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Adaptation to Climate Change and Sea Level Rise

The Case Study of Coastal Communities in New Brunswick, Canada

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ISSN 2191-5547 ISSN 2191-5555 (electronic)
SpringerBriefs in Environmental Science
ISBN 978-94-017-9887-7 ISBN 978-94-017-9888-4 (eBook)
DOI 10.1007/978-94-017-9888-4

Library of Congress Control Number: 2015935409

Springer Dordrecht Heidelberg New York London

Printed on acid-free paper

Springer Science+Business Media B.V. Dordrecht is part of Springer Science+Business Media (www.springer.com)

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Chapter 1
Introduction

Daniel E. Lane

On September 21, 2014, a massive global march took place all around the world for climate change action. The People's Climate March (http://peoplesclimate.org) was billed as "the biggest march against climate change in the planet's history." Hundreds of thousands of people participated in the march from Melbourne, Australia, to Istanbul, Turkey, to London, England, to New York City. These remarkable and coordinated worldwide protests call for immediate global action on climate change. Organizers and participants in the march believe it could be a turning point in the climate change movement (http://350.org).

Naomi Klein's book *This Changes Everything: Capitalism vs. The Climate* is linked to the march and is the latest in a long line of dire predictions for the pending changes that will wreck havoc on our global environment, small island and coastal states, the agriculture sector, the oceans sector, water infrastructure, and, consequently, the very foundation of our socioeconomic system. Al Gore's 2006 Nobel Prize Winning book and movie "An Inconvenient Truth" (Gore 2006) warned global leaders of the same future demise.

These serious condemnations of the carbon-based industrial systems that have shaped our lives since the industrial revolution have recognized these systems as the culprits of global warming (IPCC 2013). The popularized reports by Klein, Gore, and others are developed from their authors' observations, including the scientific work of the Intergovernmental Panel on Climate Change, the IPCC. The recently updated national reports of the governments of the United Kingdom (2014), the United States of America (Melillo et al. 2014), and Canada's contribution to the IPCC (Canada 2014) are further examples of clear evidence that global warming puts lives and lifestyles at serious risk of sustaining the manner in which we have become accustomed. Despite all this evidence, our governments continue on the

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S. Weissenberger and O. Chouinard, *Adaptation to Climate Change and Sea Level Rise*, SpringerBriefs in Environmental Science,
DOI 10.1007/978-94-017-9888-4_1

policy of deferring the ugly consequences of change, adaptation, reform, and transformation of economies, to future generations—the same future generations who will bear more of the evidently severe consequences of having delayed our critical adaptation to the evolving future. As Klein says:

> Climate change has never received the crisis treatment from our leaders, despite the fact that it carries the risk of destroying lives on a vastly greater scale than collapsed banks or collapsed buildings. The cuts to greenhouse gas emissions that scientists tell us are necessary in order to greatly reduce the risk of catastrophe are treated as nothing more than gentle suggestions, actions that can be put off pretty much indefinitely. (Klein 2014, p. 6).

In the face of this damning evidence, we nevertheless appear unable to make the changes needed to adapt toward improved sustainability. Klein asks the question: "What is wrong with us?" At the global level, we are not able to overcome the political difficulties of radical change to our existing industrial systems that would alter our economic status quo and cause initial hardship.

> …the annual U.N. climate summit, which remains the best hope for a political breakthrough on climate action, has stated to seem less like a forum for serious negotiation than a very costly and high-carbon group therapy session, a place for the representatives of the most vulnerable countries of the world to vent their grief and rage while low level representatives of the nations largely responsible for their strategies stare at their shoes. (Klein 2014, p. 11).

Despite the difficult past, and the daunting future, there must be hope. We all recognize that we need a shift—and we need to do it fast. That shift must move us away from the delays and blockages of global politics (and the false hope of ever achieving a workable consensus among international partners), and away from the entrenched large corporations (with their vested interests in the current economic system). At the same time, we must move toward communities. It is our local communities that need to take action on climate change by taking on the responsibility of attaining resources for developing local adaptation solutions to our vulnerabilities to change.

This book takes a refreshing perspective on our climate issues by tackling our need to "take action" at the local level. It heeds the call that we must "think globally, but act locally." The authors of this work are to be commended for their continuing efforts in this volume, as in past work (Chouinard et al. 2008, 2011, 2014, in press; Doiron and Weissenberger 2014; Noblet and Chouinard 2014; Plante et al. 2011; Weissenberger 2012; Weissenberger and Chouinard in press), to examine how communities are dealing with the local impacts of the changing coastal environment. In this particular case, the communities of the southern Gulf of St. Lawrence in Atlantic Canada are examined closely toward characterizing their changing coastal environments, and developing local solutions to the changing environments that they are experiencing. In this regard, the authors of this work are particularly interested in engaging, and thereby empowering these communities toward the development of sustainable solutions to the climate change challenges that are relevant to their local community contexts.

To develop this theme—and to realize our hope for change—the authors present this work in three parts: (1) vulnerability, (2) strategies, and (3) the application to communities. In this manner, the authors prepare the profile of the communities, formulate and understand the options, and collaborate with the communities to evaluate the options before making a local decision. Chapter 2 entitled "The Vulnerability of Coastal Zones Towards Climate Change and Sea Level Rise" provides the context for the changes experienced by communities of the southern Gulf of St. Lawrence with respect to the definitions and trends of the changing global climate. Chapter 3, "Adaptation Tools and Strategies," provides a framework for the application of local community adaptation in the southern Gulf of St. Lawrence and examines the impact of the categories of adaptation strategies of protection, accommodation, retreat, or status quo for the local communities (Pilkney and Young 2009). Finally, Chap. 4 develops the "Case Studies in Collaborative Action-Research Projects on Climate Adaptation in New Brunswick" and presents evidence of the power of engaging communities toward their capacity to understand their local situations and to develop acceptable, sustainable actions in response to the climate challenges they face.

In Chap. 2, the causes of sea level rise are presented along with the latest prediction for global sea level rise. Sea level rise pertaining to the Gulf of St. Lawrence and coastal New Brunswick is illustrated using maps and charts for the coastal communities of the southern Gulf together with the trends in extreme weather events and the changes in seasonal conditions. The unique geography of the region is presented and the related impacts of coastal erosion reviewed for the beaches, salt marshes, and cliffs of the southern Gulf area, as well as the impact of erosion and coastal retreat on buildings, infrastructure, and the tourism industry of the region.

Chapter 3 links the concepts of vulnerability, adaptation, and resilience and examines alternative models of these concepts. The operationalization of adaptation planning at the global level of the United Nations is also presented. This chapter provides a rich inventory of mega-projects that have been applied around the world in response to local community strategies for adaptation. Notable are the coastal adaptation examples from the Netherlands for the protection of flooding and sea level rise, as well as scaled applications of accommodation strategies in Bangladesh, and the precautionary approaches of New Orleans. Finally, the section on "adaptation tools" in support of strategies for the protection, accommodation, and retreat presents another extensive set of examples for the southern Gulf of St. Lawrence including the use of natural protective devices of coastal wetlands, naturally fortified sand dunes, and innovation in the building of homes.

Chapters 3 and 4 prepare the reader for the presentation of the community case studies in the New Brunswick portion of the southern Gulf. These case studies are collaborative action research projects for the local communities that take into account their vulnerabilities (Chap. 2), and their alternative adaptation tools and strategies (Chap. 3). Chapter 4 presents the dynamics and proactive processes by which adaptation in these local communities unfolds through collaborative community outreach and engagement. In the five (5) New Brunswick communities of Bathurst, Shippagan, Le Goulet, Cocagne, Grand-Digue, and Point-du-Chêne, the authors specify the community vulnerability profile and challenges, and examine the adaptation options presented to community members. It is reported that in this participatory, collaborative, and engagement process, community members increased their trust in the decision makers, achieved greater efficiency in attaining locally-tailored decisions, and reduced the level of conflict within the group thereby improving community cohesion. It was evident in these cases that the local knowledge was critically important to the realization of a viable adaptation strategy. As well, the ability of the local communities as municipalities provided local governance authority that enabled improved local adaptive capacity.

The important local community approach of this work is supported by initiatives such as the C-Change Project, the International Community-University Research Alliance (ICURA) (Lane et al. 2013). The C-Change project (http://www.coastalchange.ca) examines the management of adaptation to environmental change in selected coastal communities in Canada and the Caribbean and provides tools for the evaluation of multi-participatory and multiple criteria decisions of the vulnerability of coastal communities. As in this work, the focus of the C-Change community-based research is to structure the issues in the local context, and to enhance the capacity of the local municipality to examine and evaluate its adaptation options for protection, accommodation, and retreat. The evidence is that communities, like the communities of the southern Gulf of St. Lawrence, are well aware of their changing situation, and are particularly motivated to deal with the situation before it is too late. What is required is the role of our provincial and federal governments to provide these communities with the resources necessary to apply their locally-tailored decisions for their betterment and the sustainability of the community.

Finally, this work should be considered to be a blueprint for community engagement in the challenge we all face from the changing climate. It is one important means of answering Klein's "civilizational wake-up call" that is realized with the engagement and empowerment of our communities who, by necessity, "think globally, but act locally."

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Chapter 2
The Vulnerability of Coastal Zones Towards Climate Change and Sea Level Rise

Abstract Natural and human systems of the coastal zone are vulnerable to climate change and its various consequences. One of the main impacts of climate change is sea level rise which affects coasts world wide. Ecosystems are also vulnerable to changes in water temperature and acidity, both of which have already changed notably in the world's oceans. In many, but not all regions, the intensity of extreme weather events has increased. In addition to these, local conditions, especially winter conditions in the Gulf of Saint Lawrence, are evolving and altering the natural dynamics of the coastline. All taken together, these factors lead to a generalized increase in coastal erosion rates, in added stresses for ecosystems and ultimately threats to properties, infrastructures and the livelihood of communities.

Keywords Sea level rise · Climate change · Coastal zone · Exposure · Coastal erosion

2.1 Sea Level Rise—Causes and Future Outlook

2.1.1 What Causes Sea Levels Rise?

Sea levels have fluctuated throughout the Earth's history in response to climate changes and geological events. In the course of the last deglaciation, between 20,000 and 8000 years ago, the sea level rose at a rate of about 10 mm per year, for a total of 130 m (Alley et al. 2005). The presence of land bridges at the end of the Pleistocene allowed population movements across areas nowadays covered by water such as the British channel, the straight of Tasmania or the Bering bridge. Over the last hundred years, sea level rise, which had flattened out over the previous millennia, picked up at an increasing rate, which can only be attributed to the effects of climate change (Fig. 2.1). More precise data obtained from satellite measurements from 1992 on indicate an even faster rate for that period that that extrapolated

S. Weissenberger and O. Chouinard, *Adaptation to Climate Change and Sea Level Rise*, SpringerBriefs in Environmental Science,
DOI 10.1007/978-94-017-9888-4_2

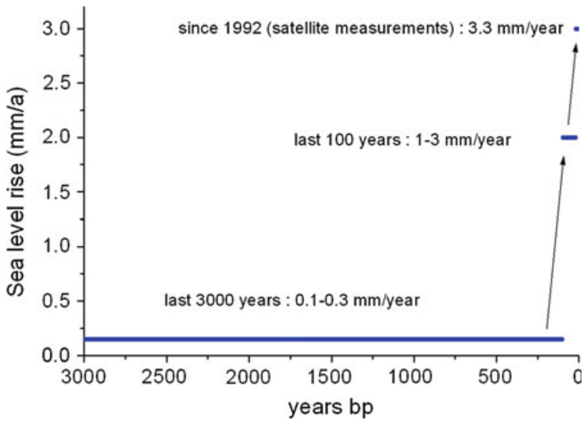


Fig. 2.1 Rates of sea level rise over the last 3000 years. *Source* S. Weissenberger, 2013

for the last century from other measurements, mainly tidal gauges. Since 1850, the sea level rose by about 19 cm worldwide (IPCC 2013).

Recent sea level rise has two main causes. One is the melting of continental glaciers and polar ice sheets; the other is the thermal expansion of the warming ocean. The numbers involved are small compared to the size of the ocean. The ocean covers roughly 71 % of the Earth's surface, equivalent to 3.6×10^8 km^2. It contains 1.3×10^{21} (sextillion) litres of water, which represents 97 % of all water on Earth. In comparison, glaciers and icecaps represent only a tiny fraction, 1.74 %, of the Earth's water. The thermal expansion coefficient of water, 2.07×10^{-4}/°C is also quite small. Thus, the 19.5 cm of sea level rise that occurred between 1870 and 2004 (Church and White 2006) represent only 5.15×10^{-6} % of the mean depth of the ocean of 3790 m. But for the world's 1,634,701 km of coastline (WRI 2012),[1] this increase in sea level has very real and tangible effects, however small it may be at the scale of the ocean. Earlier modelling efforts reflected among others in the third assessment report (IPCC 2001) were not able to match observed sea level rise with known contributions. That gap has however since been closed, such that the individual contributions from thermal expansion, glacier and ice sheet melt and continental water storage account for the 2.8 mm $year^{-1}$ of sea level rise observed between 1993 and 2010 (IPCC 2013) (Fig. 2.2).

The two main causes of sea level rise have contributed almost equally to recent sea level rise. Thermal expansion (or thermosteric sea level rise) has been estimated at 0.40 ± 0.09 mm $year^{-1}$ between 1955 and 1995, 1.6 ± 0.5 mm $year^{-1}$ between 1993 and 2003 (Antonov et al. 2005) and 1.1 ± 0.3 mm $year^{-1}$ between 1993 and

[1]Due to their fractal dimension, the length of coastlines vary according to the scale. The smaller the scale, the longer the coastline, as Benoît Mandelbrot explained in 1967 in his seminal article "How Long Is the Coast of Britain? Statistical Self-Similarity and Fractional Dimension" (*Science* **156**, 636–638). Thus, with a scale of 200 km, the coast of Great-Britain measures 2400 km, with a scale of 50, 3400 km.

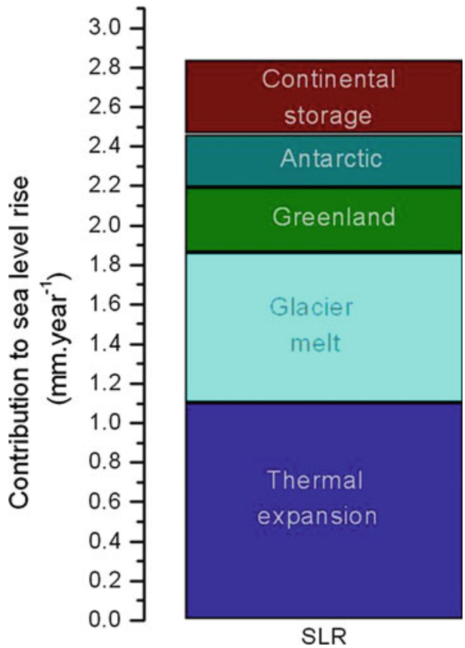


Fig. 2.2 Contributions to sea level rise from 1993 to 2010. *Source* S. Weissenberger with data from IPCC (2013)

2010 (IPCC 2013). The contribution from glacier melt, excluding the Greenland and Antarctic ice sheets, has been estimated at 0.50 ± 0.18 mm year^{-1} between 1961 and 2003, 0.77 ± 0.22 mm year^{-1} between 1993 and 2003 (IPCC 2007) and 0.76 ± 0.18 mm year^{-1} from 1993 to 2010 (IPCC 2013). The rate of glacier melt has increased in both hemispheres and remains subjected to some level of uncertainty, especially for the Greenland and Antarctic ice sheets (Bindschadler 2006) (Table 2.1).

Some human activities also influence sea levels. Thus, the increase of reservoir area behind the world's dams has caused a drop of sea level of 0.5–0.7 mm year^{-1} over the previous decades (IPCC 2001). On the contrary, groundwater extraction for agriculture or human consumption contributes to sea level rise. Although the estimate of 0.77 mm year^{-1} between 1961 and 2003 (Pokhrel et al. 2012) is likely exaggerated, groundwater extraction might add 5–8 cm of sea level rise by the end of the 21st century (Konikow 2013; Rahmstorf et al. 2011; Wada et al. 2012).

2.1.2 How Far Will Sea Levels Rise in the Future?

The estimation of future sea level rise has been the subject of many discussions during recent years. IPCC estimates have often been considered too conservative, in that they do not take into account a possible acceleration of ice sheet melt.

Table 2.1 Contribution to sea level rise from selected glaciers and ice sheets

Region	Period	Sea level rise (mm $year^{-1}$)	Source
All glaciers excluding Greenland and Antarctic	1961–1990	0.33 ± 0.17	Kaser et al. (2006)
	1961–2003	0.50 ± 0.18	IPCC (2007)
	1993–2003	0.77 ± 0.22	IPCC (2007)
	2001–2004	0.77 ± 0.15	Kaser et al. (2006)
	1993–2010	0.76 ± 0.18	IPCC (2013)
Alaska	1950–1990	0.14 ± 0.04	Meier and Dyurgerov (2002)
	1990–2000	0.27 ± 0.10	Arendt et al. (2002)
	1962–2006	0.12 ± 0.02	Berthier et al. (2010)
Patagonia	1968/ 1975–2000	0.042 ± 0.002	Davies and Glasser (2012)
	1995–2000	0.105 ± 0.011	
Rwenzori mountains	1987–2003	0.03	Taylor et al. (2006)
Greenland	1996–2005	0.5	Rignot and Kanagaratnam (2006)
	1961–2003	0.05 ± 0.12	IPCC (2007)
	1993–2003	0.21 ± 0.07	IPCC (2007)
	1993–2010	0.33 ± 0.08	IPCC (2013)
	1992–2011	0.39 ± 0.14	Shepherd et al. (2012)
Antarctica	2002–2003	>0.2	Thomas et al. (2004)
	2002–2006	0.2–0.6	Velicogna and Wahr (2006b)
	1961–2003	0.14 ± 0.41	IPCC (2007)
	1993–2003	0.21 ± 0.35	IPCC (2007)
	1993–2010	0.27 ± 0.11	IPCC (2013)
	1992–2011	0.20 ± 0.23	Shepherd et al. (2012)
	2010–2013	0.32	McMillan et al. (2013)

Semi-empirical models based on correlation analysis of historic temperatures or radiative forcing generally yield higher rates of sea level rise than mechanistic models, which are the base of IPCC estimates (Table 2.2). Mechanistic models have however improved greatly and are now able to account for all sea level rise over the last twenty years (IPCC 2013). Therefore, over time, a convergence of mechanistic and semi-empirical models can be expected. The main reason for the ranges in projected sea level rises in IPCC reports are the emission or CO_2 scenarios, followed by model ranges for a given scenario. Possible rapid changes in ice sheet dynamics resulting in faster sea level rise are not included, due to a lack of knowledge about those processes (IPCC 2013). Therefore, those estimates are not necessarily worst-case scenarios.

Table 2.2 Some estimates of sea level rise in the 21st century

Sea level rise in the 21st century (cm)	Details	Source
9–88	Likely ranges according to the different emission scenarios	IPCC (2001)
18–59	Likely ranges according to the different emission scenarios	IPCC (2007)
26–82 (98)	Likely ranges according to the 4 scenarios (assuming a higher rate at the end of the century for the RCP8.5 scenario)	IPCC (2013)
50–140	Semi-empirical model, correlation with paleoclimatic temperatures yielding a proportionality constant of 3.4 mm^{-1} $year^{-1}$ $°C^{-1}$	Rahmstorf (2007)
74–190	Semi-empirical model, correlation with paleoclimatic data, addition of rapid response term	Vermeer et Rahmstorf (2009)
60–160	Semi-empirical model, correlation with radiative forcing over the past 1000 years	Jevrejeva et al. (2010)
90–130	Semi-empirical model, correlation with temperatures over the last 2000 years	Grinsted et al. (2009)

The main sources of uncertainty in estimates of future sea level are the Greenland and Antarctic ice sheets, which contain two thirds of all freshwater and 95 % of ice on the planet. The Greenland ice sheet contains the equivalent of 6 m of sea level rise, the Antarctic 23 m, seven of which are in the more unstable West Antarctic Ice Sheet (WAIS). The future behaviour of the ice sheets remains uncertain. An increase of melting rates has been observed over the first decade of the 21st century for the Greenland ice sheet (Joughin 2006; Rignot and Kanagaratnam 2006). The melt rate has increased from 0.13 mm $year^{-1}$ SLR equivalent[2] between 1994 and 1999 (Krabill et al. 2000) to 0.5 ± 0.1 mm $year^{-1}$ between 2002 and 2006 (Velicogna and Wahr 2006a; Murray 2006). Both rates are higher than the −0.02 to 0.09 mm $year^{-1}$ from the Third IPCC report for the period 1961–2003 (IPCC 2001). In the Antarctic, the western part (WAIS) is losing ice, at a rate of 0.4 ± 0.2 mm $year^{-1}$ between 2002 and 2005 (Velicogna and Wahr 2006b), while the interior of the continent has gained 0.12 ± 0.02 mm $year^{-1}$ between 1992 and 2003 (Davis et al. 2005).

Both ice sheets have substantially melted in the past and will indeed continue to melt for several centuries or millennia in response to current climate change. During the last interglacial, sea levels were about 6 m higher than present, which is attributed to a partial melt of the Greenland and West Antarctic ice sheets (Schøtt Hvidberg 2000; Cuffey and Marshall 2000; Otto-Bliesner et al. 2006). And during

[2]Volumetric ice losses can be converted into equivalents of sea level rise via the surface of the ocean. This nomenclature is adopted in IPCC reports.

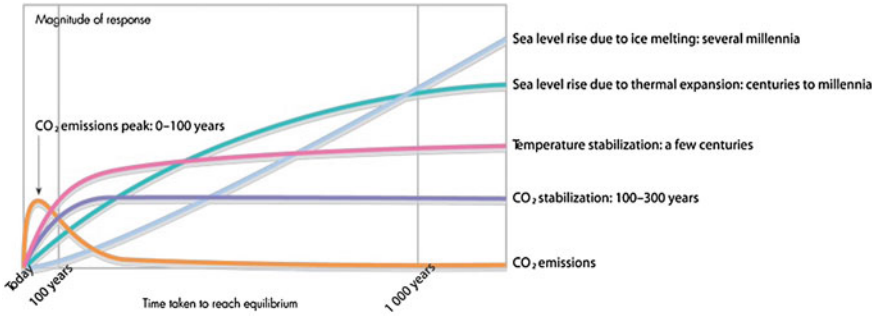


Fig. 2.3 Evolution of the different components of sea level rise over time. *Source* IPCC (2001), UNEP/GRID-Arendal, 2006

the Pliocene, around three million years ago, the last time atmospheric CO_2 concentrations were around or in excess of 400 ppm, sea levels were 22 ± 5 m higher than today; neither the Greenland nor the West Antarctic Ice Sheets existed (Miller et al. 2011).

It is important to consider that sea level rise, although often expressed as expectations for the end of the 21st century, will extend far beyond that deadline, for several hundred years after stabilization of atmospheric CO_2 concentrations for thermal expansion, equivalent to the ocean overturning period, and even several millennia for ice sheets to find a new equilibrium as function of new atmospheric conditions (Fig. 2.3).

2.1.3 Is Sea Level Rise Uniform?

Sea level rise is not uniform in time and space, as it depends on a number of variables, such as ocean currents, dominant wind patterns, climate oscillations, continental crust movements or punctual events like volcanic eruptions. Thus, the centres of the large oceanic gyres are elevated by 20 cm. El Niño creates similar sea level differences between Australia and South America. The Krakatao volcanic eruption of 1883 caused a temporary drop in sea levels by cooling surface water for several decades (Gleckler et al. 2006). The El Niño event of 2010–2011 caused massive rainfalls over South America leading to a temporary continental storage of all that water and a concomitant drop of sea levels by a centimeter during that period (Boening et al. 2012). In the northern hemisphere, isostatic rebound leads to an elevation of the continental crust in certain areas, at the center of the former ice sheets, and a subsidence of others, at the edges of those ice-sheets. In certain regions, changes in salinity can lead to sea level changes. For example, in the subpolar gyre of the North Atlantic, increasing salinity and the resulting halosteric sea level drop cancels out part of the thermosteric sea level rise (Bindoff et al. 2007).

2.1.4 Sea Level Rise Gulf of St. Lawrence and Coast of New Brunswick

Over the past hundred years, an acceleration of sea level rise could be observed on the coasts of the southwestern part of the Gulf of Saint Lawrence, as evidenced by tidal gauges measures (Forbes et al. 2006) (Fig. 2.4). Differences in the rate of relative sea level rise at the three gages stem from different rates of isostatic

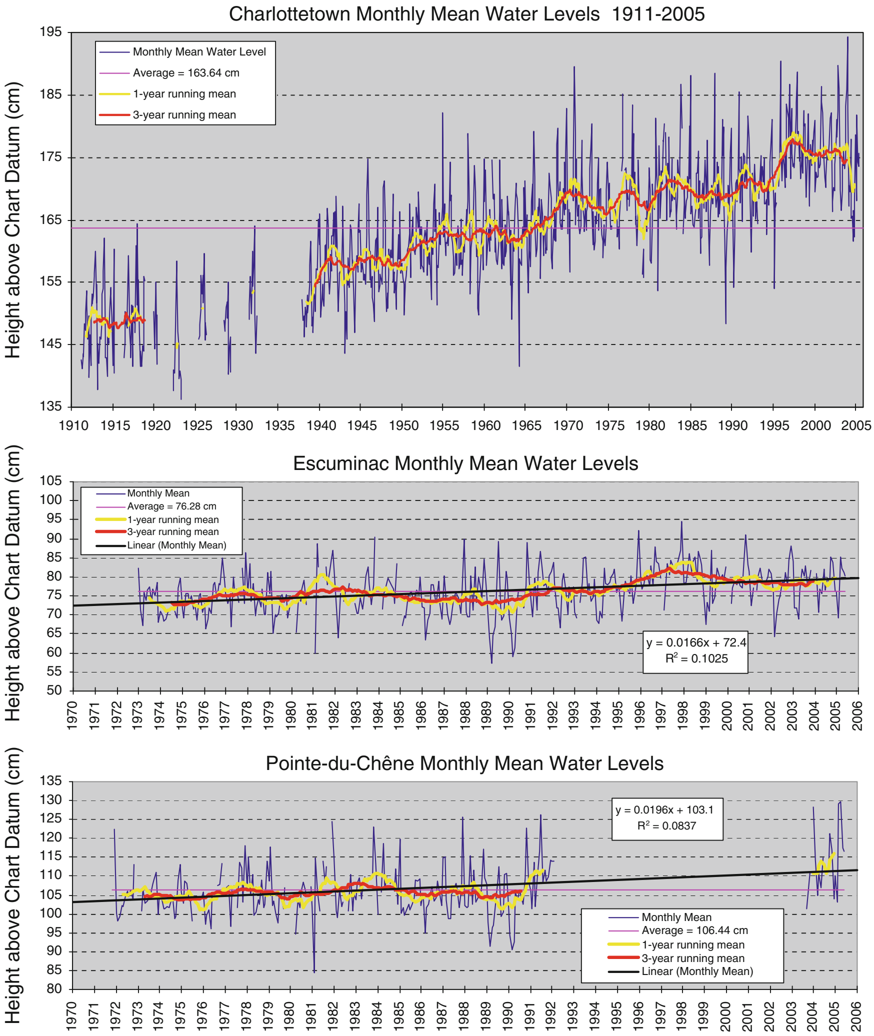


Fig. 2.4 Monthly mean water levels for three tidal gauges in the Gulf of Saint Lawrence. *Source* Forbes et al. (2006)

Table 2.3 Extrapolated rates of sea level rise for different parts of the Acadians coast in southeastern New Brunswick using a value of 44 cm for global sea level rise according to IPCC IS92A scenario (from Forbes et al. 2006)

Site	Vertical motion (cm) 2000–2100	Relative sea level rise (cm) 2000–2100
Cape Jourimain	15 ± 5	59 ± 35
Shemogue	13 ± 5	57 ± 35
Cap-Pelé	12 ± 5	56 ± 35
Shediac	10 ± 5	54 ± 35
Bouctouche	9 ± 5	53 ± 35
Kouchibougouac	7 ± 5	51 ± 35
Escuminac	6 ± 5	50 ± 35

adjustment. The exact rates of isostatic adjustment are still subject to debate (Forbes et al. 2006, Daigle 2012). Glaciers have retreated from the southwestern part of the Gulf of Saint Lawrence around 14,000 years ago (Forbes et al. 2006). At this point, large areas around the Northumberland Strait were submerged. Between 9000 and 7500 years ago, those areas emerged (Forbes et al. 2006). Subsequently, water levels rose at a decelerating rate until the 19th century.

Based on tidal gauge measurements up to 2005 and crustal motion derived from those measurements, and from sea level rise scenarios from IPCC's third assessment report, Forbes et al. (2006) extrapolate the following relative sea level rise for different points of the Acadian cost in New Brunswick (Table 2.3).

2.2 Increase in Extreme Weather Events and Changes in Winter Conditions

2.2.1 Increase in Storm Frequency and Intensity

The impact of climate change varies from region to region. In the northern mid-latitudes, a strengthening of westerly winds has been observed between the 1960s and the 1990s[3] paired with a northward migration of storm tracks, explaining the increase in storm intensity, winds speed and wave heights observed in the North Sea or in Atlantic Canada (Trenberth et al. 2007; Lefebvre 2000; Daigle 2006). Since periods of strong storm activity have occurred in the past, for example at the end of the 19th century (Alexandersson et al. 1998, 2000) and barometric measurements only started in 1880, it is difficult to extrapolate current trends for the middle and far future. However, the observations are in agreement with climate model results (Fischer-Bruns et al. 2002, 2005) and according to likely climate

[3]For a representation of the evolution in significant wave height between 1950 and 2002, see Gulev and Grigorieva (2004) in IPCC (2007), http://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-3-25.html.

scenarios, storm surges in the North Sea could increase by 20 cm in 2030 and 70 cm in 2085 (Helmholtz Gesellschaft 2007).

Hurricanes seldom reach the Gulf of Saint Lawrence and if they do, it is only as tropical storms. Hurricane activity in the north Atlantic is influenced by the Atlantic multi-decadal oscillation (AMO), whose warm phase (e.g. 1930–1960) corresponds to a higher, and its cold phase (e.g. 1905–1925, 1970–1990) to a reduced hurricane activity. The increase in strong hurricanes since the 1970s is however mostly attributed to higher water temperatures as a result of climate change, as indicated amongst others by the strong correlation between the energy dissipation index and water temperatures (Emanuel 2005; Goldenberg et al. 2001; Trenberth et al. 2007; Webster et al. 2005). In contrast, the overall number of hurricanes has decreased during the period 1957–2004 (Ren et al. 2006).

The Gulf of Saint Lawrence is characterized by a highly variable storm activity. Storm surges can exceptionally reach a height of 10 m, but 99 % of waves do not exceed 4 m. On the southeast coast of New Brunswick, an increase in overall storm frequency is not discernable, but instrumental records suggest an increase in high intensity events in the years 2000–2004 (Fig. 2.5). The data also shows the presence of underlying multidecadal cycles (Parkes et al. 2006). It must be noted that strong storms that occurred in recent years, especially in 2005 and 2010, are not yet included in the graphs below. Several tidal gauges, including Québec, Charlottetown and Pointe-du-Chêne have recorded historic maxima during the last decade. Climate models predict an increase in wave heights over the 21st century, despite a possible decrease in the total frequency of storms (Savard et al. 2008).

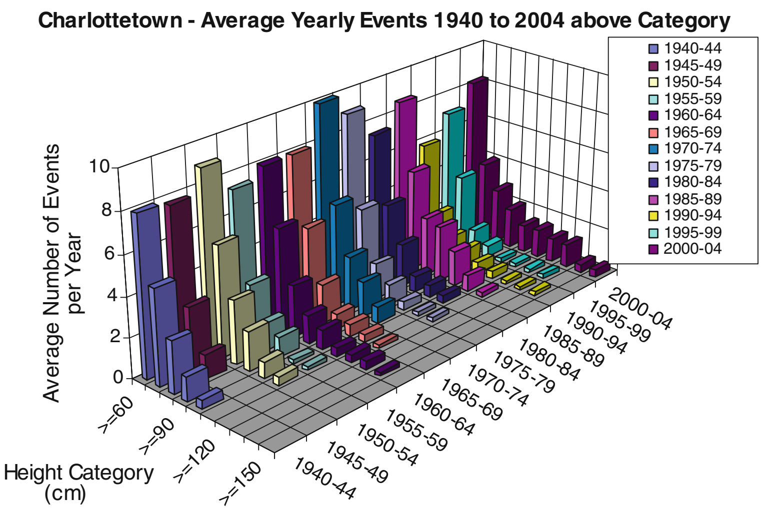
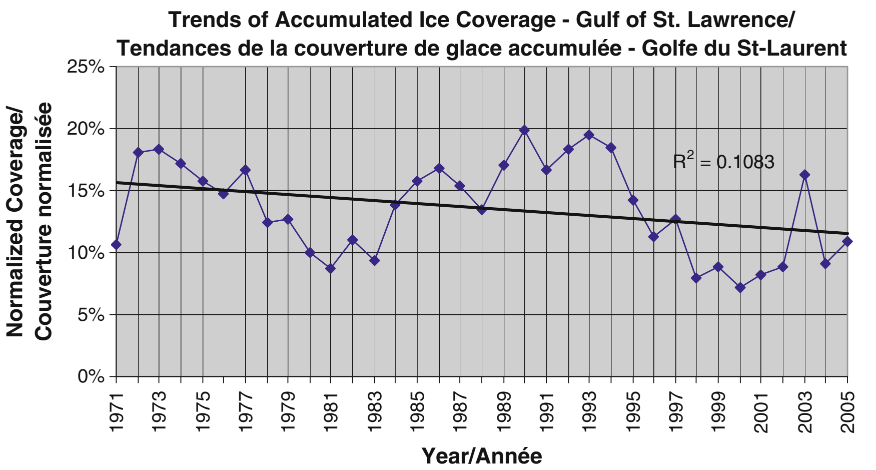


Fig. 2.5 Evolution of storm surge amplitudes by decade from 1940 to 2004. *Source* Parkes et al. (2006)

2.3 Changes in Winter Conditions

As in most northern regions, a change in winter conditions has been observed in Atlantic Canada over the past decades. Sea ice cover has been reduced in size and duration (Fig. 2.6) and thaw-frost cycles have become more frequent. In the Gulf of Saint Lawrence, the ice-covered period has decreased by about one third between 1969 and 1995 and could disappear entirely by the end of the 21st century (Savard et al. 2008). As sea ice protects the coasts from winter-storm surges, this contributes to an increase in erosion rates.



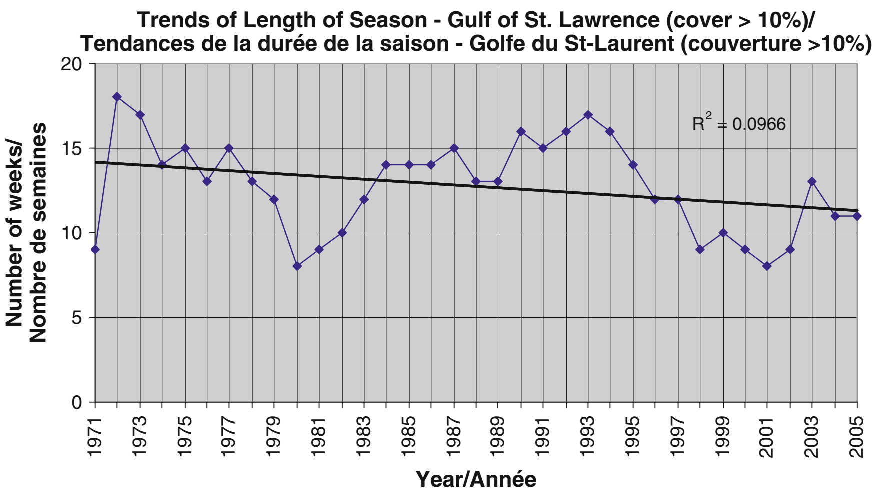


Fig. 2.6 Decrease of the duration and extent of ice cover in the Gulf of Saint Lawrence. *Source* Parkes et al. (2006)

Fig. 2.7 Cliff erosion caused by frost-thaw cycles, Carleton, Quebec, Canada. *Source* S. Weissenberger, 2012

The increase in frost-thaw cycles has a severe impact on erosion rates of friable shores, especially cliffs made out of glacial tills, as are very frequent in Atlantic Canada (Fig. 2.7).

2.4 Ocean Warming and Acidification

Ocean warming and acidification are two consequences of human CO_2 emissions which have the potential to greatly disrupt marine and coastal ecosystems, in addition to sea level rise and extreme weather events. Because of its roughly one thousand times higher heat capacity, the ocean warms more slowly than the atmosphere, while absorbing 20 times more heat (Levitus et al. 2005). Thus, oceans have absorbed over 90 % of all the energy accumulated in the Earth's surface due to increased radiative forcing since 1970, two thirds of which in the first 700 m (IPCC 2013). During the last ten years, during which the atmosphere has warmed at a slightly slower rate, the upper (0–700 m) and middle (700–2000 m) ocean has kept accumulating heat without discernable slowing down in comparison to the previous decade (IPCC 2013).

Water temperatures in the Gulf of Saint Lawrence have increased by 0.9 °C for the yearly average and 1.6 °C for winter temperatures during the 20th century (Savard et al. 2008). A recent analysis of NOAA satellite data indicates a rapid warming of 1.8 °C between 1985 and 2009, which is probably in part due to local circumstances (Galbraith et al. 2010, 2012).

Increased water temperatures affect species and ecosystems, possibly leading to (1) migration of species, (2) alteration of ecosystems, (3) adaptation of species and assemblages, or (4) deterioration of ecosystems. The possible impacts of ocean warming, and in the long term ocean acidification, on American lobster (*Homarus americanus*) include physiological effects (Camacho et al. 2006; Dove et al. 2005), activity and catchability (McLeese and Wilder 2011), reproduction (Tlusty et al. 2008), the spread of diseases (Cawthorn 2011) and other indirect effects resulting from ecosystems alterations (Parsons 1996; Scheibling 2012; Wharton and Mann 2011). Ocean warming will also significantly influence cod population, leading to a change in seasonal cycles, a northwards expansion and a further reduction in stocks in some traditional cod fishing areas such as Celtic and Irish seas, the Baltic, the Scotian shelf or the Gulf of Maine (Clark et al. 2003; Drinkwater 2005; Drinkwater et al. 2010; Fogarty et al. 2008).

Ocean acidification has often been referred to as the "other" CO_2 problem (Doney et al. 2009). Since preindustrial times, ocean acidity has increased by about 30 %, from pH 8.2 to pH 8.1 as a response to increased atmospheric CO_2 concentrations (Eq. 2.1), and might increase by a further 0.14–0.35 pH units in the course of the 21st century (Solomon et al. 2007; Orr et al. 2005). Ocean acidification is faster in high latitudes, due to the higher solubility of CO_2 in colder waters. Acidification has the potential to affect all calcifying organisms, such as crustaceans, including copepods, an essential component of zooplankton, foraminifera and molluscs. Several of those species, including lobster, snow crab, shrimps, oysters and mussels are mainstays of local fisheries and aquaculture. It has also been found that elevated acidity can disrupt physiological processes in several aquatic species that lack adaptation mechanisms towards it (Doney et al. 2009).

Carbonic acid equilibrium reactions

$$CO_2\,(atm) \xrightarrow{(1)} CO_2\,(aq) + H_2O \xrightleftharpoons{(2)} H_2CO_3 \xrightleftharpoons{(3)} H^+ + HCO_3^- \xrightleftharpoons{(4)} 2\,H^+ + CO_3^{2-} \xrightleftharpoons{(5)} CO_3^{2-}\,(s) \tag{2.1}$$

Legend (1) Atmospheric CO_2 dissolves in sea water, (2) dissolved CO_2 transforms into carbonic acid H_2CO_3, (3) and (4) carbonic acid dissociates as function of pH, bicarbonate HCO_3^- being the main species under oceanic conditions, (5) dissolved carbonate ions CO_3^{2-} are in equilibrium with carbonate in inorganic and organic particulate matter, as calcite or aragonite.

Locally, water properties such as temperature, salinity and pH can also change as a result in hydrodynamics Thus, in the Gulf of Saint Lawrence, a 4–24 % decrease in freshwater inflow from the Saint Lawrence River is expected by the mid 21st century (Savard et al. 2008). On the other hand, an increase in cold water inflow from the Labrador Sea across the Strait of Belle Isle has been observed since 1996 (Starr et al. 2002). The pH has decreased by 0.2–0.3 units since 1934 in the deep waters of the Gulf of Saint Lawrence, while remaining almost unchanged in surface waters, which is due to a stronger inflow of anoxic and CO_2 rich water masses rather than to an uptake of atmospheric CO_2 (Benoît et al. 2012).

2.5 Coastal Erosion and Its Impact on Infrastructure

2.5.1 Erosion as an Accelerated Natural Process

Erosion is a natural process by which beaches and cliffs are shaped over time. It can give rise to surprising shapes such as the Hopewell Rocks on the Bay of Fundy shore (Fig. 2.8). Natural beaches and cliffs are in a steady state, also termed as dynamic equilibrium. Material stemming from the erosion of the cliffs or dunes behind the beach replenishes the beach at the same time as wave action carries sand and other materials out to the sea. Thus, the structure of the beach remains preserved as it moves backwards into the land. Additionally, lateral currents known as the littoral drift cause a sideways movement of sand and sediments, which explains that certain spits or dunes "move" along the beach. In reality, they decrease through erosion on one side and increase through accretion on the other side. In estuaries and lagoons, the dynamics of shore evolution can be quite complex.

Climate change has lead to an increase in erosion rates in the majority of sectors of the New Brunswick coastline because of sea level rise, increased wave activity and more frequent frost-saw cycles. There are however also sectors which are in net growth, in which littoral drift carries eroding material from neighbouring sectors to. Erosion rates are particularly high on the east coast of New Brunswick, somewhat lower in the Chaleur Bay and lowest in the Bay of Fundy.

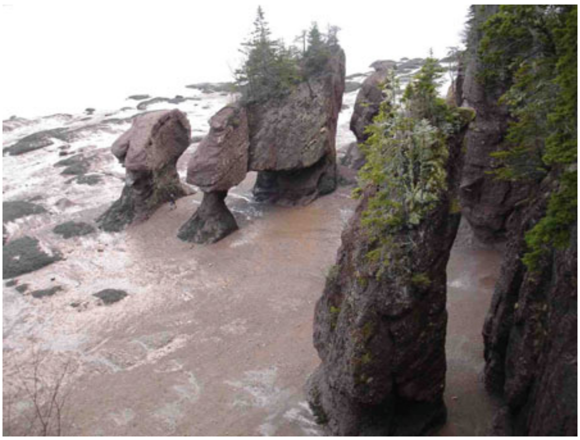


Fig. 2.8 Hopewell Rocks, Fundy Bay, New Brunswick, Canada. *Source* S. Weissenberger, 2011

2.5.2 Coast Type and Rate of Coastal Retreat

Bruun's formula from 1962 predicts a coastal retreat rate of 1.0–1.5 m per centimetre of sea level rise (Heberger et al. 2009). This is of course a very rough approximation, since the coastal retreat rate will strongly depend on the coastal substrate and the exposure to erosion agents such as wind and waves. Hard cliffs (granite, gneiss, basalt, etc.) erode much more slowly, at rates of a few millimetres per year, than soft cliffs (limestone, shale, etc.), which have retreat rates of the order of centimetres per year, or friable and loose cliffs (soft limestone, till, etc.). Unfortunately, harder substrates like granite are also more difficult and costly to build on, so that houses and infrastructure are often located on more rapidly eroding substrates. Dunes and beaches erode more quickly than cliffs. Vegetated shores are usually more erosion-resistant than sandy shores.

Insert: common types of costal substrate around the Gulf of St. Lawrence

Granite is a hard impermeable igneous rock of plutonic origin, formed by the slow cooling of magma, during which it acquires a crystalline structure. The main minerals of granite are quartz, feldspath and mica, but there are numerous variations of granite with different colours. Most of the Earth's crust, and in particular of the Canadian shield, is formed by granite, which can be over 4 billion years old.

Slate (Shale) (Fig. 2.9) is a clastic sedimentary rock formed in two stages, first by compaction in shallow waters (diagenesis) and then by metamorphosis. Depending on the degree of metamorphosis, slate, phyllite, schist and gneiss are distinguished. Slate can be made of silt, quartz, calcite or clays and can have various colours from red to black.

Fig. 2.9 Slate cliffs at Meat Cove Beach, Cape Breton, Nova Scotia, Canada. *Source* S. Weissenberger, 2013

Fig. 2.10 Phyllite cliffs in Cape Breton, Nova Scotia, Canada. *Source* S. Weissenberger, 2013

Phyllite (Fig. 2.10) is a foliated metamorphic rock formed by metamorphosis of slate. It is intermediate between slate and schist. Phyllite is commonly black, grey or light greenish with a silvery sheen (phyllic luster).

Gneiss is a metamorphic rock originating from granite (orthogneiss) or from clay (paragneiss). Flattening and stretching during the metamorphosis generate the typical banded or bedded structure, often with altering colours. Gneiss is found at the base of highly eroded mountain ranges. The St. John region in Southern New Brunswick has granite and biotite gneiss formations.

Basalt is a grey-black very hard rock of volcanic origin. Basalts are formed by rapid cooling of lava flowing to the surface during volcanic eruptions of along ocean ridges. The several hundred feet deep North Mountain basalt of the Early Mesozoic Fundy extends in the Fundy Bay between New Brunswick and Nova Scotia and is visible in places such as Grand Manan and other locations in New Brunswick, Nova Scotia and

Fig. 2.11 Banded red sandstone and black shale from the Mississippian (old carboniferous) at Cape Saint Lawrence, Cape Breton, Nova Scotia, Canada. *Source* S. Weissenberger, 2013

Fig. 2.12 The Roché Percé in Gaspé is a 433 m long, 90 m wide and 88 m high siliceous limestone formation weighing 5 million tons. The second arch (*on the right*) collapsed in 1854. *Source* D. Ménard, 2001, in Wikipédia

Maine. They are part of the central Atlantic magmatic province (CAMP) which covered 11 million km^2 shortly before the breakup of Pangea.

Sandstone (Fig. 2.11) is a detrital rock formed by the aggregation of sand and sometimes quartz in lake, river or desert sediments. Under the pressure of overlying sediments, the sand particles are cemented by silicates or carbonates to form a yellow, red or brown rock.

Limestone (Fig. 2.12) is a white sedimentary rock made of calcite (70 %) and aragonite, two carbonates of marine origin, mostly formed by plankton. It is a popular building material since antiquity. Over geological periods, limestone is water-soluble leading to erosional landforms like karsts and caves. Chalk, Travertine, Tufa and Coquina are various forms of limestone.

Till (Fig. 2.13) is a heterogeneous assemblage of glacial deposits of various sizes formed during the last glaciation. Primary deposits consist in rock carried by the glaciers. Deformation till denotes primary deposits which have been reworked and homogenized through fluvial transport or other events.

Fig. 2.13 Cliff with glacial till overlying sandstone cliff in Trout Brook, Nova Scotia, Canada. *Source* S. Weissenberger, 2013

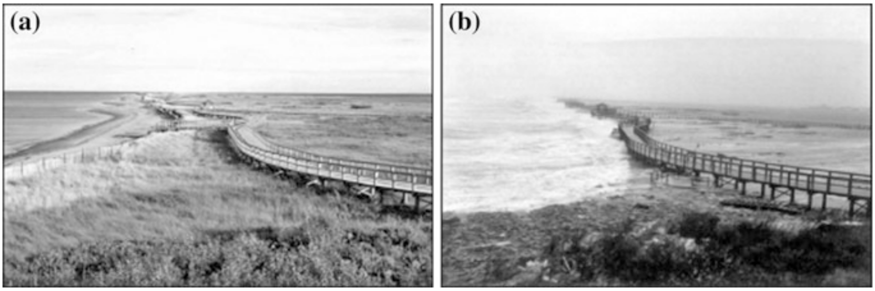


Fig. 2.14 The Bouctouche dune **a** in the summer 2000 and **b** during the storm of October 2000. *Source* Jolicoeur et al. (2010)

Tillite is a sedimentary rock formed from till that has been buried into solid rock and lithified.

Erosion is a gradual process over long time periods, but often occurs in a dramatic fashion during storms, when strong waves carry away large quantities of substrate. The accumulation of strong storm events in recent years in the Gulf of Saint Lawrence is therefore a contributing factor to high erosion rates in exposed shore segments. In the Sept-Îles area on the north shore of the Saint Lawrence estuary and in the Magdalen Islands in the middle of the Gulf of Saint Lawrence, erosion rates of up to 7 m have been measures following the storm of October 2005 (Bernatchez et al. 2008). The Bouctouche dune has been repeatedly flooded in recent years and lost considerable amounts of sand (Fig. 2.14). During the storm of December 2010, half of the walkway and 8 m of beach were lost.

2.5.3 *Coastal Retreat in New-Brunswick*

Most of the coast of New Brunswick has little elevation and relief. The coastal plain consists mainly of glacial deposits (till, moraines) overlying older bedrock. Rock cliffs can be found to a small extent on the southern part of the Acadian peninsula or on the Bay of Fundy shore. Most of the hinterland is not well drained, accounting for the strongly meandering rivers and the presence of numerous coastal wetlands. A large part of the coast is protected by dikes (Table 2.4), which have their origins in the Acadian dykes of the 17th century. The scarcity of forested coastlines is also attributable to the deforestation which occurred initially during the Acadian occupation of the land in order to create agricultural land and procure firewood and construction materials, later through English settlers and, especially in the 19th century, for shipbuilding at a time where New Brunswick accounted for up to one quarter of Canada's registered tonnage (New Brunswick Museum 2003).

Table 2.4 Constitution of the coasts of New Brunswick

Type of land	Surface area	
	Area (ha)	Percentage
Salt marshes	14,622	47.6 %
Diked lands	125,954	41.0 %
Sand dunes	2580	8.4 %
Beaches	829	2.7 %
Rock platforms	93	0.3 %

Source Authors, after data from Bérubé (n.d.)

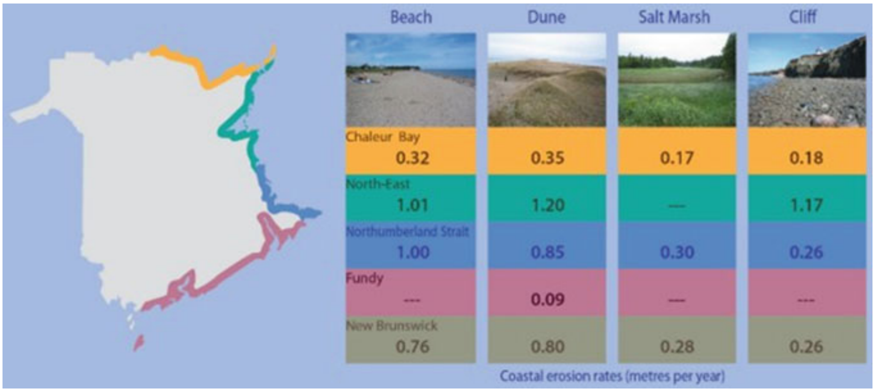


Fig. 2.15 Erosion rates measured in different sectors of the New Brunswick coast. *Source* New Brunswick Department of Natural Resources (n.d.)

In New Brunswick, average erosion rates observed are 0.26 m $year^{-1}$ for cliffs, 0.28 m $year^{-1}$ for coastal wetlands, 0.76 m $year^{-1}$ for beaches and 0.80 m $year^{-1}$ for dunes. They are higher on the east coast (North–East and Northumberland strait) than in the Chaleur or Fundy bays (Fig. 2.15).

Like large tracts of the coastal zones of the Gulf of Saint Lawrence, most of the coast of New Brunswick can be considered as moderately to highly vulnerable according to Natural Resource Canada's assessment, based on a sensibility index adapted from Gornitz (1990), which includes seven variables: relief, geology, morphology, relative sea level rise, coastline movement, wave height, amplitude of tides.

Fig. 2.16 Damages on road 113 on the island of Miscou, New Brunswick, Canada. *Source* S. Weissenberger, 2012

Fig. 2.17 Abandoned road due to coastal erosion at Richibuctou Head (Cap Lumière). *Source* New Brunswick Department of Environment/Paul Jordan

2.5.4 *Impact of Coastal Erosion on Buildings and Infrastructures*

Coastal erosion puts houses, properties, roads and infrastructure at risk. Besides an increasing risk of flooding during storm events, a receding coastline can undermine the foundation of houses, necessitating an evacuation, demolition or relocation.

Fig. 2.18 The camping ground l'Étoile Filante in Shediac, New Brunswick, Canada, flooded during the storm of December 2010. *Source* S. Doiron, 2010

Roads and railways are often built near the coast, linking villages and urban centers. In recent years, in New Brunswick, and more generally in the Gulf of Saint Lawrence, considerable damages has occurred to coastal roads and railways, necessitating costly repairs and consolidation, in some instances even landward displacement (Figs. 2.16 and 2.17).

2.5.5 *Impact of Climate Change and Coastal Erosion on Tourism*

Tourism, mainly situated on the coast, is a rapidly growing industry in New Brunswick and a considerable source of revenue and employment for the province. In 2010, tourism contributed about 1.1 billion dollar in revenue, 738 million dollars of which from non residents, representing 3.5 % of provincial GDP, and 34,700 jobs for an equivalent of 19,600 full-time jobs, representing 9 % of provincial labour force (Province of New Brunswick 2012). However, the tourism sector is particularly vulnerable to the impacts of climate (WTO 2009; Scott et al. 2012), through its effect on ecosystems, on the coastline, damage to tourism infrastructure mainly situated in coastal areas and indirectly through the visual impact of coastal protections. Extensive damage has been caused by storms in the last decade to camping sites, beach infrastructure or educational infrastructure (Fig. 2.18). On the positive side, an increase in air and water temperatures might represent an additional argument for tourists to visit New Brunswick, which bases part of its publicity strategy on having "the warmest waters north of Maine", but only if water quality, popular beaches and often visited ecosystems remain unaffected by climate change. Winter activities, such as skiing, skating or snowmobiling would suffer in equal measure as summer activities potentially benefit from a warmer climate.

2.6 Conclusion

Even after an eventual stabilization of atmospheric CO_2 concentrations and in term of the Earth's climate, sea level rise will continue for many centuries. Therefore, coastal erosion and flood risk will remain a growing problem in the world's coastal zones. When warming and increasingly acid oceans, changes in the patterns of extreme weather events and altered winter conditions are added to the equation, it becomes clear that considerable challenges lie ahead for many coastal areas. The sensitivity of New Brunswick's coasts is already becoming apparent as erosion rates and the frequency of severe flooding increase. Climate change can therefore not be ignored when the future development of the coast is considered.

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Chapter 3
Adaptation Tools and Strategies

Abstract Adaptation to climate change will be a necessity for coastal zones in decades and even centuries to come. Although adaptation to climate and environmental changes has been a feature of human societies since the evolution of modern humans, current challenges posed by climate change and sea level rise in a crowded and developed world are of a vaster nature of those faced by humanity before and will necessitate new approaches, new techniques and new strategies. A conceptual framework is being developed, centered on the notions of vulnerability, adaptation and resilience. Adaptation to climate change will necessitate international cooperation and coherent strategies, although solutions will need to be developed with respect to local circumstances. The main strategies—protection, accommodation, retreat and precaution, are declined in various tools of technical, scientific, legislative, administrative, social or physical nature.

Keywords Vulnerability · Adaptation · Resilience · Adaptation strategies · Coastal protection

3.1 Vulnerability, Adaptation and Resilience—Three Tightly Linked Concepts

3.1.1 Definitions of Vulnerability, Adaptation and Resilience

Vulnerability towards sea level rise depends on the physical characteristics of the coast, as seen in Chap. 2, but is also dependent on socio-economical and other characteristics. The notion of variability has been extensively discussed during the past decades, resulting in many definitions and evaluation methods (Hammill et al. 2013); Thywissen (in Hinkel 2011) counts 35 different definition of vulnerability. The IPCC defines vulnerability to climate change as "the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change" (Parry et al. 2007). This definition is

S. Weissenberger and O. Chouinard, *Adaptation to Climate Change and Sea Level Rise*, SpringerBriefs in Environmental Science,
DOI 10.1007/978-94-017-9888-4_3

highly theory-laden. It incorporates the importance of the socio-economic make-up of the coastal zone and not only its physical vulnerability, which is commonly referred to as *sensitivity*. It also includes the possibility of *adaptation*, defined as the ability to cope with the adverse impacts. As we will see, this entails including adaptation actions in the evaluation of vulnerability, thus making it a dynamic rather than static concept, since adaptation is an ongoing process. In a system's theory approach, the *exposure* to the effects of climate change is the perturbation that will test the system's ability to adjust and return to a desirable steady state (Adger 2006). This line of thought will be pursued further through the concept of resilience.

Adaptation, like vulnerability, is a vast field of research. Adaptation as a social phenomenon is a main characteristic of human society and has in the past catalyzed technical, social, political, agricultural and other transformations in response particularly to climatic change and variability, but has also failed in a number of instances leading or contributing to civilization decline in the Indus, the Mayan world, the Easter Island, Neolithic Sahara or the Roman Empire, just to name a few (Büntgen et al. 2011; Diamond 2005; Dixit et al. 2014; Jacques and Le Treut 2004; Kuper and Kröpelin 2006; Orlove 2005). The concept of adaptation has been initially transposed from evolution theory to human societies. While in natural systems, according to Darwin or Lamarck, it is the development of physiological (and, as was later discovered, genetic) traits by species which allows them to better cope with environmental changes, human societies, according to Smit and Wandel (2006) or Adger et al. (2009), develop behaviours and alterations of its social, economic and other systems in order to adjust to changing environmental conditions and sometimes even benefit from them. This forms the basis of IPCC's definition of adaptation as "Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2001).

Adaptation to climate change poses new challenges that necessitate a mobilisation of governments and the elaboration of public policies in order to assist populations (Adger 2003). This also marks the transition from a reactive to a proactive adaptation. Usually, at first, adaptation occurs in a spontaneous way in order to prevent in order to prevent negative effects of climate change in the short term (Smit et al. 1999). Those uncoordinated efforts are usually undertaken by the private sector, which includes individuals and all organisational entities not part of the public sector. Planned or proactive adaptation necessitates the intervention of the public sector in order to coordinate different action and provide a legislative, regulatory and economic framework enabling effective adaptation in the long term (Burton et al. 1993; Smit and Pilifosova 2001). Spontaneous adaptation is usually associated with a *bottom-up* process and planned adaptation with a *top-down* process. The distinction between a spontaneous, reactive, bottom-up, short term, private sector driven adaptation and a proactive, planned, top-down, long-term public sector-driven adaptation is however not hermetic. Thus, in practice, adaptation often occurs as a process mobilising both private and public actors. Also, planning of adaptation can be achieved by private actors while public action is not necessarily well planned and geared towards the long-term. The public sector operates at different spatial scales, from local governments to provincial or federal governments (in the case of Canada), which do not always cooperate in a seamless fashion. Furthermore, as can be observed in the case of coastal protections, spontaneous bottom-up adaptation consisting in establishing riff-raff wall in front of properties can, through a self-organised process, lead to a spatially extended adaptation strategy, without direction from the public sector.

Adaption capacity is an essential characteristic of a coastal zone and determines how the local population and activity sectors are able to cope with the adverse effects of climate change and climate variability. The adaptation capacity depends on a variety of factors (Adger et al. 2003; Smit et al. 2000; Yohe and Tol 2002), including amongst other the following:

- Economic resources—the ability to finance adaptation strategies, including coastal protections, also the mechanisms (insurances, incentives, etc.) allowing to share the risk in coastal zones and the costs of adaptation
- Technical resources—possessing the knowledge to implement various adaptation strategies
- Scientific resources—being able to evaluate and monitor the impacts of climate change, assess the vulnerability of the zone and inform decision makers
- Human resources—the presence of experts in all fields pertaining to climate adaptation
- Social capital—mutual trust and cooperation between civil society and the public sector, education and awareness and the perception to be able to act at a local level when confronted to a global problem
- Political capital—the presence of political structures allowing for efficient governance and partaking of all stakeholders involved in the management of coastal zones and coastal risks
- Legal framework—determines the ability of institutions to govern development in coastal zones, to minimize risks for the population and protect natural coastal features and ecosystems
- Information, education and awareness raising—the degree to which the coastal population is informed and mobilized with respect to coastal risk, as a prerequisite to collective and cooperative action
- Communication infrastructure—the presence of means to communicate with the public, essential for all contingency plans as well as for education, information and awareness raising campaigns

The variety of aspects necessary to build adaptation capacity is indicative of the complexity of the adaptation process in practice. The intuitive perception that "rich" developed countries will have a high adaptation capacity is often disproved in practice, sometimes in spectacular fashion like in the events around the landfall of Katrina in New Orleans. Each coastal zone has its strengths and weaknesses with respect to the different capitals or resources constituting the adaptation capacity.

The increasing perception of adaptation of a dynamic time-dependent process (De Vries 2011; Bankoff et al. 2011) over time converged with the concept of resilience, borrowed from nonlinear dynamics and denotes the ability of a system to regain a stationary state following a perturbation. It is applied in mechanics, economy, computer science, ecology (Gunderson 1999; Holling 1986; Lovelock 1979) or in psychology (Cyrulnik and Seron 2004) and extended from there to communities, especially in the context of disaster response (Norris et al. 2008) and environmental changes (Adger 2000). In the case of the resilience of communities to climate and environmental changes, the system considered is a socio-ecological system, which couples human and biophysical subsystems (Berkes and Folke 1998; Gallopin 2006; Turner et al. 2003). The notion of socio-ecological system and hence of resilience incorporates aspects of environmental dynamics, natural resource use or self-regulation. It has become a popular approach with international agencies and funding bodies (e.g. CRDI and DFID 2012; Duarte et al. 2006; NRC 2006; UNISDR 2005). The notion of resilience goes further than that of adaptation to climate change, since resilience communities will be able to face diverse environmental, and even non-environmental challenges. In its ability to prepare communities for various challenges, the resilience approach is at the same time ideally suited to the complexity and uncertainty inherent to climate change, which explains why it has been readily adopted by the climate change adaptation community.

Within the conceptual framework of resilience, the notion of bifurcations and critical perturbations, also called tipping points, which denote the point from which on the system is not able to return to its previous state, i.e. where resilience breaks down. The notion of «tipping points» has been applied to the Earth-climate system by Lenton et al. (2008). In a dynamic system, not only the amplitude and duration but also the timing of perturbations is important to assess their criticality. In the context of climate change, gradually shifting baselines, such as increasing ocean temperatures and acidity or accelerating coastal erosion lower the threshold for critical perturbation over time. In the case of extreme weather events, the frequency of events is important to consider, in addition to their amplitude.

At a theoretical level, there have been some attempts to bring together the three concepts of vulnerability, adaptation and resilience. Gallopin (2006) established a correspondence that gives most weight to vulnerability and least to resilience, the latter being a subset of both vulnerability and adaptive capacity. Eakin et al. (2009) distinguish the adaptation, vulnerability and resilience approaches according to 5 qualitative criteria (Table 3.1). These observations summarize the way in which the three approaches are interpreted by decision-makers and stakeholders when developing climate policies.

3.1.2 Mainstreaming

Given the strong link between vulnerability to climate change and the socio-economic, demographic, political, legal and other characteristics of the impacted zones, there is a strong call towards integrating adaptation issues in sectorial policies and development planning rather than formulated isolated adaptation

Table 3.1 Implicit choices made during the development of climate policies according to adaptation, vulnerability and resilience approaches

Process criteria	Adaptation approach	Vulnerability approach	Resilience approach
Spatial scale of implementation	Sector focus	Places, communities, groups	Large-scale coupled socio-ecological systems, for example, populated watersheds
Temporal emphasis of implementation	Short-term and medium-term future risks	Past and present vulnerabilities	Long-term future
Actors	Public-private partnerships	Public sector, vulnerable groups	Civil society, public sector
Policy goal	Address known and evolving risks	Protect populations most likely to experience harm	Enhance capacity for recovery and renewal
Desired outcome	Maximum loss reduction at lowest cost	Minimize social inequity and maximize capacities of disadvantaged groups	Minimize probability of rapid, undesirable and irreversible change

Source Eakin et al. (2009)

policies. Climate «mainstreaming» aims at developing integrated strategies and catalyzing institutional changes that will favour adaptation (Dalal-Clayton and Bass 2009). In its most general formulation, mainstreaming is the integration of climate change in development planning (UNEP/UNDP 2011). In practice, mainstreaming is met with institutional resistances, since integration and cross-sectorial action is contrary to usual practices, geared towards strict delimitation of responsibilities and competences between government sectors (Huq et al. 2003).

3.1.3 How to Measure Vulnerability, Adaptation and Resilience?

Vulnerability assessments have evolved over time. Initially, they were geared mainly towards measuring the physical and economic vulnerability towards climate change impacts (e.g. IPCC 1994). Over time, they incorporated social aspects, non-climatic determinants of vulnerability and adaptation capacity (e.g. Füssel and Klein 2006; Schröter et al. 2005; IPCC 1997). The notion of socio-environmental system is also being included into vulnerability assessments (e.g. Eakin and Luers 2006; Schwarz et al. 2011). Specific vulnerability assessments for coastal zones, including sea level rise, have been developed for some time by IPCC and others (e.g. Dolan and Walker 2003; Klein and Nicholls 1999; Nicholls et al. 2007).

The success of adaptation projects can be measured by quantitative indicators in several ways. A simple way to measure the success of a project is to monitor its progress, for example the timely and technically correct erection of a dam or floodgate. This does not however say anything about the usefulness of the project in question, which can be different from what was anticipated. Therefore, the World Bank distinguishes between *process indicators* and *impact indicators* (World Bank, n.d.). In the case of risk disaster projects, the number of victims and homeless or the value of material damage for comparable events before and after adaptation can be used as an impact indicator. Thus, the drastic decrease of victims of cyclones in Bangladesh since the 1970s—500,000 for cyclone Bhola in 1970, 10,000 for the cyclone Sidr in 2007—are an indicator of the spectacular success of adaptation strategies based on cyclone shelters and early warning systems adapted to the local context (Germanwatch 2004; IRIN 2007).

However, such indicators cannot always grasp the range of changes induced by adaptation strategies in communities and sectors of human activities. Some indicators also contain inherent pitfalls. Thus, the decrease in insured losses can in fact simply result from the fact that insurance companies refuse to insure properties in a certain areas rather than from a decreased vulnerability to extreme events (Pringle 2011). Therefore, international agencies in the field of adaptation and development have developed methodologies for monitoring and evaluation (M&E) allowing them to evaluate the success of adaptation processes and to include the learning process into the general adaptation process (Pringle 2011; Spearman and McGray 2011; UNFCCC 2010). One principle of M&E is to define a baseline scenario against which adaptation processes can be measured. In the context of climate change, the evolution of climate variables within the baseline scenario and its significance for future vulnerability with and without adaptation measures is a new challenge (Brooks et al. 2011). The long-timescales and the considerable uncertainty involved in climate change also pose a problem since few projects require a post-project evaluation, ideally years after completion of the project (UNFCCC 2010).

Resilience, being at the same time a relatively new concept in the field of climate change and a broad and general concept, is difficult to capture in specific metrics. Some groups like the Food Security Network, the Institute of Development Studies (Béné 2013) and others are developing a framework to assess resilience. In line with the dynamic nature of the concept of resilience, some institutions use conceptual modelling of the socio-ecological system to assess resilience (Resilience Alliance 2010).

3.1.4 Adaptation and Development

In many respects, adaptation, resilience building and development present synergies, in that the objectives of development policies generally contribute to higher social, economic and material resilience, such as those of the millennium objectives (Paavola 2008; Lemos et al. 2013; Smit and Pilifosa 2001). Thus, building resilience becomes one of the attributes of sustainable development. Of course, in practice, coastal development is often not rigorously planned and even less frequently sustainable. Long-term planning and the adoption of integrated coastal zone management will be necessary to address those questions in the future (Doiron and Weissenberger 2013).

At the international level, climate change adaptation is addressed through provisions in the United Nations Framework Convention on climate Change (UNFCCC) and the Kyoto Protocol, which also provide some of the financial assistance needed by developing countries to implement adaptation measures. Under the UNFCCC, every party has to submit national communications at intervals that differ between developing and developed countries and contain an evaluation of the climate vulnerability and of adaptation strategies. For non-annex I countries, this document is a prerequisite in order to receive funding from the Special climate change fund, established in 2000 under the UNFCCC. Developing countries must also submit a national action plan for adaptation (NAPA) since the COP-7 of Marrakesh in 2001 in order to access the Least Developed Countries Fund, established in 2001 under the UNFCCC. Further financing is provided by the Adaptation Fund, established in 2001 under the Kyoto protocol and which derives part of its funding from a 2 % levy on Clean Development Mechanism carbon credits, from the Pilot Program on Climate Resilience under the Climate Investment Fund and in the future from the Green Climate fund, first agreed on at the COP-15 in Copenhagen in 2009 and which should hold 100 billion dollars by 2020.

3.1.5 Gender Specific Vulnerability

It is generally recognized that women are particularly vulnerable to climate change and other environmental changes due to their specific role in society, to their socio-economic vulnerability and their limited mobility and access to resources (Dankelman 2008; Nellemann et al. 2011; WEDO and UNIFEM 2010). This is not only the case in developing countries, but also in developed countries like Canada. In New Brunswick, for example, women working in the fishing product transformation sector are strongly vulnerable to the impacts of climate change or vulnerability on the marine resources (Forgues and Séguin 2011). Women are also more affected by the repercussions of climate change on their physical and psychological health and on additional stress occasioned to mothers (Eyzaguirre 2009).

3.2 Adaptation Techniques and Strategies

There are numerous adaptation strategies and tools that have been used in different settings. Adaptation strategies are usually divided in three options: protection, accommodation and retreat (IPCC 1990), to which precaution can be added as a distinct option (Arlington Group et al. 2013). Adaptation tools that are needed to implement those strategies can be divided in several categories: engineering, technological, legislative, management, economic and financial, scientific, communication, decision support, etc. It is important to realize that the choice of a particular adaptation tool does not constitute a strategy in itself, but usually implies one. Thus, building riff-raff seawalls in front of properties implies that protection has been chosen as a strategy and that retreat is being ruled out, at least for the moment. Of course, strategies are not necessarily mutually exclusive. Protections, changes in land-use and retreat of some activities or population can be combined within a larger strategy of sea-level rise and climate change adaptation. Time scales are very important when considering adaptation strategies. The progressive evolution of environmental and climatic conditions, of coastal erosion, and the ongoing coastal development have to be considered so that solutions that appear suitable in the short term might not be as desirable in the long term. Tools linked to the acquisition of information and a better understanding on the natural and human coastal dynamics and tools linked to decision-making and public debate should be employed before a strategy is adopted. In most situations, decision-making and the use of adaptation tool happens in real-time, and coordination and following a rigorous protocol is often difficult.

3.2.1 Adaptation Strategies

- **Protection** aims at protecting residents and infrastructure from flooding through protection infrastructure such as seawalls, floodgates, riff-raff, dykes or natural protections. This is generally the first reflex of residents confronted with coastal inundation problems. In the long term, protection is costly and often of limited use and has environmental and visual impacts.

> The Netherlands is the best example for protection against floods and sea level rise, which is understandable considering its situation. Not only is it the most densely populated country in Europe with over 400 inh./km^2, but also a part of the national territory, the "polders", is situated below sea level. The imposing dams of the Zuiderzee and Deltawerken (Fig. 3.1) protect the country against floods up to a return time of 10,000 years for the central zones comporting the capital Den Haag and the cities of Amsterdam with Europe's fourth largest airport and Rotterdam with Europe's largest port. Similarly spectacular protection infrastructure was erected to protect London (the Thames Barrier), Venice (the MOSE project) or Tokyo (the G-Cans project). The cost of these projects run into billions of dollars.

Fig. 3.1 *Top* The Oosterschelde in the Deltawerken, *bottom* the Maeslantkering before the port of Rotterdam. *Source* (*top*) Vladimír Šiman, 2008 in Wikipedia, (*bottom*) World66, 2011 in Wikipedia

- **Accommodation** is a flexible mode of adaptation. It encompasses all the changes in building standards, land-use and human activities that allows humans to cope with climate change and sea level rise while staying in the same place. Accommodation often emerges from local bottom-up adaptation processes. Some countries have however implemented planned accommodation strategies.

Bangladesh has specialized in accommodation adaptation and has developed strategies in several sectors such as land use, agricultural practices, afforestation, alert systems and civilian protection that have gained international recognition (Saleemul Huq, in Heffernan 2012). Elevated concrete shelters have saved thousands of lives and serve as schools or communal buildings the rest of the time (Fig. 3.2). Alert systems involve tens of thousands of volunteers with equipment as simple as megaphones. The preparation of the population is done by environmental education in schools or through theater plays (IRIN 2007). In frequently inundated areas, rice growing has given way to shrimp farming or salt tolerant crops (Ali 2005). Hydroponic cultures on floating beds or aquaculture in floating cages are examples of adaptation based on traditional techniques (Hossain and Hossain 2009).

- **Retreat** is usually the last resort when protection is too expensive and accommodation unfeasible. Cases in which retreat is being implemented are low-lying coastal zones, small islands, areas with rapid erosion and particularly flood-prone sectors. Since retreat is synonymous with a loss in property and

Fig. 3.2 A cyclone shelter in Bangladesh. *Source* Nadim Roni, 2012, in Wikipedia

infrastructure values, the question of the allocation of losses arises. They can be borne by individuals or by the collectively via insurances or via government sponsored buy-out programs.

A prime example for forced retreat are small low-lying islands like Tuvalu, a small archipelago with nine inhabited islands, a population of 11,000 and an average elevation of 1.5 m with its highest point at 4 m above sea level. The islands will be uninhabitable long before sea level rise effectively submerges it due to an increasing frequency of storm surges causing floods, accelerated erosion, an intrusion of salt water in aquifers that threaten agriculture and water supply (NAPA Tuvalu 2007). In the long term, retreat to another territory will be the only option for Tuvaluans and is already inscribed in the national adaptation plan, as it is for over a dozen developing nations (López-Carr and Marter-Kenyon 2015; NAPA Tuvalu 2007). Another example for retreat is the Alaskan village of Shishmaref, which was entirely disassembled and moved further landward as it was literally falling in the sea because of rapid coastal erosion. Another Alaskan village, Kivalina, was still waiting for relocation 15 years after it decided on it as the best option, because of lack of financial and institutional support (López-Carr and Marter-Kenyon 2015). Coastal retreat poses the question of "climate refugees". Small developing insular states have a population of 50 million (UNFCCC 2005) and the total number of refugees could reach several 100 million over the course of the 21st century for the highest emission scenarios (Nicholls et al. 2007). The status of climate, or in a more general sense environmental refugees, is legally not defined and distinct from that of political or war refugees (IOM 2007). It also raises the question of "losses and damages" incurred by developing nations with low greenhouse gas emissions, but who suffer a disproportionate part of the consequences of climate change, which is regularly the object of negotiations at climate conferences and has lead to lawsuits by insular states against large national and corporate greenhouse gas emitters (Jacobs 2005; Morris 2010).

- **Precaution** means to take the climate risks into consideration when planning coastal development. This entails to identify risks and plan development such as not to put residents, buildings and infrastructure at risk of flooding or erosion. Technological progress makes it easier to map those risks. At the same time, technological progress has made protection structures more efficient and has catalyzed development in areas considered at risk. Demographic pressure and an increased desirability of coastal properties for residences or touristic development have contributed to risky development in the 20th century until now.

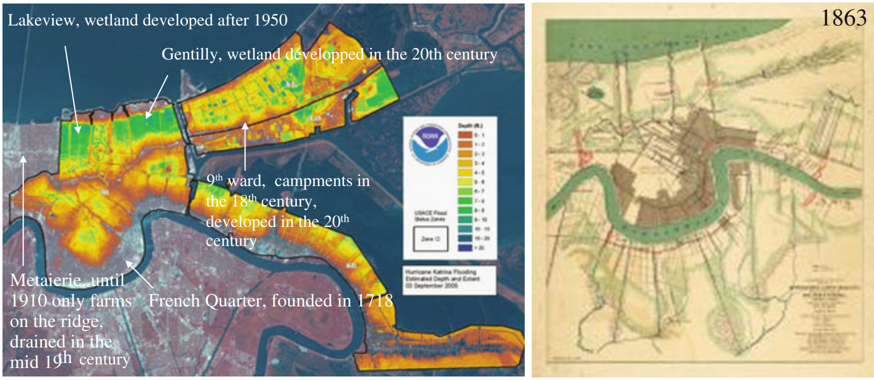

Fig. 3.3 *Left* Inundation map of New Orleans during hurricane Katrina in 2005, *right* map of New Orleans in 1863. *Source* (*left*) adapted from NOAA, (*right*) historical map

New Orleans shows in striking fashion how the precautionary principle has been abandoned in the course of the 20th century. Most areas heavily flooded during hurricane Katrina were developed during the 20th century on low-lying drained swamps and wetlands (Fig. 3.3). On the opposite, urban territory that was already developed in the 19th century is mainly located on higher ground and was not or marginally affected by the hurricane. New Orleans is not an isolated example, development in low-lying floodland is being undertaken in many of the world's cities, like in the Plaine du Cul de Sac adjacent to Port-au-Prince in Haiti or on the Cap-Vert peninsula harbouring Senegal's capital Dakar. In Dakar, due to the prolonged Sahel drought, floods have been rare in the last decades and newly arrived population is unaware of the risk (Noblet 2013). In the case of Port-au-Prince, the flood risk has been well mapped, including LiDAR models and quarters like Cité Soleil are regularly inundated. But rapid demographic and urban growth, difficult economic circumstances and a limited control of urban development by government agencies make informed risk planning difficult.

3.2.2 Adaptation Tools

Adaptation tools are designed to support the adaptation strategies enumerated in Sect. 3.2.1. They fall into several categories like protection structures, natural protections, drainage systems, building methods, emergency plans, planning tools, legislative and management tools, insurances, public participation and education, or integrated management. It is not possible to cover all existing tools here; this section should therefore be seen as a showcase rather than an inventory.

Protection Structures

The erection of protection structures is probably the first reflex most people or communities will have when faced with inundation problems. There are various kinds of structures and various types of build, ranging from haphazard structures made of detrital building material to carefully engineered multi-layered structures. Coastal protections have been used extensively in Europe since the Middle Ages. Techniques and building materials have considerably evolved over time, from wood to earth, rubble, concrete or steel. Several types of protection structures are distinguished:

- **Seawalls** are more or less vertical structures protecting from inundations and erosion. They can be made from stone, cement, concrete, wood or other materials. The cost of a seawall reaches from 150 to 4000 dollars per meter (Eastern Research Group 2013). One of the problems of seawalls is flanking erosion affecting neighbouring unprotected segments, often forcing neighbours to install seawalls in turn. Over time, this leads to an entirely artificialized littoral (Fig. 3.4). Another major impact is the increased erosion of beaches in front of seawalls, leading to a rapid disappearance of beaches with all their habitats and ecological functions. Seawalls offer only limited protection (Fig. 3.5) while coming at a considerable cost for property owners.

Fig. 3.4 Artificialized coastal zone in Beaubassin, New Brunswick, Canada. *Source* S. Weissenberger, 2012

Fig. 3.5 Seawall failures: **a** overswept riff-raff seawall, **b** damaged brick seawall, **c** overtopped concrete seawall, **d** inefficient mixed material seawall in New Brunswick, Canada. *Source* (*top*) S. Doiron, 2010, (*bottom*) D. Bérubé, na

- **Dykes** are built parallel to the coastline, or to the flow of rivers in order to protect the hinterland from floods during high tides. They are inclined to better absorb wave energy. Their structure is usually multi-layered, with a solid kernel made of earth, concrete, metal or rubble and an outer layer made of wave resistant material such as stone, concrete often overlaid with grass, which is sometimes maintained by sheep rather than heavy equipment. Breakwaters are sometimes placed in front of dykes to attenuate wave impact. The cost of dykes ranges from 100 to 1500 dollar per metre, depending on height and quality (Eastern Research Group 2013). Some regions are particularly renowned for the quality of their dykes, for example the Netherlands or in earlier times French Acadia (Fig. 3.6).
- **Dams**, contrary to dykes, are built perpendicularly to a stream and are devised to dam or control the flood of that stream, permanently for fixed dams and periodically for movable dams. In a coastal environment, movable dams are used at the mouth of large rivers to prevent the invasion of hinterland by storm surges that propagate upstream rivers. Some examples include the Maeslantkering and the Oosterscheldekering in the Netherlands or the Thames barrier in southern England (Fig. 3.7). The cost of such structures is prohibitive, 0.5–3.5 million of dollar per meter (Linham et Nicholls 2010), except when large cities like

Fig. 3.6 Acadian sea dykes (*left*) and river dykes (*right*) near Advocat, Nova Scotia, Canada. *Source* S. Weissenberger, 2012

Fig. 3.7 The Thames Barrier protects the city of London from inundations. *Source* Andy Roberts, 2004, in Wikipedia

London, Rotterdam, Venice or Saint Petersburg have to be protected. If the structure is not adequately dimensioned for future sea level rise, the risk of ending up with an ineffective dam and considerable stranded costs.

- **Breakwaters** are wooden, stone or concrete structures destined to shield a particular zone, such as a dam, a harbour or residential areas, from direct wave

Fig. 3.8 Stone jetty protecting the harbour of Stonehaven, New Brunswick, Canada. *Photo* S. Weissenberger, 2012

action. Their purpose is therefore not to be impermeable or high enough to resist floods. Therefore, they are also much cheaper than dykes. Most harbours are protected by jetties, which allow for still waters inside the harbour even during storms (Fig. 3.8).

- **Groynes** are stone, wood or concrete structures placed perpendicularly to the shoreline in order to reduce sand and sediment transport due to littoral drift (Fig. 3.9). Their purpose is to stabilise coast segments that are retreating. Groynes are an alternative to beach nourishment.

Drainage Systems

Drainage pipes, canals, sewers and culverts are an essential part of flood protection, in a coastal or riverine environment. Overflowing sewers can lead to inundations, and can also damage water treatment plants and lead to drinking water contamination. Impermeabilization of urban environments can also reduce the risk of flooding. Some areas in New-Brunswick have received increasing amounts of precipitation over the last 100 years (Arp et al. 2013) and under current climate

Fig. 3.9 Two different types of groynes, **a** stone groyne in Capbreton, Landes, France, **b** wooden pales in Markgrafenheide, Baltic Sea, Germany. *Source* **a** Tangopaso, 2009, in Wikipedia, **b** NiTen, 2006, in Wikipedia

scenarios, precipitations are projected to further increase, thus increasing the frequency and magnitude of floods (Swansburg et al. 2004; Turkkan et al. 2011). Bringing the province's hydrological infrastructure and notably the 221,528 culverts up to the standards necessary for future climate conditions can be extremely costly (Arp et al. 2013).

Natural Protections

Coastal formations and ecosystems can effectively protect coasts from storm surges, winds and inundations. Coastal development and natural resource exploitation has degraded many natural ecosystems. The role of natural formations as flood protection is increasingly recognized and protection, regeneration and replantation are often part of coastal protection plans. The costs involved are usually much lower than those for artificial structures and the environmental and visual impacts are positive, in contrast to those of artificial protections. The proper use of natural protection requires a good knowledge of local ecosystems and coastal dynamics. As an example to the contrary, in Andhra Pradesh, India, a non-native tree species, Casuarina, was planted as an inundation protection. However, the trees proved inefficient as a flood barrier and in addition, invaded local mangroves thus harming biodiversity (Feagin et al. 2009).

- ***Coastal wetlands*** are highly productive and biodiverse environments, which filter sediments and protect coasts (Fig. 3.10). Erosion rates of wetlands are equivalent to those of rock cliffs. According to Costanza et al. (2008), in Louisiana, the loss of one hectare of wetlands increases the cost of a hurricane by 33,000 dollar and the total value wetlands in the USA is 23.2 billion dollar

Fig. 3.10 Coastal wetland in Aspy Bay, Nova Scotia, Canada. *Source* S. Weissenberger, 2013

per year. Coastal wetlands are able to adapt to moderate rates of sea level rise by migrating landwards. Coastal development and coastal squeeze can limit this adaptation faculty. New Brunswick's coastal zone policy from 2002 recommends a buffer zone of 30 m around wetlands in order to maintain their ecological integrity (Carron Erosion Study Team 2009).

- ***Artificial reefs***, and specially oyster reefs from Pacific oysters (*Crassostrea gigas*), are used in the Netherlands and in the USA as breakwaves and erosion protection (De Vriend and Van Koningsveld 2012). Oyster reefs can decrease wave height by 50–90 % and wave energy by 70–99 % (Kroeger et al. 2012). Although their construction is costly, those structures can last for more than 50 years.
- ***Dunes*** offer good protection against floods, storm surges and wind. Dunes, like spits, are dynamic features of the coast and evolve or migrate with time. Dunes are vulnerable to coastal erosion and to anthropogenic pressures. Several methods for dune protection are used in New Brunswick and elsewhere, including planting vegetation, protection, regeneration, awareness raising and the construction of footpaths (GBV Cap-Pelé, n.d.). Plants such as ammmophila form deep root systems that help stabilizing the dune (Fig. 3.11a). Vegetation planting is an affordable method of dune protection, usually possible at less than half a dollar per square meter (Eastern Research Group 2013). Sand barriers (Fig. 3.11b) protect the dune from wind and wave erosion. Regeneration assisted by vegetation barriers (Fig. 3.11c) can prevent loss of sand. The usefulness of buried Christmas trees has however been put in question since they are easily washed away during storms (O'Connell 2008). As trampling and the use of motor vehicles are the main source of dune degradation, awareness raising with residents and tourists is important and should ideally be supported

Fig. 3.11 **a** Plantation of ammophila near Cap-Pelé, **b** dune barrier, **c** vegetation barrier made of discarded Christmas trees, **d** sign for visitors, Aboiteau Park, Cap Pelé, New Brunswick, Canada. *Source* **a**, **c**, **d** GBV Cap-Pelé, n.d., **b** Université de Moncton in Carron Erosion Study Team (2009)

by corresponding municipal or other legislation (Fig. 3.11d). Footpaths and lookouts can further reduce visitor impact.

- ***Beach nourishment*** is an expensive option to protect receding beaches, since the costs are 300–1000 dollars per metre (Eastern Research Group 2013). Therefore, it is usually only used for beaches presenting a particular interest, like Parlee Beach in Shediac, New Brunswick, which receives almost half a million visitors per year (Fig. 3.12). Sand can be transported by truck, like at Parlee Beach, or by barge. In the Netherlands, new techniques relying on massive punctual nourishment favouring a natural dispersion of the sand are explored, like the Delfland Sand Engine, where more than 20 million cubic metres of sand were discharged up to seven meters high (De Vriend and Van Koningsveld 2012). Restoration of sand spits is also possible, but more challenging and expensive. The restoration of the Grande Terre Island in Louisiana cost 31 million dollar (Schleifstein 2012).

Fig. 3.12 Coastal erosion over a single year in Parlee Beach, New-Brunswick, Canada. *Source* S. Weissenberger, 2012

Residential Building Methods

As the risk of an inundation cannot be reduced to zero, construction methods in potentially flood zones have to be adapted to occasional inundations. This can be achieved through an elevation of the building or terrain (Figs. 3.13 and 3.14) and through appropriate house design. Building standards are important to enforce such types of constructions, but are often lacking. The oldest building principle in flood zone is to elevate the buildings by placing them on natural or artificial mounds, as has been done in northern Europe for centuries or by building them on poles or stilts, a technique known since the stone age on several continents.

An alternative to expensive earthwork or raising a house on stilts is to use the natural elevation of the terrain and plan the layout of the house so that the living space of the house is above a certain fixed height, and only non-living spaces like cellar or garage are below this limit (Fig. 3.15), generally prescribed by the local building code in relation to maximum expected storm surges.

Additional floodproofing of houses aims at reducing the flooded area in a high water event and minimizing the consequences of a flooding (Environment Canada 2013; FEMA 2011). Waterproofing can be achieved through dryproofing via impermeable insulation materials, for example polyurethane instead of mineral fibres, water resistant doors or windows in lower floors or impermeable membranes,

Fig. 3.13 House built on an artificial mound in the county of Westmorland, New Brunswick, Canada, surrounded by water during the flood of December 2010. *Source* S. Doiron, 2010

or one-way sewer valves to prevent an overflow of sanitary installations. Wet floodproofing consists in allowing the structure to be flooded in order to balance the forces of floodwater and prevent structural damage. Fire and electrocution risks can be minimized by positioning boilers and electrical installations on higher floors rather than in the basement, as is traditionally often the case.

Novel approaches in coastal architecture include floating houses, which are being developed in the Netherlands, in Germany or in North America.[1] The foundation is replaced by a floating caisson, often extruded polystyrene (PSE) encased in reinforced concrete and the house is held in place by anchors or by metal rods along which it can slide, thus allowing the floating houses to follow tide movements.

[1]For an example of a floating house, see the «Shew» floating house in Vancouver, British Columbia, Canada, by International Marine Floatation, http://www.floatingstructures.com/gallery/floating-homes/shew-/.

Fig. 3.14 House built on stilts in the county of Westmorland, New Brunswick, Canada. *Source* S. Weissenberger, 2012

Emergency Plans

Just as appropriate house architecture is part of the individual's preparedness to extreme climate events, the formulation of emergency planning is part of the public sector's preparedness. Emergency planning is primarily the responsibility of local governments: municipalities, service districts or their equivalent. In case of larger events, specialised national or regional agencies such as Emergency Measures Organization in New Brunswick, the Ministère de la Sécurité Publique and the Organisation de la Sécurité Civile du Québec in Quebec, the Ministry of Public safety and the Government Operations Centre in Canada, or the Federal Emergency Management Emergency planning is required from municipalities and regional authorities in most countries. In France, every commune and department has to have a *Plan de prévention du risque inundation* since 1987. In Canada, the Emergency Management Framework for Canada regulates the federal-provincial-municipal collaboration in case of emergencies. In New Brunswick, municipalities, rural communities and local service districts are required to produce an emergency plan and are supported by local service districts. In Quebec, municipalities also have to prepare an emergency plan that must amongst other identify necessary resources and partners to be involved. Emergency plans include many elements such as:

Fig. 3.15 House with living spaces above the maximum flood safety line in the county of Westmorland, New Brunswick, Canada. *Source* S. Weissenberger, 2012

- Alerts
- Evacuations
- Emergency medical assistance
- Protection of people and assets
- Water and food supply

An emergency plan usually unfolds in three stages (Haddow and Bullock 2005):

- ***Preparedness***: elaboration of an efficient system, acquisition of necessary equipment and goods, recruitment and training of staff and volunteers, public information, drills
- ***Response***: evacuations, erection of emergency dams, providing immediate assistance, etc., during the event
- ***Recovery***: reconstruction, cleaning-up, return or relocation of evacuated residents, financial or in nature emergency assistance (e.g. food, drinking water, blankets, clothes, medical supplies, seeds and agricultural supplies)

Emergency plans vary depending on the context. For example, while in Illinois, USA, flood and storm warnings are transmitted through cable TV and cell phone alerts, in Bangladesh, this is done mainly by loudspeakers, since only a small part of the population, especially in the flood-prone southern part of the country, is equipped with telephones or other communication means. At a large scale, emergency plans are difficult to put in practice. During hurricane Katrina, the evacuation of the population was made impossible in part because of the lack of means of transport, the city buses being flooded themselves and thus rendered useless. The unwillingness of the population to leave their homes also contributed to the problem and revealed a lack of information and trust in the authorities to safeguard their properties (justifiably so). In other cases, emergency measures have proved very efficient at large scale. During cyclone Phailin in India in October 2013, almost one million people were evacuated, contributing to an astonishingly low death toll of 17, out of 12 million inhabitants in the path of the storm, where cyclone Orissa in 1999 killed 10,000 people. Similar success has been achieved by Bangladesh with the help of mass evacuations, reducing the death toll from 500,000 for cyclone Bhola in 1970 to 150,000 for cyclone BOB 01 in 1991 to 10,000 for cyclone Sidr in 2007. Similarly, in Mozambique, the death toll of major floods could be reduced from 700 in 2000 to 29 in 2007 thanks to an alert system, which relies on a strong participation of volunteers to monitor water levels (Heffernan 2012). These examples also show that good planning and community involvement are sometimes more important than technological and financial resources.

Planning Tools

Planning tools help developers of legislations and emergency plans. They consist in technical and organisational information and advice. In particular, geographical information tools are used to denote flood zones and land uses. New advances in remote sensing, modeling and data treatment offer new geospatial tools to development planners allowing them to assess risks and characterize the territory. For example, the analysis of areal photographs of different periods allows a precise assessment of erosion or accretion rates for surveyed sectors of a coastal zone. Georeferenced cameras and sensors on the ground can provide high-resolution data in real time. A particularly powerful tool for planners in the context of sea level rise and flooding risks is high precision digital elevation mapping (DEM), which can be constructed based on Light Detection and Ranging (LiDAR) surveys. The costs of this technique have significantly diminished over the last years making it accessible for many locations. Combined with climatic modelling, it can be used to map current and future flood risks with considerable precision (Gesch 2009; Sahin and Mohamed 2014). This technique has been used on several sectors of the eastern coast of New Brunswick through projects financed by Environment Canada, Atlantic Climate Adaptation Solutions and the Natural Resources Canada's Regional Adaptation Collaborative Program (Environment Canada 2006; SACCA 2012), in Nova Scotia's Annapolis Valley (Webster 2005), in Spain (Raji et al. 2011), in England (Thumerer et al. 2000), on large parts of the US coast through the NOAA costal Lidar project (NOAA, n.d.) and several other countries. Incorporating sea level scenarii and past meteorological date allows mapping projected flood return periods as a function of climate change (Fig. 3.16).

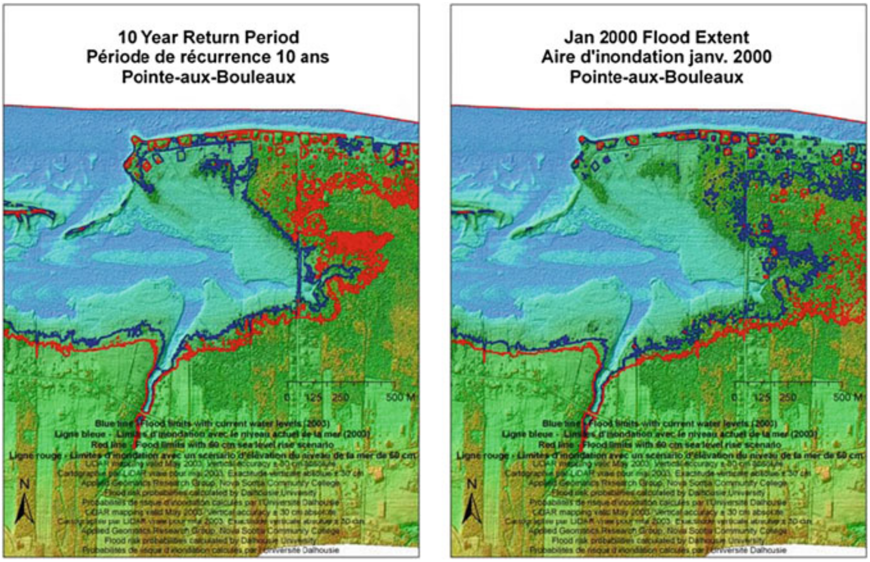

Fig. 3.16 Flood maps for a storm surge with a return period of 10 years (*left*) and storm surge of January 2000 (*right*) with and without sea level rise for the municipality of Pointe-du-Chêne, New Brunswick, Canada. *Source* Bernier et al. (2006)

LiDAR data can further be used to generate 3-D models like the COastal Adaptation to Sea level rise Tool (COAST) developed in New England, which makes it possible to assess physical damages and coasts caused by storm surges (Eastern Research Group 2013). This type of data can be combined with classical economic risk assessments (DeBaie et al. 2006; Rioux 2008) and all kinds of georeferenced ecological, geological or architectural data in order to assist the planning process.

Legislative and Management Tools

Legislation concerning coastal zones is often complex since it invokes several government levels from local to national and several ministries. A number of countries, for example Canada, France or India have voted coastal protection laws imposing a setback from the shoreline for new constructions. Future sea level rise is generally not included in this type of legislation. A fixed setback does also not take into consideration the elevation of terrain, the specific flood risk or coastal erosion rates.

Current scientific knowledge and modern geospatial modelling tools could in principle allow planners to manage coastal land uses more efficiently and establish zoning on the basis of scientifically well-founded risk assessment. However, management tools—laws, bylaws and policies—often remain a limiting factor. Conflicts of interest and political considerations can block new initiatives. For example, under the pressure of the real estate lobby, North Carolina passed a law (House Bill 819) prohibiting state agencies to use new data on sea level rise in their planning process. Real estate developers would stand to loose several development projects if the US Geological Survey's figure of 99 cm of sea level rise for this century was to be adopted for coastal planning (Harish 2012). There are however also examples to the contrary. In 2011, the rural community of Beaubassin-Ouest passed a bylaw including a limit for the living spaces of houses of 4.30 m, 1.40 m above the maximum high tide line plus the 2 m buffer, in order to allow for future sea level rise, the figure of 1.40 m being derived from semi-empirical modelling studies by Rahmstorf (Doiron 2012). Such pilot initiatives implemented at a local scale and their replication (the so-called "ripple effect") can be an effective strategy to induce changes that are difficult to provoke directly at a larger scale (Béhar 1997; Billé 2009).

Below some examples of provincial or national legislations concerning coastal development and the management of climate-related risks:

- **New Brunswick** published its coastal policy in 2002, which partitions the coastal zone in three zones with specific building restrictions: a zone A between the high and low tide marks in which only erosion protection and access structures can be erected, a zone B with a 30 m setback where only family homes and the extension by at most 40 % of existing buildings is allowed and a transition zone C where all buildings are allowed provided they are not vulnerable to storm surges and do not negatively impact the coastal environment (NB 2002). As of 2013 the policy had not yet force of law.
- In **Quebec**, the management of the development of the coastal zones is mainly the responsibility of municipalities. The province has written a *Policy on the protection of shores, the littoral and floodplains*. According to this policy, all construction is prohibited below the high tide line. Construction in floodplains is not forbidden, but subject to certain rules, for example that no living space, door or window may be located below the level of a 100 year flood (Québec 2013).
- **Prince Edward Island** has adopted legislation on coastal retreat based on historical and actual erosion rates, extrapolated from areal photography from 1968, 2000 and 2010 combined with field observations. Wetlands and streams located near a cliff must be protected by a buffer zone of 15 m or 60 times the erosion rate of the sector, whichever is larger (Arlington Group et al. 2013).
- Under **British Columbia's** Local Government Act, municipal plans must include maps specifying land use restrictions due to natural hazards such as inundation or erosion. Regional districts can establish development plans over a period of 20 years, which include provisions to minimise natural hazards. New constructions in British Columbia must resist to a flood with a return time of 200 years (Arlington Group et al. 2013).
- In **France**, the *Loi littoral* (littoral law) from 1986 imposes a setback of 100 m for all buildings, except in urban areas. In order to guarantee a better protection of the coastal area from urban development and artificialisation, the Conservatoire de l'espace littoral et des rivages lacustres, a government agency,

has bought 1500 km of coastline, about a third of France's entire coastline. New guidelines on coastal development will be developed over the period 2015–2020 through the "Grenelle de la mer", a multistakeholder consultative process piloted by the environment ministry.

- **India** has set very restrictive building limits. According to the Coastal Regulation Zone Regulation under the EPAct of 1986, amended in 2011, the setback is 200 m on the waterfront and 100 m in all zones influenced by tides. Within this zone, no new construction is permitted except harbour infrastructure and traditional fishermen dwellings in the zone between 100 and 200 m (MoE 2011).

Insurances and Cost Allocation

The question of cost sharing for coastal risks in the context of climate change and increasing sea levels is complex and important. Insurances have an important role to play as one of the main agents of financial decision-making. They have the potential to act as catalysts for adaptation if they realistically reflect current and future coastal risks. In several regions, premiums have already increased. In the Greater London Area, insurances in flood-risk zones have increased by over 30 % over recent years, which affects over two million homeowners (Herbert 2003; Hussain 2008). In the USA, coastal insurance premiums have increased by 40 % following hurricane Katrina (Stiles and Hulst 2013). Insurance companies already observe a clear signal for an influence of climate change since the costs of climate related risks have increased proportionally more than for non-climate related risks (Munich Re 2012, 2014; Swiss Re 2013) (Fig. 3.17). It is therefore not surprising that reinsurance

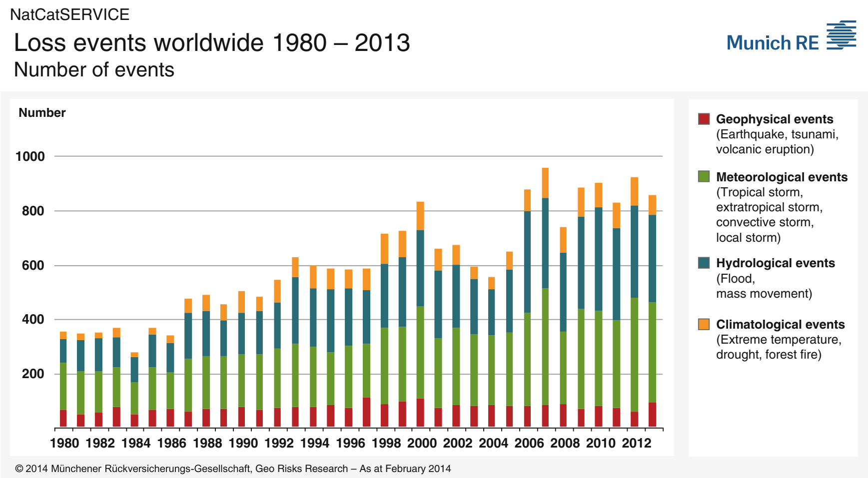

Fig. 3.17 Evolution of the number of natural disasters in the world from 1980 to 2011 by category. *Source* Munich Re (2014)

companies like the Munich Re, Allianz and others have been studying climate change since the early 1970s and lead active climate change research projects, including the reduction of coastal risks from hurricanes through storm resistant architecture (IIBHS, n.d.).

In many countries (United Kingdom, Japan, Spain, Portugal, Switzerland, Israel, etc.), flood insurance is de facto compulsory because it is included in home insurances, which are a requirement for mortgages. In other countries, it remains optional. In the USA, only half of all coastal properties were insured against flood risks in 2006 (Eastern Research Group 2013). Non-insured risks are taken over by public programs. Thus, States are responsible for 900 billion of dollars of exposed coastal property value (Stiles and Hulst 2013). Therefore, the USA created the National Flood Insurance Program administered by the Federal Emergency Management Agency (FEMA) in order to increase flood coverage by offering incentives and forcing state regulated lenders to require such insurances.

"Buy-out" is a financial mechanism available to public authorities in order to encourage retreat, when the climate risks become too important. The Quebec government used it following the important storm and flood of 2010 in order to incite coastal residents of the municipalities of Sainte-Flavie and Sainte-Luce on the Saint Lawrence estuary to relocate further from the coast. Participants meeting certain requirements were offered a compensation of 150,000 dollar for their home and property, the first being demolished and the second ceded for a symbolic dollar to the municipality. Half the targeted residents made use of the program managed by the ministry of Public Safety, with the unintended consequence that they moved to Rimouski, the nearest larger city instead of staying in the municipalities. In contrast, on Smith Island, and island in Cheasapeake Bay in the US State of Maryland, the buyout program offered by the State after hurricane Sandy was unanimously rejected by County commissioners.

Public Participation and Education and Integrated Management

An important aspect of every adaptation strategy is the acceptance and participation of the population and stakeholders. As the examples of India or Bangladesh show, well-planned emergency measures understood and supported by the population can be more effective than an emergency plan supported by up-to-date science, modeling and monitoring capacities and superior financial and infrastructure means, but lacking in some key elements of planning and in public involvement. Social cohesion is also important for other aspects of adaptation, such as the construction of seawalls, which change the hydrodynamics in adjacent sectors, thereby involving neighbours. Changes in zoning laws, land use restrictions, amendments of building codes, forced setbacks or retreat are all aspects of adaptation that lead to conflicts of interests and often passionate debates. It is therefore essential to inform population and stakeholders and involve them into the decision-making process. Such a co-construction of adaptation strategies follows the precepts of integrated coastal zone management (ICZM), which is defined as a rational decision-making process transcending traditional sectorial approaches and involving multiple stakeholders from public and private sectors in order to achieve a sustainable use of marine and coastal resources (Cicin-Sain and Knecht 1998; IOC 2005). ICZM is recommended as a guiding principle by international organisations such as the Intergovernmental Oceanographic Commission (IOC 2005), the United Nations Environmental Programme (UNEP 1995), the "Agenda 21" (Chap. 17), the European Union (EC 2010) and many countries including France (MEEDDM 2010), Germany (BMU, n.d.), the United States (NOAA 2011) or Canada (MPO 2010).

Stakeholder and public participation also allow the decision-making process to make use of local knowledge and observations, which often exceeds scientific observations in the duration and detail of observation. It has often been found that local observations are corroborated by scientific data where available (Howe et al. 2013; Stervinou et al. 2013) and thus provides valuable information. Public debate around adaptation strategies also often leads to changes in opinion and a shift in strategies. Prioritization and ranking exercises or MEAG can help stakeholders and decision-makers to identify options which were previously not favoured and develop locally adapted solutions which have a tendency to rely less strongly on artificial protection measures. Some examples will be discussed in more detail in Chap. 4. In such a context, scientific experts act more as facilitators than as consultants. Adaptation strategies emerging from such a collaborative process are more likely to be accepted and implemented by the population and stakeholders than strategies emerging from a top-down expert and administrator driven process.

3.3 Conclusion

Adaptation to climate change, especially in coastal zones is a complex undertaking that will accompany humanity for decades, if not centuries. It is a continuously evolving process that involves numerous actors. Adaptation will make trade-offs necessary and difficult questions on the sharing of costs and losses, which will be a test of social resilience of coastal communities.

Different strategies have been tested and shown their force and weaknesses. The imposing protection infrastructure put in place around the North Sea and other place has proved effective to this date. From their completion in the 1990s until 2012, the dams of the Delta system in the Netherlands were used only once, during storm "Tilo" in 2007. The Thames gate barrier and the associated dyke structure have so far prevented all human and material losses (Naughton and Pavia 2007). The level of protection of those dams is exemplary worldwide. The central part of the Netherlands is protected against a flood with a return time of 10,000 years, compared to 100–200 years for a city like New Orleans. Following hurricanes Katrina and Sandy, the USA are upgrading the defenses of New Orleans and New York. However, the price tag associated with such structures makes them inaccessible to many countries and very cost-inefficient for relatively sparsely populated coastlines like those of Canada. In the long run, when sea-level rise is taken into consideration, even the best existing structure will reveal their limitations. At the present time, the Thames barrier protects London from flood with a return time of 5000 years, but in 2030, the corresponding return time will only be 1000 years and by the end of the century, 50 years (London Assembly 2002). Therefore, the construction of a new, even larger barrier further downstream, at Lower reach or Tilbury, is already planned for the period after 2070 (TE2100 2012).

Given the inevitability of future sea-level rise, even the Netherlands do not adhere any more to a policy of 100 % protection. According to the coastal policy of 1998, buffer zones have been designated which will no longer be protected at all costs. Those zones will only be used for agricultural and pastoral use and residents have been relocated. These type of planned retreat and adapted land-use policies require a strong social cohesion, which must be rooted in a good understanding of the risk by local populations and in an involvement of stakeholders during all stages of the decision-making process. Countries like Bangladesh and India show that those goals are just as attainable in developing as in developed countries and that very successful accommodation and evacuation strategies can be put in place.

Ultimately, the adaptation to climate change poses the challenge of a sustainable coastal development. Unregulated development has the potential to "transform a natural risk into a human catastrophe" (Mancebo 2006). Future resilient coastal communities must be well planned, which can be best achieved through a participatory decision-making process and an integrated management approach. Questions of social justice must also be included in the planning process. The events surrounding hurricane Katrina revealed the social and economical determinants of the vulnerability to extreme weather events (Elliott and Pais 2006). Likewise, the ability to afford insurances or individual protection infrastructure cannot be the sole criteria regulating the access to the littoral zone.

Building resilient and well-adapted communities cannot be improvised, but requires a careful planning and consultation. It is a long process. For example, the Netherlands or Great-Britain started planning the Thames barrier and Deltawerken projects after the great North Sea flood of 1953, yet the projects only came to completion in the 1980s–1990s and adjustments still continue. Once the process of adaptation and resilience building is engaged, it becomes part of the general development of the coastal zone and thus an ongoing process.

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Chapter 4
Case Studies in Collaborative Action-Research Projects on Climate Adaptation in New Brunswick

Abstract This chapter will present some case studies of collaborative action research projects on adaptation to climate change, erosion and sea level rise in coastal communities in New Brunswick. Those communities are Bathurst/Bayshore, Shippagan, Le Goulet, Cocagne, Grand-Digue and Shediac. The projects mainly involved researchers from the university of Moncton, in collaboration with other establishments. Through the case studies presented here, it will be possible for the reader to get a better idea of how the adaptation process unfolds in the chosen approach of progresses through various stages of deliberation, risk evaluation, scientific analysis, public debate, prioritisation, legislation and implementation. It will be interesting to observe how this process differs from place to place and how often very different solutions emerge from the collective deliberation process as the ideal answer depending on the geographical, socio-economic, political or historical context.

Keywords New brunswick · Acadian coast · Community based adaptation · Case studies · Participative action-research

4.1 The Coasts of New Brunswick

4.1.1 Physical Description

New Brunswick is an essentially maritime province. It possesses 5500 km of coastline. It borders on the ocean on three sides, constituting three distinct coasts (Fig. 4.1):

1. The Acadian coast, in the east of the province, open to the Gulf of Saint Lawrence and the Northumberland strait
2. The Fundy Bay coast in the south, bordering on the Fundy Bay, part of the larger coast of Maine system
3. The Chaleur Bay and northern peninsula coast, facing the Gaspé peninsula

S. Weissenberger and O. Chouinard, *Adaptation to Climate Change and Sea Level Rise*, SpringerBriefs in Environmental Science,
DOI 10.1007/978-94-017-9888-4_4

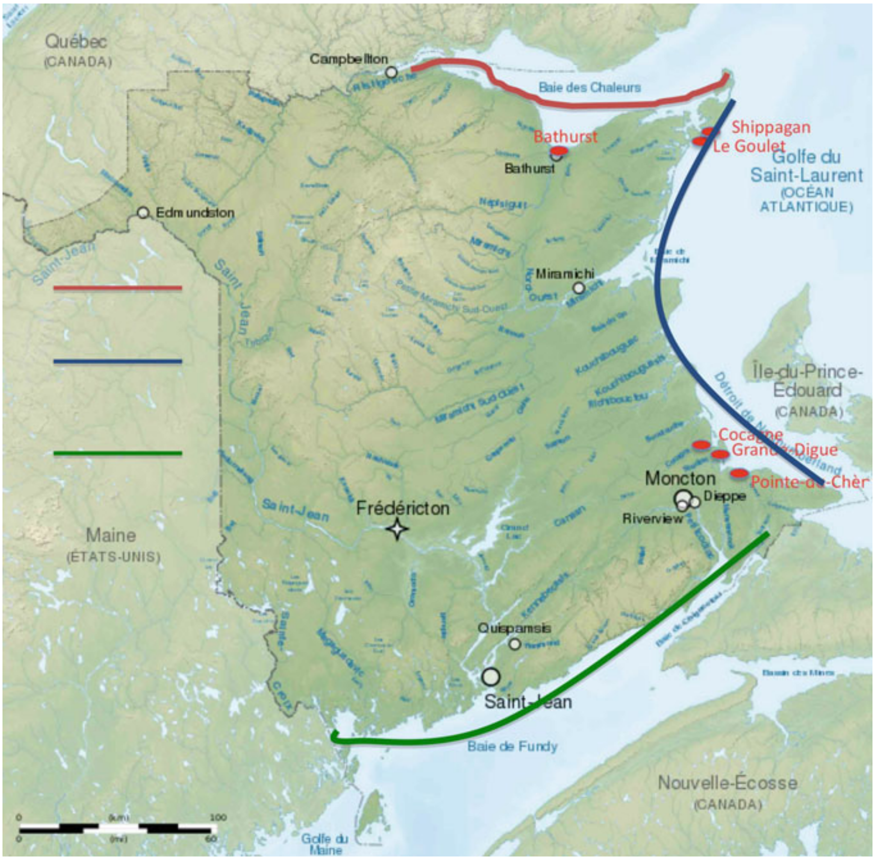

Fig. 4.1 The coasts of New Brunswick. *Source* DGT/Université de Moncton, 2012

The majority of the population lives along the coast, while the interior of the province is very sparsely populated. With the exception of the Edmunston—Grand Sault region and Fredericton, most urban centres are located on or near the coast, in the estuaries of the province's large rivers: Matapedia and Restigouche River (Campbellton), Tetagouche and Nepisguit rivers (Bathurst), Miramichi River (Miramichi), Petitcodiac River (Moncton), Saint John River (St. John).

4.1.2 Socio-economic Description

New Brunswick is the only officially bilingual province in Canada. This particularity is indicative of a long and varied immigration history. The first inhabitants of the province were the Mi'kmaq and Malecite First Nations. The French Acadians settled in New Brunswick, as well as in the neighbouring Nova Scotia and Prince-Edward Island from the 17th century on. The Acadian settlement on the island of Sainte-Croix was founded in 1604 and thereby the first permanent French settlement in North America, preceding the foundation of Quebec by four years. Scottish settlers were soon to follow in 1629 at Fort Charles, after James VI had granted the Acadian lands to the Scots (Lang and Landry 2001). The treaty of Saint-Germain in 1632 asserted French sovereignty over Acadian lands to France, allowing the establishment of a permanent colony. This colony was however permanently threatened by English raids and eventually fell to England in 1713 with the Treaty of Utrecht. The cultural and historical profile of the province changed dramatically following the "Grand Dérangement", i.e. the big disturbance, as the Acadians euphemistically call the large-scale deportation of the French Acadian population in 1755. Their place was taken by English, Irish, Scottish, Welsh, German and other immigrants, leading to the intricate mosaic of French, English and Mi'kmaq observed today.

Acadians as well as British immigrants lived in great part from fishing, until the stocks of cod and other groundfish collapsed towards the end of the 20th century. New Brunswick still counts 65 fishing harbours, the 4th highest total of Canadian provinces (dfo 2008). The French Acadians also practiced agriculture, especially in the fertile coastal plains, which they secured from the sea through the famous Acadian dykes, many of which subsist to this day (Fig. 4.2). Timber logging and shipbuilding became major activities in the 18th and 19th century, until coal engine powered steel hull boats displaced clippers, schooners and other wooden boats

Fig. 4.2 Acadian dyke building in the 18th century. *Source* Azor Vienneau, Musée de la Nouvelle-Écosse

towards the end of the 19th century. All these activities were oriented towards the coast and explain the settlement patterns observed today in New Brunswick.

New Brunswick's economic situation sharply declined towards the end of the 20th century. The collapse of ground fish stocks hurt the fishing industry while the forestry sector is comprised in a long-drawn crisis. The closing of the CN shops in Moncton and the decline of other industrial activities reduced the province's GDP and employment prospect, leading to a migration of many residents from economically depressed coastal zones like the Acadian peninsula or the north of the province towards the greater Moncton area, and more recently, in large number as temporary workers to Alberta's oil industry. The economy has shifted from a natural resource use dominated one to a service economy, which represents over 70 % of the province's GDPP (Statistique Canada 2011) and in which the tourism industry occupies an increasingly important position. Coastal areas are therefore more and more used for residence and tourism rather than for fishing, agriculture or forestry. Coastal fisheries still play an important role in the province, with 1000 lobster boats of less than 14 m, 80 crab boats from 18 to 20 m and 20 shrimp boats over 20 m as well as over 60 processing plants along the coast (Noblet and Chouinard 2014).

4.1.3 Governance

The province of New Brunswick joined the Canadian confederation in 1867. In the Canadian political system, provinces have a large degree of autonomy. According to the Constitution Act of 1867 (Art. 91–92), the coastal zone falls under the competence of the provincial governments, except for National parks, like those of Kouchibouguac and Fundy, which are under federal jurisdiction. However, the shore itself, defined as the line between normal high and normal low tide is of federal jurisdiction. Coastal development is regulated by municipalities and by regional service commissions.

At the local level, there are 107 incorporated municipalities, subdivided in five categories: cities, regional municipalities, towns, villages, and rural communities. In addition, there are 245 local service districts (LSD), which have limited powers, lacking for example legislative or taxing authority and general elections. They are placed under the tutelage of the Ministry of the environment and of local districts. Only 30 % of the territory of New Brunswick is incorporated, while 70 % consists of LSDs, but two third of the population lives in municipalities, only a third resides in LSDs. In the context of coastal planning, this lack of institutional capacities is often a hindrance. Since 2013, there are 12 Regional Service Commissions (RSC) which replace the previous regional planning commissions and provide some shared services such as land planning, waste management and facilitate the collaboration on essential services. In RSC, incorporated municipalities are represented by their mayors and LSD by delegates. RSC are responsible for emitting building permits based on municipal laws, bylaws, and on the compliance of projects with federal and provincial laws, for example on wetland and habitat protection.

The province has been working for some time on a coastal legislation. The first draft of a coastal policy was published in 1996 and in 2002, the official version of the coastal areas protection policy for New Brunswick was released (Doiron 2012). The coastal areas protection policy identifies three zones with different levels of restriction on development (New Brunswick 2002). However, this policy has not been yet been translated into legislation and thus remains unbinding. Its application is therefore at the discretion of local governments and its impact minimal (City-Spaces Consulting 2007; Fox and Daigle 2012). The province does not have any regular financial program to support adaptation to climate change (Guillemot et al. 2014). Initiatives are funded through the Environmental Trust Fund or through federal research funds.

4.2 Case Studies

4.2.1 Bathurst

Site Description

County	Gloucester
Status of the territory	city
Population	12,275 (91.86 per km^2)
Area	91.86 km^2
Language	French 50.6 % (8.2 % unilingual); English 46.3 % (27.2 % unilingual); autochthonous 1.5 %; others 1.2 %

The site of Bathurst on the double estuary of the Tetagouche and Great Nepisguit rivers has been inhabited for a long time by various First Nations, of which only the Mi'kmaq of Pabineau subsist today. The city of Bathurst is built around the Bathurst Harbour, which communicates through a narrow channel with the Chaleur Bay. This configuration makes the city vulnerable to flooding, except towards the west, where the ground rises to a height of 50 m, encasing the Tetagouche River in the Lourdes canyon. The economy of Bathurst has over time relied on mining, forestry, shipbuilding and fishing. Services now play a large role, as does the transportation sector, Bathurst being an important railway and airport hub for northern New Brunswick.

The issue of erosion is particularly prominent in the community of Bayshore Drive on the Carron Point, a 1.5 km long sand spit on the Chaleur Bay, part of a 12 km long sand dune system. The location has been used for 250 years for fishing, recreational and residential purposes. Carron Point has the highest density of houses of all sand spits in the province. The landscape is varied, alternating dune systems, sand beaches, coastal wetlands, intertidal zones and rocky outcrops (Fig. 4.3). The dune is in constant evolution; aerial photography has revealed that the cliffs to the

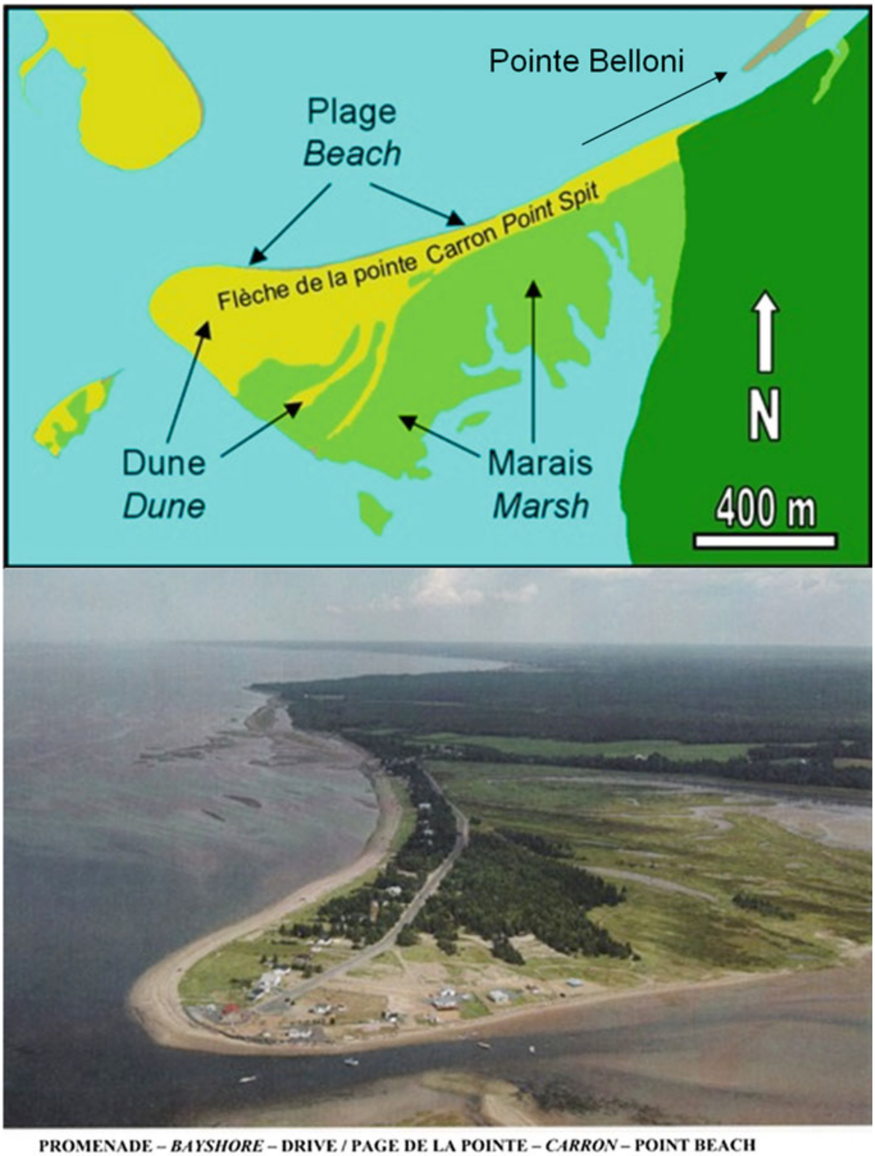

Fig. 4.3 *Map* and *photo* of the Carron Point Spit, Bathurst, New Brunswick, Canada. *Source* Service New Brunswick 1998 Digital Topographic Data Base (DTDB98); produced by the New Brunswick Department of Natural Resources Geological Surveys Branch; City of Bathurst. In Chouinard et al. (2009a)

east of Carron Point have eroded to various degree since 1939 whereas the Carron spit has extended 70 m seaward over the same period. To counter erosion, protection structures have been erected on 30 % of the length of the shore.

Research and Adaptation Strategies

Earlier flood protection structures were mainly private initiatives, which explains the diversity of structures found on the coast (Fig. 4.4). In the long term, such an approach was judged to be neither practical nor efficient. Therefore, from 2007 to 2009, a group of residents, city officials, representatives from the New Brunswick ministry of Natural Resources, members of Bathurst Sustainable Development and researchers from the University of Moncton came together in order to discuss future development and coastal protection respecting the access to the beach, the quality of ecosystem and avoiding accelerated erosion and beach vanishing. The specific objectives of the research project were (Chouinard et al. 2009a):

Fig. 4.4 Different types of protection structures at Carron Point: *1* heavy shale riff-raff, *2* small rock riff-raff, *3* cement wall, *4* large rock riff-raff. *Source* Chouinard et al. (2009a)

Table 4.1 Adaptation options mentioned by the citizens of Bayshore drive

Objective	Activity	Result
1-Creation of a local committee in partnership with the NGO Bathurst sustainable development	Establish an active committee with 12 local members	The committee was created and meets once a month on average
2-Revision and validation of the working document		The document was revised and validated in October 2008
3-Diffusion and awareness raising with the population regarding the recommendations	Three meetings were held to write a bilingual brochure	The brochure was validated by the committee and distributed to residents and in public places
4-Discussion to recommend a municipal bylaw or amendment	Meetings with municipal authorities were held. A regulation draft was composed	Three amendments to the municipal bylaw were proposed to the city of Bathurst
5-Monitoring of erosion	Workshop with geomorphologists (10 participants). Regular data collection in summer and winter 2008	
6-Project report	Project report describing all the activities realized	A project report de project has been submitted

Source After Plante et al. (2011)

1. Identify the residents' perception of the erosion problem and of different protection structures;
2. Measure the erosion rates of the last 70 years with the help of aerial photography;
3. Establish an inventory of advantages and disadvantages of existing structures;
4. Offer assistance with the decision making process for the community through the conduct of focus groups.

As a result of the research intervention process, a list of action priorities was established (Table 4.1), which are in the process of being implemented. In particular, three amendments to the municipal bylaw were proposed, aiming at strengthening the municipal legislation on erosion defense structures and harmonizing it with the province's policy on the protection of coastal zone (New-Brunswick 2002).

- *First proposed amendment*: A structure must be erected precisely from the edge of adjacent structures and must follow the contour of the shoreline.
- *Second proposed amendment*: A structure must be built of stone and must be inclined at a 45° angle in order to dissipate wave energy.
- *Third proposed amendment*: The height of a structure must be 2 m above the land-side of the beach of 2 m above the normal high water mark if no beach is present and must not extend more than 3 m into the sea from the shoreline.

Of course, such amendments raise questions among residents (Chouinard et al. 2009b). For one, the very specific design and facture of the structures is judged by some to be too coercive. On the legal side, a problem arising in that the municipal bylaw is in principle valid for the whole city of Bathurst, and not just Bayshore. The city of Bathurst will therefore have to evaluate whether it wants to extend those amendments to the whole city or limit them to Bayshore. Another potential problem is the cleaning of the beaches from rock debris originating from the protection structures. While this is legally the responsibility of the owners, it is in practice often difficult to know where debris originated. In parallel to the three proposed amendments, the residents of Bayshore have formed the *Carron Erosion Study Team and Steering Committee* in order to continue to address questions of erosion and coastal protection.

The collaborative approach adopted in this research-intervention project has resulted in a better awareness of the residents towards the problem at hand and incited them to find locally adapted solutions (Chouinard et al. 2009b). The role of the researchers was to accompany the process, facilitate discussions and consensual decision-making. The coordination and networking between regional and local stakeholders has permitted to legitimize this process and its outcome in the shape of an amendment to the municipal bylaw accompanied by an information brochure. The advantages of a such a collaborative approach to decision-making are a climate of trust, fewer contradictions and redundancies and a reduction in conflict potential leading to a greater efficiency of interventions (Rankin 2008).

4.2.2 Shippagan

Site Description

County	Gloucester
Status of the territory	town
Population	2603 (262 per km^2)
Area	9.94 km^2
Language	French 95.9 % (unilingual 53.1 %); English 2.7 % (unilingual 0.4 %); autochthonous 0.6 %; others 0.8 %

The town of Shippagan is located on the Shippagan Bay in the Acadian Peninsula (Fig. 4.5). The Shippagan Bay is 15 km long and 4 m deep, and is fairly sheltered from the open waters of the Chaleur Bay and Gulf of Saint Lawrence, with which it communicates through a narrow artificially maintained channel (Stervinou et al. 2013). For this reason, it is a privileged location for the fishing harbour of Shippagan, which counts about 90 vessels. Shippagan also counts a marina, an oyster farm, a seafood plant and the New Brunswick Aquarium and Marine Centre. The coast is characterized by numerous wetlands, which are precious nesting grounds for herons and other birds.

Fig. 4.5 Areal view of Shippagan. *Source* CAPA (2008)

Due to its situation on a peninsula, Shippagan is vulnerable to inundations and sea level rise, even more since natural subsidence is about 5 cm per century. The local sea level has already risen by 10 cm since the 1970s, accompanied by an increase in temperatures, especially in winter (3 °C between 1985 and 2011) and a decrease in length and extent of the ice cover on Shippagan Bay (Fig. 4.6). Part of the bay's coast is protected by wooden and stone structures, which limits the risk of erosion, but does not always protect from inundations, such as in 2010 (Guillemot et al. 2014). The road 113, that borders the sea in several places like the Saint-Simon Bay and crosses the harbour of Shippagan and the Inkerman Lake, is very vulnerable to flooding.

Coastal erosion is not uniform. According to a recent study (Robichaud et al. 2012), 67 % of coastal segments are stable, partly because of artificial protections, 28 % are retreating and 5 % advancing. There is some concern about the sand spit which shelters Shippagan Bay from the Gulf of Saint Lawrence. Some local observations point towards a progressive silting of the Shippagan Bay, which residents attribute rather to the construction of the bridge between Shippagan and the island of Lameque in 1959 than to the impacts of climate change. Unlike in the neighbouring community of Le Goulet, no saltwater intrusion in wells has been observed yet (CAPA 2008).

Research and Adaptation Strategies

Many residents of the coastal zone had to protect their land from erosion and inundations. In all cases, those were private initiatives. In 2008–09, the town of Shippagan initiated a collaboration with the Costal Zones Research Institute of the University of Moncton (Shippagan campus) in the context of the development of its

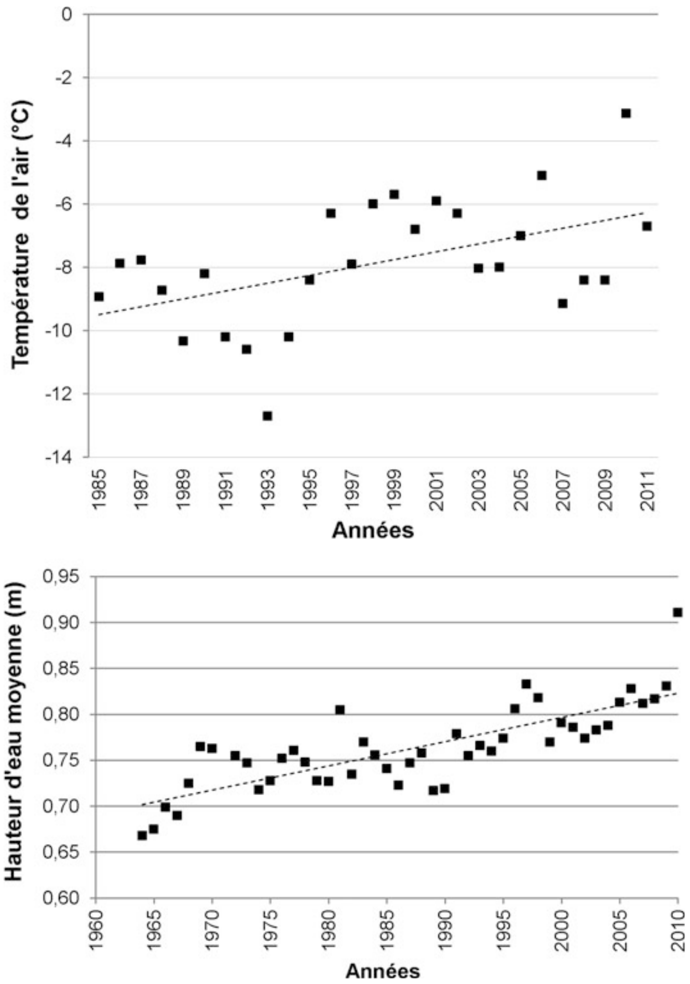

Fig. 4.6 Increase in air temperatures and sea level (Escuminac gauge). *Source* Stervinou et al. (2013)

Green Plan (Aubé and Kocyla 2012). The research project covered two main aspects:

1. A survey with the population in order to understand the perceptions of the residents on environmental changes in the study zone over the previous decades;
2. An assessment of environmental changes in Shippagan in the last 20 years based on scientific data and cartographic analysis.

Shippagan is one of three communities in the Acadian Peninsula, with Bas-Caraquet and Le Goulet, which were surveyed by LIDAR thanks to the Atlantic Regional Adaptation Collaborative (ARAC) initiative. Those studies allowed to model and map inundation risks over the territory though a collaboration of the University of Moncton, Moncton and Shippagan campuses, private contractors, the regional planning commission and the Coastal Zones Research Institute (Aubé and Kocyla 2012).

As a result of the research projects, the new Green Plan (City of Shippagan 2009) incorporates two orientations in relation to climate change, the evaluation of risks and their mitigation:

1. Evaluate the submersion and erosion risk of coastal zones due to sea level rise and identify zones at risk under different sea level rise scenarios;
2. Adopt mitigation measures for the impacts of sea level rise
   (a) Restrict development in zones at risk of inundation and erosion;
   (b) Evaluate options for the protection of Route 113 against inundations and erosion;
   (c) Educate the population about protection means of the shore that are efficient, environmentally acceptable and comply with existing legislation.

Overall, the Green Plan identified 7 strategic sectors and proposed 49 actions to be implemented over the next three years (Aubé and Kocyla 2012).

4.2.3 Le Goulet

Site Description

County	Gloucester
Status of the territory	village
Population	817 (150 per km^2)
Area	5.46 km^2
Language	French >80 %, English <20 %; autochthonous and others no data

Le Goulet is a small community of the Acadian peninsula located on the Shippagan Plain. The territory of Le Goulet consists of beaches, coastal wetlands, bogs, and of the Goulet Lake. The sea plays an important part in the economy of Le Goulet as fishing is its main source of revenue. However, the decline of the resource since 1992 has lead to a slowing down of the economy and a population decrease. The 5 km long natural beach is a touristic asset that the municipality wants to develop thanks to an interpretation center for local fauna and flora, but tourism has remained limited so far.

At Le Goulet, erosion and saltwater intrusion are major concerns and has propelled the community to some media fame (Radio-Canada 2012). Extreme weather events have regularly caused important damages to Le Goulet, the most notable being the tornado of 1982 and the storms of 1995, 2000 and 2010 (Fig. 4.7). During the January 2000 storm, a dozen houses had to be evacuated. Several houses were

Fig. 4.7 Inundations in Le Goulet. *Source* Le Goulet

also flooded in December 2010. At the same time, 28 residences experienced saltwater intrusions in their wells (Chouinard and Martin 2007). Although the beach and wetlands act as buffer against inundations, they offer only limited protection due to the flat nature of the terrain. In order to protect the harbour, a protection wall was built in 1995 and consolidated at the beginning of the years 2000. In 1997, the community had placed snow fences in order to reverse dune erosion, but the entire equipment, worth a quarter million dollar was lost during the storm of January 2000 (Chouinard and Martin 2007).

Research and Adaptation Strategies

As the municipality was investigating different adaptation options in the early 2000s, it invited the University of Moncton to conduct a research project on the adaptation to climate change in the municipal territory. After being able to secure financing, a research-intervention project was conducted from 2005 to 2009. The objective of the project was to coordinate interventions of citizens, officials and agencies in the decision making towards the adoption of sustainable practices in the adaptation towards inundations and erosion in the context of climate change.

Prior to the project, several adaptation options have been envisaged. After the storm of 2000, the construction of a seawall was seen as a priority. A consulting firm hired by the municipality recommended the construction of a 3.8 km long seawall at a cost of 3.3 million dollars (Richardson 2010). In parallel, the saltwater intrusion in wells would necessitate the construction of an aqueduct and a sewer system at a cost of over 14 million dollar (Richardson 2010).

Over the course of the discussion groups, the priority ranking of adaptation options shifted (Chouinard et al. 2009b). The seawall, clearly favoured at the onset of the project, was not on top of the list at the end of it. Instead, the municipality decided to opt for a partial retreat and proposed to move the 30 most vulnerable houses to higher grounds. The realisation that even in the presence of a seawall, inundations could occur through the wetlands on both sides of the village was a determining factor in casting doubt on the protection option. The high cost of this structure and of the aqueducts was another decisive factor. The partial retreat strategy is not unanimously accepted by the population and discussions are still ongoing. There is however a large support for a change in zoning from the planning commission of the Acadian Peninsula (CAPA) preventing the construction of houses in zones at risk from inundations and erosion.

The top priority identified by the participants was a LIDAR survey of the territory and the mapping of flood zones. With the backing of those results, the municipality, in collaboration with the Institute for Coastal Zones Research of the University of Moncton in Shippagan, was able to obtain funding from the Regional Collaborative Adaptation Program to conduct this survey, so that the municipality now possesses maps of flood risks by sectors as a function of storm levels and climate change scenario.

4.2.4 Cocagne and Grande-Digue

Site Description

County	Kent
Status of the territory	Rural community, Local service district
Population	Cocagne 2545 (38 per km^2), Grande-Digue 2182 (47 per km^2)
Area	Cocagne 66.43 km^2, Grande-Digue 46.04 km^2
Language	French majority, English minority

The Cocagne-Grande-Digue territory is situated in the drainage basin of the Cocagne River, consisting in the riverine section, the harbour and the bay (Fig. 4.8). The administration of the territory is divided between three local service districts (LSD): Dundas, Cocagne (now a rural community) and Grand-Digue. The Cocagne and Grande-Digue LSD are situated on the coast, whereas the LSD of Dundas is further inland, upstream on the Cocagne River. The town of Cocagne is located on a point at the mouth of the Cocagne River to the Cocagne harbour. The territory of Cocagne comprises sand and pebble beaches, cliffs and different kind of salt-and-freshwater marshes and bogs. The Cormierville wetland is designated as a wetland of provincial importance. The village of Grande-Digue is located on the south side of the peninsula in the north of Shediac Bay. It was founded in 1778 as the first parish in the region. Due to its geographical situation, it is appreciated as a tourism resort and the population doubles during the summer months. The territory has two important islands, the island of Cocagne, which is part of the LSD of Dundas and is recognized for its precious ecosystems and habitats and the Surette or Treasure Island, in the Cocagne LSD, which has 56 residences and is linked to the mainland by a paved causeway. Both Cocagne and Grande-Digue have experienced a significant population increase since the 1970s due to tourism and summer residences. The economy of the region relies on tourism, on services, on agriculture, especially in the Dundas

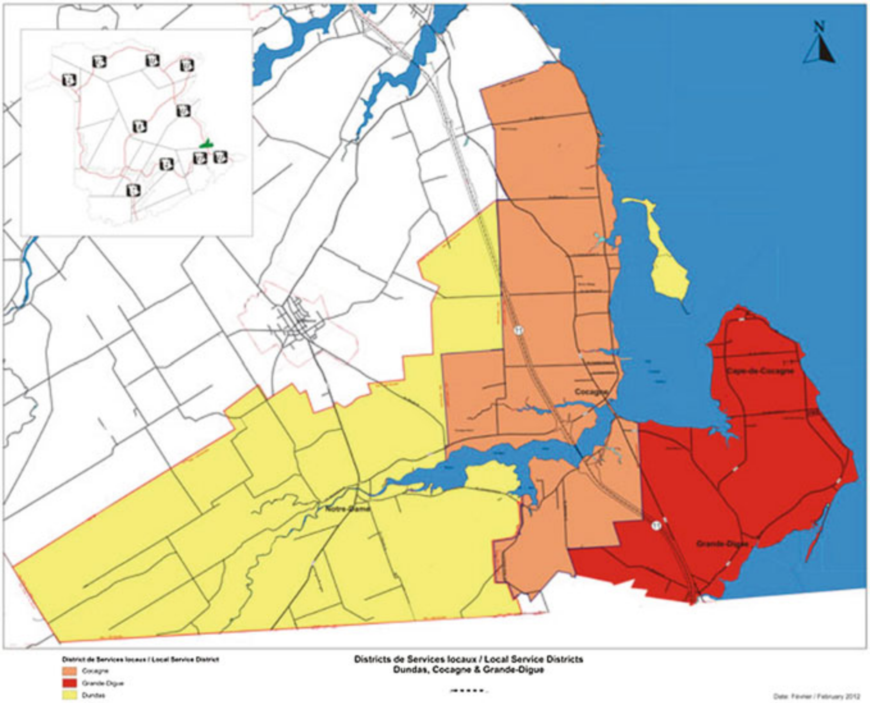

Fig. 4.8 The Cocagne-Grande-Digue territory. Cocagne LSD (*orange*), Dundas LSD (*yellow*), Grande-Digue LSD (*red*). *Source* E. Bastarache, Kent District Planning Commission, 2012

LSD, and on nautical activities. The coast counts two marinas and four fishing harbours: Cocagne marina, Cap de Cocagne marina, Cap de Cocagne wharf, Cormierville wharf, St. Thomas wharf, and Grande-Digue wharf at Cap des Caissie.

The Cocagne and Grande-Digue LSD are amongst the most vulnerable communities in New Brunswick. Erosion and sea level rise are strongly felt in Cocagne Bay and Harbour as well as in Shediac Bay. Storms have caused considerable damage in recent years (Chouinard et al. 2011). During the winter storm of 2000, the Grande-Digue quay was almost entirely destroyed by an ice pile-up (Fig. 4.9). Damages to roads are frequent and costly (Fig. 4.10).

Research and Adaptation Strategies

Following a long standing engagement of the university of Moncton in the region, a research project on climate change adaptation was undertaken in 2009–2012, consisting in discussion groups aiming at providing a decision making support for the three local service districts of Cocagne, Grande-Digue and Dundas. In the course of the discussions, observations on climate change impacts were consigned

Fig. 4.9 Ice pile up on the Grande-Digue wharf in Cap-des-Caissie. *Source* Environment Canada, 2006

Fig. 4.10 Damages to local roads caused by the storm of 2010. *Source* N. Bastien, 2010

and adaptation solutions evaluated. Residents have observed a number of changes at local levels, such as:

- "Decrease of the height of dunes, more breaches in the coast, more rain and run-off. One can see the effect of run-off, for example at the beach of Cap-des-Caissies";

- "There is more sedimentation at the end of the Cap-Cocagne wharf, it varies from year to year. There are abandoned paths in the northwest section, Cocagne River";
- "There is a lot of erosion in front of the house, 30 ft since 1975, the grass is all gone";
- "The tendency is towards coastal erosion, but I noticed that the dune on Cocagne Island has advanced";
- "Erosion is more and more frequent. The cliff at my place has lost 2 ft in 6 years. Freezing and thawing are much more frequent, they accelerate erosion and break protection structures";
- "I could see the dunes in front of my place in Pointe-Cormier 30 years ago and the riff-raff wall we installed 30 years ago already isn't effective any more".

The residents furthermore identified eight locations most vulnerable to storm surges and which should be a priority, given their importance for the health and well-being of the population. Those include some coastal road segments, bridges, the causeway to Surette (Treasure) Island, the Cormierville wharf, the Cap Cocagne marina and the Cormierville marsh/bird sanctuary. Residents also stressed the need to obtain more scientific and geomatic data on those zones.

Several adaptation options falling in the three adaptation categories were evaluated during the discussion groups:

1. Protection
   - A system of dykes built according to IPCC sea level rise predictions
   - Fences positioned at an angle like in Cape Bimet
2. Accommodation
   - Elevate buildings on stilts
   - Elevate roads
3. Retreat
   - Move the road further inland
   - Move buildings which are too close to the sea and create a fund to finance this measure
   - A governmental buy-me-out program for buildings at risk

In every case, the participants questioned the availability of institutional and technical support for the implementation of those solutions. The availability of project financing for the communities' adaptation efforts was also a general concern. Participants also raised the issue of governance. Some participants favoured the creation of a municipality for the territory while others preferred to keep the privileges linked to the LSD status and avoid the risk of a tax increase. In 2013, Cocagne held a vote on the creation of a rural community, which yielded a majority in favour of the project. The new rural community was officially constituted on May 23rd, 2014. A consultation in Grande-Digue showed no majority in favour of the project and in consequence, Grande-Digue remains a LSD. In Dundas, a vote held in 2014 resulted in a tie with 420 votes on each side, a unique occurrence in elections in New Brunswick. As the requirement for the formation of the rural community of Notre-Dame out of 4 LSD (Dundas, Shediac Bridge-Shediac River, a part of the Moncton parish and a part of the Shediac parish) was a result of 50 % + 1 vote, the project has for now be rejected (Doiron 2014).

4.2.5 Pointe-Du-Chêne

Site Description

County	Westmoreland
Status of the territory	Local service district
Population	761 (293 per km^2)
Area	2.6 km^2
Language	English majority, French minority

Pointe-du-Chêne is situated on the point between the Shediac Bay and the Northumberland Strait. It has been a holiday and transport center since the first half of the 20th century when it was the starting point of the *European and North American Railway* and a transit point for the seaplanes of the *Pan-Am*. Nowadays, the Parlee Beach is the main focal point of tourism and welcomes half a million visitors per year.

Inundations and storm damages have always been a major problem in Pointe-du-Chêne, which is exposed to storm surges from three sides. In 1868, a storm destroyed part of the wharf and of the train station. In 1924, another storm destroyed the wharf and the Paturel plant. The storms of January and October 2000 caused over two million dollars of damage and affected over 260 homes. The population is less concerned about erosion, since most erosion prone lots have been protected by stone riff-raff, in great part through the initiative of the Anglican Church that owns 70 % of coastal terrains (Chouinard et al. 2008). Parlee Beach experiences continual erosion and is replenished every year (Fig. 4.11). Up to one thousand truckloads of sand are necessary to compensate for erosion losses.

Research Project and Adaptation Strategies

In the course of the project on the impacts of sea level rise and climate change on the coastal zone of south-east New Brunswick, financed by Environment Canada, a LiDAR survey of the entire coastal sector was undertaken and digital elevation models constructed, allowing the modeling of flood zones in function of different return times and climate change scenarios (Fig. 4.12).

From 2005 to 2006, a research-intervention project was lead in Pointe-du-Chêne by the University of Moncton. One of the objectives of the project was to establish a

Fig. 4.11 The impact of erosion in Parlee Beach in the fall of 2011. *Source* S. Weissenberger, 2011

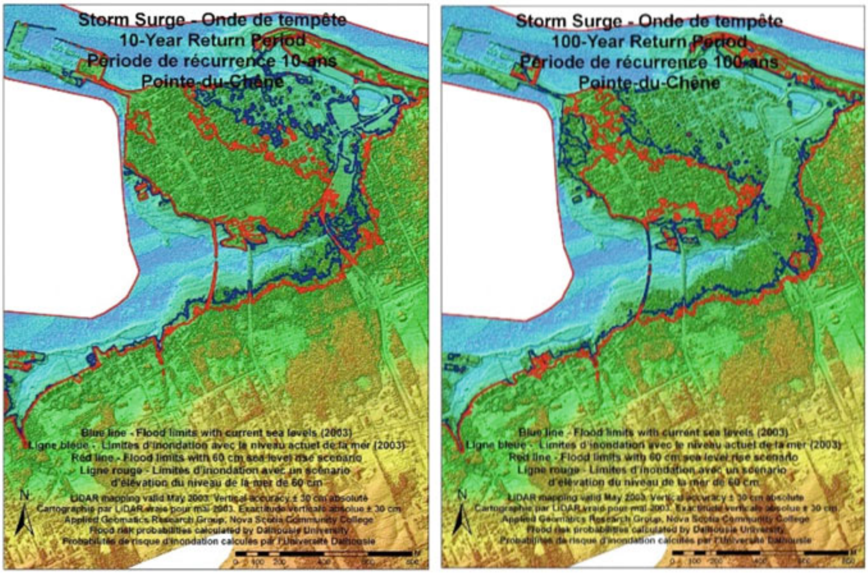

Fig. 4.12 Flood maps for Pointe-du-Chêne for 10 and 100 year storm surges with current (*blue*) and future (*red*) sea-level, based on LiDAR-based digital elevation models. *Source* Environment Canada, 2006

priority list for climate adaptation projects through a collective deliberation process. At the end of the discussion process, the participants agreed on a list of priorities (Table 4.2), the first of which was the raising of the bridge connecting Pointe-du-Chêne to the mainland and which was regularly flooded during strong storm events. Following this deliberation process, the community negotiated with the province, which agreed to build a new bridge The new bridge was finished in 2009 and proved its usefulness in 2010 when it was not submerged during the record December storm (Fig. 4.13).

Table 4.2 Priority ranking of adaptation options established by the citizens of Pointe-du-Chêne

Adaptation option	Costs	Adaptation strategy	Environmental impacts
1. Modification of the bridge	Medium	Accommodation	Small-medium
2. Dikes and dams	Very high	Protection	High
3. Restoration or replacement of the ditches	Small	Accommodation	Small
4. Guarantee an evacuation road through the park	Small	Accommodation	Small
5. Limit the sources of contamination of the wetlands during floods	Medium to high	Accommodation	Small

Source Plante et al. (2011)

Fig. 4.13 The new bridge of Pointe-du-Chêne during the storm of 2010 and in normal weather. *Source* S. Doiron, 2010; S. Weissenberger, 2012

The second option was the construction of a system of dykes and sluices. However, such a system would be very costly and have significant environmental impacts. Before considering this option further, the participants would like to commission a detailed study. Retreat is not an option in Pointe-du-Chêne as it is situated on an already almost fully built-up peninsula. Some administrative and education measures were also proposed, including more restrictive zoning rules to discourage constructions in flood-prone areas and education campaigns on coastal risks and adaptation measures.

4.3 The Importance of Community Participation in the Elaboration of Adaptation Strategies

In Canada, there has been relatively little involvement from the federal or from provincial governments in order to assist communities to reduce their vulnerability towards climate change. Communities criticize the lack of resources and of guidance put at their disposal. In this context, communities have to be largely self-reliant and have to develop their own climate adaptation strategies, adapted to their challenges and commensurate with their means. The involvement of the local actors of the communities is therefore crucial. The participation of university experts can catalyse changes in the community and is generally welcome. In fact, many of the projects described above were initiated by community stakeholders who sought out university experts to assist them with the formulation of adaptation strategies. Thus, experts from the University of Moncton (Moncton and Shippagan campuses including the Institut de recherche sur les zones côtières), the Coastal Communities Challenges CURA at the University of Quebec in Rimouski and from the University of Quebec in Montreal participated in the various projects, which received funding from Natural Resources Canada, Environment Canada, Social Sciences and Humanities Research Council of Canada via the Social Economy and Sustainability Research Network and the New Brunswick Environmental Trust Fund. Several valuable lessons could be learnt from these action research projects.

4.3.1 The Participatory Process and Locally Tailored Solutions

The research projects drew on the different methods of participatory action research (Noblet and Chouinard 2014): bibliographical analysis (Fontan 2011), participatory observation with a log book, semi-directed interviews (Savoie-Zajc 2009), focus groups (Kitzinger et al. 2004; Geoffrion 2009). In order to disseminate the results of those research projects in a universally accessible way, i.e. not only through scientific publications, brochures for the use by coastal residents were conceived (Chouinard et al. 2009a, 2011), and a web site on coastal adaptation to climate change was created, which contains a great deal of background information and numerous interviews with local stakeholders, politicians, urban planners and scientists (Chouinard and Weissenberger 2014).

The process aimed at was one of co-construction rather than an expert-consultant driven one. The participatory approach aims at negotiating the terms of the project with the communities. This can include the definition of a common objective and the setting of limits and expectations. Thus, local governance can be strengthened via the action-research process through an active involvement of stakeholders, a transfer of information and tools and a sharing of ideas (Plante et al. 2011).

An action-research process typically proceeds through three stages (Plante et al. 2011). Before starting the actual project, the initial contact serves to define objectives and terms of reference of the project, identify the stakeholders, and engage the community at large. The first stage of the research project is to establish a portrait of the local situation through questionnaires and semi-directed interviews as well as the analysis of available scientific data and cartographic body. Through this investigations, the local circumstances, the specific problems the socio-ecological system faces and the perceptions of the residents towards environmental changes, risks and adaptation and development options can be better understood.

After that, the experts from different disciplines engage with the community initiating an exchange on the different implications of climate change for the community. In order to allow the community to profit fully from the project, the exchange should be devised as an open, inclusive and reciprocal process. Accompanied focus groups allow to explore in depth the challenges that the communities want to address and the adaptation options they consider and favour. Priority ranking with collectively determined criteria is a very useful tool to help participants of focus groups measure adaptation options against each other. The comparison of the adaptation measures chosen as priorities in the 5 municipalities (Table 4.1) shows that the different localities came to very different conclusions at the end of the research process, even though they were presented with largely the same information. This is a good example of why a strong community implication in all stages of the adaptation planning is important in order to devise a strategy that is well suited to local circumstances and will be easily accepted by the local stakeholders.

A retrospective analysis of the action research project allows to identify certain factors which influence the choices and the adaptive capacity of the communities. For example, Le Goulet is a small isolated community with a dwindling population, due to the decline of the fishing activity. Its socio-economic vulnerability is thus fairly high. In comparison, Pointe-du-Chêne and Bayshore Drive are less dependent on natural resources than they once were, having made a transition to residential centres dominated by the services sector, favoured by their proximity to the urban centres of Moncton and Bathurst. This transition has also caused an influx of wealthy and highly educated population (often retirees) as well as provoked an increase of real estate value, especially on the waterfront.

It is thus not surprising that Pointe-du-Chêne and Bayshore turned towards protective structures as the preferred option, at least at the onset of the project since priorities shifted along the way. Thus, in Pointe-du-Chêne, the priority ranking exercise lead to favour the raising of the bridge connecting the peninsula to the mainland, which was systematically flooded during storm surges and isolated the community. This solution was seen as a good short-term option, much less costly than a seawall and ale to alleviate the main negative impact of storm surges, not being able to leave the community or to receive goods and emergency services during inundations.

In Le Goulet, a seawall was also strongly considered following some very damaging flood events and an expertise by a consulting firm. However, discussion groups lead to the realization in the community that a seawall could not provide absolute protection, since water can circumvent it and it would also be unable to prevent the intrusion of saltwater into wells. Planned retreat of the most vulnerable homes is now increasingly considered, as a less costly and long-lasting solution to sea level rise. For such a small municipality, the cost of building a seawall and providing aqueduct water to individual residences is prohibitive without outside help.

Bayshore Drive was the only of the 5 communities to propose a new regulatory framework as an adaptation measure. The proximity to the city of Bathurst with the presence of decentralized provincial ministries and the strong social capital (leadership, social cohesion, networking) can be seen a factor in this orientation (Plante et al. 2011).

4.3.2 A Changing Representation of the Coastal Zone

Over time, the representation of the coastal zone has considerably evolved in parallel to the change of use that it has gone through. The coastal zone is now a highly desirable living and recreation environment. A mapping of the values associated with the coastal zones in the communities described above reveals that the recreational and esthetical values are the most represented. An examination of land use maps of 1979 and 2012 and of building permits emitted by the Kent District Planning Commission shows that the building density has greatly increased in the last 30 years and that the prices of coastal properties has increased threefold over the last 10 years (Noblet and Chouinard 2014). This evolution is part of a more general trend, in which populations of the hinterland shape a new perception of the coastal zone as a place for nature, emotions, exoticism and nostalgia and thereby alters the vocation of the coastal zones and the relation between new residents and local populations (Le Bouëdec 2002, in Rabeniaina and Chouinard 2014).

4.3.3 Community Cohesion—First, Second and Third Generation Residents

The cohesion within a community is an important factor towards reaching a consensual decision on adaptation strategies. When personal circumstances and the perception of the community differ among its members, this becomes more difficult to achieve. Thus, in Pointe-du-Chêne, which is increasingly becoming a residential centre for professionals and retirees from Moncton and elsewhere, several participants expressed a preoccupation towards a growing rift between the second and third generation residents. While the second generation residents are on average less wealthy, the third generation residents are wealthier and more likely to resort to individual protection structures. The presence of seasonal residents is also viewed by permanent residents in communities of the south-eastern coast of New Brunswick as a factor that weakens community cohesion and hinders collective action (Rabeniaina and Chouinard 2014)

> "We must find a solution to implicate seasonal residents in the projects of the community" -A participant of a focus group in the SERSC
>
> "We must find a collective and not an individual solution because everybody is affected by coastal development" -A participant of a focus group in the SERSC

4.3.4 Community Empowerment—Strengthening of Local Governance and Negotiation Power Through the Appropriation of Knowledge and Science

The communities involved in the action research projects have all stressed the importance of the co-construction approach, in which they are full participants in the research process, are able to familiarise themselves with the tools and methods the researchers use and are the ones to state on the adaptation priorities. The appropriation of simple yet effective techniques such as mapping (Fig. 4.14) allows the communities to gain more autonomy in their adaptation planning. The better understanding of the research process, tools and results also empowers the communities in their negotiations with government agencies. For example, the communities of Le Goulet, Bas-Caraquet and Shippagan were in a better position to request from the provincial authorities a LIDAR cartography of the territory after participating in an action research project and Pointe-du-Chêne was able to negotiate the construction of a higher bridge.

Fig. 4.14 Mapping exercise with residents of Le Goulet. *Source* Chouinard and Martin (2007)

4.3.5 The Importance of Local Knowledge

The value of local and traditional knowledge in the analysis of climate evolution is increasingly recognized (Klintenberg et al. 2007; Nakashima et al. 2012). In several cases, local observations corroborate scientifically observed climate trends, e.g. in Burkina Faso (Thiombano 2011), in the Himalayas (Chaudhary and Bawa 2011), in Tibet (Byg and Salick 2009) or in the Canadian Arctic (Ashford et Castleden 2002). In other cases, like in the Gulf of St. Lawrence (Friesinger and Bernatchez 2010), the gradual nature of change or particular recent events can bias residents' perception of long-term environmental changes.

In the study performed in Shippagan, there is a remarkable concordance between the local observations and the on scientific data on a range of climate change and other environmental changes evaluated over a period of 25 years (Table 4.4). 7 of 8 respondents estimated that low winter temperatures are not as low as they were and occur less frequently. Indeed, winter temperatures have increased by 3 °C over the last 26 years. 4 of the respondents estimate that winters are shorter now than 25 years ago. 7 respondents also observed that the ice cover had diminished over the same period. In this case, data shows a decreasing trend since 1992, but it is not statistically significant, due amongst other to the large year-to-year variability (hence inconclusive in Table 4.3). Some observations like the evolution of snowfall were less conclusive; 3 respondents think there is less snow than in their youth and one that there is no change. No respondent mentioned changes in precipitations, which indeed have remained stable since 1982. Only one respondent mentioned ocean surface temperature, finding them unchanged. Data indicates that water temperatures have remained mostly unchanged since 2001 with some seasonal variations. A rise in sea level and/or higher storm surges was observed by 8 of the 9 respondents who mentioned this variable. Coastal erosion was the most discussed and least unanimous variable: 5 respondents think it has increased, 5 think there has been little change. This reflects the strong variability in coastal dynamics as measured by O'Carrol and Jolicoeur (pers. comm.). Of the studied transects, 67 % were stable—mainly due to protective structures, 28 % were retreating and 5 % were advancing.

Many observations on environmental changes were linked to activities in relation with nature, such as fishermen's observation on the evolution of ocean conditions and species abundances and distributions. First Nations are traditionally closely linked to nature and have been very aware of changes in the climate and the environment (Ashford et Castleden 2002; Yeo and Bhardwaj 2014) and Mi'kmaq of the Elsipogtog First Nation related gradual changes in species composition they observed, with some more southern species hitherto unknown appearing in the last decades (Chouinard and Weissenberger, pers. comm.).

This shows that local observation is a very useful tool in order to assess climate change and its impacts at a local scale. Local observations are all the more precious since the collective memory of community often reaches further in the past than instrumental data and covers the whole territory. In the study in Shippagan, some

Table 4.3 Priority for adaptation actions resulting from the research-intervention projects in municipalities of New Brunswick

Case study	Priority action at the end of the research project
Bathurst/Bayshore	Correctly built protection structures
Shippagan	• Evaluate the submersion and erosion risk of coastal zones due to sea level rise and identify zones at risk under different sea level rise scenarios • Adopt mitigation measures for the impacts of sea level rise – Restrict development in zones at risk of inundation and erosion – Evaluate options for the protection of Route 113 against inundations and erosion • Educate the population about protection means of the shore that are efficient, environmentally acceptable and comply with existing legislation
Le Goulet	A LIDAR survey and modelling and mapping of flood zones
Cocagne and Grande-Digue	1. Protection • A system of dykes built according to IPCC sea level rise predictions • Fences positioned at an angle like in Cape Bimet 2. Accommodation • Elevate buildings on stilts • Elevate roads 3. Retreat • Move the road further inland • Move buildings which are too close to the sea and create a fund to finance this measure • A governmental buy-me-out program for buildings at risk
Pointe-du-Chêne	Raising of the bridge connecting Pointe-du-Chêne to the mainland

Source Authors

Table 4.4 Concordance between local observations and scientific measurements on environmental changes in the territory of Shippagan, New Brunswick, Canada over 25 years

Variable	N	Correspondence between observations and measurements		
		Strong (≥4)	Weak (<4)	Inconclusive
Winter air temperature	8	X		
Ocean surface temperature	1			X
Snowfall	4			X
Storm frequency	2		X	
Duration of ice cover	7			X
Sea level rise	9	X		
Coastal erosion	10			X

N number of respondents who mentioned this variable. *Source* After Stervinou et al. (2013)

older residents could identify changes that happened over the last 40–50 years. One resident commented that his parents made essentially the same observations as him. Intergenerational memory is also very strong in many First Nations communities in which elders play an important role in (traditional) society. In some studies in the USA (Howe and Leiserowitz 2013), beliefs about global warming were found to influence the perception of local climate, however in New Brunswick, knowledge and understanding of climate change are generally good (Guillemot et al. 2014; Stervinou et al. 2013), so that an ideological bias can be ruled out.

4.3.6 The Importance of Local Governance

In Canada, the responsibility for the development and climate adaptation of coastal zones lies with the provincial level of government rather than with the federal level, although the environment and natural resource ministries support research and pilot projects. However, most participants in the various communities complained about the lack of legislation, public policies, guidance and political will from the provincial authorities (Chouinard et al. 2014). Therefore, the onus of formulating and implementing adaptation plans is on the local governments.

In New Brunswick, there is a marked contrast between municipalities or rural communities and local service districts. The status of an incorporated municipality gives more tools and resources to the community, including the ability to pass municipal bylaws or to formulate rural plans. Local service districts, on the contrary, hold little power over territorial planning and organisation and have little human and material resources at their disposal. This leads to a lower adaptation capacity. This deficit also translates in the new territorial organisation around regional service commissions. A recent comparative study between the Southeast Regional Service Commission (RSC7) and the Kent Regional Service Commission (RSC6) showed that the participants of the RSC6, which is dominated by local service districts, felt less able to respond to climate and environmental changes and risks than those of the RSC7, which consists mostly of municipalities (Chouinard et al. 2014). Some participants attributed the movement towards the formation of rural communities in the LSD of Cocagne, Grande-Digue and Dundas to the discussions initiated by the project on the coastal zone.

A particularly noteworthy example of local governance leadership is the decision by the Rural Community of Beaubassin-Est to include future climate change in its legislation on new development. The new municipal bylaw (CGVD28, bylaw 09-1 B, February 2011) states that the inhabitable part of any new construction has to be 4.30 m above sea level, that is 1.43 m above the storm surge of 2000, which is considered a one in a 100 year event. The extra 1.43 m is the provision for future sea level rise and is derived from semi-empirical modelling work by Stefan Rahmstorf of the Potsdam Institute for Climate Change, to which local subsidence is added (Doiron 2012). This legislation was advocated by the Beaubassin Planning Commission (now part of the Southeast Regional Commission), which managed to convince the rural community to implement this precautionary approach, likely helped by the still vivid impression of the catastrophic storm of 2010. Since then, the municipalities of Shediac and of Cap-Pelé have enacted identical legislations.

4.3.7 The Importance of Associations

Local and regional associations concerned with environmental and development issues play an important role in the adaptation process and in citizens' mobilization. A prime example of this is the The Pays de Cocagne Sustainable Development Group (PCSDG), which mobilizes citizens and smaller association around environmental issues, and in particular that of climate change and is involved in research, sensitization and policy-shaping. Associations tend to intervene in a constructive and collaborative fashion and are important actors in the elaboration of adaptation strategies. Their role is particularly important in communities organized as LSD, and hence without municipal structures. In those communities, residents often turn to local associations to initiate projects and to act as a relay between them and the higher levels of government (Chouinard et al. 2012).

4.4 Conclusion

The research projects undertaken in the different communities In New Brunswick have shown the usefulness of the participatory research-intervention approach. The engagement of communities and multiple stakeholders in an open and inclusive deliberation process resulting in the co-construction of an adaptation strategy has several advantages over the traditional mode of decision making relying on high level decision making informed by external consultants. Amongst the advantages of this approach, the following are particularly noteworthy:

- The exchanges with scientists and experts lead to an empowerment of the communities and to capacity building which allows the community to be better equipped to face future environmental and climatic challenges;
- The implication of local stakeholders and the use of local knowledge allow developing adaptation plans which are suited to local conditions;
- The deliberative and inclusive approach strengthens the social cohesion of communities. The open and constructive exchanges between stakeholders lead to a reduction of conflict potential and to a better acceptance of proposed solutions.

Top-down approaches piloted by government agencies and relying on generic scientific advice or short-term consultation processes are not likely to identify the best adaptation options at each site. The collective intelligence and knowledge of local stakeholders offers invaluable input into the construction of an adaptation plan. It is true that such a process takes more time than a classical approach. Co-construction processes like the ones described here can stretch over a number of years, whereas an external scientific expertise and a decision-making process involving only officials and agencies can be fairly expeditious. However, the economy in time can prove costly in terms of the quality of the adaptation strategy.

Ineffective coastal protections can represent large stranded costs for a community. An incorrect assessment of coastal risks or inadequate development plans can put private and public property at risk of erosion or inundation and thus incur losses to owners or the community.

The impact of a collaborative action-research project on climate adaptation strategies can best be evaluated by observing how intervention priorities change during the course of such projects. At the onset, all communities envisaged the construction of coastal protection structures as the main adaptation strategy, accompanied by other actions such as municipal zoning, securing freshwater supply or other measures, depending on the location. At the end of the project, priorities for immediate actions had in most cases shifted to other interventions.

Of course, the path from research to action is not easy. Thus, Le Goulet still has not decided on its adaptation strategy. Other municipalities are still evaluating what the middle and long-term implications of the various adaptation strategies are. The difficulty in the decision making process is rooted in part in the intrinsic complexity of municipal politics and in the difficulties in vertical integration of governance from local to provincial and federal scale, but also in the long term perspective of climate change and sea level rise, which challenges traditional strategies of project evaluation and strategic thinking. However, the case studies presented here have also shown that the collaborative approach and community involvement can reap immediate benefits. As a result of clearly identified priority actions and consensus-building in the communities, several communities could successfully negotiate the financing of adaptation measures. Thus, Pointe-du-Chêne obtained a new higher bridge and the municipalities of the Acadian Peninsula benefited from a LiDAR survey.

Climate change adaptation at municipal level is undoubtedly complex and often controversial. The restriction of coastal development is difficult to get accepted by all stakeholders, since it can lead to lost business opportunities or stranded costs on the part of some stakeholders. In turn, municipalities often have to be prepared to lose tax revenues by enacting legislation that restricts coastal development. The provincial context of New Brunswick does not offer strong legal tools for planning experts, since the provincial coastal policy is still only a policy without any force of law. However, with the background of the considerable losses and destruction experienced during recent storms, more stringent coastal legislation, such as that enacted by the municipality of Beaubassin-Est, gain wider acceptance.

Of course, legislation on new constructions does not solve the problem of already existing development that is at risk from erosion and climate change. Protection, retreat or relocation are all possible options that have to be weighed site by site. Le Goulet is leaning towards a partial retreat after having examined the difficulties of protection. In Grand-Sault, and in the neighbouring province for Quebec, governmental buy-me-out programs have enabled a planned retreat without financial losses for citizens. For other sites like Pointe-du-Chêne or the cemetery of Rexton, situated on a coastal segment under erosion, retreat is a less practical option and protection will likely remain as the main solution in the short or middle term. In all cases, it is however essential that decision makers and citizens are adequately informed about climate change and the coastal risk and are involved in the decision making process in order to develop appropriate and widely accepted strategies and to be able to adjust the decision making over time, since adaptation to climate change is not a punctual event but an on-going process.

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