Climate Change Adaptation in Coastal Cities: Insights from the Great Barrier Reef, Australia

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Abstract: Coastal cities are particularly vulnerable to the impacts of climate change, with sea level rise and extreme flood events predicted to impact critical infrastructure for a wide range of socioeconomic activities. In Australia, for example, it is estimated that more than A$226 billion in residential, commercial, industrial, and road and rail assets are exposed to future coastal climate hazards. The coastline adjacent to Australia's Great Barrier Reef (GBR) in the state of Queensland will be exposed to increased inundation under climate change scenarios from both sea level rise and extreme weather events such as floods and cyclones. This has been evidenced by the impacts from the 2010–2011 floods and 2011 Tropical Cyclone Yasi. In this context, governments at all levels, from local to national, in Australia and elsewhere, have been adopting strategies to protect coastal assets that incorporate climate change. In general, these strategies fall into four categories: 1) do nothing, 2) retreat, 3) defend and 4) adapt. This paper examines the value of these four adaptation approaches by reviewing strategies from several international jurisdictions. To gain further insights into the value of the key coastal policy responses to climate change, the case study of coastal cities along the GBR is examined. It was concluded that because the approaches analysed (do nothing, retreat, defend and adapt) have different rationales and feature both weakness and strengths, a combination of such approaches would provide the best option for climate change adaptation in the GBR and in other jurisdictions.

Keywords: Coastal Adaptation, Climate Change, Sea Level Rise, Coastal City, Policy, Great Barrier Reef, Australia

Introduction

COASTAL CITIES CONTAIN half the world's population and are vulnerable to the impacts of climate change such as sea level rise and extreme flood events. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (2007; Binfoff et al. 2007) projects a sea level rise of 0.8m by 2100. Sea level rise may result in significant environmental and socioeconomic impacts, including losses of barrier islands; accelerated erosion of shorelines and artificial beaches; loss of marina, port, road and fisheries related infrastructure; loss of biodiversity and ecosystems such as coral reefs, marshes and mangroves with resulting tourism decline, particularly as beaches erode (Pilkey 2009).

In Australia, for example, over 80% of the population lives along the coastline making it particularly vulnerable to inundation from sea level rise (Harvey and Caton 2010). It is estimated that more than A$226 billion in residential, commercial, industrial, and road and rail assets are exposed to future coastal climate hazards, and that Queensland is the most at risk in terms of quantity and replacement value compared with other states in Australia

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(DCCEE 2011). Most of the population along the Great Barrier Reef (GBR), the focus of this study, is concentrated in the Queensland coastal cities of Cairns, Townsville, Mackay and Rockhampton which all contain low lying areas with significant infrastructure vulnerable to inundation (ABS 2006; DCCEE 2011). Adaptation is therefore paramount to coastal cities on the GBR, particularly in terms of incorporating climate change projections, mostly inundation, into coastal planning policy. Australia has historically experienced extremes in climate variability and subsequently provides numerous cases of the adaptation strategies undertaken to achieve resilience following a natural disaster (Palutik of 2010). These characteristics make Australia a useful case study to examine climate change adaptation policy.

Adaptation is "a process of deliberate change in anticipation of or in reaction to external stimuli and stress" (Nelson et al. 2007). Adaptive capacity can come in the form of adjustments that are either anticipatory actions, taken before the impacts are observed (planned) or reactive actions, taken after the impacts have been felt (autonomous). Anticipatory actions that create adaptive capacity and mitigation of flood disaster events through building and engineering solutions include planning legislation, building codes and urban design tools (Smit 2000). Local, state and federal governments have commenced formulating coastal policies that incorporate anticipatory adaptation to climate change with a trend of four distinct approaches emerging, namely (Norman 2009; Bonyhady et al. 2010): 1) Do nothing, 2) Retreat-relocate away from the coast, 3) Defend-protect the coast against the impacts seas level rise, and 4) Adapt-accommodate climate change and sea level rise. This model of coastal adaptation to climate change has evolved from work undertaken to respond to coastal erosion that dates in Australia back to the 1970's (Public Works NSW 1978).

The model of climate change response that categorises anticipatory coastal policies into four approaches is discussed in this paper in relation to its effectiveness for cities along the GBR coastline. A policy scan of international jurisdictions was undertaken to provide a variety of coastal climate change adaptation cases for each of the model's adaptation approaches. The various options for coastal adaptation provided from examples internationally, are discussed in the context of the key coastal cities along the GBR. This paper is structured as follows: the next section introduces the GBR case study; it is followed by a review of adaptation strategies from international jurisdictions; the subsequent section examines adaptation in coastal cities of the GBR and the last section briefly presents the concluding remarks.

Great Barrier Reef Coastal Cities and Climate Change

The Great Barrier Reef (GBR) has been recognised as being particularly vulnerable to the impacts of climate change with ocean acidification and increased sea surface temperatures likely to result in coral bleaching (Johnson and Marshall 2007; Bindoff et al. 2007; IPCC 2007; GBRMPA 2009a). Coastal ecosystems adjacent to the GBR, such as wetlands, have been found to play a critical role in maintaining the resilience of the reef to climate change impacts but the loss of wetlands, salt marshes, mangroves and barrier islands that protect coastlines are predicted result from climate change (GBRMPA 2009a; Johnson and Marshall 2007). The Great Barrier Reef may perform some functions as a bioshield reducing the impacts associated with climate change but storm surge recordings associated with tropical cyclones along the Far North Queensland coastline demonstrate the damage that can be done to the coastline (Hardy et al. 2004).

Population increase and subsequent intensified coastal development along the GBR coastline will be exposed to increased inundation under climate change scenarios from both sea level rise and extreme weather events such as floods and cyclones (IPCC 2007; Elsner 2008; DOCC 2009). The impact of the 2010-2011 floods in Queensland and Tropical Cyclone Yasi where the entire state of Queensland was declared a disaster zone, demonstrates the impacts of increased sea surface temperatures where cyclone formation is facilitated and produces associated heavy rainfall events on both coastal cities and the GBR itself (BOM 2011; GBRMPA 2011).

Under climate change scenarios, the coastline of the GBR is anticipated to experience inundation through four key sources: 1) sea level rise (IPCC 2007), 2) flash floods (Apan et al. 2010), 3) river floods exacerbated by tidal increases (Apan et al. 2010), and 4) storm surge associated with cyclones (Hardy et al. 2004). The history of flooding in the coastal cities of Cairns, Townsville, Mackay and Rockhampton (Figure 1) and associated causalities between 1913 and 2011 are shown in Table 1 (EMA 2011). This history is likely to be exacerbated by climate change and the importance of the adaptation of coastal cities adjacent to the GBR has been identified by the *Great Barrier Reef Climate Change Action Plan 2007–2012* which has identified (GBRMPA 2007).

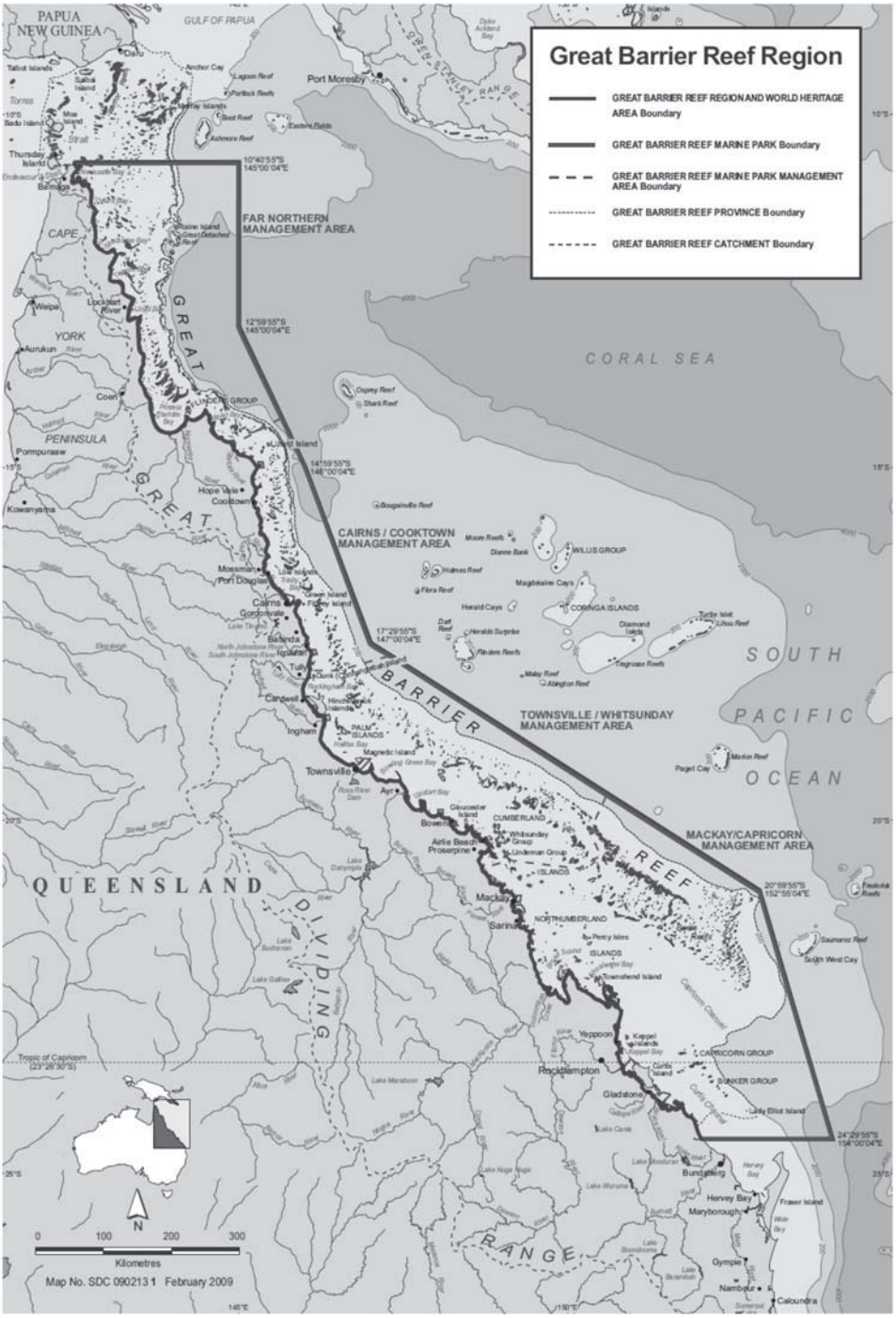

Figure 1: Largest Cities along the GBR Coastline

Table 1: History of Flooding of Cities on the GBR Coastline

City	Years	Flood Events	Related Deaths	Injured
Cairns	1913; 1927; Early Jan 1930; late Jan 1930; 1932; 1934; 1979; Dec 1990-March 1991; Dec 1990 – Jan 1991; 1996; Feb 1999; March 1999; Dec 1999; 2000; 2007; 2008 (Monsoonal); 2008 (Widespread)	18	58	176
Townsville	1934; 1958; 1996; 2000; 1930; 1932; 1934; 2007; 2008; 2009; Dec 1990-Jan 1991; 2001; 1997; 1999; 1998; 1990; 1929; 2008; 1930	19	128	92
Mackay	1930; 1932; Feb 1958; April 1958; 1959; Dec 1990 – Jan 1991; Dec 1990 – March 1991; 2000; 2007; Jan 2008; Feb 2008; Feb 2008 – March 2008	13	20	40
Rockhampton	1959; Dec 1990 – Jan 1991; Dec 1990 – March 1991; 1997; Jan 2008; Feb 2008-March 2008	6	7	55

Source: EMA database (2011)
Note: Information from the 2010–2011 floods in Australia had not been updated on the EMA database at the time of writing.

Coastal structures such as pontoons, jetties, wharfs, helipads, marinas, dredging activities, installation of discharge and intake pipes, aquaculture facilities and revetment developments are all located in the Great Barrier Reef Marine Park and world heritage area (GBRMPA 2003; UNESCO 2010) and will be inundated by sea level rise (GBRMPA 2007). Coastal recreational spaces such as playgrounds and businesses including coastal and island resorts may be encroached from a shoreline recession with Surf Lifesaving Clubs along the GBR particularly at risk (SLSQ 2011).

Queensland development trends have enabled residential development on freehold land adjacent to the shoreline which contrasts to other states such as Victoria where much of the coastline is buffered by crown land (VCC 2008). Businesses particularly vulnerable include commercial and recreational fishery facilities, ports, factories, warehouses, refineries, dive shops and training areas, and general beachfront enterprise such as restaurants, resorts, cafes and souvenir shops.

Climate change adaptation in coastal cities on the GBR and elsewhere in Australia involves all three tiers of government. Land use planning is legislated at the state government level, but assessed and activated at the local government level. This approach is similar for emergency management, climate change adaption and environmental management. The federal government provides a coordinating role between the various states in Australia and the overall policy direction is informed by international agreements. The legislative framework

for coastal disaster planning that applies to the GBR coastal cities is outlined in Table 2. Coastal disaster planning approaches are still being developed at the international level and the existing strategies currently have limited interplay with Australian policy. Further work is required at the international level to define the global direction for coastal disaster planning and recommendations that can be implemented at the local level.

Table 2: Coastal Disaster Planning Management Framework in Australia

Jurisdiction	**Agency responsible for emergency management**	**Agency responsible for planning**	**Agency responsible for coastal management**	**Agency responsible for climate change adaptation**
International	United Nations International Strategy for Disaster Reduction (UNISDR 2005)	United Nations Human Settlement Program–UNHAB-ITAT (2011)	United Nations Environmental Program (UNEP 2011)	International Council for Local Environmental Initiatives (ICLEI 2011)
Federal	Emergency Management Australia, Attorney-General's Department (AGD 2009)	Department of Infrastructure and Transport Planning Institute of Australia	Council of Australian Governments (COAG) Department of Sustainability, Environment, Water, Population and Communities	Department of Climate Change and Energy Efficiency
State	State Disaster Management Group (2010), e.g., Queensland State Disaster Management Group, *Disaster Management Act 2003*	State planning departments, e.g., Department of Planning and Infrastructure (DIP), *Sustainable Planning Act 2009*	State environment departments, e.g., Department of Environment and Resource Management (DERM), *Coastal Protection and Management Act 1995*	State climate change departments, e.g., Office of Climate Change (2007), Climate Smart Adaptation 2007–12 Plan

Regional	District Disaster Management Group (DOCS 2009), e.g., Mackay District Disaster Management Group	Regional plans are implemented by regional bodies, e.g., Whitsunday, Hinterland and Mackay (WHAM) region, Whitsunday, Hinterland and Mackay Regional Plan	Natural Resource Management Regional Bodies or Catchment Management Authorities, e.g., Mackay Whitsunday Natural Resource Management (NRM) Group, Mackay Whitsunday NRM Plan	Natural Resource Management Regional Bodies or Catchment Management Authorities
Local	Local Disaster Management Group, State Emergency Services, Rural Fire Brigade, community groups and NGOs (DOCS 2010), e.g., Mackay Regional Council (MRC) Emergency Action Guide	Local Councils, e.g., Mackay City Planning Scheme (MRC 2006)	Local Councils, community groups and Non-Government Organisations (NGOs), e.g., Mackay Beaches Project and Plans	Local councils, community groups and NGOs
Source: Adapted from Thomas et al. (2011)				

The study of cities on the GBR coast allows the exploration of the scope of adaptation options, including the identification of potential limits to adaptation and mitigation strategies, which may also prove useful to other jurisdictions.

Coastal Adaptation: Insights from International Practice

Different jurisdictions have different coastal planning policy approaches in response to climate change. The four classifications of coastal planning policy (do nothing, retreat, defend, adapt) have been widely used to examine climate change response (for example Norman 2009; Coast to Coast 2010; EA 2010). Each of these approaches is reviewed below in terms of their capacity to respond to climate change, using examples from various international jurisdictions.

"*Do Nothing*"

The "do nothing" approach involves maintaining coastal development and planning at the current standards without the costly modifications that incorporate climate change predictions–Table 3 presents some examples. The choice for this approach is largely explained by the uncertain nature of the impacts associated with climate change and the difficulty in modelling and predicting these impacts due to the multiple factors influencing the systems involved. In this case, cost-benefit analyses of implementing mitigation solutions with uncertain outcomes are overridden in preference of emergency management solutions that apply disaster response policies (Macintosh 2010).

Table 3: Examples of the "Do Nothing" Approach

Location	Policy	Climate change adaptation
United States	*Envisioning Our Coastal Future 2008* (NOAA 2007)	No reference to climate change and sea level rise.
United States	National Flood Insurance Program (FEMA 2010)	A government funded flood insurance scheme.

The case of the United States is illustrative of this approach. However, whilst no federal coastal policy that recognises sea level rise is currently present in the United States (US), the US EPA has developed work on the adaptation of estuaries to climate change (2011). The US Coastal Zone Management Act 1972 comprises two programs, the National Coastal Zone Management Program and National Estuarine Research Reserve System which produced the Rolling Easements report by the US EPA (Titus 2011) that outlines options for adaptation to climate change (NOAA 2011). The national US coastal policy should be revised to incorporate the recommendations by the US EPA to ensure greater implementation at the local level to reduce the economic burden on emergency management.

One current US national policy that may be considered an adaptive approach is a national government funded flood insurance scheme but this approach results in a lack of private responsibility to adapt to climate change by households, businesses and agencies. A more local based pro-active approach is required to consider climate change in risk analyses otherwise poor coastal planning decisions will continue and exacerbate the situation.

"*Retreat*"

The retreat approach involves relocating development and coastal activities to less exposed locations (McDonald 2010). Retreating from the shoreline allows for the protection of infrastructure, communities and sensitive ecosystems. The retreat policy enables a clear buffer for damage to the built environment as a result of sea level rise. However, in some cases, the retreat approach has resulted in conflicts and litigation. In the Australian state of Victoria, retreat policy has been challenged in the courts by land holders in local government areas due to its impact on land real estate value, which no longer can be developed (Briggs et al. 2010). Table 4 presents examples of the retreat approach.

Table 4: Examples of the "Retreat" Approach

Location	Policy	Climate change adaptation
Victoria (Australia)	Victorian Coastal Strategy (VCC 2008)	The South Gippsland Shire Council has incorporated the planned retreat approach.
New Zealand	New Zealand Coastal Policy Statement (Department of Conservation 2010)	Recognises the need for public open space in coastal areas. Objective 5 specifically aims to: locate development away from zones at risk to climate change impacts, managed retreat, and restore natural defences.
Great Britain	Making Space for Water (DEFRA 2005)	Managed retreat
Canada (New Brunswick)	Impacts of Sea-Level Rise and Climate Change on the Coastal Zone of South-eastern New Brunswick (Environment Canada 2006)	Climate change considered in environmental impact assessment processes. Coastal Lands Buffer Area to protect from inundation and includes a Coastal Transition Area.

"*Defend*"

The defend approach refers to engineering solutions to protect coastal development from the impacts associated with climate change such as sea level rise (MacDonald 2010). Defence constructions often comprise levees, sea walls and stormwater drainage. The defence approach aims to modify or prevent the events and allow for the continued land use patters whilst protecting existing coastal development. The defence approach assists in maintaining the lifestyles to which many coastal dwellers are accustomed. The danger is that when coastal defence mechanisms fail, a disaster could occur with cities unprepared; for example, in the case of the levees being breached in Hurricane Katrina (Nicholson 2005; Burton & Hicks 2005). The defend approach has been implemented in a number of jurisdictions, particularly in NSW and the Gold Coast in Australia where these policies have been applied to protect the value of real estate, constituents lifestyles and coastal tourism (Table 5).

Table 5: Examples of the "Defend" Approach

Location	Policy	Climate change adaptation
New South Wales (Australia)	NSW Sea Level Rise Policy Statement (NSW 2009)	Promotes emergency coastal protection works such as sandbagging under the *Coastal Protection and Other Legislation Amendment Act 2010*
Gold Coast (Australia)	Gold Coast Planning Scheme: Our Living City (GCCC 2007)	Boulder wall built to withstand 1/100 ARI[1] storm. Currently three quarters completed due to historic building. Requires all beachfront properties to be protected by a boulder wall designed prior to development (Boak et al.). Also requires a vegetated dune to be established over the top of the wall.
Gold Coast (Australia)	Climate Change Strategy 2009–2014 (GCCC 2009)	Defend–foreshore seawall; Adapt–Emergency Management solutions. Risk Management and risk reduction approach.
Italy (Venice)	Proposed MOSE project (Poggioli 2008)	Rows of mobile electronically operated gates to protect the city from flooding. There are 78 buoyant flap gates arranged in 4 rows.
China (Xiamen)	Program of shoreline defence	Xiamen, China restored the mangrove system in Tong'an Bay in 2007 (Norman 2009).

[1] ARI = Average recurrence interval (ARI; Middelmann et al. 2000) is the average, or expected, value of the number of years between exceedances of floods events of a given magnitude (gauge height or magnitude).

"*Adapt*"

The adapt approach involves change whether through coastal use, location of development and activities, or behaviour (McDonald 2010). Adaptation recognises the changing scenario and uses creativity to find solutions to continue operating in a new form in the changing environment. Adaptation may be costly and a fear reaction to circumstances that never eventuate or where technologies emerge that enable climate change impacts to be mitigated. On the other hand, adaptation does allow for a creative approach that establishes new scenarios and is itself an invention, such as the proposed operation 'Rialto' in Venice (Table 6).

Table 6: Examples of the "Adapt" Approach

Location	Policy	Climate change adaptation
Australia (Pittswater Council, NSW)	Flood Risk Management Policy (1991)	Resulted in almost 40% of houses in floodplains being lifted (Gordon and Pang 2004).
United States (New York)	*PlaNYC* 2030 (The City of New York 2007)	Creates an Intergovernmental Task Force to Protect vital infrastructure (defend), works with vulnerable neighbourhoods to develop site-specific protection strategies (adapt), and launches a citywide strategic planning process for climate change adaptation (adapt) (Rosenzweig et al. 2011).
China (Xiamen)	Functional Zonation Scheme (People's Republic of China 2011)	The 'sea use' zoning is integrated into the city's land use scheme (Norman 2009).
Cambodia (Sihanoukville)	Coastal Use Zoning Scheme (PEMSEA 2008)	Zoning scheme for both land and sea that aims to manage an integrated approach to coastal management.
Italy (Venice)	Operation 'Rialto' (AFP 2008)	Proposes to lift buildings by 1m using piston-supported poles at the base of each building.
Kiribati	Republic of Kiribati National Adaptation Program of Action (NAPA, 2007)	Includes a prioritisation rating for the implementation of adaptation projects for implementation (Eirick & Kay 2009).
South Africa	Draft Coastal Protection Zone By-Law (City of Cape Town 2011)	Considers: rehabilitating, monitoring and evaluating human activities and planning.

Coastal Adaptation to Climate Change in Cities along the GBR Coastline

Similar to other jurisdictions, climate change adaptation strategies have also been developed and adopted for the GBR coast; however, a comprehensive coastal development strategy for adaptation is still to be developed (Table 7). The existing strategies are examined here in order to provide further insights into the adaptation approaches discussed in the previous section. The analysis of specific strategies used on the GBR coast, such as coastal defences, conservation incentives, land use planning and growth management, natural systems and resources management helps developing a better understanding of issues and limits to the adaptation approaches under consideration (do nothing, retreat, defend and adapt).

Table 7: Examples of Climate Change Response Policies on the GBR Coast, Australia

Jurisdiction	Policy	Climate change adaptation
National	Great Barrier Reef Climate Change Action Plan	**Adapt** – Reef Guardian Council Program (GBRMPA 2009a)
State	Queensland Coastal Plan (2011)	A combination of: do nothing, retreat and adapt: **Do nothing** – accepts abandoning functional marine infrastructure and coastal development in the case of sea level rise. **Retreat** – relocation of built structures outside erosion prone areas. **Defend** – last case scenario with beach nourishment as the preferred method. **Adapt** – accepts functional marine infrastructure and coastal development that may be relocated.
Local	Cairns Regional Council Climate Change Strategy 2010–2015 (2010)	Multi-solution focused: **Retreat (Avoid)** — location of new development in areas not vulnerable to the impacts of climate change; **Retreat (Planned)** — systematic abandonment of land, ecosystems and structures in vulnerable areas; **Adapt (Accommodate)** — continued occupation of near-coastal areas but with adjustments such as altered building design; **Defend** — protect vulnerable areas, population centres, economic activities and coastal resources.
Local	Mackay Coastal Management Guidelines (MRC 2009)	**Adapt** — Beach Plans

Retreat

Coastal Defences

Coastal defences involve conserving land in coastal areas by removing development through acquisition and implementing conservation easements, and strategic plans that incorporate coastal buffer zones with focus on community open spaces (CUES; cited in Norman 2009). Along the GBR coastline, the Strand beach front in Townsville has some aspects that act as a coastal buffer through green space that incorporates recreational opportunities and result

in social benefits. Buildings adjacent to the green space located on the Strand are zoned as mixed residential and limits building heights to a maximum of three stories according to the Townsville City Plan (TCC 2005; SO2, PS 2.1). This retreat approach results in both aesthetic benefits and reduces the population at risk from storm surge events. Conversely, the Strand includes restaurants location on reclaimed headlands built up by rock walls that will be particularly vulnerable to damage from sea level rise and storm surge. In addition, despite the building height restrictions in the planning scheme, multi-storey apartments have also been approved and constructed on the water front located adjacent to the Breakwater marina, which are particularly vulnerable to impacts of sea level rise and intensified cyclones.

Conservation Incentives

The proposed Ella Bay Integrated Resort development, in the Cassowary Coast Region, is an example where conservation incentives have been applied. The location consists of coastal wetlands that are vulnerable to both sea level rise and flash floods. In this case, offsets, such as revegetation of 14 hectares, research programs, and a strategic regional planning and corridor protection have been proposed to mitigate possible environmental impacts (Satori Resorts Pty Ltd 2008). Offsets provide a means of conserving environmental values that may not be otherwise achieved. A weakness of this approach is that projects need to be assessed on an individual basis so that coastal values are not compromised.

Land Use and Growth Management

Land use policies (for example, overlay zones) may be enacted to minimize development in coastal hazard areas (for example by locating development away from coastal hazards and retreating or relocating public facilities and infrastructure) and low lying interior areas. In Queensland developments have traditionally taken place adjacent to shorelines which are coastal hazard areas for sea level rise and floods. Marina developments, such as Mackay, Shute Harbour in Airlie Beach, Breakwater marina in Townsville, Port Hinchinbrook Marina in Cardwell, Cairns and Port Douglas are typical examples. Cyclone Yasi brought millions of dollars of damage to the Port Hinchinbrook (2011) marina. Further port developments are planned by the Queensland Government with the Queensland Coastal Plan (DERM 2011c) identifying marina development areas along the coast.

Land use planning needs to incorporate growth management by allocating land for long-term potential population migrations. The Far North Queensland Regional Plan 2009–2031 (DIP 2009) acknowledges the growth within the region and has matched this with available residential land in the area. It has addressed growth by advocating policies that protect rural land, intensify urban populations to make public transport options more viable, and to facilitate service delivery. A consideration is that greater urban population located in coastal areas along the Great Barrier Reef shoreline creates increased pressures on the reef through the anthropogenic impacts of coastal development. It also results in larger populations located in hazardous areas.

Land Use and Coastal Erosion

The modelling of sea-level rise and flood scenarios effects on coastal erosion needs to be incorporated into natural hazard codes in planning schemes. This way, land suitability criteria may be revaluated to prevent the development of vulnerable land. DERM released the "Queensland Coastal Hazards Guideline" (2011a) that recognises the importance of incorporating climate change into existing storm tide inundation area assessments. The guideline recognises the costs required to update the current datasets, which is beyond the capacity of local governments to fund storm tide inundation area assessments. Current data may be supplied through the floodplain mapping occurring throughout Queensland, as part of the Queensland Reconstruction Authority (QRA 2011) "Planning for stronger, more resilient floodplains" guideline.

Natural Systems and Resources

Programs that facilitate species migration could be developed to protect natural systems and resources from sea level rise. This involves creating and preserving existing biodiversity corridors for habitats such as seagrasses which are critical for shorebirds, turtles and dugongs. Seagrass-Watch, for example, is a program that monitors the health of seagrasses along the Queensland coast and has highlighted the vulnerability of seagrasses to both sea level rise (McKenzie 2011) and floods (McKenzie & Unsworth 2011). The Australian Government (AGLC 2011) has provided $1.08 million to address immediate impacts of the 2010–2011 floods and cyclones on the GBR. This funding includes assessments of these impacts on dugongs and seagrasses, and the early detection and eradication of new pests expected to arrive as a result of the cyclone and floodwaters. Whilst, monitoring programs for seagrasses are in place, management actions are currently limited to those programs undertaken by port authorities, which are required to have Dredge Management Plans approved in accordance with DERM guidelines (2011b).

Another example is Mon Repos, located 15km from Bundaberg, which contains the largest rookery of nesting turtles on the Eastern Australian mainland. Despite not suffering impacts of the 2010–2011 floods, adaptations are required to mitigate against any future events (Bundaberg Region Limited 2011; Fuentes et al. 2011).

Re-creating natural systems with endemic species and habitat coverage, in particular, for wetlands is also a means of facilitating species migration. For example, the case of the Cattana wetlands, a former private cane farm and resource site that has been rehabilitated by the Cairns Regional Council (2011). In the Tyto wetlands in Ingham, another example, the Hinchinbrook Shire Council (2011) has invested in a public education program to facilitate the preservation of wetlands that serve as biodiversity corridors for species migration. Other prospects include freehold land owners implementing covenants under the *Income Tax Assessment Act 1997* to preserve wetlands as biodiversity corridors, which also play a critical role of absorbing flood waters and protecting the reef.

Defend

Coastal Defences

Constructing hard structures such as seawalls and floodwater control gates, where appropriate, are examples of policy mechanisms to defend the coastline. Mackay, for example, has floodwater control gates as a defence against tidal inundation used, particularly, when the Pioneer River heights are elevated after heavy rainfall in the catchment (BOM 2010). These Pioneer River floodwater control gates could also be used in the cases of high tides that may coincide with associated storm surge from cyclones. There are limitations to defence solutions, for instance, the floodgates in question do not prevent tidal flooding in South Mackay where development has occurred in what was formerly the site of the Pioneer River (DERM 2004). Defence engineering solutions may also increase sediment transport to the Great Barrier Reef and impact on water quality (GBRMPA 2009b; DPC 2009).

Adopting soft defence strategies is another mechanism of coastal defence available in the GBR. They include, for instance, establishing aquatic vegetation beds using natural or artificial breakwaters and beach nourishment where appropriate (e.g., shorelines that are less developed and where a seawall would inhibit wetland migration and damage natural defence systems). The Cassowary Coast Regional Council's (CCRC 2011) Shoreline Erosion Management Plan, for example, includes beach nourishment as a soft defence strategy.

Adapt

Buildings and Infrastructure

The adaptation of buildings and infrastructure to climate change involves strengthening building codes to provide additional protection for properties from sea level rise and storm surges. Building codes for coastal dwellings and flood prone areas could be designed to ensure that new developments incorporate adequate measures so that they are built off the ground but allow for water passage on ground levels. Placing car parking on the ground is a means of allowing water passage but underground or enclosed car parks has the potential to be hazardous and lead to people being trapped with no windows for escape.

Changing the placement and design of infrastructure, for example, for water supply, wastewater treatment, power plants and other utilities, and transportation will also be required to adapt to the changes in climate. The Cairns City Council (2009) in its *Climate Change Adaptation Action Plan* advocates the progressive upgrading of the drainage and transport infrastructure in existing development areas, aiming to provide protective infrastructure where necessary.

Retrofitting roads and bridges, rebuilding these structures at higher elevations, developing engineering techniques that allow to float or withstand flooding also comprise adaptation options. The road system in Townsville, for example, was designed so that when it floods, the roads are used to divert water from development and out to sea (Thuringowa City Council 2000). Section 14.2 Avoidance of Damage to Property refers to the road reserve being used as part of the drainage network but more detailed criteria are not specified (Thuringowa City Council 2002).

Provisions under the National Disaster Relief and Recovery Arrangements could be created to require disaster flood damaged houses to be rebuilt above 1/100 ARI flood line; and ap-

propriate building materials such as plastic cladding rather than timber cladding to be used in houses located in floodplains.

Coastal Defences

Port master plans need to be revised to reflect the impact of sea-level rise. The Port of Townsville (2010) released the *Port Development Plan 2010–2040*, which has no mention of climate change and associated impacts. Climate change impacts should also be addressed in plans for working waterfronts. An example of this would be the incorporation of adaptation to climate change in the Port Douglas Waterfront Master Plan (Cairns City Council 2011).

Emergency and Hazard Planning

Working with at-risk neighbourhoods to develop site-specific approaches to emergency and flood planning is a means of adapting communities by incorporating hazard management into local plans. Residential developments in Bushland Beach, Townsville are located fronting the tidal zone and will be particularly at risk of shoreline erosion and storm surge associated with sea level rise (Thuringowa City Council 2003). The impact of sea-level rise or flooding and storm surges and more frequent and intense tropical storms should be taken into account in local emergency evacuation plans. In addition, elevating structures above the 1/100 ARI flood line should also be considered. A cost-benefit analysis or other economic model could be undertaken to account for any greater costs incurred to the council and subsequently rate paying residents from any disaster impacts from proposed developments.

Concluding Remarks

This paper examined the value of four climate change adaptation approaches that have emerged in coastal planning policies, namely “do nothing”, “retreat”, “defend” and “adapt”. The value of these approaches was discussed by reviewing strategies from several international jurisdictions, with emphasis on cases from coastal cities along the Australian GBR coast. Each of the adaptation approaches presents different rationales and features both weakness and strengths so their combined use would reduce the risks associated with relying on only one approach – which if failed could result in devastating impact on coastal cities. The review undertaken demonstrates the need to develop a climate change adaptation strategy for the GBR coastline. A combination of approaches may in fact provide the best framework for climate change adaptation on the GBR coast and in other jurisdictions.

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About the Authors

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A strong interest in coastal disaster planning policy and adaptation to climate change. Worked on the key research projects for the Centre for Disaster Studies at James Cook University in Australia including a Social Resilience study using case studies of four different natural disasters in Australia funded by the Department of Climate Change and Energy Efficiency and a report for Australia's peak climate change adaptation research body NCCARF titled "The 2008 Floods in Queensland: A Case Study of vulnerability, resilience and adaptive capacity". There have been various publications associated with this work and I have given presentations at various university seminar series, national and international conferences. Currently work for the Australian Department of Sustainability, Environment, Water, Population and Communities. Formerly worked for the Great Barrier Reef Marine Park Authority, the Victorian Department of Sustainability and Environment and also in Queensland local government.

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My research, in a broad sense, focuses on the social and institutional dimensions of environmental governance. The notion of systems of policies, regulations, norms, decision-making-processes and property rights (known as institutions) that govern human-environment interactions is central to my research. I am particularly interested in examining how institutions, at multiple levels and scales, can be designed and changed to promote improved environmental governance. This includes: examining institutional responses to overuse and degradation of natural resources, and to climate change; analysing institutional interactions at multiple levels (local, sub-national, national, international and intermediate levels); and, identifying governance attributes that promote (or otherwise) sustainable resources use and management. Examples of my current research include investigating the governance of large-scale complex marine resource systems in Australia and Southeast Asia.