How climate change responses by land managers could benefit biodiversity

A think piece on the opportunities

By

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May 2014

Contents

Executive summary

In response to climate change there are diverse mitigation and adaptation measures proposed or being implemented. Given the disappointingly slow progress by governments at international levels to address the major drivers of climate change and slow the increases of greenhouse gases, attention is increasingly focused on the need for adaptation measures. The theme of this think piece is to identify the positive opportunities and practices for land managers to implement adaptation and mitigation measures that benefit New Zealand's native biodiversity. Some adaptation options to climate change, including some proposed or in place, can be maladaptive and harmful to biodiversity. The challenge is to identify these and be successful in identifying, promoting and implementing positive alternatives.

The paper first summarises for the general reader broad global trends in climate change, including some of the unexpected complexities and new mechanisms climate scientists have discovered that are driving changes and major disruptions to the climate system. These reinforce the point that global systems are not only complex, but are increasingly inter-linked in their impacts. New 'surprises' will continue to emerge. Whether we can respond to them successfully is the question and an ongoing challenge.

The likely changes to New Zealand's climate variables in coming decades are now reasonably well understood. The main changes will be warmer winters, drier conditions in eastern regions (already prone to drought), wetter western regions, more frequent extreme rainfall events as well as stronger winds and more frequent storm surges. Sea level rise will continue and may accelerate as Greenland's glaciers destabilise and if Antarctic glaciers do likewise. The possible effects of these changes are explored for New Zealand ecosystems (coastal, freshwater, forests) and how the impacts of predators, weeds and fire may change. It is argued that, collectively, these impacts warrant a different level and type of response than the current approaches to conservation management on public and private lands.

Unfortunately, our current high-level policy framework with respect to climate change impacts on biodiversity and appropriate responses is inadequate. Climate change is not referred to in the New Zealand Biodiversity Strategy, released in 2000. Climate change is also not referenced in the 2011 proposed National Policy Statement on indigenous biodiversity. In the absence of policy piecemeal responses are more likely and coherent, effective responses across sectors are correspondingly less likely on climate issues.

The Australian approach, in comparison, was to give climate change serious consideration in both their 1996 and 2010 national biodiversity strategies. The Australian 2010 Strategy emphasises the potential negative impacts of climate change on natural systems warning that 'business as usual' responses were unlikely to be effective. It urges a rethinking of traditional approaches to biodiversity conservation. A greater emphasis on risk management and adaptive management approaches are identified as priorities for planning. Two important concepts that Australian policy rates as highly relevant to future conservation management in the face of climate change are recognising and responding to 'uncertainty' and the importance of 'building resilience'.

This paper proposes that whether the measures taken by land managers turn out to be adaptive or maladaptive will be strongly influenced by how concepts of 'resilience' are understood and applied. Accordingly, a section is devoted to explaining 'resilience' in ecological and social contexts and its application to management practices. The paper 'frames' the issues of useful adaptive responses within the concept of social-ecological systems and stresses the importance of considering the resilience of both social and ecological components. When social-ecological systems are sufficiently stressed and their resilience is low they can be 'tipped' into more degraded states from which recovery is unlikely. Two case studies are explained to show how the dynamics of the social and ecological are linked and how the resilience of the systems (or lack of it) influenced the outcomes. Win-win outcomes are possible; they are not inevitable.

A recurrent theme in the literature and from case studies is the long-term inadequacy of quick technological fixes for adaptation that superficially address the apparent management problem. These often assume solutions can be found without changing the dynamics of the system that created the problem. Underlying causes then go undetected, but eventually surface and need to be faced, ideally with a different way of thinking.

There are many positive management options and generic approaches that can be promoted and implemented to enhance biodiversity as part of climate change adaptations. The paper describes a number in relation to coastal management, agriculture and forestry practices. Adaption in coastal areas is constrained by existing development practices, as well as urban, agricultural and forestry land uses.' 'Soft ecological', as opposed to 'hard engineering' approaches can be successful at a range of scales. Many New Zealand indigenous plants are superbly adapted to our wild coasts and well suited to enhancing degraded coastal areas. While community coastal care groups can point to many successes around the country it will require stronger planning and regulatory frameworks if coastal adaptations are to succeed on the scale that will be required.

From ridgetops to valley rivers, there are many opportunities to anticipate the worst of climate change by building resilience into rural landscapes using native species and habitats in positive ways. Creating riparian zones using native plants along waterways meets several objectives: reduced nutrient runoff, reduced in-stream temperatures for native invertebrates, streams and rivers are better able to withstand the impacts of flooding from extreme weather events, important habitat is provided for many indigenous plants and animals. Natural and restored wetlands also provide these benefits on farmlands. They also act as natural sponges, regulating waterflows in times of flood or retaining it during droughts. Exotic trees used for these purposes in the past, such as willows, have adverse effects on ecosystems that are avoided by using native species.

Exotics do have a place in helping to cope with climate changes and can help to diversify production systems in ways that make them better resistant to shocks. Yet they can also make situations worse, particularly when exotics become invasive, whether as wilding pines or invasive grasses. A big adaption challenge to agriculture will be how the various sectors respond to more severe and more frequent droughts. Responses may be adaptive or maladaptive with beneficial or detrimental effects on native biodiversity. Positive options have been identified through research with farmers. One that continues to attract attention is the ‘adaptive farm system’ developed on Bonavaree Farm in response to a long drought period in north-eastern Marlborough. The successful no-irrigation approach using lucerne also incorporated on farm measures that significantly improved native habitat by fencing off wetlands and bush gullies and planting more native species. It was a major adaptive shift from ‘business as usual’ options that could not be sustained in the long term. The Bonavaree initiative also showed the importance of social resilience that provided the local support and research so essential to eventual success on the farm.

As farmer attitudes continue to shift away from viewing scrub, gullies, wetlands and forest remnants as ‘non-productive’ towards acknowledging their role in maintaining overall farm health, opportunities will increase for introducing the option of ‘wildlife corridors’ to further enhance native biodiversity. Corridors have long been promoted for conservation reasons; given climate change imperatives they may also make it easier for some species to shift to more favourable areas. On a larger scale than riparian strips, well designed corridors could provide larger buffer zones against extreme events and thus make it easier for ecosystems, as well as farms, to recover from climate shocks. An ambitious programme called “Reconnecting Northland” aims to use ecological corridors as part of a region-wide restoration initiative. Building resilience to climate change is one of its objectives.

One of the biggest barriers to successfully implementing innovative adaptive practices is psychological resistance to change. Another barrier is the mismatch of institutions and governance structures that were designed for a more stable, predictable, less complicated, and less interconnected world. Together, these can make or break the best and most useful of initiatives. There are strong arguments for critically assessing our institutions for their responsiveness, flexibility, openness to learning and ‘fit-for-purpose’ capacities to respond to climate change challenges. They will need to operate at multiple scales, spatial as well as institutional, from community to local and central government levels, and be able to respond appropriately to future surprises. They will also need legislative frameworks that provide the necessary powers and oversight functions to function effectively at community and regional scales.

Many New Zealanders have a deep love of, and engagement with, their natural world. They value what is special about our amazingly diverse landscapes, plants and animals and devote much personal time caring for their special local places. Over the lifetime of the current generations those values and energies will be challenged as never before by climate change, on productive as well as protected lands. Successful adaptions will depend on knowledge and the ability of communities and institutions to respond as complex adaptive systems themselves to the surprises that lie ahead.

KEY POINTS
After each section the key points are summarised in boxes for quick reference.

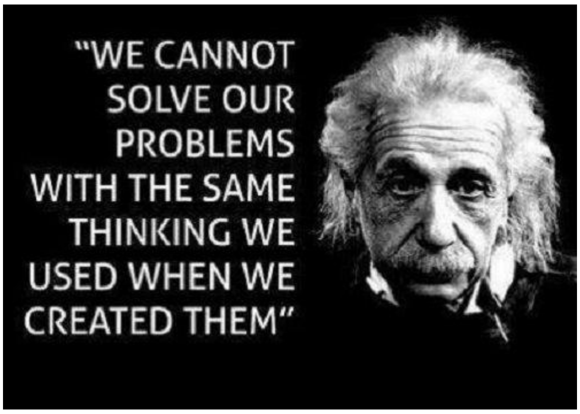
Think piece approach

Among developed countries New Zealand is unique in the extent of its dependence on primary production from its lands to drive its economy and increase wealth. All of the land management sectors – forestry, dairy, sheep and beef, horticulture, cropping, viticulture – are potentially affected by climate change. Our native plants and animals – our biodiversity – will also be affected by climate change, but in different ways. In short, the conservation, agriculture, forestry, as well as the renewable energy sector will all face adaption and mitigation[A] challenges from the effects of climate change in order to protect and sustain their future well-being.

The central theme this paper explores is the win-win opportunities land managers have to adapt and mitigate against the effects of climate change in ways that will also benefit the conservation of our native biodiversity, the plants and animals that define New Zealand and New Zealanders. It also argues that the policy context needs better elaboration.

Such benefits will need to be developed with caution. A 2011 review of climate change impacts on our native biodiversity warns that adaptation and mitigation responses taken to combat climate change by primary production and energy sectors might pose more significant risks to biodiversity than climate change effects in the short term.[1] A global review came to a similar conclusion, arguing that current policy approaches for mitigation and adaptation that seek short-term benefits and simple technological fixes to complex climate problems could potentially have worse impacts than direct effects of climate change.[2] The basis for these concerns will be explored and elaborated in later sections.

This paper proposes that to be successful with adaptation and mitigation opportunities we need to approach the substantial challenges of adapting to climate change very differently than in the past. A much better understanding of the role played by social-ecological systems that include communities as well as conservation and primary production activities is required. For too long environmental management has been approached as an



optimization problem, often framed in economic terms. We assume that managing individual components of an ecological system, such as fertilizer levels or irrigation inputs, or catch quotas for fish, will lead to an optimal balance of supply and demand. We assume other parts of the system will be largely unaffected over time. As our understanding of ecological and human systems has improved these assumptions are being shattered. Ecological systems are extremely dynamic. Responses to stresses are not linear. What's 'optimal' can change from one year to the next.

[A] The Intergovernmental Panel on Climate Change (IPCC) defines climate change adaptation as "Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities", and mitigation is defined as "Technological change and substitutions that reduce greenhouse gas emissions (sources) and enhance sequestration processes (sinks)."

‘Surprises’ are common. The basic framework driving modern Western approaches to environmental management is often based on false assumptions. The result is the global environmental problems documented in the 2005 Millennium Ecosystem Assessment (next section).

Given the dynamic nature of ecological and social systems it is as important to manage systems to enhance their ‘resilience’ as it is to focus on supplying particular products. The term ‘resilience’ risks becoming overused and misused, but remains a powerful ecological concept in understanding the behaviour of ecological systems. In this paper it is defined as: *Resilience is the capacity of a system to absorb disturbance and still retain its basic function and structure.* Using a resilience framework challenges our thinking on ideas such as sustainability and efficiency, both of which often feature in adaptation and mitigation responses to climate change. Applying ‘resilience thinking’ offers a way to break from the failed approaches of the past.[3] Understanding these concepts is the first step towards developing and implementing better adaptation responses to climate change ‘disturbances’ for both natural and productive systems.

Understanding these concepts is necessary, but is insufficient in itself to effect change. We also need to consider if we have the right social structures that are capable of creating and implementing the innovative thinking that moves us beyond ‘more of the same’. In other words, the need for ‘resilience’ applies to social systems as well as to natural systems. ‘Social structures’ is used in a wide sense of the term to include political and management structures as well as communities and other social entities. Much scientific literature now exists on how linked systems of humans and nature (social-ecological systems) behave.[4, 5] These various concepts are elaborated in subsequent sections.

This think piece is structured as follows.

1. It starts with a brief summary of the international efforts to address climate change, the broad features of global climate change and then describes the expected changes to New Zealand's climate in different regions.

2. Based on these expected changes in climate, the potential impacts currently projected for New Zealand’s native ecosystems and primary production systems are summarised.

3. Next, the main concepts that underpin resilience thinking will be outlined as they apply to social-ecological systems. Two case studies from Australia and the Caribbean will then show how concepts of resilience explain the breakdown of two very different social-ecological systems.

4. The lack of an overall policy framework in New Zealand relating climate change impacts to the implications for management of biodiversity by agencies is described. This is contrasted with the policy approaches adopted by Australia since 1996.

5. The paper then proposes adaptation and mitigation responses for coastal management and primary production systems that would benefit native biodiversity using a social-ecological systems framework.

6. The final section looks at the social/institutional that might be required to implement successful adaptation practices at regional and national levels. If adaptation to extreme events requires transformational change we will need responses greater than those that motivated individuals can make

A caveat.

Although neoclassical economists believe humans are rational opportunity maximizers, history provides ample examples to the contrary. Stark evidence of collapsing over-exploited environments has not stopped past societies from continuing their same self-destructive behaviours.[6] Neither, in a historical context, has the availability of more sensible options prevented some rulers and countries from taking decisions that were clearly folly, despite being recognised as folly at the time as well as in hindsight.[7] In the modern context of climate change Gowdy argued in a 2008 paper "… the standard economic approach to climate change policy, with its focus on narrowly rational, self-regarding responses to monetary incentives is seriously flawed."[8] Gowdy proposed that drawing more strongly on the characteristics of human nature associated with cooperation, non-materialistic values and a shared sense of urgency "…might get us through this impending crisis."

Our responses to the threats from climate change are more likely to effective and beneficial if we better understand how ecological – social systems work and therefore what management responses are likely to be required. However, our diverse values, ethics and our attitudes to risk and uncertainty may well have a bigger influence in what societies choose to do with this increased knowledge.[9] But one thing is certain. We need an active ongoing dialogue within our society at many different levels to identify a way forward that is in the best interests of New Zealand, the places and natural landscapes that make it so special.[10] This think piece is offered as a contribution to that end.

Context of climate change

International responses are inadequate

How countries respond to the diverse challenges posed by climate change will be the defining test of human ingenuity and cooperation in this century. At the international level the climate challenge is not being met. Under the UN Framework Convention on Climate Change (UNFCCC) states have been meeting annually for decades to try and work out ways, acceptable to all, to cut greenhouse gas emissions (mitigation) and to fund the actions necessary to do so. Progress has been slow, increasingly frustrating and often divisive between developing and developed countries.

In 2007, the Bali conference under the UNFCCC agreed that the already industrialised world needed to cut emissions to 45 per cent below the 1990 levels by 2020 to keep temperature increases within safe limits. That goal seems increasingly elusive. Successive conferences (Copenhagen 2009; Doha 2012) saw the unravelling of commitments to cut carbon dioxide emissions. A lack of political will was also evident at the 2013 Warsaw negotiations that included an unprecedented walkout by labour, environmental and development NGOs in protest at the lack of progress. Policy coherence on climate change has been lacking in New Zealand[11] where the primary effort has been on mitigation options rather than adaptation.

Many commentators now consider temperature rises above dangerous levels (more than $2^{o}C$) are increasingly likely as shown in Figure 1.[12] Levels of carbon dioxide (the main greenhouse gas) in the atmosphere were around 280 parts per million (ppm) at the start of the industrial revolution; in May 2013 levels reached 400 ppm, a symbolic and worrying milestone.[B] Adaptation responses to climate change therefore demand greater attention as global efforts at effective mitigation continue to flounder.

Climate science

The science of climate change is complex and involves an increasingly wide range of scientific disciplines, well beyond the atmospheric scientists who first raised concerns about warming trends and the role of greenhouse gases. The Intergovernmental Panel on Climate Change (IPCC) is the international body set up in 1988 to provide governments with a clear view of the current state of knowledge about the science of climate change, its potential impacts, and options for adaptation and mitigation. The IPCC does this through regular assessments and synthesis of the most relevant peer-reviewed information published in scientific, technical and socio-economic literature worldwide. IPCC assessments are policy-relevant, but not policy-prescriptive. The Fifth Assessment consists of four separate reports released in 2013 and 2014. Three Working Party reports ('The Physical Science Basis', 'Impacts, Adaptation, and Vulnerability', 'Mitigation of Climate Change') will be followed by a Synthesis Report in October.[13] Summaries for policy makers were also published.

[B] http://www.guardian.co.uk/environment/2013/apr/29/global-carbon-dioxide-levels?goback=.gde_1140337_member_238671909 Accessed 17 May 2013

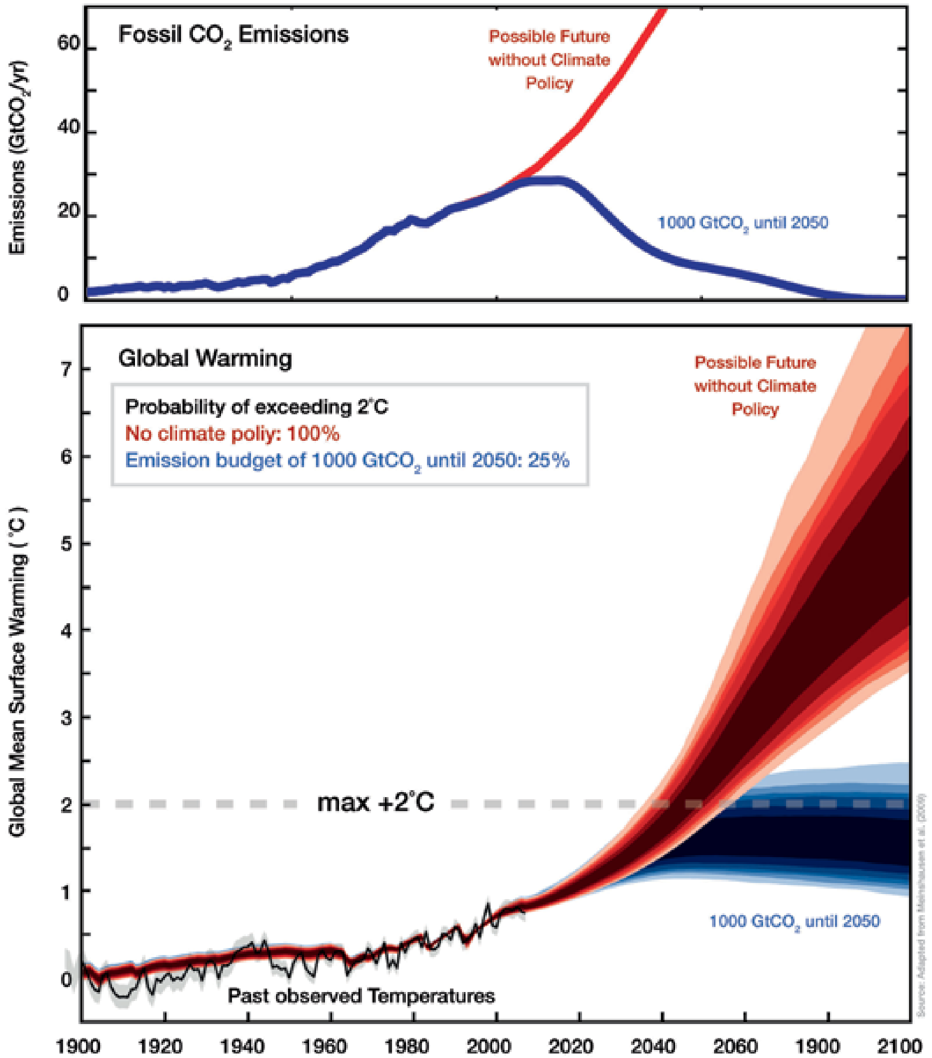


Figure 1. Top panel: Fossil-fuel CO2 emissions for two scenarios: one "business as usual" [red] and the other with net emissions peaking before 2020 and then reducing rapidly to near zero emissions by 2100, with the cumulative emission between 2000 and 2050 capped at 1000 billion tonnes of CO2 [blue]. **Bottom panel:** Median projections and uncertainties of global-mean surface air temperature based on these two emissions scenarios out to 2100. The darkest shaded range for each scenario indicates the most likely temperature rise (50% of simulations fall within this range). Adapted from Meinshausen et al. (2009).

These Working Party reports (over 2000 pages) by 803 scientific authors had more than 3500 expert reviewers. The warnings in these reports are stronger than in earlier assessments including the evidence that negative climate change impacts are already happening. The Adaptation report concludes "*A large fraction of both terrestrial and freshwater species faces increased extinction risk under projected climate change… especially as climate change interacts with other stressors, such as habitat modification, over-exploitation, pollution, and invasive species*." It cautions that high-emission scenarios "*…pose high risk of abrupt and irreversible regional-scale change in the composition, structure, and function of terrestrial and freshwater ecosystems, including wetlands*."

Global environmental well-being

How well countries will be able to cope with climate change will depend, in large part, on the existing well-being and coping ability of their natural environments. Unfortunately, the global situation is not good. In 2005, the Millennium Ecosystem Assessment (MEA) was released.[14] This was an international analysis by over 1,360 biological scientists of the state of the world's ecosystems. It defined 24 'ecosystem services'[C] and concluded that over the past 50 years four have shown some improvement, five are generally stable, while fifteen ecosystem services are in serious decline. The summary report by the MEA Board stated: *"Human activity is putting such strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted."*[15]

The MEA shows that many natural environments, both marine and terrestrial, are seriously degraded and consequently are more vulnerable now than 50 years ago to further shocks, such as rapid climate change. On a positive note, the MEA concluded that with appropriate actions it is possible to reverse the degradation of many ecosystem services over the next 50 years, but noted that the changes in policy and practice required are substantial and are not currently underway.[16] The 2012 'Global Environment Outlook' by the United Nations Environment Programme (UNEP), came to similar conclusions. It concluded that exceeding several critical thresholds could lead to "abrupt and non-linear changes" to life-support systems.[17] Also: *"Traditional expert-driven, top-down approaches to problem solving are not flexible enough to address complex, non-linear changes in the Earth System effectively."*

The management challenge

Land and biodiversity managers are therefore faced with managing in novel circumstances. On one hand, levels of CO_2 have risen by over 40% in just 200 years, an unprecedented rate of change in the Earth's climate history. Carbon dioxide levels were last at 400 ppm during the Pliocene epoch, about 3.2 – 5 million years ago when the Earth's climate was much warmer than today. Plants and animals are always adapting to change but at rates usually driven by slower natural rhythms, not those we are currently living in. On the other hand, the stressed and degraded state of so many of the global ecosystem services means that their resilience – the ability to absorb the climate change disturbances and still retain their basic function and structure – is low. What can happen when resilience is low and natural systems are then further stressed is explored in later sections.

KEY POINT

- Governments have failed so far to adequately respond to the increasing scientific evidence that climate change is having major adverse impacts and may lead to irreversible changes in many ecosystems. This will add to ongoing declines in ecosystem services and poses major adaptation challenges for land managers.

[C] Ecosystem services are the processes and resources provided by nature. The MEA defines four categories: *provisioning*, such as the production of food and water; *regulating*, such as the control of climate and disease; *supporting*, such as nutrient cycles and crop pollination; and *cultural*, such as spiritual and recreational benefits.

Slow, fast and other complexities of climate change

There is a vast popular and scientific literature describing the mechanisms and processes of climate change, the roles of different greenhouse gases, emission rates, and the wide range of effects. Since this paper is focused on adapting to climate change impacts this section will only selectively highlight some aspects of climate changes relevant to later sections. It will cover:

- Broad, long-term trends at the global level;
- Growing significance of more frequent and more intense, extreme events;
- Examples of the inter-connectedness of systems; and
- The relevance of surprises.

Broad trends

Successive evaluations by the International Panel on Climate Change have increasingly strengthened the evidence that human activities are responsible for significant changes in the global climate regimes.[18] As computing capacity has increased and climate models have been improved the trend has been, unfortunately, to predict more warming and more severe impacts than initial estimates suggested. In 2007, the Fourth Assessment report by the IPCC raised the most likely warming from a doubling of carbon dioxide from 2.5°C to 3°C, with a range between 1.5°C and 4.5°C. Hence achieving the 2°C target that climate negotiators have been aiming for through mitigation strategies will be much harder than previously thought. In their 2012 report CSIRO and the Australian Bureau of Meteorology warned that average temperatures across Australia could rise by up to 5 °C by 2070.[19]

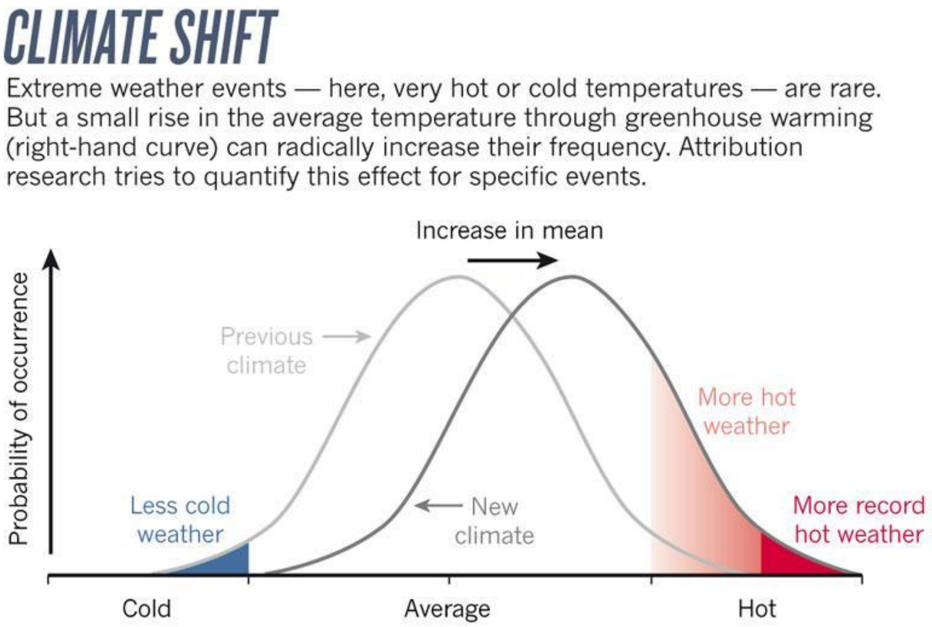
In 2007, the Fourth Assessment estimated future sea-level rises (from more ice melt and expansion of sea water as it warms) for this century as being up to 0.79 metres. In the following 5 years extensive new research on the rates of ice-sheet loss in Greenland, and also in Antarctica, have led to a doubling of the median estimates. This rate of increase in sea levels would be unprecedented and has major implications for coastal ecosystems as well as coastal settlements and industries. The amount of rise will vary between regions and countries. New Zealand is likely to have more rise than the global average. The rate of these changes is also expected to increase which probably reduces the number of response options. Research findings reported in 2014 on the destabilization of Greenland's glaciers indicate a new phase of greater melting and higher rates of sea-level rise may now be underway.[20] Should these findings prove to be accurate then the implications for coastal regions are for a faster rise of sea-levels than are currently predicted. Levels of carbon dioxide in the atmosphere and ocean warming will only reverse very slowly, even if current emissions were to stop today.

About 30 to 40 percent of the carbon dioxide released by humans into the atmosphere dissolves into oceans, rivers and lakes. Some of it reacts with sea water to form carbonic acid which increases acidity levels. The current rate of ocean acidification is faster than at any time in the past 300 million years.[21] Such rates of change make it extremely difficult for affected marine life, e.g. coral reef systems, to adapt through natural selection which happens over longer time periods. Coral reefs are particularly threatened by acidification.

Changes in precipitation patterns have major implications for biodiversity, agriculture and food production. Globally, more rain is expected but with substantial shifts between regions and in patterns of rainfall. In general, currently dry regions will tend to become even drier, while wet regions will become wetter. This holds true for New Zealand as well as other countries. Asian monsoons are likely to be more erratic and drop more rain in shorter time periods since warmer air holds more water, leading to more intense rainfalls. Consequently farming will be more difficult and erosion more likely. Glaciers will continue to retreat and snow cover is projected to contract.

All of these 'first order' physical changes to climate (e.g. higher carbon dioxide levels, temperature and sea-level rises, changed rainfall patterns) will have a range of 'second order' impacts on plants, animals and ecosystems. These cannot be predicted with the same level of confidence as physical changes as biological systems are much more complex in how they respond to changed conditions. The conclusions in the last two IPPC's assessment reports, however, are that climate change is a major driver of biodiversity loss in a range of ecosystems ranging from the Arctic tundra to tropical forests.

Extreme events



A warming earth as greenhouse gases trap more heat increases the amount of energy in the earth's climate system. More energy can increase the intensity and frequency of extreme weather events, such as hurricanes, storms, droughts, heat waves and floods. In theory, the distribution shown in the graph could not only shift, but also widen as weather becomes more variable. This increases the frequency of extreme heat events, while also leading to occasional extreme cold conditions. If average temperature rises are regarded as the 'slow' climate change effects, extreme events are its 'fast' effects and may well turn out to have more serious consequences for biodiversity and therefore are more important when assessing how we approach adaptation and mitigation options with biodiversity in mind.

While extreme weather events are part of human history, extraordinary events, in line with those predicted to reflect climate change, are now occurring at a rate that is beyond the predictions of climate models.[22] Some examples from the last decade include:

- 2003: A summer heatwave in Europe was so hot that over forty thousand people died. Summer temperatures were the highest for at least 500 years.
- 2007: England and Wales suffered major flooding from the wettest May-July period since records started in 1766.
- 2010: An even greater heatwave affected Russia (deaths exceeded fifty thousand) as rainstorms caused worst floods in Pakistan's history; 20 million affected, 3000 deaths
- 2010: Another mega-heatwave hit Europe, again breaking the '1 in 500 year' record.
- 2011: Extreme flooding in Queensland (biggest in a century) with other extreme and deadly floods in Sri Lanka, Brazil, Philippines, and Colombia (one of its worst natural disasters). In September, southwest China had its worst recorded floods since 1847.
- 2011: Other parts of China were seriously affected by freezing rain and heavy snow with a prolonged drought over seven provinces; ranked the worst in 60 years.
- 2011: Droughts in north-east Africa were the worst in 60 years.
- 2011: Record deaths from tornadoes in the USA where droughts and wildfires all broke records as well. Texas had its worst fires on record. Crop yields were down.
- 2011: Storm hit the East Coast, New Zealand, with flooding and damage that may have been worse than Cyclone Bola in 1988.
- 2011: At the end of the year north-eastern USA had record snowfalls; three million homes were without electricity.
- 2012: Severe drought in continental USA. Abrupt rise in global food prices due to crop losses.
- 2012: Hurricane Sandy developed into the largest Atlantic hurricane on record and caused over US$65B in damage, second only to Hurricane Katrina (US$80B) in 2005.

- 2013: In January, Australia had its hottest nationwide temperature (40.3^{o}C) as uncontrolled fires burnt across Tasmania, Victoria and New South Wales. Little rain in recent months had left plants and soils completely dry while vegetation across the regions, revived by rains over the past two years, provided extra fuel in the extreme heatwave.
- 2013: Drought conditions were officially declared covering the whole of New Zealand at the same time. This was a first for the country.

The extreme events reported above occurred in a world that, on average, warmed by just 0.9^{o}C over the past century. Small average warmings led to more extreme weather events.

Given the continued rise in greenhouse gas emissions, scientists are suggesting that rises exceeding 2°C (the agreed global commitment) are increasingly likely within the next 90 years, or sooner. A report produced for the World Bank by the Potsdam Institute of Climate Impact Research and Climate Analytics predicted warming of over 3°C without further action to reduce greenhouse gas emissions.[23] If current pledges to reduce emissions are not met the report states that a warming of 4°C "…*could occur as early as the 2060s. Such a warming level …. by 2010 would not be the end point; a further warming to levels over 6°C, with several metres of sea-level rise, would likely occur over the following centuries.*"

Reports of extreme events usually cover human fatalities, damage to infrastructure, food losses and economic costs, but impacts on species and ecosystems generally go unreported. Some impacts are obvious – destruction of habitat and waterways by floods, wildlife deaths from fires, or coastal erosion. Other effects are more subtle as, for example, when extended periods of high temperature exceed a species' physiological tolerances and widespread deaths occur, but are not observed.

Ironically, it is tropical species that are often most vulnerable to unusually hot weather. Unlike polar bears, they are not adapted to wide variation in seasonal temperatures and many are 'thermal specialists'. Extreme heat waves in Australia have killed giant fruit bats in large numbers. In 2002, one heat wave killed at least 3,600 fruit bats in nine colonies along 250 km of New South Wales coastline. All deaths occurred where temperatures exceeded 41.7°C.[24] Nineteen thousand fruit bats died during extreme heat waves in tropical Australia between 2003 -2006. The RSPCA estimated 100,000 could have died from heat exhaustion in southern Queensland in a January 2014 heatwave that also killed parrots, emus and kangaroos.[25] Only a few such mass die-offs were recorded before 1994. The white lemuroid possum (right) lives only in the cooler mountainous forests of tropical northern Queensland. In late 2005, a severe heat wave led to its sudden disappearance and it was only a major survey in 2009 that finally located just four surviving individuals. Its long-term survival prospects are tenuous given its small tolerance to high temperatures.

An unusually high proportion of New Zealand's 80+ lizard species are adapted to cool environments.[26] Understanding how they would respond to heat waves might be instructive to assessing future risks they face, in addition to predation, especially for those species that are currently endangered.

Systems are interconnected

While this paper will discuss the implications of the inter-connections between and within social-ecological systems for mitigation and adaptation responses, climate scientists are identifying new mechanisms that are driving changes to the climate system. Some of these were unknown a decade ago and serve as a reminder that we still have much to learn about how complex systems work.

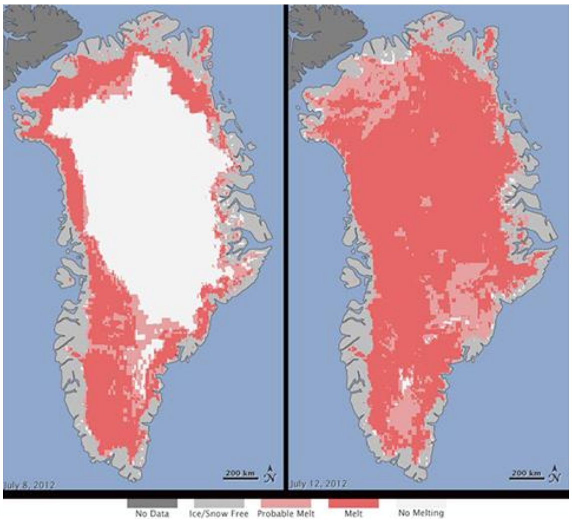
Why glaciers melt quickly

Scientists used to think that just surface warming accounts for glaciers melting. Three new mechanisms have been identified at work on the massive glaciers of Greenland and the Antarctic Peninsula that significantly increase melting rates. Warm temperatures create pools and rivers of melt water on top of the ice. On the Greenland ice sheet, the melt water penetrates through cracks in the ice down to the bedrock. There it acts as a lubricant, speeding up the movement of glaciers towards the ocean. This process was only discovered a few years ago. On the Antarctic Peninsula the penetrating water opens up networks of cracks and carves the ice shelves into thin vertical slabs. Eventually these thin slabs topple like dominos, at a faster rate than do thicker slabs of ice.

Warmer waters from the ocean, however, may pose the greatest threat of all. Normally the Antarctic ice shelves and the ends of the Greenland outlet glaciers are bathed in very cold water. Unusually warm water, not from climate-warmed seas, but possibly driven in by climate shifts in wind and surface currents (the mechanism is presently unclear), is now penetrating beneath the ice and can melt away the ice at an astonishing rate – up to 100 meters per year. These various mechanisms help explain why the rate of ice-sheet loss in Greenland has been accelerating for 20 years. Research published in 2014 shows that all of Greenland's major glaciers are now destabilised with the massive northeast ice stream (600km long) being the most recent to do so.[27]

Tundra fires, soot and Greenland

Warmer conditions are making the vast northern tundra more fire-prone which may, in turn, be responsible for the freak 2012 melt of the Greenland ice sheet one week in July. Melting areas for 8 July are shown in red in the left panel. On 12 July they covered the entire country (NASA images). While warm temperatures and clear skies contributed, it now seems likely that soot particles (which are black and absorb lots of heat) had blown over from Arctic wildfires, settled on the Greenland ice and captured more of the sun's heat. Hence warmer temperatures which increase the number and duration of tundra wildfires (in Russia and Canada) can (temporarily) increase the melting rates of Greenland's ice.



Rain-maker role change for tropical forests

The role of forests in generating water vapour, clouds and essential tropical rains is well known, but this role could decline in the future.[28] The process is called evapo-transpiration. Plants take in carbon dioxide from the atmosphere for photosynthesis through tiny pores on their leaves called stomata. But in doing so they release water; for every carbon dioxide molecule taken in about 180 molecules of water leave via stomata. Dense tropical forests are therefore huge sources of water vapour. Around half of the rain falling on tropical forests is returned immediately to the atmosphere to produce clouds and fuel the next rains. These clouds have two important functions; reflecting much solar radiation at tropical latitudes back into space (slowing global warming) and acting as a vital source of rainfall. This is especially important in dry-season months when forests are stressed and vulnerable to fire. As levels of carbon dioxide in the atmosphere continue to rise plants won't need to open their stomata for so long to take in carbon dioxide and therefore will generate less water vapour. This may mean fewer clouds and a reduction of the dry-season rainfall in the tropics. The future magnitude of such changes is not currently known.

Relevance of surprises

These are a few examples of how new mechanisms and inter-connected feedback loops may be increasing warming rates and influencing the frequency of extreme events.

Some are 'surprises' that scientists have only recently begun to understand while others represent changes in systems that were already understood. The concept of surprises as being an intrinsic part of social-ecological systems, and therefore a reason for some 'management humility', has been around for some time.[29] It also shows the value of considering systems as a whole, rather than concentrating on parts, and the recognition that unpredictable, abrupt transformations can happen. Climate change is now driving its own set of transformations, in physical, biological and social systems, and at an increasing rate. It puts greater pressure on the need for sustainable adaptive systems and enhancing the features that keep them responsive, cooperative, learning-focused and resilient.[30]

The IPCC correctly recognised back in its Second Assessment (1996) that there were likely to be more surprises ahead:

> *"Future unexpected, large and rapid climate system changes (as have occurred in the past) are, by their nature, difficult to predict. This implies that future climate change may also involve 'surprises'. In particular, these arise from the nonlinear nature of the climate system. When rapidly forced, nonlinear systems are especially subject to unexpected behaviour."*

Or in plain English: "Messing with climate in a big way will probably lead to nasty surprises."

The 'framing' challenge

It seems a paradox that while rapid change, extreme events and surprise are emerging as the most important effects of climate change the public's perception of climate change is that it is a long, slow process. This may, in part, be due to the media's focus on mitigation efforts to reduce long-term temperature increases and the real difficulty, even the impracticality, of specifically attributing any one extreme event to climate change.

Hence the climate change link to sudden surprises is less appreciated by the public. Both the 'long-slow' and the 'sudden-surprise' are essential aspects of climate change impacts yet these apparently disparate aspects make it difficult when 'framing' the challenges of climate change and appropriate responses. How people frame, or perceive, an issue strongly influences their understanding and response to it. Frames are inevitable and we all use them all the time. It is instructive that a major New Zealand conference to launch an ongoing dialogue on how to respond to climate changes recognised the importance of how to frame the challenge of anthropogenic climate change, "…*but no conclusion was drawn on the best ways to frame the issue*."[31] Finding the right frame is important for both developing and implementing an effective policy response, not to mention the difficulties of holding a useful dialogue between agencies, sectors and interest groups that have very different ways of viewing climate change issues.

Heading towards 'new normals'

The conclusion from this section is that climate change is already having significant negative global impacts, primarily through the increase in extreme weather events. These are hard to categorically link to climate change, although their increased frequency and severity is in line with predictions of climate change effects. It has also thrown up a number of 'surprises', revealing new mechanisms and interconnections between systems that were not known to researchers just a few years ago.

Extreme events are forcing countries to redefine 'threats'. In Australia, after deadly fires in 2009 a new level of fire risk labelled 'catastrophic' was added. Then the country-wide record heatwave and bushfires in January 2013 led to the addition of two new colour categories to Australia's weather prediction maps to cover temperatures above 50^{o}C.

New Zealand farmers have now experienced two 'once-in-70 years' droughts only five years apart (2008 and 2013). The need to define a 'new normal' is being increasingly mentioned in the media.[D]

These examples strongly suggest that land management based on past practices or 'business-as-usual' may no longer be appropriate in tomorrow's climate-changed world. What an effective response to the 'new normal' might look like will be examined after the likely impacts on our native ecosystems and primary production systems have been explained. It will be argued that the best response to the new normal will be developed using the concept of ecological resilience and its application within social-ecological systems. The reality that 'surprise' will always lurk is also an argument in favour of building in opportunities for shared learning between institutions and communities along the way.

[D] The Guardian Weekly (21-12-2012) in reviewing record extreme temperatures and weather events in 2012 quoted the UN Secretary-General Ban Ki-moon as saying "*The abnormal is now the new normal*." During 2012 alone this included record low levels of Arctic sea ice, severe droughts in the USA, Russia, Siberia, China, Brazil, and serious flooding in Niger, Chad, Nigeria, southern China and Pakistan. Hurricane Sandy killed hundreds in the Caribbean and the USA. Super-typhoon Bopha killed at least 900 people and displaced hundreds of thousands in the Philippines soon to be dwarfed by the destruction and deaths (over 6,100) from Typhoon Haiyan in November 2013. Haiyan was the strongest storm at landfall in recorded history and caused US$13 billion in damage in the Philippines and Vietnam.

KEY POINTS

- Broad trends of global climate change mask major regional differences, e.g. already wet regions will tend to get wetter and dry areas drier. Extreme warming and drying events are more likely to affect the tropics than temperate zones.
- More frequent and more severe extreme events, rather than steady climatic changes, are already having major impacts on human and ecological systems worldwide, and are very relevant when considering what adaptive responses are needed now.
- Climate systems are extremely complex with feedback loops. Extreme events (floods and heatwaves) can be interconnected across regions. New mechanisms influencing the rate of climate change are still being discovered. These mechanisms have led to accelerated rates of climate changes.
- These 'surprises' are difficult to predict and may well lead to substantive negative impacts on ecosystems.
- This underscores the point that responses based on just modifying 'business-as-usual' practices may be ineffective and inadequate given the size and scale of future changes.
- The recognition that 'new normals' may now characterise our climate underscores the importance of new thinking and new approaches to adaptation.

Changes to New Zealand's climate

This section summarises the predicted changes to climate variables in New Zealand. The following section will look at the likely effects of these changes on natural and productive systems. The nature of the probable climate changes for New Zealand over the next fifty-plus years have been well researched although predictions are being continually refined. Brett Mullan and colleagues summarised the consensus view of researchers on climate changes for New Zealand over the next 80 years.[32] The key changes they predicted are listed in Table 1.

Table 1. Size and nature of changes in main climate variables for New Zealand to 2090

Climate variable	Size and nature of change
Mean temperature	Increases are highly likely. Greatest increases will be in winter and in northern regions. Temperature rises will accelerate. By 2040, mean temperature rise will be 1^{0}C, with a projected range from 0.2 – 2.0^{0}C and 0.7 – 5.1^{0}C by 2090. See Fig. 2 for likely mean temperature changes by region.
Mean rainfall	There will be substantial variation around the country and with seasons. More rain is predicted in the west, but decreases in the east. This likely to lead to more frequent severe droughts in many eastern regions by 2080. Refer to Figure 3 for regional differences. Areas affected by drought where 1-in-20 year droughts could occur 2-4 times more frequently are in Northland, Coromandel, Bay of Plenty, Hawkes Bay, parts of Wairarapa, Marlborough, eastern Canterbury, inland and north Otago.
Extreme rainfall	Increases in the frequency of heavy and extreme rainfall (floods) are likely and are most likely in regions where mean rainfall increases; Westland and Stewart Island. But heavy rainfall events may also be more common in areas where mean rainfall decreases because of changes in the frequency of storm events.
Fire risk	Wildfires are more likely and will probably be more intense, especially in eastern regions.
Winds	Westerly winds will be stronger, notably in winter and spring, with a possible increase in severe wind events.
Snow	Increased temperatures will lead to less snow at low altitudes, shorter seasons of snow lying, fewer frosts and fewer freeze-thaw cycles.
Sea level	Sea level rise will be at least 18-59 cm between 1990 and 2100.[E]
Waves and storm surges	The increased westerlies will lead to more frequent heavy swells in exposed regions. Storm surges will also be more common.
Ocean temperatures	These will continue to rise slowly. Changes in ocean currents are also likely. Impacts on marine biodiversity will vary between ecosystems. Some effects could be severe, especially as oceans become more acidic.

More extreme events would be superimposed on this broad pattern of temperature and rainfall changes. Figure 2 shows the fairly uniform projection of warming across New Zealand as the consequence of being a long 'thin' country surrounded by moderating effects of oceans. In contrast, Figure 3 projects much more varied changes in rainfall shaped by

[E] Sea-level rise will be greater if the large ice masses in Greenland and parts of Antarctica melt faster. Current research suggests this is now likely, even if greenhouse gas emissions are significantly reduced.

wind patterns and topography. These very different rainfall impacts for the regions will be important when developing more localised adaptation responses.

Being surrounded by oceans means our estimated temperature rises will be less than the global averages. The implications of this for native biodiversity can be misleading, however, as the potential for adaption is related to the amount of variability ecosystems have adapted to in the past.[33]

Our climate is benign with monthly mean temperatures staying within a range of about 10^{o}C from winter to summer. A mid-range estimate for warming in New Zealand is 2^{o}C this century. The Northern Hemisphere, by comparison, can expect a 3^{o}C rise, but it has much larger summer to winter temperature ranges than New Zealand. Consequently, a 2^{o}C rise may have a larger impact on our biodiversity than a 3^{o}C rise would have in the Northern Hemisphere. This is consistent with a recent study showing that impacts of climate changes have already been larger in tropical regions where seasonal variation is much narrower than in northern mid-latitudes.[34]

The earlier work summarising likely climate changes for New Zealand has been updated in a summary report (2013) by the Office of the Chief Science Advisor.[35] It includes a summary of projected changes which are in line with those reported above. With respect to adaptation, the report does not consider policy questions but concludes:

> "*The impact of change is likely to be greatest in domains unable to adapt quickly or in those areas already close to limits of tolerance. These include natural and farming ecosystems evolved to function in current conditions and infrastructure requiring a long lead-time to plan and build, but also areas with high vulnerability such as those already prone to flooding or drought.*"

KEY POINTS

- There will be several key changes to New Zealand's physical climate that have implications for native biodiversity and primary production systems.
- Temperatures will rise in all regions and there will be substantial changes to rainfall patterns by region and season. Stronger winds, more frequent and more intense wildfires, with more frequent extreme rainfall events are predicted.
- Sea levels and ocean temperatures will slowly rise for many decades and coupled with more frequent storm surges, will affect coastal areas.
- Increased drought risks in already dry eastern regions have implications with respect to agriculture and adaptation responses.
- Our relatively narrow summer-to-winter temperature ranges may make some native species more susceptible to extreme temperatures than their Northern Hemisphere counterparts which normally experience much larger temperature fluctuations between seasons.

Climate change impacts on biodiversity

Before discussing adaptation and mitigation options we need to have a broad understanding of how climate change is likely to affect native biodiversity and thereby identify the important priorities to address. Are there some species or ecosystems that will particularly be at risk? Should these be a focus in adaption plans? Projecting how the different species and ecosystems within New Zealand might be affected by climate change is, however, much harder than predicting changes in climate variables. There are a number of reasons for this. The relationships between species and their non-living environments are extremely complex and far from predictable, let alone studied. Many species remain undescribed.

Despite these caveats about the difficulties of predicting how our biodiversity will be affected by climate change it has been attempted.[36,37,38] McGlone and Walker[39] summarised research on how New Zealand's terrestrial and freshwater biodiversity has responded to past climate change and potential impacts on New Zealand's biodiversity to future climate change. The following sections are largely drawn from their report to which the reader is referred for more detail.

Coastal ecosystems

Sea level rise will be the most important consequence for coastal ecosystems. Soft shores (dune systems, estuaries, lagoons and marshes), as opposed to hard rocky shores, will be most affected. This will be due to their greater vulnerability to erosion and the usually greater extent of adjacent, low-lying land. Changes in estuaries will affect mangroves, saltmarshes and seagrass meadows all of which are highly productive in ecological terms. Many important inshore fish species start life in estuaries and coastal areas where they are vulnerable to a variety of impacts ranging from pollution, sediment runoff, reduced freshwater flows and habitat destruction. Major storm surges can damage the structure of coastal ecosystems, destroy particular habitats and reduce productivity.

Soft shorelines without housing and infrastructure might be capable of natural adjustments over time, providing the rate of change is not great and other stresses from human activities (sedimentation, pollution, and eutrophication) are not excessive. Estuaries will be particularly vulnerable to warming and extreme warming events. Where development has led to 'coastal squeeze' councils and residents are unlikely to let new areas of dunes, marshlands or estuaries establish. This will lead to limited opportunities for natural change and adaptation and a likely loss of biologically rich areas. Agriculture, forestry, settlements and exotic species have all had negative impacts on coastal dune systems. Sea level rise and coastal squeeze will add to these impacts. There is likely to be a faster loss of productive estuarine habitats. Where estuaries function as important 'nurseries' for fish species there may be a decline of fish abundance and of coastal bird populations if food supplies become scarcer. Storm surges are likely to be more frequent with local impacts that will become more severe when sea levels rise.

Freshwater ecosystems

Although many native freshwater fish species can tolerate higher temperatures the invertebrates many feed on are adapted to cool waters. As glaciers shrink and alpine streams warm, alpine mayflies (*Deleatidium* spp) are likely to suffer reduced ranges and local extinctions.[40] Other freshwater organisms are also likely to be strongly affected if temperatures rise above 16-18^{o}C. This is likely to happen in streams where tall shading vegetation has been removed from the banks which is common in many agricultural lands. For example, Collier and Smith[41] found that water temperatures are more commonly lethal for stoneflies in streams flowing through pasture rather than forested landscapes. Water temperatures also rise when there is less water flowing because of drier conditions or greater removal of water for irrigation. Reduced flows from either cause have adverse effects on freshwater organisms.[42] Pollution from runoff and water removal for irrigation is already stressing our lowland and eastern freshwater ecosystems. Droughts, superimposed on artificially low water levels in rivers, are a major threat to aquatic life. Both are more likely in future given the predicted shifts in rainfall coupled with current rates of water extraction for agriculture which are highly likely to increase in the future given the over allocation of water in vulnerable regions.[43]

These impacts – pollution, water extraction, drought, low water levels, and higher temperatures – can also have negative effects on lakes, especially on smaller ones. At the global level, and possibly in New Zealand, climate change will likely have its most negative impacts on rivers that have already been dammed and extensively developed.[44]

Forest ecosystems

How changes in climate will affect New Zealand's forest ecosystems is difficult to predict. Where plants thrive is determined not only by temperature and rainfall, but also by soils, topography, wind, interactions with other plant and animal species, and more subtle aspects of their specific habitats. Some plants can migrate, over time, as temperatures change. Our geological record does not suggest, however, that tree species moved long distances in response to the last glacial-interglacial cycles in New Zealand.[45] Fortunately our mountainous landscapes provide big changes of temperature and rainfall over short distances; some plants should be able to migrate to adjacent cooler places.

A modelling study of global biodiversity 'hotspots' predicted only 2.5 percent loss of our native species assuming perfect migration and broad specificity of species, but about 40 percent loss of native species using the assumption of zero migration and narrow species specificity.[46] Such percentages are necessarily speculative. The value of such studies is to show that outcomes and threats are heavily influenced by specific characteristics of species, rather than by broad changes in the environment. Unexpected impacts may come from currently benign sources, such as native insects, as has happened with the mountain pine beetle in western Canada.[47] A sequence of mild winters led to an unprecedented outbreak and death of mature lodgepole pine forests on a massive scale. Hundreds of millions have been allocated to control of this small beetle and reduce the impacts on communities.

Predators

The existing problems caused by mammalian predators (e.g. rats, mice, stoats, ferrets and possums) on native animals and plants could be worse in some regions under warmer, more variable climates. For example, a likely increase in the frequency of large seed crops (mast seeding) would boost numbers of rodents. Increases in predator numbers would quickly follow (particularly stoats) increasing the predation pressure on native birds and invertebrates. Milder conditions in alpine areas would also improve survival rates of predators (rodents and stoats in particular) and put invertebrates and endangered birds such as kea under more pressure. The impacts of introduced insect predators may also change. Common wasps (*Vespula vulgaris*) and exotic ant species already reduce populations of many native animals and their numbers can increase rapidly in warm, dry conditions.

Rabbits also prefer warm dry climates; conditions that are predicted to become more common east of the Southern Alps. More rabbits lead to higher populations of feral cats and ferrets which could, in turn, increase predation pressure on native animals.

Weeds

New Zealand has a significant and expensive weed problem thanks largely to the enthusiastic and deliberate introduction of over 30,000 exotic vascular plant species, many as ornamentals for gardens. Over 2,000 of these have now naturalised (i.e. have self-sustaining populations in the wild), which is nearly as many as the total of native vascular plants (about 2,200). About 10% of these (200+) are classified as weeds (aquatic plus terrestrial) and are under varying levels of control. Every year 2-4 more exotic plants naturalise and increase the pool from which more will become 'weedy'. On balance, warmer climates will favour an increased rate of exotics becoming weeds thus adding to the current costs and difficulties of weed control. Although the Department of Conservation (DOC) has a comprehensive weed strategy[48], the weed problems at the national level are a growing concern for conservation managers as well as primary production sectors.

A major threat is from 'ecosystem transforming weeds'. Such weeds can dominate an ecosystem to such an extent that all essential ecosystem processes are controlled by nonnative plants leaving few native plants. In New Zealand important (e.g. *Pinus contorta*, *Pseudotsuga menzesii*, and *Larix decidua*), also referred to as 'wilding pine'. A 2011 report identified ten introduced conifer species are responsible for most wilding pine problems.[49] This report noted that in 2007 approximately 805,000ha in the South Island and 300,000ha in the North Island were affected by wilding pine (about the same total area as Fiordland National Park). (Photo: Wilding pine in Craigiburn Range, Canterbury, by www.flickr.com/ photos/mollivan_jon/.)

These conifers grow faster than native tree competitors, spread lots of seed, and dominate open landscapes such as in the central North Island and Otago. Although different management agencies are concerned about possible impacts of wilding pines a workshop held in 2003 concluded there was insufficient coordination between land managers to assess the true cost or develop appropriate nationwide responses.[50] This situation had not changed 8 years later.[51] Milder winters will increase the threat exotic trees already pose to rare species above the tree-line. A region at particular risk from weeds under a warmer climate is Northland, but for different reasons. There are already large numbers of weed species in Northland, including sub-tropical species. Under warming conditions possibly 100 species could be a problem in the region; 17 are already in an exponential growth phase.

Fire

A consequence of warmer drier conditions will be an increase in the frequency and intensity of damaging, uncontrolled wildfires due to drier conditions with more thunderstorms and lightening. Natural fires were not common in New Zealand's past hence native species are generally poorly adapted to survive and recover from fires.[52] Ecosystems most at risk will be those in eastern regions under warmer, drier climates. There are also implications of increased fire risk for planted exotic conifer forests and in areas with naturally spreading 'wilding pines'.

General and long-term impacts

Given New Zealand's evolutionary history the projected temperature rises could have severe impacts on our plants, animals and some ecosystems given that they largely evolved under cooler average temperatures than current ones. During much of the 2.5 million years of the Pleistocene period New Zealand was 2-6^{o}C cooler than it is now. Predicted warming this century will force adjustments to conditions that are potentially 2 - 5^{o}C warmer. Much of lowland, northern New Zealand will have subtropical temperatures and be warmer than it has been for the past 3 million years. In contrast, the alpine areas will certainly shrink in size and these species-rich habitats may well lose many species.[53]

This summary of the diverse possible impacts on New Zealand's biodiversity suggests that, collectively, they warrant a different level and type of response than the current approaches to conservation management on public and private lands.

KEY POINTS

- Climate change impacts are considered for three broad ecosystem types (coastal, freshwater, and forests) with the caveat that predicting climate change impacts on diverse and complex ecological systems is very difficult and much climate-related research remains to be done.
- Soft shorelines and estuaries, already stressed by inappropriate development, sedimentation and pollution, will be further stressed by sea level rise, warming events and storm surges. 'Coastal squeeze' developments will make it difficult for natural change and adaptation to occur in many areas.
- Freshwater ecosystems, including wetlands, are already in decline and stressed by pollution, habitat loss and water extraction. The invertebrate species that native fish feed on are strongly affected by high temperatures. More frequent droughts will be a major threat to aquatic life.
- If water extraction rates are not adjusted to sustain aquatic systems during droughts the consequences for many freshwater systems will be serious.
- It is particularly difficult to predict impacts on New Zealand's diverse forest ecosystems. The capacity of species to migrate to more favourable places as temperatures change is not well known although this will strongly influence their capacity to adapt to rapid changes.
- Across various ecosystems and regions climate change will change the impacts predators, weeds and wildfires have on native biodiversity. In all cases, these impacts are likely to be more severe and create additional demands on management agencies quite apart from responding to adaptation issues on private land.
- The rate and extent of temperature changes will be unprecedented for plants and animals that evolved under cooler temperatures. The rate of change may lead to extinctions if species fail to adapt quickly enough.

Climate change impacts on land-based primary industries

Given the importance of land-based primary industries to New Zealand's economy the potential impacts of climate change have been the subject of several assessments. The economic effects on agriculture were the focus of a large review of past research in 2008[54] and effects of climate change on planted forests were also summarised in 2008.[55]

Although these reports are broad-scale, one of the important points emerging is that climate impacts on both sectors will vary significantly between different regions and different production systems. Hence national-level assessments concluding little change in future economic performance mask the likelihood of significant, long-term disruptive effects in some regions while others are relatively unaffected.[F] This is important when looking at mitigation and adaptation options in relation to biodiversity and social-ecological systems. The economic modelling in these studies also excluded the effects extreme events because of their unpredictability, despite their importance, as well as factors such as changes in weed effects and new diseases.

The following tables are only indicative and provide partial summaries of these effects for some regions based on the two reports mentioned above and a related summary report.[56] Even partial information highlights the different impacts by region, the potential for surprises and the complexity of responses of biologically-based production systems.

Table 2. Potential impacts on agricultural systems

Climate factor	Region	Likely impacts
Droughts	Northern New Zealand	Vulnerable. Declines for dairy and sheep/beef in average and driest 'scenario years'. In addition, small catchments means there is little natural storage capacity. Water shortages likely.
	Eastern North Island	Particularly vulnerable: Bay of Plenty, Hawke's Bay, Gisborne, and Wellington. Eastern areas of both islands are the major cropping areas. Hot, dry weather will increase crop demands for water and reduce supply (rain). Dryland farmers will be more limited in range of crops they can grow. Under 'high carbon' conditions current 1-in-20 year droughts are likely to occur every few years by 2080.
	Central and western North Island	Waikato is less affected by droughts until the worst scenarios are considered. Droughts are much less likely in Taranaki. Production likely to increase with warmer temperatures and higher rainfall, leaving aside other growth requirements.
	Eastern South Island	Particularly vulnerable: Tasman, Marlborough, and Canterbury. Same drought frequencies possible as for eastern North Island. Already relying on extensive irrigation

[F] For example, the above report on agricultural production suggested no strong trend this century in production for dairy and sheep/beef at the national level.

		for dairying and cropping and is currently water-short. Water demands likely to exceed natural supply levels. However, alp-fed rivers in Canterbury and Otago are expected to increase, on average. Whether this will be sufficient to off-set increased demand is not known.
	Westland	Wetter, so pastoral farming production should increase. But the region provides a small percentage of national production volumes.
	Southland	Increased rainfall will reduce likelihood of droughts. Pastoral farming production should increase with warmer conditions.
Floods & cyclones	Northern New Zealand	Lies within the tropical cyclone area. More intense events would damage infrastructure and horticulture. Erosion risks and damage to freshwater ecosystems and coastal areas.
	Eastern North Island	Within the tropical cyclone area: Bay of Plenty, Hawke's Bay. Hill country without forest is susceptible to extensive erosion with subsequent damage to streams, rivers and coastal areas. Long recovery times after major storm events.
Pests (incl. weeds)	Variable	A variety of invertebrate pests and weeds will be favoured by changed conditions, especially, but not only, in northern New Zealand. Conditions for rabbits may improve in drier regions.
Landslides	Variable	Theoretically likely to increase, although human activity is a factor of equal or greater importance.[57]

Table 3. Potential impacts on forestry

The following effects of climate change have been identified for New Zealand's planted forests[58] and are summarised in the following table. Major weather events have affected agriculture and forestry over the past forty years, ranging from severe winds, to extra-tropical cyclones, floods and droughts. Some had significant economic impacts.

Climate factor	Region	Likely impacts
Increased CO_2	All regions	The 'CO2 fertiliser effect' will benefit growth in the absence of other limiting factors. Likely to especially benefit forests in drier regions. Likely interactions on ground water levels have not been explored.
Fire	Most regions	Fire danger is likely to increase significantly in some areas. The fire season will also lengthen.
Wind	Upper and eastern North Island	These regions may experience more severe extra-tropical cyclones. Damage could increase substantially, but impacts will vary widely.
Plant pests	Most regions	Range expansion is likely for *Eucalyptus* and *Acacia* spp. and the spread of weed species such as broad-leaved paperbark and kudzu. Shift of *Dothistroma* blight risk to South Island.
Insect pests	Unpredictable	Likely increase in the risk of establishment of new species from warm-temperate and sub-tropical regions with better winter survival. Unknown effects on tree productivity.

Listing climatic factors and likely impacts separately can be misleading as it overlooks the reality that climate impacts will not always occur separately. It is highly likely that, over time, there will be combined and synergistic effects. For example, a longer fire season coupled with increased severe wind events could increase the likelihood of uncontrollable major fires in forestry plantations. Or prolonged drought could increase the susceptibility of forests to disease or insect attack.

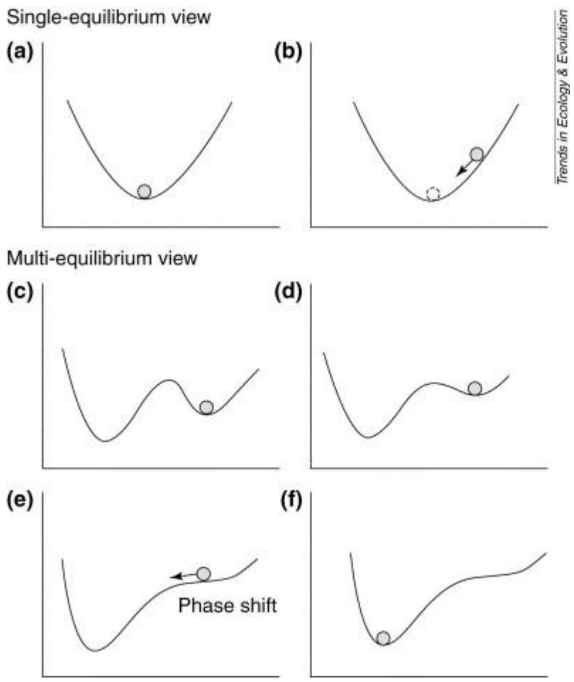
KEY POINTS

- Broad-scale reviews of climate impacts on agriculture and forestry indicate the impacts will vary significantly between regions and production systems.
- Mitigation and adaptation options may therefore miss the mark if a 'one-size-fits-all' approach is adopted.
- Eastern farming regions of both islands will be particularly vulnerable to drought.
- Droughts and floods in key productive regions are major risks for some agricultural systems especially those that currently rely on extensive irrigation.
- More frequent floods and cyclones in northern regions will increase risks of erosion, damage to streams and rivers and siltation in coastal areas.
- Plantation species may grow faster, but be at greater risk from fire and wind damage.
- It is very difficult to predict how plant and animal pests will affect agricultural and forestry sectors as the climate changes. Some pests and weeds may become more serious under warmer conditions with mild winters favouring pests from warm-temperate and sub-tropical regions.
- Adaptive planning for separate factors can miss the greater consequences of impacts when factors occur together, e.g. drought coupled with wildfires.

The relevance of resilience

This section covers the ideas behind 'resilience thinking' and their relevance to how we respond to climate change impacts. It necessarily starts with some ecological theory to explain concepts of resilience as they have been developed in the ecological literature and been applied to management practice. To recall the definition of 'resilience':
Resilience is the capacity of a system to absorb disturbance and still retain its basic function and structure.

Resilience has two definitions in the ecological literature that reflect different aspects and views of stability. The more common definition focuses on efficiency and a reliance on constancy and predictability. Holling termed this '*engineering resilience*' which conceptualises ecological systems as existing in a stable steady state.[59] Engineering resilience focuses on the speed of return to a steady state after a disturbance. It is represented in the diagram on the left by the 'single-equilibrium' view in (a) and (b). When the system "state" (the ball) is disturbed (b), engineering resilience is about how quickly the system can absorb a disturbance and return to business as usual. It assumes that ecosystems always function as a single stable state. If the 'zone of stability' in (a) has steep boundaries, its resistance to disturbance is high and the system will return more quickly to its stable state (in (b)). Such systems are often viewed as very resilient – at least from engineering or economic viewpoints.



The other definition of resilience is '*ecological resilience*' which emphasises that systems can exist in more than one stable state.[60] This is the 'multi-equilibrium' view shown in (c) to (f) above. In (c) the system "state" is relatively stable because of the height of the boundaries (thresholds) in the stability basin. After disturbances it will most likely return to its previous structure and function. However, should the 'stability landscape' change and one of the threshold boundaries starts to flatten as resilience decreases (d) and then disappears (e), then the system can shift or flip into another "state" (f). The diagrams above ((c) to (f)) are a representation of one such shift from a coral to a seaweed system in the Caribbean.[61] The dynamics of what happened to move this marine system into a different and degraded state with low likelihood of a 'return' is explained in Case Study 2 in the next section.

In diagrams (c) to (f) a 'threshold' changed that shifted the system (ball) into a different state with changed structure and functions. Thresholds are very important concepts in understanding the resilience and behaviour of social-ecological systems. "*Thresholds are the levels in controlling variables where feedbacks to the rest of the system change – [they are]* *crossing points that have the potential to alter the future of many of the systems that we depend on."*[62]

The first of the following case studies is an example of a social-ecological system that crossed a threshold and now behaves differently. An important point of difference between the approach of engineering resilience or ecological resilience to thresholds is that the former pays them little attention, while the latter is strongly focused on identifying and understanding thresholds. When a threshold has been crossed it can be difficult (or sometimes impossible) to get back.[63] The resilience of a system can be understood as the distance of the system from its thresholds. The closer to a threshold, the easier it is to shift or flip the system into another state. For example, if the ball in (c) was positioned at the top of the 'hill' and closer to the threshold then it is more likely to tip over to the left into a different "state"; its resilience is lower. Likewise in (e) it takes less effort to move the ball out of one state and into another because the low threshold no longer acts as a boundary returning it to the previous state.

Ecological resilience is not focused so much on how *quickly* a system will bounce back after a disturbance, but rather looks at the *capacity of the system* to absorb disturbance and still behave in much the same way as previously. In other words, the *ability to get back* is more important than the actual time taken to get back. These are the characteristics of social-ecological systems that will be important in the context of the disturbances and diverse stresses imposed by climate change. The following two very different case studies look at the (in)ability of two systems to absorb disturbance because of changes in thresholds, i.e. their loss of resilience.

There are now many examples in the scientific ecological literature of natural and managed social-ecological systems flipping or shifting into very different states.[64] These studies have shown the importance of understanding the underlying variables that are so influential in the function of social-ecological systems as well as identifying the thresholds associated with those variables.

Two other concepts are relevant to later discussion about appropriate management responses to climate change. The first is the relationship between sustainability, resilience and efficiency. Improving efficiency (of resource use or services) is often promoted as contributing to sustainability. In a narrow context, greater efficiencies can contribute to sustainability. However, a single focus on efficiency can undermine sustainability:

> "*Why? Because the more you optimize elements of a complex system of humans and nature for some specific goal, the more you diminish that system's resilience. A drive for an efficient optimal state outcome has the effect of making the total system more vulnerable to shocks and disturbances*."[65]

Improving efficiencies is often associated with simplifying systems (e.g. reducing numbers of specialist staff, removing backup support systems, cutting information systems, reducing stock inventory to "just-in-time" deliveries, outsourcing core functions) that makes the total system more vulnerable to stresses and unexpected shocks.

The other important concept is the relationship between resilience and stability. If a system faces few disturbances then it is relatively stable while large disturbances are normally associated with unstable systems. Does this make stable systems more resilient? Not necessarily. In the earlier section titled “Extreme Events” the example was given of climatically stable tropical ecosystems that are less able to cope with temperature fluctuations than temperate ecosystems that are adapted to wide seasonal variations in temperature. If disturbances increase the ability of a system to respond (i.e. to adapt over time) to similar disturbances in the future then instabilities can add to the system’s overall resilience.

Take home message

In summary, thinking in terms of *resilience* means thinking in terms of *systems*. This has relevance for land managers when they are considering their different options for responding to the consequences of climate change. ‘Systems thinking’ requires land managers to recognise that:

> “*We all live and operate in social systems that are inextricably linked with the ecological systems in which they are embedded; we exist* <u>*within*</u> *social-ecological systems. Changes in one domain of the system, social or ecological, inevitably have impacts on the other domain. It is not possible to meaningfully understand the dynamics of one of the domains in isolation from the other*.”[66]

The premise that managers, farmers, policy makers, scientists, developers, communities and even organisations in a particular place are all part of an inter-linked system means that everyone is subject to feedback responses from other parts of the system. Many management approaches ignore or pay little attention to a lot of these feedbacks.

Systems thinking also requires recognition that social-ecological systems are *complex adaptive systems*. The way they change is not predictable, linear or incremental. They can exist in different states with different structures and feedbacks. Complex is different from complicated. Getting Neil Armstrong to the moon and back was a complicated undertaking but nearly all the variables involved were predictable and measurable. In contrast, raising a child or developing and sustaining the terraced rice paddy fields of Asia (photo right, Korea) is complex. Both behave in ways that cannot be predicted by just looking at parts of the system. Managing for just a part of the system can lead to long-term problems.

Finally, to these two concepts of systems thinking – inter-connected systems of which we are a part, and that these systems are complex, non-linear and unpredictable – we need to add a third concept. That is the idea that developing resilient social-ecological systems is the key to long-term sustainability.

If the social-ecological systems we live in are resilient, that is, if they have the capacity to absorb unwelcome and unexpected disturbances, then they also have a greater capacity to provide us with the goods and services that sustain us. What happens to social-ecological systems when resilience is reduced and external shocks occur is explored in the following two case studies.

The reader is asked to keep one important point in mind when reading these case studies. The profound changes these systems have gone through were not predicted or even knowable by considering any one part of the system, or the known risks, at the time. The thresholds in these social-ecological systems are the key to understanding what happened.

Yet much of the guidance provided to agencies on preparing for climate change, for example, the 2008 guidance to local government by the Ministry for the Environment[67], tends to focus on individual factors and known risks. It is appropriate for councils to plan for how infrastructure and management of natural hazards will be affected by climate change. But these are only components of bigger systems. These guidelines overlook the potential for interactions between different factors, the unpredictability of how whole systems might respond. Current approaches to risk assessments focus therefore on known likely changes, but are silent on how to respond to complex system changes, or how to identify thresholds that are likely to be affected by climate changes. By not considering how the resilience of whole systems might be affected the emphasis tends to focus on adjustments related to sustaining 'business as usual'. We are back with the 'framing problem' – what is the appropriate way to think about climate change – the extreme events and long-term changes – so that we respond appropriately and don't make matters worse.

KEY POINTS

- Concepts of ecological resilience are helpful in appreciating the importance of the factors/drivers that unexpectedly 'flip' an ecosystem from a desired to a degraded condition from which it does not recover. Climate change can cause such flips.
- 'Thresholds' are the crossing points past which recovery may not be possible when a system flips. Strong thresholds are a property of resilient systems.
- The resilience of the whole 'social-ecological system' needs to be considered, not just the ecological or social components in isolation from each other.
- Resilient systems are those that can recover from shocks over time and are the key to long-term sustainability.
- Understanding these systems as 'complex adaptive systems' is the key to developing effective management responses to climate change impacts.
- All of these concepts are relevant when developing adaptive responses for better land management with climate change.

Case study 1. When thresholds are crossed: a balancing act for farmers

Farmers (dairy and horticulture) in the Goulburn-Broken Catchment of northern Victoria in Australia (hereafter "the catchment") have developed one of Australia's most efficient and productive agricultural systems. As a consequence, however, this highly productive region now has frighteningly little resilience to any future major shocks to the system. What happened in this 300,000 ha catchment is a story of the consequences of radically altering a natural ecosystem to optimise production while overlooking the one 'slow variable' that effectively controls and constrains the whole system – the rising groundwater table. The following overview of this system change is drawn from the analysis in "Resilience Thinking".[68]

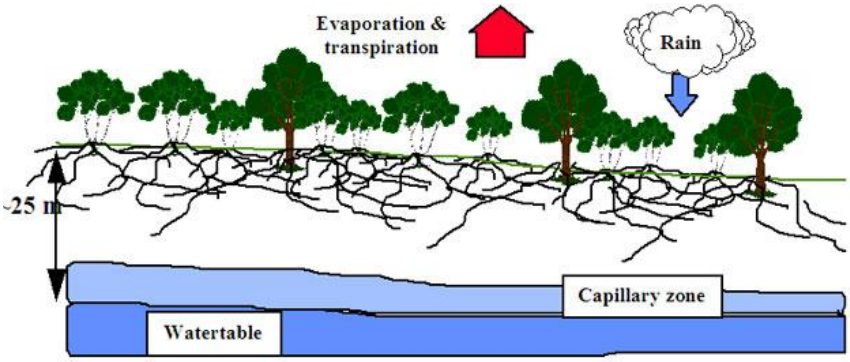
Trees, water and salt

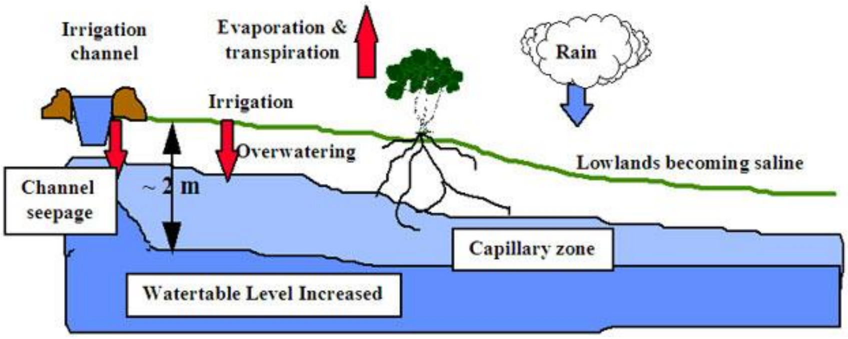
As in other parts of Australia this rural area has to cope with droughts and floods, neither of which is good for agricultural productivity. It's 'Goldilocks country' – too much or too little water is a recurring problem. The obvious solution for the past 130 years has been to irrigate pasture and fruit trees by building a series of ever-larger dams to increase and regularise the water supply. High rainfall from 1950 to 1960, while dam-building was being finished, created boom times for the region. These good times encouraged farmers in the catchment to invest heavily in their irrigation systems. Production was high, as were commodity prices, and farmers steadily locked themselves into irrigation practices through their investments.

Early European settlers had progressively cleared the catchment of most of its native forests and woodlands; from 70 percent to less than 2 percent in the irrigated lands. *This major change in the landscape in the 1800s set in motion the problems of today.* Prior to European settlement the groundwater tables (as elsewhere in Australia) were in long-term equilibrium, some 25 to 50 metres deep below the surface. Native vegetation was effectively responsible for maintaining this equilibrium. The diverse mix of species, from shrubs to deep-rooted trees (to survive droughts), fully exploited the annual input of rain in the soil. By taking up water across the whole soil profile native plants prevented most of the water from continuing down to reach the groundwater level (top diagram, next page). It is the groundwaters that contain ancient marine salts, originally blown in from the oceans and flushed deep down through the soils over millennia. The massive change in vegetation, replacing deep-rooted perennial plants with shallow-rooted plants that might only grow for a few months, fundamentally changed the water balance. No longer were the annual rains all used up each year. Much more rain water now filtered through the soil to the depths of the groundwater. As a result, the previously deep groundwaters started to rise, bringing with them the salts from ancient seas that are so damaging to plants.

It was not only the removal of the native vegetation and the failure to capture and use the annual rains that led to the rise in the groundwater – the massive amount of water being used for irrigation was adding as much water again as fell during the annual rains. As a result the buffer that the previously deep watertable provided to the wide fluctuations of rainfall was rapidly used up. The wet phase of 1950 to 1960 wiped out the buffer as the ground water level rose to within 5 – 6 metres of the surface.

Hence the catchment had effectively lost its resilience to any future shocks of extended wet periods. The productive 'good times' of the 1950s had set the system to 'tip' into a new ecological regime when the next wet period arrived. The rising water table moved the whole farming system closer to the threshold of a new regime. The next wet period of 1973 – 1977 produced the crisis when the shallow water table rapidly rose into a critical two-metre zone over a third of the region (lower left diagram). Dairy production was reduced; many high value crops were lost including 30-50 percent of stone fruit crops. The immediate response to the crisis was to install groundwater pumps and protect fruit trees by lowering the water table. The pumped, salty water was discharged into the Murray River thereby moving, but not solving, the underlying problem.





The social system response

The water table crisis produced a positive 'social system change'. A social threshold was crossed with the recognition that only coordinated responses across the wider Murray-Darling region might avert future crises. Farmers acting alone could not solve what was now a common-resource problem. The outcome was the establishment of new community groups and networks. These "Landcare" groups were created to work within a broad ethic of land stewardship, which differed sharply from the previous single-focus groups. There was also a major shift in decision-making powers in times of crisis from state and federal control to regional communities. Integrated catchment management is done through Catchment Management Authorities based on community

decision-making. These now exist around Australia.

Hundreds of pumps carefully manage ground water extraction into a regional irrigation channel and drainage network for reuse or removal based on salt levels. The catchment is now just coping, but has not 'solved' the problem. The water table remains close to the root zone. The scale and cost of revegetation required, the long delays as trees grow, plus farmer reluctance has meant only limited planting has been done, although it remains part of the long-term solution. The new regime of high, ground water tables is very hard to escape as costs rise (pumping is expensive) and salt levels increase. The biological system now lacks resilience and is vulnerable to economic and environmental shocks.

The big positive was the ability of the community to create local networks and institutions that have sustained its productive base. It developed high adaptability. But it also *failed to fully address the underlying cause of the problem* and explore alternative futures that could have led to a transformed and less risky future. Instead, all effort was devoted to getting back to business as usual. But in reality big changes were needed and still are. These might include: switching from high water use systems (dairy) to lower water uses (horticulture); significantly reducing total input to the groundwater; significant revegetation efforts; novel land-use that needs no irrigation. A prolonged wet period would be much worse than the one in the 1970s because the groundwater level is so much higher now. The buffer has gone. However, the communities have developed significant capacity to work together and this may be the critical factor in the resilience of this social-ecological system.

Photo: Goulburn-Broken floods, March 2012

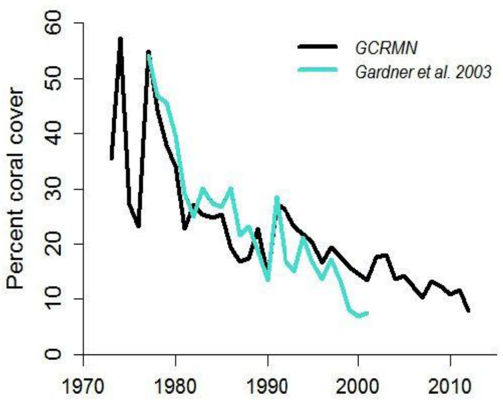
The Walker-Salt conclusion of this case study is instructive in contexts beyond Australia.[69] They write: "*This Goulburn-Broken story demonstrates the critical importance of understanding the underlying variables that drive a social-ecological system, knowing where thresholds lie along these variables, and knowing how much disturbance it will take to push the system across these thresholds. To ignore these variables and their thresholds, to simply focus on getting better at business as usual, is to diminish the resilience of the system, increase vulnerability to future shocks (droughts, wet periods, and economic fluctuations) and reduce future options. Being more efficient is not by itself a pathway to sustainability. Because resilience was not being consciously factored into the management of the region, <u>greater production efficiency has actually reduced the possibilities of the system being sustainable</u>*." (Underlining added)

Case study 2. Collapse of the Caribbean coral reefs

What has happened to the coral reefs of the Caribbean countries provides a further insight into how several disturbances combined to reduce the resilience of an ecosystem and tipped it out of one stable state into another, much more degraded state, from which recovery is unlikely. This account is also drawn largely from 'Resilience Thinking'.[70]

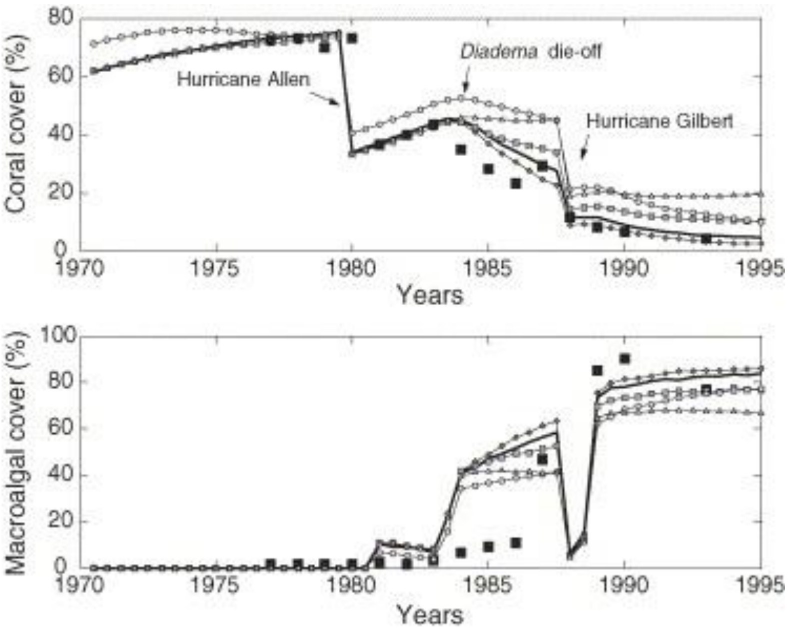
In 2000, the annual net economic value of the Caribbean coral reefs was estimated $3.1 - $4.6 billion from dive tourism, fisheries and shore line protection (from hurricanes). The reefs provide food for millions and are the magnet for a major tourism industry. Despite these enormous economic and physical benefits to people these reefs are now in severe decline.

The clearest measure of this failing system is the drop in the percentage of live hard corals over the past forty years (graphs below). The proportion of live corals in the reef systems dropped from around 50 per cent in the 1970s to a current level of 8 per cent. Fleshy seaweeds now dominate many reefs which lack the diversity of fish typical of healthy reefs (photo above).



What happened? In short, several different disturbances steadily lowered the resilience of the coral reef ecosystems. These disturbances included overfishing, pollution from increased nutrient and sediment runoff, disease and bleaching caused by rising sea temperatures. The sediments smothered coral while excess nutrients favoured the growth of fleshy seaweeds that was no longer controlled by grazing fish, especially parrotfish. Through the 1960s and 70s the *Diadema* sea urchin kept the fleshy seaweed from taking over. By doing so the sea urchin provided much of the reefs' resilience in the face of severe disturbances: more frequent hurricanes (every decade), increased pollution and colonisation by seaweeds.

Then in 1983, a disease outbreak decimated *Diadema* sea urchins throughout the Caribbean. Thirty years later, sea urchins are still regarded as 'functionally extinct', i.e. they no longer provide the ecological function previously performed (controlling seaweed levels). The *Diadema* sea urchin was a keystone (very important) herbivore; its effective disappearance tipped the now-vulnerable coral reef system into what is now essentially a seaweed system. The stable, resilient state of healthy coral reefs that existed for millions of years has switched, over 40 years, into a much less resilient state. Hard corals provided resilience to the occasional hurricanes; their loss at a time when hurricanes are more frequent and more severe, perhaps as a consequence of climate change, had even more impact.



This is a good example of the earlier definition of resilience in action, namely: *Resilience is the capacity of a system to absorb disturbance and still retain its basic function and structure.* The graphs on the left show two main points. First, the negative effect of two powerful hurricanes (Allen in 1980, Gilbert 1988) on the survival of hard corals that were already weakened by pollution and other stresses. The percentage of live hard corals crashed from over 60 percent to about 10 percent in 8 years. Secondly, the rapid rise in seaweed ('macroalgal cover' in lower graph) after the demise of the sea urchin populations in 1983. The explosive growth in the mid-1980s (less than 10 percent to 90 percent) was temporarily reversed when Hurricane Gilbert stripped the reefs of algae (just as hurricanes strip trees of leaves). The rapid regrowth of seaweeds, which was assisted by high nutrient levels, was a non-linear response to disturbance.

Coral reefs as social-ecological systems

Coral reefs worldwide are being affected by rising sea temperatures and increasing acidification of oceans from climate change leading to widespread bleaching and death of corals. These are the controlling 'slow variables' behind global declines in the health of coral reefs. Is restoration of Caribbean reefs feasible? Leaving aside climate change, this would involve addressing root causes at a regional level. Restoring the natural regeneration processes of fast corals would mean working on two key factors – restoring depleted fish stocks and improving water quality. Both are dependent on human responses.

Many people therefore advocated the establishment of 'no take areas' that prohibit fishing and other damaging activities which would allow fish populations to build up. Research had shown that parrotfish (right), as seaweed grazers, play a key role in controlling seaweed now that sea urchins have largely disappeared. However, they are heavily over-fished. Parrotfish can help corals to persist (and perhaps recover), providing fish populations are not exploited and nutrient levels from run-off are low.[71]

The call for ‘no take zones’ led to the establishment of 285 marine protected areas covering about 20 percent of the region’s reefs. A survey of their effectiveness, however, concluded that only 6 percent were effectively managed. Nearly 50 percent had inadequate management; there was little protection for the resources they were intended to protect. These failures reflect a number of shortcomings: lack of planning engagement with local communities; failure to share financial or other benefits arising from protection; diversity of management jurisdictions (35 countries and territories) leading to poor coordination; widespread poverty; weak infrastructure and low capacity; a history of colonial exploitation and resource extraction.

The conclusion by Walker and Salt was that:
“Even though the problems are largely understood, the Caribbean as a social-ecological system doesn’t have much capacity to address the main issues that are threatening it. It has low adaptability.”[72]

KEY POINTS

- These two very different case studies show how a lack of resilience in social-ecological systems can explain the unexpected collapse of natural systems despite the best of efforts to stop it.
- In the case of the Goulburn-Broken Catchment a strong collective response by the community and State agencies averted an economic disaster, but has yet to resolve the underlying environmental problem.
- In the Caribbean, solutions to stem the loss of critical corals were known, but could not be effectively implemented because of weaknesses in the social and political systems. Loss of ecological resilience tipped the coral system over a threshold into a degraded state from which recovery is unlikely.
- These examples of systems as ‘complex adaptive systems’ provide a relevant framing with which to assess our response options to climate change and the importance of understanding the variables that drive the systems.

Policy context for climate change and biodiversity

This section argues that New Zealand lacks a broad policy and planning framework to guide an effective adaptation response to climate change impacts on biodiversity. Such frameworks are already well developed in Australia and elsewhere. A high-level framework developed to enhance ecological resilience in the face of shocks from climate change would benefit both native biodiversity and primary production systems.

Relatively little effort has been made to investigate the impacts of climate change on New Zealand's native biodiversity in the context of the implications for land management and conservation. The New Zealand Biodiversity Strategy (2000) makes no reference to climate change impacts, nor has there been any subsequent effort to comprehensively address this gap and consider the broad policy or management implications of climate change for our biodiversity. In 2005, the independent review of the Strategy[73] had recommended:

> *"That an objective and actions relating to the impacts of climate change on biodiversity and related research questions and adaptation options be developed and added to the Biodiversity Strategy."*

No such action has been taken so far. A related recommendation that also awaits action was:

> *"That the potential impacts of climate change on biodiversity be accorded a higher priority in the New Zealand climate change policy, recognizing also the opportunities for whole-of-government links to investments in monitoring regimes between climate change and biodiversity objectives."*

By contrast, the topic had already been extensively considered in Australia. In 1996, Australia's first national biodiversity strategy explicitly addressed climate change threats.[74] Subsequently, in 2009, an expert advisory group assessed the likely severity of climate change impacts on Australia's biodiversity.[75] Its report concluded (Page 1):

> *"The magnitude and rate of climate change pose particularly severe challenges for natural ecosystems. The interaction of climate change with existing stresses – such as land clearing, fire and invasive species – adds further levels of complexity. Significant changes are required in policy and management for biodiversity conservation to meet these types of challenges."*

This report also noted the difficulty of predicting future effects given that (1) climate change will interact with other stressors that currently affect biodiversity, and (2) the properties of ecosystems are often non-linear and can be difficult to understand and predict. It did note, however, that use of basic ecological principles would identify general trends.

The Australian report concluded with principles for biodiversity management in the light of climate change, three of which are specifically relevant to New Zealand. They are:

1. There should be a focus on maintaining the provision of ecosystems services through sustaining a diversity of well-functioning ecosystems;
2. There should be a *focus on enhancing ecosystem resilience*, including through developing connectivity of fragmented ecosystems, protecting key refugia, implementing more effective control of invasive species, and developing appropriate fire and other disturbance management regimes;
3. Policy and legislative frameworks should be reoriented, including by introducing *integrated regional approaches* tailored for regional differences in environments, climate change impacts, and socio-economic trends. (emphasis added)

The report by the experts recommended pursuing a number of landscape or regional approaches including bioregional planning as these and related approaches "…*should encourage broader decision-making and active adaptive management, providing mechanisms better suited to dealing with climate change adaptation*."

This recognition that significant changes in policy, approach and institutional arrangements were warranted repeated an earlier message in 'Australia State of the Environment 2006'[76] that identified the need for "*reform in governance to move away from short-term and sectoral management towards a more systematic, integrated and planned approach to monitoring and managing*" in all environmental sectors.

Australia's second Biodiversity Conservation Strategy was released in 2010.[77] The issue of climate change and its potential negative impacts on natural systems was again emphasised. In this context the theme that climate change impacts were unlikely to be effectively addressed by a 'business as usual' approach was emphasised:

> *"Traditional approaches to biodiversity conservation need to be rethought. Planning approaches that include managing for uncertainty will be critical, with greater emphasis on risk management and adaptive management approaches. These must be based on high-quality information, monitoring and experimentation."*

The Strategy stressed that the important management response to climate change actions was to maintain the resilience of natural systems. This was elaborated as follows:

> *"Building resilience will be the key to ensuring that natural systems have the capacity to adapt to shifting climatic conditions. Addressing the full range of threats to biodiversity, securing critical intact habitats, restoring habitat connectivity through rehabilitation and revegetation on private land, and linking core terrestrial, aquatic and marine protected areas (MPAs), will all be critical to ensuring species' resilience and to maintaining ecological processes and systems."*

This is not to suggest that specific impacts of climate change on biodiversity that concern Australian management agencies will be the same in New Zealand. The countries are very different with respect to geography, climate and biodiversity as well as economic and social systems. Consequently, the climatic effects on natural and productive systems will vary considerably. The important point is that Australia has systematically explored and identified the potential impacts and implications for its biodiversity policies and management. It has concluded that 'business as usual' for conservation is no longer appropriate, that major reforms in governance are required for more appropriate management. Australia has also identified two important concepts to apply to future conservation management. The first is recognising and responding to 'uncertainty' and the second is the importance of 'building resilience'. A similar level of analysis has yet to be done in New Zealand and we therefore lack a broad appreciation of the potential management implications for our biodiversity, let alone appropriate adaption responses.

In Canada, a survey of agencies responsible for protected areas management published in 2011 found that all agencies thought that climate change was an important management issue 'now or in the very near future'.[78] Ninety four percent thought it would "*substantially alter protected areas policy and planning over the next 25 years."* Despite this awareness the survey found that there was little related policy, planning, management or research currently underway. Existing research was seen as being dominated by ecological science at the expense of social science considerations, or else it was too generic to be useful to managers. Agencies also conceded they lacked the capacity for an effective response to climate change. This gap between awareness and action was attributed to constraints such as limited financial resources, limited internal capacity and lack of understanding of real or anticipated climate change impacts.

Protected areas agencies in Canada wanted to strengthen and develop relational networks at all scales, from the local to the continental, recognising complementary strengths and weaknesses. The paper concluded that:

> "…*inadequate investment in climate change adaptation may lead protected area managers to maintain the status-quo or rely on reactive adaptation (vs. proactive adaptation) despite concerns about the long-term viability of current planning and management practices. Considering … the potential for non-linear ecological responses (in other words, ecological surprises), the length of time required for species and ecosystem response to management interventions, and the relatively slow process of implementing new policies within protected areas agencies, the time to begin developing proactive, and integrative climate change adaptation strategies is now."*

A similar sense of urgency to develop proactive strategies to adapt to climate change on New Zealand's protected conservation lands has yet to be articulated.

Resource management legislation

The major piece of environmental law in New Zealand is the Resource Management Act 1991 (RMA) which is the primary law for environmental management. In 2004, the phrase "the effects of climate change" was inserted under 'Section 7 Other matters' as something that people exercising powers and functions under the Act "…shall have particular regard to". Other matters already listed under this section include: the ethic of stewardship; the maintenance and enhancement of amenity values; intrinsic value of ecosystems; maintenance and enhancement of the quality of the environment; any finite characteristics of natural and physical resources.

For over 20 years this reformist legislation with its 'matters' listed under Section 7 has led to "…*the concept of the ecosystem as a dynamic unit of resource management*."[79] Geoff Park saw the RMA as providing a systems-based, integrative approach to sustainability that "…*makes the inter-relatedness and inter-connectedness of living things visible and operational*." And with its respect for the intrinsic values of ecosystems "…*allows nature some safeguarding and to retain some real independence from humanity*."[80]

Hence the RMA's Section 7 'Other matters' provides a key legislative justification for the development of comprehensive policies and legislation for resource management in the context of adapting to climate change. Over the past 20 years, however, the continuing loss of native habitats on private land and the inconsistent or inadequate approaches by councils to biodiversity management has shown that policy improvements are still needed for better management of native biodiversity.

Government currently has the opportunity to address this long-standing problem and also introduce important climate change policy directions at the same time. The proposed National Policy Statement on indigenous biodiversity (NPS) could be amended to consider the effects of climate change on native biodiversity. The intent of the NPS is to provide clearer direction to local authorities on their responsibilities for managing indigenous biodiversity outside public conservation lands. The absence of any reference to climate change impacts in a future NPS on indigenous biodiversity will, like the current Biodiversity Strategy, continue the unfortunate policy gap referred to at the beginning of this section.

KEY POINTS

- The New Zealand Biodiversity Strategy (2000) has no objective to consider climate change impacts on biodiversity. One should be added to provide a high level policy framework with principles and priorities across all lands.
- There has been little research into the impacts of climate change on native biodiversity from conservation or land management perspectives.
- Both gaps are major constraints on developing adaptive responses that are better than piecemeal. Policy guidance is needed for the development of adaptive responses at the right scales for public and private lands.
- In contrast, the topic has received extensive consideration in Australia where potential impacts of climate change on natural ecosystems have been addressed in two biodiversity strategies and by expert advisory groups.
- A strong feature of the Australian approach is an emphasis on the importance of enhancing ecosystem resilience and on the need to reorient policy and legislative frameworks accordingly, as well as governance reforms.
- The proposed National Policy Statement on indigenous biodiversity should be amended to take account of climate change impacts on indigenous biodiversity.

Challenges for land managers

The following sections bring together the topics covered so far: climate changes and the likely impacts on New Zealand's biodiversity and primary production; the importance of ecological resilience and how it can be undermine; and the value of a social-ecological system framework for analysing problems and developing solutions. They suggest how these analytical frameworks can be used by management agencies to respond proactively to climate change threats while protecting and enhancing native biodiversity. They offer alternatives to quick-fix solutions that undermine biodiversity to benefit one productive sector in isolation of the wider environment.[81]

Improving coastal management

The ecological resilience of coastal ecosystems and the built environment will not be strengthened by only building hard structures to counter rising sea levels. This approach has been tried and has failed on numerous occasions over the past century here and overseas. The past 50 years have also provided lots of examples of both good and bad ways to manage coastal holiday development. The history and consequences of New Zealander's love affair with our dynamic coasts, especially for recreational purposes, has been very well documented.[82] The cumulative effects of weak planning controls over coastal development has weakened, degraded or removed completely many of the costal ecosystems that can effectively absorb and respond to storms, flooding and erosion. These same systems can provide the best adaptation mechanism against rising sea levels.

Native plants, such as spinifex (*Spinifex sericeus)* and pingao (*Ficinia spiralis*) grow on foredunes where they trap sand blown off the beach. As the dunes grow in size, the plants extend seawards to continue dune building and to provide a buffer when storms hit and remove sand. If dunes have a sufficient cover of pingao and spinifex they can arrest erosion and start the dune rebuilding process. Introduced marram grass (*Ammophila arenaria*) and animal grazing has, however, severely reduced the distribution and abundance of pingao which originally occurred nationwide. Ecological resilience has been reduced and with it the capacity of the system to recover.

Coastal care

The coast care movement started in 1993 as a community restoration initiative in the Bay of Plenty and has grown into a much wider and successful initiative extending to many other coastal areas throughout New Zealand. It is based on the simple premise that restoring the original native vegetation (spinifex and pingao) to denuded, trampled and eroded foredunes can rebuild dunes naturally and also protect infrastructure. After three years the foredunes become self-maintaining and some coast care groups then plant back dunes with other indigenous species to further stabilise the dune systems. Thirty community coast care groups, including iwi-based ones, are now active in the Bay of Plenty alone and have planted nearly 500,000 native dune plants along more than 100km of coastline. The cost of supporting the projects by councils and DOC is orders of magnitude cheaper than building seawalls as well as being more effective in the short and long term.

The coastal care example cited in the box above[83] also demonstrates a positive social-ecological response to the problem. A community that saw the destructive consequences of the original coastal 'development' and erosion identified the problem that threatened their beachfront properties. The adaptive response, research, extensive planting and initial maintenance needed long-term support and modest capital. These are provided by local councils working in a genuine partnership with Coast Care groups. The Coast Care groups advise the Bay of Plenty Regional Council which work they regard as priority and get together to plant and protect the dunes at their beach.[G] Responding to rising sea levels is part of the rationale given by Bay of Plenty authorities for supporting Coast Care.

Despite the local gains made by coast care groups coastal management faces a number of obstacles to protecting coastal ecosystems (dunes, wetlands, estuaries, and mangroves) against storms and rising sea levels. Can the example of a social-ecological system that is operating so effectively at a small community scale work at larger regional and national scales? Pressure to develop coastal areas will increase. New Zealand has numerous examples of badly designed, ecologically destructive, sprawling coastal developments and, fortunately, some well-designed developments to show what can be done.

What is required is a major shift in thinking, backed by strong central government policies, for development that sustains and strengthens coastal landscapes and does not undermine its natural resilience to respond to shocks and change. We know a great deal about the superb adaptability and suitability of native grasses, shrubs and trees in coastal places and to avoid earlier mistakes of using introduced plants to 'solve' coastal problems. However, allowing sufficient space for dunes to retreat and reform landwards and thus continue to provide a resilient buffer to storms and rising sea levels, as they did for millennia before humans arrived, will test the resolve of councils, developers and communities alike.

Raewyn Pert's comprehensive account of our use and abuse of the New Zealand coast since European settlement documents the outcome of an ethos that only occasionally put public and ecological good ahead of private gain.[84] The result has been a loss of resilience and adaptability of what is inherently a highly resilient ecosystem due to the filling in of wetlands and streams, removal of indigenous vegetation, coastal development, pollution and sedimentation of estuaries and harbours from agricultural and urban activities. The following example shows that promoting adaptive change to rising sea levels that affect individual property rights can be difficult.

As required by the 2010 National Coastal Policy Statement, the Kapiti Coast District Council had a coastal expert assess coastal erosion risks for the next 50 and 100 years. In August 2012, it notified 1800 residents of predicted future erosion lines of their beachside properties, put the information on the Land Information Memorandum and

[G] Details available at http://www.boprc.govt.nz/environment/coast/coastal-care/ Accessed 4 May 2013 proposed amendments to its relevant policies. This led to an uproar, the formation of 'Coastal Ratepayers United', plus allegations that the expert's report was flawed and that the hazard lines 'present an overly alarmist picture'.[H] The Council was accused of 'taking beachfront properties by bureaucratic stealth'. In March 2014, an expert panel decided the lines were not 'robust'; more work will now follow. (The Dominion Post, 22 March 2014) Similar issues are likely to face other councils in the near future despite the preference in the NZ Coastal Policy Statement for a planned and managed retreat and the avoidance of hard structures. The above photo (Ross Giblin/Fairfax NZ) shows home-made sea walls for coastal properties in Raumati South, Kapiti.

Opting for 'soft' ecological over 'hard' engineering solutions to coastal erosion and rising sea levels is increasingly favoured overseas. The Dutch, who lead the world in designing engineering solutions to sea-level rises, are experimenting with adding volumes of sand to eroded coastal regions instead of hard structures. In 2011, the Delfland Sand Engine project (photo, right) created a two kilometre sand bar with an estimated 20-year life cycle in a high flood area to protect 8 million people.[85] About 20 million m^3 was put into the natural system and is expected to be re-distributed alongshore and into the dunes, through the continuous natural action of waves, tides and wind. Dune formation will occur gradually along a larger stretch of coastline over a period of 10 – 20 years, contributing to protection against flooding. Left alone for 20 years, it will provide an undisturbed habitat for wildlife. The conceptual framework the Dutch used identified three elements: a *resilient system* that can withstand disturbance; *social learning* that includes different stakeholder's views; *provision of ecosystem services* such as coastal defence and filtration of drinking water. This is a good example of applying a 'social-ecological systems' approach to the framing of a major environmental threat that has significant economic implications.

In 2011, a wide-ranging scientific review of the role of coastal wetland vegetation in protecting shorelines assessed whether it was the ecosystems, or other coastal geographical features, that were more important in providing protection.[86] It concluded that protection came from the vegetation itself. The plants slow water speed, reduce turbulence, trap sediment and enrich soil with organic material. It reported on a large scale study in Thailand; areas with mangrove forests had substantially lower erosion rates than those without. There was also evidence that coastal wetland ecosystems are able, to some degree, to protect against rising water levels from storms. Even small wetlands give substantial protection from waves since the relationship between wave attenuation and wetland size is non-linear. The review suggested that combining man-made structures with

[H] http://www.stuff.co.nz/dominion-post/comment/8410415/Kapiti-erosion-Head-to-head Accessed 4 May 2013 wetlands in ways that mimic nature is likely to increase coastal protection. There may also be benefits that help to counter rising sea-levels:

> "*Finally, coastal wetland vegetation modifies shorelines in ways that increase shoreline integrity over long timescales and thus provides a lasting coastal adaptation measure that can protect shorelines against accelerated sea level rise and more frequent storm inundation*."

In a broader New Zealand context this means making greater use of the many native plants that are superbly adapted to our harsh coastal environments whether it is mangroves in estuaries, gnarled pohutukawas on rocky coasts, pingao on dunes, or raupo, harakeke and even kahikatea in wetlands. The badly named cabbage tree (ti kouka), which is really a large tree lily, is also well suited to regenerating bush and coasts where it originally occupied small river flats and swampy areas.

These species will all thrive in places where diverse coastal ecosystems are given a chance to recover. This will require more than the local efforts of coastal care groups to make a significant difference given the scale of climate change impacts. It will require integrated planning approaches developed by regional authorities, with their communities, backed by strong, enabling legislation.

KEY POINTS

- Diverse approaches have been tried to strengthen the adaptability of coastal ecosystems to climate change impacts, ranging from the successful to the unsuccessful and harmful.
- Approaches can be called 'hard' or 'soft'. 'Hard' approaches that rely on structures, e.g. sea walls, often have negative outcomes and are increasingly being replaced by more dynamic 'soft' options that also are better for system resilience.
- Many New Zealand native plants, ranging from grasses to trees, are superbly adapted to our harsh and stormy coastal areas. These include pingao, raupo, harakeke, mangroves, ti kouka, pohutukawa and kahikatea in coastal wetlands.
- Studies have shown that shorelines are better protected by wetland vegetation than by other coastal features and vegetation provides protection against storms and rising sea levels.
- There is a strong 'coastal care' movement in New Zealand, supported by local councils. These are a good example of a positive and effective social-ecological response to coastal degradation.
- The magnitude of the threats to coastal ecosystems requires, however, a higher-level integrated planning and regulatory response to counter further inappropriate coastal development in the face of inevitable sea-level rise.
- The ethic of exploiting our coasts has lowered the resilience of many coastal areas and, unless it is transformed to one of ecological care, the exploitation ethic will be the major threat to protecting these crucial ecosystems in the future.

Adding 'resilience' to agriculture

The section summarising potential impacts of climate change on different agricultural systems stressed the point that impacts will vary considerably by region and land use. As a consequence, adaptation options will need to be regionally developed to be effective. Different regional economic and social systems are important overlays to add to this mix. This paper will not explore region-by-region options, but instead will describe a number of adaptation options for agriculture that are consistent with the theme of 'resilience thinking' and that will also enhance native biodiversity. The broad issue of farm resilience and adaptive capacity has been well researched by Gavin Kenny who worked with 'real-world smart farmers' to develop a comprehensive model of the multiple aspects of that constitute resilient farming practices in response to climate change in eastern New Zealand.[87] Kenny also stresses the importance of addressing 'the psychology of change' to get wider engagement on better approaches to climate change.

Looking after streams, rivers and lakes

Riparian zones are strips of land bordering rivers, streams, lakes and wetlands. They provide vital ecological functions in all terrestrial ecosystems and will be increasingly important for climate change adaptation. They have a disproportionately large influence on the stream conditions given the relatively small area they occupy. (Photo: John Gilardi, Golden Bay Streamcare) In farm pastures, planting up riparian areas keeps stock out of streams, filters and reduces the amount of undesirable nutrient run-off that enters waterways and creates suitable habitats for a wide range of native species. By establishing plants that overhang streams landowners can lower water temperatures and make conditions more favourable for native invertebrates that cannot tolerate high temperatures. Making streams and rivers on private land more resilient to the impacts of droughts will require more attention to good riparian management. The added benefit of reducing the nutrient levels is highly relevant in its own right, given the recent findings of the Commissioner for the Environment into the impacts of land use and nutrient pollution on water quality in New Zealand.[88]

Many native plant species are superbly adapted for riparian plantings, which is not surprising because they 'belong' there. Harakeke (flax) is an excellent 'starter plant' that can establish in grasslands and act as a nurse species for later successional plants. It is also drought-tolerant as well as flood-tolerant, making it ideal for many habitats from coasts to inland farms.[89] The likelihood of 'weather bombs' becoming more frequent, even in drought-prone regions, further underscores the value of good riparian management as a buffer against erosion along stream beds and in gullies after floods. A range of helpful publications on managing riparian areas are available, including from regional councils.

Riparian buffers of native forest within exotic forest plantations have equally high ecological values that need to be protected during logging operations. These can be maintained during logging operations by leaving intact buffers (average of 18 m wide on either side) otherwise clear-felling with logging slash in the stream means streams can take 7-10 years to recover.[90] This disturbance period is about one third of the time of each forest rotation. Forest roads and log landings can generate sediment that ends up in streams with harmful effects on in-stream Sspecies.

All of these benefits are threatened if owners do not maintain minimum water flows at key times when drought threatens. Where water is being removed from waterways for irrigation, use rates should always allow for minimum flows to be maintained for the health and survival of freshwater ecosystems.

Improving wetlands

The areas of New Zealand's wetlands have been reduced by drainage for pasture by about 85 percent in the last 150 years. Losses have been as high or higher in eastern regions of both islands where greater droughts are expected. Wetlands are highly productive ecosystems, support a wide range of plants and animals and provide a range of ecological and economic benefits that are generally undervalued (except by tangata whenua) and patchily addressed with respect to national and regional policies.[91] They will be increasingly important in the context of adaptation responses to climate change.

Wetlands provide many ecosystem services of indirect economic value. These include water storage and controlling floodwaters, waste disposal and water purification, erosion control, maintenance of water table and the retention, removal and transformation of nutrients. Yet their resilience and survival is under continued pressure from draining, grazing, nutrient runoff and the impacts of pest animal and plants. Their resilience will be further stretched by climate change as the vast majority of smaller wetlands are on private agricultural lands and afforded little protection. Wetlands play important roles in maintaining the resilience of agricultural landscapes and as such need stronger national policies, regulations and monitoring to prevent further losses.[92]

Introduced grey and crack willows (*Salix cinerea, S. fragilis*) have caused major problems in streams and wetlands and their further use in farms should bear this in mind. They invade and block waterways, change water tables, form a thick canopy that shades native plants that are not normally shaded and add leaf fall to a non-deciduous system. These species have been widely used along private waterways, spread readily and are expensive to kill. Like a number of other exotic species they have become 'tree weeds'. They are not 'friendly' to native ecosystems and there are more beneficial native species for the health of wetlands and waterways that would be better used instead.

The New Zealand Landcare Trust has developed a practical online resource (WETMAK) aimed at assisting community groups with the assessment and monitoring aspects of wetland restoration projects in New Zealand (http://www.landcare.org.nz/wetmak).

An excellent example of what can be achieved for farm values and biodiversity through restoration and removal of grey and crack willows is shown in the example of Lake Kaituna in the Waikato, an area once rich in wetlands (Photos: Waikato Regional Council).[l]

Lake Kaituna before restoration

Dense willow stands (left photo) meant surface water in downpours ran straight through the willows and into the lake along with damaging nutrients. Fencing and removal of willows (a seven year task) led to surprisingly rapid regeneration of native plants and more habitat for native and game birds. [93] Native sedges, rushes and shrubs act as far better wetland ’sponges’ than willows (right photo). This means soil moisture is higher in adjacent paddocks in the summer in dry times while winter conditions are also improved due to better water retention by the restored wetland. Stocking rates have not diminished, but nutrient inputs (and later losses to waterways) have been cut considerably.

Tree planting

Notwithstanding the negative comment about willows, there are many advantages to turning to exotic trees for multiple roles in adapting and mitigating climate change, particularly as a defence against drought. There are also risks from other ‘tree weeds’ that need to be avoided, however, if native biodiversity is to benefit.

South Wairarapa farmer, Peter Gawith, has been feeding willow and poplar cuttings to his sheep and cattle since the 1970s droughts as emergency feed. Plantings also protect the unstable hills (only 2 percent of the farm is flat) from flood impacts. Plantings now cover most of the farm such that in 2006 when 200 mm of rain fell in one event there was little damage. Research under the Sustainable Farming Fund found that high tannins in these willows and poplars aid digestion and help to improve and sustain lambing rates, even during droughts. The regional council sells 38,000 poplar and willow annually from its Akura nursery.

[l] More information on the Lake Kaituna story is available on the Waikato Regional Council website: http://www.waikatoregion.govt.nz/Environment/Natural-resources/Water/Lakes/Shallow-lakes-of-the-Waikato-region/Peat-lakes/Lake-Kaituna-B/ (Accessed 14 March 2104)

Willows and poplar cuttings are a well-proven source of reliable feed for cattle and sheep in drought conditions (refer above Box story[94]).Trees provide shelter and shade benefits for livestock and reduce physiological stress on stock when temperatures are extreme.

No tillage as mitigation measure

In 2013, Massey University research reported on the benefits of farmers using no-tillage technology both for climate change mitigation and soil health.[J] The press release quoted a soil scientist as saying "…the more progressive New Zealand arable farmers now lead the world in applying low disturbance no-tillage." The 3-year study, in line with overseas research, showed that tillage, or ploughing, releases about three tonnes per hectare more CO_2 into the atmosphere that Cross-Cut no-tillage technology which has been refined in New Zealand. No-tillage farming retains more carbon thus helping water retention, soil structure and microbes with more nutrients available to plants. There is considerable capacity, however, to increase the area in New Zealand currently seeded by no-tillage techniques (currently 20 percent). As the negative impacts of climate change put more stress on our soils such techniques will become more important in retaining healthy soils, increasing yields and thereby retaining the resilience of agricultural systems.

International implications of farming practices

In contrast to the beneficial effects of no-tillage systems, other farming practices have negative international implications related to climate change. Maintenance of high dairy stocking rates, including through droughts, is increasingly reliant on feed supplements such as palm-kernel expeller (PKE) which is a product of the palm oil industry in south-east Asia. Establishment of large palm oil plantations have been at the expense of tropical forests and accompanying increases in greenhouse gas emissions. More intensive farming in New Zealand has also required increasing volumes of synthetic fertilisers (from fossil fuels), particularly nitrogen. A 2004 report by the Parliamentary Commissioner for the Environment called for a 'redesigning for sustainability' of farming. This would be needed from the individual farm, to regional approaches (integrated catchment management) and at the national level (policies and strategies to support changes and appropriate economic instruments).[95] At regional and national levels such an undertaking would be most useful within a social-ecological system framework that looks at the resilience of the whole system rather than the economic profitability of specific agricultural activities.

A warning about grasses

One adaptation to drier conditions that has been suggested for pastoral farmers is to switch to more resilient grasses. This is a potentially useful approach, often promoted by agricultural specialists, but is one that can also carry significant risks for indigenous species. The report by the Chief Science Advisor on climate change implications mentions the option of shifting to faster growing, subtropical grasses and mentions kikuyu grass (*Pennistum clandestinum*), noting these grasses are already growing in northern New Zealand.[96] Kikuyu

[J] http://www.scoop.co.nz/stories/ED1306/S00006//massey-study-shows-harmful-effects-of-tillage.htm (Accessed 14 March 2014) grass is inexpensive, drought-tolerant and provides pasture for stock, but less energy than ryegrass or clover. It is also a rapid and aggressive plant, classified as a noxious weed in at least twelve countries outside its native Kenya. It has a high invasive potential, suppresses other plant species, chokes ponds and waterways. It produces herbicidal toxins that kill competing plants while its tangled mats can smother and kill small trees, including in orchards. Eliminating kikuyu is extremely difficult and its accidental spread via ploughing and digging machinery is common. The features of such grasses that attract farmers, namely rapid vegetative growth few pests and diseases plus drought tolerance, are also traits of invasive species.

Switching to more adaptive grasses is one adaptation to climate change, but wrong choices can have permanent and negative consequences for biodiversity despite potential benefits for a sector. Such an outcome may provide a 'quick biological fix' that puts the larger ecological system at greater risk.

Responses to drought

In 2008 and 2013, New Zealand farmers experienced what were both described as one-in-seventy-years droughts. Climate change predictions are that similar droughts will be likely in the future at a return time closer to ten years rather than one hundred years unless global mitigation efforts substantially improve. The photos (right) of New Zealand in March 2012 and March 2013 indicate the widespread impact of the latest drought on key North Island agricultural regions. The South Island agricultural regions were similarly affected. Papers headlined "The end of farming as we know it" (Sunday Star Times, 10 March 2013) reporting climate scientists as saying: "*Drought is likely to become the 'new normal' in some parts of eastern and northern New Zealand*."

How agriculture responds to the threat of more frequent droughts is a crucial issue for adaptation, not just for native biodiversity, but also for many rural communities and the wider economy. Options described above – better riparian management, improving wetlands, no-tillage methods and judicious use of trees and grasses – are important and effective solutions. They provide multiple adaptation benefits for farmland, biodiversity and mitigation. But collectively they would be insufficient should 'one-in-seventy-years' droughts become much more frequent. This especially applies to dairy farming with its demands for well-watered pastures. Leaving aside the current water quality issues associated with the unparalleled expansion of the diary sector[97] it also raises questions about the adaptive capacity of continued dairy expansion in regions likely to get drier in the future, such as Canterbury and the eastern North Island.

From the perspective that seeks higher stocking rates and maximum production per hectare, the answer is obvious – increase the capacity of irrigation systems. After the 2013 drought, Irrigation New Zealand, an advocacy group for irrigation interests, argued that "*Irrigation smooths out the climatic booms and busts of production, minimises risk and provides income certainty for farmers…*". It also argued that irrigation "*future-proofs all kinds of agriculture*" and "*…promotes sustainability, helping to ensure crops maximise the uptake of applied nutrients from the soil and convert this into quality produce of consistent yield.*" (The Dominion-Post 17 April, 2013)

This approach offers a technical fix to environmental adversity and promises to provide certainty and sustainability in an unpredictable, non-linear future. High debts carried by dairy farmers to pay for expensive conversions from sheep and cattle farms are also 'drivers' for more reliable water supplies. The current high prices for dairy commodities may justify that risk (assuming prices stay high for a long time) although the push for high stocking rates to maximise production and quickly reduce debt has been criticised on environmental grounds[98] as have the economics of big irrigation schemes.[99]

> **Ruataniwha Plains project**
> Hawkes Bay suffers from periodic droughts which are projected to increase in frequency. There are plans to build the country's largest water storage west of Waipukurau that would irrigate 25,000 ha and benefit farming for a variety of land users on a further 17,000 ha. Projected costs are around $250 M to build with costs of a further $300 M to farmers to get the water to their properties. Opponents are concerned about the heavy financial costs to ratepayers and adverse environmental impacts such as on the Tukituki River which is already polluted from farming runoffs. They argue it would be less risky and more resilient to make smaller on-farm investments and in the catchments. (Sunday Star Times 10 February 2013)

Adaptive farm systems

More ecological responses to drier conditions that do not rely just on irrigation are possible. Kenny consulted extensively with farmers and others in Hawkes Bay to increase their capacity to adapt to climate change by developing more resilient farming systems that are both economically viable and ecologically sustainable.[100] As well as water supply problems, monitoring was identified as important as well as the need for better information and education within the farming community. Work with 'smart farmers' showed what was possible and established local role models.

A more recent example of the benefits of adapting to nature and working with native biodiversity is the success story of Bonavaree Farm in north-eastern Marlborough. In this already dry climate with its thin topsoils an extended drier period for a decade after 1996 pushed many farms in the area close to collapse. The successful adaptive response was "*…to utilise water where it fell with plants that could survive drought and flourish when rain occurred*."[101] This was not possible with the usual ryegrass, clover and brassica-based system given the expense of re-establishing pasture after each drought.

Local farmers established the Starborough Flaxbourne Soil Conservation Group, obtained assistance from Landcare Trust and three properties were used to trial alternative systems. The outcome was a new farming system that relies heavily on extensive use of lucerne. The deep lucerne roots access soil moisture while lucerne fixes nitrogen that pastures need for growth. Lucerne produces large quantities of high quality feed at the end of a drought. It requires less fertiliser input and no extraction of water for irrigation. Less grazing on hill pastures has allowed vegetative cover to improve year by year. By 2012, gross profit had increased fourfold in a decade and the farm value has also quadrupled.

Farmers are justified in holding to conservative views on farming practices until they can be convinced of the benefits of change. “Show me the results” are best achieved with field days. A field day (above) at Bonavaree attracted over 400 farmers, scientists, local government officials, and rural service providers. (Photos by Alan Porteous and Anthony Clark)

Resilience thinking at work in the farm context
The story of Bonavaree and its recovery is a good New Zealand example of the application of resilient thinking to solve a significant land use problem. While resilience jargon does not feature in an article about the owner, Doug Avery, (North & South, November 2013, pp 66-71) all the key social-ecological aspects can be identified. Social resilience was built and strengthened through the creation of the soil conservation group and engagement with the NZ Landcare Trust. The research involvement of various experts over several years, along with on-farm experimentation, built up a good understanding of the variables in the system and how to manage them. In the process Avery came to appreciate the benefits of working within the limits and capacities of the natural systems. As well as winning the 2010 South Island Farmer of the Year award the owners at Bonavaree have also won an environmental award for preserving native habitats. Fencing off wetlands and bush gullies and planting more natives has improved the quality of the farm as well as adding to the farm’s value. “Non-productive’ farmland is actually quite productive when appreciated in its broader ecological context.

The slow, inevitable decline of soil quality through succeeding droughts could have become the slow moving variable that tipped this dry pasture system into another ‘system state’. The threshold of the system was lowering, and with it resilience was being lost. With more dry years it is likely this would have precipitated a ‘tip’ if farm practices had not been changed.

Adaptive farm systems: take home message

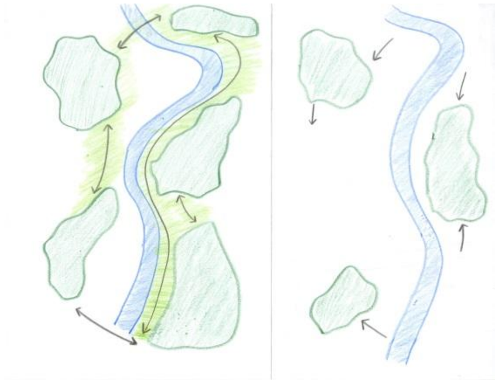
There are well proven options for improving the adaptive capacity of agriculture to major climate change that also enhance our biodiversity. Of those described above the non-use of irrigation in the dry Marlborough landscape of Bonavaree Farm presently seems the most radical. Yet it has quadrupled the value of the farm and improved native habitats of ‘non-productive' parts of the farm. In the context of a climate-stressed world and future surprises this approach of 'adaptive farm systems' may end up being the most conservative and also the most sustainable. In contrast, the push to maximise production of milk products per hectare by further intensification of our dairy farms comes at the price of less eco-efficiency than is obtained from low input systems.[102] Maximising production per hectare is also increasingly dependent on debt-funded irrigation infrastructure and high commodity prices in an unstable world. One of the lessons from the Goulburn-Broken Catchment case study (see earlier) was to recognise that being more efficient was not, of itself, a pathway to sustainability. Getting better at 'business as usual', continuing the same agricultural practices, ended up diminishing the resilience of the whole social-ecological system and undermining the wellbeing and prosperity of the community.

KEY POINTS

- As New Zealand's largest land use sector, the adaptations that are made on agricultural lands have enormous capacity to benefit both native biodiversity values and improve resilience for these land managers.
- Impacts from more frequent floods and droughts can both be reduced by establishing more riparian zones alongside streams and rivers and by the restoration and establishment of wetlands.
- These two adaptive measures have multiple benefits: improved water quality, reduced flood damage and erosion, increased habitat for wildlife, while better retaining water during droughts and building up carbon that helps with mitigation. These benefits all increase the resilience of the farm system.
- Riparian buffer zones can have similar benefits in exotic forests where their protection needs to be part of good logging practices.
- Many native plants are ideal for planting in riparian zones and wetlands where they naturally 'belong'. Harakeke (flax), native sedges, rushes and shrubs are far better 'sponges' than introduced willows that clog waterways, suppress native plants and do not retain surface waters in downpours.
- No-tillage technology reduces CO_2 releases and retains carbon. By benefiting soil health no-tillage methods improve the resilience of farmlands.
- There is a risk that in response to more frequent droughts too much reliance is placed on irrigation and use of resilient exotic species, including grasses.
- Irrigation alone does not bring the resilience to extreme events that riparian zones and healthy wetlands provide. Exotic grasses that thrive in droughts are often invasive and have caused extensive damage to native and productive landscapes in many countries.
- Farmers in drought-prone regions are already implementing adaptive practices that are consistent with the principles of working within complex adaptive systems and showing that protecting native habitats can benefit farm output and value.

Establishing wildlife corridors

Improving the survival chances of species and ecological processes by creating 'wildlife corridors' has long been an approach promoted by conservation biologists and managers. The potential value of corridors rises when climate change impacts are added to the mix. Corridors can provide an interconnected system of habitats which otherwise exist as dispersed and isolated fragments. The scale can be small or corridors can operate at much larger regional scales to link extensive conservation areas. There is considerable scientific and management literature on the theory and benefits of such corridors and they exist in many countries in response to the fragmentation of wildlife habitats.[103] While ecologists agree that landscape corridors are likely to benefit natural communities and ecological processes, there is debate over the best habitat configurations to achieve optimum results.



Creating corridors has been proposed as one adaption to climate change that would make it easier for some species to respond to shifting climate by moving from one area to another. Equally important is the ecosystem resilience that corridors can provide against climate change impacts (especially extreme events) by expanding riparian areas, creating larger buffer zones, restoring wetlands and generally improving the capacity of ecosystems to absorb and recover from shocks.

Reconnecting Northland
An ambitious large landscape restoration programme 'Reconnecting Northland' aims to restore and reconnect the landscape of Northland as a whole. It is a partnership between WWF-NZ and NZ Landcare Trust with support of The Tindall Foundation, HSBC and the ASB Community Trust. It aims to restore a range of natural processes and ecosystems across the whole region, while also building environmental, social, cultural and economic resilience. The intention is to create ecological corridors, buffer zones and riparian strips to reconnect a mosaic of ecosystems so they can function more efficiently as a whole landscape.

Building resilience against climate change impacts was one of the criteria behind the choice of Northland for this unique initiative. Northland suffers alternately from droughts (exacerbated by short rivers and small catchments) or floods from tropical cyclones, both of which are projected to markedly affect Northland in coming decades. Effective restoration will reduce the damage from erosion, retain more water in times of drought and improve habitat for endangered species already threatened by introduced plants, predators and habitat fragmentation. Half the northern kiwi populations are on private land which makes landowner and iwi involvement critical.

Funding of about $3 million is secured for the first five years. Smaller pilot projects are already underway with local iwi and communities supported by partnerships with businesses, local and central government agencies, science providers, and others.

The Northland restoration initiative (box above) may set a successful example that other regions follow, both to offset climate change impacts and improve the survival chances of many of our endangered species, especially the less charismatic invertebrates and plants. Certainly there will be a great deal of social and ecological learning out of this project that will benefit any that may follow.

Wildlife corridors and related ideas for restoring native biodiversity are particularly relevant on private land where loss of habitat and ecosystems continues to be the major threat to many of New Zealand's endangered species. This applies to iconic species (e.g. half of the Northland populations of kiwi are on private land) as well as to the less visible plants and many invertebrates. (Photo: Whangarei farmland) Unfortunately the habitats of a high proportion of New Zealand's endangered species are on lands that enjoy low levels of legally protected status. Losses of these crucial, but unprotected biodiversity habitats are continuing.[104] This is made worse in regions such as Canterbury with the additional overlay of future risks from climate change (especially drought) in areas where dairy conversions increase the demands for already over-allocated water and diminish habitats (especially fresh-water) for wildlife.

KEY POINTS

- Establishing wildlife corridors has multiple benefits in the context of climate change adaptation.
- Connecting isolated areas of habitat can make it easier for species to shift from an increasingly unsuitable climatic zone to one that makes survival more likely.
- When wildlife corridors include expanded riparian and wetland areas they can add all the climate-associated benefits that those ecosystems provide.
- Wildlife corridors and restoration initiatives have particular value on private lands where important and endangered native habitats are steadily being lost in the absence of any protective status.

Forestry and adaptation

Forestry may become a more attractive land use option for storing carbon and providing more wood products that use less fossil fuel to produce. Production of biofuels as a renewable energy initiative and mitigation measure may also stimulate the planting of new woody species and certain grasses.

The concern for indigenous biodiversity in either option is the risk of adding to the problems already evident from 'tree weeds' or through the introduction of possible biofuel species that are invasive. The concerns described above regarding grasses that might be drought resistant, but also invasive, applies equally to potential biofuel species. There are numerous sources that detail lists of biofuel species, either in use or proposed, that are invasive and should be avoided.[K]

The Australian Invasive Species Council has warned that the hype surrounding a potential biofuels industry risks adding to Australia's weed invasion problems that already cost agriculture alone $4 billion a year in control and lost productivity.[105] In addition, extreme weather creates more opportunities for weeds to replace native species.[106] Weed species are often less vulnerable than native plants to droughts, fires or floods and quickly colonise bare spaces after extreme weather events. The C3 weeds (using one of two types of photosynthetic pathways) benefit from higher CO_2 levels. These include the brooms, gorse and acacias whose growth will be stimulated by CO_2 levels and not constrained by low nitrogen levels. The same favourable CO_2 conditions will also make them more water-efficient potentially allowing them to move into drier habitats and become weeds.

The section headed 'Weeds' under 'Climate change impacts on biodiversity' describes the existing serious weed problem caused by ecosystem transforming weeds, many of which are tree species. There is a long list of such species, including shrubs, which are well known to regional councils and other management agencies, including the Department of Conservation.

Tree planting for erosion control usually relies on exotics such as poplars and willows due to their rapid production of roots that stabilise soil and hillsides. Planted forests have shown the value of having tree cover in place on unstable soils before major storms; events that are projected to happen more frequently even in drought-prone regions. The photo (by Graham Hancox) shows the benefits of forest cover after a 2004 storm in the Manawatu region. Native forest cover has the same stabilizing effect in similar landscapes.

[K] For example: www.issg.org/database and www.invasives.org.au

Wider use of native species would help restore our original landscapes while also reducing erosion. Although native species have been used sparingly and few are known to colonise bare soil there have been promising new studies on the stabilisation characteristics of native trees and shrubs.[107] More research on the suitability of other native plants for erosion control would be a positive step. Toetoe (*Austroderia* spp.) and harakeke have shown the greatest total root length – 500m develops within three years. While this is less root length than willows or poplars produce, roots of these natives tend to be stronger and are a viable option from nursery seedlings in a 3-year time horizon.

Cabbage trees (ti kouka, *Cordyline australis*) are also valuable as an erosion control species as they produce high above- and below-ground biomass and deep roots. (Photo by Margaret Todd.) Both ribbonwood (*Plagianthus regius*) and manuka (*Leptospermum scoparium*) also have very good root spread and are ideal for erosion control. Manuka's national distribution, tolerance of wind, drought and frost, as well as being unpalatable to cattle, sheep and goats makes it an ideal candidate for use in erosion control. Unlike exotics, manuka provides an ideal nursery cover for other, slower growing native plants. Overturning a century of farmer prejudice against manuka and kanuka as 'unwanted scrub' remains a barrier to their wider use. The high market value of manuka products is helping to replace those pioneer attitudes with a positive view of its worth, something Maori have long held.

KEY POINTS

- Exotic forestry will continue to be an important component in the New Zealand economy. Exotic forests, as well as native forests, can provide benefits by reducing erosion in regions of unstable soils where extreme storms are more likely in the future.
- There is a risk that pressures to grow exotic species for biofuels could lead to the introduction and establishment of more 'tree weeds' a role that wilding conifers now play in many regions of New Zealand. Biofuel species have many characteristics common to invasive weed species.
- Much more use could be made of native tree species in the context of planting trees to reduce erosion. New research has shown the benefits of planting toetoe, ti kouka, ribbonwood and manuka given their strong and spreading root systems that effectively hold soil.
- Manuka is a particularly hardy plant in a range of conditions as well as being unpalatable to cattle, sheep and goats.

Are our social/political systems ready for climate change?

This think piece has traversed various topics related to adaptation options for land managers that would also enhance our native biodiversity. They range from well-known, on-farm practices to catchment and regional scale restoration options, from minor land use changes to the option of making major shifts in agricultural paradigms and practices. That same scrutiny could be applied to other land use activities including energy and forestry.[L]

All mitigation and adaptation options, small and large, need people or organisations to implement them. This section will briefly look at the sorts of social and organisational systems best suited to successfully implement adaption practices. There is a larger question, not explored here, but which needs to be discussed if mitigation and adaptation endeavours are to have long-term value. A significantly changed climate in a country highly reliant on generating wealth from primary production will eventually challenge the *status quo* social contracts between citizens and the state. Resilience thinking provides valuable insights into what types of social contracts we are likely to need in the context of climate change, given our current development pathways are tending to undermine our future wellbeing.[108]

At the scale of individual landowners, mitigation and adaptation in the context of resilient farming, as Gavin Kenney has argued, requires ongoing communication and education, coordination between all parties, support for on-farm innovation and, importantly, role models of what sustainability and resilience means in practice.[109] Kenny's research shows that many farmers are aware that profitability increasingly needs to be measured against long term sustainability, given recent droughts and pollution issues. The potential gains for native biodiversity are considerable, but will require a broad approach between individuals, communities and institutions as Kenny has identified.

The psychology of change is complex, however, and involves a multi-faceted approach including environmental knowledge, community engagement, effective legislation and a shared vision for the future at the catchment level between land managers, local communities, researchers, policy-makers and regulators. These are some of the conditions identified in a study that drew out key lessons on how science and environmental knowledge have been used in the past in New Zealand with respect to land management to achieve desired environmental outcomes.[110]

Early adapters, such as Doug Avery and the Hawkes Bay farmers described by Gavin Kenny, are crucial to increasing the rate of acceptance of new adaptive approaches of farming along with the add-on benefits to biodiversity. Behavioural research suggests that attitudinal changes follow behavioural change, not the other way around. Early adaptors help to re-define social norms, make the positive changes on the ground that others aspire to, and then try out for themselves. Over time, these successes change wider group

[L] For example, on 1 August, 1975, nor-wester winds up to 170 k/h flattened a plantation of mature *Pinus radiata* trees in Eyrewell Forest, Canterbury. With more frequent storms and higher fire risk such plantations may well be uneconomic or too risky to plant in some places currently growing *P. radiata*.

perceptions of what 'works' and move local attitudes to new norms. Adaptive practices can be effectively implemented when communities have the capacity to work together, with good local networks and high levels of social resilience.

At this time we may not be facing the New Zealand equivalents of inexorable rising water tables or the collapse of coral reefs as described in the case studies. Nonetheless, it would be useful to look our institutional and social systems through the framing of social-ecological systems and ask if they are fit-for -purpose or could be improved, i.e. made more resilient and responsive to the unexpected shocks that are increasingly likely from climate change.

Such is the complexity of climate change issues that some commentators are questioning if we need different governance forms that are more responsive to the unique challenges and scales of climate impacts. In particular there is a need for governance structures and institutions that are flexible, deliberately open to learning and experimentation, more participatory, and include 'redundancy'. In this context redundancy in institutions serves to increase the system's diversity and flexibility when circumstances suddenly change.[111] This is different from the usual meaning of redundancy as a reduction of staffing numbers to levels to provide basic services. A study of the implications of climate change for New Zealand's biosecurity framework provides one example of the relevance of questioning the adequacy of institutional structures.[112] The report concluded there is a tension between the increasingly formally organised nature of biosecurity and the high levels of uncertainty that are associated with climate change. Resolving this tension remains an institutional challenge.

One concept gaining popularity is 'multi-level governance' (sometimes called polycentric governance) to develop flexible solutions and self-organisation where more formal procedures seem to fail. This thinking has been applied at the global level of governance for climate change.[113] A good example of this approach in New Zealand is the Land and Water Forum. This Forum was set up as an independent body by the government to develop a consensus view on how to improve the management of New Zealand's freshwater resource. It was a successful attempt to resolve conflicts over water use that had been unresolved for decades given the conflicting objectives of numerous stakeholders. Over three years, more than 60 stakeholder organisations developed the trust necessary to deliver a new consensus for a major reform of water laws and practices. Its third report recommended integrated decision-making at the catchment level, community engagement, continuous improvement of management practices to improve water quality and clearer rights to take and use water within set limits. Regions would be accountable for managing within limits.[114] Realising the gains made on paper by the Land and Water Forum depends on how central government responds to its recommendations. This would require retaining the necessary regulatory functions at regional level.

The common elements to these initiatives are flexible learning institutions, mechanisms for effective community engagement and education, strong and responsive local structures for governing with necessary regulatory and monitoring powers. It would be useful to evaluate proposed reforms of the Resource Management Act in this light to see if they will enhance or diminish these capacities at regional levels.

In the absence of good policy and fit-for-purpose institutions there is always the potential for 'maladaptation'. This is defined as "*Action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups*."[115] Barnett and O'Neil define five types of maladaptation: increasing emissions of greenhouse gases; disproportionately burdening the most vulnerable; high opportunity costs; reducing incentives to adapt; path dependency.

Large irrigation schemes such as the proposed Ruataniwha Plains project arguably meet all five criteria for maladaptation responses.

The 'business as usual' attitudes or opting for quick fix mitigation or adaptation solutions to big climate problems are likely to lead to maladaptation actions and negative outcomes for biodiversity. In the context of growing national wealth and increasing exports, spokespeople for agriculture and forestry interests reasonably argue that long-term investors need policy stability and certainty. Unfortunately, the only certainty that future climate change offers us is unexpected and, sometimes, unpleasant surprises. Pressure to provide investor certainty can lead to policy trade-offs and subsidies for the *status quo* that increase short-term certainty, defer adaption options, and increase long-term risk by lowering resilience even if there are gains in efficiency.

When we consider the many adaptation options available to benefit our biodiversity from climate change impacts, across small to large scales, it is clear that resilient communities and responsive, fit-for-purpose institutions, capable of learning and adapting themselves, will have crucial roles to play. It will be as important to debate, discuss and improve these components of our social-ecological systems as it is to reduce emissions.

KEY POINTS

- The earlier case studies and the literature on social-ecological systems underline the relevance and importance of developing social and institutional systems that are resilient and responsive to the challenges of climate change.
- In the absence of policy and fit-for-purpose institutions there is a greater potential for 'maladaptation' leading to poor adaption responses.
- Different governance models may be better suited to respond to the unique challenges of climate change than our current institutional structures. It is timely to have a discussion on these topics at national and regional levels.
- Are our legal, institutional and social systems fit-for-purpose to implement positive adaptive responses or could they be improved?

Conclusions

This think piece has identified a range of options open to land managers for effective and positive adaptations to climate change that will also benefit New Zealand's native biodiversity. These options are realistic and sustainable; they will add to the resilience of natural systems and take them away from thresholds where stresses might otherwise push them into less preferred and degraded states. It has not explored the future possibility that major changes in climate could make adaptation impossible for some current land uses, whether for ecological, technological or economic reasons. Given that current projections are for greenhouse gas emissions to continue rising to dangerous levels the inability to adapt to all future situations remains an unwelcome possibility. Unfortunately, the human capacity to believe current problems will eventually be solved ignores lessons from history and is used as a justification for deferring tough decisions.

Climate change projections for how the different regions of the country will be affected by changed rainfall, more extreme events, warmer winters, sea-level rise, etc. are now well researched. Changes in rainfall patterns and increased frequency of extreme events (e.g. droughts, storms, floods and fires) are probably the more significant threats with respect to native biodiversity. It is less clear how biological systems will respond although broad impacts have been identified for some ecosystems (coasts, freshwater and forests) and for processes such as predation, invasive weeds and increases in fires. These are summarised in the paper.

In brief, given the inevitable rise in sea levels coastal ecosystems will come under further pressures that are already severe from poor coastal developments, pollution, agriculture and habitat destruction. Freshwater ecosystems are under often stress now or have been destroyed (especially wetlands). More severe and frequent droughts, coupled with increased extraction of water for irrigation, will add to these stresses. Likely impacts on our diverse forest ecosystems are harder to identify. They may be more threatened by fire and extreme events, although they have been shaped by floods and droughts in the past. Threats may come from unexpected and unpredictable sources, such as currently benign forest insect pests, native or introduced, that might become more destructive.

New Zealand already has major weed problems. The characteristics of weedy species are favoured by climate change impacts as floods and erosion provide bare patches that weeds can quickly invade and become established. Native ecosystems can be the losers. The 'ecosystem transforming weeds' includes ten conifer species; some could move into alpine zones as temperatures warm. In the north of the country tropical weeds that are already present will benefit from warmer conditions and add to the stresses on the remnants of native ecosystems that remain.

How might land managers respond positively to these changes and improve conditions for native biodiversity while avoiding mistakes? The framework for action that is most likely to be effective is to acknowledge that we operate within social-ecological systems that vary in their 'resilience' to shocks and disruptions. The definition used in this paper is: "*Resilience is the capacity of a system to absorb disturbance and still retain its basic function and* *structure."* It is more about the ability to bounce back, rather than the time it takes to do so. It is a characteristic of both social and ecological systems. Both are also 'complex adaptive systems'. This means that they are not predictable, behave in non-linear ways and when management focuses on optimising just one part of the system then long-term problems are more likely to emerge. Two case studies were included to show how analysis of ecological disturbance in terms of resilience theory provides insights into why systems might collapse unexpectedly and how increasing the resilience of systems can prevent collapse or irreversible change. They also point to the key role played by management agencies in the process.

Adaptive management at the scales described in the case studies required action over large landscape scales and multiple organisational levels. It needed to be guided by appropriate policy frameworks. In New Zealand, the policy framework to guide an appropriate response to climate change impacts on native biodiversity is poorly developed. Consideration of climate change impacts is absent from the 2000 Biodiversity Strategy and from the proposed National Policy Statement on indigenous biodiversity. In contrast, extensive analytical work on climate change impacts has been done in Australia where various studies and reports have identified the need to adjust policy and regulatory frameworks, alter institutional arrangements, reassess governance systems, and rethink planning and management approaches to conservation. The importance of enhancing ecosystem resilience while 'expecting the unexpected' from climate change is a theme that runs through the Australian approach.

Although the current policy gaps in New Zealand make a piecemeal response more likely there are a variety of options available to improve resilience and enhance native biodiversity on private lands in agricultural and forestry settings. Coastal management options to adapt to climate change impacts can use native species to good effect. The active rehabilitation of streams, rivers, lakes and wetlands within agricultural lands has been widely and successfully achieved throughout the country. Native plant species used for riparian plantings and wetlands have increased the resilience of these habitats to extreme events, such as flooding and droughts, and are more effective than introduced species in many situations. Use of no-tillage technology maintains healthier soils than ploughing and releases less carbon dioxide.

Exotic tree species can be used in the adaptation tool kit. They provide important shade and fodder crops, especially in heat and droughts, although it is important to avoid adding to New Zealand's already significant weed problem by using the invasive species. In this context, the introduction of drought-resistant grass species is often proposed as a solution to drought conditions by agriculturalists. While they may be adaptive, there is a critical obligation to avoid introducing grasses that are highly likely to become invasive pest species as has happened in other countries, including Australia.

One point made in the paper is that some adaptions may be maladaptations in the long-term. Invasive grass species are one example. Another is the recourse to large irrigation schemes as the technological solution to meet expanding demands for water now in eastern regions that are likely to be more prone to droughts in the future. This is a good example of a 'business as usual' response to a future that looks increasingly unlikely to be a repeat of the past. In the short term, large irrigation systems might meet the needs of farming practices that rely heavily on large volumes of water to grow lush pasture. Given the high proportion of water that is already allocated in our drier eastern regions this response becomes increasingly vulnerable when droughts become more frequent. Such pressures will add to the importance of freshwater adaptations and the maintenance of adequate water flows for plant and animal life. In contrast, many ‘smart farmers’ recognise the future is going to require more complex approaches to climate change and have already been adapting their farming systems accordingly. Significant benefits can accrue to farm profitability and biodiversity alike as the example of the radical changes that were made at Bonavaree Farm in the dry Marlborough landscape clearly demonstrate. These ‘adaptive farm systems’ show how principles of resilience thinking are being applied in New Zealand, albeit at a local scale at present.

The final section in the paper asked whether we have the social and institutional systems that are themselves sufficiently resilient and adaptive to be able to deliver the sorts of changes that are needed. While individuals can, and will continue to make smart adaptation decisions, it is at the level of community, legislation, regulation and institutions that the test of how resilient our special landscapes and biodiversity are to climate change will ultimately be played out.

Figure 2. Projected changes in temperature

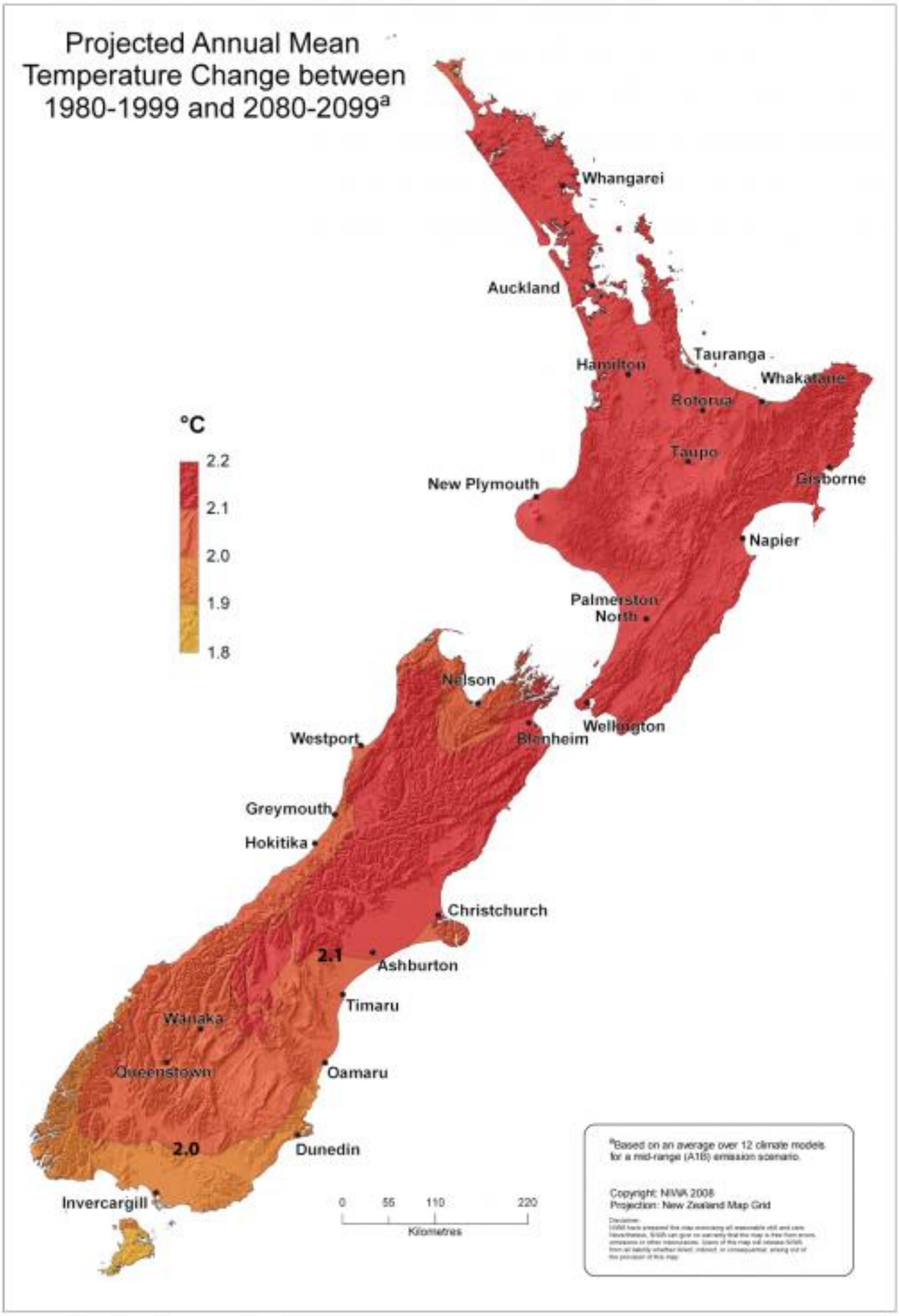
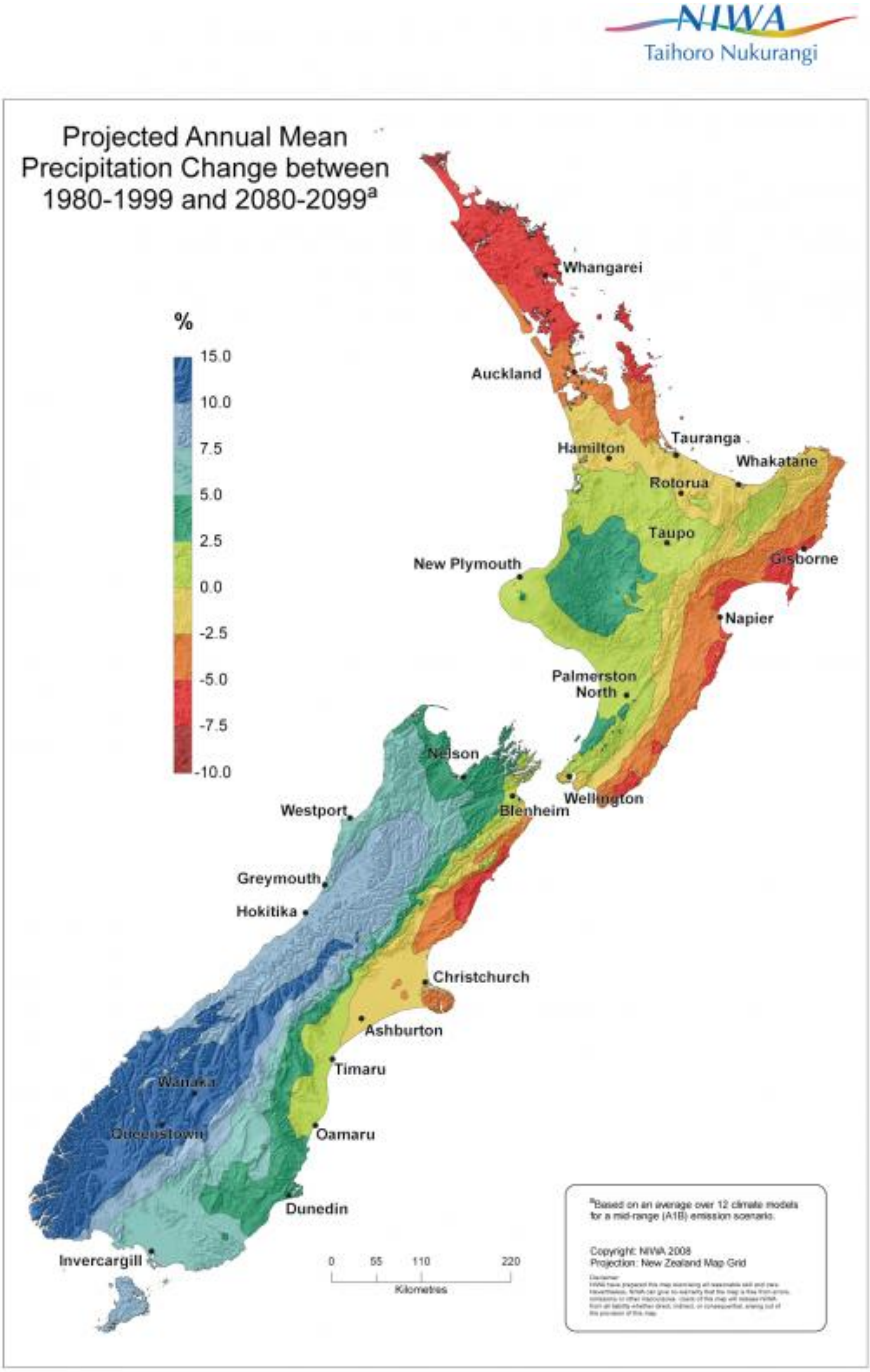


Figure 3. Projected changes in precipitation



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