Ocean and Coastal Management 211 (2021) 105788

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Adaptation to climate change in small coastal cities: The influence of development status on adaptation response

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ABSTRACT

In contrast to coastal towns and small urban settlements, small coastal cities (population of between 50,000 and 100,000) may exhibit comparable knowledge and planning infrastructure as larger cities or be similarly connected to research institutions. However, at a global level, there is little statistical data about small cities, and their numbers and locations are thus so far unknown.

In this paper, five cases of small coastal cities, two of which are located in the USA - Miami Beach and Milford - and three, in Australia (Mandurah), Bangladesh (Sundarbans), and South Africa (Knysna) respectively, are presented and discussed in view of adaptation to climate change.

All cases reported vulnerability to sea level rise, with impacts compounded by increasing storminess (and even hurricanes of increasing intensity), tides, inland flooding and loss of natural habitat. Changes in precipitation resulted in both reduced river flow, leading to sediment deficits and coastal erosion (from the sea) or increased river flow with similar damage (from the land). Adaptation response was most clearly delineated along lines of development status with wealthier, more highly developed cities pursuing more technologically advanced solutions, whilst the two cities of the Global South focused more on governance and capacity building solutions.

Also, it was clear from the Knysna case that if a city or municipality lacks the capacity to effectively respond with adaptation measures, local private wealth may dominate and result in haphazard adaptation responses to the detriment of regional adaptation planning efforts.

While this paper provides a first step in establishing a richer understanding, it is clear that more case studies across global regions and economic categories are required to deepen our understanding of climate change adaptation planning in small cities.

1. Introduction

Despite numerous, recent calls to 'leave no city behind' (see e.g. the UN SDGs, Acuto & Parnell (2016), Mahor and Juhola (2016), and Acuto et al. (2018)), the main focus in research and studies of cities and climate change is still on 'the usual suspects', the larger cities, for example represented through C40, 100 Resilient Cities, and similar organizations.

Smaller cities, but also including urban/rural municipalities, delineated for the purposes of this special issue by population size of over 50,000, but less than 100,000 inhabitants, are under-represented in climate adaptation research. This has resulted in a gap in our understanding of their risks, experienced hazards and vulnerabilities, their needs, responses, and capability to implement solutions and build resilience. Globally, we also have very little information about their numbers or locations; the United Nations' population statistics work with a resolution of +300,000; everything else is 'residual'.

The call from leading scientists to develop a 'global urban science'

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https://doi.org/10.1016/j.ocecoaman.2021.105788
Received 19 August 2019; Received in revised form 9 October 2020; Accepted 2 June 2021
Available online 20 June 2021
0964-5691/

and an 'ecological understanding of cities', and to 'leave no city behind' further emphasizes the disconnect between this universal theory and the realities, challenges and opportunities of coastal climate risk experienced in smaller cities and municipalities. In reviewing literature for this special issue, we found numerous examples of papers in, for example, Nature that reflected on coastal climate adaptation in Durban, Singapore, Chicago, London, Copenhagen, New York, Paris and Montreal, however no papers addressing smaller cities.

1.1. Small giants

In contrast to very small communities and (smaller) towns (see for example chapters 4 and 5 in this issue), small cities or small urban municipalities, may often have some extent of resources available, be they financial, political and/or planning expertise, in order to deal with sustainability, climate change planning, risk reduction and resilience. They can thus be looked upon as located in between the large cities with well-resourced planning and/or research departments to support knowledge creation and solutions, and the small towns that may often totally lack these infrastructures.

These small cities, recently and in the EU context and in respect to the concept of Smart Cities also referred to as Small Giants (EIP-SCC, 2018), may be very innovative and able to make rapid advancement. In addition, they can take the perspective of a smaller city, and 'design for small' rather than accept designs made by large.

Whether this delineation by size holds true between geographic regions, especially comparing the Global North and South, or between well-resourced or poorly-resourced small cities, will be discussed further in this special issue. In this paper, two key determinants were used to classify responses reported within the case studies. They were developmental status of the case study (broadly from Global North or South, implying a level of development and access to resources) and proximity to natural resources (implying access to ecosystem services). Discussion is framed around the impact these two key determinants have on decision-making and adaptation response.

The purpose of this paper is to exemplify decision-making for climate change adaptation in small coastal cities of less than 100,000 inhabitants. The paper aims, through an identification of typologies in both climate change and non-climate challenges, and approaches chosen for adaptation within the settlements, to enhance our understanding and begin learning from 'the small giants' of the collective 'unusual suspects'.

It is the aim of the paper to begin bridging the gap between science and practice and thereby provide new opportunities for adaptation in other global cities of similar size to the ones in focus here; see Table 1 for an overview of the cases that are included.

2. Case studies

In this paper, we are concerned with small coastal cities and/or municipalities - comprising of smaller urban and rural settlements - of between 50,000 and 100,000 people. Of the five case studies included in this paper, see Fig. 1, four are settlements associated with estuaries, which have important environmental (in terms of biodiversity and ecosystem services) and socio-economic value to the settlements, while the fifth, Miami Beach, is a largely man-made island. For all five cases, a tourism industry plays an important role in the local economy.

Table 1
Case studies included for the chapter analysis.

Name of settlement(s)	Population	Location	Comments
Burigoalini, Gabura, and Munshiganj	88,000	Bangladesh	Sundarban Mangrove and Estuary
Knysna Municipality	75,000	South Africa	Estuary
Mandurah	81,000	Western Australia	Estuary
Miami Beach	92,000	Florida, USA	Largely transformed, man-made island
Milford	55,000	Connecticut, USA	Estuary

For Miami Beach, tourism is largely associated with its beaches and its proximity to the much larger city of Miami. For Burigoalini, Gabura, and Munshiganj (hereafter collectively referred to as the Sundarbans), Knysna, Mandurah, and Milford, the tourism industry is associated with leisure industries and up-market developments, watersports and bird-watching (estuaries typically provide habitat for both resident and migrating bird species of interest). All four estuaries also have important fisheries, which support both leisure and subsistence fishing activities, with the Bangladesh settlements having the highest reliance upon ecosystem services for livelihoods.

The five settlements have in common that they are threatened by both climate change and development pressure leading to transformation of natural habitats and loss of ecosystem services.

There is a wide range of spatial footprints for each settlement, with Miami Beach covering just 19.8 km^2 and the Sundarban mangroves and the Knysna Municipality the largest at 6000 and 1058 km^2 respectively, suggesting a wide difference in densities and types of settlements that correspond with wealth and development index. Where Mandurah, Miami Beach and Milford are located in countries with a high Human Development Index (HDI $>$ 0.9), the HDIs of the Sundarbans in Bangladesh and Knysna in South Africa are medium (0.608 and 0.71 respectively). There differences correspond with the former three being classified as Global North and the latter two Global South, reflecting their development status.

Two case studies, Mandurah and Knysna have a Mediterranean climate with hot dry summers (Cfb), Milford features a humid continental climate (Dfb), Miami Beach has a tropical monsoon climate (Am) impacted by occasional hurricanes, and the Sundarbans have a tropical savanna climate (Aw).

2.1. Knysna

Knysna Municipality is located within the Garden Route National Park on the southern Cape coast, South Africa. It is one of seven local municipalities in the Eden District Municipality, and is home to about 75,000 people, making it the fourth largest municipality in the District. Knysna Municipality experienced a development boom between 1980 and 2008, as a result of the development of tourism and leisure industries supported by the high value of the municipality's environmental assets. The municipality contains South Africa's richest and most diverse estuary, as well as the largest area of protected indigenous forest in the country. Growth and development have not occurred equally across the municipality. Knysna has high levels of poverty and inequality. A significant socio-economic gradient is evident between residents living in informal settlements and rural villages and retirees, tourists and holidaymakers, who reside in high income coastal properties and gated eco-estates. (Sutherland, 2016). As such, Knysna is characterized by high levels of income inequality with some of the most expensive eco-estates in South Africa, while 6% of households are considered indigent. The global and national recession of 2008 and recent droughts, floods and fires have had a major impact on the socio-economic and environmental well-being on the municipality and its urban settlements (Sutherland, 2016). The case study intends to highlight the challenges of addressing climate adaptation in a municipality facing multiple social, economic and environmental risks.

2.2. Miami Beach

Located across the Bay of Biscayne from Miami, almost the entire surface area of the barrier island on which Miami Beach is located is human-created with only the beaches considered environmental areas. The population is about 92,300 and with a predominant wealthy

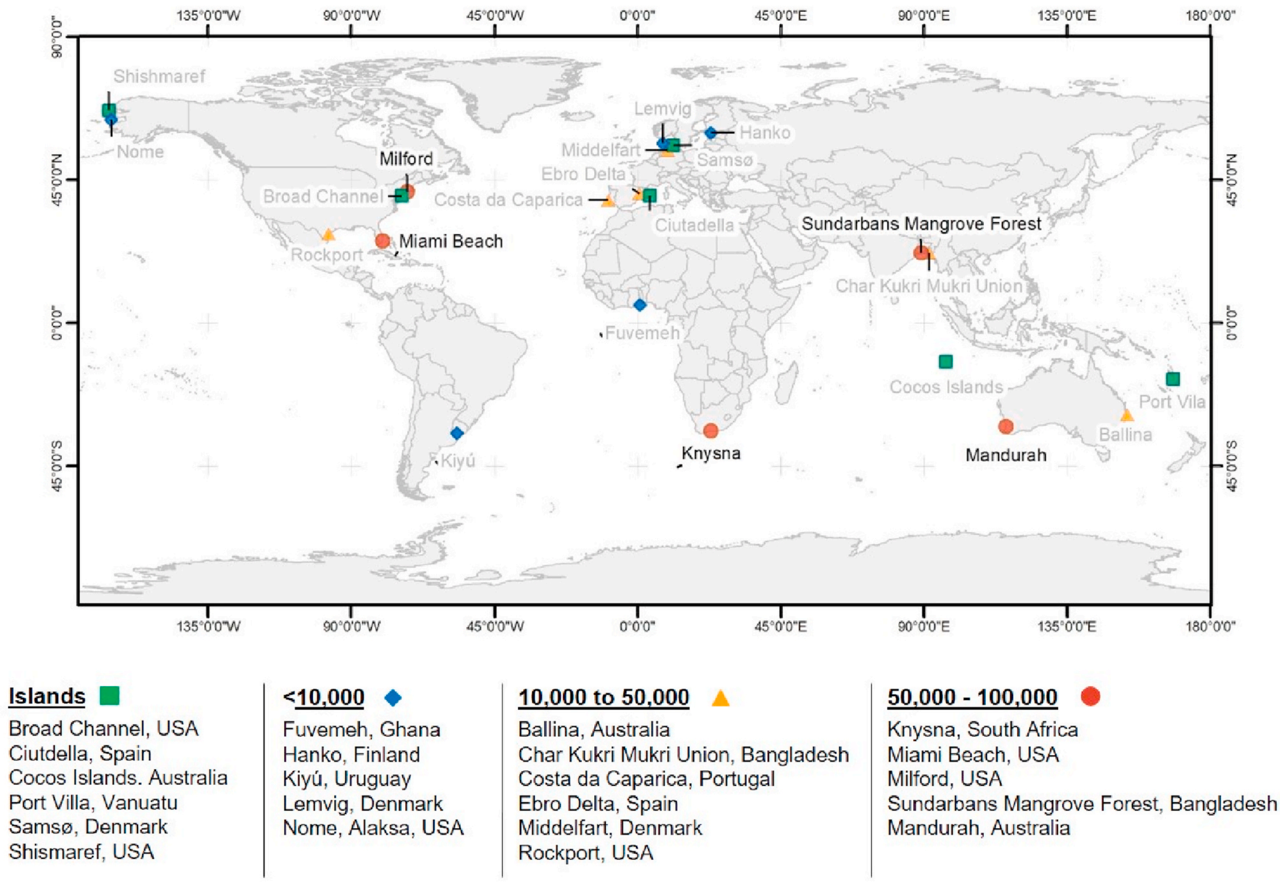

Fig. 1. Map showing the location of case study towns pertinent to this article and within the wider special issue.

resident base. The city has experienced serious flooding at the highest "king" tides, and the city administration is well aware of rising sea levels caused by climate change. Using primarily its own funds, the city has embarked on a program of at least US $400 million to raise roads and install water catchment basins and pumping stations to deal with current flooding and rising sea levels.

2.3. Milford

Milford, Connecticut, is a small city with approximately 55,000 residents. It is located on the north shore of Long Island Sound, with a coastline of more than 27 km. Several recent major storms, such as Hurricane Irene in 2011, and Superstorm Sandy in 2012, have evidenced how flooding along the mixed-use – residential, public, industrial, and commercial – coastline can cause direct economic damages to the built environment. Increasing vulnerability of coastal property and land has raised concerns about future adverse impacts and the associated economic costs of climate change. The Milford case study focuses on local level model development and the derived detailed assessment of tidal-influenced sea level rise and storm damage costs to valuable coastal properties.

2.4. Sundarbans

The three unions of Munshiganj, Burigoalini and Gabura are situated right beside the Sundarban Mangrove Forest (SMF) in Bangladesh. The SMF is the largest mangrove forest in the world and is a World Heritage Site, since 1999. Altogether, the three unions have a population of approximately 88,000 people. The area is exposed to cyclones, tidal surges and seasonal flooding making it further vulnerable to the impacts of climate change. The case study focuses on the linkages between ecosystem services and human wellbeing.

2.5. Mandurah

Located just south of Perth on the south-west coast of Australia, Mandurah is small city with a population of about 85,000 (according to the most recent numbers from the Australian Bureau of Statistics released in March of 2019). The city is growing and has for the past five years welcomed around 1500 new residents per year; its forecasted growth rate up until 2036 is 1.85% per year.

Mandurah is predominantly residential and has only little manufacturing or industry, of which construction makes up the vast majority of jobs as well as value-added. However, and in somewhat contrast to Western Australia in general, Mandurah's tourism sector is vital and accounts for about 16 percent of employment and almost 12 percent of value-added. The case study of Mandurah is focused at creating local-level ecosystem services assessment and quantification for climate change adaptation decision support.

3. Impacts

Climate change impacts (see Table 2 for detailed overview) on small coastal cities and urban/rural municipalities include sea level rise and storm surge associated with increasing severity of coastal storm systems (or hurricanes, in the case of Miami Beach, the Sundarbans and Mandurah), resulting in saline intrusion into freshwater aquifers. In the case of Milford, sea level rise is compounded by tidal height (where the average daily tidal range is greater than 2 m), as is the extent of damage due to storm surge, with greatest damage occurring when storm surge coincides with the spring (full and new moons) high tides. Sea level rise and storm surge is exacerbated by changes in inland river flow, where

Table 2
Impacts associated with climate change in small coastal cities and urban/rural municipalities of less than 100,000 inhabitants.

Impact:	Miami Beach	Knysna	Sundarban	Mandurah	Milford
Sea Level Rise	Impacts of SLR exacerbated by the low elevation (1.34 m). Serious regular flooding during "king" tides. Biscayne aquifer subject to serious salination.	Impacts of storm surge and wave set up on coastal areas with extensive beaches and ocean facing edges within the Knysna estuary, including Leisure Island and the Heads. Storm surge and wave set up and SLR partially attenuated by size and flows within the Knysna estuary. Low lying development is at risk.	Impacts of SLR exacerbated by a 2.2 mm per year subsidence of the area. Saline water intrusion both in surface and sub-surface water, serious scarcity of safe drinking and irrigation water.	+0.47 m SLR by 2070. +0.79 WA STATE estimate of SLR by 2100 +1.10 m SLR by 2100 (high end scenario presented in the NCRA ((European Innovation Partnership on Smart Cities & Communities [EIP-SCC], 2018)(ECNA News, 2018) DCC, 2009)	LiDAR and tidal data indicate sea levels are rising and they are compounded by tidal cycles, leading to temporary and permanent flooding of coastal properties. Storm surge is tidal dependent.
Increasing storm intensity	Return periods for hurricanes and major hurricanes expected to decrease from 6 to 14 years respectively. Impacts are exacerbated by low elevation.	Increasing storm intensity from mid-latitude cyclones and cut off low pressure systems, which causes storm surges as well as flooding of coastal areas from inland rivers and surface water flow	In November 15, 2007 super cyclone SIDR, a category 4 cyclone with 200–240 km/h wind speed hit the area and caused widespread devastation to the people and their livelihoods. (see typology for other examples)	100 Year Ocean Level 1.2 m–1.67 m Mandurah is prone to cyclone events	Milford is prone to nor'easter storms and hurricanes
Coastal erosion	Significant	Increase in coastal erosion due to storm surges, wave action along beaches and ocean facing edges of the estuary and from flooding of the Salt River. Flooding from the Salt River also leads to increasing sedimentation	Raising plantations on islands and along the embankments. This also reduces river bank erosion and protect from storm and cyclones.	Regional Storm-Tide Modelling (STM) for Mandurah forecasts that between 160 km^2 to 330 km^2 of beach dunes may be subject to erosion by 2030 in the Mandurah Local Government Area (LGA). The area potentially eroded from the shoreline increases significantly to between 300 km^2 to 1400 km^2 by 2100.	
Decreasing river flow	N/A no significant streams	Drought and abstraction for municipal consumption from the Knysna River is impacting upon the salinity of the Knysna estuary in its lower reaches.		−19%Rainfall (annual) −27% Rainfall (spring)	
Increasing river flow	N/A no significant streams	Flooding of Knysna River and Salt River due to storm events related to mid-latitude cyclones and cut-off low pressure systems leads to both erosion and sedimentation.	The area was severely affected by Aila, a severe cyclone occurred on May 25, 2009, commercial shrimp farming using saline water, and high level of poverty led large rural out-migration.	N/A	
Increasing air temperature				+2.7 °C; Days over 35 °C = 28 to 53	
Increasing sea temperature					
Fire		Drought, accumulation of dry biomass and climatic conditions increase fire risk, which is exacerbated by strong winds associated with both high pressure and low-pressure cells.			

for example in Knysna, increased flooding is caused by a combination of both seaward and landward movement of water as a result of storm events. These storm events are most commonly associated with cut off low pressure systems and mid-latitude cyclones.

Milford faces impacts from both nor'easters and hurricanes. A nor'easter is a type of cyclone that has leading winds blowing in from the northeast. Nor'easters form around low-pressure systems in the atmosphere and are fueled by cold air. Similar to cyclones, nor'easters cause storm surges and coastal flooding due to the associated low-pressure system and high winds.

Increasing coastal erosion, as well as adaptation responses to erosion, were reported in all case studies.[1] On November 15, 2007 super cyclone SIDR, a category 4 cyclone with 200–240 km/h wind speed tore through the Sundarbans affecting 9 million people across 30 districts and was responsible for around 4000 deaths.

Changes in river flow impact on the Knysna estuary and are associated with extreme weather events, including both flooding and droughts and the Sundarbans associated with changes in rainfall intensity. Increasing storm intensity was reported by Miami Beach; the possibility of increased flooding from this cause will be reduced by adaptation measures under way. Mandurah reported decrease in river flow associated with decreasing rainfall and increasing temperatures, within an almost double increase, to 53 days, in the number of days >35 °C.

3.1. *Compounding factors*

In Miami Beach, deteriorating water quality in Biscayne Bay from effluent from the detention basins is causing additional impacts for residents of the Miami area, whilst the porous nature of the limestone bedrock is resulting in saltwater intrusion into the Biscayne Aquifer and will limit the scope for future adaptation to sea level rise. In Knysna, an increase in storm surges and storm events, and, greater surface run-off due to development and urbanization place shorelines along the estuary, and islands within the estuary, at risk. In Bangladesh 28% of the population lives within coastal regions, and in the Sundarbans, over three million people are directly or indirectly dependent upon ecosystem services from the mangrove forests. Habitat transformation (vegetation coverage reduced by 0.04% per year from 1928 to 1995), illegal timber extraction, poaching, water extraction, overfishing, plant disease and river pollution are impacting negatively on ecosystem services, which is increasing vulnerability. In Mandurah, the canalization intervention has not improved important ecological indicators and further development pressure is likely to compound deteriorating ecology of the Peel-Harvey Estuary. In Milford, residents construct expensive homes on highly exposed coastal properties.

4. Adaptations

4.1 Main types of adaptation: the focus of adaptation response differed in the case studies. In Miami Beach, which has little ecological infrastructure and wealthy residents, the adaptation response is based on using highly technological solutions, like pumping stations and raising road heights, which require substantial budgets (raised through the wealth of residents and the willingness to pay to protect valuable assets). In the State of Florida, in which Miami Beach is located, climate change denial has resulted in limited state support for adaptation, but this has been countered by in-situ wealth and a willingness by local government to act.

In Milford, there is no comprehensive climate change adaptation plan; however, the city's Hazard Mitigation Plan identifies flooding as the primary natural hazard. The local government thereby proposes flood safety, hazard mitigation, and coastal resilience measures, and additionally encourages (and sometimes requires) property owners to purchase flood insurance protection. Some homeowners have even invested in raising structures to avoid flood damages to coastal real estate.

In the Sundarbans, raising plantations on islands and embankments helps reduce river bank erosion, protects from storm and cyclones, reduces saline intrusion and functions as a transport route. A potential maladaptation exists when the ability to withstand flood waters associated with cyclones is exceeded. Access to ecosystem services significantly increases availability to cleaner water for household use in the Sundarbans, and facilitates greater social freedom, encourages better collaboration and cooperation leading to better social cohesion. Access to ecosystems services can have a significant impact on human well-being; however, without integration of other wellbeing development programs, sole dependency on the ecosystems would cause resource degradation.

Two of the case studies, Knysna and the Sundarbans, prioritize socio-institutional response to adaptation, with the Knysna study seeking to understand the development of adaptation knowledge and climate governance processes for small towns; this being done within the broader context of development challenges and redressing past inequality in South Africa. The Knysna Municipality has begun to develop coastal by-laws and coastal adaptation plans, which it plans to integrate into the Municipality's Spatial Development Framework in 2019/2020 using the Integrated Coastal Management Act (Act 24 of 2008) and the Climate Change Bill to support their inclusion in planning and development legislation and policy (Knysna Municipal Official, September 02, 2018). This will ensure that the local authority has some influence on coastal activities drawing on the setback lines proposed by the Western Cape Provincial Government, without having to rely on the blue and green Scorpions (Environmental Enforcement Agency) at national government level, who monitor non-compliance to coastal and environmental legislation, but who have a slow turnaround time on addressing these challenges (Knysna Municipal Official, September 02, 2018).

In Knysna the municipality invests in the ongoing maintenance of the Leisure Island sea wall to protect the coastal road and coastal edge. Affluent households have invested in and raised money to build seawalls and have used sandbags to protect their properties as the assistance from the municipality has been limited due to budget constraints. However, these interventions are done without approval from the municipality and often increase the impacts of coastal erosion, as the risk is transferred to further along the coastline, as has been the case in Milnerton in Cape Town (Sowman et al., 2016).

Environmental degradation and the loss of ecosystem services are key issues raised in the three case studies – Sundarbans, Knysna, and Mandurah – that have extensive natural habitats, which support tourism related industries and fisheries. Similarly, the case of Miami Beach, tourism income and value-added is closely associated with the popular South Beach, one of the limited examples of natural infrastructure on the island but one which provides tourism related services. The Mandurah case study used the Ecosystem Approach to better understand interactions between anthropogenic impacts, estuarine functioning and society. Being settlements of already considerable size, it is common that all case studies are focused on in-situ adaptation with retreat from sea level rise considered a limited option, if at all.

5. Lessons from case studies

5.1. *Miami Beach, Florida, USA (Major & Major-Ex, 2019)*

Miami Beach, Florida is an island city with a land area of a little more than 18.2 km^2 across the Bay of Biscayne from Miami. It is included in this chapter because of its close proximity to Miami and its physical and economic integration into the greater Miami area. The population of

[1] The case study of Milford, CT, and Mandurah were of slightly different nature than the other cases included in this section, and focused primarily on developing knowledge and data for decision support.

Miami Beach is an estimated 92,000 (2017) residents; the total number of people is significantly greater during the tourist season. The city has an average elevation of 1.34 m and has experienced serious flooding during the highest “king” tides and is at risk from sea level rise and potentially more intense hurricanes. The city administration is well aware of rising sea levels from climate change and has established a reputation as a leader in climate change adaptation. Using primarily its own funds, the city has embarked on a program of at least US $400 million to raise roads and install water catchment basins and pumping stations to deal both with current flooding and rising sea levels. The scope for long-term adaptation to sea level rise is constrained by the porous nature of the limestone bedrock, which eliminates using dykes and surge barriers as solutions to rising seas. Flood walls have a role in adaptation, as for example the sea wall along Indian Creek Drive. Other issues include water quality deterioration from effluent from detention basins and a state government with a history of climate denialism.

5.2. Knysna, South Africa (Sutherland, et al., 2016)

Knysna Municipality is a coastal municipality endowed with valuable environmental assets, including South Africa's richest and most diverse estuary, the Knysna Estuary, Swartvlei Estuary, long sandy beaches and bays, and numerous rivers that flow from the Outeniqua Mountains, which contain the country's most protected indigenous Afromontane forests, in to the ocean, mostly through estuaries, Knysna Municipality, with its range of coastal towns, including Knysna and Sedgefield, exemplifies the challenges of balancing rapid economic growth and development with social and environmental transformation that is just and sustainable. High income development has focused on the valuable coastal zone, with the mitigation of environmental and sea level rise impacts being achieved, to a certain extent, through legislated Environmental Impact Assessments and consideration of the National Environmental Management: Integrated Coastal Management Act, Act 24, 2008. However, coastal erosion of beaches, including Buffalo Bay, and bays and sea walls along estuary islands, including Leisure Island, reveal the impacts of storm surges on the coastline. In many instances, private property owners, who have invested in high income properties, use their own resources and exercise power beyond the state, in an attempt to manage the risk to their properties. They often act outside of the legislation, policy and practices of the state, reducing risk on their properties, but transferring it elsewhere, through their use of rock walls, sand bags and other infrastructure.

The urban and rural poor of Knysna Municipality live inland of the coastal zone, and in the case of Knysna town, live within low-cost housing projects and informal settlements on the top of the hills and slopes of the Knysna Estuary Basin. The rapid growth of these settlements due to the economic boom in the town, has led to increased runoff due to a lack of services and drainage infrastructure. These settlements, as well as high income developments which did not take in to account the sensitivity of their sites, such as the Simola Golf Course development, have led to increased surface water flow due to an increase in hard surfaces and the loss of ecosystem services. An increase in the severity of storm events, particularly those associated with coastal low-pressure systems, in combination with an increase of surface water flow due to urbanization, has increased the risk of flooding, which in turn impacts on estuaries and the coastline. Coastal erosion and sedimentation are therefore being caused by both seaward and landward movement of water (Sutherland, 2016, Marker, 2004; Marker and Maree, 2004). Overtopping caused by peak tides often coincides with storm events. Increases in coastal erosion are expected due to storm surge and wave action along Leisure Island, located within the Knysna estuary, which is currently defended by sea walls and the beaches along the coastline including Sedgefield, Buffalo Bay and Brenton (Knysna Municipality, 2015; Hughes, 1992). Storm surges increase the effects of SLR. Tides, the effect of barometric pressure change (the hydrostatic force) and winds blowing over water bodies also increase the impacts of SLR in the Knysna Municipality (Knysna Municipality, 2015). SLR is partially attenuated by the size of, and tidal flows within the estuary (Largier et al., 2000; Hughes, 1992), but remains a concern due to development on low-lying land adjacent to the estuary, which contains significant infrastructure including roads, the Knysna wastewater treatment plant, as well as high-income housing developments.

5.3. Burigoalini, gabura, and munshiganj (sundarban mangroves), Bangladesh (Kibria et al., 2019)

Munshiganj, Burigoalini, and Gabura are administrative units situated right beside the Sundarban mangrove forest in Bangladesh. Along the coastline, residents of villages are exposed to cyclones, tidal surges and seasonal flooding which have particularly made the city vulnerable to climate change. The Sundarban mangrove forest of Bangladesh, the largest mangrove forest in the world, is a UNESCO World Heritage Site. Biodiversity in the region is much higher than that found in other large mangrove ecosystems in the world. Over three million people are directly or indirectly dependent on the forest (Roy et al., 2013). Hence, the forest is of enormous importance ecologically and economically at local, national and global scales. This valuable forest ecosystem, however, is currently under numerous threats including illegal timber extraction, poaching of wildlife, sea-level rise, upstream water extraction/divergence, overfishing and harvesting of aquatic resources, plant disease, and river pollution. Local people are also frequently attacked by pirates, who are active inside the forest, unless they buy a pirate's permit in advance. Some of the poorest families live in close proximity to the forest and have a high dependence on the ecosystem services of Sundarbans. Ensuring the wellbeing of these people is an essential step forward in order to achieve sustainable conservation of the forest, therefore, access to ecosystem services is crucial to improve local wellbeing and conservation of the Sundarbans. The narrative provides details of the effect of access to services has on residents in this case study.

5.4. Mandurah, WA, Australia (Haddaden and Hipsey, 2019)

Mandurah lies on the western edge of the Swan Coastal Plain, in close proximity to the Indian Ocean and the Ramsar-listed Peel-Harvey Estuary. This is the largest estuarine system in Western Australia with a significant commercial fishery (blue swimmer crabs) and environmental value, supporting key wildlife habitats, tourism and specific cultural and societal value systems. The estuary is impacted by hyper-eutrophic conditions resulting in algal blooms and fish kills. A major rehabilitation intervention, the Dawesville Cut entrance channel, has not alleviated these impacts. Ecological evidence shows pronounced decline in some aspects of estuarine health from pre-Cut periods (mid-1980s) to post-Cut periods (mid-2000s) (Wildsmith et al., 2009); an issue which necessitates a better and holistic understanding of the linkages and drivers of health for estuarine-societal systems. The estuary is also subject to further development pressures from the canal system intervention, habitat transformation both within the system and from upstream impacts, like water impoundments. Understanding the interactions between anthropogenic impacts, estuarine systems and society is important for managing ecosystem services within the Peel Harvey Estuary. This is being done using the Ecosystem Approach (The VALMER Project, 2016), where ecosystem services are valued in terms of their contribution to economic, social and cultural wellbeing.

5.5. Milford, Connecticut, USA (Johnson, 2019)

Milford is located on the north shore of Long Island Sound, an estuary on the eastern seaboard of the United States with a Humid Continental climate zone. Due to the coastal location and vicinity to New York City, property around Long Island Sound is both valuable and vulnerable to coastal flooding. Milford has a coastline 27.2 km in length, occupies an area of 68 km^2 and has a population of 55,000. The case study focuses on the quantification of flood damage costs associated with sea level rise and its interaction with tidal cycles and storm surge. Increasingly, properties in the two areas of focus; one residential and the other mix-zone with property values in the hundreds of millions of dollars for land and structures, are being damaged by flooding, with storm surge damage greatest when surge peak coincides with the biggest tides in the monthly tidal cycle, and which are compounded by sea level rise. Increasingly this is leading to both temporary and permanent flooding. The high-resolution, neighborhood-level analysis carried out in the Milford case study is intended to provide insight on future flooding impacts, and thereby highlight adaptation needs at the same scale.

6. Conclusions

The conclusions and typology that can be drawn from the submitted cases are limited by the number of case studies that this chapter is based upon. There is a need to increase this number substantially, given the wide range in types of settlements, densities, development indices, wealth and other contributing factors like natural habitat/ecosystem services, topography, catchment size, land use types and industries. These factors appear to influence adaptation response substantially with the more developed and very wealthy Miami Beach adopting a highly technological response, while the others focus more on ecosystem services and human responses.

In developing the typologies of small coastal cities and towns, it will be important to interrogate how we define small coastal cities. Knysna Municipality for example, is not a city; it is a rural/urban municipality with a coastal town of over 75,000 people. Can it really be called a city? Similarly, the Sundarban case study may not really be characterized as a city either. It is important to address this as we will need to clarify those elements that help us characterize cities, rather than just population size.

Given the high levels of vulnerability in small African coastal cities, both because of the geographic vulnerability of the continent to climate change and because of the socio-economic and development deficits in cities and small towns, it is imperative that more case studies are secured to deepen our understanding of adaptation planning and implementation processes. In communicating the call for this special issue, a database of African researchers from coastal cities was secured through the Intergovernmental Panel on Climate Change. Despite the extensive list of researchers contacted, very few researchers responded indicating interest. It would be useful to know whether this was because of communication challenges on the continent, or whether these researchers are only interested in larger urban centers, about which there are a growing number of peer review publications. Developing a well-rounded database of highly developed, wealthy cities may not provide the type of learning that can be applied to poorly resourced, weakly-governed and highly vulnerable African coastal cities. Pursuing a database of these latter cities should be considered an urgent action emanating from this special issue, especially given the rise of climate change-related disasters globally.

The majority of the case studies reported significant benefits from ecological infrastructure associated with their adjacent estuaries, and these benefits spanned both developed and developing economy cities. Common services included the establishment of commercial, recreational and/or subsistence fisheries, eco-tourism activities and increases in property values. Existing modelling tools that aim at quantifying ecosystem services are either (1) place-specific: customized for a particular geographic location, but can also be applied elsewhere, or (2) generalizable tools that can be applied at various contexts if locally appropriate data are available. Generally, models need to have concrete documentation and can be easily parametrized in order to enable their adoption in a different context. However, addressing the adaptability of existing biophysical, biogeochemical, hydrodynamic, and hydrological models to ecosystem services is yet to be investigated. To the best of our knowledge, no framework has been established yet, which associates an approach that can connect outputs from an environmental model with the projected "goods and benefits", and finally translates the results into "societal values" which can be used for communication with decision makers. We have developed a framework at a conceptual level and proposed a "niche approach" which will enable the assessment of ES at any local context, through the use of a hydrodynamic-biogeochemical model. We used Mandurah as a case study to demonstrate this approach.

Deliberation is required, in the case of Knysna, in respect of the relationship between state and private sector in managing and implementing strategies and practices to deal with sea level rise impacts. In Knysna, adaptation response was dominated by private owners and developers who used science and technology and environmental design principles to argue for the Thesen Islands Development (Sutherland, 2016). This development has been successful to date but if sea level rise increases beyond what is currently expected, the risk of a maladaptive outcomes could be realized. With the limited government response, private property owners on Leisure Island, Buffalo Bay and Sedgefield Beach, believing that they had the right, took the initiative to protect their property, potentially at the risk of shifting the erosion points downstream. This issue of rights and contextualizing action within a larger spatial extent is critical to raise as such coastal pressure points are increasing in Knysna. In this case, long term planning is required in Knysna Municipality to ensure that integrated coastal management and adaptation plans are incorporated into the town's spatial development framework. This remains a challenge due to capacity constraints in government. However, the municipality has begun a process of ensuring that coastal adaptation is integrated in to integrated spatial development framework of the municipality.

Small coastal cities from developing countries, with limited budgets and conflicting priorities, may be forced to prioritise immediate needs over long-term adaptation planning and implementation. For example, how does Knysna Municipality address climate change adaptation, which will have the greatest impact on wealthy landowners who live adjacent to the coast and socio-economic issues related to poverty and inequality in the townships, informal settlements and rural settlements of the Municipality, which are not located close to the coastline, but rather on the periphery. This challenge results in initiatives for climate adaptation being wrested by the private sector, which will not meet the municipality's development requirements in equal and inclusionary ways. This situation is exacerbated by the reactive nature of the municipal response to unfolding events and disaster. There is a need to improve on how the municipality interacts with its residents, especially in communicating existing and new policies that the municipality will implement.

The impact of the private led adaptation response combined with the poorly capacitated local government has been mediated by the economic recession in South Africa, such that the slowing down of development from 2008 'saved' the environment of Knysna. Whilst this status quo remains, there is an urgent need to include the value of ecosystem services provided by the natural environment into the area spatial development framework and climate change adaptation plans to reduce sea level rise risk. The major socio-economic impact of the 2016 fire in Knysna Municipality highlights the importance of improving capacity and planning for the wide range of impacts such a disaster brings and for building resilience.

References to supplemental material

(Major & Major-Ex, 2019).
(Sutherland, 2016)
(Kibria et al., 2019).
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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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