the coast (Nicholls et al. 2007). Coastal areas are among the world's most diverse and productive environments (McLean et al. 2001), which currently are experiencing growing exploitation pressures (Nicholls and Lowe 2004). Coastal systems, including estuaries, are among the most vulnerable areas to many impacts of climate change (U.S. EPA 2009; Camarsa et al. 2012) that could affect coasts in various ways (Zikra et al. 2015). Coastal areas are now affected by increasing flooding, accelerated erosion, water scarcity and droughts, water pollution, habitat destruction, loss of biodiversity, and seawater intrusion (Nicholls and Lowe 2004; Camarsa et al. 2012). These events have environmental, economic and societal impacts, and are already altering the livelihoods of coastal communities (Camarsa et al. 2012).

Impacts of Climate Change in Coastal Areas: An Overview

As documented in various chapters on this book, the impacts of climate change may be classified into 3 main areas: social impacts, economic impacts and environmental impacts. Due to their relevance, they will be outlined in turn.

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1. ***Social Impacts***: Even though it is often overlooked, damages associated with or caused by climate change in coastal areas have strong social impacts. In particular, they may lead to displacements of proportions of older residents and transient populations, who may need to move away from the coasts to become less vulnerable. The process may also lead to higher level of unemployment levels and high seasonality of work, up to physical isolation due to poor transport links.

Other negative effects as listed in the literature (e.g. McLean et al. 2001) which may be mentioned are:

- increased loss of property and coastal habitats;
- loss of renewable and subsistence resources;
- loss of tourism, recreation, and transportation functions;
- loss of non-monetary cultural resources and values;
- decline in soil and water quality.

However, it is important to recognize that the aforementioned impacts are largely associated with human settlements and developed areas. In general, most unaltered and naturally functioning shorelines are capable of adapting or responding to sea-level rise (Boesch et al. 2000).

2. ***Economic Impacts***: Climate change also threats key economic activities in coastal areas and leads to loss of a related share of GDP. For instance, in Europe the economic value of coastal areas within 500 m from the seas accounts between €500–1000 billion. According to the European Commission, the annual costs of taking mitigating and adapting measures are estimated at around €6 billion by the year 2020 (European Commission 2016). The economic impact of tropical storms and hurricanes might reach billions of dollars in insured losses alone (Boesch et al. 2000).
3. ***Environmental Impacts***: This area, which is the focus of this paper, is probably the one characterised by a greater degree of complexity and will therefore be described at a greater level of detail.

Coasts are sensitive to sea level rise (Zikra et al. 2015), which is considered to be one of the most significant threats to shoreline systems (Boesch et al. 2000). About 70% of the coastlines worldwide are projected to experience a sea level change within ± 20% of the global mean (Core Writing Team et al. 2014). The Pacific region is among the most vulnerable ones (Leal Filho 2017).

Increasing sea level leads to a number of impacts. These are:

(a) coastline retreat
(b) flooding
(c) swamping of low land on coastal plains
(d) coastal erosion
(e) underground seawater intrusion and
(f) destruction of the seawall and drainage systems (Cai et al. 2009; European Commission 2016).

In particular, overtopping of seawater results in the salinization of the surficial and sub-surficial zones of inland coastal areas (Yang et al. 2015). The induced rate of erosion is about two orders of magnitude greater than the rate of sea level rise. As beaches are lost, fixed structures nearby are increasingly exposed to the direct impact of storm waves, and will ultimately be damaged or destroyed (Zhang et al. 2004).

The erosion of the dune systems makes it more difficult for the water to recede back to sea through the drainage system (Gray et al. 2014). Increased anthropogenic activities (e.g. excessive pumping or intensive building close to the shore) in combination with climate change affect coastal groundwater systems globally (Oude Essink et al. 2010). Seawater intrusion caused by sea level rise diminishes an availability of fresh groundwater resources in coastal areas (Pham and Lee 2015; Tam et al. 2016).

A special mention should be made to **coastal erosion**, a matter of major concern to many countries, and subject to many climate change adaptation efforts (Leal Filho 2015). The already-severe coastal erosion problems seen in many parts of the world, are expected to exacerbate in the 21st century (Zhang et al. 2004). Coastal erosion threatens habitats and wildlife and has dramatic effects on coastal development and infrastructure (Boesch et al. 2000; European Commission 2016). Erosion events might also be a result of storms and extreme events (Boesch et al. 2000), and sediment budget reduction (Cai et al. 2009). In addition, chronic coastal erosion brought about by large wave events or changes in wave direction that shift coastal sand and sediments (Australian Government, Department of Climate Change 2009). Increased coastal erosion can reduce water clarity, limiting the depth at which sea grasses can grow (Paice and Chambers 2016a).

In terms of **losses of habitat and biodiversity**, some evidences are also available. The potential impacts of invasive species in response to climate change are relevant for all coastal ecosystems (Hellmann et al. 2008). Invasive plants and animals are a serious threat through predation and interference with food webs, competition for habitat and resources, and direct health effects on native plants and animals. Moreover, some native species may also become invasive, if they are able to tolerate high temperatures (Paice and Chambers 2016a). Rising global seas temperature and altered salinity stress temperature-sensitive organisms such as corals and causes their death or morbidity. It also makes estuary and near shore habitats inhospitable to species with narrow temperature tolerances (Agardy et al. 2005).

Changes of precipitation patterns are also a matter which deserves mention. Climate change affects rainfall amounts and their seasonal patterns (Paice and Chambers 2016a) as well as the frequency, severity and positions of cyclones and other storms (Australian Government, Department of Climate Change 2009). Altered frequencies and intensities of precipitation, and increased water temperatures impact the health of the coastlines (U.S. EPA 2009), exacerbate coastal erosion and flooding events, influence and damage many vital ecosystem services provided by coastal ecosystems (Paice and Chambers 2016b). The rising acidity of the ocean have significant impacts on coastal environments and marine ecosystems (Zikra et al. 2015) by limiting growth of carbonate-dependent organisms, including corals and shellfish (Paice and Chambers 2016a).

Impacts in Some Countries

Depending on a geographical location, coastal areas experience different direct and/or indirect impacts of climate change. Below are examples of climate change impacts in different coastal areas.

Indonesia is the world's largest archipelagic state with over 81,000 km of coastline that is very vulnerable to climate change. Increasing trend of sea level rise, warmer ocean temperature and an increase of waves height are among significant climate change impacts in the country (Zikra et al. 2015).

South China experiences increasing occurrence and intensity of storm surges, aggravating saltwater intrusion, accelerating coastal erosion, exacerbated problems in urban drainage and flood control, inundating lowland areas, degrading mangroves and coral reef ecosystem (Cai et al. 2009; Du et al. 2013).

In **Senegal** about 25% of the shoreline is deemed to be at high risk of erosion and shoreline loss, notably, in the deltas and estuaries of the three main rivers. It is estimated that by 2080, as a result of a sea level rise, 75% of the coastline could become at high risk of erosion that will be accelerated by sand extraction and beach-top urbanization. It is also expected that by 2080 two thirds of the coastal area could be facing a high risk of submersion (World Bank 2013).

Climate change brings significant change to **Australia**'s coastal zone as well. It increases risks to settlements, industries, and natural ecosystems. Rising sea levels will have a large impact on many coastal environments such as beaches (e.g. beach loss), estuaries, coral reefs, wetlands (e.g. salinisation) and low-lying islands (e.g. inundation) (Australian Government, Department of Climate Change 2009).

Many coastal areas in **Europe** are already confronted with the effects of climate change, i.e., flooding, erosion, saline intrusion, and the loss of natural ecosystems such as wetlands (Camarsa et al. 2012). Despite the fact that each European coastal member state is exposed to different impacts of climate change, the following trends can be observed. For instance, (Directorate-General for Maritime Affairs and Fisheries European Commission 2009):

- Along the **Baltic** coastline, the overall vulnerability to coastal flooding and erosion due to sea level rise is expected to be low. Most climate change impacts are projected for marine species, because migration from the semi-enclosed Baltic Sea will be difficult when the sea surface temperature rises.
- The main climate risk in the Atlantic marine basin and the North Sea basin is flooding due to the sea level rise and storm surges. Southern countries could become more exposed to freshwater shortage in the future due to prolonged and more intense periods of drought.
- The coastline of the Mediterranean marine basin is highly exposed to erosion, large areas are affected by saltwater intrusion and dry periods projected to increase in length and frequency.

About 53% of the total **U.S.** population live on the 17% of land in the coastal zone, and this number is growing. Atlantic and Gulf coastlines are especially vulnerable to long-term sea-level rise and an increase in the frequency of storm surges or hurricanes (Boesch et al. 2000). Moser et al. (2014) compiled the regional threats from climate change, for instance:

(a) **Pacific Northwest**: The substantial global sea level rise is regionally moderated by the continuing uplift of land. Coastal storm surges are expected to be higher due to increase in sea level alone, and more intense persistent storm tracks will increase coastal flooding from inland runoff.
(b) **California**: Coastal storm surges are expected to be higher due to increases in sea level alone, and more intense persistent storm tracks will increase coastal flooding risks from inland runoff. There is also a growing risk of coastal erosion, temporary flooding, and permanent inundation.
(c) **Alaska**: Current and projected increases in Alaska's ocean temperatures and changes in ocean chemistry are expected to alter the distribution and productivity of Alaska's marine fisheries.
(d) **Gulf Coast**: Hurricanes, land subsidence, sea level rise, and erosion already pose great risks to the area, causing among others permanent land loss. Coastal inland and water temperatures are expected to rise; coastal inland areas are expected to become drier. There is still uncertainty about future frequency and intensity of Gulf Mexico hurricanes, but sea level rise will increase storm surges (Moser et al. 2014).

Adaptation and Mitigation Responses in Coastal Areas

Adaptation and mitigation measures responses to the impacts of climate change in coastal areas are expected to vary strongly among and within regions and countries. According to the European Commission, the integrated coastal management approach builds the foundations for sustainable coastal management and development, supporting socio-economic development, biodiversity and ecosystem services (European Commission 2016). It includes all steps: information collection, planning (in its broadest sense), decision making, management and monitoring of implementation (Cai et al. 2009). In addition to the integrated approach, coastal adaptation options based on local community participation, disaster risk reduction and ecosystems-based approaches (Core Writing Team et al. 2014).

Structures as seawalls, breakwaters, jetties, groins, and offshore dikes beach nourishment, man-made dunes, planting of mangroves and rise grass, and coastal shelter belts are used to control coastal erosion (Cai et al. 2009) and sand fences' (made of dry willow branches or wicker) for dune systems (Camarsa et al. 2012).

Catchment management activities that improve drainage design (e.g. flood retention basins, retrofitting of existing artificial drainage networks) can protect coastal stability during flooding, and may be important in areas where the frequency of intense rainfall events is predicted to increase (Paice and Chambers 2016a). U.S. EPA divides adaptation options for coastal areas into the following categories (U.S. EPA 2009):

- Maintain/restore wetlands: focus on facilitating wetland migration through changes in legislation and regulations, and prohibitions on shoreline hardening;
- Maintain sediment transport: include either trapping sediment that would otherwise migrate or reintroducing sediment into systems;
- Preserve coastal land/development (including infrastructure);
- Maintain shorelines utilizing "soft" measures: aim to develop living shorelines through beach nourishment, planting dune grasses, marsh creation, and planting submerged aquatic vegetation;
- Maintain shorelines utilizing "hard" measures: e.g., constructing bulkheads, seawalls, revetments, and breakwaters, or reinforcing dikes and headlands;
- Invasive species management;
- Preserve habitat for vulnerable species;
- Maintain water quality and
- Maintain water availability.

This list of measures is by no means comprehensive and their degree of applicability is likely to differ among countries, but it does illustrate the wide range of areas where action may be taken.

Conclusions

Global climate change affects the physical, biological, and biogeochemical characteristics of the coasts, modifying their ecological structure, functions, and provided goods and services (McLean et al. 2001). The major impacts are summarized in sea level rise, storm surge and erosion that are aggravated by unsustainable management (Elsharouny 2016). These threat key economic activities, lead to loss of development, destruction of cultural heritage and competition between stakeholders for resources (Camarsa et al. 2012). Both long-term planning and updated protection measures are required to eliminate the adverse impacts of the hazard and guarantee sustained and harmonious development of the coastal economy (Cai et al. 2009).

But in order to yield sustainable benefits, technical measures need to be complemented by fostering the capacity to prepare for climate risks and recover from specific events, and by the development of targeted support for those most vulnerable, especially—but not only—in developing countries.

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