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REVIEW ARTICLE

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Coastal adaptation to climate change in Aotearoa-New Zealand

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ABSTRACT
The most recent Intergovernmental Panel on Climate Change reports conclude that for Australasia, without adaptation, further changes in climate, atmospheric CO_2, sea-level rise and ocean acidity are projected to have substantial impacts on climate sensitive systems, sectors and populations. In the context of varying geographical, social, cultural and policy contexts, this paper reviews research contributions and activities concerning coastal adaptation to climate change in Aotearoa-New Zealand. It reflects on the insights derived from this emerging pool of scholarship and considers what lessons have been learned to help us address the future challenges of adaptation to climate change on our coasts and estuaries. In particular, future progress will require strong understanding of natural coastal systems, clearer national direction and guidance in balance with regional flexibility, and collaborative processes to help communities understand, implement and evaluate adaptation pathways for a sustainable and resilient future.

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Introduction

Over the next 30–40 years, Aotearoa-New Zealand will face significant adaptive choices to tactically and strategically deal with shifts in climatic conditions (Gluckman 2013). One of Aotearoa-New Zealand's top three risks from climate change will be the threat to coastal infrastructure, communities and low-lying ecosystems from continuing sea-level rise (SLR) (NZCCC 2014; Table 25-8 in Reisinger et al. 2014). In addition to SLR, climate change will also affect wind regimes, waves, storms, sediment supply and sea temperatures, leading to exacerbation of erosion and retreat of soft shorelines, increased frequency of sea inundation, potential salinisation of near-coast aquifers and rivers, drainage and ground-water issues, increasing squeeze on development along estuarine and coastal margins and changes to ecosystems (Bell et al. 2001; MfE 2008a; Lundquist et al. 2011; Kettles & Bell 2015). These changes to coastal biophysical systems are expected to impact land use, economic investment and sociopolitical arrangements.

Aotearoa-New Zealand has the seventh longest coastline in the world (Rouse et al. 2003) and the majority of New Zealanders live, work or recreate near the coast (Hayward 2008). '[A]s a coastal nation the impact on our beaches, buildings, roads and

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other infrastructure, and on our communities will be considerable' (PCE 2014, p. 9). Despite only 0.7% of the land area being below 3 m relative to the mean high water springs mark, the normally resident population in this elevation zone is 6.6% of the Aotearoa-New Zealand population and the building replacement costs are 4.4% for residential buildings and 6.9% for non-residential buildings of New Zealand's building stock, with NZ$52 billion (2011 data) potential exposure for all buildings, mostly in urban or peri-urban areas (Bell et al. 2015, 2016). This highlights that land area is not a reliable proxy for coastal risk exposure to climate change. From an ecosystem perspective, the extent of coastal influence extends much further than the coastal margin, it extends inland into catchments that drain to the coast as well as offshore (Glavovic et al. 2015).

Given this context and a growing interest in how to adapt to coastal change, this review paper summarises recent published work and accessible 'grey' literature on the topics of coastal climate change impacts and adaptation in Aotearoa-New Zealand. We first introduce Aotearoa-New Zealand's planning and policy setting before summarising the projected impacts of climate change on coastal biophysical systems for Aotearoa-New Zealand. We introduce general climate change adaptation concepts and approaches and review which of these have been employed to date in Aotearoa-New Zealand, often when addressing current coastal hazard issues. Next we review research that has been completed alongside different actors facing coastal adaptation challenges, including consideration or risk perception and competing values. Diverse barriers to adaptation and enablers to address such barriers are then reviewed, before considering future options for meeting the adaptation challenge to ensure a more resilient future for Aotearoa-New Zealand's coastal environments and communities.

To put the developments reviewed in this paper into context a timeline of key initiatives in coastal climate change adaptation is shown in Figure 1.

Aotearoa-New Zealand policy and planning context for climate change

Internationally, the Intergovernmental Panel on Climate Change (IPCC) has led the way in reviewing and communicating the latest science on climate change to help policymakers

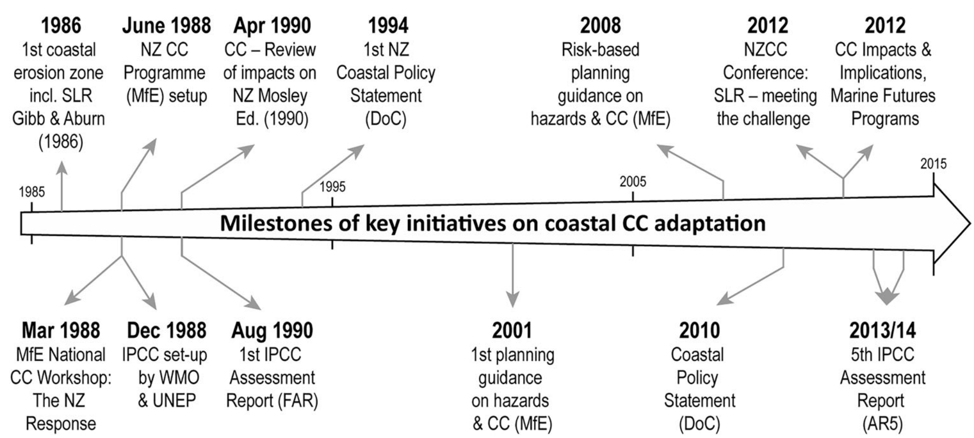

Figure 1. Milestones of key initiatives on coastal climate change adaptation.

decide on plans of action. The IPCC was formed[1] in 1988 (Figure 1) to provide a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts globally.[2] Since then, the IPCC has produced a series of detailed assessment reports at 5–6 year intervals on the physical science basis (Working Group I), impacts, adaptation and vulnerability (Working Group II), and climate mitigation[3] options (Working Group III) along with synthesis reports and summaries for policymakers. The most recent round of assessment reports, the fifth, were published in late 2013 (Working Group I) and 2014 (Working Groups II and III).

Earlier in the same year that the IPCC was formed, the New Zealand Climate Change Programme was formed within the Ministry for the Environment (MfE) to 'respond to the rapidly increasing understanding that climate is not unchanging' (Mosley 1990, p. 9). The programme included similar working groups to the IPCC, to better understand the scientific basis of climate change (RSNZ 1988, 1990), the potential impacts including on coasts and estuaries, and to make recommendations for responses, as well as a Māori working group to advise on issues relating to Māoridom and the Treaty of Waitangi (Mosley 1990).

In 1993, an information and guidance booklet for local government (Allan 1993) was aimed at raising awareness of climate change issues and initiated a role for local government in climate-change management (Reisinger et al. 2011). Since then, the understanding of climate change and associated impacts on Aotearoa-New Zealand has improved, while the political importance of climate-change issues has varied. For example, a carbon tax was mooted in 2002 and abandoned in 2005, before the current emissions trading scheme was introduced in 2008 (Price et al. 2009). The MfE has continued to lead Aotearoa-New Zealand policy response to climate-change issues as the agency responsible for developing, coordinating and implementing 'whole-of-government' climate change policy.[4] In general, these comprise either mitigation policies (through managing greenhouse gas emissions) or adaptation policies (preparing for climate change impacts likely to occur), with more emphasis on the former in the 1990s and early 2000s (Reisinger et al. 2011). The need for adaptation is now well established (e.g. Denton et al. 2014; Mimura et al. 2014; Noble et al. 2014), as it is acknowledged that at least some level of climate change is inevitable and will require adaptation along coastal margins by way of SLR from a commitment already built into the earth–ocean system from emissions to date.

This national policy role for climate change, particularly for adaptation, is aligned to MfE's functions under the Resource Management Act 1991 (the RMA), and in particular the 2004 amendment to the RMA which requires decision-makers to have particular regard to the effects of climate change (MfE 2008a; Reisinger et al. 2011; Lawrence et al. 2015). Under the RMA there is a hierarchy of responsibilities and instruments; MfE and the Department of Conservation (DOC) are responsible for national policy for climate change and coastal management, respectively, whereas regional and territorial (or unitary) councils are responsible for regional policy, regional plans, district plans and resource consents which operationalise those policies. Such national roles are recognised as critical to adaptation as they provide both information, and legal and policy frameworks for local actors (Mimura et al. 2014).

The RMA allows for the promulgation of national instruments such as national policy statements and national environmental standards, but neither has been developed to date with regard to the management of climate change. A national framework for adapting to climate change based on four work areas—information, responsibilities, investment and action—has been more recently produced (MfE 2014), but this brief document simply states high-level responsibilities and does not provide any direction for adaptation work. Instead, a key area of activity by MfE has been the development of guidance manuals to help local government to adapt to and manage the unfolding impacts of climate change, centred on a risk-based framework.[5] The guidance on coastal hazards and climate change (MfE 2008a) and its summary document (MfE 2009) are well used and relied on by local government (Reisinger et al. 2015), particularly for selecting appropriate SLR values to adopt in plans and regional policy statements. MfE (2008a) is based on the previous Fourth Assessment Report of the IPCC (released in 2007) and is currently being updated to assimilate the Fifth Assessment Round (AR5) reports and other more recent activities and approaches. Such guidance documents have also been found to be useful by engineers, planners and consultants (Reisinger et al. 2011).

The MfE has also produced other guidance (e.g. MfE 2004) and case studies to help councils, such as a case study of coastal planning issues in the Bay of Plenty (MfE 2003). Other useful guidance for councils has been developed by other parties such as guidance to help councils implement community-based dune management schemes (Dahm et al. 2005), NIWA's 'Pathways to Change' guidance for adaptation planning (Britton et al. 2011), urban infrastructure and built environments (NIWA et al. 2012) and best-practice guidance on defining coastal hazard setback zones (Ramsay et al. 2012).

Under the RMA, DOC has responsibility for national policy leadership in the coastal environment. The 1994 New Zealand Coastal Policy Statement (NZCPS) was the first national-level tool under the RMA (Figure 1), which required councils to 'recognise the possibility of a rise in sea level'. The updated NZCPS 2010 contains objectives and policies that together seek to manage the natural and physical processes, natural character, recreational values, and coastal hazards of the coastal environment in such a way as to enable people and communities to provide for their economic, social and cultural wellbeing, with appropriate reference to delivery of Treaty of Waitangi principles. With regard to climate change, the NZCPS 2010 requires that areas potentially or at high risk of being affected by coastal hazards are identified and assessed, including the cumulative effects of SLR and climate change, 'taking into account national guidance and best available information on the effects of climate change' (NZCPS, Policy 24). The NZCPS also stipulates that 'at least 100 years' is used as the appropriate planning timeframe, which means national guidance (MfE 2008a) currently being updated should be aligned with the NZCPS (Britton et al. 2011).

The importance of local government as an actor in climate change adaptation is well recognised (Noble et al. 2014). In Aotearoa-New Zealand, regional and territorial authorities have policy and operational responsibilities relating to coastal issues and climate change not just under the RMA but also under the Local Government Act, the Civil Defence Emergency Management Act, the Building Act and others (Lawrence et al. 2015). These responsibilities involve coastal-hazard identification and management (including land-use planning and building controls) and hazard-risk management across the '4 Rs' of reduction, readiness, response and recovery (Ministry of Civil Defence & Emergency Management 2008). Under the RMA, all regional (and unitary) authorities are required to produce a regional coastal plan for their Coastal Marine Area (CMA; which extends from the territorial sea boundary 12 nautical miles offshore to the mean high water springs line on the coast, estuaries or river mouths). Some regions (e.g. Environment Canterbury, Bay of Plenty Regional Council, Hawke's Bay Regional Council) have produced regional coastal 'environment' plans which extend beyond the CMA into the coastal hinterland, in order to achieve integrated management of the CMA and coastal environment. For example, Environment Canterbury consider that its approach enables better management of four matters: hazards, access, areas of high natural, physical or cultural value, and coastal water quality (Environment Canterbury 2012). Due to the hierarchical nature of the RMA, regional and district plans must give effect to the NZCPS, and district plans must give effect to regional policy statements (Makgill & Rennie 2012), but the timing of plan reviews means there is often a time-lag before that happens (e.g. Britton 2010; Lawrence et al. 2015). To inform hazard-management activities, councils have been undertaking coastal hazard assessments (CHA) and since as early as the mid-1980s (prior to the IPCC) consideration of SLR has been included in erosion setbacks (e.g. Gibb & Aburn 1986). However, a survey of staff from 24 local authorities in 2009 (Britton 2010) found that five of 12 regional or unitary council staff considered that their regional policy statements or regional coastal plans did not specifically mention climate change or adaptation; and of all respondents, 15 of 24 generally thought that they were not doing enough to address adaptation issues in their region.

The varying responsibilities of national, regional and local actors under different legislation lead to gaps and overlaps in the management of coastal environments and the effects of climate change. Policy development is spread between national and regional levels and between agencies, and there is no overall national strategy for climate change adaptation (Manning et al. 2015), nor clear direction (by way of policy) from national to regional levels (e.g. Rive & Weeks 2011), nor integration with disaster risk reduction and the 4 Rs. In particular the lack of national direction results in councils potentially needing to 'reinvent the wheel' in terms of developing adaptation approaches, and especially prior to the NZCPS 2010 being introduced, led to a reliance on case law for interpretation of legislative requirements, and good practice established through guidance documents, which potentially exposed councils to challenge (Lawrence et al. 2015). Some of the councils' operational responsibilities for coastal hazard management (such as terrestrial planning) are shared between regional and local levels so that attention is needed to ensure district and regional policies and operational approaches are aligned. Planning timeframes vary between legislative frameworks. The 'at least 100 year' timeframe now required by the NZCPS 2010 is not reflected in 50 year design life requirements of the Building Act (with no requirement to include climate change), despite the relative permanence of buildings and associated infrastructure. The landward boundary of the CMA extends to the mean high water springs mark, and not all regions extend their coastal plans beyond this present-day shoreline boundary into the immediate hinterland which may limit their ability to plan for adaptation activities across that broader area as the shoreline migrates inland with rising seas. Estuaries are a coastal environment that potentially fall between the cracks of national policy statements for freshwater and the coast (Kettles & Bell 2015). Some of these gaps are barriers to climate change adaptation (Britton 2010; Lawrence et al. 2015; Manning et al. 2015) and are explored further later in this paper. As a backdrop to reviewing coastal climate change adaptation in more detail, we next outline some of the most recent climate change projections and potential impacts on Aotearoa-New Zealand's coastal environments.

Overview of biophysical climate impacts on coasts and estuaries and management responses

Climate change observations and projections

Climate change observations and projections for Aotearoa-New Zealand generally correspond with global trends as summarised in Table 1. Biophysical impacts on coastal and estuarine systems will be dominated by ongoing SLR and to a lesser extent changes in waves, storms and rainfall, but ecosystems will also be influenced by changes in temperature and pH (MfE 2008a; RSNZ 2010; Lundquist et al. 2011; Kettles & Bell 2015). Figure 2 shows both historic SLR for Wellington and Auckland spliced with the IPCC AR5 projections for the lowest and highest Representative Concentration Pathway scenarios, capturing the sea-level trajectory over more than two centuries.

Physical impacts on Aotearoa-New Zealand coasts and estuaries

A prerequisite for adaptation is an appreciation of the plausible range of physical impacts from climate change, over and above risks already being experienced. The first comprehensive national review of coastal physical impacts was undertaken by Hicks (1990) just prior to the first IPCC report. Physical effects of coastal climate change include: exacerbation of coastal erosion and inundation (including tsunami); poorer drainage and increased groundwater ponding; salinity intrusion up rivers and into coastal aquifers; estuarine and nearshore sedimentation influenced by catchment run-off and rainfall changes; and rises in water temperature (Hicks 1990; Bell et al. 2001; MfE 2008a; Kettles & Bell 2015). Significant advances have been achieved in past decades in research on coastal physical processes for the coasts and estuaries of Aotearoa-New Zealand, but gaps in knowledge and capability have been identified (e.g. Hume et al. 1992, 1997). Of relevance are the identified needs to investigate climate change, SLR and the consequences for coastal land use, and to improve baseline databases and knowledge to support a more sustainable approach driven by the RMA and NZCPS. Some progress has been made on these aspects in the past decade (e.g. MfE 2008a; Ramsay et al. 2012), especially with the increasing sophistication of numerical models, particularly for coastal inundation, and the adoption of risk assessment approaches.

In Aotearoa-New Zealand, not only are there direct climate change impacts to be considered for adaptation planning, but consideration also needs to be given to other human pressures arising from coastal or hinterland development and land-use change (e.g. effects on sediment run-off and water quality), growing instances of coastal squeeze from legacy development located too close to the shore (Blackett et al. 2010a) or in situ seabed modifications such as harbour dredging and shellfish harvesting (Kettles & Bell 2015). These existing pressures may be compounded further by human responses to climate change impacts leading to maladaptation (see Table 2) in an attempt to counteract the negative impacts of climate change. Examples of such responses include shoreline protection, reclamations, increased abstraction of upstream freshwater, ‘improved’ drainage, and measures to reduce flooding such as channel dredging, barrages and stop-banks (Kettles & Bell 2015).

Coastal erosion

Coastal erosion is influenced by multiple drivers that are either directly or indirectly influenced by climate change, such as SLR, extreme total water level (storm tide and

Table 1. Observed and projected changes in key coastal climate variables and associated certainty of projections for Aotearoa-New Zealand, based on IPCC 5th assessment (projections as per Reisinger et al. 2014 and other referenced sources).

Climate variable	Observed change	Projection
Temperature	• Mean air temperatures: increased by 0.09 ± 0.03 °C per decade since 1909 (very high confidence) (Mullan et al. 2010) • Sea-surface temperatures: increased by 0.07 °C per decade since 1909 (very high confidence) (MfE 2008b)	• Projections of mean air temperature increase of: 0.3–1.4 °C by 2040 (A1B) and 0.7–2.3 °C by 2090 (B1) and 1.6–5.1 °C by 2090 (A1FI) • Sea-surface projections for coastal waters similar to mean air temperature • Increases and decreases, respectively, in number of hot and frost days (Tait 2008)
Precipitation	• Mean annual rainfall: increase from 1950–2004 in south and west of South Island and west of North Island; decrease in northeast of South Island and north and east of North Island (very high confidence) (Griffiths 2007) • Decrease in extreme annual 1 day rainfall in north and east; increase in west since 1930 (medium confidence) (Griffiths 2007)	• Mean annual rainfall: increase in south and west of South Island and west of North Island; decrease in northeast of South Island and north and east of North Island (very high confidence) • Increase in intensity of daily rainfall extremes, with larger frequency of severe rain events (medium confidence) (Carey-Smith et al. 2010). Intensity may increase by 7%–20% (Wratt et al. 2006)
Sea-level rise	• Relative sea-level rise of 1.7 ± 0.1 mm yr^{-1} since 1900 (very high confidence). Absolute sea-level rise of 2.0 mm yr^{-1}, allowing for glacial isostatic adjustment (Hannah & Bell 2012) • Extreme sea levels (storm surges, storm tides) have risen at a similar rate to global sea-level rise (Menendez & Woodworth 2010)	• Depending on the emission trajectories, global mean sea level by 2100 is likely to be between 0.28 to 0.61 m higher for the lowest RCP2.6 pathway (severe emission cuts and zero net emissions by end of century) or up to 0.52 to 0.98 m for the RCP8.5 pathway (business-as-usual emissions and population growth) (Table13.5; Church et al. 2013). Higher rises of several decimetres cannot be ruled out if collapse of polar ice sheets accelerates (Church et al. 2013). Regional sea-level rise very likely to exceed historical rates, with offshore sea-level rise predicted to be up to 10% greater than global average rates (Ackerley et al. 2013) • Escalating increase in frequency of extreme storm and wave inundation events (high confidence). Present day 1% annual exceedance probability events will increase to occur annually on average with only modest rises in mean sea level e.g. 0.3 m for Wellington and Christchurch, up to 0.45 m rise for Auckland where tide range is higher (Table 3.2, PCE 2015)
Ocean acidification	• Average global pH of surface waters has decreased by 0.1 since the mid-19th century to a current value of approximately 8.11. This corresponds to a 26% increase in acidity (Howard et al. 2012)	• Global prediction of further decrease in pH ranging from 0.06–0.32 units (15%–109% increase in acidity) by 2100 for different RCP scenarios
Wind and storm events	• Increase in mean westerly flow during 1978–1998 period (medium confidence) (Mullan et al. 2001; Parker et al. 2007)	• Westerly flow predicted to increase in frequency in spring (20%) and winter (70%) and to decrease in summer and autumn (20%) (medium confidence) (Mullan et al. 2011; Reisinger et al. 2014) • Projected increase in conditions conducive to storm development by 3%–6% by 2070–2100 relative to 1970–2000, with largest increases over the South Island (medium confidence) (Mullan et al. 2011; Reisinger et al. 2014)

(*Continued*)

Table 1. Continued.

Climate variable	Observed change	Projection
Waves	• Statistically significant increase around Aotearoa-New Zealand in the 99 percentile wave height based on 1985–2008 period (Young et al. 2011)	• A continuing trend of increasing wave generation, particularly in the Southern Ocean (Hemer et al. 2013). Increases of order 5% in wave height for 2070–2099 for parts of Aotearoa-New Zealand exposed to Southern Ocean swell, but less and variable elsewhere (R Gorman, NIWA, pers. comm. July 2015)

wave run-up), net direction and rate of wave-driven alongshore transport and supply of sediment to the littoral system (MfE 2008a; Komar & Harris 2014), while different shore types respond to SLR in different ways (Figure 3.3 in MfE 2008a).

A coastal erosion hazard zone (CEHZ) or coastal setback zone has been the primary statutory tool used by local government in Aotearoa-New Zealand for managing present and future coastal development (Ramsay et al. 2012), both for redevelopment of existing properties and establishing setbacks on greenfield development.

Since the CEHZ set for Pauanui in 1986 (Gibb & Aburn 1986), setback zones have incorporated SLR into their determination. Until recently, in most cases the shoreline response has been described by the Bruun rule or variations thereof (Bruun 1962) and equivalent models for barrier-beach systems (e.g. Rosati et al. 2013). These are simple geometric predictors based on an equilibrium seabed/sand beach profile that relates retreat rate directly to the rate of SLR and inversely to beach slope, which implies that gently sloping dissipative surf beaches should retreat more than steep, reflective beaches.

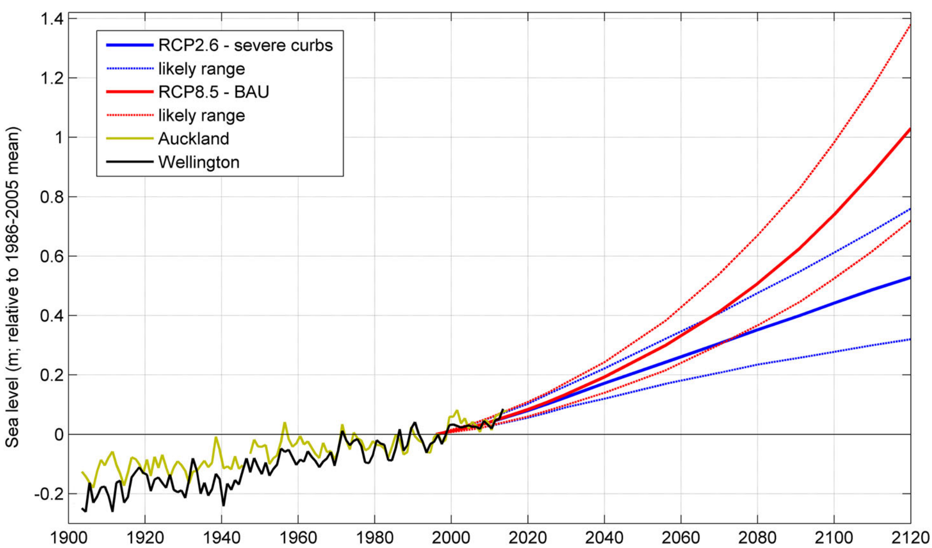

Figure 2. Composite of historic annual mean sea level from Auckland (Waitemata) and Wellington post-1900 with IPCC AR5 projections for global mean sea-level rise for the lowest and highest Representative Concentration Pathway scenarios (RCP2.6 is blue and RCP8.5 is red). The dashed lines represent the 'likely' range of the relevant RCP i.e. a 66% probability of lying within the range (Church et al. 2013). The IPCC projections to 2100 have been extrapolated out to 2120. The baseline for all data series is the average sea level from 1986 to 2005 inclusive.

Table 2. Adaptation terminology and definitions.

Term	Definition	Source
Adaptation	Undertaking of actions to minimise threats or to maximise opportunities resulting from climate change and its effects. Various types can be distinguished: • anticipatory—adaptation that takes place before impacts of climate change are observed; • autonomous—adaptation that does not constitute a conscious response to climate stimuli but is triggered by other factors such as ecological change in natural systems or market changes in human systems; • planned—adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to or maintain a required state	MfE (2008a)
Adaptive capacity	The ability of a human system or an ecosystem to: adjust or respond to climate change (to both variability and extremes); moderate potential damages; take advantage of new opportunities arising from climate change; or cope with and absorb the consequences	MfE (2008a)
Limitation adaptations	Adaptations aimed at lessening or minimising the consequences of the most adverse effects of climate change as they arise over time	MfE (2008a)
Low regrets adaptation	Low-cost policies, decisions and measures that have potentially large benefits	MfE (2008a)
No regrets adaptation	Adaptations that generate net social, economic and environmental benefits irrespective of anthropogenic climate change, or adaptations that at least have no net adverse effects	MfE (2008a)
Maladaptation	'Bad' adaptation—actions that foster adaptation in the short term but insidiously affect systems' long-term vulnerability and/or adaptive capacity to climate change	Magnan (2014)
Limit	The point at which an actor's objectives or system's needs cannot be secured from intolerable risks through adaptive actions: • hard adaptation limit—no adaptive actions are possible to avoid intolerable risks; • soft adaptation limit—options are currently not available to avoid intolerable risks through adaptive action	Klein et al. (2014)
Barrier	Factors that make it harder to plan and implement adaptation actions	Klein et al. (2014)
Enabler	Factors that make it easier to plan and implement adaptation actions, that expand adaptation options, or that provide ancillary co-benefits	Klein et al. (2014)

CEHZ techniques are more developed in general for sandy systems than for gravelly or muddy environments due to the long history of development and use of Bruun-type models for the former, while for eroding cliff systems, Dickson et al. (2007) found cliffed coasts have a broader range of responses and lower overall vulnerability to SLR than predicted by the Bruun rule. A comprehensive technical manual on determining a CEHZ was compiled by Auckland Council (previously Auckland Regional Council) to foster good practice (Auckland Regional Council 2000). Tools and models beyond the Bruun rule are still in various developmental stages worldwide (Shand et al. 2013; Passeri et al. 2015). Other modified or empirical methods to incorporate SLR into a CEHZ have been undertaken in Aotearoa-New Zealand, for example a shoreline response model adapted from Komar et al. (1999) applied to the Kāpiti Coast (Shand 2012); a geometric model based on total water level including SLR (Ruggiero et al. 2001; Komar et al. 2002) applied in mixed sand/gravel shorelines of Hawke's Bay (Komar & Harris 2014); recession of unconsolidated cliffs of the South Canterbury coast north of the Waitaki River mouth (in Ramsay et al. 2012); and recently, as advocated by Ramsay et al. (2012), a probabilistic approach to developing CEHZs as undertaken in Northland

Table 3. Advantages and disadvantages of coastal adaptation options.

Methods	Advantages	Disadvantages
Do nothing	Low cost and low effort for present generation	No future certainty for any of the actors; projected impacts would occur with consequences for people, property and infrastructure; ignores risks that are projected on to future generations
Protect	Hard engineering approaches: immediate protection for high-value infrastructure; Soft engineering approaches: aligned with natural processes, allows for cyclic erosion	Expensive: physical impacts on adjoining beach and consequent effects on communities values; based on assumptions of static risk/single number; leads to misperceptions of risk; direct coastal squeeze of ecosystems and amenity values
Accommodate	Working more with natural geomorphic processes, allowing for periodic erosion or inundation; retrofitting will give immediate removal of current risk (e.g. raising bridge); seeks to minimise risks/ consequences	Moderate cost depending on retrofitting or relocation of assets/infrastructure; based on assumptions of static risk/single number; leads to misperceptions of risk; requires a change in expectations of use/service of infrastructure (e. g. basements may periodically flood); requires careful communication so that inundation or erosion events are seen as strategically allowed for; still some potential for coastal squeeze of ecosystems and amenity values
Retreat	Allows for dynamic risk/range of potential futures, allows ecosystem resilience to be maintained; seeks to avoid risks	Potentially expensive for councils due to relocation of infrastructure; compensation for private dwelling owners; impinge on private property rights and thus tend to cause intense community resistance; needs long timeframe to be implemented without major community disruption

(Shand et al. 2015) and Christchurch (Tonkin & Taylor Consultants 2015). Following community pushback on the Kāpiti CEHZ developed by Shand (2012), an expert panel review (Carley et al. 2014) concluded that the hazard lines recommended were not sufficiently robust to be incorporated into the Proposed District Plan. The review recommended that setback lines derived earlier by Lumsden (2003), based on the Ruggiero et al. (2001) approach, should be updated for short-term storm impacts and combined with the long-term trends (rising sea levels and the progressive erosion of the shoreline) of the proposed CEHZ of Shand (2012). This highlights the need for the application of good scientific practice, appropriate for the temporal and spatial data sets available and the type of coastal geomorphology, within a probabilistic framework with transparency in the level of uncertainty, which then enables decision-makers in consultation with communities to make a call on which scenario or probability should apply in setting a setback zone (see Ramsay et al. 2012; pp. 78–79).

Developing a robust probabilistic CEHZ in such a contested 'space' that incorporates SLR and other climate change effects and sensitivities, such as groundwater, changes in beach sediment and catchment run-off budgets, waves, storms and attribution of past trends to historic SLR, will require considerable ongoing monitoring and research (Ramsay et al. 2012; Shand et al. 2013; Carley et al. 2014; Shand et al. 2015; Tonkin & Taylor Consultants 2015).

As part of a national overview of shoreline susceptibility to climate change, Goodhue et al. (2012) used an expert panel approach to classify the sensitivity of sedimentary segments of the Aotearoa-New Zealand coast to coastal erosion arising from climate change.

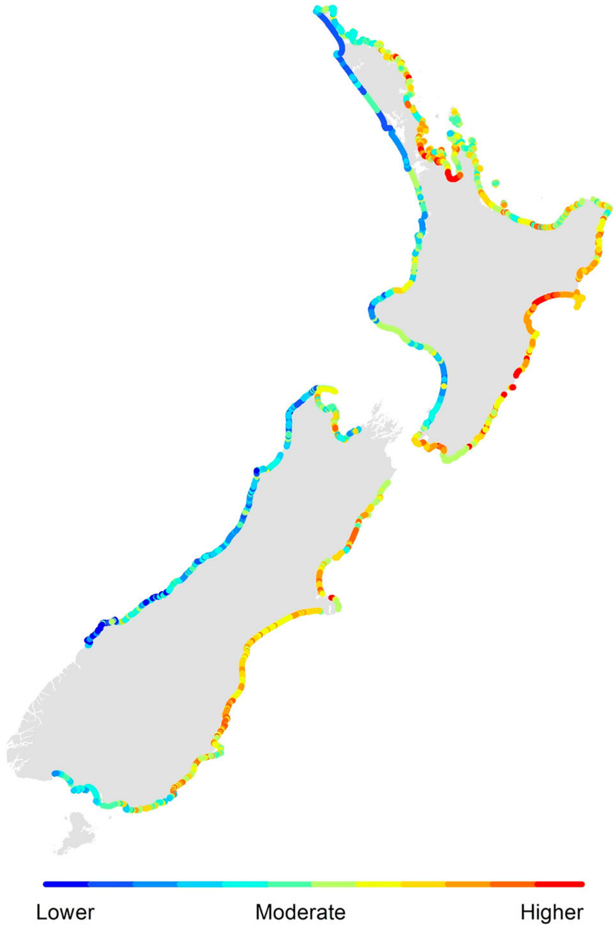

Figure 3. Sensitivity to climate change-induced coastal erosion for 'soft' segments of the Aotearoa-New Zealand coast (from Goodhue et al. 2012).

This was underpinned by NIWA's coastal classification and weighted sensitivity indices of geomorphic and coastal variables. The overall coastal sensitivity index (Figure 3) shows that the east coasts of both North and South Islands are more sensitive to erosion caused by climate change by virtue of a combination of factors: mainly wave exposure, relatively low tidal range, sediment budget deficits, low-lying backshore and proximity to tidal inlets. West coast shores are less sensitive to climate-driven change, mainly because they are already regularly exposed to high wave energy.

Inundation and drainage of coastal land

Climate change will increase the incidence and extent of inundation in coastal areas in three ways: by increasing the frequency and volume of inundation by storm tides and wave run-up and overtopping; through higher groundwater levels with more frequent ground saturation; and by impeding land drainage due to reverse hydraulic gradients as the sea level rises (Bell et al. 2001; MfE 2008a).

With SLR, the zone of influence of the tide and other drivers of short-term sea level variation will also rise and reach further inland, including up lowland rivers and wetlands (MfE 2008a; Kettles & Bell 2015). Thus the incidence of episodic inundation of lower-lying areas from the combined effects of tide, storm surge and waves overtopping natural or artificial defences will increase in frequency and spatial extent (Ramsay et al. 2012; PCE 2014; Reisinger et al. 2014). Such changes will be further compounded in areas with smaller tide ranges (Bell 2010) and increases in the magnitude and frequency of storm surge and wave events as a result of climate change (Table 1).

Little research and few case studies have been undertaken in the freshwater estuary/coast transition zone (Kettles & Bell 2015), but changing climate conditions are likely to lead to increased flooding of combined freshwater/river systems, rising groundwater levels and increases in the salinity of wetlands, lowland rivers, aquifers and soils (Bell et al. 2001; Kettles & Bell 2015).

Unlike CEHZs, coastal-inundation mapping for land-use planning and setting coastal inundation hazard zones (CIHZ) or setback lines has only been implemented in Aotearoa-New Zealand over the past decade. This has been largely driven by cost efficiencies in flying high-resolution LiDAR[6] surveys of coastal plains, in tandem with development of joint probability tools for combining the contributing factors to coastal-storm inundation (tides, storm surge, wave run-up, beach aggradation) including interdependencies and incorporation of SLR (e.g. Goring et al. 2011; Robinson et al. 2014). Modelling to underpin CIHZ in Aotearoa-New Zealand is undertaken at different levels of complexity and spatial scales (Ramsay et al. 2012), ranging from static storm-tide GIS modelling ('bath-tub' approach) to coupled storm-tide (+ SLR) and wave hydrodynamic models, usually applied to smaller areas (rather than regions) where accurate high-resolution results are necessary. Examples of the application of these modelling approaches based on LiDAR digital elevation models are: the Christchurch SLR and coastal hazard assessment studies (Tonkin & Taylor Consultants 2013, 2015); a climate change adaptation case study of Mission Bay to St Heliers–Auckland (Hart 2011; Reisinger et al. 2015); and preparation of region-wide storm-tide inundation maps with 1 and 2 m SLR for inclusion in the proposed Auckland Unitary Plan (Stephens et al. 2013; Stephens & Bell 2015). SLR and coastal-storm inundation in tandem with rising groundwater levels poses a risk for many low-lying coastal cities and settlements in Aotearoa-New Zealand, as highlighted by the Parliamentary Commissioner for the Environment (PCE 2015). Risk assessments and adaptation options are increasingly being commissioned (e.g. Fitzharris 2010; Tonkin & Taylor Consultants 2013), with options ranging from engineered solutions such as pumping stations for south Dunedin (e.g. Beca 2014) to planning measures to restrict development in flood management areas in Christchurch.

Goodhue et al. (2012) also mapped the sensitivity of the Aotearoa-New Zealand coast to climate change-induced coastal inundation using a similar approach as used for coastal erosion (described above). The results showed that the segments more sensitive to inundation typically lie on the east coasts of both North and South Islands by virtue of their relatively lower tidal ranges, common estuaries, and barrier shores with low-lying backshores—generally the same areas that are also sensitive to coastal erosion.

Coastal and estuarine sedimentation

Coastal and particularly estuarine sedimentation will be significantly influenced by not only coastal/ocean changes but also a complex interaction of climate change-related changes in rainfall and land use, leading to significant changes in catchment sediment run-off and responses from human modifications to estuary/harbour shorelines to halt landward extension of estuaries (McGlone et al. 2010; Kettles & Bell 2015). Thus 'coastal squeeze' will invariably result as coastal buffers, intertidal areas and habitats progressively diminish (Bell et al. 2001; Blackett et al. 2010a; McGlone et al. 2010; Kettles & Bell 2015), increasingly exposing shorelines to more frequent storm damage and reducing space and capacity for intertidal ecosystems.

Considerable research has been conducted on quantifying sedimentation and the underlying processes, particularly for estuaries and harbours in the upper-North Island, Wellington/Porirua and Banks Peninsula (e.g. Sheffield et al. 1995; Goff et al. 1998; Abrahim & Parker 2002; Swales et al. 2002; Burge 2007; Hart et al. 2008; Oldman et al. 2009; Hart 2013; Bentley et al. 2014; Swales et al. 2015). Sedimentation rates from these studies show that intertidal areas of estuaries have been typically accreting at 2–5 mm/yr, increasing to 10 mm/yr in more sheltered tidal creeks (e.g. side inlets of upper Waitemata Harbour), with lower rates of 1–2 mm/yr in large exposed harbours (e.g. Tauranga and Manukau Harbours) although higher in the deeper Wellington Harbour (3–5 mm/yr). At the other end of the spectrum, rates of 25 mm/yr have occurred since the 1920s in the southern Firth of Thames from sediments exported from large hinterland catchments with changing land use (Swales et al. 2015). While there has been little place-based research to date on predicting the effects of climate change on sedimentation, these studies set the baseline for understanding the role climate change poses for future seabed accumulation and morphological change in Aotearoa-New Zealand estuaries, particularly when SLR rates exceed these present-day seabed surface elevation gains and how that will affect, for example, mangroves (Lovelock et al. 2015). When SLR exceeds the sedimentation rate, the increased water depths and estuary area associated with ongoing SLR will increase the estuary's headward 'accommodation space' and volume of its tidal prism with consequential effects on the size, shape and location of the intertidal areas, the tidal channel network, the exchange of sediment between the different morphological elements of the system and possible erosion in the main inlet channel (van Maanen et al. 2013). Such conditions would in turn drive an increase in the equilibrium sand volumes held in the ebb- and flood-tidal deltas either side of the estuary inlet (Hicks & Hume 1996; Ranasinghe et al. 2012; van Maanen et al. 2013), with sand stocking these tidal deltas drawn from the adjacent littoral cells, and consequently may exacerbate erosion of the adjacent beaches to these inlets.

Ecological responses

Ecological responses of coastal and estuarine species to climate change have been poorly documented in Aotearoa-New Zealand (Lundquist et al. 2011), so impacts due to climate change have been inferred mainly from international studies. Increasing air and sea surface temperatures are likely to cause range shifts as species track suitable temperature regimes southward. Latitudinal range shifts of rocky intertidal species have been recorded elsewhere on continental margins (e.g. Helmuth et al. 2002; Burrows et al. 2014), although they have not yet been documented in Aotearoa-New Zealand coastal species. Helmuth et al. (2014) stress the need to identify biologically relevant metrics of environmental change that couple physical environmental responses to climate change to species' ecological responses to physical climate in order to identify range shifts due to climate change. For example, rocky intertidal species respond to physical stressors such as changing heat stress, desiccation and changes in wave frequency and intensity; none of these metrics shows simple linear relationships with increases in average sea surface temperature, but they do correspond to changes in species distribution (Mieszkowska & Lundquist 2011; Schiel 2011). Temperature can also result in direct mortality in some coastal species, with mass mortalities observed of common soft sediment infaunal species (e.g. cockles *Austrovenus stutchburyi* and heart urchins *Echinocardium cordatum*) when high temperatures coincide with daytime low tides (Wethey et al. 2011). Some coastal and estuarine habitats such as kelp forests are also likely susceptible to declines due to warmer sea temperatures; declines of kelp forests and the ecosystem services provided by this structural habitat have already been observed in Tasmania (Edgar et al. 2005).

Intertidal zones in estuaries provide a broad range of ecosystem services from food production to water quality to coastal protection (Thrush et al. 2013), which are at risk from a variety of climate-related changes. SLR will have a key influence for intertidal and shallow subtidal coastal and estuarine species that must migrate inshore as sea level rises in order to track the particular tidal depths for which they are adapted, or the habitat upon which they depend. Mangrove forests and saltmarsh habitats are particularly susceptible to coastal squeeze where man-made structures prevent shoreward expansion (Lundquist et al. 2011; Kettles & Bell 2015; Lovelock et al. 2015). Sedimentation caused by climatic changes in the frequency and severity of storm events is predicted to have negative impacts on coastal and estuarine ecosystems (Thrush et al. 2004). Sedimentation causes a range of direct and indirect impacts, from increased turbidity and decreased light penetration, which can reduce primary productivity, to changes in sediment characteristics that reduce suitability of habitats for species, to direct mortality events from smothering by catastrophic sediment loads (Thrush et al. 2004, 2008).

Other climate-related changes are poorly understood, such as global circulation patterns that may result in changes in dispersal and distributions of flora and fauna. Changes in frequency of El Niño Southern Oscillation events that drive inter-annual variability in upwelling dynamics are likely to result in changes to coastal ecosystems through disruption of nutrient cycles and oxygen fluxes upon which species coastal food webs are dependent (Giles et al. 2007; MacDiarmid et al. 2009; Sydeman et al. 2014). Ocean acidification is likely to have significant impacts on carbonate-forming species, which include a large range of species from plankton to molluscs to echinoderms to corals (reviewed in Doney et al. 2009). Key biological processes that are likely to show negative impacts for coastal benthic invertebrates include calcification rates, and reduced developmental rates and survival of larvae (Doney et al. 2009). Also at risk are the ecosystem services provided by these benthic invertebrates such as the provision of structural habitats (e.g. mussels, oysters), food provisioning resources (e.g. shellfish commercial and recreational fisheries, aquaculture) and nutrient cycling such as that provided by the echinoderm *E. cordatum* in shallow coastal waters of Aotearoa-New Zealand's continental shelf (Lohrer et al. 2010; Cooley et al. 2012; Capson & Guinotte 2014). More Aotearoa-New Zealand specific research is needed in this area.

Coastal adaptation approaches and concepts

Adaptation is commonly defined as 'the undertaking of actions to minimise threats or to maximise opportunities resulting from climate change and its effects' (MfE 2008a, Table 2).

There is increasing recognition of the importance of adapting to climate change, as reported in the latest IPCC assessment reports. Along coastal margins, the 'commitment' from past emissions to future SLR and long ocean-response times, means that we need to plan on adapting to changing sea levels for many decades and centuries to come (Church et al. 2013; Wong et al. 2014; Manning et al. 2015). SLR will continue to increase well beyond 2100 even if carbon emissions are reduced to zero, so a key challenge for Aotearoa-New Zealand is to adapt to the increasing risk facing low-lying coastal communities and infrastructure (NZCCC 2014; Reisinger et al. 2014).

As outlined earlier, in Aotearoa-New Zealand a national framework for adapting to climate change (MfE 2014) and the NZCPS (e.g. the hazard and climate-change policies) provide national direction for coastal adaptation activities, but there is as yet no national policy instrument to direct climate change adaptation activity. Proposed reforms to the RMA and a possible national policy statement (MfE 2015a) in regard to natural hazards may address this gap to some extent. Further, the PCE in her report (PCE 2015) issued eight recommendations, for example in relation to national direction, guidance, accurate land topography, separating science from decision-making and improved engagement with communities that would better prepare Aotearoa-New Zealand for rising seas, some of which will be actioned with the revision under way of the current national guidance (MfE 2008a).

The responsibility for undertaking adaptation activities at the coast lies primarily with local government. In general, other than 'do nothing' (which provides no future certainty for any of the actors), there are three potential approaches to climate change adaptation at the coast (e.g. Bell et al. 2001; MfE 2008a; Wong et al. 2014; Reisinger et al. 2015) that local authorities can take: protect, accommodate or retreat (Table 3). These approaches, explored below, are invariably focused on socio-economic considerations, but each will have associated biophysical effects to address.

Protect

Protection, or defence, is often translated as a need to 'hold the line', traditionally using hard engineering approaches and structures such as seawalls usually in the form of rock revetments in Aotearoa-New Zealand (Blackett et al. 2010a). Engineered and technological adaptations are still the most common worldwide (Noble et al. 2014) and protection of people property and infrastructure is a 'typical' first response (Wong et al. 2014). The scale of these works in Aotearoa-New Zealand is small and ad-hoc compared with global practice, but remains as the primary response (Johnston et al. 2003; Blackett et al. 2010a; Reisinger et al. 2015). Examples of such protection measures include river stopbanks (e.g. Hutt River, Manning et al. 2011, 2015; Lawrence et al. 2015), seawalls (e.g. Auckland, Hart 2011; Reisinger et al. 2015; St Clair, Opus 2014) and rock revetments (e.g. Waihi Beach, Dahm et al. 2005; Urenui, Blackett et al. 2010a; Kāpiti Coast, Lumsden 2003). There is a tendency for such defences to proliferate in response to erosion events, especially in smaller coastal communities. Such engineering structures have traditionally been built based on assumptions of stationarity of the climate, which are not appropriate given projected changes in climate (Lawrence et al. 2015; Manning et al. 2015; Reisinger et al. 2015). Such structures can result in direct and indirect biophysical impacts on the adjoining beach (isolation from active dune fields, loss of the high-tide beach or estuarine intertidal areas, and increased erosion at the ends of the structure) and loss of natural character, public access and recreational or amenity values (Dahm et al. 2005; Hayward 2008).

One of the disadvantages of taking a protective stance is the establishment of a 'development-defend' cycle (MfE 2008a), where building a shoreline structure to literally defend a line in the sand can lead to a false sense of security about people and property being defended (Lawrence et al. 2015; Manning et al. 2015). Further development in these newly defended 'safe' areas can increase the value of infrastructure at risk, with pressure to strengthen or raise defences, leading to 'serial engineering' and eventually decreasing protection to a rising hazard exposure (Manning et al. 2015). The NZCPS explicitly states that a range of options should be considered including natural defences against coastal hazards (policy 26) and where possible risks managed in such a way that reduces the need for hard structures (policy 27). However, where hard structures are already in place, it may be difficult to help communities consider other options, as outlined in the section titled 'Coastal community adaptation to climate change' below. Strategic coastal adaptation, rather than adhoc, reactive works, will be required to enable this to happen.

Softer protection measures are increasingly being used (Wong et al. 2014) and include the protection or restoration of natural systems such as sand dunes, salt marshes or mangroves to provide protection, but in this protect sense are still used to hold the line albeit using a better understanding of beach sediment budget and vegetation dynamics. In Aotearoa-New Zealand, the management of sand dunes as natural coastal defences is well established (e.g. Bay of Plenty, Canterbury, Waikato; Dahm et al. 2005; Blackett et al. 2010a). Many regions have community dune-care groups established to assist with dune plantings using native species (e.g. spinifex and pingao), trapping moving sand while simultaneously encouraging beach visitors to minimise their impacts on such systems by walking on designated pathways. Such activities also raise community awareness and encourage community participation in local coastal management decisions (Dahm et al. 2005).

Accommodate

Accommodation is a more adaptive approach working with nature, where human activities or infrastructure are altered to make them more resilient in the face of climate change (Wong et al. 2014); in other words, the line is no longer 'held' but allowed to be breached in certain events. Examples include raising bridges and causeways, altering the use of ground floor levels in buildings, or retrofitting them, the use of coastal erosion or inundation hazard mapping with land-use planning such as establishing recreational spaces in flood prone areas, and flood warning systems (Wong et al. 2014). These actions have been shown to improve the flexibility of habitable areas so that natural cycles in erosion and intermittent storm events can be accommodated.

Retreat

Retreat involves moving away from the coast to some extent or in stages, with complete withdrawal considered as the last option to be taken when nothing else is possible (Wong et al. 2014). It often implies that a strategic and long-term decision has been made to migrate away from the coast, and proactively remove key infrastructure from coastal areas (Reisinger et al. 2015). Retreat also includes allowing wetlands, marshes or intertidal areas to migrate inland, developing shoreline setbacks in planning documents and managed coastal realignments such as breaches in defence works to allow for an intertidal area to redevelop further inland (Wong et al. 2014). The transition from accommodate to partial or full retreat implicitly recognises the dynamic risk that coastal hazard zones will, over the foreseeable future, migrate inland. Reisinger et al. (2014) concluded that for Australasia, managed retreat is a viable long-term adaptation strategy for human systems but that retreat options for natural ecosystems are limited owing to the rate of change and lack of suitable space for landward migration of those ecosystems, typically because of human systems established in the coastal hinterland. If left unmanaged, this potentially may lead to coastal 'squeeze' of coastal ecosystems and loss of ecosystem resilience with an associated reduction in ecosystem services for humans. A similar challenge faces human systems, which are in turn squeezed by landward migrating coastal systems unless there is room for them to migrate in turn.

Implementing managed retreat policies is a multidimensional problem (Hayward 2008; Reisinger et al. 2011; Manning et al. 2015; Reisinger et al. 2015). Councils have to communicate and defend their retreat 'line', weigh private versus public good, and address compensation for affected individuals and groups including costs of foregone opportunities (Reisinger et al. 2011, 2015). Hayward (2008) argues that while retreat is an option favoured by planners as a 'rational, cost effective, long-term solution' (p. 52), communities are vociferous and litigious in their opposition, so that very few examples of retreat have been implemented in Aotearoa-New Zealand. Examples at the coast include small-scale relocations of surf club buildings and car parks (e.g. Muriwai, Port Waikato) and the access road to Clifton, where Komar (2010) suggested retreat was the best option on this southern Hawke's Bay coast.

Planning approaches

Planning can be used to assist in all three of the options outlined above. The NZCPS encourages strategic planning, long-term (at least 100 years) assessment of risks, and appropriate focus on a range of management options including planning options such as retreat. In Aotearoa-New Zealand, councils often include coastal hazard zones in their regional plans under the RMA (Section 3), which then are implemented through district land-use planning such as development restrictions, and other tools like minimum ground levels, allowance for inundation or erosion freeboard (MfE 2003; Reisinger et al. 2014) and trigger clauses on consent conditions for building removal in some locations (e.g. Ohiwa, Tauranga City). However, hazard lines and zones can produce similar outcomes as hard protection structures in terms of risk perception, with resulting complacency and potential for maladaptation by building in apparently 'hazard free' zones. Like protective approaches, they are often based on the same assumption of stationarity (even with SLR included out to a defined end point) and the same requirement for certainty and 'a single number' to meet the needs of the planning framework (Reisinger et al. 2014; Lawrence et al. 2015; Manning et al. 2015). Reviewing CEHZ and CIHZ once established in plans is technically relatively straightforward, but politically difficult for communities to understand and accept.

Describing the above 'options' for adaptation may suggest that, in response to projected SLR and other climate-related coastal effects, there is a single solution available to a coastal community. However, this is an over-simplistic view, as there is sometimes overlap between these options and the reality is that a community may be best served by a number of complementary activities, i.e. a policy package (Reisinger et al. 2015). There are many potential barriers to adaptation, and the chosen package may include a number of actions to overcome these including buying time and staging responses. Before we go on to explore barriers to coastal adaptation in Aotearoa-New Zealand, and the possible enablers to overcome these, we will review research conducted alongside different Aotearoa-New Zealand communities and some of the lessons that can be taken from such work to help understand both barriers to adaptation and ways to overcome them.

Coastal community adaptation to climate change

In response to the challenges facing Aotearoa-New Zealand, the demand for knowledge and guidance surrounding the planning and implementation of adaptation for coastal communities as a strategy for climate risk management is increasing (Reisinger et al. 2011). To date, coastal community adaptation studies in Aotearoa-New Zealand have comprised a divergent range of efforts ranging from exploratory work based on public-policy-science engagements and conversations about climate change impacts, values, risks and adaptation (Stewart et al. 2010; Rouse et al. 2011; Schneider 2014), to projects developed by Māori authorities that provide frameworks for articulating values, issues and aspirations surrounding climate change risks and wider natural resource management objectives (Te Rūnanga o Kaikōura 2007; Ngāi Tahu ki Murihiku 2008; Raukawa Settlement Trust 2015), as well as adaptation assessments for iwi- and hapū-based communities via computer modelling of coastal river reach systems and integrated metrics of vulnerability and endurance (King et al. 2011, 2012, 2013). Some important and complementary insights have come from these different efforts and are discussed in more detail below.

Public policy–science engagement and conversations

Given that adaptation is a social process that requires individuals and communities to change practices and behaviours and make trade-offs between things of value, the importance of community involvement in developing adaptation strategies is now well recognised (Blackett et al. 2010b; Stewart et al. 2010; Rouse et al. 2011; Schneider 2014). The concept of trade-offs is a deceptively simple one; as the name implies, something that is valued must be traded or given up in favour of something else that is valued. Understanding the values of all actors in an adaptation-planning situation requires dialogue and trust building, before those actors can begin to understand how those values compare and how to weigh those in decision-making. Rouse et al. (2011, 2013) engaged with members of the highly mobile coastal community at Whitianga in the Coromandel Peninsula using a two-step process. Step one was an open day designed to provide a forum for members of the public to discuss with scientists and regional council staff the potential impacts of coastal erosion, coastal inundation and estuarine vegetation change on what the community valued. A subsequent workshop furthered these conversations and encouraged participants to explore different potential adaptation strategies with respect to conflicts and tensions between them. Although no adaption decisions were required as a result of this community research, it provided a valuable first step toward such decisions for three reasons: first, because it began the conversations about how climate change could potentially affect things of value to the community; second, it facilitated dialogue between the public, council staff and scientists around climate change; third, it provided an open forum to discuss all potential adaption options and explore implications for their community, with council staff present but not led by council. Rouse et al. (2011, 2013) argue that these are essential first steps for adaption planning because adaption benefits from being a locally negotiated process.

In a subsequent study of local perspectives on climate change and national and international policy guidance, Schneider (2014) concluded that the principal goals for coastal communities must be to reconcile contested interests, develop learning and trust, enhance understanding and manage scientific input. However, in order to realise this, safe spaces for deliberation and dialogue need to be created; understanding and knowledge with consideration of culture, values, interests and priorities must be shared; and the opportunities and limitations of existing policies and plans to address adaptation must be examined critically. Both of these studies highlight the importance of managing the communication of the potential impacts of climate change and associated uncertainties to help communities better understand the issues faced.

Perceptions of risk

Current knowledge of the perceptions and concerns of coastal communities around climate change issues can be drawn from both national and local scale quantitative research. The National Coastal Survey (Johnston et al. 2003) provided a highly detailed national level perspective on the perceptions and preparedness of 42 coastal communities ($n = 2995$; 40% return rate) around Aotearoa-New Zealand for coastal hazards. Although not primarily focused on climate change, this survey provides an insight into perceptions of, and experiences with, coastal hazards subject to a changing climate. Some 68% of respondents thought coastal erosion was the most likely hazard to affect their community and demonstrated awareness that SLR would impact coastal properties in the future, with only 12% believing that there would never be an impact (Johnston et al. 2003). In contrast, a survey of Waihi Beach, Ocean Beach (Tairua) and Whangapoua suggests the majority of respondents did not consider SLR to be a serious threat and that it could be managed (Stewart et al. 2007). More recent work by Stewart et al. (2010) in the low-lying coastal plain of Ruby Bay/Mapua ($n = 252$) reported that 31% of respondents felt climate change 'will adversely affect my lifestyle within my lifetime' while 23% were neutral and 38% disagreed. Further still, 28% of respondents revealed that SLR was a consideration when buying their home in the Ruby Bay/Mapua area.

Preferences for coastal erosion management alternatives vary geographically. For example, Stewart et al. (2007) found strong preferences for dune replanting at Waihi

Beach, Ocean Beach and Whangapoua, while in the 2003 survey, 57% of respondents in St Clair (Dunedin) favoured seawalls—the highest for that category across the surveyed communities (Johnston et al. 2003). For the former, all three beaches had active dune restoration groups with very visible successes in erosion management. In addition to strong preferences for 'softer' mitigation options, more than half the respondents in Waihi Beach, Ocean Beach and Whangapoua approved of managed retreat, in contrast to the national survey where on average only 8% approved. This social setting contrasts with that of St Clair where a seawall has been present for more than a century, and may reflect that attitudes are influenced by previous experience with local erosion mitigation activities (Blackett & Hume 2006).

Although quantitative surveys do not provide detailed insights into people's risk perceptions and beliefs, they do allow some general conclusions to be drawn. First, the results suggest that climate change and SLR are generally viewed as distant threats that will impact on coastal communities and property through coastal erosion, flooding and drainage issues. Second, risks are more keenly felt by those who are currently experiencing them. Third, views on management options tend towards hard engineering solutions, with the exception of areas where beach renourishment or dune replanting have already demonstrated benefits. Support for managed retreat appears to be highly variable (see 'Barriers' below). Fourth, there is a high level of geographical variation in perception and views of risks and management options indicating that each community is unique and should be approached as such. How risks are perceived coupled with the impacts and implications of SLR on things that the community value (including cultural ties) will shape the conflicts that arise. Moreover, they will shape how the conflicts evolve, the different positions that emerge and ultimately what adaptations are adopted. King et al. (2011, 2012, 2013) suggest that given that perceptions of risks are known to be important in influencing communities' actions, tailored information and the 'right people' to communicate such information would greatly assist meeting such challenges for different populations across Aotearoa-New Zealand.

Community values and conflicting values

Several authors have considered the potential impacts of SLR, coastal erosion and inundation, and estuarine habitat change, on what communities value. This research is tied to specific locations including Mapua/Ruby Bay (Stewart et al. 2010), Whitianga (Rouse et al. 2011, 2013), Temuka, Manaia and Mitimiti (King et al. 2011, 2012, 2013) and Te Puru, Mercury Bay and Kennedy Bay (Schneider 2014). An examination of these values (see Table 4) demonstrates the considerable breadth and pervasive nature of the potential impacts of SLR on coastal communities. Almost every aspect of life is directly or indirectly identified. The diversity of these values also exposes the potential for tension and highlights that adaptation planning will require trade-offs between these because it may be impossible to retain everything of value.

There are several key conflicts and tensions present within Aotearoa-New Zealand coastal communities that will be exacerbated by SLR. Blackett et al. (2010a) suggest that central to debates about how to manage coastal erosion is the challenge of reconciling the interests of those whose private property is at risk from coastal erosion with public interest in community safety and sustainability, such as the maintenance of safe public

Table 4. Coastal community values that could be affected by sea-level rise, coastal erosion and inundation in Aotearoa-New Zealand.

Private property and businesses
Homes/businesses flooded
Beachfront property at risk due to beach erosion or inundation
Financial stability of community; property loss, compensation and insurance
Land values—devaluation due to erosion or inundation
Loss of productive land and due to salt water intrusion
Loss of land holdings, farm stock and related economic opportunities
Local infrastructure
Lifeline infrastructure and community facilities
Storm-water and waste water systems
Access and safety of roads along the foreshore
Cultural assets—marae, urupa, kura kaupapa
Community lifeways and recreation
Community events
Beach access for recreation and public use
High tide sandy beach—loss due to erosion or coastal protection works
Supplementing household supplies (and incomes) through hunting and harvesting of wild foods (e.g. shellfish)
Persistence, safety and usability of public coastal reserves and estuaries
Sacred places and sites—degradation resulting in loss of identity, whakapapa and well-being
Displacement of people
Ecology and biodiversity
Coastal habitat, potential to lose certain species
Rare species (i.e. New Zealand dotterel)
Degradation of ecology leading to loss of traditional knowledge about species and harvesting techniques
Adverse impacts on mahinga-kai and whānau health from damage/destruction of sewer lines and septic tanks
Human-environment relationships and well-being
Salt water intrusion (salinisation) into fresh water resources
Aesthetics
The natural appearance of the beach, estuary and surrounding landscape, especially if hard engineering solutions are enacted
Affect the appeal of the area as a nice place to live, affect 'community feel'

Based on: Stewart et al. 2010; King et al. 2011, 2012, 2013; Rouse et al. 2011; Lawrence et al. 2015; Schneider 2014.

access to high tide beaches, which is also a requirement of the NZCPS 2010. Typically, an erosive event that threatens beachfront property stimulates the formation of a beachfront property owner lobby group which demands coastal armouring (e.g. sea walls, rock revetments) to protect their interests (Blackett & Hume 2010a). To counter this position, other members of the community seek to protect and maintain access to the intertidal sandy beach (with its associated aesthetic and use values) by requiring soft engineering options and, in some cases, managed retreat. This scenario leads to each group appealing for local and national support for their argument (Blackett & Hume 2006). Blackett et al. (2010a) suggest that how the negotiations over solutions proceed is contingent on: (1) local authorities facilitating group learning and establishing cooperative relationships; (2) community leadership and resourcing; (3) addressing perceived as well as actual risks; (4) testing any claims by lobby groups to represent the wider community; (5) introducing scientific information at the right time and in accessible language; and (6) keeping good records documenting the physical situation and past attempts to resolve problems. Subsequently, Blackett et al. (2010a) found that if these conditions are (mostly) met then the outcome is more likely to result in a soft engineering solution. Conversely, hard engineering solutions are more likely when these conditions are not met.

Coastal climate change will intensify this debate for several reasons: first, the incidence of coastal erosion events will increase markedly; second, soft engineering adaptation options may have only limited effectiveness which will refocus communities on the tension between coastal armouring and managed retreat; third, the gentrification of beachfront holiday homes over the past two decades (Cheyne & Freeman 2006) is likely to continue, thus increasing the economic value of the properties at risk (Peart 2009; Reisinger et al. 2015). As the value of coastal property increases so does the power and influence leveraged to protect private interests at the risk of barring wider community interests (Schneider 2014). How the tension between private property or existing-use rights and community beach access and amenity is resolved will have a profound influence on the future appearance and value of the Aotearoa-New Zealand coast.

In spite of the disagreement between some coastal scientists over the most suitable method to establish the width of coastal hazard setback zones (Blackett & Hume 2006; Carley et al. 2014), such zones are an accepted approach to manage and reduce the effects of coastal erosion and prepare for potential SLR in new residential coastal developments or greenfields (Blackett & Hume 2006; Ramsay et al. 2012). However, where hazard zones are applied retrospectively to existing residential areas they are highly contentious, particularly with members of the community whose property is directly affected (Carley et al. 2014). How property owners respond to the proposed addition of hazard lines to their Land Information Memorandums (LIMs) can be explored with reference to recent events on the Kāpiti Coast. In this case, the local authority proposed the addition of hazards lines over existing residential developments to reflect SLR over the next 100 years (outlined above). The affected property owners criticised the science underpinning the hazard lines in two ways. They questioned the method applied to establish the hazard zones: 'the Kāpiti Coast erosion hazard assessment that has been used to justify the changes was inaccurate, unreliable and overly conservative' (Giblin 2013; Carley et al. 2014); and disputed the evidence of a changing climate: 'In about 100 years, according to scientists, they are saying it [the sea] will come through the living room and half the kitchen. I think they have the science, the law and the facts badly wrong' (TV3 News 2013). Additional media reports detailed residents' concerns around the impacts of a perceived reduction in property values, future insurance premiums and the prospect of losing a property into the sea (Blundell 2012). Following the peer review of the CEHZ (Carley et al. 2014), Kāpiti Coast District Council is currently navigating a way through this conversation using collaborative processes. For the application of the science, one of the key messages was the adoption by the consultant of a precautionary 'worst case' scenario to set the CEHZ, rather than present decision-makers with a range of plausible outcomes for erosion setbacks to cover the range of uncertainty—a point raised by the PCE (2015) in her recommendations with the need to separate the two processes. The aforementioned issues are likely to be ubiquitous in Aotearoa-New Zealand principally because where coastal adaptation strategies affect private property rights, and impact on people's lives and the things that they value, management strategies will be challenged. As a consequence, coastal managers will need to explore the potential impacts and implications on the community for a range of timescales and predictions covering the uncertainty band as part of their adaptation planning process.

Working alongside Māori community members from Manaia Settlement in the western Coromandel Peninsula, King et al. (2012) identified an ongoing 'competition of values' that is occurring. This 'competition' was described in terms of government policy directions, societal development paths and linked regulatory regimes that conflict with traditional Māori views about the intrinsic value and integrity of the ecological system as well as neglect of the inherent duties and responsibilities of the living to future generations.

These perspectives reveal sharp tensions about power, governance and ethics, as well as other spheres of influence that determine human behaviour, choices and actions.

Māori community adaptation and vulnerability

Considerable work has been undertaken by Māori authorities and governance structures across Aotearoa-New Zealand generating iwi and hapū environmental management and natural resource management plans that identify climate change issues and implications (Hauraki Māori Trust Board 2003; Ikin et al. 2007; Ngāi Tūāhuriri Rūnanga et al. 2013; Ngāti Tahu—Ngāti Whaoa Iwi Runanga 2013) as well as comprehensive policy responses and linked adaptation opportunities (Te Rūnanga o Kaikōura 2007; Ngāi Tahu ki Murihiku 2008; Raukawa Settlement Trust 2015). These documents provide important mechanisms through which Māori approved positions, interests and visions about climate change adaptation and the wider management and protection of natural and physical resources can be addressed. Further, it is evident from many of these documents that the need to reduce the vulnerability of their 'communities' to climate-induced coastal risks through adaptation (and mitigation of greenhouse gas emissions) is well recognised, as well as the linked need to strengthen the capacities of iwi, hapū, whānau and Māori business to assess, plan and respond to these challenges.

A series of place-based studies examining the contextual conditions that underpin coastal Māori community adaptation and vulnerability have also been recently completed by King et al. (2011, 2012, 2013; also in Manning et al. 2011, 2015). Using a vulnerability framework, these integrated assessments of coastal adaptation to climate variability and change involved: (1) the modelling of past and future scenarios of climate change-induced coastal hazards and risks; and (2) grounded analysis of the socio-ecological conditions that influence the exposure, sensitivity and adaptive capacity of each community to effectively respond to climate-induced changes. From this work, our understanding of the factors and processes that constrain and facilitate whānau and wider community choices and responses to coastal hazards, risks and stresses has improved, highlighting the inseparable links between iwi/hapū development, natural hazards management and climate change. Identification of these determinants of vulnerability (and endurance) reveal sharp tensions about power, governance and ethics, as well as other spheres of influence that determine human behaviour, choices and actions. They also reveal valuable opportunities or entry points for tactical and strategic adaptation interventions.

Notwithstanding the insights gained from these collective efforts, more attention is required to better realise the range of opportunities that exist and how they might create enabling conditions for Māori coastal community adaptation. Further, more integrated assessments of climate change impacts, adaptation and socio-economic risk for other Māori and non-Māori coastal communities are desirable, especially when set within the wider context of other multiple stresses. More also remains to be done to effectively use the knowledge gained from such studies to facilitate adaptation more broadly.

Barriers, enablers and approaches to adaptation in Aotearoa-New Zealand

There are a number of factors and/or spheres of influence that may make it harder or easier to adapt to coastal climate change, and a growing terminology has emerged to keep up with developments in this area (Table 2). In particular, the terms barrier, obstacle and constraint are all used to imply that there will be contextual and/or outcome challenges to overcome in adaptation planning or implementation. Conversely, enablers, solutions, opportunities or success factors are determinants that are likely to facilitate overcoming such barriers. Meanwhile, a limit to adaptation is an absolute stop point, where no steps are available to enable a manager to undertake actions that will achieve their adaptation goals for an area.

Barriers

Several authors have explicitly written about barriers to climate change adaptation in Aotearoa-New Zealand. Early consideration of adaptation to the climate change impacts concluded that both society and ecosystems could adapt if the rate of climate change were slow (Mosley 1990). However, it was also noted that any changes in the frequency and severity of extreme events may trigger the need for more urgent action, and that impacts would be felt by parts of society less able to adjust, likely requiring government action to deal with public concern and help address equity issues (Mosley 1990). Bell et al. (2001) noted much broader barriers including planning timeframes, conflicts between the desire to protect property and the potential for adverse environmental effects, a lack of public awareness of climate change impacts at the coast, and the need for local and regional responses due to the diversity of the Aotearoa-New Zealand coast. More recently, Britton (2010) surveyed councils to ask about barriers to implementing climate change adaptation programmes within councils, and identified barriers such as political attitudes and awareness, community awareness and understanding, national guidance,[7] risk information, and decision-making processes and timeframes including the mismatch of these to election cycles. Similar barriers were identified by Lawrence et al. (2015).

Meanwhile, King et al. (2011, 2012, 2013) identified a range of constraints that influence how semi-rural and rural Māori communities cope with and adapt to climatic risks. Key among these were: degraded (and substandard) infrastructure systems; access to finance and inadequate resourcing; limited capacity (and relevant expertise) to represent (and lead) community-related affairs; increasing competition for environmental resources; degradation of local ecology and habitats; loss of traditional knowledge, practices and skills; inequitable representation and participation in local and regional planning; and, greatly altered relationships between people and their environment. It is evident from this work that such constraints represent windows of opportunity for strategic community, iwi and government-level planning and policy development on climate change adaptation.

Most recently, Lawrence et al. (2015) identified institutional barriers including professional practice constraints (e.g. engineers versus planners) and confusion over roles and responsibilities between and within scales of government. Lawrence et al. (2015) group institutional barriers (and enablers) for local government into six groups: information, capability, funding, community expectations, roles and responsibilities, and national instruments. Manning et al. (2015) provide slightly different categories including relationships and institutions, and governance and policy instead of the national instruments category of Lawrence et al. (2015). Reisinger et al. (2014) note that for coastal erosion and inundation, barriers to adaptation include high costs of infrastructure upgrades, and contested rezoning or relocation decisions due in part to impacts (real or perceived) on property prices.

This literature and the preceding sections highlight particular barriers caused through lack of national policy direction, and difficulty communicating potential climate change impacts and adaptation options in part due to lack of understanding and perceptions of risk in our communities. These barriers mean that adaptation is difficult both technically and politically and, unsurprisingly in this environment, councils have struggled to strategically plan for adaptation. A summary of barriers and enablers to adaptation in Aotearoa-New Zealand is provided in Table 5.

Enablers

Many enablers can simply be thought of as the inverse of a barrier; for example, where a barrier exists through variability in awareness or acceptance of climate change as an issue, an enabler can be improved education programmes or other activities that help raise awareness. Again, views on climate change adaptation enablers in Aotearoa-New Zealand have evolved since Mosley (1990) stated that normal activity levels will enable adaptation, assuming the rate of climate change is slow. Since this time, enablers of climate change adaptation have been reported for a number of publics across Aotearoa-New Zealand. For example, Bell et al. (2001) identified a need for enablers to inform local and regional analyses and responses, such as: improved public awareness of climate change issues; more information such as topographic and cadastral databases; and a greater understanding of adaptive capacity of local communities. Basic spatial information infrastructure such as high-resolution LiDAR topography is another key enabler to improved definition of exposure to SLR that some councils have utilised, but there is a need for a consistent approach and access to such resources throughout Aotearoa-New Zealand (LINZ 2014; Bell et al. 2015, 2016). Britton's (2010) survey of councils identified the need for enablers such as: stronger national policy guidance; more robust data and locally specific information; increased community and political awareness; and updated guidance material. While the NZCPS 2010 provided more direction (Lawrence et al. 2015), further national policy is probably needed in order to give councils the ability to overcome the technical and political barriers above, and to help socialise the need for stronger management with communities. Current planned reforms to the RMA increase focus on natural hazards management and these may help in this regard (MfE 2015a). Further still, for Māori communities dealing with climate change impacts and risks, King et al. (2011, 2012, 2013) identified the importance of leveraging economic support and technological resource pathways, strengthening sociocultural networks and related cultural conventions and values, learning new strategies and practices, and integrating climate change into iwi/hapū management planning. Other enablers to overcome barriers to adaptation are presented in Table 5.

Finally, in exploring how to overcome barriers to adaptation planning, including communicating about climate change issues, Rouse & Blackett (2011) identified a number of 'success factors' to help successful collaborative adaptation planning. The principal factors included access to high-quality data (such as topographic data or local knowledge), a multidisciplinary team, appropriate financial and human resources, and commitment to the

Table 5. Barriers and enablers to coastal adaptation to climate change impacts in Aotearoa-New Zealand.

	Barrier	Enabler
Information	• Variability in data quality such as topographic data at coast • Issues around levels of certainty of impact projections and timescales • Availability of non-market valuation data for recreational assets and ecosystems to weigh in cost-benefit assessments for action • Access to information and information not always audience relevant (e.g. Māori aspirations) • Difficulty integrating information into a risk management approach • Limited ability to communicate uncertain and risk-based information • Climate change information sometimes complex and confusing	• Shared information at both international and national levels • National and regularly updated data sets (e.g. LINZ topographic data) • Improved valuation methodologies • Consistent risk assessment methodologies/tools for risk assessment • Collaborative processes to discuss climate change issues using local information—'bottom-up' interactions • Tailored information and the 'right people' to communicate information to specific groups (e.g. Māori)
Capability	• Lack of climate change expertise among coastal practitioners • Variability in capability between institutions responsible for adaptation actions • Potential to perpetuate professional practice differences • Shortages of skills and community leadership to deal with complexity of climate change implications	• Shared expertise between communities of practice (case studies, workshops) • Guidance documents to aid risk assessment, economic assessments, facilitation of collaborative processes • Graduate programmes focusing on coastal climate change issues and adaptation • Mutual support and collective action based on traditional Māori values • Māori knowledge, environmental skills and awareness of local risks
Resourcing	• Limited ability to fund climate change risk assessments or undertake adaptation option assessments • Lack of funding to commit to collaborative processes • Conflict between using general vs targeted rate for funding adaptation options • Legacy costs of existing protection structures • Substandard infrastructure or remote Māori communities • Limited access to new technologies and equipment	• National funding options e.g. for risk assessment or data collection, or to fund studies to inform good practice • Tools to aid scoping and prioritising of most vulnerable areas • Case studies to demonstrate benefits of collaborative approaches (upfront costs rather than litigated planning processes)
Community perceptions and expectations	• Lack of awareness or even denial of risks by some • Opposition to transparent hazard information • Resistance to land-use zoning changes • Confusion between regional and district council responsibilities • Perception that council will protect their property • Barriers at a personal level to individual action: the seven 'dragons' (limited cognition, ideologies, other people, sunk costs, discredance, perceived risks, limited behaviour; see Gifford in Lawrence et al. 2011)	• Consistent climate change information at national and regional levels • Separate adaptation from mitigation discussions • Continuous communication with communities • Tools to aid planning and delivery of public awareness programmes (e.g. risk communication) • Clarification or integration of planning provisions across local and regional scales • Robust discussion about council's approach to public vs private debate • Group 'citizenship' responses (e.g. Christchurch earthquake student army); encourage the few individuals who are taking direct action; encourage other related activities that indirectly address the problems

(*Continued*)

Table 5. Continued.

	Barrier	Enabler
RMA implementation issues	• Inconsistent or confusing district vs regional plan provisions and responsibilities • Clarity of provisions across CMA • Inability for RMA plans to allow for agility (perpetuating quest for a 'single number') • Weak or confusing plans devolve decision-making down to individual consent level • Mismatch with other legal frameworks (e.g. Building Act, Civil Defence Emergency Management Act)	• Provision of national direction in terms of planning requirements • Clarification or integration of planning provisions across local and regional scales • Integrated 'all hazards' planning approach • Legislative changes to align key drivers for adaptation
Institutions, governance and policy	• Market-led approach to decision making (high weight on private property rights) • Overlapping responsibilities from local to national level • Lack of national instruments specific to climate change, for example no standard for SLR • Lack of political will to make long-term decisions • Inequitable participation and representation of Māori in local planning arrangements • Unstable or weak institutions, agencies and governance structures	• NZCPS provides clear approach to coastal hazards management and climate change but more national direction in climate change space needed to provide bottom lines • National guidance documents produced and regularly updated • Strong Māori-led institutions and governance • Use collaborative processes to build community-based development paths • Marae planning and preparation for climate-related natural hazards

Source: Bell et al. 2001; Britton 2010; King et al. 2011, 2012, 2013; Lawrence et al. 2011, 2015; Reisinger et al. 2011; Manning et al. 2015.

process from the appropriate decision-making organisation (e.g. council). The collaborative process moved through phases of dialogue (what are the issues from your perspective?), debate (what could we do about it?) and negotiation (what will we actually do?) (Forester & Theckethil 2009). More active research with coastal communities exploring adaptation options would provide valuable insights to adaptation planning processes. Such collaborative approaches are already being explored in freshwater management under recent national policy initiatives and in proposed amendments to the RMA (MfE 2015a), addressing similar barriers driven by issues with devolved management and weak national direction (e.g. Pyle et al. 2001 among many others). Activity in this area by councils is proving that collaborative approaches can indeed help to produce grounded and strong environmental policies (e.g. Fenemor 2014; Henley 2014; MfE 2015b). It is noteworthy that these collaborative freshwater processes are backed by clear direction from a national policy level including provision of 'bottom lines' for environmental success.

Coastal adaptation approaches for Aotearoa-New Zealand

Internationally, concepts in adaptation to help overcome such barriers are evolving and proliferating (Hinkel & Bisaro 2015), as summarised in chapters from the recent 5th IPCC assessment reports (Denton et al. 2014; Klein et al. 2014; Mimura et al. 2014; Noble et al. 2014; Wong et al. 2014). Adaptation studies in Aotearoa-New Zealand have been exploring similar concepts and challenging existing paradigms and approaches

(Lawrence et al. 2011, 2013; Reisinger et al. 2011, 2014, 2015; Manning et al. 2015). For example, in a top-down 'scenario approach' to adaptation planning, the dominant paradigm in Aotearoa-New Zealand is to pick a 'single number' for the potential change (such as *x* cm SLR by 2050 or in 100 years) whether for engineering or planning purposes. This static type of approach has led to the 'permanence of coastal settlements far beyond the lifetime of individual buildings … ' (Reisinger et al. 2015, p. 294). Instead, researchers outline the reasons why the provision of a range (from *x* cm to *y* cm by 2050, or by *x* cm by some time between 2050 and 2100) can be more useful. One of these reasons is the uncertainty inherent in the projections, based on ocean climate models and anticipating the emissions trajectory, but these uncertainties are no reason not to act. Use of different scenarios for the future, especially SLR, enables a range of reasonably expected potential outcomes to be considered, including for greenfields and new infrastructure (e.g. MfE 2008a; Palmer 2011; Cudby 2014) and is part of a recommended risk management approach (MfE 2008a; Britton et al. 2011; Britton & Rouse 2012; Klein et al. 2014).

A key challenge remains to assist engineers, planners and communities to understand that successful adaptation is not just a process of picking a single number, selecting a single option for action, and thus 'solving' the issue, which has been the approach adopted by many councils in traditional CEHZ or CIHZ hazard line or zone setting. Various authors (e.g. Wilby & Dessai 2010) have identified issues with 'top-down' adaptation planning, which includes adaptation that is based on downscaling of modelled climate scenarios. In Aotearoa-New Zealand, this approach supports a 'protect' paradigm enacted through defence structures and single line hazard planning, and combined with social perceptions of risk and the barriers for local government action, these habits are exceedingly hard to break. Instead, 'bottom-up' approaches use understanding of the existing events and issues being experienced by a community at a given location, to assess local tipping points where consequences would be intolerable and help develop options for management that are relevant to those issues and adopt a 'monitor and review' mechanism to delay or advance the next stage (e.g. Thames flood and barrage study, London [Reeder & Ranger 2013] discussed in Britton et al. 2011). Most adaptation is a mixture of both top-down and bottom-up (Mimura et al. 2014), and the studies reviewed in the section titled 'Coastal community adaptation to climate change' have used mixed approaches but with a clear emphasis on gathering local information as well as sharing modelling results (King et al. 2011, 2012, 2013; Rouse et al. 2011, 2013). Progress in the freshwater space suggests that collaborative approaches will provide a useful tool to help councils and communities plan together for coastal climate change (MfE 2015b), especially when backed by clear national direction and provision of some 'bottom lines'.

To facilitate coastal adaptation planning, many researchers are discussing the concept of adaptation 'pathways' (e.g. Haasnoot et al. 2013; Denton et al. 2014) and exploring alternatives for adaption to SLR that allows flexibility in timing of certain stages of protection works such as the Thames Barrier (Reeder & Ranger 2013). This approach was partially applied to the design for upgrading the Waterview causeway on Auckland's northwest motorway (Bell et al. 2014), again demonstrating that there is potential for this approach to work in Aotearoa-New Zealand. Work is under way in collaboration with Haasnoot et al. (2013) to develop a simulation game for decision-makers in Aotearoa-New Zealand that develops the dynamic adaptive pathway approach to climate-change adaptation planning and policy for coastal and flood plains (J Lawrence, Victoria University, pers. comm. November 2015.).

In Aotearoa-New Zealand, adaptation planning for SLR is becoming widely adopted although implementation is often piecemeal (Reisinger et al. 2014). Managed retreat remains an important adaptation option for Aotearoa-New Zealand's coastal communities to explore (Reisinger et al. 2014), but as outlined earlier there remain many barriers. Reisinger et al. (2015) studied the relative success of managed retreat 'policy packages', exploring criteria such as transition timeframes, distribution of costs, barriers and enablers of each approach, and implementation detail. For success of retreat policies, Reisinger et al. (2015) identified key factors including the need to engage affected communities early, to consider economic, social, cultural and environmental implications of protection versus retreat, and to collect risk assessment and cost-benefit information to make decisions. Reisinger et al. (2015) identified the Twin Streams project in Auckland as a precedent example of using a collaborative approach to agree a robust and accepted adaptive plan, suggesting that such approaches will be possible to help Aotearoa-New Zealand communities. There are also options planning for the next 'at least 100 years' (as required by the NZCPS) to undertake a graduated approach with more stringent planning and development controls for, say, the 50-year horizon for a CEHZ, for which climate change impacts on the coast are more certain, and less so for areas possibly impacted over the 50–100 year timeframe. This approach is used by some councils for their CEHZs e.g. Waikato Regional Council and Tauranga City Council, which recognises that the likelihood of impacts, particularly for erosion, is not evenly spread over the 100 years. However, such approaches need to be grounded within the wider context of an adaptation strategy in tandem with regular monitoring and plan reviews, given that sea level will continue to rise beyond 100 years and coastal areas are exposed to increasing risk from multiple hazards (e.g. storm or tsunami inundation and groundwater) besides coastal erosion.

Glavovic et al. (2015) outline a new conceptual framework called 'reflexive adaptation', which outlines the importance of people, places and processes. This framework outlines the importance of adaptation at the coast being: (in terms of process) responsive; deliberative; transformative; holistic; (in terms of place) integrative; and (in terms of people) inclusive, equitable and empowering. This framework offers new and as yet untested opportunities to assess adaptation planning in Aotearoa-New Zealand in the future.

The future

This review has identified a growing body of scholarship focused on understanding and facilitating pathways that support and enable adaptation to climate change in coastal and estuarine areas in Aotearoa-New Zealand, with some significant milestones shown in Figure 1.

Research gaps on adaptation are acute in biophysical systems that transition between marine and freshwater systems, such as estuaries, saltmarshes, wetlands and lowland streams (Lundquist et al. 2011; Kettles & Bell 2015). These systems, both surface and groundwater, will be subject to an increasing landward translation of brackish waters, with ongoing SLR and consequential human pressures to protect the adjacent built environment or 'productive land'. Specifically, there has been little research on natural adaptation of these ecosystems, future sediment budgets and their effect on the morphology and functioning of different types of water bodies, groundwater impacts (salinisation, surface drainage and effects on the utility of the built environment), as well as attendant sustainable approaches to adaptation of the built environment to avoid maladaptation and negative environmental side effects. This information is vital to ecosystem-based adaptation (Wong et al. 2014). However, despite these information gaps, in many cases there is sufficient information at hand to enable adaptation planning to begin, and the next challenge lies in clear communication of this information and its uncertainties to communities involved in adaptation planning.

Other than single-building examples of retreat from the coast, there are no examples of a coastal community mapping out pathways towards a more sustainable future (which may eventually require partial retreat). Consequently, there is considerably more research required in the policy/planning space and with astute community engagement processes, to better prepare and support communities and decision-makers in commencing and undertaking strategic adaptation planning. Lessons to be learnt from freshwater management in Aotearoa-New Zealand may help here, where stronger national direction and environmental 'bottom lines' have been developed and provide a framework within which regions and individual communities can work collaboratively to set objectives to meet their future needs.

Practical and aspirational research and activities for the next decade might therefore include:

- Addressing specific barriers to coastal adaptation planning and action such as land tenure, fixed-term consents and rolling easements;
- Integrating climate change adaptation with disaster risk reduction (which focuses on present risks) and integrated coastal zone management best-practice approaches to get win-wins (e.g. Glavovic et al. 2015);
- Advancing towards resilient biophysical systems and communities adapting in synergy, rather than the current human-centric approach which may result in maladaptation and unforeseen environmental side effects;
- Adopting smart technologies and approaches to changing coastal land use that enables communities to adapt in a socio-economic sense, for example working with water rather than fighting it (Cudby 2014);
- Exploring new opportunities such as in the tourism or aquaculture industries;
- Staging of adaptation and implications on costs (including near-term and foregone opportunity costs versus future social costs) and benefits (e.g. Chambwera et al. 2014); and,
- Engaging with communities to map out options for flexible adaptive pathways for a sustainable and resilient future.

And finally, as our coastal margins will be in a state of continual change for at least several centuries, it is vital that tools are developed to support regular monitoring (of SLR, the environment and policy effectiveness) and reviews of adaptation plans and strategies. Such measures will help to track progress along agreed adaptation pathways as well as inform communities of any changes that might be required at some future juncture.

Notes

1. It was formed by the World Meteorological Organization and the United Nations Environment Programme.
2. http://www.ipcc.ch/organization/organization.shtml accessed 30 March 2015.
3. Used in climate-change sector for reduction in the drivers of climate change e.g. greenhouse gas emissions.
4. http://www.mfe.govt.nz/climate-change/overview-climate-change/roles-and-responsibilities accessed 30 March 2015.
5. http://www.mfe.govt.nz/climate-change/climate-change-resources/guidance-local-government accessed 30 March 2015.
6. Light Detection And Ranging laser surveys measure land height and surfaces (vegetation, building roofs, etc.).
7. This survey was conducted before the NZCPS 2010 was released.

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