

# Chapter 1

## The METROPOLE Project – An Integrated Framework to Analyse Local Decision Making and Adaptive Capacity to Large-Scale Environmental Change: Decision Making and Adaptation to Sea Level Rise in Santos, Brazil



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**Abstract** Assessment of the risks due to exposure and sensitivity of coastal communities to coastal flooding is essential for informed decision-making. Strategies for public understanding and awareness of the tangible effects of climate change are fundamental in developing policy options. A multidisciplinary, multinational team of natural and social scientists from the USA, the UK, and Brazil developed the METROPOLE Project to evaluate how local governments may decide between adaptation options associated with SLR projections. METROPOLE developed a participatory approach in which public actors engage fully in defining the research problem and evaluating outcomes.

Using a case study of the city of Santos, in the coast of the State of Sao Paulo in Southeastern Brazil, METROPOLE developed a method for evaluating risks jointly

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L. H. Nunes et al. (eds.), *Climate Change in Santos Brazil: Projections, Impacts  
and Adaptation Options*, [https://doi.org/10.1007/978-3-319-96535-2\\_1](https://doi.org/10.1007/978-3-319-96535-2_1)

with the community, comparing ‘no-action’ to ‘adaptation’ scenarios. At the core of the analysis are estimates of economic costs of the impact of floods on urban real estate under SLR projections through 2050 and 2100. Results helped identify broad preferences and orientations in adaptation planning, which the community, including the Santos municipal government, co-developed in a joint effort with natural and social scientists.

**Keywords** Sea-level rise · Adaptation options · Adaptive capacity · Participatory approach · Santos · METROPOLE project

## 1.1 Introduction

How decision makers and the public perceive and respond to potential local impacts of large-scale change, including economic and health risks, depends on social, cultural and political context and on how scientific evidence is presented. The METROPOLE (*An Integrated Framework to Analyse Local Decision Making and Adaptive Capacity to Large-Scale Environmental Change*) project focuses on identifying the factors that facilitate a shift in knowledge, attitudes, values and decision making about local climate risks and adaptation strategies among decision-makers and stakeholders in case study of coastal communities in Brazil, United Kingdom, and the United States (Marengo et al. 2017a, b; Paterson et al. 2017). The Belmont Forum-G8 Initiative Collaborative Research through grants from the FAPESP-Sao Paulo State Research Foundation, the US National Science Foundation and UK Natural Environment Research Council and Economic and Social Research Council, supported this project. The goal was to combine expertise from diverse scientific backgrounds to develop an integrated framework to analyse local decision-making and the adaptive capacity to local environmental change driven by large-scale processes like climate.

The hypothesis is that risk knowledge is best understood as being co-produced by science and by the social, political and cultural context. The research developed at METROPOLE concurrently analysed social context factors that affect adaptation planning and policy changes (adaptive capacity) and responses by local stakeholders when presented with interactive computer-based scenario simulations in participatory planning meetings to cope with sea level rise (SLR) and coast flooding. The project used (1) state-of-the-art visualization tools developed in the US and Brazil, (2) sophisticated survey and choice evaluation tools, and (3) a risk assessment Adaptive Capacity Index developed in the UK. The visualization tools integrate scientific and economic data at the community level for local jurisdictions, and illustrate potential impacts, economic risk, adaptation options, and cost-benefits analyses projected over time. The data included changes in sea level, temperature, storm frequency, precipitation and other variables in the past decades and high resolution projections in 5–10 year increments to 2100 under the IPCC AR5 sea level scenarios.

Expected results include a new framework to evaluate the impact of integrating scientific, economic, and cultural context data on adaptation planning and decision-making. This will improve the ability of scientists to interact with stakeholders by developing an understanding of social context, and garner knowledge of best practices for the Brazilian case study.

## 1.2 Background

Nearly 7% of all human communities have developed in areas where the elevation is less than 5 m. from historical sea level (McGranahan et al. 2007; Wong et al. 2014; Reguero et al. 2015). Most of the world's 60 million poor people living in low elevation areas reside in just 15 countries, including Brazil, the United States of America and the United Kingdom (Barbier 2015). Urban low elevation coastal zones are expanding faster than elsewhere and this trend is expected to continue into the future (Seto et al. 2011). Globally, between 660,000 and 1,200,000 km<sup>2</sup> of land, 93–310 million inhabitants and 3100–11,000 billion USD of built capital are currently located at elevations less than the present 100-year sea level flooding event, but by mid-century there could be an increase in global flood losses for the 136 largest coastal cities (Reguero et al. 2015). Of these, approximately 40 million are exposed to major flood risks, and these risks are expected to increase over the next 50 years.

One of the clear signals of present climate change is sea level rise. There is mounting evidence of other changes, including warmer temperatures in many localities, and changes in the intensity and frequency of extreme meteorological events, including wind, rain, storms and waves that can generate coastal flooding. Damages are compounded when tidal fluctuations and surges due to severe storms are superimposed on these estimates. A rising sea level combined with high tides and storm surges is expected to impact the human built environment along coastal zones of the world as well as coastal ecosystems such as wetlands, coral reefs, beaches, and estuaries. Higher sea level typically leads to increase in coastal erosion, high risk of flooding, and contamination of fresh water sources through saltwater intrusion (McLeod et al. 2010). Many of these coastal ecosystems are already impacted by human uses that have weakened their resilience (Hinkel et al. 2010). Extremes in meteorological events can also lead to erosion of coastal areas, landslides, and floods. These can have direct impacts on human communities, but also important indirect impacts through changes in biodiversity and other ecosystem services (IPCC 2014).

Sea-level rise is a tangible and tractable effect of climate change that poses significant challenges to society from the next 50 to 100 years, or earlier (Hauer et al. 2016). Global mean sea level rose by 0.19 (0.17–0.21) mm year<sup>-1</sup> over the period 1901–2010 based on historical tide gauge records; these rates are observed globally on average, as measured using satellite data collected since 1993. Between 1993 and 2010, the average global sea level rise rate was near 3.2 (2.8–3.6) mm year<sup>-1</sup>.

Similarly high rates likely occurred between 1920 and 1950 (IPCC 2014). A gradual increase in average sea level of 1 m often cited as a possible scenario within a 100-year timeframe (Rhein et al. 2013; Wong et al. 2014), would seriously affect some coastal populations in Brazil (ECLAC 2011), the USA, and the UK (GEI Consultants 2015, 2016).

### 1.3 The METROPOLE Project

To improve resilience, policymakers need to understand current adaptation processes and obstacles, and plan accordingly to be effective. These processes depend in great measure on how decision-makers and the public perceive and respond to changes and the perception of risk. In order to evaluate how local government may respond to risks associated with sea level rise projections, a group of natural and social scientists from the United States (US), United Kingdom (UK), and Brazil developed the *METROPOLE* Project.

The METROPOLE study goals were to determine to what extent stakeholder beliefs, values, and preferences regarding adaptation options and funding choices may facilitate or hinder adaptation. The METROPOLE project encompassed a three-part, integrated environmental, economic, and social analysis embedded in a municipal planning effort involving stakeholders and decision makers in Brazil, the UK and the US. The first part included the use of the COastal Adaptation to Sea Level Rise Tool (COAST) model (Catalysis Adaptation Partners 2015) to show visualizations of SLR, infrastructure impacts, costs/benefits for adaptations, and small group discussions to define stakeholder estimates for action. The second piece involved administering pre- and post-workshop surveys to participants, to identify links between risk experiences, beliefs, values and attitudes about local government priorities for possible adaptation actions and public financing, and to assess change after seeing the COAST visualizations and discussing scenarios. The third element was the Adaptive Capacity Index (ACI), an assessment of institutional and individual interactions that shape local and regional adaptive capacity. The project was conducted in: the city of Santos (state of São Paulo, Brazil), city of Selsey (West Sussex, United Kingdom), and cities in Broward County (Florida, United States). The three study sites present both similarities (coastal cities threatened by the risk of sea-level rise) and differences (the size of the population and of the local economy), which make the comparison of the attitudes and values about local climate risks and adaptation strategies among decision-makers and stakeholders particularly challenging. This paper focuses on the Brazilian component in the city of Santos.

METROPOLE used the approach of Daniels and Walker (2001) and Burch (2010) to explore the complex issue of how communities of different cultural backgrounds respond to risk and adaptation related to climate change. The IPCC defined this as the process of adjustment to actual or expected climate and its effects, including either moderate harm, or the opportunity to exploit beneficial opportunities. For this study, the IPCC Glossary (IPCC 2012) was adopted to establish the theoretical

framework for adaptation and evaluation of risks, hazards, and vulnerability. The exception is that in the context of METROPOLE, “mitigation” means risk management or reduction of risk due to a hazard, and not reduced emissions of greenhouse gases.

The METROPOLE project involves developing visualization tools that integrate scientific information and socioeconomic data at the municipal level in each country, and illustrate the potential impacts, economic risks, adaptation options and analyses of cost-benefit projected over time. The central theme of the METROPOLE project is, therefore, to show, in an integrated way, how some coastal areas under different climate regimes and human pressures would be affected by SLR caused by climate change, and if society and the government would be prepared or not to take proper and fast adaptation measures. Recent studies on climate adaptation enhance the importance of engaging or activating communities and supporting community roles in understanding climate change and adaptation needs (Ross et al. 2015). Responses from cities to improve their resilience are urgent but policymakers need to understand current adaptation to plan comprehensively and spend effectively (Georgeson et al. 2016).

On the three case studies, Santos is a coastal city in the State of Sao Paulo in southeastern Brazil. Santos and areas adjacent to the city is strategic economic center for Brazil, with a large concentration of industries located along the coastal zone. The Port of Santos, the key economic asset for the municipality of Santos, is responsible for the transport of products from the largest industrial park in Brazil and handles some 25% of Brazil’s foreign trade. Founded in 1546, Santos is one of the oldest settlements of Brazil. It occupies an area of 281 km<sup>2</sup>, of which 39.4 km<sup>2</sup> lies in the insular domain (São Vicente Island) and 231.6 km<sup>2</sup> correspond to the mainland part of the municipality (Marengo et al. 2017a). Around 99.3% of the Santos population live in the insular domain. The Port of Santos alone is responsible for the transport of products from the largest industrial park in Brazil, handling around 25% of Brazil’s foreign trade (ICF-GHK 2012).

The municipality of Santos is also a portrait of the social asymmetry of the country, featuring upscale neighbourhoods especially closer to the shoreline and poor neighbourhoods concentrated at the Northwestern Zone of the island, on the hill-slopes and the wet lowlands. The irregular occupation of the hill-slopes and mangroves, the pollution generated by industries located around the area, and deforestation of the Atlantic Rainforest, which reduced the water retention capacity of the soil and increased the continental runoff, accelerated common processes in the area such as landslides, mudslides and floods, putting a large contingent of the population under constant threat. The region is affected by tropical, subtropical and mid-latitude weather systems. During summer, when convective activity is greater, the SACZ (South Atlantic Convective Zone) influences the rainfall regime, with a cloud band and rainfall remaining semi-stationary for several days. Frontal systems are common in the area, mainly during autumn-winter. Storm surges have historically affected this region. Nowadays, storm surges typically cause destruction or urban infrastructure and damages related to traffic interruption at the southeastern ending of the Santos coastline (ICF-GHK 2012).

## 1.4 Sea Level Rise and Adaptation Options: The Case of Santos, Sao Paulo/Brazil

For the Latin America and the Caribbean Atlantic coast, SLR between 1950 and 2008 rose  $\sim 2$  mm year<sup>-1</sup> (Losada et al. 2013) and the Brazilian coastal areas are being affected by coastal erosion and coastal inundation (Souza et al. 2005; PBMC 2014), with the southern part of the State of São Paulo and Rio de Janeiro seeing rates of between 1.8 and 4.2 mm year<sup>-1</sup> since the 1950s (Alfredini et al. 2013; Harari et al. 2007). According to (Harari and Camargo 1995), the mean sea level in Santos has risen at a rate of 1.2 mm year<sup>-1</sup> since 1940s, with an increasing trend in the past decade. This rate is slower than the global mean sea level rise rate. This suggests that additional factors such as estuarine circulation patterns, land subsidence and/or anthropogenic interferences like dredging may be affecting local sea level rate.

Flooding events normally occur in two main areas of Santos: at the Northwestern Zone NWZ and at the Southeastern Zone SEZ. The latter is closer to the mouth of the Santos estuarine channel, along the seafront (Marengo et al. 2017a). At the NWZ, flooding is caused by the combination of heavy rainfall and high tides, so that the waters from the watersheds discharges summed to the superficial continental runoff flowing down towards the estuarine channel are blocked by the tidal waters rising into the existing drainage system. At the SEZ, flooding is caused by coastal inundation related to storm and tidal surges, in general associated to extra-tropical cyclones passage. SLR may affect the Port of Santos, the key economic asset for the municipality. Most sections are built to withstand water level increases of as much as 3 m above the current mean sea level (ICF-GHK 2012). The interaction between SLR and flood frequency may be of greatest concern.

The METROPOLE project incorporated an evaluation of risks and impacts of SLR and tested the city's Adaptive capacity. SLR risks were estimated using the COAST platform (Merrill et al. 2008; Marengo et al. 2017a). The METROPOLE project incorporated an evaluation of risks and impacts of SLR and tested the city's Adaptive capacity. SLR risks were estimated using the COAST platform. COAST estimates SLR and storm surge impacts by calculating damage from storm surge events cumulatively over time, given a changing base water level. It then calculates relative benefits of various adaptation scenarios in terms of cumulative *avoided* damages over time. The model is intended to be used by municipalities, state agencies and other groups interested in benefit-cost analysis for adaptation strategies aimed at reducing damages from SLR and storm surge.

COAST allows users to (a) calculate how much building damage may be avoided over time if such strategies are implemented; (b) confirm whether the projected benefits outweigh the costs; and (c) evaluate which strategies seem the most cost-effective. The process includes creation of data projections for coastal changes and potential economic and environment consequences of flooding scenarios resulting from a rise in sea level and extreme storm surge events. Financial ramifications are calculated using inputs from local stakeholders and confirmed by

expert engineering review. Use of the tool in public process also allows stakeholders to articulate and modify potential adaptation strategies. The conceptual model developed for application of COAST in both the NWZ and SEZ affected by hydro-meteorological risks in Santos is shown in Marengo et al. (2017a). Data required to run COAST for the two case studies (district, land area, construction area, assessed value of the land, value of construction and value of the property) was obtained from the Municipality of Santos.

To advance the understanding of connections between stakeholder beliefs, values and preferences regarding adaptation options and funding choices, as well as to improve understanding of barriers to adaptation in Santos, decision makers, citizens, representatives of public and private sectors and of NGOs of Santos were engaged with the METROPOLE process through two stakeholder workshops. These workshops were directed to engage decision makers, citizens, and representatives of the public and private sectors to develop and evaluate adaptation options for NWZ and SEZ of Santos. To create the data for the workshops, our team and municipal managers reviewed the estimated SLR/flood risks and discussed potential adaptation actions. After consulting with other staff and elected officials, the municipal managers selected several realistic and potentially useful combinations of actions to be discussed by stakeholders at Workshop 1. The workshops presented and discussed maps of future flooding projections due to sea level rise for 2050 and 2100. Workshop participants were shown the respective estimates of economic damages to real estate for the SEZ and NWZ zones of Santos. The small group discussions at these workshops focused on adaptation options for the community of Santos. As a result of these workshops, participants coming from various sectors of society living in Santos proposed some adaptation measures, that were later on incorporated in the COAST model (Marengo et al. 2017a b).

For the city of Santos, the most preferred adaptation options were fortification (66%) and accommodation (30%). For the NWZ, the fortification (50%) and accommodation (43%) actions were also preferred, while relocation was the least preferred option, with 4% in the SEZ and 7% in the NWZ (Marengo et al. 2017a). Table 1.1 shows that the adaptation measures selected by participants (i.e. fortification and accommodation) would be cost effective in both the lower scenario of sea level rise (0.36 m; for the period 2010–2100) and for the higher scenario (0.45 m by 2100). Santos adopted dredging and mangrove restoration for the northwestern sector, while for the southeastern sector reinforcement of existing walls and beach nourishment were the selected options. The community evaluated beach nourishment, dune restoration, structural enforcement of existing sea-walls, water pumping and improvement of tide control gates in existing drainage canals. In the southeastern sector of the city the damages from a 100-year flood in 2050 under low and high SLR scenarios would be US\$34 and US\$38 million, while in 2100 these damages could reach US\$60 and US\$75 million, respectively (Table 1.1).

However avoided damages for the NWZ might be greater than was modelled because of challenges encountered in obtaining accurate real estate valuation data from the Municipality of Santos. According to the Municipality of Santos, the NWZ shows buildings up to four floors, and there are a lot of commerce activities (stores,

**Table 1.1** Cumulative damages without and with adaptation scenarios in Santos. Scenarios for a 100-year flood with SLR, for 2010–2100, with fortification (beach nourishment + dune restoration, structural enforcement/improvement of existing sea-walls) for SEZ

Item	Santos, Brazil	
	SLR scenario	
	Low	High
Cumulative damage without adaptation (billions USD)	\$0.242	\$0.467
Cumulative damage with adaptation (billions USD)	0	0
Avoided damages (benefit, billions USD)	\$0.242	\$0.467
Cost of adaptation measures (millions USD)	\$10.1	\$10.1
Benefit-cost ratio	23.9	28.7

Modified from Marengo et al. (2017b)

supermarkets, restaurants, offices). The SEZ zone is mostly upper-level class residential with apartment buildings, hotels and shops that can reach up to 20 floors or more on the seaside.

Commercial buildings were not included in the list of properties. This represents an underestimate of risk and of damages. COAST also did not estimate damage from winds, erosion forces, or rainwater drainage backups, which might also cause building damage, substantially threaten health and other property, and changes local ocean circulation, salinity, etc. that may in turn also affect local sea level. Natural sedimentary processes in tidal flats and the probable expansion and/or retraction of mangroves into the estuarine system, or the resilience of these ecosystems as well as impacts to public services, urban infrastructure, or business interruptions or clean-up costs after extreme weather events were not included, Data from commercial properties are not geo-referenced and could not be included in the COAST running.

## 1.5 Adaptive Capacity Index (ACI) Analysis Sao Paulo/ Brazil

The Adaptive Capacity Index (ACI) has been developed to provide a theoretically grounded measurement tool and coupled analytical framework that can help practitioners and researchers surface the negotiated pathways through which adaptive capacity accrues and is deployed within administrative regimes (Paterson et al. 2017). Evaluating the ACI is an analytical process that engages a range of stakeholders in a comprehensive and thoughtful assessment of community resilience and ability to proactively seek change. The METROPOLE Project focused the ACI assessment on key actor organisations within the environmental risk scene. Respondents commented on contemporary capacities for the 2015 timeframe and



for two others (2005 and 2010), in order to develop a trend analysis and compare current and historical shifts in adaptive capacity. Developing the ACI required conducting surveys. The METROPOLE team specialists conducted 24 interviews in Santos. The interviewees included a broad cross-section of government, civil, and private sector actors, representative institutions and organizations active in evaluating risk scenarios in Selsey, Broward County and Santos.

Table 1.2 presents the overall ACI scores for Santos evaluated over the 2005–2015 decade (Marengo et al. 2017b; Paterson et al. 2017). The results demonstrate general variability with some subcomponents showing limited variation over time, with some factors increasing and others decreasing over the decade under examination. Santos demonstrated consistent and progressive increases in adaptive capacity between 2005 and 2015. The community’s response was to attribute any trends to changing management responsibilities, shifts in political ideology, and social contracts. Overall respondents from Santos returned higher results, closer to outstanding (strong formal capacity with integrated and strategic planning across sectors. A decline in the ACI in a category was attributed to a decrease in available resources, the inability to control existing resources, and to austerity measures that have been in place and enforced at a national level. A positive trend was observed in the ability to learn and to plan for the future, suggesting that collaborative action between organizations increased in the 2005–2015 timeframe. Respondents pointed to the importance of partnership funding and co-funding mechanisms now required for capital projects as a catalyst for closer working relationships between the different levels of government. It was also pointed out that the re-organization of the structures of major governmental agencies has provided greater interconnectedness between these agencies, promoting cross learning and joint planning efforts.

In Santos, the ACI analysis showed some progression toward adaptability, but this was slow or stagnant in some factors (Table 1.2). Lack of progression across the components of the adaptive capacity index from the perspective of local actors was accounted for through: (i) a lack of organisational integration and (ii) the dominance of the adaptation agenda by Civil Defence. This suppressed leadership and innova-

**Table 1.2** Overall adaptive capacity index (ACI) sub-components scores for Santos-Brazil

Subcomponents	Santos, Brazil		
	2005	2010	2015
Critical self-reflection	3.03	3.14	3.41
Ability to experiment	2.69	2.69	2.94
Ability to learn	2.91	3.12	3.41
Ability to plan for the future	2.99	3.17	3.43
Command over available resources	2.37	2.59	3.01
Organizational responsibility	3.11	3.33	3.61
Organizational architecture	2.77	2.91	3.18
Levels of capital	2.99	3.19	3.40
	22.86	24.14	26.39

Modified from Marengo et al. (2017b)

tion especially between agencies. Global economic pressures were also felt by Santos. While the global economic downturn of 2008 had a limited effect on the Brazilian economy at the time, greater impacts were noted post 2014 with more constrained resources and funding opportunities reported across all sectors and agencies. Together these pressures served to hold Santos' adaptive capacity. In Santos, the private sector expressed high levels of adaptive capacity across many components with the exception of 'command over available resources'. This suggested that adaptive capacity and the development agenda in Santos was driven much more by the private sector than either the civil or government sector (Paterson et al. 2017).

Experience from previous recessions shows that economic downturn has a detrimental effect on getting resources to environment issues in the country because resources to cope with economic recession might be considered more urgent, with climate change initiatives neglected. But recent severe storm surges in the city (April, August and October 2016), which affected the study area harshly, might contribute to keeping adaptation actions on the political agenda (Marengo et al. 2017b).

## 1.6 Conclusions and Final Remarks

Projections of SLR impacts from the COAST model under the no-action scenarios provided an initial estimate of the possible cost of SLR and storm surge through 2100 for some key regions of Santos. Model runs with adaptation options in place indicated the possible efficiency of these means of addressing the challenges of SLR and storm surge in the city. Model results provide useful information for Santos, a strategic area of the country, and especially for the Port of Santos, the most important coastal economic resource in Brazil. However more research is needed to better understand possible impacts the adaptation options evaluated may have on local revenue over time.

As in the other regions where COAST has been used, in Santos, evaluations about priorities and community values were particularly meaningful and useful outcomes from the study. In recognition that the municipality of Santos needs to be creative about its future, most attendees wanted to explore feasible possibilities using structural and ecological options.

Like for many other coastal areas of the world, in Santos, the threat of SLR appears to be an issue when combined with the threat of extreme rainfall events and storm surges. Model results for this important Brazilian coastal seaport city showed that SLR alone is not likely to inundate buildings, but the Santos Municipality should consider SLR when planning for protection from large flood events. The benefit-cost ratio for elevation was highly positive for the SE Zone. Although these benefits could theoretically be obtained immediately, decisions around most adaptation strategies require substantial public support and will take years or decades to develop and implement.

The ACI analysis for Santos shows that there are choices for increasing resiliency against sea level rise that have a high benefit-cost ratio. Specifically, these communities found that fortification of the coast, elevation of real estate, and flood proofing are important investments that help mitigate higher costs due to flood risks 60–100 years from now. Based on the surveys' results, there is a clear sense from each community of the risk of floods due to intense storms, and of the benefits of engaging as a community early in a process that helps people to understand risks, impacts, and costs. A majority of workshop participants prioritized pursuing physical infrastructure and green infrastructure actions now or within the coming years or decades. This will have benefits that include a social and natural science basis and that address the local and regional social, political and cultural context. Assessment of the risks due to exposure and sensitivity of coastal communities to coastal flooding is essential for informing decision-making. Strategies to promote public understanding and awareness of the tangible effects of climate change are fundamental in developing policy options.

The multidisciplinary, multinational nature of METROPOLE was key in providing local governments with scientific evidence of the need for adaptation to SLR. At the core of the analysis are estimates of economic costs of the impact of floods on urban real estate under SLR for middle- and long-term twenty-first century projections. The institutional arrangement articulated in the document involves city and state government, civil society, the private sector, and universities and research institutes in Santos. It is an important step towards efficient multilevel governance processes aiming to cope with risks associated with climate change. The METROPOLE project has helped Santos demonstrate innovation in governance issues and provide valuable lessons to other coastal locations in Brazil.

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