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Global Lessons for Adapting Coastal Communities to Protect against Storm Surge Inundation

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ABSTRACT

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Coastal inundation as a result of global sea-level rise and storm surge events is expected to affect many coastal regions and settlements. Adaptation is widely accepted as necessary for managing inundation risk. However, managing inundation risk is inherently contentious because of many uncertainties and because a large number of stakeholder interests and values are mobilised. For these reasons, among others, adaptation progress in many countries has been slow. Despite progress in adaptation research, a critical knowledge gap remains regarding the appropriateness and applicability of various adaptation options, including their transferability between different coastal settings. We review the international literature on coastal adaptation options (including options to defend, accommodate, or retreat) to manage inundation risk, focusing on developed, liberal economies of Western Europe, North America, the U.K., Australia, and New Zealand. In doing so, we identify the favoured strategies adopted by these nations, probe the influence of physical and institutional context on the selection of these options, and identify what lessons might be exchanged or future directions inferred. The review places particular emphasis on the Australian experience as a comparative device to highlight some important distinctions. These distinctions focus on how government responsibility is exercised, including the degree of centralisation; the "fit" of options to local coastal environments and social values (*i.e.* their suitability and acceptability); and the transferability of different adaptation options in international contexts.

ADDITIONAL INDEX WORDS: *Accommodate, adaptation, climate change, defend, government, policy, retreat.*

INTRODUCTION

Coastal inundation has caused significant damages around the world (Wilby and Keenan, 2012). The potential severity and frequency of inundation events is projected to worsen as coastal cities grow (Guofang, Fukuzono, and Ikeda, 2003; Hallegatte and Corfee-Morlot, 2011) and sea levels rise (Hallegatte *et al.*, 2011). The spatial distribution of inundation risk varies at all scales, from region to region, suburb to suburb, and even property to property. For the purpose of this review we refer to inundation risk in general terms to describe coastal flooding under both current and future climate scenarios. This heterogeneity is a reflection of physical factors, such as the risk of storm surge and the topography of the landscape, as well as socioeconomic factors, such as the level of development and the capacity within the community to adapt (Leitch, Harman, and Lane, 2010; Linham and Nicholls, 2012). Although the events themselves may be unavoidable, coastal communities can adapt to protect against some of the likely future damages of inundation. Although mitigation of global greenhouse gas emission remains a critical component of the policy challenge, adaptation to "locked-in" effects is widely accepted as a key strategy of risk reduction among scholars and planning practitioners (Adger, Brown, and Tompkins, 2005; Alexander, Ryan, and Measham, 2012; Baker *et al.*, 2012). Adaptation practice has been slow in many countries, and it is often hampered by complex institutional (Tompkins and Adger, 2005) and cross-scale governance arrangements (Adger, Arnell, and Tompkins, 2005; Verschuuren and McDonald, 2012). The need to address these complexities and challenges to advance adaptation has been recognized in coastal planning and management regimes worldwide (Linham and Nicholls, 2012).

Previous adaptation research acknowledges the need to improve our understanding of the appropriateness and applicability of various adaptations, including their transferability to different coastal settings (Klein *et al.*, 2001). More recently, Linham and Nicholls (2012) discuss a number of specific technologies used in both developed and developing countries, with a particular emphasis on the importance of enhancing knowledge and monitoring requirements for effective implementation within an integrated coastal governance framework. This review seeks to build on the existing body of work, examining coastal adaptation practices from developed countries including Australia, New Zealand, the United States, the U.K., Canada, Singapore, and several Western European countries. The main focus of this analysis is on coastal inundation risk as a result of sea-level rise and storm surge. The paper takes a global perspective but also provides links to

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Australian adaptation practice. We specifically investigate Australian practices because they have been underrepresented in the international coastal adaptation literature, particularly in the context of other developed nations. In doing so, we bring additional empirical material to the coastal adaptation debate. We use the three widely recognized strategies of "protect, accommodate, and retreat" (Bray, Hooke, and Carter, 1997; Few, Brown, and Tompkins, 2007; Klein *et al.*, 2001; Nicholls, 2011; Tol, Klein, and Nicholls, 2008) to better understand the preferences and contexts of different nations for coastal adaptation. We frame these preferences in light of the different physical and institutional contexts in which coastal adaptation is proposed or enacted. We then identify and discuss some of the critical challenges for the transfer of coastal adaptation lessons between these developed countries.

PROTECT

Coastal defence measures involve the use of both hard and soft approaches to protect vulnerable coastal areas from inundation and sea-level rise.

Hard Defences

Hard defences, such as seawalls, dikes, levees, and groynes, are common strategies for managing coastal flooding and erosion (Klein, 2011; Linham and Nicholls, 2012). Many European countries, such as Germany, the U.K., and The Netherlands, have a long history of using hard coastal defence structures. For example, northern Germany's first dike rings were erected about 1000 years ago to protect farmland from flooding, and by the 14th century, the entire German North Sea coast was protected by a continuous dike line (Hofstede, 2008). In The Netherlands, dike rings are used to protect most low-lying parts of the country from coastal flooding. The national government has responsibility for the main dikes and embankments along the coastline.

Several countries are currently upgrading their existing levees and dikes to account for sea-level rise–induced flooding (Deltacommissie, 2008; Ligtvoet *et al.*, 2012). In Germany, safety standards of dikes have recently been raised by an average of 25 cm to protect against inundation risk (Garrelts and Lange, 2011). Dutch pilot projects even plan to situate entire residential areas on top of Delta Dikes (EEA, 2009). In Singapore, where nearly 80% of the coastline is protected from inundation by hard defences, existing seawalls and revetments are also currently being strengthened and reinforced to combat the long-term effects of rising sea levels (MEWR, 2008). Another adaptation technology gaining popularity is the construction of storm tide barriers. These large-scale coastal defence projects typically involve movable or fixed barriers or gates that are closed to prevent flooding when an extreme water level is forecast. They are usually located at narrow tidal inlets to reduce the length of the structure and cost of construction (Linham and Nicholls, 2010). These structures exist, for example, in Singapore (Marina Barrage; Harley and Guan, 2009), London (Thames Barrier; Shallcross, Buskes, and Dagastine, 2011), The Netherlands (Maeslantkering; Madlener, Smetsers, and van Eekelen, 2010; Samyn *et al.*, 2007), and Italy (MOSE project; Vergano, Umgiesser, and Nunes, 2010).

For the majority of the Australian coastline, coastal defence is rarely needed, although in a number of locations erosion and storm surge inundation is a chronic and expensive problem (Short and Woodroffe, 2009). In these locations, seawalls are the most common strategy for shoreline protection, although the condition and integrity of these structures vary, and many have been illegally placed (DCC, 2009). Perhaps the most well-known stretch of defended coastline in Australia is the 35 km between the New South Wales–Queensland border at Point Danger and the Nerang Inlet (Short and Woodroffe, 2009). The establishment of groynes, revetments, and artificial reefs to manage sediment transport in coastal communities are also commonly used practices for coastal engineers and managers (New South Wales Government, 2010; Tomlinson and Helman, 2006).

For many Australian coastal communities, the beaches are a major asset because they attract a significant number of tourists, both domestically and internationally, and thereby contribute to the local economy (Short and Woodroffe, 2009). The Gold Coast is a popular exemplar. With approximately 52 km of beachfront to the Pacific Ocean, it benefits from some of the best and most popular surfing beaches in Australia (Lazarow, 2007; Raybould and Lazarow, 2009). The Gold Coast has a legacy of intense beach erosion during major cyclonic events, and the long-term process of erosion and accretion along the beaches is incompatible with the spatial pattern of urban development and the local beach-based economy (Bowra *et al.*, 2011). As a result, the local council invests heavily in programs to manage beach erosion and storm surge inundation under the provisions of the Shoreline Management Plan (GCCC, 2003). A major component of this investment has been the implementation of the A-line seawall as a last line of defence against inundation risk during major storm surge events (GCCC, 2012a).

Ownership of coastal frontage is shared between public and private landowners. The responsibility to fund the construction of seawalls is shared between private property owners and the local government. However, construction of seawalls is not readily accepted by landholders given the relative high costs involved (Bowra *et al.*, 2011). Despite the benefits associated with the construction of hard coastal defence structures, a number of concerns have been raised (Rupp-Armstrong and Nicholls, 2007), including asset deterioration and failure (DEH, 2005), construction and maintenance costs (Sovacool, 2011), and changes in erosion and sediment patterns (McLaughlin, 2011; Scyphers *et al.*, 2011; Tomlinson and Helman, 2006). Subsequently these practices are usually accompanied by other measures such as beach nourishment.

The use of submerged structures (also known as artificial reefs) using geotextile materials for multipurpose benefit is a relatively new coastal management concept compared with the more traditional hard-engineered responses to manage coastal erosion and storm surge (Edwards and Smith, 2005). These multipurpose structures exist in Australia, New Zealand, the United States, and the U.K. (Fletcher, Bateman, and Emery, 2011). In Australia the Narrowneck Reef, located on the Gold Coast, has reportedly achieved both beach protection and improved surfing conditions (Jackson *et al.*, 2007). However, as can be seen in the U.K., not all artificial reefs are considered successful (Fletcher, Bateman, and Emery, 2011).

Construction of seawalls in Australia is largely funded by local governments and private actors, depending on the nature of the asset being protected. By contrast, in many countries, particularly those with a legacy of dealing with inundation risk, funding and responsibility for seawalls rest with state and national governments. In many cases, the construction of seawalls in Australia (sometimes unauthorized construction; P. Watson, *personal communication*) and failure to augment with other strategies, such as sand nourishment, has also led to downstream effects (Horton and Cameron, 2012; Short and Woodroffe, 2009; Tomlinson and Helman, 2006).

Soft Defences

Soft coastal defence measures, such as beach nourishment and sand dune restoration, adapt to and supplement natural processes. Beach nourishment, in particular, has seen a rapid growth in interest and application over the past few decades (Linham and Nicholls, 2010; Rupp-Armstrong and Nicholls, 2007). It presents a flexible no-regrets approach to deal with climate adaptation, in that it is reversible and can also be easily modified to the actual rate of sea-level rise (Hofstede, 2011). It often complements hard protection measures such as seawalls. The natural appearance of beach nourishment projects also means these schemes are aesthetically pleasing, promoting recreation and tourism (Linham and Nicholls, 2010).

Beach nourishment has a long history of application in many developed countries, such as Germany, The Netherlands, and the United States. Since 1963 in Germany, for instance, almost 40 million cubic meters (Mm^3) of sand has been nourished on the beaches of Sylt, a German island in the North Sea (Hofstede, 2008). Beach nourishment is also a major focus of the Dutch government to protect its communities from coastal flooding on the North Sea and on the Wadden Sea Islands (van der Wal, 2004). Approximately 12 Mm^3 of sand has been nourished at selected locations along the Dutch coastline on an annual basis since 2000 (Bakker *et al*., 2012). An innovative experimental sand nourishing project is also proposed. It involves the dredging and positioning of a superdune of sand in the sea in such a way and in a location that enables hydrological forces to spread the sand to where it is needed (Bakker *et al*., 2012). Beach nourishment is also one of the preferred methods of erosion and inundation control along coastal parts of the United States, with the great majority of the Atlantic and Gulf Coast states utilizing beach nourishment practices (Trembanis, Pilkey, and Valverde, 1999). Most of these receive federal or state funding for beach nourishment activities, either as an ongoing program or provided on a case-by-case basis (Higgins, 2008; Trembanis, Pilkey, and Valverde, 1999).

In Australia, the use of beach nourishment and sand dune restoration programs to manage erosion is also widely practiced (Cooke *et al*., 2012; McLachlan *et al*., 2013). These measures are seen as viable options to manage destructive coastal processes, particularly where amenity and costs are concerned. However, the effectiveness of beach nourishment programs is expected to decrease over time as beaches become more unstable (DCC, 2009, p. 152). Beach nourishment and sand dune restoration are especially common in areas dependent on beach use for tourism (*e.g*., Gold Coast and Sunshine Coast, Queensland). For example, the Maroochy Beach on the Sunshine Coast attracts almost three million visitors per year, which contributes approximately A$88 million of economic benefit to the region (SCRC, 2012). The Sunshine Coast Regional Council (SCRC) has recently endorsed a substantial nourishment program to increase the erosion buffer and protect assets, such as parks, footpaths, and roads (SCRC, 2012). The Gold Coast City Council has been undertaking beach nourishment projects since 1974 (GCCC, 2012b). A number of bypass projects in Australia use sand for nourishment purposes. For example, Bandy Creek Harbour (Western Australia), Noosa (Queensland [QLD]), Tweed River Entrance (New South Wales [NSW]/QLD), and Port of Portland (Victoria [VIC]) (Cooke *et al*., 2012). The Tweed River Entrance Sand Bypass Project has pumped nearly 7 Mm^3 of sand since becoming operational in March 2001 (New South Wales Government and Queensland Government, 2013).

A recent study investigating beach nourishment practices in Australia revealed that a total of 130 beaches are currently managed by artificial nourishment, replenishment, or beach scraping programs (Cooke *et al*., 2012). However, compared with beach nourishment programs being conducted in European countries, Australian programs are typically smaller in scale, shorter in duration, and more frequent (Cooke *et al*., 2012). When compared with international beach nourishment programs, Australian efforts also lack sufficient monitoring to inform ecological impacts and efficiency of program delivery (Cooke *et al*., 2012).

Despite its perceived benefits, beach nourishment also has some limitations. Periodic renourishments are needed to maintain a scheme's effectiveness, which requires ongoing and regular monitoring (Bakker *et al*., 2012). The unit costs of beach nourishment typically vary from US$3 to 15 per m^3 (at 2009 price levels) where dredge sites are available locally (Linham and Nicholls, 2010). However, costs can increase depending on transport distance of available sites for sand exportation. The increasing popularity of beach nourishment worldwide may cause sediment availability constraints (Linham and Nicholls, 2010). In The Netherlands, a limited availability of contractors, coupled with an increase in demand for nourishment projects, has already caused cost increases for nourishment projects (Hillen *et al*., 2010).

In the United States, debates have emerged about the appropriate federal role in beach nourishment activities and who should pay for the high costs (Trembanis, Pilkey, and Valverde, 1999). Some opponents argue that federal funding spent on nourishment projects is wasted and has also led to the accelerated development of vulnerable coastal areas, thereby putting even more people and properties at risk (Jones and Mangun, 2001; Pielkey and Young, 2005). Additionally, protection benefits are seen to be temporary and poorly documented, whereas the primary beneficiaries usually are private property owners and recreational interests (Carter, 2012).

Living Shorelines

The use of "living shorelines" as a third defence approach (Scyphers *et al.*, 2011) is described as "a suite of bank stabilisation and habitat restoration techniques to reinforce the shoreline, minimise coastal erosion, and maintain coastal processes while protecting, restoring, enhancing and creating natural habitat" (Latta and Boyer, 2012, p. 1). A living shoreline can provide a viable alternative to hard coastal defence structures such as seawalls (Mitsova and Esnard, 2012; Swann, 2008). One example is the GreenShores project in Florida, which created more than 30 acres (>12 ha) of oyster reefs, salt marsh, and seagrass habitat along 2 miles (3.2 km) of urban waterfront (DEP, 2012).

Studies suggest that the construction and maintenance of living shorelines can be more economical than hard defences and require less maintenance over time (Pace, 2011; Roberts, 2006; Walker, Bendell, and Wallendorf, 2011). However, they are not suited for high-energy areas like open beaches, where beach nourishment remains a better means for addressing erosion and coastal flooding (Pace, 2011). The concept of living shorelines is embedded in conservation planning literature (Chapman, 2013); however, implementation and practice is not well advanced in international contexts, in which there is a lack of quantitative and comparative assessment between traditional responses as well as a lack of monitoring success (Mitsova and Esnard, 2012). This is also the case in Australia, where hard coastal defence measures along with major infrastructure investment in highly urbanized coastal environments are key barriers that prevent the construction and migration of natural defence measures (*e.g.*, wetlands; Abel *et al.*, 2011; Burley *et al.*, 2012). Consequently, the use of hard structures (*e.g.*, seawalls) and sand nourishment continue to dominant coastal management practices in Australia.

ACCOMMODATE

Accommodation measures seek to allow the continued or extended use of at-risk areas by reducing the sensitivity, exposure, or both to sea-level rise (Alexander, Ryan, and Measham, 2012; DCC, 2009). A range of measures are utilised to allow the continued use of at-risk areas, including changes to building codes and urban design standards, elevated floor and increased setback requirements, hazard insurance, improved drainage, and the preparation of emergency evacuation plans.

Building Codes and Urban Design Standards

Building codes and design standards play an important role in making development more resilient to a changing climate. They can address a number of issues, including building elevation, foundation design, moisture entrapment, and damage from debris (Nichols and Bruch, 2008). The Finnish City of Helsinki on the Baltic Sea began to initiate changes to design standards addressing coastal flooding and sea-level rise in the late 1980s. For instance, the City Planning Department held its first seminar on the issue in 1989, which resulted in the decision to raise floor levels in the inner city suburb of Ruoholahti from 1 to 3 m above mean sea level (Lehtonen and Luoma, 2006; Peltonen, Haanpää, and Lehtonen, 2005).

In The Netherlands, the City of Rotterdam is emerging as a frontrunner in the field of climate adaptation through its innovative Rotterdam Climate Initiative and the Rotterdam Climate Proof Programme (Dircke and Molenaar, 2010). Rotterdam lies approximately 2 m below mean sea level, making the city highly vulnerable to coastal inundation (Ward *et al.*, 2013). The Rotterdam Climate Proof Programme is forecast to make Rotterdam climate resilient by 2025 (Dircke and Molenaar, 2010). For instance, Rotterdam has plans to build floating urban districts, such as Stadshavens, an area of 1600 ha outside the levee system (PSR, 2008). By 2040, approximately 1200 floating homes will be built in Stadshavens (PSR, 2008).

In Australia, "buildings are designed and constructed in accordance with the federal Building Code of Australia (BCA) to withstand climate related hazards such as cyclones and extreme winds, intense rain, bushfires and to some extent flood" (Australian Building Codes Board, 2010, p. 2). Although the standards for construction of buildings are constantly reviewed on the basis of the performance after major hazard events and via on-going research and design, the current BCA is likely to be deficient if their climate changes in accordance with the high-emissions scenario proposed by the Intergovernmental Panel on Climate Change (IPCC; Australian Building Codes Board, 2010). For planning purposes, flooding risk is defined by the 1in 100-year average recurrence interval or 1% annual exceedance probability (AEP). State-based flood-related planning controls require residential development to be constructed so that the habitable floor levels are located at or above the level of the 1% AEP flood (Queensland Floods Commission of Inquiry, 2012). At the local scale, most local governments implement an additional freeboard amount above the 1% AEP state level requirement to allow for a margin for modelling uncertainty and local risk. This is also consistent in coastal urban areas, where local planners are familiar with modelling uncertainties in relation to sea-level rise and storm surge inundation (Walsh *et al.*, 2004). In general, the freeboard level above the 1% AEP ranges between 0.3 and 0.5 m (DCCEE, 2011). However, specific levels are determined by local councils to factor in local circumstances (DCCEE, 2011). In some states, freeboard levels are not mandatory and thus are left to local government discretion (Queensland Floods Commission of Inquiry, 2012). As a result, many local authorities throughout Australia have not implemented freeboard levels to cater to climate variability and uncertainty.

Public Disclosure

Public disclosure is a risk management tool used to notifying home buyers of potential coastal inundation threats. In the United States, disclosure statutes require the seller to identify whether the property has been affected by floods or are located in a flood zone or on a floodplain (Ruppert, 2011). For example, in California, property owners are required to disclose whether they are selling residential property that is located in a flood hazard area (Grannis, 2011). The disclosure can take several forms, including generic notification that the property is in a zone vulnerable to sea-level rise or a more specific notification that the particular property has experienced flooding or storm damage in the past (Nichols and Bruch, 2008). Although it is not likely that public disclosure would prevent sales, it can affect the ultimate sale price to reflect increased risk of sea-level rise and of future regulatory measures (Nichols and Bruch, 2008).

At present, there is no consistency in risk protection standards or risk disclosure requirements relating to climate change risk management in Australia (DCCEE, 2011). Implementation of public disclosure of risk in the context of climate change adaptation is predominantly limited to New South Wales and, to a certain extent, Victoria and South Australia (DCCEE, 2011). (At the time of writing, the NSW sea-level rise Policy, including planning benchmarks, has since been revoked and thus it is not a requirement.) Similar to the international context, there was strong objection from the community to the inclusion of climate change risks on land title (Scarlett and Gangaiya, 2012). Equity concerns were raised about the fairness of the notations given the uncertainty associated with hazard assessments, and it was feared that notations would affect property prices and insurance premiums (Scarlett and Gangaiya, 2012).

RETREAT

Coastal retreat refers to the planned or managed withdrawal from hazard-prone areas of the coast (Alexander, Ryan, and Measham, 2012). This may involve relocating or abandoning assets in high-risk areas, preventing development in coastal areas, and allowing development to take place on the condition that it will be abandoned if necessary (Linham and Nicholls, 2012).

Planned Retreat

Planned retreat is a coastal management approach that acknowledges unsustainable inundation risk and long-term recession as a dominant factor in planning for the use of coastal areas. Planned retreat allows the temporary use and occupation of coastal lands until the erosion escarpment encroaches within a specified distance from a development, which will be required to be relocated (Alexander, Ryan, and Measham, 2012). Planned retreat is typically not considered appropriate for highly developed urban environments (Rupp and Nicholls, 2002). Investing in planned retreat today can save communities from future costs of flood protection (Abel *et al*., 2011). Additionally, planned retreat protects existing and creates new intertidal habitats, which are a natural form of flood protection (Abel *et al*., 2011; DCC, 2009). For these reasons, among others, planned retreat policies are increasingly being considered an alternative to the use of hard structures in many countries (DEFRA, 2005; Luisetti *et al*., 2011).

Implementation of planned retreat schemes can be seen in England and Germany (Rupp-Armstrong and Nicholls, 2007). However, the term "planned retreat" has been renamed because of its negative connotations and is now called "managed realignment" (Rupp-Armstrong and Nicholls, 2007). Managed realignment in the U.K. includes the deliberate breaching of existing sea defences, allowing the land to be flooded (Moeller and Spencer, 2002). An example of a managed realignment project in the U.K. is the Hesketh Out Marsh in Lancashire, which utilised voluntary agreements with landholders to abandon their land (Tovey, Pontee, and Harvey, 2009). Regulated tidal exchange techniques are also commonly used in the U.K. as part of a longer term realignment strategy (Environment Agency, 2003).

The New Zealand Coastal Management Statement 2010 encourages the consideration of planned retreat in areas of high coastal hazard risk (DEC, 2010). This includes the relocation or removal of existing structures and their abandonment in extreme circumstances (DEC, 2010). In the United States, market-based instruments, such as transferable development rights, are also being investigated for their use in sea-level rise adaptation (Lausche, 2009).

In Australia, planned retreat techniques have been implemented along sections of the Australian coastline (*e.g.*, Marion Bay, South Australia; Lakes Entrance, VIC; and Byron Bay, NSW; Niven and Bardsley, 2013). Byron Shire, in northern New South Wales, was one of the first councils to initiate and implement a policy response of planned retreat (Byron Shire Council, undated). The policy was implemented in 1988 via the Local Environmental Plan and associated Development Control Plans (DCPs) for "Coastal Lands" in the Byron Shire. The policy was instituted after the extensive effects of storms on the shire from the late 1960s to mid 1970s that resulted in the abandonment of the village of Sheltering Palms (P. Watson, *personal communication*). (Phil Watson is the Principal Coastal Specialist, Office of Environment and Heritage, NSW Department of Premier and Cabinet; he was subpoenaed as an expert witness during the above-mentioned court proceedings.) The DCP for Coastal Lands was underpinned by detailed coastal process and hazard investigations by the (then) NSW Public Works Department, which administered the Coastal Protection Act 1979 (P. Watson, *personal communication*).

Under the provisions of the DCP, which give effect to the "planned retreat" policy, protective structures (*i.e.* seawalls) are prohibited, and built structures are to be relocated or removed when the erosion escarpment encroaches to within a predetermined threshold distance from the structure (P. Watson, *personal communication*). Although the retreat policy had been in place since 1988, it should be noted that an extensive array of ad hoc protection structures were already in existence along Belongil Spit, having been placed during the storms of the 1970s with no formal approvals (P. Watson, *personal communication*). However, despite the prohibition on protection structures since 1988, several additional protection structures have subsequently been added along Belongil Spit—similarly with no formal environmental, planning or land occupation approval—to combat systemic erosion and recession of the coastline in this location (P. Watson, *personal communication*). The only protection works with formal approval were several sand-filled geotextile structures installed in 2002 by the local council as "interim" structures to limit erosion occurring at five key public access points along the Spit while council prepared an Integrated Coastal Zone Management Plan for the shire (P. Watson, *personal communication*).

Attention was focused on Byron's retreat policy during much-publicized NSW Land and Environment Court proceedings in 2009 (*Vaughan v. Byron Shire Council*) involving a Belongil resident without protection works, whose property suffered erosion damage during extreme storms in May that had adjoining rock protection works on one side and a significantly damaged council "interim" sand-filled geotextile structure adjoining on the other side (P. Watson, *personal communication*). Although these proceedings themselves provided no specific examination of the planned retreat policy, the Court upheld council's obligation to maintain the "interim" sand-filled geotextile structures until the coastal zone management plan was finalized in accordance with the original design and development approvals (P. Watson, *personal communication*). Furthermore, it is understood the parties agreed to extend the "interim" structure in front of Vaughan's property to link in with the adjoining rock protection works and be managed and maintained accordingly (P. Watson, *personal communication*).

One of the most recent examples in which local government considered planned retreat as an option to manage chronic erosion problems was seen in the case of Port Macquarie Hastings Council (PMHC) in New South Wales. The proposal generated significant community concern and angst, with the council receiving an overwhelming response from the community in support of constructing a revetment wall and beach nourishment to manage erosion (Port Macquarie-Hastings Council, 2012).

Given that much of the Australian coastline has already been developed, it is perhaps not surprising that planned retreat policies have been met with significant community disquiet and have been difficult to implement. As a result, the general approach currently being advocated throughout Australia is to allow for long-term staged retreat by prohibiting new development or intensification in high-risk areas or allowing time-bound approvals based on development with a limited life span (DERM, 2012; Verschuuren and McDonald, 2012).

Although experience in the application of planned retreat is growing, the approach is still relatively young, and uncertainties exist. The main barriers to the successful implementation of planned retreat include (1) lack of public acceptance, (2) legal and financial difficulties, (3) high costs, and (4) lack of available land needed to relocate infrastructure in densely populated coastal areas (Linham and Nicholls, 2010, 2012). Attempts to implement planned retreat schemes in other countries have also often been met with considerable opposition from affected property owners and have created conflict within communities (Helman, Thomalla, and Metusela, 2010). For example, in the United States, planned retreat initiatives have proven difficult to implement because coastal property carries high value and wealthy property owners have exerted political pressure to build along the coast (IPCC, 2012; Ruppert, 2008). These same concerns are also mirrored in the Australia context (Scarlett and Gangaiya, 2012), where it is rarely implemented because it is regarded as politically and economically unacceptable (Healy and Soomere, 2008).

Setbacks

Setbacks are restrictions that provide a buffer between a hazard area and coastal development (Nichols and Bruch, 2008). Setback policies are widely used in many northern European countries (Sano *et al.*, 2011), as well as the United States (Mitsova and Esnard, 2012; Rabenold, 2013) and Canada (IPCC, 2001). Florida began incorporating setbacks into its shoreline management plan in 1970, with an initial 50-foot (15 m) setback for construction along sandy beaches (Pace, 2011). In parts of Rhode Island, residential development must be set back at least 30 times the average annual erosion rate (Higgins, 2008). Although setbacks have costs, they are generally considered a low-cost alternative to hard coastal structures, such as sea walls or dikes, and also help to preserve natural shoreline dynamics (Mitsova and Esnard, 2012). However, over time, rising sea levels will reduce the size of the buffer between structures and the sea. As a result, setbacks will need to be reviewed periodically to ensure that buffer zones continue to provide sufficient protection. Florida and South Carolina in the United States reassess their setback distances every 10 years (Harris *et al.*, 2009).

In Australia, most state governments have implemented setback criteria for beachfront development, although these vary between states according to local circumstances (Tomlinson and Helman, 2006). For example, setbacks in South Australia are based on a 100-year erosion trend and storm surge flood level with a projected sea-level rise (IPCC, 2001). The Western Australian Government prohibits development within 100 m of the horizontal setback datum, with additional setbacks for erosion areas based on the 100-year erosion trend (WAPC, 2003). On the Gold Coast, QLD, the foreshore seawall line, or A-line, sets a minimum setback requirement for oceanfront properties at a distance of no less than 8.1 m from the A-line wall (GCCC, 2012a).

Regulatory Instruments

Many countries are utilizing regulatory instruments to prohibit urban development in flood-prone areas. In some cases, such as Germany and Finland, these regulations take into consideration the latest scientific knowledge concerning climate change effects, such as expected sea-level rise (Hilpert, Mannke, and Schmidt-Thomé, 2007). In Germany, the *Flood Control Act 2005* prohibits the development of new human settlements in floodplains. The basis for designating floodplains is the 100-year flood. In The Netherlands, the Delta Programme is an annual plan with a 6-year planning horizon detailing all measures necessary to combat flooding as a consequence of climate change (Verschuuren and McDonald, 2012). The Spatial Planning Act is a regulatory instrument that is used to avoid inappropriate land use developments taking place (Verschuuren and McDonald, 2012). The U.K. adopted the *Flood and Water Management Act* in 2010, an integrated piece of water legislation with a focus on coastal adaptation (Verschuuren and McDonald, 2012). The measures that can be taken to reduce coastal flood risk are comprehensive and include hard defences, the removal of buildings, and the restoration of natural processes (Verschuuren and McDonald, 2012). Although implementation occurs at the local level, the U.K.'s Environment Agency is also responsible for funding flood and coastal risk management (Verschuuren and McDonald, 2012). In the U.K., the Shoreline Management Plan, a nonstatutory instrument, is an important strategic plan for coastal adaptation planning (Verschuuren and McDonald, 2012).

All Australian states have planning laws that relate to coastal hazards, with many of the states amending these to include measures that relate specifically to hazards exacerbated by climate change and sea-level rise (Verschuuren and McDonald, 2012). In Queensland, coastal planning and management is largely guided by the provisions contained with the *Sustainable Planning Act 2009* and the *Coastal Protection and Management Act 1995*. The latter, for example, provides that a land surrender condition may be imposed on a development situated within an erosion-prone area (DERM, 2012). Land is surrendered to the State to ensure that land remains undeveloped to allow natural processes to occur as a condition of allowing bonus development rights on the remaining unaffected land outside the erosion-prone area (DERM, 2012). Until recently, most Australian states had either developed or adopted sea-level rise planning benchmarks to guide land use planning and development assessment activities. However, both NSW and QLD have since revoked their respective sea-level rise planning benchmarks. Importantly, these changes coincided with recent state government elections in both jurisdictions.

While local governments have statutory responsibility for local planning and development assessment, they do not generally have the operational capability to manage the legal, political, and financial risks generated from many of the planning decisions (Taylor, Harman, and Inman, 2013). As a result, many local governments engage in discrete strategies of scaling up and scaling out to reduce these risks (Taylor, Harman, and Inman, 2013). Although it is widely accepted that adaptation to sea-level rise is a local practice driven by local circumstances (Measham *et al.*, 2011), the need for stronger leadership and support at higher scales of governance in times of uncertainty is also recognized (Taylor, Harman, and Inman, 2013). In addition to regulatory controls, state governments can also provide targeted financial support to local governments for coastal protection and management (*e.g.*, the NSW government grants scheme; DEH, 2013). These programs can be tailored to target specific priority issues such as sea-level rise, but this paper does not provide a detailed assessment of the feasibility or effectiveness of these programs in supporting local adaptation needs. However, this is an area that could be looked at in more detail in future research.

DISCUSSION

We have detailed the preferences for and prevalence of different adaptations to protect against coastal inundation in a number of developed nations across Asia Pacific, Western Europe, and North America. In the following discussion, we focus on the more significant differences between national preferences and the reasons for these differences. These reasons can be grouped by the themes of responsibility for, and suitability and acceptability of, specific coastal adaptation strategies and technologies. In turn, we conclude these factors influence transferability of particular options between different physical and institutional settings in the international domain.

Responsibility

In the countries reviewed, adaptation in urban coastal settlements is presently dominated by regulatory planning controls and engineering structures. Indeed the "normal" culture—historical responses and investment—revolves around large-scale engineering works for protective barriers to coastal flooding risks with, in many nations, decades if not centuries of cultural and institutional investment. In European countries, this investment is coupled with a strong legacy of understanding and managing extreme water levels, including spatial variability, which is more advanced than the Australian context, where available data is often lacking and research is still progressing (see Church *et al.*, 2006; Haigh and Pattiaratchi, 2010). Much of the implementation of coastal adaptation is done at the local scale; however, one of the fundamental differences between Australia and the international context relates to the degree of centralisation of financial and regulatory control. For many countries, the responsibility to fund major protection works is carried out by state and national governments. In Australia, coastal adaptation practices and funding are predominately the responsibility of the local authorities, with the exception of some major infrastructure projects that cross jurisdictions and ad hoc state funding grants for coastal planning and management works. In many cases, private landholders have responsibility to fund the construction of seawalls.

Although local actors are inevitably responsible for the implementation of many adaptation measures, the effectiveness and broader acceptance of these measures largely depend on the success and strength of multiscale planning and governance arrangements (Niven and Bardsley, 2013; Taylor, Harman, and Inman, 2013). Adaptation efforts in Australia have been constrained by inconsistency between existing institutional-cultural-political norms and the need for greater government intervention to manage the risks to public safety, property, ecosystems, and infrastructure (Measham *et al.*, 2011; Norman, 2009). The fact that decisions about adaptation are in the hands of local governments creates conflict with other interests that have material stake in development outcomes at the local scale. That is, councils are faced with the short-term, parochial interests of local stakeholders and investors while attempting to implement far-sighted, public-good change without the necessary regulatory or legal support of central governments (*i.e.* recent changes to NSW and QLD policy). In contrast, international efforts suggest a high level of state and national involvement in local adaptation planning with significant support and investment, particularly in coastal defence. The absence of higher order institutional guidance to support local adaptation needs contributes to fragmented responses to inundation. Conversely, in the European countries reviewed, roles and responsibilities for certain adaptations, such as levees, are clearly articulated and legally mandated, facilitating a more certain, coordinated and effective response to inundation risk. Within a broad category of developed nations, the Australian case highlights significant differences in the level of centralisation, the stability of the policy frameworks that structure local action, and the degree of vertical integration between tiers of government to provide coherence and appropriate levels of subsidiarity.

Technical Suitability and Social Acceptability

The suitability and acceptability of different adaptations are important components of implementation given that responses to coastal inundation are both reliant on technical capabilities and embedded within sociopolitical contexts. Both Australian and international examples show an emphasis on hard coastal defence structures to manage inundation risk in densely populated areas. This tendency reflects the significant investment in coastal assets and infrastructure and the institutional limitations and political risk associated with measures that have adverse effects on well-entrenched private property rights in the coastal zone. Many European countries have relied on coastal defences for hundreds or even thousands of years. Although construction and maintenance costs are a major consideration of implementing hard coastal defence measures, the approaches are often favourable because they don't require major institutional change or affect private property rights. Conversely, planned retreat has proven to be extremely controversial. Despite the potential long-term benefits of implementing more novel instruments such as planned retreat, these types of practices continue to be politically unpopular and socially unacceptable in highly urbanised areas where tensions exist between public and private values (Linham and Nicholls, 2012).

International experience implementing planned retreat policies are more advanced in the U.K. compared with progress in Australia, although some have been concerned in the U.K. about negative connotations associated with current terminology. In Australia, policies of planned retreat have created conflict between local authorities and private landholders. This conflict is exacerbated by the ongoing debate and confusion over roles and responsibilities between tiers of government in coastal planning and management (Lazarow *et al*., 2006) and commonly held private property rights and development expectations within vulnerable coastal areas (Verschuuren and McDonald, 2012). Notwithstanding, the success of strategies such as planned retreat for managing inundation risk and erosion "depends … on the social acceptability of options for adaptation; the institutional constraints on adaptation; and the place of adaptation in the wider landscape of economic development and social evolution" (Niven and Bardsley, 2013, p. 204). Planned retreat may be more politically acceptable in areas less densely populated (Linham and Nicholls, 2012). Planning for long-term staged retreat by preventing development in potentially vulnerable areas through zoning mechanisms appears consistent with international (Linham and Nicholls, 2012) and Australian contexts (Verschuuren and McDonald, 2012). The strategy of beach nourishment to complement hard coastal defence structures is also widely preferred in high-amenity environments dependent on tourism. However, the suitability of beach nourishment programs in high-energy beach environments is likely to decrease over time as beach systems become more volatile under changing climatic conditions.

CONCLUSIONS

Hard coastal defence structures, along with beach nourishment practices to manage erosion and inundation risk as the result of storm surge, continue to dominate coastal planning and management efforts worldwide. The risk of inundation and the capacity of communities and governments to adapt, however, vary strongly between countries and among localities within countries. In Europe, the area to be protected from inundation is much smaller and much more densely populated. Australia, on the other hand, has a much longer coastline and is sparsely populated (Williams and Thompson, 2007). Although many coastal settlements are at risk of future inundation as a result of rising seas (DCC, 2009), Australia does not face some of the major risk faced in Europe, where significant cities have developed below sea level (*e.g.*, Rotterdam) or in the path of expected sea-level rise (*e.g.*, Venice) (Camuffo and Sturaro, 2004). Instead, Australia faces a large number of at-risk communities spread along a very long coastline. Because of its emphasis on local government, many of Australia's adaptations are local in scale. However, not all adaptation options are economically feasible at the local scale, nor are they socially and political acceptable. By comparison, adaptation options in the international realm are often addressed at a state or even national level of government (see Groven *et al*., 2012), allowing much larger adaptations to be considered. In practice, the optimal choice may also depend on the socioeconomic structure of the community at risk (Turner, Adger, and Doktor, 1995). The large spatial distribution of inundation risk in Australia and diverse coastal settlement types imply poor economies of scale, small-scale adaptations managed at the local scale, and a diversity of responses. Consequently, options that are cost-effective in Europe might not be cost-effective in Australia, where there is greater reliance on identifying and tailoring locally specific responses.

The development of more innovative technologies for managing inundation risk appears well entrenched in international settings, particularly European countries, where governments and communities have a legacy of dealing with inundation risk. In contrast, Australia does not currently require the same level of technological intervention as do many of its international counterparts. As a result, adaptation decision making will likely continue to be incremental. Although in many cases this is the most pragmatic approach, given the scale of the problem and the extensive coastline, in some instances it may lead to suboptimal or inequitable adaptations and increased risk over the longer term.

This review has endeavoured to contribute to the gap in knowledge regarding the appropriateness and applicability of various adaptation options, including their transferability to other coastal settings. In paying particular attention to the Australian experience in the context of the international communities' response, we have highlighted three influential factors that shape both applicability and transferability. First is the tier of government that has primary responsibiity over coastal adaptation and the legal and financial resources at their disposal to direct private action and authority to lead other tiers of government. Second is the influence of existing (including historical) institutional arrangements and culture relating to the management of natural hazards such as coastal inundation. Third, adaptation preferences are strongly shaped by the spatial distribution of risk and physical character of settlements and populations on coasts. Although locally managed adaptations are likely to underpin Australia's approach to adaptation into the future, in some cases, funding support and a coherent and consistent legal framework from state and national governments are likely to be important.

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