Freshwater conservation under a changing climate

Proceedings of a workshop hosted by the
Department of Conservation,
10–11 December 2013,
Wellington

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Department of
Conservation
Te Papa Atawhai

Cover: Whataroa River, south Westland. *Photo: Philippe Gerbeaux, DOC.*

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Freshwater conservation under a changing climate

Proceedings of a workshop hosted by the Department of Conservation, 10–11 December 2013, Wellington

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Executive summary

Addressing the impacts of climate change on freshwater ecosystems will require collective action by government agencies, iwi, industry and community, based on a robust scientific knowledge base. However, it remains largely unknown how climate change will influence freshwater ecosystems in New Zealand. The lack of information is critical, as conservation initiatives and water resource planning continue to operate without consideration of climate change projections.

A national workshop was seen as an effective way to identify key issues with respect to climate change and freshwater conservation, bringing together an interdisciplinary group of researchers, policy advisers and people involved in freshwater management. The Department of Conservation (DOC) organised a two-day inter-agency meeting in Wellington in December 2013, with 24 participants covering specialist fields of freshwater and estuarine ecology, conservation, physical impacts of climate change, policy and Mātauranga Māori. The programme focused on 'what are the issues?' on Day 1 and progressed to 'what can we do?' on Day 2.

These proceedings reiterate that climate change is unequivocal and will result in changes to the ecological functioning of aquatic ecosystems in New Zealand, and is likely to contribute to the loss of native species. The challenge is identifying where and how the physical changes will manifest, predicting how significant the changes will be, and whether the corresponding changes in our lakes, rivers, estuaries and wetlands are acceptable, or need to be avoided.

The authors of these proceedings describe the vulnerability of freshwater ecosystems to climate change impacts and identify the priorities for information sharing and research needed to underpin an adequate policy response and to inform future management. In many situations climate change is likely to exacerbate the pressures already being experienced by vulnerable ecosystems and threatened species. For example, lake ecosystems affected by nutrient enrichment may become more susceptible to algal blooms resulting from changing wind and temperature patterns.

A decision framework is introduced to help natural resource managers identify the situations where adaptation to climate change through human intervention may be required. Priorities for scientific research, policy development, and communication are also detailed.

While it is tempting to focus on the areas of scientific uncertainty, this must be balanced by acknowledging that many countries are investing in actions to facilitate climate change adaptation. Freshwater conservation in New Zealand will also benefit from an approach that is future focused, rather than reactionary.

1. Introduction

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Freshwater ecosystems are at risk, globally, from a multitude of anthropogenic pressures, or threats. Climate change is one of these threats.

We are already experiencing changes in our climate, and more change is projected, with long-term trends towards higher temperatures, further hot extremes, fewer cold extremes, and altered rainfall patterns in some regions of New Zealand (IPCC 2014). Changes in the hydrological dynamics of watersheds, sea-level rise, increased water temperature and altered land use patterns that occur in response to a warming climate will impact on the ecological function, resilience, and values of lakes, rivers, wetlands, estuaries and groundwater systems in New Zealand; although the degree of impact to these systems is still largely unknown.

Internationally there has been significant investment in climate change research to aid management (e.g. Heller et al. 2009; Bates et al. 2011; Jeppesen, et al. 2011; Palmer et al. 2014;). In New Zealand, initiatives to date have mostly addressed the impacts of climate change on primary industries (e.g. Clark et al 2012) and terrestrial systems (e.g. McGlone & Walker 2009; Christie 2014), with less attention paid to freshwater species and their habitats..

However, there is now increasing recognition of climate change as a significant threat in New Zealand, with national initiatives being recently established including:

- The New Zealand Climate Change Centre (NZCCC) being launched in 2008. This organisation aims to improve collaboration across providers of science-related climate research and services, and initiate mechanisms to facilitate interactions with end-users.
- A four-year Ministry of Business, Innovation and Employment (MBIE)-funded research project established in 2012 (Climate Changes, Impacts & Implications for New Zealand (CCII)). This aims to update and improve projections of climate trends, variability and extremes across New Zealand out to 2100, generate new knowledge about the potential impacts and variability on New Zealand's environment, including focussing on case studies of our main natural ecosystems and native species (e.g. alpine, upland, lowland, coastal and marine), and impacts on productive activities.
- Investment by government agencies in climate change assessment and adaptation projects.

The Department of Conservation (DOC) as lead conservation agency has an important role in identifying how freshwater ecosystems will respond to climate change, and how best to manage important ecosystems and species. Adoption of any new approaches to conservation will require scientific information to assist people to understand the key climate change impacts on New Zealand's freshwaters, and the highest priority research and management actions required to address them.

1.1 Workshop

A national workshop was seen as an effective way to bring together an interdisciplinary group of researchers, policy makers and managers to collate current knowledge of how freshwater ecosystems will react to climate change, recommend priority actions for science, management and policy, and establish and further develop linkages between natural resource management agencies and science institutions.

Twenty-four participants (Appendix 1) covering specialist fields of freshwater and estuarine ecology, conservation, management, climate change, policy and Mātauranga Māori met in Wellington on 10–11 December, 2013 (Appendix 2). To offset the carbon used by the participants to attend the workshop, we supported the National Wetland Trust to restore native vegetation at Rotopiko/Lake Serpentine (Waikato).

Key themes of the workshop were:

- Vulnerability of freshwater ecosystems under climate change, including estuaries, wetlands, rivers and lakes.
- What are we aiming for? Setting freshwater conservation targets under climate change.
- Adapting management and policy for freshwater ecosystems.
- Developing a national strategy for freshwater conservation under a changing climate.

The workshop was opened by Rosemary Miller (Freshwater Manager, DOC), with Lou Sanson (Director General of Conservation) and Dr David Wratt (Director, New Zealand Climate Change Centre (NZCCC) (at the time of the workshop)). Both speakers provided an overview of climate change research and initiatives underway in New Zealand, why climate change is such a major environmental challenge and why it is critical that its affects are addressed and managed to ensure the protection and sustainability of our freshwater ecosystems.

These proceedings collate information presented and discussed at this workshop. They describe the current thinking on climate change and freshwater conservation in New Zealand and the lessons that can be learnt from elsewhere. They will also provide a platform for sharing information with decision makers and for identifying key information needs and priority future work requirements.

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2. Setting the scene

2.1 Evidence and projections of climate change

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2.1.1 Background

The 'greenhouse effect' is a naturally-occurring energy-balancing phenomenon which results in the surface air temperature of Earth being kept at an average of around 14°C (IPCC 2007). A steady increase in greenhouse gas (e.g. CO_2, N_2O, CH_4) concentrations in the atmosphere over the last 100 years from anthropogenic sources (principally from the burning of fossil fuels, deforestation, and intensive agriculture) has enhanced the greenhouse effect, and has produced 'global warming' of the order of approximately 0.85°C since 1880. This warming, in turn, has affected global weather patterns, resulting in changes to other climatic elements such as rainfall, snow cover, sea ice extent, evaporation and wind patterns across the globe. The combined effect of these human-related influences on the climate is referred to as 'anthropogenic climate change', and the effects are likely to be present for centuries to come (IPCC 2007).

2.1.2 IPCC AR5 working group 1 headlines

Recently, Working Group 1 of the Intergovernmental Panel on Climate Change (IPCC) released its contribution to the fifth assessment report (IPCC 2013), along with a number of 'headline statements' from the report. A selection of these statements, which re-emphasise the conclusions in the previous fourth assessment report, is as follows:

- Warming of the climate system is unequivocal and since the 1950s many of the observed changes are unprecedented over decades to millennia.
- Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850.
- Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010.
- The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia.
- The atmospheric concentrations of carbon dioxide (CO_2), methane and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years.
- Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes.
- Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system.
- The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.

2.1.3 Evidence showing the effects of anthropogenic climate change

There is growing evidence from climatic and climate-related data records from around the globe that the Earth is warming and that the climate is changing. For example, the average global temperature record shows a clear upward trend, particularly from the 1950s (Fig. 1). Figure 2 shows trends in other datasets, some with relatively short records, consistent with this warming.

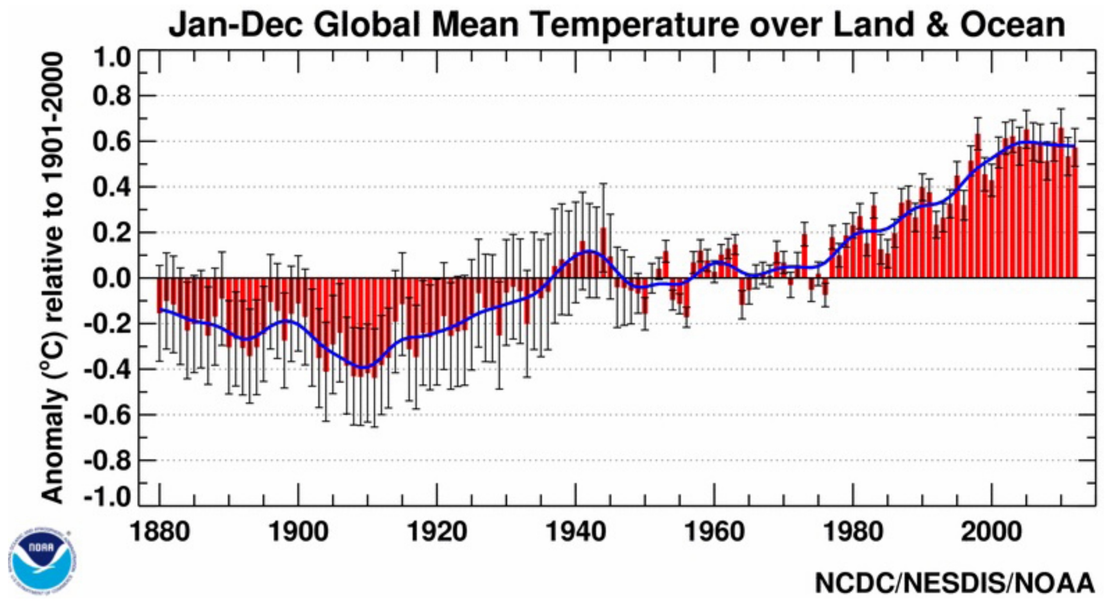

Figure 1. The trend in the global mean annual temperature, from 1880 to 2012 (from the NOAA National Climate Data Center).

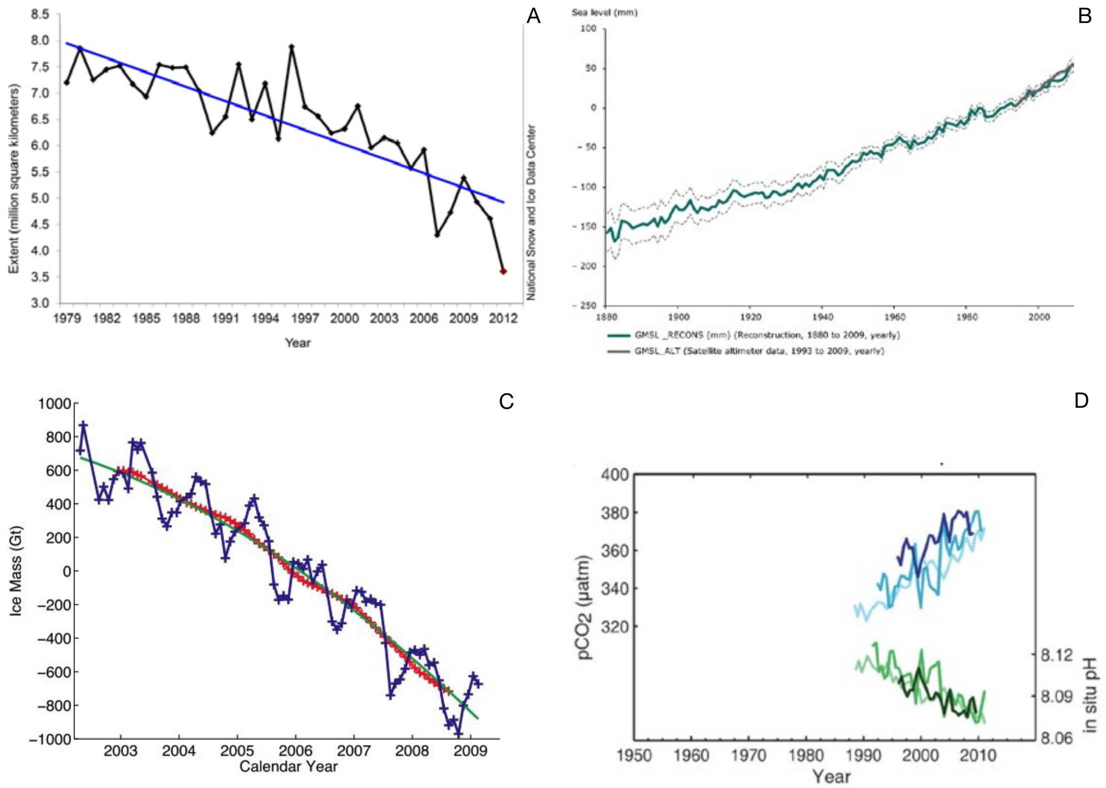

Figure 2. Examples of trends in warming; A) Trends in monthly Arctic sea ice extent (from National Snow and Ice Data Center), B) Global sea level (from European Environment Agency; Data from CSIRO, Australia), C) Ice loss from Greenland Ice Sheet (from Velicogna 2009), and D) surface ocean CO_2 and pH (from IPCC 2013).

2.1.4 Climate change in New Zealand

New Zealand's average temperature has risen at a similar rate to the global average (Fig. 3). Climate model projections of future annual average temperatures for New Zealand are, for a mid-range emissions scenario and averaged over the entire country, approximately 0.9°C warming between 1990 and 2040 and another 1.2°C warming to 2090. There is significant variability around these projections, associated with different emission scenarios and climate model uncertainty. Table 1, from MfE (2008), summarises the climate change projections for New Zealand (temperature, as well as many other climate variables), taking into account this uncertainty.

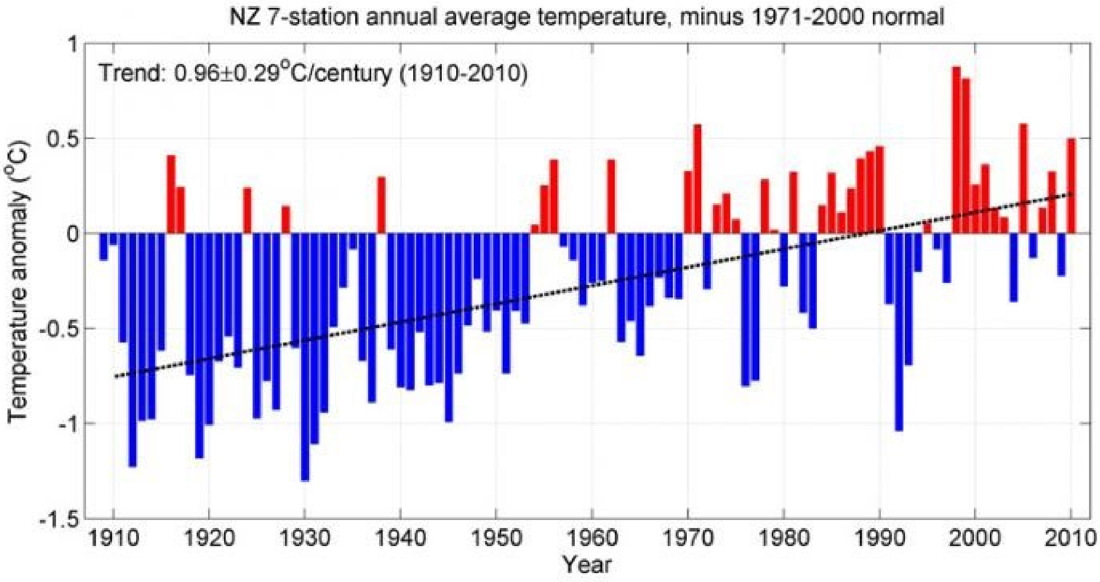

Figure 3. Trend in New Zealand's average annual temperature, from 1910 to 2010 (from NIWA).

2.1.5 Summary

The effects of climate change are not, and will not be, equally distributed around the world. While projections for New Zealand are less severe than for some other regions of the world, the country is not immune to the effects of anthropogenic climate change, particularly with respect to sea level rise and changing average and extreme rainfall patterns (see Table 1). Also, all climate changes projections vary spatially within New Zealand. The final 'headline statement' listed above from the IPCC AR5 WG1 (The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions) is not only relevant for the Earth, but for New Zealand as well. Managing the country's valuable freshwater ecosystems in the face of such climate changes will be a challenge for many decades to come.

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Velicogna, I. 2009: Increasing rates of ice mass loss from the Greenland and Antarctic ice sheets revealed by GRACE, *Geophysical Research Letters 36*, L19503, doi:10.1029/2009GL040222, 2009.

Table 1. Main features of New Zealand climate change projections for 2040 and 2090 (from MfE 2008 (Table 2.1; p. 14).

CLIMATE VARIABLE	DIRECTION OF CHANGE	MAGNITUDE OF CHANGE	SPATIAL AND SEASONAL VARIATION
Mean temperature	Increase (****)	All-scenario average 0.9ºC by 2040, 2.1ºC by 2090(**)	Least warming in spring season
Daily temperature extremes (frosts, hot days	Fewer cold temperatures and frosts (****), more high-temperature episodes (****)	Whole frequency distribution moves right (see 2.2.3 of the source report)	See 2.2.3 of the source report
Mean rainfall	Varies around country, and with season. Increases in annual mean expected for Tasman, West Coast, Otago, Southland and Chatham Islands; decreases in annual mean in Northland, Auckland, Gisborne and Hawkes Bay (**)	Substantial variation around the country and with season (see 2.2.2 of the source report)	Tendency to increase in south and west in the winter and spring (**); tendency to decrease in the western North Island, and increase in Gisborne and Hawke's Bay, in summer and autumn(*)
Extreme rainfall	Heavier and/or more frequent extreme rainfalls (**), especially where mean rainfall increase predicted (***)	No change through to halving of heavy rain return period by 2040; no change through to fourfold reduction in return period by 2090 (**)	Increases in heavy rainfall most likely in areas where mean rainfall is projected to increase (***)
Snow	Shortened duration of seasonal snow lying (***), rise in snowline (**), decrease in snowfall events (*)		
Glaciers	Continuing long-term reduction in ice volume and glacier length (***)		Reductions delayed for glaciers exposed to increasing westerlies
Wind (average)	Increase in the annual mean westerly component of windflow across New Zealand (**)	About a 10% increase in annual mean westerly component of flow by 2040 and beyond (*)	By 2090, increased mean westerly in winter (> 50%) and spring (20%), and deceased westerly in summer and autumn (20%) (*)
Strong winds	Increase in severe wind risk possible (**)	Up to a 10% increase in the strong winds (>10 m/s, top 1 percentile) by 2090 (*)	

2.2 Physical changes to New Zealand's freshwater ecosystems under climate change

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2.2.1 Introduction

There is a growing body of research indicating that climate change is an important consideration for freshwater conservation management. In order to support analysis and discussion of how these management activities may proceed, this article outlines the foreseeable physical changes to our freshwater systems. They include changes to water temperature, the volume and timing of flow, water level, sediment supply, and channel morphology, all of which have been studied in relative isolation from one another. Cast in ecological terms, these physical changes affect the viable habitat, habitat connectivity, species ranges, provision of food and nutrients, and disturbance regimes.

2.2.2 Water temperature

As air temperatures rise, so too will water temperatures. Preliminary research using data from the National River Water Quality Network demonstrate the strong correlation between mean air and water temperatures as well as evidence of an increasing trend in temperatures over the last 25 years (P. Verberg, NIWA, pers. comm.). Whether this trend is attributable to anthropogenic climate change has not been determined, and it is likely that changes in both air temperature and river flow would have an effect on water temperatures. Effects of higher water temperatures are expected to include changes in nutrient cycling (e.g. Trolle et al. (2011)), primary productivity and species ranges.

2.2.3 The water cycle

Changes in air temperatures and atmospheric circulation will also have a range of implications for the water cycle, altering the extent of snow and ice cover, and the hydrological regime of rivers and groundwater.

Reductions in glacier volumes across the Southern Alps by 15% between 1976 and 2008 have been tied to shifts in circulation patterns across New Zealand (Chinn et al. 2012). This trend is projected to continue, with a middle-of-the-road estimate of retreat for the Franz Josef glacier of 5 km (38% of its mass) by 2100 (Anderson et al. 2008). The additional water that the glaciers are projected to receive is more than offset by higher temperatures, resulting in net retreat. Similar trends have also been projected for snow packs, with a decrease in seasonal snow cover, particularly below 1000 m (Hendrikx et al. 2012). The loss of glacier and ice coverage has implications for alpine and downstream rivers that have a significant snow- or ice-melt component, in terms of water temperature, discharge, and the extent of habitable channels.

Changes in river flow will stem from changes in the amount and timing of precipitation across catchments, increased temperature and other factors controlling evaporation, and increased snow melt. National patterns of the change in mean annual flow (Fig. 4), using a modified version of the model presented by Woods et al. (2006) and based on middle-of-the-road climate projections, reflect the temperature and precipitation patterns described by Tait (2014; see Section 2.1). Flows in most South Island rivers are expected to increase, with the exception of the shorter Canterbury Plains rivers (e.g. the Ashley River/Rakahuri) and Marlborough rivers. Flows in the North Island are more likely to decrease, particularly along the east coast (e.g. the Tukituki). Variations in flow throughout the year also exhibit important patterns, as earlier snowmelt for snow-affected rivers increases winter flows at the expense of spring flows (e.g. Zammit & Woods 2011).

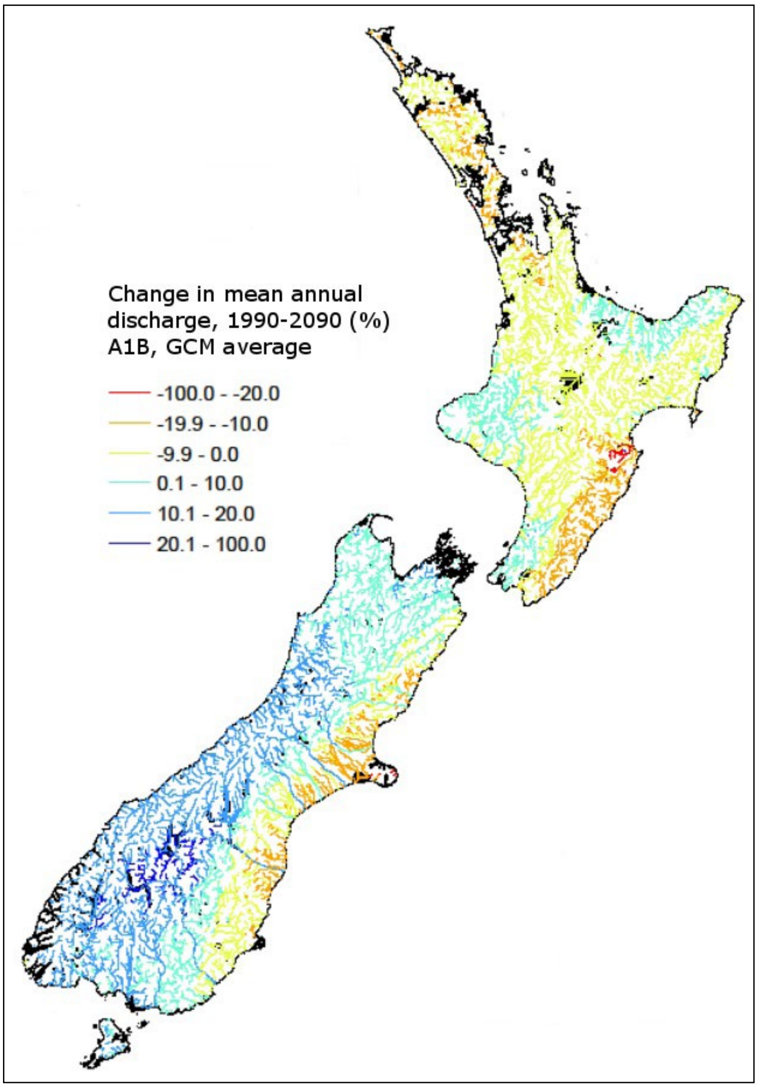

Figure 4. Change in mean annual discharge between 1990 and 2090, based on the middle-of-the-road A1B emission scenario and multiple General Circulation Models (GCMs).

In terms of low flows, mean annual low flow (MALF) for the Waipaoa River, Gisborne, is projected to decline slightly (Collins 2012), though the decrease is comparable to the uncertainty in MALF. For a national picture, a useful inference may be derived from a study of soil moisture drought (Clark et al. 2011). Low flows are sustained by groundwater, which is in turn primarily sustained by water draining from the soil above. Longer dry spells thus translates to lower groundwater recharge and potentially to lower and longer low-flow conditions. This would have implications for river connectivity.

At the other extreme, floods are also projected to become more extreme (e.g. McMillan et al. 2010), and there are two overarching causes. Firstly, warmer air is capable of holding more moisture. When rainfall occurs, more intense storms are possible and, hence, more intense floods. In the second instance, changing atmospheric circulation patterns may increase the frequency of extra-tropical cyclones reaching New Zealand.

Very little attention has been given to physical changes in lakes and groundwater, and none to wetlands. Renwick et al. (2010) projected that water levels in Te Waihora/Lake Ellesmere would drop due to increased evaporation. In other lakes, changes in inflows may be the controlling factor. In addition to the inference of groundwater recharge made above, Aqualinc Research Ltd (2008) concluded that recharge in the lower Rangitata River basin in Canterbury would decline, while the groundwater levels for the Waimea Plains in Tasman District are expected to remain roughly steady, presumably because it is dominated by recharge from the overlying river (Zemansky et al. 2012). Rising sea levels will further alter the water cycle from the increase in coastal groundwater levels, as well as salinisation.

2.2.4 Sediment and channel morphology

The intensity, frequency and timing of storms and floods are key drivers of erosion, sediment transport along rivers, and channel morphology. With changes in storm characteristics as described above, changes to sediment flux and channel morphology would follow. In terms of erosion, and hence sediment delivery to waterbodies, modelling results are highly variable, albeit with a tendency for erosion in the future to increase (e.g. Schierlitz 2008; Elliott et al. 2010). More intense storms are able to erode and transport more sediment, although possible reductions in the frequency of these storms could act to reduce long-term sediment yield. Increased sediment supply to river networks may lead to channel aggradation, as projected for the Waipaoa River, Gisborne, in its middle reaches (Gomez et al. 2009). The same study also projects an increase in bed level near the coast due to sea level rise. This effect would likely be true for all alluvial rivers around New Zealand.

2.2.5 Indirect effects

In addition to direct physical effects of climate change on freshwater systems, there would likely also be indirect effects stemming from societal change. These adaptation effects have received no systematic study in New Zealand to date, though some were discussed by Collins et al. (2012) and are the subject of a Ministry of Business, Innovation and Employment (MBIE)-funded research programme. In some instances it is possible that the interventions themselves may have greater impacts on freshwater ecosystems than the direct physical changes. Three potential effects are presented here.

Perhaps the most likely societal response to climate change will be an increased demand for water for irrigation. With warmer air temperatures there would be greater crop water requirements in order to maintain productivity. This would drive greater water demand and allocation, and an increase in small- or large-scale water storage schemes. Both the volume and the timing of withdrawals may be a concern for freshwater conservation.

Changes in the demand for hydropower as a low-carbon energy source may drive the development of more hydropower schemes in previously undammed rivers, while changes in electricity demand may either inhibit or foster the opportunity for dams to release channel-flushing flows. Similarly, increases in carbon-sequestering forest or bush may reduce catchment water yield (e.g. Davie & Fahey 2005).

Thirdly, given that New Zealand's economy is substantially based on agricultural exports, climate change-induced changes in international demand and supply of similar goods would trickle down to national land use choices. The relative profitability of different land uses may shift, leading to local land use change with associated consequences for water demand and water quality.

2.2.6 Uncertainties

While the projections outlined above describe a picture of physical and ecological change, it is vital that the uncertainties around both the observations and the projections are well-understood. In terms of observations, our naturally variable climate means it is not only hard to detect changes, but also to be certain that they relate to anthropogenic climate change. Other than rising sea levels, only two such trends have thus far been identified – increases in air temperature and reductions in glacier volumes. Detecting changes in other freshwater variables will be harder. Separating the noise associated with inter-annual variability from the signal of climate change may only become statistically significant towards the end of the 21st century, if not later. This is decades after the physical changes may have become relevant in a societal context (e.g. water allocation) or ecological context. This is an issue of the signal-to-noise ratio. In colloquial terms, this signal-to-noise issue is akin to trying to listen to a quiet conversation in a noisy bar, waiting for the conversation to become louder. The timing for delivery of irrefutable evidence of a climate impact would differ among variables but at this point in time only mean annual river flow has been considered within New Zealand.

Climate projections are also highly variable. When projections are made, they begin with one scenario of future climate change or another (see section 2.1), which drives a suite of general circulation models (GCMs) which, in turn, drive regional climate, weather, hydrological and then geomorphological or ecological models. At each step along this modelling chain more uncertainty is introduced, which means that projections of ecological change would have the most uncertainty. The uncertainty introduced by the GCMs alone could mean the difference between increased or decreased river flows (e.g. Mullan et al. 2003). A paucity of studies that focus on particular freshwater systems add further to the uncertainties. This particularly applies to wetlands, estuaries and lakes.

2.2.7 Implications for freshwater conservation

The physical implications of climate change for New Zealand's freshwaters, in terms of direct and indirect effects, have important consequences for freshwater conservation. Some of these changes may be negative (e.g. lower low flows), some equivocal (e.g. temperature increases), and some possibly beneficial (e.g. increased river flows). The same river may experience both higher average flows as well as lower low flows. These physical impacts must therefore be translated through to their effects on habitat and community dynamics in order to assess their consequences for conservation, and then suitable interventions may be devised that would reduce the risks and take advantage of any opportunities.

The delayed detectability of a climate change signal means that adaptive management – adjusting freshwater management practices based on empirical observations – could come too late to be useful. Some degree of anticipation is thus required. However, the climate models themselves are also uncertain leaving us with only ranges of possible changes. Prudent conservation management may thus use model projections to guide interventions that are robust to the uncertainties, while maintaining adaptive management as a fail-safe. In all of this it would be important to integrate projected temperature, sediment and flow effects together.

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3. Vulnerability of freshwater ecosystems due to climate change

3.1 River ecosystems

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3.1.1 Background

Overview of New Zealand rivers and their conservation values

There are over 70 river networks in New Zealand. These have an even greater number of streams feeding into them, ranging from tiny first-order ephemeral streams to large multi-channel braided or single-channel meandering rivers (Harding et al. 2004). These streams and rivers may be lake-fed, spring-fed and/or fed by runoff. Furthermore, they may run through the relatively pristine public conservation estate or be heavily modified by land use activities, water abstraction, pollution, damming and/or river engineering for flood and infrastructure protection.

These waterways and their associated flood plains provide habitat for a highly unique biota of fish (diadromous and non-diadromous), invertebrates, plants, birds, bats, lizards and microorganisms, many of which are only found in New Zealand (McDowall 1990; Collier & Winterbourn 2000; O'Donnell 2004). In turn, the waterways and the biological communities within them are important for many aspects of New Zealand society, including commercial, recreational and customary uses, and they also have cultural, spiritual and ecosystem health values for society. Many of the values are not only important for business and recreation, but are an integral part of the actual essence of who many New Zealanders perceive themselves to be. Many of the species living and using rivers are facing increasing pressures. These pressures, combined with a lack of formal protection[1], have had impacts on many of these species; for example, 74% of New Zealand's native fish are classified as threatened or at risk (Goodman et al. 2013).

Key potential impacts from climate change on rivers

The ecological integrity, biodiversity, quality and volume of water in rivers and streams around the world, including New Zealand, are in decline (Dudgeon et al. 2006; Vorosmarty et al. 2010; Wohl 2010; Feld et al. 2011). This is the result of multiple interacting pressures including water abstraction for consumptive and agricultural needs (Poff et al. 2003; Arthington et al. 2006; Dewson et al. 2007a; Poff & Zimmerman 2010), changes in flow regime (Poff et al. 1997, 2007), invasive species (Olden et al. 2010) channelisation, sedimentation, eutrophication (Carpenter et al. 1998; Allan 2004) and, in the future, projected changing climate regimes. Climate change may intensify the pressures already having impacts on New Zealand's rivers (Woodward et al. 2010; Death et al. 2015).

Throughout the world the climate is on a trajectory of altering thermal, wind and hydrological characteristics, with corresponding shifts in precipitation and temperature (IPCC 2013). Both the mean and variability of those conditions are likely to alter and, as a consequence, the occurrence of extreme hydrological events will also change. The frequency, intensity, spatial extent, duration

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[1] Most freshwater species are not formally protected in New Zealand, and some formal protection mechanisms exclude waterways and do not protect instream habitats.

and timing of weather and climate extremes are all likely to alter, significantly affecting riverine biological communities exposed to the new conditions (Grantham et al. 2010; Aldous et al. 2011; IPCC 2013). See sections 2.1 & 2.2 of this report for more detail.

Potential changes that may occur in New Zealand rivers that will require management consideration include changes in base flows, altered seasonal flow patterns, changes in water volumes (increase or decrease), altered frequency and timing of ecologically important flow events (e.g. fre3 floods (flows greater than 3× the median)), increased flooding in some catchments, increased average and maximum water temperature, increased erosion and sediment transport in some catchments, more aseasonal, extreme and severe weather events, sea level rise that may increase salinity of river mouths, reduced freshwater habitats especially in short catchments, and dry river mouths, tributaries and riparian wetlands that will block or disrupt migration pathways (Woodward et al. 2010; Aldous et al. 2011; Jones et al. 2013; Death et al. 2015). However, depending on flow source the effects of these changes may vary dramatically among catchments. As a result, the level of uncertainty in predicting national and, especially, more localised outcomes of these future climate patterns is very high (Macklin & Rumsby 2007; Macklin & Harrison 2012; Death et al. 2015). It is also likely that human responses to climate change will further exacerbate the climatic stress placed on rivers, with increased water abstraction, dam and irrigation schemes, along with flood prevention engineering in response to threats to human life, infrastructure and the economy (Dewson et al. 2007b, c, d; Death 2008, 2010; Death et al. 2009, Death & Death 2012, 2014; Lessard et al. 2013).

3.1.2 Vulnerability of rivers to climate change

Climate changes will interact with other stresses on aquatic systems

Ecosystems are complicated and highly interconnected. They often have complex feedback loops, thus, any direct biological effects of climate change act within a sensitive network of highly interconnected environmental drivers (Fig. 5). For example, the distribution of riparian

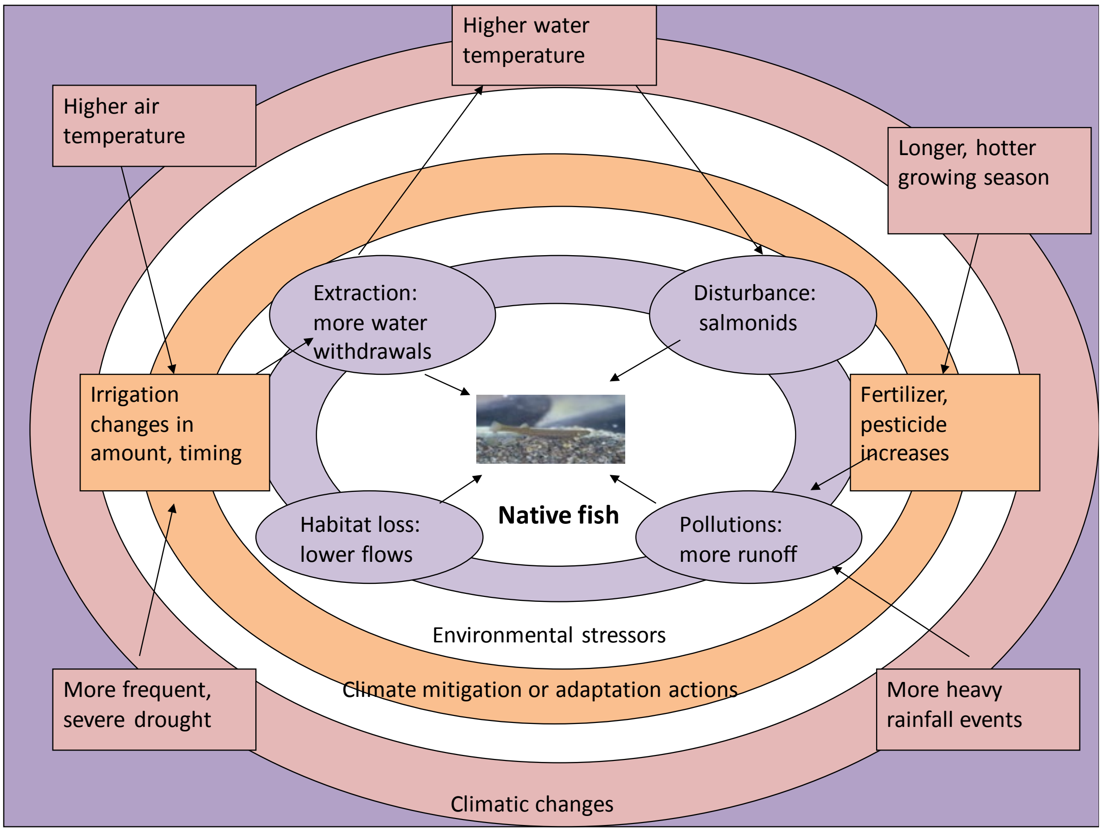

Figure 5. Diagram (modified from Staudt et al. 2013) of some interactions between climate change and other anthropogenic stressors on native freshwater fish.

vegetation is likely to alter as temperatures and rainfall change. The ability of that vegetation to mitigate floods may decline and, as a result, the effect of floods on the vegetation could increase, potentially creating a feed-back loop with increasingly severe effects (Death et al. 2015). For waterways near urban or rural areas the outcomes of climate-related changes are likely to be exacerbated by the detrimental impacts on river biota of current development-related activities (Allan 2004), and future human activities aimed at mitigating flood effects on people and infrastructure (Macklin & Harrison 2012, Foulds et al. 2014). For example, there are likely to be increasing distributions of already established invasive species (both plant and animal) and new species that are likely to establish.

Many native species (e.g. non-migratory galaxiids, wetland birds) are already under extreme pressure from predation and competition by introduced species (McIntosh et al. 1994, 2010; Cruz et al. 2013). Shifts in the amount and distribution of suitable habitat resulting from increasing temperature, changing flow regime disturbance, and biological interactions with invasive species are complex (Nixie Boddy, Canterbury University, pers. comm.) and need to be considered in future management. The Central Otago roundhead galaxias (*Galaxias anomalus*) has 12 confirmed local extinctions as a result of trout movement/invasion, with only 26 remaining populations not at immediate risk of further trout invasion and extinctions (Fig. 6). The distributions of some non-migratory galaxiids appear to be severely truncated as trout push into cooler spring-fed headwater catchments where they have not previously been (Pete Ravenscroft, DOC, pers comm.).

Water quantity

One of the most likely outcomes that will arise from climate change, particularly on the east coast of New Zealand, is less rain (IPPC 2013) and, thus, potentially lower base flows, more and extended droughts (IPPC 2013), the increased possibility that rivers or specific reaches will dry completely (Lake 2011; Clark et al. 2012; Ledger et al. 2013; Sections 2.1 &2.2, this report) and connections between waterways and the coast may be lost. In turn, these changes are likely to prompt increases in water abstraction and more dam construction for water storage and irrigation schemes that will further exacerbate the pressure on river flows (Chisholm et al. 2014).

Reductions in flow and/or changes to the natural flow regime from both water abstraction and lower average rainfall may have some dramatic effects on riverine biology (Poff et al. 1997; Dewson et al. 2007a; Lake 2011). Altered natural flow patterns may result in invasive predators gaining increased access to habitats critical for sensitive lifecycle stages (e.g. to islands in river channels used by nesting birds) and changes in habitat type (e.g. river-mouth riffles that are critical for glass eel migration may disappear). Habitat size, availability and quality may all be reduced for some species (Jellyman et al. 2014). Increased intensity and frequency of extreme droughts may threaten already isolated fish and invertebrate populations because of the increased potential for population crashes and/or extinctions (e.g. brown mudfish (*Neochanna apoda*), Richard White, Canterbury Unviersity, pers. comm.). Whereas other species could be better protected from invasive species because the invasives may no longer be able to reach key native fish locations (e.g. non-migratory galaxiids). Reduced flows in spring and summer may also reduce food availability for specialist river birds that are dependent on riffle faunas (e.g. wrybill plover (*Anarynchus frontalis*); Pierce 1979). Increased floods and flows may impact species' lifecycles and existence by altering environmental cues that they use to complete their lifecycle (e.g. whitebait species lay their eggs on vegetation and substrates along riparian margins during autumn floods and rely on further flood flows to inundate eggs, which cues hatching and migration to the sea; Charteris et al. 2003)

Some aquatic species (e.g. invertebrates) are likely to be more impacted by changing climate than others, depending on their life cycles. For example, the damselfly *Xanthocnemis* can survive up to eight days out of water and has a flexible life cycle allowing it to cope to some degree with changing flow regimes, whereas other species (e.g. water boatman *Sigara*) are unable to cope

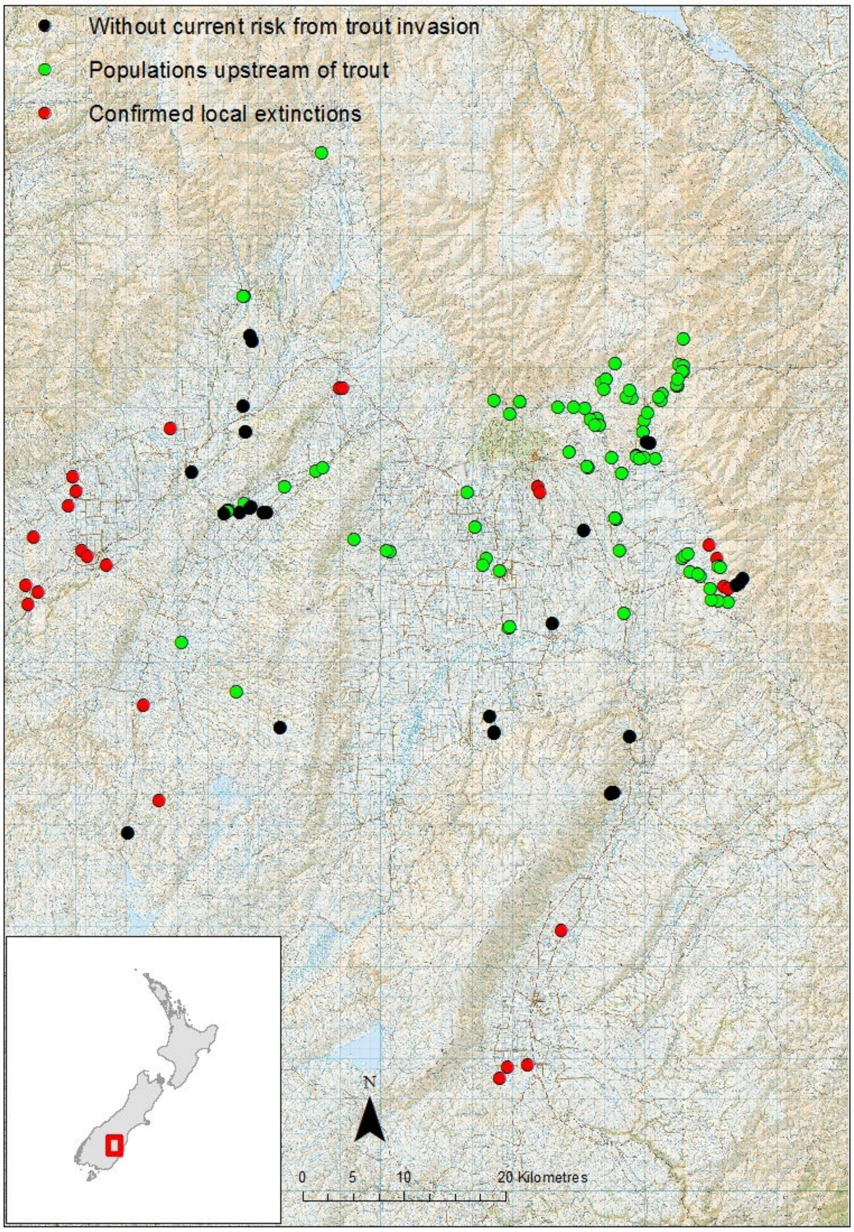

Figure 6. Known distribution of Central Otago roundhead galaxias (*Galaxias anomalus*) in inland Otago, with confirmed local extinctions (red circles), populations at risk from upstream trout (green circles) and without current risk from trout presence (black circles) (Source: Otago Freshwater Team, Department of Conservation).

with any drying and are not flexible so will likely be highly impacted (Mark Galaotowitsch, Canterbury University, pers. comm.). Tadpole shrimps (Notostraca) can survive extended periods of drying; however, if their current limited distribution in ephemeral ponds is further reduced by droughts it is uncertain how they may be able to colonise new habitats unaided.

Changes in stream flows are expected to differ significantly across sub-catchments. For example, work in the Hakataramea Valley (a dry catchment in south Canterbury) has found that stream flows are likely to decrease in spring and increase in other months (Khadka 2013). If seasonal stream flows change over time, this may have an impact on species found within these catchments, as flow patterns (e.g. flood flows) can be crucial cues vital to completion of their lifecycle (e.g. flood flows cue spawning of some migratory fish (McDowall & Charteris 2006)).

Temperature

Water temperatures are predicted to increase; in fact, most of the international focus around climate change is related to changes in biological distributions resulting from altered thermal regimes (IPCC 2013). In New Zealand, the temperature effects on the distribution of riverine organisms are likely to be secondary to the changes from altered flow regimes (Death 2008, Death et al. 2015). However, increased temperatures will affect many species, directly or indirectly, through decreased dissolved oxygen in water (Woodward et al. 2010). Change in temperatures will favour some invasive species such that their distributions will increase. However, other introduced fish species (e.g. salmonids) that can negatively impact native species are likely to experience even greater reductions in distribution in response to increasing water temperature than the more tolerant native species (McIntosh et al. 2010). Small increases in temperature can have subtle effects on the physiology and thus productivity and survival of some species (e.g. sex ratios may be altered and water balance affected; Adams & Hayes 2008; Barclay 2012). The life cycle patterns of many species may change (e.g. spawning time / cues for life history patterns / location of spawning for species (e.g. eels that have marine spawning sites), conditions triggering migration). There may be hybridisation of species as changes in conditions (e.g. floods, droughts) bring previously separated species into contact. The suitability of particular areas of rivers for reserves are likely to vary over time because changing temperature regimes will create unsuitable habitat and force movement of species into other more suitable habitat elsewhere. Fixed reserves are therefore unlikely to be good for future protection of fish (Rahel 2013).

Flow patterns

In contrast to terrestrial systems, changes in river flow regimes resulting from changing precipitation are likely to have far larger impacts on the biological communities in rivers than increases in temperature (Death et al. 2015). There are likely to be more severe floods, fewer smaller ecologically significant floods (e.g. fre3) and changes to flood timing (Dankers et al. 2013). Given the extremely important role of floods in New Zealand rivers for maintaining ecological integrity and many life history patterns, the changes to biological communities may be dramatic (McDowall 1990; McDowall & Charteris 2006; Death 2008; Death et al. 2015). The effect on many already fragmented and threatened species (e.g. non-migratory galaxiids) may be even more dramatic with limited ability for unassisted re-colonisation (Luque et al. 2013). Death et al. (2015) discuss many of the potential effects of more frequent and severe flood events, such as loss of habitat complexity and breeding locations. Flooding already impacts significantly on the breeding success of a number of threatened river-dwelling bird species (e.g. wrybill plover, black-fronted tern (*Chlidonias albostriatus*), and blue duck (*Hymenolaimus malacorhynchos*); O'Donnell 2005, Whitehead et al. 2008), so any marked changes to flood frequency and magnitude may have significant effects on population viability.

Many of these effects may also be exacerbated by the pressures already placed on rivers by humans (e.g. gravel abstraction, river channelisation, use of instream structures that impede fish passage) and their actions in response to future increased high flow events(e.g. increased flood management). Refugia and recolonisation pathways between rivers that previously operated following floods may have been severed through land use change and channelisation; recovery of ecosystem functions following floods may be compromised by nutrient and sediment influx; toxic chemicals may become mobilised in floods and invasive species may change their distribution. Human activities to manage for the effects of more severe flooding will also result in increasing human modification of geomorphological condition and habitat quality in order to redirect floods to protect human life and infrastructure, with consequential, potentially deleterious, effects for the biota. Some people view flood flows as wasted resources and a number of irrigation schemes in New Zealand are planned to harvest floods, with unknown consequences for the functioning of river ecosystems. We believe, on balance, that the effects of changes in flow resulting from climate change will be negative for most of New Zealand's native riverine biota. However, changing attitudes by river engineers to managing increased flood size and intensity may be to restore or increase the flood plain and this would have a positive effect on our native ecosystems (Death et al. 2015).

Indirect effects of climate change from other ecosystems

Although people often perceive rivers as beginning and ending at the water's edge, the links among within-river ecosystems and those in the wider flood plain, the hyporheic zone, groundwater and riparian vegetation are both strong and integral to maintaining the ecological health of rivers. Consequently, any changes from altered climate patterns within rivers and the intimately linked ecosystems listed above will feed back between the respective ecosystems. Changes to the land will influence the river and associated freshwater habitats (e.g. wetlands), just as changes to the river will influence the land.

In areas where rainfall is expected to increase, a corresponding increase in runoff and thus increasing sediment levels in streams could impact some species. For example, banded kokopu (*Galaxias fasciatus*) has been found to have reduced abundance in turbid waterways, so increasing run off and sediment flowing into streams could limit their distribution (Rowe et al. 2000).

Similarly, for species that use rivers for only part of their life cycle (migratory birds and fish), the effects of climate change on over-wintering habitats, migration stop-over points or the marine environment where some birds and fish spend significant parts of their life cycle may influence survival in the long term. For example, the wrybill plover breeds on 22 braided rivers on the east coast of the South Island, but then stops over in small flocks at coastal lakes, estuaries and river mouths before almost the entire population reaches their overwintering sites on estuaries in the northern North Island (mainly Manukau Harbour and the Firth of Thames; Ficke et al. 2007).

Both as larvae within rivers and as flying adults, river invertebrates form an important dietary component for both aquatic (e.g. fish; McDowall 1990) and terrestrial (e.g. birds, spiders, bats; Pierce 1979; Polis et al. 2004; Winterbourn 2004; O'Donnell 2005; Burdon & Harding 2008)) food webs. Changes to riparian and riverbed habitat will alter the viability of those adult stages, altering food webs and also potentially altering the viability of instream populations (Collier & Scarsbrook 2000; Collier & Winterbourn 2000, Smith et al. 2002, Smith & Collier 2005).

Many fish and bird species in New Zealand use the riparian zones along waterways for egg-laying (Charteris et al. 2003; McDowall & Charteris 2006; Whitehead et al. 2008). Changes to riparian zones (e.g. invasion of weeds) and riparian vegetation may lead to increased predation on these eggs by a variety of pest species. Changes in temperature and humidity in these zones, may also impact on the development and survival of eggs. Terrestrial insects and mammals (e.g. mice) from riparian zones also form a major component of the diet for many fish at certain times of the year, so changes to terrestrial communities from climate alteration will also feed back to animals within the water (Main 1988; McDowall, 1990). Even changes to water temperature and ocean currents in marine and estuarine habitats will affect life history patterns of many species of fish (e.g. migration of eels to Tonga for spawning).

Wilding conifers are rapidly spreading throughout high country catchments (rate has been around 5% per annum since 1900), and these trees have significant impacts on water yields in water-sensitive catchments (Fahey & Watson 1991; Fahey 1996). So, with increasing wilding conifer spread we should expect impacts on future water yields (Keith Briden, DOC, pers. comm.).

3.1.3 Key considerations for future river management under climate change

The biggest issue in deciding how to manage rivers for future climate change effects is the high level of uncertainty around both the climatological changes and the response of plants and animals to them. However, some change is clearly inevitable and it is thus important to carefully monitor current populations and ecosystems in a way that will ensure the greatest opportunity for detecting change and to respond effectively to that change when it is detected. The latter is likely to be most easily achieved by applying models or food web robustness metrics to identify the ecosystems most sensitive to change (Dunne et al. 2002; Pascual & Dunne 2006; Evans et al. 2013). For some of the species with restricted distributions and identified as highly threatened from changing climate regimes (such as the non-migratory galaxiids) it would be relatively easy to model the effects of change in temperature and flow within the range of possible climate outcomes for their respective regions. From this it would then be possible to predict how these species might interact with their current distributions and climate change effects on predators, and develop strategies for protection. However, there may always be a danger that current threats will assume overriding importance and that future precipitous effects will be relegated to the 'nice to deal with if we had time' category such that when any future devastating changes do occur, current efforts have all been a waste of time and resources. With species such as the longfin eel that will be affected by more complicated and wider-scale climate effects, it is difficult to see how to respond to climate change other than to maintain the current populations in the best possible condition. To assist with this, we need more basic biological research on the 'bottom lines' for maintaining these species in our rivers.

A proactive management strategy incorporating the potential effects of climate change needs to be used in long-term management and designation of key sites for species protection. As many possible stressors as possible should be removed; however, fixed reserve design is unlikely to be effective for river systems and migrating species (Ficke et al. 2007).

3.1.4 Summary

The potential for climate change to adversely impact riverine biological communities is very high; however, there is great uncertainty in what and where changes to temperature, wind, precipitation and river flow will occur and this needs further research. However, there is also great uncertainty around the biological responses to those climate changes, particularly as the changes in most cases will be affecting already anthropogenically highly stressed and fragmented systems. We also need more research on how to measure ecosystem resilience so we can target protection measures to the most important or sensitive ecosystems or, alternatively, increase the robustness of those communities. Riverine ecosystem function and many riverine organisms in New Zealand are intimately linked with the current flow regimes and, in particular, floods. Thus, while changes to temperature and water quantity will impact riverine communities, the largest impacts may come from changes to flood regimes, with a reduction in smaller flood events in some parts of New Zealand and an increase in more severe catastrophic floods on others. Both flood types are critical for the functioning of freshwater ecosystems and species.

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3.2 Estuarine ecosystems

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3.2.1 Background

Biophysical environment

Estuarine systems, the places where freshwater and saltwater mix, have their own distinct values, pressures and management needs. Just as changes in catchments and their waterways impact estuarine systems, changes in the marine environment also can impact freshwater systems upstream, primarily through sea-level rise.

There are approximately 450 estuarine systems in New Zealand. They comprise a wide variety of types, each with different physical and ecological characteristics and they therefore are difficult to tightly define[2]. The types range from smaller coastal lagoons and tidal creeks up to large embayments, sounds and fjords (Hume et al. 2007). A structured typology[3] provides a basis for recognising diversity and informing a consistent management or conservation approach for types which are more or less sensitive to climate-change impacts.

Although they only comprise a small area of New Zealand, estuarine systems have high biodiversity and provide high–value ecosystem services. Globally, estuarine systems are estimated to contribute around 12% of the world's ecosystem services, even though they make up only 0.35% of the world's surface area (Costanza et al. 1997). The contributions they make to human welfare includes their role as nursery grounds for fish species, , nutrient cycling, carbon sequestration and providing buffering of adjacent land and waters from storm inundation. New Zealand estuarine systems provide habitat for a wide range of threatened and at risk species including birds (e.g. Australasian bittern (*Botaurus poiciloptilus*), royal spoonbill (*Platalea regia*), bar-tailed godwit (*Limosa lapponica*)), plants (e.g. pygmy clubrush (*Isolepis basilaris*)) and freshwater fish (e.g. longfin eel (*Anguilla dieffenbachii*), īnanga (*Galaxias maculatus*)) that migrate through estuarine systems as part of their lifecycle.

This section outlines some of the potential changes to estuarine systems from climate change including the ramifications of these for adjoining freshwater systems. Some key areas of research are flagged that should be undertaken within the wider freshwater and coastal research context.

Policy and planning framework

Managing estuarine systems is caught between the separate management regimes and policies that have been developed for marine and for freshwater environments and this poses challenges for a sustainable and integrated approach to their management. Coordination between agencies is therefore essential for managing the interfaces between the two systems and climate change will only confound this already complex policy and management setting, as the present-day interfaces undergo a landward migration.

The Resource Management Act 1991 is the key piece of legislation for management of freshwater and estuarine values in New Zealand and involves national agencies (DOC for the coast and MfE for freshwater) and local government. The 'coastal marine area' (CMA) has been defined for estuarine sites and associated river mouths and this determines which RMA policies (freshwater or coastal) apply for management.

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[2] **One definition**: An estuarine system is a body of water that is: 1) coastal; 2) geographically distinguished from an open-ocean coast; 3) is permanently or intermittently connected to the sea, and has at least one of the following features: a) seawater mixes with freshwater (river or groundwater); b) when the mouth is open, tidal exchange with the sea occurs; c) affected episodically by wave overtopping of the coastal barrier [adapted from Kimmerer & Weaver 2013].

[3] The **typology** is being developed by the Department of Conservation in partnership with MfE, NIWA and the University of Canterbury. The approach will link typologies with other classifications used for wetlands and freshwater systems and will be invaluable for climate-change adaptation planning and assessing susceptibility.

With climate change effects (primarily those arising from sea-level rise and salinisation; but also elevated water and groundwater levels), the ecological and physio-chemical boundaries as well as the CMA jurisdictional boundary will progressively move inland. Knowledge of where the ecologically relevant CMA boundary lies is particularly important for setting appropriate limits to achieve environmental objectives. Likewise, the landward boundary of the 'coastal environment' defined by Policy 1 of the New Zealand Coastal Policy Statement (DOC 2010) will progressively change.

3.2.2 Physical impacts on estuarine systems

Present pressures

Estuarine systems vary in their geographical context from remote pristine locations to urbanised harbours in our coastal cities. On time scales relevant to climate change (50–100 years), many other human-induced influences on estuarine systems, and the ecosystem services they provide, will also change (see the outer layer of the schematic in Fig. 7). These human pressures result from population growth and development flanking estuarine systems and their associated catchments (e.g. water abstraction, fine-sediment runoff, wastewater and stormwater discharges of nutrients and pathogens and changes to drainage patterns) and in-situ changes to habitat (e.g. alteration as a result of dredging or reclamation, shoreline armouring, shellfish take, introduced marine pests).

Future impacts

Considering the range of estuarine types, some of those more sensitive to climate change and associated sea-level rise may even change their type once they reach a tipping point (e.g. coastal lakes may become coastal lagoons, or hillside streams may have more frequent openings to the sea).

The potential impacts of climate change on estuarine and lowland river systems highlights a complex web of interactions that need to be understood in management and conservation (see the inside layer in Fig. 7).

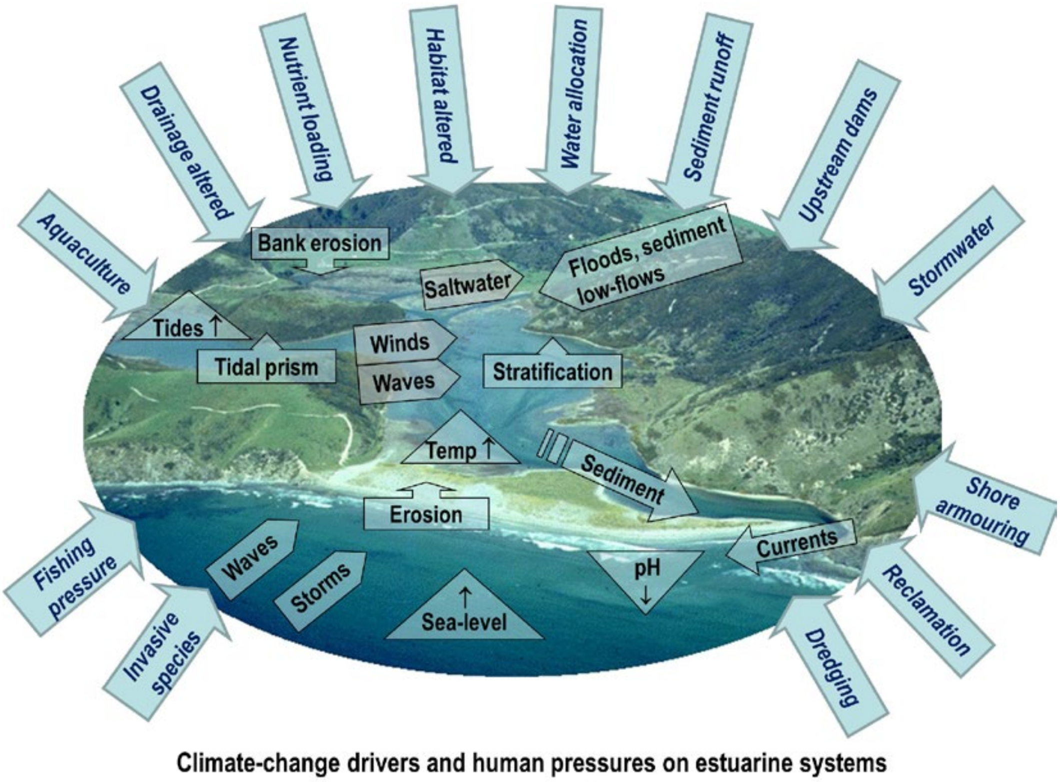

Figure 7. Schematic of climate-change drivers and impacts in conjunction with external human pressures on estuarine systems.

Climate change may influence estuarine systems and lowland river systems in several ways (both direct and indirect), but the five main drivers will be:

1. **Sea-level rise** – the New Zealand-wide average rise over the last century was 0.17 m (Hannah & Bell, 2012). Projections from the IPCC 5th Assessment Report estimate average global sea levels could rise by between 0.5 and 1 m by 2100 (IPCC 2013). Similar projections will apply to New Zealand, but with local differences affected by vertical land movement. The future balance between higher sea levels and sediment budgets will determine changes in depth, tidal-exchange volumes and geomorphology of estuarine locations. Also, the balance between freshwater flow inputs and relative sea-level rise will determine the extent of salinity intrusion upstream into adjoining freshwater bodies. Ultimately, changes to these balancing factors will determine where a change of estuarine or freshwater type could occur.
2. **Storm intensities are likely to increase**, with increases in wind, waves, barometric pressure and more frequent exceedances of storm-tide levels perturbing estuarine systems more often.
3. **Temperature rise** – average surface atmospheric temperature rises of between 1.5 and 4°C predicted to occur by the end of the 21st century in New Zealand (IPCC 2014) will lead eventually to similar or slightly lower increases in mean water temperatures in the country's estuarine systems.
4. **pH decrease in the world's oceans** will change the acidity of estuarine water bodies, with projections ranging from a decrease of 0.14 to 0.35 pH units (Lundquist et al. 2011).
5. **Changes in catchment run-off of freshwater and associated sediments to estuarine systems** will arise from potential shifts in the mean-state and extremes of the present hydrological regime. Of particular concern are short-duration high-intensity and long-term rainfall patterns, with concomitant effects on sediment delivery. In some places this will lead to physical changes to shorelines (including along the open coast), basin morphology, stratification characteristics, positions of turbidity maxima, and rates and patterns of estuarine sedimentation.

The future physical functioning of each estuarine system, and how this will impact adjoining freshwater systems, will be the result of the combined influence of these five main drivers in each unique situation. Future resource management and conservation of estuarine and freshwater systems will require an understanding of the degree of impact and will rely on monitoring to observe trends and significant changes.

Running in parallel with the impacts of climate-change will be the ongoing direct and indirect anthropogenic pressures that already significantly affect some estuarine systems. These existing influences may be further compounded by future human responses to climate-change through maladaptation in an attempt to counteract the impacts (e.g. shoreline protection works, reclamations to reinstate shoreline buffers, abstraction of upstream freshwater, alteration to drainage patterns and pressure for channelization through dredging and stopbanks to reduce inundation).

Generalisations about the long-term trajectories of changes to estuarine systems are unwarranted without consideration of regional to local differences in the drivers and both natural and human responses (Kimmerer & Weaver 2013).

3.2.3 Effects on estuarine and adjoining freshwater ecosystems

Any changes to estuarine systems (in-situ or from ocean or catchment inputs) induced by climate change will affect the biological communities that live there or use the area. Increased water temperatures and less-frequent cold/frost days will affect aquatic ecosystem composition (Lundquist et al. 2011). Some species may already live at their tolerance limits (e.g. upper intertidal thermal stress) and under changing climates maybe be displaced by more-heat-tolerant species. The geographic range of species is likely to change. Mangrove habitat may extend southward as temperatures warm and subtropical species may establish in northern regions (Morrisey et al. 2010). Processes such as biochemical transformations and carbon recycling may also be affected (Canuel et al. 2012).

Mangrove habitat within northern estuarine systems will either move inland or seaward depending on whether sea level rise is greater or less than in-situ sedimentation rates. Likewise, changes in the extent of saltmarsh will depend on the balance of these two processes. Saltmarsh and coastal habitats will be able to adapt better if there is a longer horizontal distance between the low and high tides and if there is available space landward. Without space to migrate these habitats will experience 'coastal squeeze' (e.g. King et al. 2012). Further, potential impacts on intertidal areas due to heat stress or coastal squeeze will affect resident invertebrate communities such as bivalves.

Carbonate availability (through pH changes) will have direct ramifications on the sustainability of carbonate species (e.g. bivalves, zooplankton) and larval survival and growth (Lundquist et al. 2011).

A decline in seagrass (which provides a high level of ecosystem services) is predicted (Clone et al. 2010). Seagrass is particularly sensitive to both low salinities and high temperatures. It is also adversely affected by sediment discharges, either through direct smothering or increased turbidity (Morrison et al, 2009). Coastal fish nurseries would be affected if seagrass extent declined. Juvenile fish could also be affected by changes in water temperature, including stratification, and freshwater inflows.

Any impacts on estuarine habitats and food sources can, in turn, have impacts on species higher up the food-chain (e.g. shore birds). Freshwater fish species that utilise estuarine systems during part of their life cycle, could also be affected. Īnanga spawning sites are located at the upper limit of brackish conditions. Sea-level rise may result in migration of the saltwater interface to less-favourable habitats for spawning further upstream. Conversely, sea level rise could enhance the potential area available for spawning. Affects could extend to other life-history characteristics (e.g. spawning success, feeding behaviour and migration triggers).

Warming may result in increased estuarine eutrophication and increased algal blooms and macroalgae. In terms of exotic species we may have new incursions established from overseas, and existing exotic species may expand their range (Crafton 2013).

There are likely to be multiple or cascading effects arising from climate change. For instance, a temperature change could alter the trophic state, affect fish life stages (e.g. spawning, juveniles), change biological communities, increase exotic species invasion risk (e.g. to aquaculture), and extremes of temperature could affect bivalve survival. The effects of climate change (e.g. temperature, pH decrease, freshwater inputs, circulation, depth, sea level rise) on biological communities are therefore likely to be complex and cumulative in nature, especially when taken in context with existing stressors on estuarine systems (Fig. 7).

Restoration of estuarine and adjacent freshwater systems may help to mitigate the effects of climate change (e.g. margin vegetation can provide buffering for climate change scenarios where coastal inundation is predicted to increase (Mattox et al. 2011) and restored saltmarsh provide a sink for carbon (Grimsditch et al. 2013)). While recognising that human pressures and associated maladaptation may compound or exacerbate ecological changes resulting from climate change.

3.2.4 Information needs for adaptation

Just as knowledge of how freshwater riverine systems are affected by climate change can be used to inform decision making in the estuarine receiving environment, knowledge of the effects on estuarine systems of other drivers is of value to decisions relating to the adjoining freshwater systems.

Detailed information (on state, pressure and response) is needed to plan for adaptation to climate change in relation to valuable estuarine and associated freshwater systems. In New Zealand there is little estuarine science with a climate change focus, other than some case studies (some in progress), e.g. Coromandel Harbour (Graeme & Dahm 2006), Gisborne (Savage 2006), Avon-Heathcote Estuary, the Inner Hauraki Gulf / Firth of Thames and lowland wetland systems in the Bay of Plenty.

There is much information that could be collated and interpreted with climate-change adaptation at coastal margins in mind; this includes: LiDAR data; spatial habitat information; limit setting science and Regional Council State of the Environment monitoring data (e.g. sedimentation and nutrients); revised mapping of estuarine system classifications; sea-level/temperature projections and hazard maps; Freshwater Environments New Zealand (FENZ) data (e.g. water quantity/quality flux and state), freshwater fish and īnanga spawning site databases.

International best practice approaches to addressing climate change in estuarine systems could also be reviewed, which would assist with prioritisation of the science needs across disciplines, assessment of vulnerable systems and in planning sustainable adaptation strategies. This type of review would build on existing national reviews and adaptation guidelines (e.g. Willis et al. 2007; MfE 2008; McClone et al. 2010).

Environmental monitoring is a key component of a strategic approach to climate change adaptation. Understanding variability and trends (both natural and anthropogenic) in estuarine systems is a necessary precursor to assessing longer-term climate change effects. Regional Councils undertake State of the Environment monitoring in many estuarine systems around the country. The Department of Conservation has a programme for monitoring estuarine marine reserves. Strategic assessment of the current initiatives may allow for additional monitoring that would provide further information from vulnerable estuarine systems. Monitoring at wider spatial scales (e.g. range of typologies) and temporal scales (e.g. more time-series sites) is required. There is also potential for extending the Government's Tier 1 biodiversity and statistics programmes to include sea level rise, coastal/estuarine temperatures and pH to enable more transparent disclosure of trends in estuarine systems and increase public awareness. Mātauranga Māori can also offer a long-term perspective on changes to estuarine systems over time.

3.2.5 Summary

Any changes to estuarine systems (in-situ or from ocean or catchment inputs) induced by climate change will affect not only the estuarine ecosystems and their services but also adjoining freshwater values. The likely environmental changes to estuaries are complex, as is the situation with their management, which is characterised by multiple and overlapping jurisdictions. Knowledge of how estuarine systems will respond to climate change can be used to inform decision making in adjoining freshwater systems. Likewise, understanding the climate change impacts on catchments and run-off will better inform estuarine management. It is vital that the agencies and policies governing both estuarine and freshwater systems are well integrated.

Effects of climate change on estuarine systems and their associated habitats and species will arise from a complex interplay between sea level rise, salinity, changes in freshwater flow (averages and extremes) and catchment sediment run-off that will progressively alter estuarine systems' bio-physical states. Impacts on ecosystems will be further compounded by changes in temperature and pH. Tipping points for some may occur when, for example, sea level rise exceeds sedimentation rates or when there are extended drought periods. The extent of estuarine habitats (e.g. mudflats, seagrass, saltmarsh and mangroves) may change both locally within a system and across a geographic range.

In terms of freshwater conservation, some predominantly coastal-lowland freshwater bodies may transition to estuarine types. Decisions about whether to protect a particular water body from saltwater intrusion will depend on the rarity of the values at the site. Further, as the biophysical characteristics of other estuarine types gradually change this may affect freshwater fish species which use the estuarine systems during parts of their life cycle, particularly spawning īnanga. Ongoing anthropogenic pressures, coastal squeeze, and potential maladaptation measures implemented in an attempt to counteract negative impacts of climate change on the built environment may also affect estuaries.

Understanding the connectivity of estuarine systems to both the catchment and adjoining sea and their functioning is fundamental to management. Generalisations about the long-term trajectories of changes to estuarine systems are unwarranted without consideration of local to regional differences in the drivers and natural and human responses. There is a lot of available information both from within New Zealand and overseas that can help with planning for the effects of climate change. Monitoring at regional and national levels is essential for tracking changes and understanding the variability and trends of climate-change effects. However, monitoring of estuarine systems in New Zealand is still far from comprehensive, even though a few intensive monitoring programmes are currently being developed to detect changes (e.g. in the Kaipara Harbour).

We recommend the following actions over a two-year period as a precursor to strategic planning for adaptation to the climate-change effects on estuarine and adjoining freshwater systems:

Year 1: Formation of an estuarine climate change working group consisting of estuarine and freshwater scientists with involvement from associated management agencies. The Group would undertake a referenced stocktake of New Zealand information and overseas best practice relevant to climate-change impacts on various estuarine systems and their freshwater and ocean interfaces.

Year 2: Development of a science and monitoring strategy with recommendations for science, monitoring and management.

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3.3 Wetland ecosystems

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3.3.1 Background

The original extent of wetlands in New Zealand has been reduced by 90%, primarily through drainage and conversion to agricultural land since European settlement in the 1840s (Ausseil et al. 2011a). Yet wetlands support a high proportion of the country's threatened species (Holdaway et al. 2012) and are sensitive to land use activities within a catchment (Clarkson et al. 2004; Ausseil et al. 2011b).

Human activities since the industrial revolution have increased greenhouse gas (e.g. CO_2, N_2O, CH_4) concentrations in the atmosphere which has led to warming of the Earth's surface and, subsequently, affected global weather patterns (climate change) (IPCC 2007). Climate change will likely affect both New Zealand's productive and natural landscapes. Whilst there have been evaluations of climate effects on productive land such as dairy, horticulture and forestry (Warrick et al. 2001; Renwick et al. 2013;), there have been no similar studies for freshwater wetlands of New Zealand (McGlone & Walker, 2011).

This section presents an initial investigation into wetland vulnerability under a mid-range emissions scenario (IPCC scenario A1B) with approximately 2.1°C warming to 2090. Here vulnerability is defined as 'the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change' (IPCC 2007). At the extreme end, climate change effects may result in the loss of a wetland system.

3.3.2 Approach to assessing wetland vulnerability

Wetland vulnerability to climate change was explored using a framework (Fig. 8) that combined exposure to a defined climate change stressor, sensitivity of an ecosystem to change, impacts and adaptive capacity (Allen Consulting Group 2005). This initial investigation examined exposure of wetlands to the climate change stressor, water availability.

Exposure to water availability was assessed as the change in precipitation for New Zealand between 1980–1999 and 2080–2099 as modelled by NIWA (Fig. 9) (MfE 2008). Using GIS, these likely precipitation changes were intersected with the current extent of different freshwater wetland types (Leathwick et al. 2010). Freshwater wetlands were classified into bog, fen, swamp, marsh, seepage, gumland and pakihi following Johnson & Gerbeaux (2004). Broad assessments of sensitivity, impacts and adaptive capacity were determined through literature and expert knowledge.

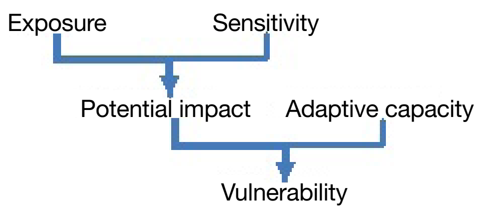

Figure 8. Framework to identify vulnerability as a function of exposure to a defined climate change stressor, sensitivity to change and capacity to adapt (Allen Consulting Group 2005).

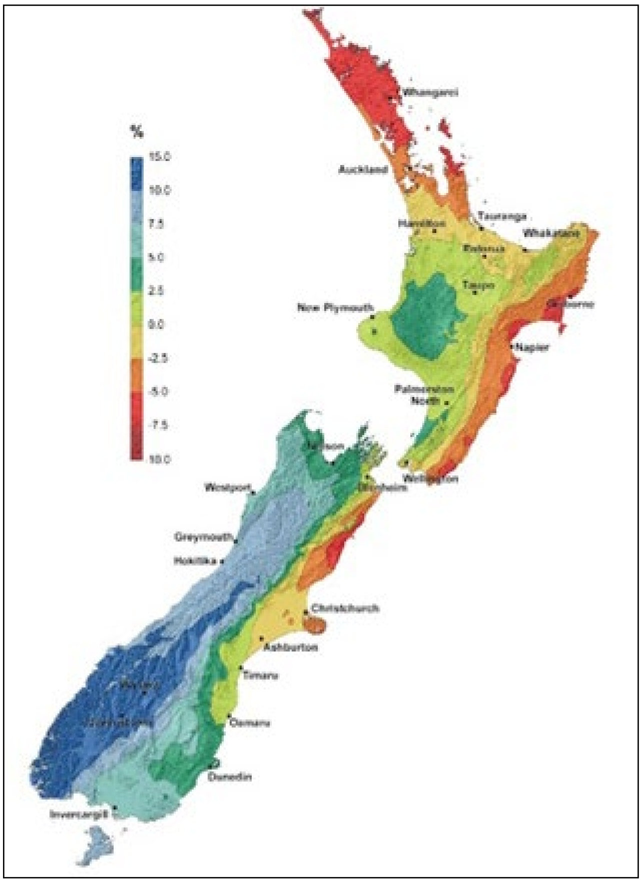

Figure 9. Projected annual mean precipitation changes for New Zealand between 1980–1999 and 2080–2099. Based on an average over 12 climate models for a mid-range (A1B) emission scenario. (Source: NIWA). Note: NIWA can give no warranty that the map is free from errors or omissions.

3.3.3 Potential impacts of climate change on wetlands

Considering the framework (Fig. 8), the following wetland vulnerability results were identified:

Exposure

Figure 10 illustrates expected changes in precipitation for each wetland type by percent of current wetland area. Of the current area occupied by swamps 12% will receive less rainfall, 37% will receive approximately the same rainfall (+/– 2%) and 51% will receive more rainfall. Wetland types that are most likely to be affected by reduced rainfall are bogs (22%) and gumlands (20%). Most other wetland types will likely receive approximately the same (+/– 2%) or more rainfall. Fen (68%) and pakihi (64%) may receive in excess of 6% more rainfall.

Sensitivity

Changes in precipitation will likely be accompanied by other climate-related disturbance events such as floods, fire, droughts, frost, moisture stress and erosion. The sensitivity of a wetland to changes in precipitation and climate-related events will depend upon wetland type, location, size and species composition.

Impacts

Table 2 identifies potential impacts of changes in water availability, as determined by changes in precipitation, for each wetland type.

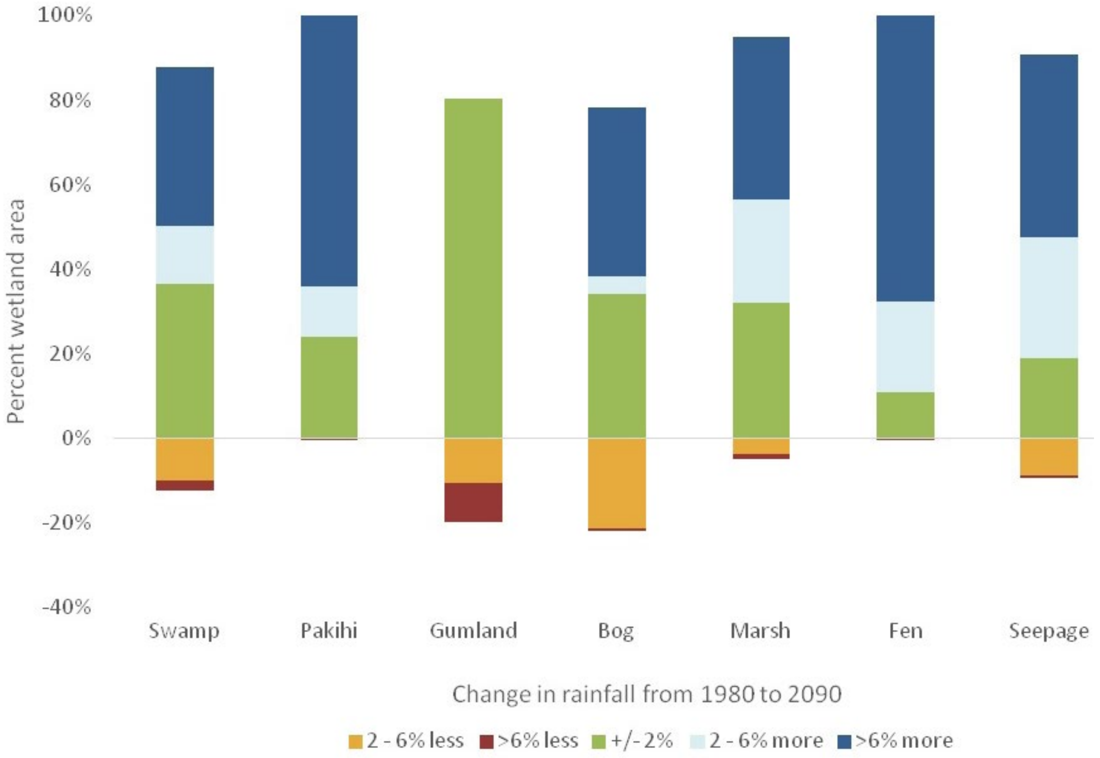

Figure 10. Percent change in rainfall from 1980 to 2090 by wetland type.

Table 2. Potential impacts of change in water availability by wetland type

WETLAND TYPE	WATER SOURCE	CHANGE IN WATER AVAILABILITY	POTENTIAL IMPACTS
Bog	Rain	Decreased rainfall	• Peat growth halted or declines (decomposition) • Lagg zone vegetation may change to fen swamp/terrestrial
Fen	Rain Groundwater	Increased rainfall / groundwater Decreased rainfall/ groundwater	• Greater nutrient input from surface run off • Reduction in peat formation • Loss of peat
Swamp/marsh	Surface water	Increased hydrology fluctuations	• Pulses of nutrients and sediments from surrounding catchment land use
	Groundwater	Decreased surface and/or groundwater	• Wetland extent decreased • Ecotone extent increase with dryland species invasion
Gumland	Rain	Decreased rainfall	• Increased fire frequency and / or intensity • Peat loss • Invasion of dryland species • Loss of extent
Pakihi	Rain	Increased rainfall	• Ponding with shallow water accumulation
Ephemeral	Rain Groundwater	Increased rainfall Decreased rainfall	• Shift to permanent wetland or aquatic habitat • Loss of plant species adapted to wet/dry fluctuations • Loss or reduction in wetland extent • Invasion of dryland species

Adaptive capacity

Lower rainfall would increase pressure on obligate wetland plants. Conversely, increased rainfall would increase pressure on wetland plant species that require wet/dry cycles, such as ephemeral turf plants, or a lower water table.

3.3.4 Discussion

Reduced precipitation is most likely to affect bogs in the north and east of both the North and South Islands, and gumlands in Northland. Increased precipitation, particularly in the west of the South Island, may induce a change in wetland type to a permanently wet state (e.g. ephemeral to swamp); a higher-nutrient system (e.g. fen to swamp), or a more aquatic system (shallow water, pond or lake). Lower rainfall would increase pressure on obligate wetland plants and therefore vegetation types dominated by these species.

The majority of wetlands will receive similar or greater rainfall. However, changes in rainfall periodicity or intensity may increase the extent of wetland margins and thus favour facultative dryland species, many of which are alien weeds such as blackberry (*Rubus fruticosus* agg.) and gorse (*Ulex europaeus*).

Overall, changes in precipitation may affect wetland extent, wetland condition, and community composition or, ultimately, force a change in wetland type or loss of wetland to a different ecosystem. In addition, the effects of climate change may alter land uses within a catchment that subsequently increase pressure on wetland systems and reduce wetland ecological integrity.

3.3.5 Acknowledgements

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3.4 Lake ecosystems

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3.4.1 Background

In contrast to other temperate regions, research on the effects of anthropogenic climate change on lake ecosystems in New Zealand is sparse. The reasons for this may be that, relative to many sites in the Northern Hemisphere, warming in mid-latitudes of the Southern Hemisphere has been modest over the past century (Mullan et al. 2008) and the trend predicted for the South Pacific region containing New Zealand is relatively minor – around 2°C by the year 2100 (IPCC 2007). Nevertheless, this is a substantial degree of warming, and changes in climate variability and in the frequency and intensity of extreme climate events will be strongly expressed in New Zealand. Secondary effects due to sea level rise will also impact strongly on New Zealand, with its >15,000 km of coastline. In this section we summarise current knowledge of how global climate change will affect the ecology of New Zealand lakes.

3.4.2 Ecological responses to key climate drivers

Lakes are effective sentinels of climate change (Williamson et al. 2008; Adrian et al. 2009). Hamilton et al. (2013) discussed the implications of climate change for New Zealand lakes, indicating that it is expressed in four direct drivers of lake ecology: 1. climate warming, 2. changes to precipitation patterns and intensity, 3. increased wind energy and 4. rising sea levels.

Warming

Temperature affects biological, chemical and physical processes. Increasing temperatures will increase the weathering rate of rocks and the breakdown of organic matter from catchment vegetation, increasing the flux from land to lakes of elements essential for the growth of aquatic organisms. Increasing temperature also allows for increased metabolic rates such as rates of nutrient uptake, nutrient mineralisation and reproduction. In the surface waters of lakes, where light is sufficient for photosynthesis, plant growth will benefit from warmer temperatures, whereas in dark, bottom waters, respiration rates will increase, resulting in faster rates of oxygen depletion from the water and nutrient remineralisation from organic detritus.

Eutrophication: Warming seems to have resulted in enhanced eutrophication in many lakes (Michelutti et al. 2005; Matzinger et al. 2007; Visconti et al. 2008) and has been linked to proliferations and blooms of cyanobacteria (Paerl & Huisman, 2009).This response has also been predicted by water quality models using model input data of future climate projections (Trolle et al. 2011). However, there are lakes which are exceptions (e.g. Lake Tanganyika), in which warming may have resulted in a decrease in productivity (O'Reilly et al. 2003). Generally, the balance of higher rates of nutrient generation and recycling with elevated metabolic rates of primary and secondary production resulting from climate change, as well as interactions with the physical environment (e.g. thermal stratification), is not well understood. For example, while cyanobacteria have many physiological features to indicate that they may be preferentially favoured over other phytoplankton taxa under climate change (Carey et al. 2012), nutrient availability may ultimately drive changes in cyanobacteria populations.

Phenology: Many lakes, especially deep lakes, exhibit sequential temporal dynamics whereby different species of phytoplankters and zooplankters consistently dominate the plankton at different times of year. This sequential association of species is called phenology, which here refers to consistent times of bloom formation and clear-water phases in lakes during the annual cycle. In the Northern Hemisphere, earlier onset of spring phytoplankton blooms in a warming climate has been associated with earlier break-up of ice cover and onset of summer stratification

(Meis et al. 2009). Climate warming has been implicated in the decoupling of important temporal dynamics of phytoplankton and zooplankton in such lakes (i.e. altered phenology), reducing the efficiency of transfer of nutrients and energy from primary producers to grazers (Winder & Schindler 2004) and, potentially, to top predators.

Mixing: Thermal stratification results in the temporary isolation of bottom water from the atmosphere. While climate change may increase the thermal stability of lakes by warming surface waters more than the bottom waters, the temperature of the bottom waters of lakes may also rise (Hamilton et al. 2013). Bottom waters of stratified lakes can become depleted of oxygen, resulting in the loss of habitat for organisms and the release of phosphorus, hydrogen sulphide, ammonium, iron, manganese and other chemically reduced elements from the sediments to the water column. Thus, climate change has the potential to decrease the vertical mixing of lake waters, thereby increasing the thermal stability of lakes and altering biogeochemical cycles.

Precipitation

Global warming increases both evaporation rates and the energy content in the atmospheric system, resulting in more intense weather events (IPCC 2007; Mullan et al. 2008). This is predicted to intensify certain weather systems, such as the westerly and south-westerly air streams that already dominate New Zealand's weather and climate system (Mullan et al. 2008). Unlike temperature, which is predicted to increase throughout New Zealand, precipitation is predicted to increase in the west and southwest and decrease in the north and east of New Zealand by 2090 (Mullan et al. 2008).

Floods and droughts: As a result of the intensification of the westerly/south-westerly weather system, the west and south coasts are predicted to experience wetter conditions (especially in winter) and the north and east coasts are expected to experience drier conditions (especially in summer). In association with these changes, episodic floods and seasonal droughts will also become more common in the respective regions, altering the hydrology of lakes. In particular, the hydraulic residence times (flushing rates) of the lakes will change, affecting diverse aspects of lake ecology including nutrient flushing and retention efficiency as well as sedimentation. Where there are greater surface and groundwater inflows, there will be increased nutrient loads to lakes. In areas experiencing drier conditions and reduced inflows, the greater demand for irrigation water will further reduce inflows. To alleviate the increasing disparity between water supply and demand in these areas, more water storage ponds and dams will be constructed, potentially opening up new aquatic habitats (Gibbs & Hickey 2012), although the suitability of such ponds and dams as reservoirs of valued species and native biodiversity is questionable.

Lake water level variation: The predicted increased frequency and severity of droughts and floods, along with increasing demand for water for industrial and agricultural uses, indicates that lake water levels should fluctuate more as climate change progresses. Riis & Hawes (2002) showed that water level variations in lakes have marked impacts on the distributions and community structure of macrophytes in lakes. Water level variations also have impacts on shoreline erosion, benthic invertebrate communities, fish spawning sites and habitats, bird habitats, fringing wetlands and wind-induced sediment resuspension in lakes (James et al. 2002). Thus, it could be expected that there will be increased pressures on aquatic vegetation and benthic invertebrate, fish and bird communities at lake margins. In addition, as lake water level fluctuations increase in frequency and extent, turbidity will increase and water clarity will decrease.

Wind

Greater energy in the weather system will intensify winds, particularly the predominant westerly and south-westerly winds, but also the frequency and severity of storms (Mullan et al. 2008). Winds affect the ecology of lakes in diverse ways.

Mixing: Stronger winds will result in more mixing, reducing the stability (thermal stratification) of lakes. However, surface warming will increase the stability. How these two climate change impacts will combine and interact to affect the thermal structure of seasonally stratified lakes is not easy to predict and will be dependent on lake-specific factors including water clarity, which itself is subject to direct and indirect effects of climate change (Bayer et al. 2013).

Air-borne dust (loess): Lakes in areas such as Canterbury, which are affected by strong dry winds, are subject to inputs of air-borne soil particles (loess) from the Southern Alps. No work has been done on the effects of such loess materials on New Zealand lakes; however, air-borne dust from Australia has been reported to contribute sediments and nutrients (e.g. iron) to the Tasman Sea (Calvo et al. 2004) and to the West Coast of New Zealand (Collyer et al. 1984). Thus, air-borne sediment and nutrient loads to lakes are expected in increase with climate change.

Sediment resupension: Winds have direct effects on water clarity and water quality of New Zealand lakes by re-suspending sediments from the lake bed into the water column. Severe impacts on aquatic macrophyte cover, water clarity, nutrient and sediment concentrations in lakes have been demonstrated in New Zealand (Hughes et al. 1974; Hamilton & Mitchell 1996, 1997). Predicted increases in mean wind speed and storm frequencies could increase the turbidity of lakes (especially shallow lakes), thereby increasing benthic-pelagic coupling and reducing the suitability of lake habitats for filter-feeding organisms and macrophytes.

Hydrology: Increasing wind speeds will increase evaporation rates, particularly for lakes in dry, wind-exposed areas. This change will alter the hydrology and water residence times of such systems. In addition, salinity could increase in coastal lagoons due to enhanced evaporation, sea spray drift and/or overtopping of lagoon barrier bars by waves, particularly in the presence of sea level rise (see below).

Sea level rise

Sea level on the New Zealand coast has been rising by around 1.6 mm/y for the past century, or 2.1 mm/y when corrected for present-day glacial-isostatic effects (Hannah 2004). The IPCC predicts that the mean global rate of sea level rise will accelerate in the future as a result of climate change.

Salinisation of coastal lakes: A major impact of sea level rise on coastal freshwater and brackish lakes will be their progressive salinisation as seawater penetrates further inland (Schallenberg et al. 2003). Salinisation of freshwater systems reduces biodiversity, radically altering community structure and ecological function (Schallenberg et al. 2003). In estuaries, even slight increases in salinity from marine intrusions can cause major reductions in aquatic biodiversity (Remane & Schlieper, 1972).

Migration of species and habitats: The inland migration of the coast will also lead to inland migrations of freshwater and brackish ecosystems. Whether the ecosystem values and services (e.g. whitebait spawning habitat) provided currently by coastal freshwater and brackish systems will be maintained during this inland migration will depend on the specific geomorphological conditions upstream and the future hydrological conditions specific to each system (Schallenberg et al. 2013). However, the potential exists for the loss of entire coastal freshwater and brackish biomes as a result of sea level rise.

3.4.3 Four cases illustrating potential responses to a changing climate

Reduced mixing

Very large monomictic lakes in the upper North Island may respond to climate change by failing to undergo regular winter mixing. Hamilton et al. (2013) showed that during a strong El Niño phase and an exceptionally warm winter in 1998, the water columns of Lake Taupo (max. depth 160 m) and Lake Pupuke (max. depth 55 m) did not mix throughout their entire depth ranges. In oligotrophic Lake Taupo the resulting extended period of stratification did not severely deplete oxygen from the hypolimnion, but in eutrophic Lake Pupuke there was an extended period of anoxia until mixing re-established fully, in winter 2001.

The effects of incomplete winter mixing may also be severe in monomictic lakes in which dissolved oxygen in the hypolimnion is only moderately depleted during summer stratification. With climate change, a second or third year of continuous stratification would likely induce hypolimnetic anoxia, leading to the chemical reduction of metal oxides and the release of phosphorus from bottom sediments into overlying waters. Productivity in these lakes is likely to become more variable as a result of this intermittent internal load of nutrients to the lake surface layer.

Polymictic lakes are also likely to be vulnerable to changes in stratification as a result of climate change. Bottom waters of eutrophic Lake Rotorua (Bay of Plenty) become anoxic when stratification persists for longer than about two weeks, which normally occurs two or three times each summer (Burger et al. 2008). Simulations of thermal structure of this lake using future climate change scenarios indicate that the frequency and duration of stratification events are likely to increase, impacting available faunal habitat as well as biogeochemical cycles in the lake (Özkundakci et al. 2012).

The formation of new lakes

In the South Island, during past ice ages, cycles of glacial advance and retreat formed a large number of lakes which are classified as glacial lakes (Lowe & Green 1987). Changes in sea level and coastal geomorphology during the Holocene formed many of New Zealand's coastal lakes and lagoons (e.g. Schallenberg et al. 2012). With the predicted accelerations in sea level rise and global warming, we can expect that changes in these glacier- and sea level-related drivers of lake formation will occur over shorter time frames. For example, Lake Tasman became a contiguous lake in 1990 in response to retreat of the Tasman Glacier at a rate of approximately 194 m/y from 1986 to 2008 (Vivero 2013). Tasman Lake is still increasing in size and in 2008 it had a depth of 245 m, length of 7 km and width of 2 km. Another example is Lake Waihola, which was temporarily an estuary around 4000 years ago because the sea level around New Zealand rose slightly at the time due to the mid-Holocene sea level highstand. A shift to a largely freshwater flora and fauna accompanied the subsequent decline in sea level, however, once again, rising sea levels (this time due to anthropogenic climate warming) are transforming this lake into an estuary (Schallenberg et al. 2012).

Impacts on freshwater fish biodiversity

Globally, freshwater biodiversity is declining significantly faster than terrestrial and marine biodiversity (Abell, 2002; Jenkins, 2003; Dudgeon et al. 2006). Freshwater fish are particularly vulnerable because they are severely affected by a variety of human endeavours including over-exploitation as a food resource, hydrological modifications to fish habitats, habitat destruction due to land development, vulnerability to invasive species and increasing eutrophication. In 2014, 74% of all native fish taxa in New Zealand were considered to be threatened or at risk (Goodman et al. 2014) compared with 65% in 2009 (Allibone et al. 2010).

Perhaps the greatest climate change threats to freshwater fish in lakes are: 1) the potential for trophic mismatches to develop, reducing trophic transfer efficiency and fish production, 2) the southward migration of thermophilic pest fish species and, 3) the loss of summer habitat in stratified lakes with anoxic bottom waters.

Winder & Schindler (2004) showed that lake warming resulted in a disconnect between annual peaks of phytoplankton biomass and the presence of zooplankton grazers that were able to assimilate the phytoplankton into secondary production. This type of trophic mismatch can occur if different components of the food web respond to different seasonal cues. Presently, little is known about the seasonal cues of phytoplankton, zooplankton and planktivorous fishes in New Zealand lakes, but it is likely that similar trophic mismatches will occur with rapid global warming and its associated impacts on lakes.

A number of thermophilic exotic fish species have been introduced to New Zealand freshwaters including gambusia (*Gambusia affinis*) (formerly known as mosquito fish), grass carp (*Ctenopharyngodon idella*) and silver carp (*Hypophthalmichthys molitrix*). These have been mainly introduced into North Island lakes and the latter two species are thought not to breed in New Zealand due to unsuitable habitat and temperatures being too low for breeding success. The herbivorous grass carp prefer temperatures above 15–17°C for active feeding to occur (Clayton & Wells 1999) and both carp species require temperatures above 20°C for successful spawning and rearing, generally in large rivers (Cudmore & Mandrak 2004; Naseka & Bogutskaya, 2011). Tsuchiya (1979) noted grass carp breeding in rivers in Japan at temperatures of 19–23°C and in river reach lengths not dissimilar to many in New Zealand, suggesting that particularly with climate change, grass carp breeding could occur. Champion et al. (2002) suggested that the generally colder water temperatures of South Island lakes may prevent the development of large coarse fish (e.g. perch, tench) populations in the South Island, were the northern populations to disperse further southward or be introduced. It is possible that climate change will result in the progressive improvement of conditions for pest fish species to colonise New Zealand lakes, to breed and to compete with, or otherwise negatively impact, native species (Ling 2010). Similarly, the warming of New Zealand lakes to temperatures outside their natural ranges will make the lakes more vulnerable to invasion by new warm-water species (fish, macrophytes, invertebrates, etc.) and could enhance the competitive advantages of non-native warm water species already naturalised in New Zealand over native species.

Salmonids are sensitive to environmental conditions and can be considered a sentinel species, reflecting environmental changes that could be relevant to New Zealand native fishes. In Lake Hayes (Central Otago), brown trout (*Salmo trutta*) appear to be under pressure from climate change. Lake Hayes is thermally stratified in summer and this condition leads to severe anoxia of the bottom waters, up to the depth of the thermocline. Above the thermocline, summer water temperatures can reach as high as 20°C. At temperatures above 20°C, brown trout become physiologically stressed and cease to feed (Scott & Poynter 1991). Climate warming will increase surface water temperatures in lakes, which could begin to exclude trout and native species from lakes which lack cold, oxygenated bottom water habitats (refugia). Lakes at risk of losing fish habitat in this way include those with anoxic bottom waters or shallow lakes which do not have thermoclines and are mixed to the bottom. Recent data from Lake Hayes (Schallenberg unpubl. data) shows that in some years, anoxia extended from the lake bed to a depth of as little as 6 m, similar to what has been observed in eutrophic Lake Okaro (Özkundakci et al. 2010). At the same time, during late summer, the mixed layer above 6 m depth showed temperatures of around 20°C. Clearly, further warming will make this lake uninhabitable for trout and may begin to stress other fish species present. Similarly, Scott & Poynter (1991) calculated that a 1.5°C rise in lake temperatures in the North Island would result in a contraction of the distribution of brown trout in northern parts of the island.

All the news may not be bad news

Despite the many serious impacts that climate change can have on lake ecosystems and their biota, there are some potentially positive aspects of climate change adaptation to consider.

Water storage reservoirs: Increasing drought in some areas of the country will encourage the creation of water storage reservoirs, ponds and irrigation networks (e.g. Gibbs & Hickey 2012). These could be considered to be new freshwater habitats. Could such habitats be co-managed for the enhancement of native freshwater biodiversity, particularly in light of the perilous state of native freshwater fishes?

Exclusion of salmonids: Salmonids are known to have strong negative impacts on some native fish species in river systems (Townsend 2003). Less is known about their impacts on native fish in lakes, but anecdotal evidence suggests that they can have severe impacts on koaro (Rowe & Graynoth 2002). As salmonids (especially brown trout) are more sensitive to high temperatures than most fish species, the northern distribution of salmonids in New Zealand will contract as a result of warming due to climate change (Scott & Poynter 1991) and this might release native fish communities in some lakes from salmonid predation.

Biological adaptation: Some fishes have been reported to undergo rapid evolutionary adaptation to temperature shifts. For example, Barrett et al. (2010) showed that sticklebacks developed an additional 2.5°C cold tolerance over three years of exposure to colder-than-normal conditions. If New Zealand native fish are also able to adapt to temperature stress, then they may escape some the direct effects of climate warming. However, if salmonids are also able to adapt, then any biodiversity gains from the exclusion of salmonids may be lost.

Effects on macrophytes

Hamilton et al. (2013) speculated that the small number of submerged macrophytes that colonise brackish coastal lakes and lagoons (*Ruppia* spp., *Stuckenia pectinata,* and *Myriophyllum triphyllum*) may begin to disappear with climate change because of their reliance on periods of low salinity for reproduction. For the case of naturalised populations of tall-growing invasive submerged macrophytes in freshwater lakes (e.g. *Egeria densa, Ceratophyllum demersum, Lagarosiphon major*), they suggest that these species may be favoured over native species under climate change due to increases in lake turbidity and nutrient status, but direct evidence of such changes is scant.

3.4.4 Summary

The most profound changes in lake ecosystems in New Zealand over the past century relate to land use change and subsequent eutrophication, as well as introductions of exotic flora and fauna. These impacts may act synergistically with future climate change, which is likely to increase rates of biogeochemical cycling and productivity as a consequence of increasing water temperature. Such indirect effects of climate change may be of similar or even greater significance than direct effects, such as warming. For example, warming causes changes in the thermal stratification of lakes, which then can alter biogeochemical cycles and habitat availability in some lakes through the depletion dissolved oxygen in their bottom waters.

Much of the uncertainty in predicting the extent of climate change relates to understanding the magnitude of change in the climate system (e.g. air temperature precipitation, wind) and related impacts such as sea level rise, which could profoundly influence salinity and distributions of organisms in coastal lakes. Our understanding of how climate change can affect freshwater fish species and distributions is growing, but we know less about its likely impacts on lacustrine macrophytes and invertebrates.

Effects of climate change on lake ecosystems in New Zealand may be difficult to discern due to the simultaneous existence of other anthropogenic pressures including the continued spread and new introductions of non-native species. Nevertheless, pressures from climate change will intensify through time. There is considerable uncertainty in predicting whether the dominant responses will result from direct or indirect climate drivers. However, our understanding of the effects so far indicates the dominant climate drivers will depend on lake type, morphology, trophic status and lake locations.

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3.5 Climate change and terrestrial biodiversity: integrating threat assessments across terrestrial and freshwater environments

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3.5.1 Background

As the lead agency for biodiversity management in New Zealand, the Department of Conservation (DOC) is responsible for protecting native biodiversity from threats, such as climate change (Christie 2014). Integrating climate change threat management into DOC systems is a challenge, because the effects of climate change will be apparent across all terrestrial ecosystems, including freshwater ecosystems. As the first stage, DOC commissioned a high-level review of the likely impacts of climate change on native biodiversity (McGlone & Walker 2011). Subsequently, a framework for managing and monitoring the impacts of climate change on native terrestrial biodiversity was developed (Christie 2014).

3.5.2 Response of terrestrial biodiversity to climate change

An increasing number of changes to native terrestrial biodiversity in New Zealand have been attributed to climate change (e.g. McGlone et al. 2010; McGlone & Walker 2011; Lundquist 2011). However, unlike the Northern Hemisphere, few of these changes have yet to be proven with scientific confidence (McGlone & Walker 2011). This is partly due to a lack of sufficient long-term data, but also because New Zealand's fluctuating oceanographic climate makes finding a relationship between climate and biodiversity response difficult, and means native species may also have a level of resilience to fluctuating weather (McGlone & Walker 2011; Christie 2014). Furthermore, the distributions of many native species are restricted by invasive species and habitat loss rather than climate (Christie 2014). However, with rapid warming (+ 1 °C by AD 2040) and decreased rainfall in eastern regions being predicted for the future (Mullen et al. 2008), a more obvious response to climate change from biodiversity seems likely in the long term (McGlone & Walker 2011).

Predicting how biodiversity will respond will be difficult (McGlone & Walker 2011), but based on evidence from the Northern Hemisphere (Parmesan 2006), New Zealand should expect to experience shifts in range and altitude, southwards and upwards; changes in local abundance, including extirpation of populations and loss of ecosystems; changes in the timing of seasonal and annual events (i.e. breeding or flowering); and shifts in interactions across trophic levels. Furthermore, climate change is expected to exacerbate current anthropogenic pressures (e.g. invasive pests, sedimentation) on biodiversity (McGlone & Walker 2011). There will also be new anthropogenic threats from other land-based sectors seeking to adapt and mitigate (e.g. increased irrigation, dam construction for hydroelectric power generation) to protect themselves from the effects of climate change. These might pose more significant risks to biodiversity than climate change in the short to medium term (McGlone & Walker 2011; Christie 2014).

While all terrestrial biodiversity will be affected by climate change, some ecosystems and species will be particularly vulnerable to the combined effects of climate change and increasing anthropogenic pressure. Freshwater and coastal ecosystems have been identified as some of the more vulnerable ecosystems (McGlone et al. 2010; McGlone & Walker 2011). These ecosystems are particularly vulnerable because they are already subject to high levels of anthropogenic pressure. Native freshwater ecosystems will be affected directly by climate change through increasing flood frequency, drought (in the east and north), high temperatures, and sea level rise (McGlone et al. 2010; McGlone & Walker 2011), and indirectly through increased water abstraction pressure for farming and hydroelectric power generation, and increased aquatic pest and weed pressures. In coastal ecosystems (e.g. estuaries, coastlines, offshore islands), rising sea levels will 'squeeze' native ecosystems against developed hardened landscapes (McGlone et al. 2010; McGlone & Walker 2011). Increased sedimentation as a result of increased flood frequency will also be a problem (McGlone & Walker 2011). Some native species may also be particularly vulnerable to the impacts of climate change, including Canterbury mudfish (*Neochanna burrowsius*) (which exist in ephemeral streams; Allibone et al. 2010), wrybills (*Anarhynchus frontalis*) and other bird species which nest on braided river beds (Dowding & Murphy 2001); and coastal species such as shore plover (*Thinornis novaeseelandiae*) (Davis 1994). These species are generally highly specialised, have been through genetic bottlenecks, or have limited distribution (McGlone & Walker 2011).

3.5.3 Adapting to climate change – a proposed framework

A framework has been developed to manage the threat of climate change on New Zealand's terrestrial native biodiversity by Christie (2014). This framework focuses on the effects of climate change on terrestrial native biodiversity and includes land-based or predominantly land-based native species, ecosystems and natural processes (Christie 2014). Included in it are freshwater, estuarine and coastal ecosystems. The framework does not cover managing the impacts of climate change on marine ecosystems, historic heritage, recreational assets or other ecosystem services. Nor does it identify trade-offs between reducing carbon emissions and optimising biodiversity, as these have either already been, or will be assessed separately (e.g. Walton 2007; Willis et al. 2007).

The framework comprises five broad strategies. These are aimed at a national level and cover the full range of conservation management actions, from research and development through to management and raising awareness. The strategies are:

- Improve knowledge of the impacts of climate change on species and ecosystems
- Develop decision support tools and adaptation methods
- Incorporate climate change adaptation strategies into existing management and research programmes, planning and policy
- Improve management and restoration of existing species and ecosystems to facilitate resilience to climate change
- Raise awareness and understanding of the impacts of climate change on biodiversity.

Progress is being made on strategy one, 'improving knowledge', of the impacts of climate change on native species and ecosystems. This strategy has three main actions: identify native biodiversity most vulnerable to climate change, identify climate change-induced changes in invasive pests and land use, and identify information requirements and knowledge gaps (Christie 2014). Current DOC research is focussing on alpine ecosystems, which were identified by McGlone & Walker (2011) as being particularly vulnerable to climate change. Additional research by a joint NIWA and Landcare Research-led programme is investigating climate change impacts and implications across New Zealand's land-based sectors. However, specific research priorities still need to be identified for vulnerable species, freshwater ecosystems and estuarine ecosystems.

The other strategies within the framework have yet to be implemented. The intention is to implement these though existing research, monitoring and management, such as the DOC national monitoring programme (Christie 2014). Climate change may also be integrated into DOC's ecosystem management prioritisation systems alongside other threats. However, in addition to this, new tools may need to be developed. Planning and policy measures which protect native biodiversity from the impacts of climate change adaptation by other land use sectors will also need to be specifically identified.

3.5.4 Summary

The Department of Conservation commissioned a high-level review of climate change impacts on terrestrial biodiversity, including freshwater, estuarine and coastal ecosystems (McGlone & Walker 2011). In this review freshwater, coastal and alpine ecosystems and certain species were identified as being most vulnerable to the impacts of climate change. In response to this review, a framework has been developed by Christie (2014) to ensure that management and monitoring of climate change impacts is integrated into existing DOC research and management systems and processes. More detailed research is currently being carried out on some of the ecosystems identified by McGlone & Walker (2011) as being vulnerable. However, specific research priorities still need to be identified for freshwater ecosystems and estuarine ecosystems. Planning and policy measures which protect native biodiversity from the impacts of climate change adaptation by other land use sectors will also need to be specifically identified (Christie 2014).

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4. What are we trying to achieve? Setting freshwater conservation goals under climate change

4.1 What are other countries doing to develop climate change strategies for freshwater ecosystems? An Australian perspective

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4.1.1 Background

Australia's National Climate Change Adaptation Research Facility (NCCARF) was established in 2008. The role of the Facility was to lead the Australian research community to generate the biophysical, social and economic information needed by policy- and decision-makers in government, and in vulnerable sectors and communities, to manage the risks of climate change impacts.

NCCARF pursued this role through four main programmes:

- Research to develop new information,
- Synthesis and integration of existing information
- Networks that coordinate Australia's research community, build capacity and support effective interaction between research and decision-making communities
- Communication and knowledge adoption.

All these activities focussed on delivering information to decision makers to support climate change adaptation investments and initiatives. Community and end user engagement was a key component of all activities undertaken by NCCARF.

During the first Phase of NCCARF, a substantial body of knowledge was generated in nine thematic areas and in the cross-cutting synthesis and integrative research area (NCCARF 2013). Several areas of research are specific to freshwater, estuarine and coastal wetlands, while others considered aspects of adaptation that are relevance to the management of these systems.

This section provides details of some of the key research projects that were funded, and which are of relevance to wetlands. It also discusses the roles and activities of relevant networks and identifies several outputs from these groups that are relevant to wetland managers.

4.1.2 The Freshwater Biodiversity National Climate Change Adaptation Research Plan

The Freshwater Biodiversity National Climate Change Adaptation Research Plan (Freshwater Biodiversity NARP) identified critical information gaps and priority research questions for the most urgent and important climate change adaptation issues. Development of the NARP involved the active participation of both the research community and adaptation stakeholders.

Research questions in the Freshwater Biodiversity NARP were based around the following five areas (Bates et al. 2011).

- Incorporate climate change adaptation into management of freshwater species and ecosystems.

- Identify climate change adaptation options for Australia's freshwater biodiversity refugia.
- Understand climate change adaptation interactions between freshwater biodiversity and other sectors.
- Understand the role of environmental policies in protecting freshwater biodiversity under changing climate conditions.
- Cross-cutting theme: Ensure that adaptation initiatives for freshwater biodiversity and other sectors are mutually supportive and integrated where appropriate.

Other NARPs also prioritised several knowledge areas of relevance to the freshwater and wetland sectors. A cross cutting Synthesis and Integrative Research Strategy (NCCARF 2011) also identified a number of key areas for research, many of which have strong relevance to wetlands.

4.1.3 Summary of key NCCARF projects

Below is a synopsis of projects funded during NCCARF's first phase, some of which focus on wetland environments and issues. The resulting reports and some others can be downloaded from the NCCARF website (www.nccarf.edu.au). NCCARF funded more than 140 projects which delivered about 200 reports. NCCARF also delivered several fact sheets and 12 Policy Guidance Briefs covering a range of issues including adaptation on the coast, and freshwater ecosystems.

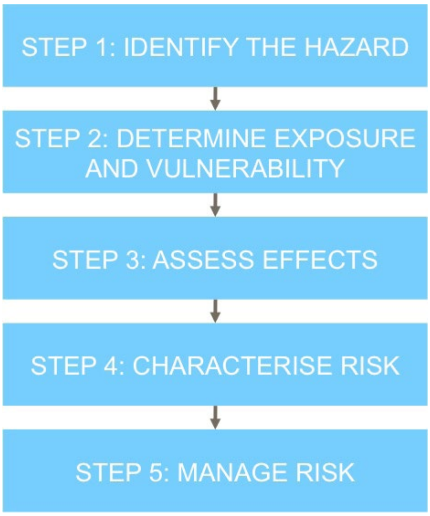

Figure 11. Risk assessment protocol (Chambers et al. 2013a).

Adapting to climate change – a risk assessment and decision framework for managing groundwater-dependent ecosystems with declining water levels

This project developed and tested a risk assessment and decision-making tool (Fig. 11) for managing wetland and cave ecosystems that depend on groundwater. The tool was tested in southwestern Australia, a global biodiversity hotspot and one of the earliest regions impacted by climate change. It was then modified to help manage similar ecosystems across Australia. (Beatty et al. 2013a; Chambers et al. 2013a, b; Chilcott et al. 2013; Mitchell et al. 2013; Neville, 2013, Nugent et al. 2013; Sommer et al. 2013; Speldewinde 2013).

Adaptive management of Ramsar wetlands

The Macquarie Marshes are iconic Australian wetlands, recognised for their international importance in providing habitat for waterbird breeding, as well as complex and extensive flood-dependent vegetation communities. The Marshes are predicted to be increasingly affected by climate change impacts. This project brought together current management and available science to help develop an adaptive management framework. It took a generic approach to enable the framework to be utilised for other wetlands (Bino et al. 2013).

Integrating climate and hydrological projections with freshwater ecosystem values to develop adaptation options

The study integrated downscaled climate model outputs with spatially resolved hydrological models and freshwater biodiversity data to scope adaptation actions at local, regional and state scales for Tasmania. It also explored how adaptation priorities might be set. The approach refined projections for climate-driven risks to aquatic environments, enabling spatial and temporal hazards and risks to be compared at a variety of scales. The main issues for improved and timely modelling were identified, these included:

- Improved frameworks for using and downscaling outputs from global climate models;
- Better data on thermal tolerances of freshwater biota; and,

- Improved methods for predicting key water temperature variables from air temperature and other biophysical predictors.

Improvements are also needed in updating and maintaining high-quality biodiversity data sets, and better spatially explicit information on the contributions of groundwater to surface waters and rates of recharge (Barmuta et al. 2013).

Building the climate resilience of arid zone freshwater biota – identifying and prioritising processes and scales for management

Important wetlands in the Lake Eyre Basin, Western Plateau and Indian Ocean Drainage Divisions of Australia's arid zone include springs, relic streams, rock holes and river pools. Climate change, including rising temperatures and more variable rainfall will alter connections between these sites, fragment existing habitats and force aquatic animals to follow suitable habitat. Understanding the processes that allow arid zone aquatic communities to persist is critical to understanding how the environment can be managed to help animals adapt to climate change in this region. This project produced national management guidelines for planning, policy and management decisions and actions across the Australian arid zone (Davis et al. 2013a, b).

Impacts of elevated temperature and CO_2 on the critical processes underpinning resilience of aquatic ecosystems

Climate change will affect freshwater ecosystems through changes in temperature, the amount of sunlight reaching streams and changes in atmospheric carbon dioxide. These impacts could affect the processes that support animal life in streams, including the amount of algae and how fast nutrients are recycled and used. One way in which those effects could be reduced would be to plant trees close to streams to provide shade to reduce stream temperatures. This project used experimental streams in Victoria to determine the potential effects of climate change on life-supporting processes. Data from streams with and without riverbank vegetation indicated that replanting trees along the riparian zone could reduce the effects of climate change (Thompson et al. 2013).

Novel methods for managing freshwater refuges against climate change in southern Australia

Freshwater refuges are areas that provide important safe habitat for aquatic animals and plants. This project assessed a variety of methods for managing refuges to determine which would be most effective as part of a climate change adaptation strategy for freshwater biodiversity. Researchers evaluated the usefulness of each method to provide guidance for environmental managers (Beatty et al. 2013b; Chester et al. 2013; Cook et al. 2013; Cummings et al. 2013; Robson et al. 2013).

Identification and characterisation of freshwater refugia in the face of climate change

Refuges from climate change within freshwater systems will be crucial for both freshwater biodiversity and for the terrestrial biodiversity that use freshwater habitats during hotter and drier periods. How such refuges will be affected by climate change, however, is poorly understood. This research has improved understanding of which parts of the landscape provide natural refuges in the face of global climate change. Identified refuges were mapped and assessed to determine what species and habitats they will protect across a range of possible future climates. The research quantified the biodiversity assets of each refuge and assessed their relative vulnerability under future climate scenarios, enabling management actions to be prioritised to ensure cost-efficient allocation of resources (James et al. 2013).

Predicting water quality and ecological responses

Changes to climate are predicted to affect stream flows with resultant implications for freshwater ecosystems and water quality. Interactions with other stressors such as population growth, community-driven land use change and management policies will complicate effects. Managers of freshwater ecosystems and water supplies could benefit from being able to predict the scales of likely changes. This project developed and applied a modelling framework to assess climate change impacts on water quality regimes and ecological responses. The framework is designed to inform water planning and climate adaptation activities. It integrates quantitative tools and predicts relationships between future climate, human activities, water quality and ecology, thereby filling a gap left by the considerable research effort so far invested in predicting stream flows. The modelling framework allows managers to explore potential changes in the water quality and ecology of freshwater systems in response to plausible scenarios for climate change and management adaptations (Dyer et al. 2013).

Human adaptation options to increase resilience of conservation-dependent seabirds and marine mammals impacted by climate change

Climate change impacts and adaptation options for marine birds (seabirds and shorebirds) and marine mammals have not been widely or consistently considered. This is a major impediment to ongoing conservation management and planning in the face of climate variability and change. Monitoring approaches for some of these species may also need to be reassessed and modified in order to better detect the impacts of climate change. Efficient ongoing monitoring is also required to allow adaptation responses to be validated. This project focused on climate-ready monitoring to identify adaptation options for conservation-dependent seabirds and marine mammals. It linked ongoing monitoring programmes around Australia, and developed practical adaptation guidelines for science and management, including on-ground monitoring protocols (Hobday et al. 2013).

Adaptation strategies for Australian birds

Climate change is likely to result in a number of bird species needing additional human help to survive. For some, dispersal corridors may be needed. Others may need help to cross barriers as their favoured habitat shifts across the landscape. Some may even need to be taken into captivity. This project identified key adaptation actions, and costs, over the next 20–50 years for the conservation of bird species vulnerable to climate change (Garnett et al. 2013).

Adapted future landscapes – from aspiration to implementation

Regional adaptation to climate, market and social changes is possible by changing what we do where on the land. Productivity and conservation goals can be achieved by farming to land capability, changing land use to capitalise on the emerging carbon market and identifying land use practices that provide a mosaic of production and conservation uses. This project worked with two regions in South Australia to develop an experimental process that uses future land use projections to assess different policy options and incentives (Meyer 2013; Meyer et al. 2013).

Identifying low-risk climate change adaptation in catchment management while avoiding unintended consequences

Risks, costs and benefits are inherent in all adaptation options. Decision makers need to select options that reduce risks from climate change impacts and provide overwhelmingly beneficial outcomes. This project tested a method for more integrative climate change adaptation that increased resilience and avoided maladaptation. The key lessons that emerged from this research were (Lukasiewicz et al. 2013):

- Many of the management activities underway, if extended and linked, would comprise a substantial ecosystem-based approach to adaptation. It is notable that many of these activities had not previously been considered in an adaptation context
- Research confirmed the need to look at a suite of complementary actions that spread risk rather than investing in one or two perceived best actions
- Adoption of an ecosystem-based approach is constrained by institutional complexity and socio-economic considerations that should be included in assessments of climate change adaptation
- Adaptive management provides a basis for the implementation of an ecosystem-based approach to climate change adaptation

Limits to climate change adaptation in floodplain wetlands – the Macquarie Marshes

The Macquarie Marshes is one of Australia's most significant wetlands; a protected area recognised as a wetland of international importance under the Ramsar Convention. The ecological character of the Marshes is also impacted by water resource development. This project will determine what opportunities and limits exist for adaptation to climate change in the Macquarie Marshes in ecological and socio-economic dimensions. Trade-offs between adaptation strategies (i.e. environmental flows or dam re-operation) and implications for other users (i.e. town supply, irrigators, graziers) were examined (Jenkins et al. 2011).

Climate change adaptation in the Coorong, Murray Mouth and Lakes Alexandria and Albert

The project investigated actual and perceived ecological, economic, technological and social limits to adaptation for the Lower Murray River, South Australia. It examined current adaptation strategies (including maladaptation) and recommended adaptation pathways. The study investigated the less tangible but keenly-perceived social limits to adaptation from the perspective of stakeholder groups (covering ethics, knowledge and attitudes to risk and culture) in response to anticipated temperature rises as well as the more tangible limits in the ecological, economic and technological domains (Gross et al. 2011).

Contributing to a sustainable future for Australia's biodiversity under climate change – conservation goals for dynamic management of ecosystems

Likely changes in climate and ecological processes due to climate change mean it may not be possible to retain biodiversity and ecosystems in the same form or place. This project established a broad set of goals and objectives for natural resource management (NRM) that will accommodate the inevitable changes of biodiversity in response to climate change and other pressures (Dunlop et al. 2013).

Coastal ecosystems response to climate change

This project synthesised knowledge of climate change impacts on various Australian coastal ecosystems including estuaries, coral reefs, sandy beaches, dunes and headlands, to review and integrate current understanding of potential adaptive pathways, both ecological and human, to identify priorities for future research and management (Hadwen et al. 2011).

Supporting climate change adaptation and decision making for regional natural resource management

Guidance material was developed by NCCARF in the knowledge that climate change will have a direct effect on the natural resources and human communities that are the focus of NRM groups. At the same time, climate change will exacerbate the existing pressures that are managed by NRM groups. It was recognised that NRM groups have been involved in developing NRM plans for long periods of time and that most plans are developed to be adaptive in nature. However, most of the NRM plans in Australia have not fully taken climate change into account and have not fully considered actions aimed at adapting to climate change.

We developed a series of guidelines to help NRM groups to self-evaluate their strategic plans and support them to make adjustments where necessary. We outlined a series of key challenges associated with climate change, which included:

- Making decisions for multiple possible futures
- Employing flexible and adaptive planning processes
- Explicitly identifying and preparing for likely future decisions
- Strengthening the adaptive capacity of people and organisations

We developed a checklist around five common stages or components (Fig. 12). These are built into an iterative process, which is necessary because the most effective responses to climate change problems may not be known and outcomes may only be achieved after trying a range of options, assessing the responses, and making appropriate changes (Rissik et al. 2014).

We considered the risks associated with not addressing these components (Fig. 12) effectively, and supported improvement through the provision of links to case studies, tools and information. The guidance material did not aim to answer all questions or to provide links to all answers, but to help practitioners to ask some of the right questions and to start the adaptation planning process (Rissik et al. 2014).

Figure 12. Five critical components for assessing the effectiveness of NRM plans in addressing the projected impacts of climate change.

4.1.4 Summary

A significant amount of climate change research has been undertaken in Australia over the past 5 years. This work provides a useful resource for users outside of Australia. Research results include process information, frameworks and approaches for determining adaptation actions. Research gaps still remain and there is a need for additional integration and synthesis of results.

NCCARF is a useful resource and has capacity and skills to support the development and delivery of end user-focussed research. NCCARF has received additional funding for 3 years. A strong focus of activities will be to synthesise and integrate information, and to develop and deliver a risk management framework for climate change adaptation on the coast.

Priorities for climate change adaptation

Below is a summary of key points that can help to achieve positive outcomes from adaptation projects:

- There is a need for coordination across all levels of government. Ecosystems do not recognise human-derived boundaries and integrated approaches are essential.
- Good, clear communication is essential and community engagement should be continual.
- Understand the implications of climate change for your area. What is the future it faces?
- Climate change adaptation will, ultimately, be about people – understand the adaptive capacity of people who live in and around wetlands and empower them to build resilience in themselves and their systems.
- Existing stressors must be minimised through targeted actions to maximise adaptive capacity of ecosystems.
- Determine the optimal scales at which strategies and actions should be planned and implemented.
- When determining actions, consider the limitations of these actions and ensure that they can be changed if desired outcomes are not being achieved. Ensure that you do not lock yourself into particular actions.
- As climate change becomes increasingly severe, difficult decisions may need to be made about where investments are warranted and where certain freshwater ecosystems may need to be left to transition
- Long-term monitoring is essential and trigger points must be identified and acted on to ensure there are effective responses.

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4.2 Adapting the DOC ecosystem prioritisation framework for a changing climate

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4.2.1 Background – protected area management and climate change

Earlier contributions to these proceedings identified that in New Zealand many rivers (Section 3.1), estuaries (Section 3.2) wetlands (Section 3.3) and lakes (Section 3.4) will be vulnerable to changes in species composition and ecological function in response to climate change. Threats to freshwater biodiversity including flow modification, water pollution, habitat degradation, species invasion and over-exploitation (Dudgeon et al. 2006) are all likely to be affected by climate change, with many pressures exacerbated.

A fundamental question for the conservation of biological diversity is how well the current network of freshwater protected areas (FPAs) in New Zealand, such as national parks, scientific reserves, ecological areas and private land covenants will enable freshwater ecosystems and species to adapt to changing climatic and environmental conditions. In an international review of FPAs, Hannah et al. (2007) noted that existing reserve boundaries may not align with species ranges under future climate projections, and early action to shift or create FPAs may be more cost-effective than attempting to restore ecological communities.

The Department of Conservation's (DOC's) approach to the management of freshwater ecosystems and species within FPAs should also consider future climate scenarios. For example, some lowland freshwater lagoons are expected to transition to brackish estuaries that may require different approaches to management over time. It is unknown to what degree current investment by DOC and other ecosystem management agencies will have to change in response to climate change (e.g. wider distribution of invasive species will require increased management response).

No New Zealand-wide assessment of the vulnerability of freshwater conservation values due to climate change has occurred, which is an impediment to informing a conservation management response. But tools are available; for example, Dawson et al. (2011) developed a framework to identify species vulnerability and to support the design of conservation responses. In contrast, there has been extensive study of projected climate change impacts on Australian freshwater ecosystems (Section 4.1). In this context, an overview of the DOC approach to conservation of freshwater ecosystems is provided, with a focus on the adequacy of the system for adapting to climate change.

4.2.2 Department of Conservation ecosystem prescriptions

A more systematic approach to managing New Zealand's natural heritage has recently been implemented by DOC to achieve specific 'outcome objectives' (DOC 2013). The outcome objectives seek to:

- Conserve a full range of New Zealand's ecosystems to a healthy functioning state
- Conserve nationally threatened species to ensure their persistence

To achieve these objectives, a prioritisation process utilising the Zonation geospatial model (Moilanen et al. 2012) and expert opinion was applied to determine the sites of highest priority for the conservation of natural heritage. Around 1000 sites across New Zealand were identified that represent a comprehensive range of terrestrial and freshwater ecosystems and key sites for threatened species. These were termed 'biodiversity management units' (BMUs). A significant number of rivers, lake and wetlands were encapsulated within BMUs.

The allocation of resources across BMUs takes into account the uniqueness of the site, current condition of the BMU (human-induced pressures), management cost to reduce pressures over a 50 year period, and an estimate of the difference made due to management. The combination of conservation management actions required at each BMU is termed an 'ecosystem prescription'. The prioritisation process and ecosystem prescriptions do not currently consider impacts associated with climate change, but this could be incorporated into subsequent iterations.

4.2.3 Assessing the adequacy of ecosystem prescriptions

Given climate change is projected to affect freshwater ecosystems via altered water flows, water quality and sea-level rise, it is sensible to assess whether the current suite of BMUs and their ecosystem prescriptions are adequate. The degree of adequacy will depend on the vulnerability of the BMU and is a function of geographic location (exposure) and the type of freshwater ecosystem (sensitivity) as illustrated in Fig. 13.

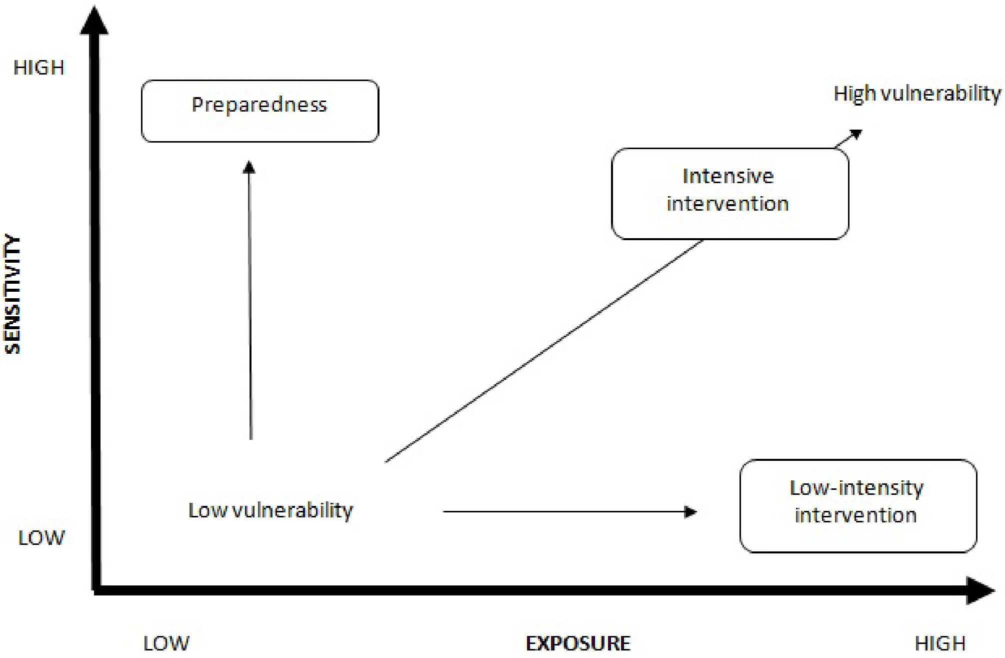

Figure 13. Vulnerability of freshwater ecosystems to impacts from climate change is defined by the relationship between exposure and sensitivity. Based on Dawson et al. (2011).

4.2.4 Whangamarino wetland ecosystem prescription: case study

Whangamarino wetland is a 7000 ha lowland swamp/raised bog wetland complex on the floodplain of the Waikato River. It is a BMU managed by DOC and listed as a wetland of international importance under the Ramsar Convention. The wetland varies in ecological integrity from a relatively good condition raised bog at higher elevation to poor condition swamp dominated by invasive species, altered hydrology and high rates of sedimentation (Blyth et al. 2013). The wetland also forms part of the Lower Waipa Waikato Flood Control Scheme (FCS) that releases water into the wetland for flood storage (Fig. 14).

Rainfall patterns in the central North Island are projected to become more variable in the future due to climate change, with increased occurrence of extreme events (Section 2.1). This is likely to result in the FCS releasing greater volumes of water into the Whangamarino wetland, or for such flooding to occur more frequently. The altered hydrological regime is likely to exacerbate sedimentation and provide a pathway for aquatic weeds.

Table 3 presents an assessment for Whangamarino wetland that applies four exposure criteria and seven sensitivity criteria to determine ecosystem vulnerability to impacts caused by climate

Figure 14. Whangamarino wetland inundated by water following release of flood water from Lake Waikare and inflows from the Whangamarino River. *Photo: DOC 2010*.

Table 3. A rapid vulnerability assessment of Whangamarino wetland using key criteria to assess the exposure and sensitivity of freshwater ecosystems to climate change impacts.

EXPOSURE & SENSITIVITY CRITERIA		VULNERABILITY	OVERALL VULNERABILITY
Exposure	Sea level rise	Low	Very high
	Altered hydrological regime	Very high	
	Temperature	Moderate?	
	Wind disturbance	Low	
Sensitivity	Hydrological processes	High	High
	Salinity regime	na	
	Eutrophication / Productivity	Unknown	
	Invasive species	High	
	Buffer zones/Migration opportunity	Moderate	
	Species migration corridors	Unknown	
	Species refugia	Unknown	

change. For a number of these criteria the vulnerability of the wetland is assessed as high, but there also exist knowledge gaps with unknown sensitivity to some attributes, such as sensitivity of the wetland to eutrophication.

Given the high vulnerability score for exposure and sensitivity of Whangamarino, the ecosystem prescription for this BMU should take into account 50 year and 100 year climate projections. For sites that are deemed to have low vulnerability, status quo approaches to conservation management are expected to be sufficient.

The existing 50 year ecosystem prescription for Whangamarino wetland covers a range of management actions (Table 4). The costs associated with the prescription were designed based on current status of the site and catchment with little consideration of how these pressures may change in the future. Improving the adequacy of the prescription is proposed through expert-panel or detailed modelling evaluation of likely conditions at the site at 2050 and 2100. Climate change adaptation options identified should then be built into the ecosystem prescription (Table 4) to ensure the natural heritage values of this Ramsar site are maintained into the future.

Table 4. Summary of the BMU prescription for Whangamarino wetland, potential adaptation options and their likelihood of success in mitigating climate change impacts.

MANAGEMENT ACTION IN 50 YR BMU PRESCRIPTION	ANNUAL BUDGET ($K)	CLIMATE CHANGE ADAPTATION (REVISED PRESCRIPTION)	POTENTIAL BUDGET SHIFT	ADAPTATION LIKELIHOOD OF SUCCESS
Weed control – willow, yellow flag, alligator weed, *Glyceria.*	50	Increase resources likely to be required as changing environmental conditions promote weed dispersal.	Increase	High
Predator control – cats, mustelids, rats.	30	Uncertain how predators will respond to altered hydrology.	No change	–
Water quality – advocacy for improved flood control scheme (FCS) operation.	25	Increased resources likely to be required to mitigate water quality impacts in response to FCS operation.	Increase	Low-High (depending on action taken)
Hydrological regime – advocacy for improved flood scheme operation.	25	Increased resources likely to be required to mitigate water regime impacts due to FCS operation. May need alternative flood storage.	Increase	Low-High (depending on action taken)
Herbivory – boundary fencing to reduce stock access.	10-30	Not applicable.	No change	–
Wetland extent/ buffer – retire grazing concessions.	10	Not applicable.	No change	–
Threatened flora – fire application to promote habitat for rare orchid.	20	Potential for incidence of natural fires to increase. May reduce requirement for fire application to enhance threatened plants.	Decrease	Uncertain
Monitoring and Research.	50	Funding required to model future climate scenarios and impacts on ecological function.	Increase	High

4.2.5 Summary

It is well accepted that for effective conservation of natural heritage the management of a comprehensive, adequate and representative network of protected areas is critical (Margules & Pressey 2000). The development of a system of freshwater protected areas has been limited in New Zealand to date. Given climate change projections for New Zealand and their potential impact on freshwater systems, a review of the adequacy of freshwater protected areas under a changing climate is recommended.

A simple framework is presented for evaluating the vulnerability of priority ecosystems (BMUs) managed by DOC. Freshwater ecosystems such as Whangamarino wetland are expected to be highly exposed and sensitive. Without reassessment, current management is not likely to be adequate to ensure highly vulnerable species and ecosystems will be protected into the future. Broader application of this assessment framework across BMUs will identify those freshwater ecosystems likely to be resilient to climate change impacts, and those requiring additional investment to facilitate adaptation.

Adjustments to the level of investment in priority ecosystems to account for 50–100 year climate change projections may result in a reduced funding resource, limiting the number of BMUs that can be managed by DOC. This will increase the need for partnerships with other agencies and stakeholders to mitigate pressures on freshwater protected areas. In the longer term, adapting reserve design may be more effective in ensuring that freshwater biodiversity currently represented in conservation areas is buffered from both the direct and indirect impacts of climate change.

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4.3 Adapting approaches to freshwater management in the Waikato region

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4.3.1 Background

The Waikato Region supports a great diversity of freshwater ecosystems. These include cold-water or geothermal springs arising in volcanic, pumice and karst geologies; dune, peat and riverine lakes in lowland settings; large internationally recognised wetlands; many kilometres of hill-country streams and lowland drains; and large rivers with extensive historical floodplains and unique delta ecosystems.

A small proportion of these freshwater ecosystems drain catchments that are legally protected, mostly at mid-to-high elevations with poor protection in lowland areas. Outside these protected areas, freshwater environments in the region are subject to multiple pressures that progressively accumulate and affect water quality, ecological function and biodiversity as water moves downstream. The dominant stressor on freshwater environments in the Waikato Region is agricultural development, but in some parts of the region urbanisation, flow regulation, mining, forestry and a proliferation of pest species also have impacts on ecological values.

Climate change will influence this multiple stressor environment through altered rainfall, wind and temperature patterns, rising sea levels, and elevated levels of UV radiation (Hader et al. 2011; Ruiz-Gonzalez, 2013). The combination of these effects can be expected to accelerate degradation of freshwater ecosystems in some places, raising the question of how management can respond to ensure no net loss of existing ecological values.

Climate change forecasts for the Waikato Region indicate mean annual temperature increases by 1.2 °C by 2050 and 2.2 °C by 2100, with summer increases of up to 2.5 °C by 2100 (Li et al. 2011). Variable changes are expected in precipitation, ranging between a decrease of around 5% and an increase of 7% by 2050, and a decrease of around 7% and an increase of 17% by 2100. Increases in precipitation are expected to be highest in the southern parts of the region around Waitomo, Otorohanga and Taupo, while the largest decrease in precipitation is projected to occur in the Thames-Coromandel and Hauraki districts (Li et al. 2011). Projections for extreme daily precipitation changes indicate an increase in northeast parts of the Waikato region (Hauraki and Thames-Coromandel districts), with consequent effects on peak stream flow.

Projected changes in potential evapotranspiration deficit suggest that the highest drought-related stress will occur in the Hauraki and Matamata-Piako districts by 2100. More widespread but less-severe effects are expected across central, northern and eastern parts of the region. The sea level rise projection used for regional planning is a minimum of 0.8 m by 2090.

4.3.2 Policy response

The Waikato Regional Policy Statement (RPS) (Waikato Regional Council 2013) identifies climate change as a regionally significant issue because of its potential to have impacts on wellbeing (Issue 1.2). Specifically, it identifies key issues of increased potential for storm damage and weather-related natural hazards, and long-term risks of sea level rise to settlements and infrastructure. The RPS also acknowledges by way of explanation that changing climate will affect the habitat range of plant and animal species, including pest and domestic species, creating challenges in managing indigenous biodiversity and biosecurity. RPS objective 3.5 (Adapting to climate change) indicates that land use is to be managed to avoid the potential adverse affects of climate change-induced weather variability and sea level rise, including the effects on indigenous biodiversity and natural character. It is recognised that local authorities should, and regional and district plans shall, recognise and provide for the projected effects of climate change (Policy 4.1.14).

The projections for regional climate by Li et al. (2011) are recognised in the 2012–2022 Long Term Plan (Waikato Regional Council 2012a). This is mainly in terms of changes to hazard zones and requirements for event warning, but also through recognition of potential changes to the quality and quantity of natural resources (including water), and greater demands on water resulting from increased drought frequency. The Regional Plan addresses the potential effects of climate change on water resources through Variation 6, which states that establishing and reviewing allocable and minimum flows have particular regard to the effects of climate change on surface water resources and sustainable yield of groundwater resources (Waikato Regional Council 2012b).

Various zone plans address climate change impacts at a high level by including forecasts in flood control scheme design, monitoring of levels, and liaising with national agencies (e.g. Waikato Regional Council 2011). Adverse environmental effects are recognised as one of the consequences of climate change and, because the risk is assessed as routine, the management response is typically to continue current practices and upgrade assets such as stopbanks to offset climate change effects (see Section 4.4.4).

4.3.3 Strategies for dealing with climate change

A review of natural hazard responses highlighted that the Waikato Regional Council has no climate change adaptation policy to guide river and catchment management, with no guidance on the specific actions required to avoid or mitigate potential effects (Environment Waikato 2008). More recently, Li et al. (2011) made a number of recommendations on Council strategies for dealing with climate change including:

1. Integrating climate change projections into biodiversity and biosecurity management, water and land management, and regional planning strategies,
2. Determining thresholds for the likely implications of changing habitat conditions and ecosystem dynamics with a particular focus on SNAs located in the Hauraki district and surrounding areas, and
3. Adopting policies that will accommodate strategies to cope with different thresholds of sea-level rise.

A number of specific actions could be integrated into planning and management activities within the Waikato Region to increase resilience of freshwater ecosystems to climate change. These include:

1. using floodplains as storage zones to attenuate increased flood-flows;
2. requiring shade on large urban impervious surface areas (e.g. car parks) to reduce the heating of stormwater runoff;
3. extending riparian planting along streams to create shade and reduce water temperatures;
4. future-proofing spawning habitats where rising sea level might alter the suitability of existing areas for key species such as whitebait;
5. managing connectivity between freshwater ecosystems to enable native species to access refugia while excluding pest species;
6. protecting resilient habitats such as springs, forested areas and existing riparian plantings;
7. increasing surveillance and control of pest species spread; and
8. enforcing the reduction of non-climate stressors (e.g. nutrient runoff, drainage, sedimentation) to off-set the added effects of climate change on existing multiple cumulative stressors, in particular around sensitive wetlands and shallow lakes.

4.3.4 Climate change adaptation strategies and other considerations

A major driver of climate change responses within the Waikato region has been the threat of increased flooding from more extreme precipitation events and sea level rise. The approach to date has involved adjusting defence heights and capacities as flood control assets come up for review, and requiring that climate change predictions be taken into account for stormwater designs in new subdivisions.

For example, the stormwater planning section at the council uses Ministry for the Environment (2008) guidance on factors influencing extreme rainfall per degree temperature increase projected up to 2090 to determine the percentage increase in design capacity of structures required to maintain consented hydrological conditions. However, this approach does not account for stormflow changes that will be experienced in existing urban areas, or likely increases in the temperature of runoff from hotter impervious surfaces.

In terms of water allocation and water quality, minimum stream flows have been set to sustain certain water quality targets, such as for dissolved oxygen. Furthermore, the duration of most water take consents is being limited to 15 years, thereby allowing flexibility in the face of future declines in summer low flows attributable to climate change.

Currently, 10–30% of summer low flow is allocated in the Waikato Region, and riparian planting is required in over-allocated dairy catchments to help mitigate adverse effects of reduced summer flows on habitat and water temperature (Waikato Regional Council 2012b). In the future, increased rainfall in intensively farmed catchments can be expected to increase runoff to receiving waters. Streams and rivers around the region are already increasing in turbidity and nitrogen concentrations associated with intensification of pastoral farming in lowland parts of the region (Vant 2013), and climate change may exacerbate these increases.

Several pest species, in particular fish such as koi carp (*Cyprinus carpio*) and gambusia (*Gambusia affinis*), can be expected to increase their potential range and numbers in response to reduced flows and elevated water temperatures. These species can adversely affect native biota or, in the case of koi, degrade water quality and contribute to bank erosion when feeding (Parkos et al. 2003). There is also the possibility that more subtropical invertebrates (e.g. disease-carrying mosquitoes) could establish or that conditions become suitable for aquarium species that are currently unlikely to breed in the wild except around thermal discharges (e.g. apple snails; Collier et al. 2011).

Change in the timing and/or magnitude of flood-flows, coupled with temperature cues and rising sea levels, will have implications for life cycles of both introduced and some native species. For example, upstream migrations of the dominant whitebait species, inanga (*Galaxias maculatus*), are typically initiated by large floods in spring, and spawning occurs on certain types of riparian vegetation near the extent of saline intrusion during very high tides in autumn. Rising sea-levels may mean that suitable habitat for spawning is steadily pushed further upstream where vegetation and bank gradients may not be favourable. It has been estimated that 93% of potentially suitable whitebait spawning habitat in the Waikato delta has already been lost due to stop-banking (Jones & Hamilton 2014), and further loss could have significant implications for the whitebait fishery. As noted above, it would be prudent to protect or restore likely future spawning habitats to address this issue.

The regional council has recently undertaken mapping of Significant Natural Areas (SNAs) for all ecosystems including streams and rivers, lakes, wetlands, and karst (note that springs were not included). This information will provide a focus for future biodiversity management on private and council land. Unfortunately, this exercise did not consider what areas might provide important biodiversity refugia from climate change, or what actions might be needed to offset future changes. Many of the currently mapped areas are in native forest catchments that should provide resilience for some native aquatic species, and work is currently underway to identify key corridors between SNAs that could facilitate species movement to refugia.

SNA mapping identified high-value stream and river sites in the lower Piako catchment on the Hauraki Plains where projections are for increased drought stress. Spatial and temporal changes in the ecological condition of sites in this area are assessed annually as part of State of the Environment Monitoring (Collier & Hamer 2012). This information will provide indicators of regional climate change impacts on native and introduced species if sampling is sustained over the long term. A key feature of this sampling network is the inclusion of native forest reference sites which indicate regional-scale changes, such as those wrought by climate change, in the absence of catchment-based human activities that affect water quality, habitat quality and connectivity.

4.3.5 Summary

The Waikato Region is endowed with a wide variety of freshwater ecosystems with varying levels of biological integrity, sensitivity and resilience to climate change impacts which could have additive, multiplicative or antagonistic effects with existing stressors. Council policy recognises the significance of climate change to the region and potential implications for freshwater management. The response to date has involved:

1. incorporating required infrastructure changes during successive asset renewals/ replacements (e.g. stormwater structures),
2. reducing duration of relevant consents such as those for water abstraction (Variation 6),
3. considering alternative solutions in order to achieve the agreed level of service,
4. relying on central government guidance and district councils to develop their own policy and approach for local conditions.

A range of other options is available to enhance resilience of freshwater ecosystems and provide refugia from climate change impacts in the Waikato Region.

4.3.6 Acknowledgements

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5. Freshwater systems and climate change policy

5.1 Current policies for freshwater conservation

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5.1.1 Background

Freshwater conservation requires management of the water, the land within the waterbody (the bed), land within the catchment and freshwater biodiversity. Management is needed to address the threats to natural heritage values, including climate change.

There is a range of policy options for dealing with freshwater conservation issues, these include:

- Changing property rights (e.g. purchase of land)
- Regulating (e.g. setting bottom lines, prohibiting activities)
- Providing central government direction on what councils or other agencies must address
- Determining scientific standards / best practice standards
- Providing tools (new technology, models, etc.)
- Providing other support for change (financial and non-financial)

5.1.2 Current policy framework for climate change and freshwater conservation

Under current New Zealand law, water is not owned by anyone, but is principally managed by the Crown under the Resource Management Act 1991 (RMA). The government controls taking, damming, diverting and discharging into water through the RMA. Flood mitigation is managed under the Soil and Rivers Conservation Act and the Local Government Act. The RMA also manages land uses in catchments that could affect waterbodies.

The RMA has a number of provisions that directly relate to climate change. It defines climate change as:

> *a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods*

Section 7 of the RMA requires decision makers to have particular regard to the effects of climate change, but the Act limits the extent to which contributions to climate change (i.e. greenhouse gas emissions) can be addressed in plans and consents.

The RMA provides a range of mechanisms for dealing with climate change and freshwater, including the creation of national policy statements, national environmental standards, and regional plans. The current National Policy Statement on Freshwater Management requires councils to consider the effects of climate change when developing freshwater objectives and limits (refer Section 2.3.3).

In terms of legislation relating to conservation, the National Parks Act 1980, Conservation Act 1987 and Reserves Act 1977 are key pieces of legislation for which the Department of Conservation (DOC) is the lead agency. These Acts provide for the setting aside of protected areas, control of activities within those areas, and management of freshwater indigenous and sports fisheries.

While there is no specific reference to climate change in these acts, they provide tools to address the direct and indirect impacts that are projected due to climate change. For example, the beds of waterbodies can, like any other land, be given protected area status under the Acts, or other legal protection mechanisms. Protected area status allows control of all activities within the area, although it does not give full control of the taking of water. However, at present the protected area network is not representative of all freshwater ecosystems and waterbody types. Increasing the representation of freshwater habitats in conservation land is a potential strategy to enhance the resilience of New Zealand's native species and ecosystems.

There is increasing scientific evidence that healthy systems are more resilient in the face of climate change effects. Actions could be taken under the Conservation Act in relation to fisheries, protected area-related Acts in relation to habitat, and the Biosecurity Act in relation to biosecurity threats, to improve the resilience of ecosystems and populations. Actions might include protecting buffer zones to allow wetlands to respond to changes in rainfall; reducing the impact of trout and other introduced species on native fish so they can better cope with changes in water quantity and temperature; addressing fish passage barriers that reduce habitat availability for fish; and addressing potential new pest outbreaks that result from changing temperatures. Control of fire risks under the Forests and Rural Fires Act can help protect wetlands from fire risk during the expected increase in drought periods as a result of climate change.

Wildlife are protected and managed under the Wildlife Act. Freshwater fish are not protected in the way wildlife are, but managed under the Conservation Act, Fisheries Act and freshwater fisheries regulations. Management of other fauna and flora is largely determined by landowners. Adjustments could be made to management of harvested species to recognise impacts of climate change on those species. There can also be non-regulatory actions to enhance resilience of harvested species, such as restoration of spawning sites.

5.1.3 Policy needs for freshwater conservation under climate change

Key policy needs are:

- To ensure that all policies and allocations of freshwater recognise and address the likely changes in hydrology and temperature that will result from climate change.
- Predictions of likely effects on freshwater species and ecosystems. Having an agreed set of predictions used by all government authorities, based on best science, will reduce the potential for litigation and confusion.
- To actively address key existing threats on priority freshwater ecosystems and threatened species, to increase their resilience to new impacts.

5.2 Freshwater systems and climate change policy – land-based primary sectors and biosecurity

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Ministry of Primary Industries (MPI).

5.2.1 Background

The Ministry for Primary Industry's (MPI's) role covers the key primary industries (agriculture, horticulture, forestry, aquaculture and fisheries) and MPI has an important role in getting produce into export markets. MPI is also charged with leadership of the New Zealand biosecurity system and has roles in food safety and animal welfare. The biosecurity role is broader than just primary industries and includes cultural, social and environmental values; facilitating international trade; protecting the health of New Zealanders; and ensuring the welfare of New Zealand's environment, flora and fauna, marine life and Maori resources. Changes in freshwater systems have the potential to affect all areas of MPI's role, as freshwater systems are a key part of New Zealand's environment and contribute to primary production.

This paper focuses primarily on the impacts of climate change on freshwater systems as they relate to land based primary sectors and biosecurity. Much of this paper is drawn from an MPI-funded three-year research project on the impacts of climate change on land-based sectors (Clark et al. 2012a). MPI recognises that freshwater aquaculture and fisheries management will also be affected by climate change, including physiological and habitat changes, but this is not the subject of this paper.

Biosecurity and land-based primary industries management occurs across multiple scales and levels of governance, environment, and social factors. Figure 15 outlines the key components important to managing biosecurity and land-based systems in New Zealand.

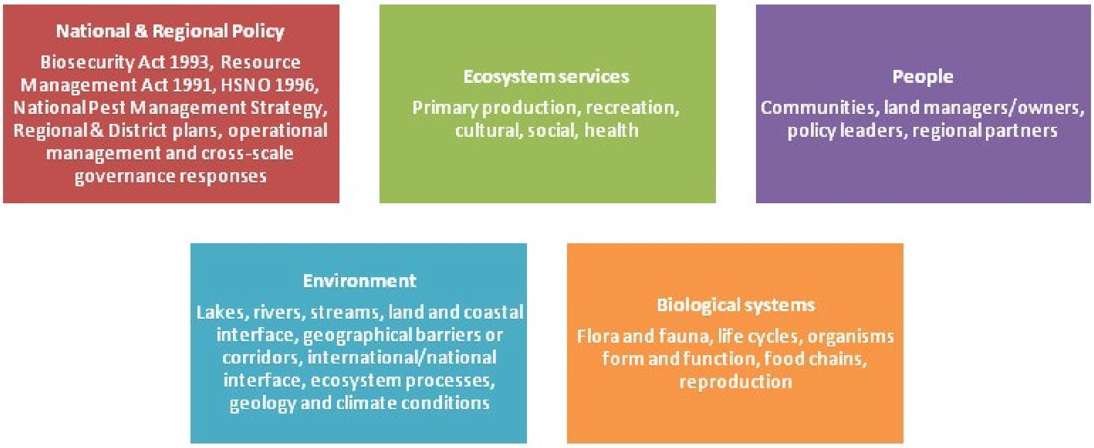

Figure 15. Key components important for managing biosecurity and land based systems.

5.2.2 Impacts on biosecurity and primary industries

A changing climate will bring increased temperatures to New Zealand and changes in precipitation, affecting freshwater ecosystem processes and resilience. Temperature and precipitation are key limiting factors in streams, lakes and rivers and are important factors in understanding and managing biosecurity and production risks. A changing climate has consequences for biosecurity management and primary production systems and will change the risk profile of MPI's work. Not all changes will be negative; however, management changes may be needed to realise potential opportunities.

Moreover, with more extreme weather events expected, climate change will add further stress to ecosystems and ecosystem services, leading to increased vulnerability. In addition, thresholds may change – what isn't a problem now may become a problem in future. Expected changes in pest and disease management include extended geographical ranges and breeding seasons (e.g. increased temperatures may have this affect on the Argentine stem weevil biocontrol agent (Gerard et al. 2010)).

Tackling climate change involves understanding the behaviour of complex systems (including economic and social consequences); in particular:

- Changes to accepted norms – challenging the way we determine acceptable levels of risk
- The way biological systems respond to change
- Increased vulnerability that may change responses to other stressors, such as pests
- Increased uncertainty – both in how systems behave and the amount and rate of warming that should be expected or managed for.

Biosecurity

The MPI biosecurity system is risk based and covers three core areas: pre-border, border and post border. Climate change will affect known as well as potential pests, diseases, vectors, invasive species and pathways. Climate is considered when assessing biosecurity risk. A changing climate will change the existing risk – it is the additional or changed risk profile that will be important to understand and manage. Current tools and practices will remain an integral part of management approaches.

The projected impacts of climate change will alter the risks of sleeper pests and new pests in a number of ways. There is an increased risk that a suite of pests could enter and survive in New Zealand and the distribution and impact of pests already established will also change. Increased temperatures, CO_2 concentrations and changes in water availability will change the effectiveness of pest management practices. Individual species in a biocontrol system are likely to be affected differentially (e.g. changed rates of development and reproduction, and susceptibility to parasitism and diseases).

Land-based primary sector

In the land-based production systems, the projected increases in average temperature are likely to boost plant growth and may increase water demand from freshwater systems already under pressure from precipitation changes. The management and maintenance of water infrastructure could become increasingly important including the potential demand for new or different infrastructure. On-farm and local government water and asset management planning will need to factor the effects of climate change into infrastructure decisions, including impacts on freshwater systems.

Increased erosion and sedimentation rates, along with more flooding, are also expected. This will further affect freshwater systems and associated infrastructure (e.g. stock water systems, bridges and flood protection works). Additional maintenance and operation costs may occur, leading to shifts in the ability of production systems to respond to further climate changes.

The impacts of climate change on biosecurity and land-based production systems overlap. Modelling shows that biocontrol agents used in pasture pest management respond to warming temperatures differently across the country. In some areas the control becomes better but in other areas it becomes worse. This will require adopting management techniques, such as biocontrol refugia, for the biocontrol to remain effective and the pasture system productive. Pasture cover affects sediment and nutrient pathways to water bodies in turn affecting species and freshwater ecosystems.

The impacts of climate change are local and specific. How those impacts are managed will be part of a wider conversation with local communities on how water is best managed, including cultural, community and environmental values. There is increased awareness in farming communities of a changing climate and the need to make farm systems more resilient.

5.2.3 Policy implications

National level

The effects of climate change on biosecurity management affect decision making at both the local and national level in diverse biophysical, social and economic settings. Central government, regional councils, land managers and communities are all affected and all have an interest ensuring that the biosecurity system remains effective. Current priorities may change in response to the different risk profiles that come with a future warmer climate.

The biosecurity system takes a risk-based approach that is suited to dealing with climate change, but management decisions may change. Pre-border and at the border biosecurity is mainly managed by MPI, but post-border management requires working closely with a range of different partners who may experience the risks differently. Pre-border investigation and analysis will be critical to learning how pests and diseases establish in countries that are both similar and different to ours. The MPI risk system also monitors global trends and events to identify new risks and threats, including potential impacts on freshwater systems.

In terms of primary industries, there are a number of policy considerations. In the foreseeable future, primary industry will continue to be an important part of New Zealand's economy. Water is a key input in production systems to grow plants and provide drinking water for stock. Ensuring that climate change is appropriately factored into water policy will be important to enable primary industries to adapt to such changes.

At present our systems are based on the current norms of droughts and floods; however, those 'norms' may need to be adjusted to reflect a different 'business as usual' in the future. A drought that occurs (on average) once every 20 years could in future occur between once every five and 10 years. That is, two to four times more frequently than at present. In some areas this represents a decline in pasture production from around 70% of an average year to closer to 50% (Ministry of Agriculture & Forestry 2007).

Finally, common to both the biosecurity system and the primary industries, a key challenge will be adapting to multiple stressors and cumulative impacts that occur not only in New Zealand but also internationally.

Regional level

Although we can set biosecurity policy at a national level, the impacts occur at a local level, which means working effectively with regional councils and communities. Regions will be affected differently as the impacts become apparent, with some regions being more affected than others. In some instances, current management approaches will be sufficient, while other approaches will need to be altered. There are opportunities for experience and lessons learnt to be shared across regions.

For biosecurity, the policy implications at a regional level are uncertain – they will vary by region and the approaches that are taken. What is certain is that planning will have to be future focussed; while tools and approaches may remain the same how they are used may need to change.

There are several strategies available for adapting pest management under climate change (Clark et al 2012 a & b). This includes potential win-win opportunities if actions align with existing pest management goals, or have economic benefits that increase resilience in the long term, such as water efficiency.

At a regional level for primary industries, it will be the practices on farms and the regulatory environment that will determine how the primary industries affect freshwater systems under a changing climate. Adaptation is a management response to a changing climate and a way of future-proofing land-based sectors and the New Zealand economy. There is no 'one size fits all' approach to adaptation. The impacts depend on production system, management choices, local climate conditions, as well as the rate and extent of the changing climate.

Water resource decisions have long-term planning horizons, so decisions made now will need to take account of future climate but will also need to allow flexibility as systems behave in uncertain or unexpected ways. The primary industries are one of a number of key stakeholders involved in water management and increasingly a more collaborative approach is being used across the country.

Finally, understanding the respective roles, strengths and expertise of stakeholders will be an important to enable change on the ground in a way that promotes good water outcomes for all. Good information on what can be expected from a changing climate will be critical to making good decisions, which means a variety of perspectives and disciplines will need to be brought to the table. Effective collaboration will be key to managing water for the range of values important to the community, including economic, environmental, social and cultural uses.

5.2.4 Summary

Policy is about decision making, complexity and uncertainty. The complexity of how impacts of climate change may play out in New Zealand freshwaters is illustrated in the intersection of primary industries, biosecurity and water. And this complexity exists within a wider and more complex environment of national and regional policy and decision making. Key agencies, local government, researchers and stakeholders with an interest in water management will need to work together to develop enduring solutions.

We need to ensure we have the right tools available to make good decisions about the impacts of a changing climate, as well as monitor progress to ensure we move in the right direction. MPI has a number of fact sheets, research reports and an adaptation toolbox to facilitate information transfer and planning.

Refer to: http://www.mpi.govt.nz/environment-natural-resources/climate-change.

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5.3 Policy requirements under the National Policy Statement for Freshwater Management

Kirsten Forsyth

Ministry of Environment (MfE). Email: Kirsten.Forsyth@mfe.govt.nz

5.3.1 Background

The National Policy Statement for Freshwater Management (NPS FM) came into effect in May 2011. It applies to all freshwater – rivers, lakes, wetlands and aquifers. Regional councils must give effect to national policy statements in their regional plans and policy statements. Some specific matters the Freshwater NPS directs regional councils to provide for are:

- Safeguard the life-supporting capacity, ecosystem processes and indigenous species of freshwater, including their associated ecosystems
- Set freshwater objectives and limits in regional plans
- Avoid over-allocation, and phase out existing over-allocation
- Maintain or improve the overall quality of freshwater within a region
- Set targets (a limit) in over-allocated situations, including defined timeframes within which those targets are to be achieved.

When setting freshwater objectives and limits, the council must have regard to (among other things) the 'reasonably foreseeable impacts of climate change' (Freshwater NPS policy A1). The term 'reasonably foreseeable impacts of climate change' is not defined and will rely on councils making judgements with a physical science basis that reflect projections from reputable scientific bodies.

For water quantity, a limit is the amount of water that can be taken out of the water body while achieving the objective. For water quality, a limit is the amount of contaminants that can be added to the water body while achieving the objective. The two are intrinsically bound together.

5.3.2 Policy requirements under the Freshwater NPS

The NPS-FM 2011 was amended in 2014 so that regional councils apply the requirements of the NPS-FM in a consistent way across the country (New Zealand Government 2014). A key feature of the 2014 amendments was the inclusion of the national objectives framework, which prescribes the process councils must follow and the matters they must consider in setting freshwater objectives in regional plans. They must choose from a selection of national values, two of which – ecosystem health and human health – apply to all water bodies. Regional councils must use a suite of specified attributes (water quality characteristics) to set objectives for those values (Table 5). The state of some attributes will be affected to varying extents by direct and indirect impacts associated with climate change.

Four states (A, B, C and D) are described for each attribute, with the bottom of the C state being the minimum acceptable state which can still provide for the value. For the compulsory values of ecosystem health and human health, the minimum acceptable state is the national bottom line for that value. Except where specified exceptions apply, objectives cannot be set below a national bottom line.

The national values and their descriptions provide a common language for communities throughout New Zealand to talk about what they want for their local water bodies. The attributes provide common yardsticks to measure water quality and check that the value is being achieved.

Table 5. Attributes included in the NPS-FM (2014) for safeguarding ecosystem health in lakes and rivers.

FRESHWATER ECOSYSTEM	ATTRIBUTE	ATTRIBUTE UNIT
Lakes	Phytoplankton	mg chl-a/m^3
	Total Nitrogen	mg/m^3
	Total Phosphorus	mg/m^3
	Ammonia toxicity	mg NH_4-N/L
Rivers	Periphyton	mg chl-a/m^2
	Nitrate toxicity	mg $N0_3$-N/L
	Ammonia toxicity	mg NH_4-N/L
	Dissolved oxygen	mg/L

5.3.3 Setting a freshwater objective – periphyton

Councils must use the specified attributes applicable to the particular water body type to set freshwater objectives for each selected value. One specified attribute for the compulsory value of ecosystem health in rivers is periphyton. Periphyton, which attaches to stones on the river bed, is the basis of the food chain and a primary source of food for invertebrates. However, excessive blooms of periphyton can smother habitat, reduce invertebrate diversity and abundance, and affect dissolved oxygen levels in the water (Snelder et al. 2013). Too much periphyton can also make stream beds slippery and unpleasant for people.

Periphyton grows in response to the right combination of nitrogen, phosphorus, light, and temperature. The conditions that promote periphyton growth are complicated and dynamic, but in the right conditions periphyton will generally continue growing until there is a flushing flow.

The Freshwater NPS directs councils to choose a freshwater objective for periphyton in terms of chlorophyll-a (chl-a) levels. If excess nutrients are an issue in a water body, the council will need to set limits on the total load of nutrients in order to meet their objective. This limit would be set at a level so that periphyton levels don't exceed the chosen freshwater objective between flushing flows. To achieve the objective they may also need to set limits on the amount of water taken out. During this process, councils must also have regard to the reasonably foreseeable impacts of climate change on periphyton dynamics.

5.3.4 Having regard to climate change when setting objectives

Two reasonably foreseeable impacts of climate change are that projected lower rainfall in the east and north of the country will prolong periods of low flows in rivers and at the same time increase demand for water abstractions.

Longer periods of stable low flows in rivers, even with a nutrient limit in place, will allow periphyton to continue growing to a point where chlorophyll-a levels more frequently exceed the objective set in the regional plan. The policy consequences of this are that if the objective cannot realistically be met, the council and community will need to re-assess the situation and either change the objective or change the limit – in this case the nutrient load. If either of those options was not sufficient, they would need to investigate management options to control other drivers of periphyton growth such as temperature and shade, or perhaps improve water quality elsewhere in the region. Adopting or changing any option must follow the statutory consultation process required under the Resource Management Act 1991.

Climate change may also have reasonably foreseeable impacts on the behaviour of some other freshwater attributes, and their subsequent effect on ecosystem health. Councils must have regard to these impacts when they set objectives and limits for each of the relevant attributes to the compulsory values, and any other attributes they choose for any applicable national value.

The likelihood of having to reassess limits to accommodate the effects of climate change should be identified when the limits are first established and set in regional plans or on resource consents. This will help reduce expectations that the limits will be permanent.

5.3.5 References

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6. Science needs

6.1 Scientific information needs for freshwater conservation

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There is international consensus about climate change projections for air temperature, sea level rise and precipitation, due largely to efforts of the IPCC (IPCC 2013) supported by various research institutions. These projections also apply to New Zealand (see Section 2.1) and indicate that freshwater ecosystems will be exposed to higher temperatures, sea level rise and changes in flow patterns (see Section 2.2).

The challenge for freshwater ecosystem conservation is to refine and interpret the projections, alongside other predicted changes in catchment management, to ensure our knowledge base is sufficiently robust for informed decision making.

Scientific information is needed to:

- Refine climate projections for New Zealand at regional and catchment scales (projections)
- Differentiate climate change impacts from other human-induced impacts and natural climate variability (detectability)
- Determine the vulnerability of wetland, lake, estuary and river systems in different geographic regions (ecosystem vulnerability)
- Evaluate and recommend adaptation strategies and policy options (management and policy response), and
- Provide tools that help inform decisions about where conservation investment is needed the most (conservation priorities)

6.1.1 Projections

Climate change projections are derived from a variety of models that operate at global, continental and national scales (IPCC 2013). Within New Zealand, the National Institute of Water and Atmosphere (NIWA) is leading the refinement and interpretation of climate projections (e.g. Clark et al. 2011; Collins et al. 2012). Reducing uncertainty in model projections remains a key scientific issue, to deliver 'down-scaled' climate models that can be reliably applied to address freshwater conservation questions – such as in CHES (Cumulative Hydrological Effects Simulator) models.

While efforts to decrease the variability in climate projections have advanced, associated river flow and water table predictions, water temperature estimates for different environment types, and models of sea level rise in estuarine and lowland freshwater habitats are less developed. For example, although there are broad level assessments of changes in flow patterns (see Section 2.2), further research is required for climate change impacts on river flows to be detailed at local and regional scales. It is at these local scales where policy is most commonly applied, as councils are called on to set limits for 'Freshwater Management Units' under the National Policy Statement for Freshwater Management (MfE 2014).

Consequently, investment is needed to improve models that integrate climate projections with physical and ecological responses (e.g. where changes in mean annual low flows are projected over 10, 20, 50 and 100 year time scales). Model variability must be reduced to the extent that stakeholders are comfortable in their application in policy settings, and when allocating freshwater conservation resources.

6.1.2 Detectability

Detecting the disturbances to natural environments caused by climate change is the subject of many forums (e.g. Rosenzweig et al. 2008). While there is scientific acknowledgement of the current and projected climate change, few studies in New Zealand have quantified the predicted impacts on freshwater ecosystems relative to existing threats.

In pristine environments where there are few human-induced pressures, climate change impacts may be relatively easy to detect – due to the absence of 'noise' from other disturbances. However, these locations are rarely the subject of biophysical research and often have no long-term record from which to ascertain the effects of climate change on ecological processes.

Palaeoecological studies and the use of stable isotopes, however, provide tools to reconstruct the environmental history of freshwater sites, which may be applied to detect climate impacts. Long-term changes in the fire regimes of peatlands (e.g. McGlone 2009), water levels of inter-montane lakes and wetlands (e.g. Woodward et al. 2014), and sediment loads in lowland rivers (Reeve et al. 2010) can be inferred from sediment cores. More widespread application of palaeoecological techniques is recommended to expand our baseline knowledge on the climatic, hydrological and ecological history of aquatic systems.

Sections 3.1, 3.2, 3.3 and 3.4 in these proceedings indicate that climate change is likely to exacerbate existing pressures on freshwater environments in New Zealand. For example, climate change is likely to increase the eutrophication risk to freshwater lakes (Section 3.4). Differentiating climate change impacts from other threatening processes, ideally, would be achieved by quantifying the relative change in environmental pressures due to climate change, for a defined period of time. In the absence of long-term monitoring or palaeolimnolgical investigation, incremental changes in freshwater ecosystems may continue to be disregarded.

Building research capacity on the detectability of climate change impacts is considered critical for New Zealand. Scientific information is needed to separate the background noise due to existing threats from climate-induced changes in the composition, structure and functioning of different ecosystem types. Early warning indicators that signal a climate response also need to be identified.

6.1.3 Ecosystem vulnerability

The vulnerability to climate change of New Zealand's rivers, lakes, estuaries and wetlands was described during this national workshop. Common themes emerged, including likely shifts in the distribution of native and invasive species, the consequences of altered hydrological regimes, and degradation or loss of some habitat types. Changes in water availability have often been the focus of research, but a wider ecosystem focus to vulnerability assessment is needed.

Scientific uncertainty about which freshwater ecosystems are likely to be most sensitive, and the geographical regions most at risk, was a recurring issue during the workshop. While other countries have invested in science to determine which water-dependent ecosystems are likely to be impacted by climate change (e.g. Section 4.1), this is only an emerging field of research in New Zealand. For example, while shifts in the estuarine/freshwater boundary in lowland environments due to sea level rise has been identified as a significant risk to breeding habitat for whitebait (Section 3.1), to date, no national assessment has been undertaken to provide guidance for future management. Published research on the predicted shifts in the distribution of freshwater species is also limited for New Zealand, relative to other regions of the world.

The degree that ecosystem fragmentation due to altered river flow patterns will impact on migratory and non-migratory species is also largely unknown, as is the resilience of many wetlands to projected changes in precipitation in western and eastern parts of the country, and the sensitivity of many freshwater taxa to water temperature fluctuation.

These examples illustrate the extent that our knowledge of the vulnerability of freshwater ecosystems to climate change is incomplete.

6.1.4 Management and policy response

The Department of Conservation has developed a process for assessing the management needs of terrestrial ecosystems under a changing climate (Christie 2014). There are also clear intentions within the RMA (1991), NPS for Freshwater Management (2014), and in biosecurity planning for climate change to be taken into account when making water resource decisions (see Sections 5.1, 5.2 and 5.3).

However, to date, there have been very few examples where management or policy responses have catered for climate change impacts on freshwater ecosystems. An absence of technical information that succinctly and explicitly defines the management options (adaptation strategies) and policy options for New Zealand was identified as key factor during the workshop.

There is a need to further integrate climate change projections into regional planning strategies, biosecurity responses and catchment limit setting. Adoption of approaches implemented by Australia and other countries (see Section 4.1) is also advocated, as many of the management and policy recommendations will be relevant to New Zealand. A review of existing international information is likely to produce practical guidance material for councils, iwi, industry and other groups.

While there is a conflict in terms of addressing scientific uncertainty prior to providing practical management and policy options, it is expected that precautionary approaches to freshwater management can be applied that are beneficial for freshwater conservation, and will also build resilience to climate change. Furthermore, technical guidance to assist management and policy decisions will also reduce the likelihood of maladaptation – where development of infrastructure to address climate change has negative consequences on the management of natural ecosystems.

6.1.5 Conservation priorities

A key theme that emerged during this workshop was the need for decision support tools that enable freshwater managers to determine when to **accept** the consequences of climate change on freshwater values, or, when to **avoid** climate change impacts through management intervention.

Making the decision to **accept** or **avoid** is dependent on scientific information about:

- The relative value of the ecosystem, community or species in question
- The vulnerability of the ecosystem, community or species
- The extent that management intervention is expected to mitigate the impacts associated with climate change

The nexus between **accept** and **avoid**, in essence, provides the basis defining conservation priorities for different natural resource management agencies, iwi and community groups. To be fully informed, the integration of physical, ecological, and ecosystem service (value) models is advocated.

Without a strong science platform, it is unlikely that resource allocation for freshwater conservation will take into account a longer-term perspective. While some regional authorities are taking into account climate change in freshwater management (see Section 4.3), these efforts are not widespread.

6.1.6 References

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Clark, A.; Mullan, B.; Porteous, A. 2011; Scenarios of regional drought under climate change. *NIWA Client Report WLG2010-32* prepared for Ministry of Agriculture and Forestry. 135 p.

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7. Bringing it together

7.1 Key issues and future directions

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7.1.1 Workshop goal

The workshop on *freshwater conservation under a changing climate* provided the first national forum in New Zealand dedicated to the management of freshwater ecosystems and species in the context of climate change. The main objectives of the workshop were to record current knowledge about the vulnerability of New Zealand's lake, river, wetland and estuarine ecosystems; identify relevant adaptation mechanisms – in terms of both management and policy; and to detail the critical knowledge gaps that impede the development of a national approach to addressing projected climate change impacts.

Attendance at the workshop (Appendix 1) and the calibre of the participants' contributions to the workshop and these proceedings exceeded our expectations.

There are many critical recommendations in this document that will require specific consideration. But there are also a number of cross-cutting themes which, collectively, provide a synopsis of key issues relating to the conservation of New Zealand's freshwater biodiversity in the face of climate change.

7.1.2 Physical impacts

That global warming of the world's climate is taking place is now unequivocal, with many of the observed changes since the 1950s unprecedented over decades to millennia (IPCC 2014). Although there remains incomplete scientific understanding of how the specific physical impacts of climate change will manifest in different New Zealand catchments, many changes are projected to occur in New Zealand (see Section 2.2).

Key physical changes will include:

- Sea level rise
- Temperature increases
- Altered flow patterns

The changing climate is expected to have adverse effects on the ecological functioning of many freshwater environments, but the severity of the effects will depend on their geographical location. For example, alterations in flow patterns are not expected to be uniform, with eastern regions of New Zealand likely to experience more droughts and low flows while western regions are likely to be susceptible to increased occurrence of extreme rain events.

Physical changes are also likely to manifest through responses to climate change in other land use sectors. Greater demand for water resources due to climate uncertainty may exacerbate pressures on freshwater habitats.

7.1.3 Vulnerability of freshwater ecosystems and species due to climate change

Many rivers, lakes, estuaries and wetlands in New Zealand may be affected by climate change, and biodiversity values are likely to change as well. Without action, local extinctions of freshwater species and shifts in the distribution of native and exotic taxa are predicted. For example, spread of some exotic species is predicted as conditions become favourable for growth and reproduction across non-typical habitats.

But critically, there has been no national assessment on the vulnerability of freshwater ecosystems due to climate change.

To explore the issues in undertaking vulnerability assessment, a workshop session implemented a simple two-factor approach. Participants had to select a site or ecosystem type of interest (e.g. Waituna Lagoon, Southland) or a freshwater species (e.g. Inanga) and indicate where on a two-way scatterplot the site or species is likely to be positioned. The two axes (Fig. 16), based on Dawson et al. (2011), related to the geographic location of the site or the species predominant habitat (**exposure** to the physical impacts of climate change), and the expected resilience of the species life-history strategy or site ecological functioning (**sensitivity** to the physical impacts of climate change).

What became clear during this workshop session is that even when limited by scientific uncertainty, the relative vulnerability of freshwater environments informed discussion about priorities for management intervention and the development of policy.

It was also possible to make rapid assessments of multiple sites. For example, the expert panel approach was able to identify that many of New Zealand's Ramsar sites (wetlands of international importance) are susceptible to changes in ecological functioning and species composition as a consequence of climate change.

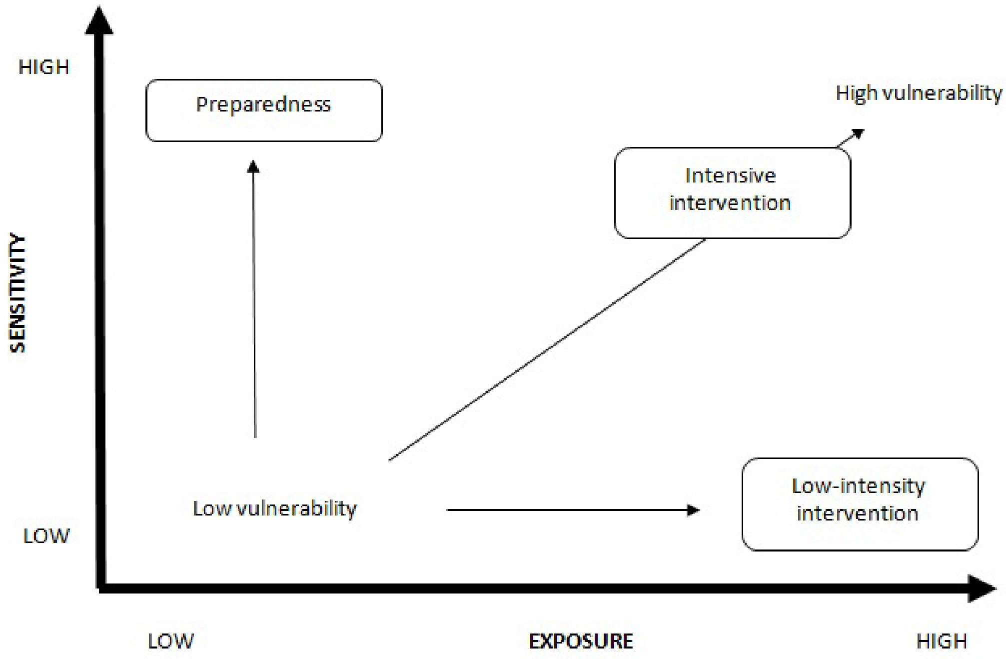

Figure 16. Vulnerability of freshwater ecosystems to impacts from climate change is defined by the relationship between exposure and sensitivity, based on Dawson et al. (2011). Intensive intervention is required to avoid impacts where the species or ecosystem is highly sensitive and is subject to high exposure due to its geographical location.

7.1.4 Adapting management and policy for freshwater conservation

Natural resource management agencies, such as the Department of Conservation (DOC) and regional councils, are increasingly applying strategic approaches to freshwater conservation, although few programmes appear to specifically consider climate change. Resources invested in freshwater restoration and regional planning rarely take into account future climate change scenarios. For example, under climate change, some lowland freshwater lagoons are expected to transition to brackish estuaries that require different management approaches. Consequently, management decisions should be informed by projected changes in freshwater ecosystems over >50 year timeframes.

Promoting adaptation is fundamental, both in terms of facilitating the natural adaptation of indigenous ecosystems and adapting management and policy responses. For example, adapting New Zealand's network of freshwater protected areas to cope with climate change is likely to help some species respond to such changes, and is particularly important where key refuges or migratory paths are at risk. Policy responses to climate change need to be enduring, involving the full spectrum of stakeholders involved in water management decisions.

Creating dialogue about adaptation options is advocated. To illustrate how a 'future thinking' approach can facilitate adaptation, a further workshop session applied a step-wise framework (Fig. 17) to explore which sites or species may be high priority for adaptation actions.

This process asks respondents to identify long-term (> 50 year) management objectives and then to consider the likelihood of a climate change impact, and the feasibility of being able to address the impact. In scenarios where there is no viable management response, the only option is to 'accept' the situation.

More direction in regional and national policy is also called for to protect freshwater ecosystems under a changing climate. The RMA (Section 7) and the National Policy Statement for Freshwater Management (2011) have clear provisions for climate change. What is slowing progress appears to be the lack of a strong technical evidence base, which provides clear guidance for policy and planning.

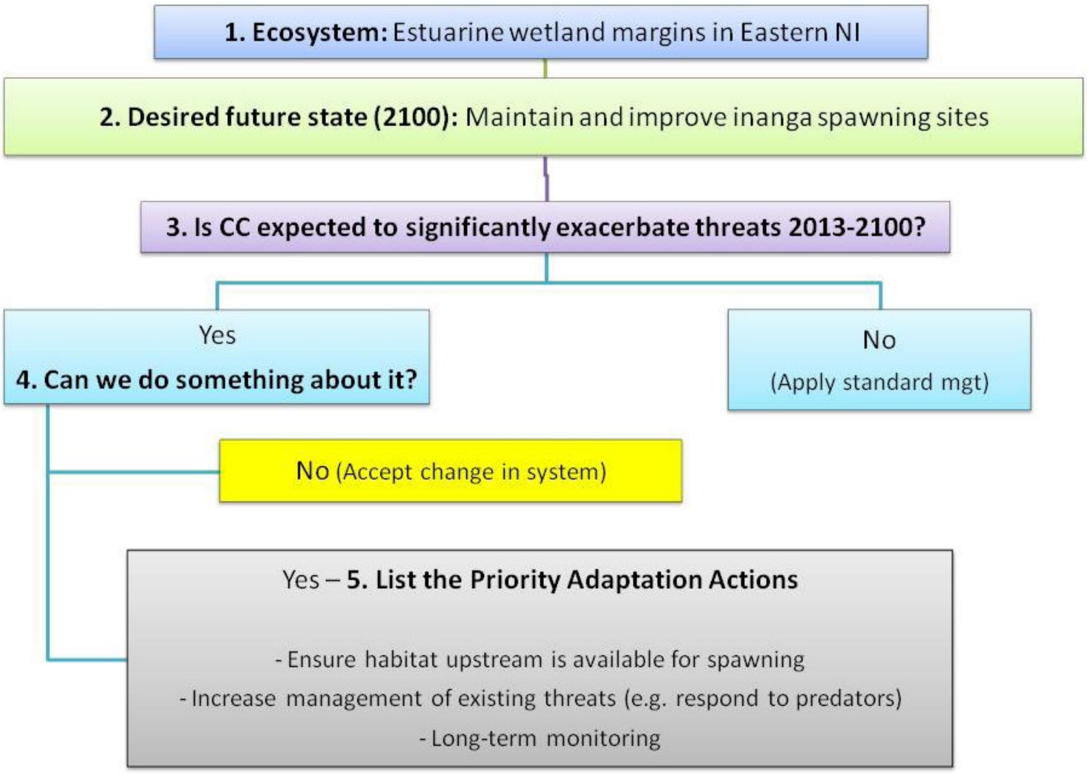

Figure 17. Framework applied to identify priority adaptation actions for freshwater conservation. Example illustrates the application of the framework for inanga (*Galaxias maculatus*) spawning sites in estuarine wetlands of the eastern North Island, New Zealand.

7.1.5 Where to from here?

There exists sufficient scientific consensus on the projected impacts of climate change, both globally and for New Zealand, to implement a precautionary approach to freshwater conservation. It is apparent that a number of freshwater ecosystems, and threatened species, are vulnerable to the consequences of a changing climate.

The following seven focus areas are recommended for immediate action and investment:

- **Implement a science programme** to fill key knowledge gaps – including assessment of the freshwater and estuarine ecosystems and species most vulnerable to climate change impacts.
- **Improve linkages** between natural resource management agencies and science institutions, including integration of Mātauranga Māori into policy and management decisions relating to climate change.
- **Foster increased awareness** through publication of guidelines for policy makers and planners on 'how to build resilience to climate change'
- **Review approaches to freshwater ecosystem management** to consider the effects of climate change, and decide in what situations to accept or avoid projected changes in ecological integrity
- **Learn from international studies** and policy responses, and adopt approaches in New Zealand where applicable
- **Establish monitoring** that is future focused, using indicators and methods that can reliably detect climate change effects
- **Apply a precautionary approach to water management** – given the projected changes in sea level, temperature and catchment runoff in New Zealand may exacerbate the existing pressures on freshwater ecosystems and species.

7.1.6 References

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7.1.7 Acknowledgements

The national workshop was funded by the Department of Conservation (DOC). We would like to acknowledge the in-kind support of Massey University, the National Institute of Water and Atmospheric Research (NIWA) and DOC to allow time for the editors to prepare these proceedings. The contribution of Richard White (University of Canterbury) in recording the key themes and discussions during the workshop is particularly appreciated. We also thank Brent Cowie for his assistance in facilitating the workshop and providing comments on water resource management in New Zealand. Thanks also to Rosemary Miller (DOC) for project oversight/peer review and Lynette Clelland (DOC) for editorial review.

Appendix 1

List of participants

Name	Organisation
Sjaan Bowie	DOC
Hugh Robertson	DOC
Rosemary Miller	DOC
Andrew Tait	NIWA
Daniel Collins	NIWA
Paula Warren	DOC
Trecia Smith	MPI/NRS
Victoria Jollands	MPI
Kirsten Forsyth	MfE
Russell Death	Massey University
Rob Bell	NIWA
Helen Kettles	DOC
Colin O'Donnell	DOC
Kerry Bodmin	NIWA
David Hamilton	Waikato University
Marc Schallenberg	Otago University
Jenny Christie	DOC
Kirsten Forsyth	MFE
David Rissik	NCCARF / Griffith University, Australia
Brent Cowie	Cowie Resource Mgt Limited
Kevin Collier	Waikato Regional Council
Kura Stafford	Tiakina te Taiao / EPA Maori Group
Richard White	Canterbury University (PhD Candidate)

The workshop also welcomed the opening addresses given by Dr David Wratt (then Director of the NZCCC) and Mr Lou Sanson (Director-General of Conservation)

Appendix 2

Workshop Programme

Freshwater Conservation under a Changing Climate

Workshop Programme

10–11 December 2013

Conference Room G.01

Department of Conservation

Conservation House

18-32 Manners Street, Wellington

Department of Conservation
Te Papa Atawhai

DAY 1. Tuesday 10th December. 9.00 am - 5.00 pm.	
Registration	9.00
Welcome / Introductions – Rosemary Miller (Freshwater Section Mgr, DOC); Lou Sanson (Director General, DOC) & David Wratt (Director, NZCCC)	9.30
Outline of Workshop Objectives 1. Overview of issues to consider during workshop – Hugh Robertson (DOC) 2. Plan for workshop including outputs (draft proceedings) – Sjaan Bowie (DOC)	9.45
Morning tea	**10.00-10.30**
SESSION 1: SETTING THE SCENE	
1. Future climate change scenarios - current model predictions – Andrew Tait (NIWA)	10.30
2. Physical changes to New Zealand's freshwater ecosystems under climate change -- Daniel Collins (NIWA)	10.50
3. Freshwater systems and climate change policy	
a. Current policies for freshwater conservation – Paula Warren (DOC)	11.10
b. Primary industries and biosecurity policy - Trecia Smith (MPI/ NRS) & Victoria Jollands (MPI)	11.20
c. Policy requirements under the NPS-Freshwater Mgt -- Kirsten Forsyth (MfE)	11.30
Group discussion 1: Predicted changes and existing policy ***Output goals:*** *i. Summarise the main predicted changes to climate, and how will these impact on freshwater resources (broadly speaking)* *ii. Are our current policies and plans adequate – why or why not?*	11.45
Lunch	**12.10-13.00**

SESSION 2: VULNERABILITY OF FRESHWATER ECOSYSTEMS DUE TO CLIMATE CHANGE

1. River ecosystems -- Russell Death (Massey University), Sjaan Bowie (DOC), Colin O’Donnell (DOC)	
2. Estuarine ecosystems -- Rob Bell (NIWA), Helen Kettles (DOC)	13.00
3. Wetland ecosystems -- Kerry Bodmin (NIWA)	13.30
4. Lake ecosystems -- David Hamilton (University of Waikato), Marc Schallenberg (University of Otago)	14.00 14.30
5. Integrating threat assessments across terrestrial and freshwater environments -- Jenny Christie (DOC)	
	15.00
Afternoon tea	**1515-1545**

DAY 2. Wednesday 11th December. 8.30 am - 4.00 pm.

SESSION 3: WHAT ARE WE TRYING TO ACHIEVE? SETTING FRESHWATER CONSERVATION GOALS UNDER CLIMATE CHANGE

1. What are other countries doing to develop climate change strategies for freshwater ecosystems? An Australian perspective – David Rissik (NCCARF (National Climate Change Adaptation Research Facility))	9.00
2. Setting freshwater conservation goals: is our current system of ‘DOC ecosystem prescriptions’ adequate -- Hugh Robertson (DOC)	9.20

SESSION 4: AVOID OR ACCEPT? ADAPTING MANANGEMENT AND POLICY FOR FRESHWATER CONSERVATION

1. Pressures and Responses: Adapting national management and policy for conservation of freshwater ecosystems – Brent Cowie (Cowie Resource Management Ltd)	9.40

Morning tea **10.00 – 10.30**

SESSION 4: CONTINUED

2. Adapting approaches to freshwater management in the Wellington region --- (presentation cancelled) 10.30

3. Adapting approaches to freshwater management in the Waikato region --- Kevin Collier (WRC) 10.50

<u>Group discussion 3 – Future management and policy</u> 11.10

Overview of key questions to cover during discussion

- *What do we mean by 'adaptation' in relation to the conservation of freshwater ecosystems?*
- *Is there evidence of adaptation in New Zealand*
- *Are there useful examples of adaptation from elsewhere?*
- *What is our ideal future state?*
- *Are we on the right track?*

***Output goals**:*

i. Describe the types of adaptation or avoidance strategies that should be promoted (and those where caution is needed)
ii. Identify trade-offs between different adaptation decisions
iii. Describe the role of freshwater conservation in climate change mitigation
iv. Identify where revised approaches to management or policy is most urgent – i.e. what are the consequences of not adapting our approach to management

Lunch **12.00-13.00**

Group discussion 3 – Continued 13.00-13.30

Group discussion 4: Science to underpin adaptation 13.30-14.30

Overview of key questions to cover during discussion

- *When to avoid and when to accept – information needs*
- *What science is required to inform adaptation strategies for:*
    - *Rivers*
    - *Wetlands*
    - *Lakes*
    - *Estuaries*
- *What research is underway that will help address key knowledge gaps?*
- *What opportunities exist for science to inform policy?*

***Output goals**:*

i. *Describe the science needed to support adaptation decisions*
ii. *Summary table of current/recent projects*
iii. *List opportunities where science can inform management and policy*

FINAL SESSION: FRESHWATER CONSERVATION UNDER A CHANGING CLIMATE: WHERE TO NEXT?

1. Bringing it together 14.30-15.00

(Summarise key points from each session in draft proceedings)

Afternoon tea	**15.00-15.30**
1. Bringing it together -- continued	15.30-15.50
2. Next steps (write-up) and workshop feedback	15.50-15.55
Thank you and close	**15.55-16.00**