JOURNAL OF THE ROYAL SOCIETY OF NEW ZEALAND
2024, VOL. 54, NO. 4, 523–546
https://doi.org/10.1080/03036758.2023.2267016

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REVIEW ARTICLE

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Climate change impacts on Aotearoa New Zealand: a horizon scan approach

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ABSTRACT

Many of the implications of climate change for Aotearoa (New Zealand) remain unclear. To identify so-far unseen or understudied threats and opportunities related to climate change we applied a horizon-scanning process. First, we collated 171 threats and opportunities across our diverse fields of research. We then scored each item for novelty and potential impact and finally reduced the list to ten threats and ten opportunities through a prioritisation process. Within the 20 items presented in this paper, we uncover a range of climate-related costs and benefits. Unexpected opportunities evolve from economic reorganisation and changes to perspectives. The threats we highlight include the overall failure to interconnect siloed policy responses, as well as those relating to extreme events and feedbacks, as well as pressures that undermine the coherence of society. A major theme of our work is that climate change effects in Aotearoa are likely to transgress the boundaries of research disciplines, industry sectors and policy systems, emphasising the importance of developing transdisciplinary methods and approaches. We use this insight to connect potential responses to climate change with Aotearoa's culture and geography.

ARTICLE HISTORY
Received 31 March 2023
Accepted 27 September 2023

KEYWORDS
Climate change; adaptation; mitigation; transdisciplinarity; climate consequences; complex systems; extreme events

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/03036758.2023.2267016.

Introduction

The impacts of climate change are broad-reaching and some impacts will be difficult to predict (Macinnis-Ng et al. 2021; Kemp et al. 2022). Many of the anticipated solutions to problems caused by climate change focus on the perspectives of large centralised economies. Examples include the development of the solar industry in China or electric car manufacturing in the US, Asia and Europe (Hawken 2017). It is often unclear how such solutions will play out in other regions (Lyth et al. 2016). To highlight issues that are likely to emerge in Aotearoa, we used a method known as 'horizon scanning' to identify key, under-discussed topics relevant to Aotearoa's response to climate change.

Distinctive features of Aotearoa will inevitably interact with climate change responses. Aotearoa is in a unique geographic position as a continental landmass, largely isolated from other geographic or population centres. This comparative isolation shapes Aotearoa's ecology, culture and economy. For example, Aotearoa's isolation over millions of years has produced a distinct biological assemblage with many endemic species. Some examples of this phenomenon are iconic, such as kiwi, (Bellingham et al. 2010). This isolation also shapes the vibrant mixing of Māori, Pākehā (European), Pasifika and other cultures. Isolation has also had economic implications, stereotyped as *the tyranny of distance,* causing reliance on primary production (with dairy, meat and forestry as the top three export industries), and difficulty connecting value added manufacturing to distant markets, except for niche industries (Easton 2020).

Given the uniqueness of Aotearoa and the predicted effects of climate, issues are likely to emerge here which are not well-known elsewhere or issues may be expressed differently here. To identify a collection of potential topics, we use a horizon scan approach (e.g. Sutherland et al. 2011; Stanley et al. 2015) to collate climate change issues. All authors are members of Te Pūnaha Matatini (TPM, The Centre for Research Excellence in Complex Systems). We are a research cluster that includes a diverse range of specialties, with members from all six of the universities and many of the other research facilities across the country. Our team draws on its diverse disciplinary backgrounds and approaches to research to explore a complex problem in a novel way. Our aim was to draw on the collective expertise of TPM to produce a collection of areas for further research that stretches across disciplines. Despite the unique suite of characteristics of Aotearoa, many countries, or regions (Lyth et al. 2016) share similar population size, isolation, island systems or other characteristics that will lead to commonalities in impacts of climate change. Therefore, we expect our findings to be relevant to a range of smaller countries around the world.

Materials and methods

Horizon scanning is an established method used by ecologists to identify potential emerging threats (Stanley et al. 2015). It is a systematic approach to identifying medium- to long-term threats or opportunities that have not yet been identified in a particular field (Sutherland et al. 2011) but in a defined geographic area, they may also be threats or opportunities that are known elsewhere but have received only limited attention locally. In brief, the process involves a broad call for predicted issues/challenges or opportunities that are receiving little attention in current research efforts. In our case the call went out to members of TPM and 20 investigators responded with suggested challenges and opportunities. These items were collated into a long list. This list was organised to clarify writing and merge overly similar items, and then the team of authors ranked the items independently to focus on a short list of the top 20–30 items in each category of challenges and opportunities. These were scrutinised one-by-one as a group to identify the top 10–12 likely important items requiring research in each category. For our scan, the focus was on uncovering potential threats and opportunities that are both novel and of importance to Aotearoa. Important threats were likely to be highly impactful (economically, ecologically, environmentally), while important opportunities were likely to be highly beneficial. Some of the items may not be completely unknown but are understudied or have received less attention to date. The process draws heavily on the collective expertise of the team to inform decisions around which items score highly. Our expertise includes environmental science, ecology, complex systems, physics, science and policy, climate science, science communication, human geography, ecological economics and Indigenous philosophy (see Table S1 for full details). Therefore, the resulting list is not intended to be an exhaustive collation of future threats and opportunities but it is indicative of some potential areas that need further investigation based on broad expert opinion. The details of the steps in our horizon scan process are outlined in Figure 1. At each scoring step, participants were asked to focus on novel and important climate change related issues that, based on their knowledge and experience could impact Aotearoa in the medium to long-term (several decades or more). Some items may be well-established elsewhere in the world or may not be unique to Aotearoa.

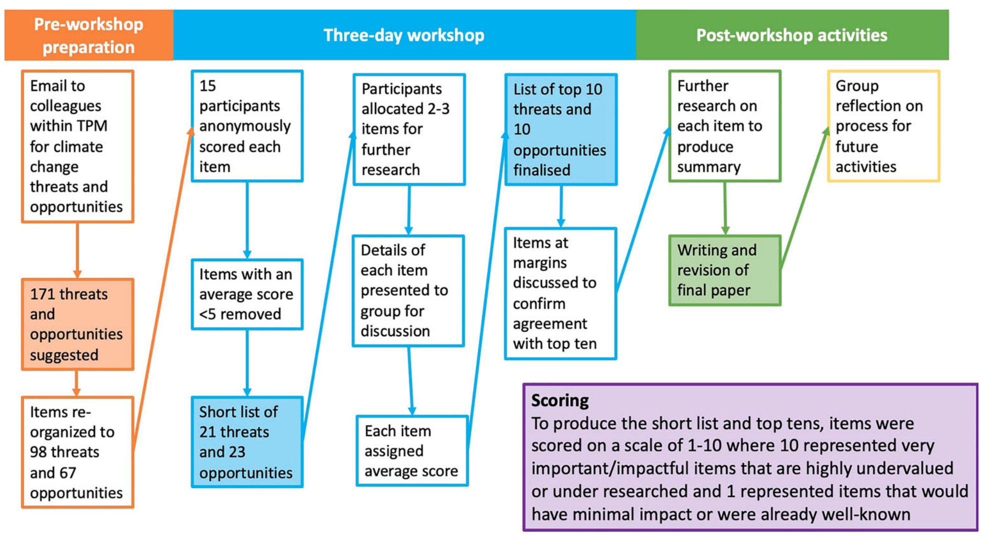

Figure 1. Schematic diagram of horizon scanning process for our paper. Activities were divided into pre-workshop preparation, a three-day workshop and post workshop paper preparation and reflection. Scoring for ranking of items was based on a scale of 1–10 as explained in the scoring box. TPM is Te Pūnaha Matatini, the Centre for Research Excellence in Complex Systems.

Results

Our results identified several overarching themes (grouped after the top tens had been decided), including opportunities for cultural change, and opportunities for economic reorganisation. Threats can be organised into social issues, extreme events and poorly understood feedback between living things and the environment (Figure 2). Throughout we highlight how these general themes relate to issues particular to Aotearoa.

Opportunities

Economic reorganisation

Benefits from deploying technological solutions

Callaghan (2011) set out to understand where and how Aotearoa could succeed with technological development. Many of Callaghan's points shed light on the role of technology in Aotearoa's response to climate change. Aotearoa has a comparative advantage in developing 'weird and weightless' high-tech export products with global reach, such as software and digital technology development. Such products may represent a small portion of the global market but still be significant at the scale of Aotearoa's economy (0.2% of the global economy). Existing examples are Sauvignon Blanc wine and mānuka honey, which have a high value for their weight.

Aotearoa has the opportunity to develop high-tech products to mitigate climate change. Propelled by Aotearoa's abundant renewable energy sources we can shift away from fossil fuels at nearly every level of our economy. At the top of our opportunities

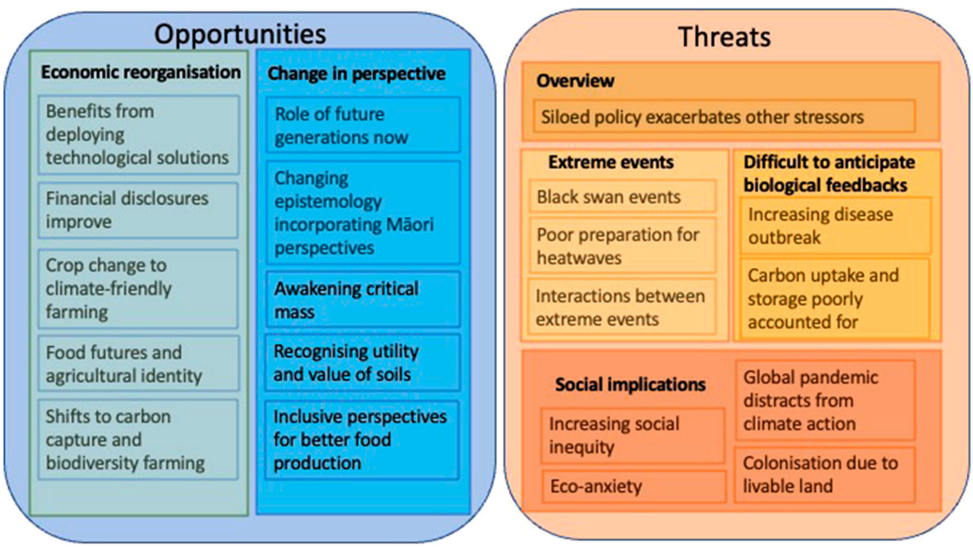

Figure 2. Summary of opportunities and threats identified through horizon scanning. Opportunities fell into two main groups reflecting economic and social opportunities while threats fell into four groups associated with broad issues, extreme events, biological feedbacks and social implications. The groups were created by the lead authors after the top ten threats and opportunities had been identified, to provide some structure to the results and for synthesis in the discussion.

for transformation is transport, which is about three times more efficient when converting electricity to motion, compared to fossil fuels (Climate Change Commission 2022). For example, Wellington Harbour now features the Southern Hemisphere's first routinely operated full battery electric ferry service (Tso 2022). The same economic imperatives that drove previous waves of innovation in Aoteraoa's economy have an important role to play in mitigating the effects of climate change. We acknowledge that this opportunity may not be newly discovered but we believe there is huge potential for research and development in this space.

O2. Improved financial reporting of climate related risk drives transparency and transitions

Aotearoa has the opportunity to better understand the local economic impacts of climate change. Financial damages are amongst the most significant climate change risks (Ministry for the Environment 2021a). As of now, there are difficulties in using climate projections to manage climate-related financial risks across economies (Fiedler et al. 2021). For example, accurate climate risk assessments at the individual asset scale are often felt at scales much smaller than those typically simulated by regional climate models.

In response to this, Aotearoa's government has led the way in moving towards mandatory reporting aligned with the Taskforce for Climate-Related Financial Disclosures (TCFD). This would require organisations to disclose their vulnerability and exposure to climate-related risks in their annual financial reporting (TCFD 2020). The National Climate Change Risk Assessment (Ministry for the Environment 2020) identified knowledge gaps associated with 'how climate change will affect the banking and insurance sectors, and the flow-on effects on the financial system'. This likely represents wider concerns around critical knowledge gaps and a lack of tools for quantifying risk and fulfilling reporting requirements (Edwards et al. 2020). Developing and improving estimates of financial risk may have significant benefits for Aotearoa and elsewhere, by providing information to efficiently mitigate the worst potential effects of climate change. This is a rapidly evolving space that deserves ongoing attention as significant capability building will be required to support these efforts.

O3. Responses to climate enable shifts to more sustainable food production

At present, some agricultural practices are detrimental to our natural environment and health (Swinburn 2019; Ministry for the Environment 2019) but responses to climate change are likely to shift modes of agricultural production and this is particularly relevant to Aotearoa with an economy that is currently heavily reliant on high-methane agriculture. Encouraging a lower emissions diet can reduce greenhouse gas emissions by 15% (Barnsley et al. 2021), since greenhouse gas emissions from plant-based foods (and some seafoods) are lower than from animal-based foods, even in Aotearoa (Drew et al. 2020).

Parts of this transition have already begun. Internationally, food technology for producing animal cell-generated meat and dairy, and cow-less plant-based dairy (Waltz 2022) is advancing rapidly with huge potential for New Zealand industry and consumer takeup. Effective ways to encourage people to consume less meat and more plant-based foods are also being developed (Attwood et al. 2020). Changes that make plant-based food more accessible to consumers will also improve water quality (due to reduced effluent from cattle) and health outcomes. While willingness to shift to plant-based diets is associated with a number of behaviours (Wang and Scrimgeour 2021) and political beliefs (Milfont et al. 2021), growing environmental concerns are likely to shift demand for more sustainable food options (Wang and Scrimgeour 2021).

O4. Adopting sustainable practices by re-thinking agricultural identity

Changes in the food system of Aotearoa are not just a matter of economic reorganisation. They also bring opportunities to re-think cultural assumptions about farming and food. Food is tightly linked to culture and when food is used to distinguish people from other groups, it is known as food identity. Aotearoa's modern food identity has been tied to its colonial history which has strongly influenced Aotearoa's landscape (Pawson 2018). From land dispossession to a series of practices that included draining of wetlands, chemical intensification of land, and agricultural management to establish 'empires of grass' (Pawson and Brooking 2008), Aotearoa has physically been reconstructed as an 'English farm in the Pacific' (Singleton and Robertson 1997). This has implications for the ways our nation might adopt new climate conscious food futures, including food economy interests that are reimagined with Indigenous food production knowledges and practices intact.

There is a growing market for premium, eco-friendly foods. A historical survey found international consumers would purchase 54 percent less Aotearoa-sourced dairy products if they were perceived to be environmentally degrading, with a potential loss to the Aotearoa economy of $241 to $569 million (Ministry for the Environment 2021). There are potential opportunities to capitalise on the willingness to pay extra for specific food attributes. For example, consumers in China, UK and India, showed an increased willingness to pay for lamb, meat and dairy products that are officially certified as minimising emissions (Tait et al. 2016).

O5. Redesigning farming to value shift to carbon/biodiversity

There can be a tension between farming for food products and farming for carbon capture and storage because agriculture emits carbon. Economic theory suggests that one of the most effective tools to reduce CO_2 emissions is a cap and trade scheme for the right to emit CO_2. Aotearoa's emission-trading scheme (the ETS) was phased in in several sectors from 2008, including forestry, with mandatory emissions liabilities and voluntary credits. Pricing mechanisms changed to overcome low prices associated with banked units and free allocation, with auctions beginning in June 2021 (Leining 2022). Auctions have seen the price of emissions rise steeply, and since early 2022, the right to emit one tonne of CO_2-equivalent (a NZU) has traded above NZD 60 (but dropped to NZD 56 as of 31st March 2023, rising to NZD 65 on 26th July 2023 before falling again). Changes in the price of carbon have the potential to dramatically increase the profitability of forestry in Aotearoa but this is a highly active space politically at time of writing.

At present, the scheme favours the planting of fast-growing exotic species, including *Pinus radiata,* which are predicted to sequester carbon dioxide at rates 3–4 times faster than indigenous forest (but estimates vary, see Suryaningrum et al. 2022). At a trading price of NZD 80 for one tonne of CO_2-equivalent, a hectare of plantation *Pinus radiata* could earn NZD 2200 per annum (Ministry for Primary Industries 2017). This rate of return is comparable to dairy farming, or sheep and beef farming. With the price of NZU expected to rise further over the coming decades, current policy settings would drive a significant shift to exotic plantation forestry on less productive pastoral farmland.

Change in perspective

O6. Climate change re-emphasises the perspectives of future generations

The challenges posed by climate change give us the opportunity to re-think our relationships with future generations. Māori and other Indigenous philosophies redirect our thinking in important ways. In particular, they understand future generations not as passive recipients of the decisions made and actions taken today, but rather as both custodians and agents of change and transformation toward the future we hope will one day materialise. Future generations are, thus, important *now*.

We see examples of this approach in marae communities around Aotearoa. Project Kāinga[1] shines a light on a range of marae communities that have been developing and implementing strategies that priorities future generations in the face of a changing climate. The tribal community of Ngāti Manu in the Kāretu valley of Northland, like many other communities elsewhere (UN Sustainable Development 2015; UNDP 2022; Awatere et al. 2021), has been developing projects that protect biodiversity, enable food security, and empower young people to enact practices of kaitiakitanga. Enabling these and other communities to develop, pursue, and realise these plans, grounded as they are in decision-making that centres future generations, is critical and represents an underdeveloped and growing opportunity.

O7. Broader theories of knowledge that incorporate Māori perspectives

Solutions to climate change require the integration of practices from multiple different disciplines; Indigenous studies, economics, social studies, and STEM fields. One impediment to this goal is the tendency of contemporary science's theory of knowledge (i.e. its epistemology) to compartmentalise the world into discrete disciplines (Weart 2013). In contrast Māori philosophy offers a holistic and interconnected relationship with nature and its resources which spans from the beginning of time to the imaginable future (Kawharu 2000). Māori philosophy connects humans and non-human entities such as animals, plants, land, water, and culture and knowledge (including Māori language and ancestral lineage) to create a natural balance (Harmsworth and Awatere 2013). Thus, seeking natural balance is embedded in Māori values.

Despite evidence that Indigenous knowledge and practices promote ecological restoration (Mistry and Berardi 2016; Chanza and Musakwa 2022), very few are widely promoted and practised, and the bearers of Indigenous knowledge are excluded from policy-making (Hall et al. 2021). At this point in history, when Aotearoa is boosting its efforts of ecological restoration, incorporating Māori values into practice by involving Indigenous Peoples in the development of a restoration framework is an opportunity waiting to be brought to light (McAllister et al. 2023).

O8. Awakening and mobilising a critical mass

Climate change is a collective problem that depends on 'critical mass' behaviour that can either accelerate or decelerate positive action (Oliver et al. 1985). Implementing solutions to climate change gives Aotearoa experience in solving such collective action problems. For example, in a political sphere, critical mass theory proposes that marginalised communities require a minimum representation in decision-making spheres to have genuine agency. Critical mass as conceptualised in sociology and game theory (Schelling 2006) refers to a critical number or proportion [of people] 'involved in some activity that is self-sustaining once the measure of that activity passes a certain minimum level'. The number of people or ratio that is 'enough' is called a 'threshold', where net benefits begin to exceed the costs for that particular actor (Granovetter 1978). Examples include the growth and uptake of communication technologies (mobile phones), energy-related technologies (electric vehicles) and social technologies (Web 2.0 and social media).

Perhaps the most salient example of building critical mass in climate action in Aotearoa is that of Generation Zero (Dodson and Papoutsaki 2017). This group originally attended international climate negotiations in 2010, but, disappointed with the lack of progress, realised they were in a position for young people to create solutions. In 2016 they started drafting climate change legislation and lobbied the government to adopt the Zero Carbon Act. A small group worked with a range of partners to create a comprehensive climate law that all political parties could support. The Act was passed into legislation in 2019 as an example of how developing critical mass can be successful.

Regardless of the mechanism utilised, the potential to achieve critical mass in an awakening of environmental awareness poses a huge opportunity for accelerated implementation of new environmental policy and action.

O9. Recognising soil's diverse utilities and values

The IPCC's 6th assessment (Pörtner et al. 2022) ranks agricultural soils as the fourth largest potential carbon sink globally. This resonates with the Minister of Agriculture's reasoning that soil carbon research should be funded, despite Aotearoa's already large soil carbon stocks, because the link between healthy soil and productive ecosystems can extend carbon sequestration and improve climate resilience.[2] Recognising soil (in natural and agricultural systems) as a capital stock of carbon, nutrients and water also places strong focus on maintaining healthy, sustainable and productive ecosystems as a whole.

Despite being the foundation of healthy ecosystems, there has been relatively little recognition in many areas of the world that the most productive soils are often lost (Amundson 2018). Soil supports nearly all Aotearoa's food production and ecosystems on land, yet too often remains an unseen opportunity to enhance ecosystem function and natural capital, including drought resilience, moisture retention, and erosion prevention on the one hand, and circular economy that enhances carbon sequestration and nutrient recycling on the other. The loss of many healthy soils to building cities and urban sprawl (Richardson 2022), and obliteration of our carbon-rich wetland soils to expand agriculture, has resulted in a new National Policy Statement for Highly Productive Land and wetland provision of the National Environmental Policy Standard for Freshwater. Climate change re-emphasises the value of our soils, which may lead to new opportunities for restoration (Fischer 2022).

O10. Inclusive perspectives for better food production

Food production is dominated by certain demographic groups, and the need to respond to climate change provides an opportunity to rethink the ethics and practices of care in agricultural production (Goodman et al. 2010). The history of food production in Aotearoa, has traditionally been masculinised and colonial (Bell 1997). 'Conventional' narratives focus on a productivist food economy, (Jay 2007) with historically Pākeha, male pastoralist lenses. These systems overlook marginalised forms of care (Carolan 2020) performed by other actors, for example women (Sultana 2014) and Māori (Huambachano 2016). Given the benefits of heterogeneity in complex systems for socio-economic resilience (Sultana 2014), accounts of diverse agrifood care in Aotearoa are sparse.

In the context of a conventional, industrialised and productivist (yield-and-profit based) approach to dairy and meat production, 'care' is framed as meeting food safety and export standards (Campbell 2011). However, conventional settler agriculture approaches may actually reproduce knowledges and practices of farming that lead to the agrifood crises. Responding to climate change requires diverse pastoralist knowledges and practices, particularly practices that are currently being marginalised, for better social, ecological and economic outcomes.

Threats

T1. Siloed policy exacerbates other stressors

The policy challenges presented by climate change are difficult to define, and reduce into simpler sub problems (Gilligan and Vandenbergh 2020). As a result, a policy choice designed to mitigate one facet of climate change may unintentionally conflict with other values.

For instance, conflict is evident in the collision between climate mitigation and adaptation efforts in the Tairāwhiti region (BDO Group 2021). Current policies imply that more than 80% of Te Tairāwhiti's grasslands will undergo conversion to exotic forestry in coming years. Such a conversion would have significant social and economic impacts on local communities, placing around half of the region's current employment at risk. *Pinus radiata* plantations, which currently dominate Aotearoa's sequestration efforts, will be at elevated risk from fire and storm damage under a changing climate (Watt et al. 2019) with corresponding detrimental environmental effects for the region. This maladaptation is furthered by the fact that exotic pine plantations have negative biodiversity impacts (Suryaningrum et al. 2022).

Lessons might be taken from Aotearoa's COVID-19 response, which was characterised by a highly adaptive all-of-government approach to decision-making (Webster 2021). The success of the response relied heavily on informal networks, both between central government agencies as well as between local and central government (Reid 2020). Formal and informal networks rather than hierarchical relationships were also crucial for the integration of science into the response (Hendy 2022). A balance between hierarchical structures that allow for specialisation with self-governing collective structures that reward shared success is crucial (Warren 2021). The question for Aotearoa is how to strike the right balance to deal with a challenge that is less time-bound, but no less consequential.

Extreme events

T2. Black swan events impede our ability to anticipate the effects of climate change

Taleb (2007) describes as 'Black Swan' events as unpredictable and improbable, with high impact, for which we attempt to find explanations in retrospect. Climate change effects in Aotearoa are likely to manifest in such black swan events. One example is the 'atmospheric river' that delivered an unprecedented volume of rainfall in Auckland on 27th January 2023, closely followed by the effects of Cyclone Gabrielle (Harrington et al. 2023) across much of the North Island on 9th to 16th February (Figure 3), overlaid with the ongoing COVID-19 pandemic.

Managing such black swans requires a re-orientation towards a consideration of low likelihood, high impact extremes. Several strategies are possible in this regard such as 'hunting the Black Swans' i.e. seeking out unexpected sources of risk, avoiding or mitigating known risks, and bet hedging strategies to reduce the impacts of individual extreme events (Hajikazemi et al. 2016).

While the full cost of the recent flood and cyclone events continues to grow as recovery efforts continue, it is useful to re-examine other extreme events such as the Canterbury earthquakes of 2010–2011 to understand what climate-induced black swan events may look like in Aotearoa. These earthquakes close to Christchurch led to an estimated

Figure 3. Tamaki Drive land slip after the extreme rainfall event on 27th January 2023. In this photograph, a large tree that fell onto the road had already been partially cleared. This is a major road serving the eastern bays of Auckland and it remained closed for several days.

capital loss of 40 billion NZD and killed 185 people (Crowley and Elliott 2012). These events had not been predicted because they occurred over previously unknown faults close to the city of Christchurch and one decade on, recovery remains incomplete. The challenge is to recognise that the comfortable status quo is likely to be pierced regularly by such events, due to climate change.

T3. Poor preparation for heatwaves

While there is a growing literature on impacts of marine heatwaves (e.g. Keegan et al. 2022), terrestrial heatwaves have received less attention. Recent heatwaves in the Northern Hemisphere have highlighted the potential threat of temperature extremes. Impacts include strong and extreme stress in plants, animals, humans and infrastructure (Ruthrof et al. 2018). Recent simulations with and without greenhouse gas forcings have shown that heat extremes in Aotearoa New Zealand are two to three times more common because of greenhouse gas emissions (Thomas et al. 2023). The occurrence of heat extremes is also projected to increase rapidly with further warming. Harrington and Frame (2022) define the regions of Aotearoa most at risk of increasingly frequent and severe heatwaves but indicate we remain underprepared.

Heatwaves that coincide with drought are especially damaging for plants, with a global signature of heat being associated with forest mortality events (Hammond et al. 2022). There is limited understanding of heatwave impacts on plants in Aotearoa but plants adapted to mild temperatures are likely to be highly sensitive to heat stress.

Across the globe, heatwaves also cause human mortality (Amengual et al. 2014). Analysis for Stockholm, Sweden suggested maintaining the current number of heat-related deaths in the 2050s under RCP4.5 would require a 75% reduction in the vulnerability of adults over the age of 75 years. Ade and Rehm (2022) found newly built apartments for elderly people in Auckland were prone to overheating in January and February, despite holding green certifications, indicating a need to modify building standards to accommodate future climate scenarios.

T4. Multiple extreme events combine to have compounding effects

There is increasing concern that climate change will lead to an increase in compound extremes, where two or more extreme events overlap in space or time (Hao et al. 2018). When such climatic events combine with other stressors or extremes, the effects can be particularly detrimental for humans and ecosystems alike (Thonicke et al. 2020).

Ecological systems are quite susceptible to such compound events. For example, floods that follow severe wildfires can have particularly detrimental effects on water quality (Dahm et al. 2015) and lead to catastrophic shifts in stream invertebrate communities (Dahm et al. 2015).

Extreme climatic events can also compound with seemingly unrelated sources of change. For example, the 7.8 Mw 2016 Kaikōura earthquake in Aotearoa led to a loss of 75% of the canopy of southern bull kelp, *Durvillaea* spp., along the Canterbury coastline, which was followed by a further 35% loss in response to a marine heatwave. These effects can often be relatively persistent, with non-kelp communities dominating previously kelp-dominated locations four years post-earthquake (Thomsen et al. 2021).

Natural feedbacks become difficult to anticipate

T5. Climate change amplifies disease outbreaks in humans and wildlife

Vector-borne diseases will increase under climate change globally (Caminade et al. 2019) and many of the changes in disease exposure and severity under future climates in Aotearoa are well known (Bennett et al. 2014). For instance, while cases of dengue fever in Aotearoa have been increasing due to travel, local transmission is unlikely despite rising cases globally due to climate change (Messina et al. 2019). Ross River Virus is also likely to increase in the region under climate change but is more likely to spread within Aotearoa due to the presence of appropriate vectors (Damtew et al. 2022). Wildlife, horticultural, and agricultural species are also likely to be affected with a wider range of diseases being able to establish in Aotearoa. While the potential impacts of drought on plant diseases have been reviewed for Aotearoa (Wakelin et al. 2018), less is known about how other diseases might develop. Despite some good information about likely new diseases in Aotearoa under climate change, there is a lack of action to prevent or reduce new arrivals and reduce the impacts of such diseases.

Furthermore, new diseases may be less expected. A recent case in Australia of a live nematode usually found in carpet pythons being extracted from a woman's brain (Hossain et al. 2023) was reported extensively in the media. The patient was immunocompromised and was considered to be an accidental host but with more interactions between humans and wildlife in a changing climate, such infections may become more frequent. In Aotearoa, Māori are particularly vulnerable to climate-induced disease impacts due to closer relationships with the natural environment, existing disparities of health burdens and access to care, socioeconomic deprivation and other complicating factors (Jones 2019; Johnson et al. 2021). Addressing health inequalities must be accompanied by preparation for unknown health burdens.

T6. Losing track of the big sources, sinks and feedbacks of carbon on land and in the ocean as climate changes

Climate change has significant negative feedbacks with sinks of carbon such as soil. The latest generation of models addressing this feedback has only marginally reduced uncertainty (Arora et al. 2020). Concerningly, these global models do not adequately represent Aotearoa's most widespread terrestrial ecosystem types – broadleaf evergreen temperate forests and high-fertility grazing land. In effect, we are flying blind when it comes to C cycle feedbacks.

The most paradoxical accounting issues occur in relation to erosion. Erosion represents a carbon sink due to deposition and soil replacement, which are not represented in earth system models. The eroded flux is a large proportion of C emissions for NZ, with high uncertainty in burial–possibly also intersecting with interest in 'blue carbon' in coasts and estuaries (Scott et al. 2006). Estimates of the sign and magnitude of the flux vary with spatial scale and timeframes (Van Oost and Six 2023), and are both high and unusual given Aotearoa's steep and active terrain interacting with land use, and with potential implications of elemental yields to the ocean (most notably iron).

On land, forests and grasslands can release large amounts of stored plant and soil carbon during drought (Harte et al. 2006; Jiang et al. 2019); in the oceans, marine heatwaves are causing kelp dieback, also releasing carbon (Thomsen et al. 2019; Starko et al. 2022). Timeframes for recovery of carbon stocks are unclear but as the frequency and magnitude of extreme events increases, ecosystem recovery prior to the next event is less likely.

Social implications

T7. Climate crises aggravate social inequality

Climate risks exacerbate existing vulnerabilities and social inequalities (Pörtner et al. 2022). Islam and Winkel (2017) outline a threefold mechanism by which this operates, (1) greater exposure to climate hazards, (2) greater susceptibility to damages caused by climate hazards and (3) reduced ability to cope with and recover from damages caused by climate hazards. In Aotearoa, flooding, sea level rise, and coastal erosion, will all lead to loss of land. Māori communities, many of whom are sited close to the coast, are likely to be particularly affected. For example, it is estimated that almost 50% of the total Māori asset base is invested in 'climate sensitive' industries such as forestry, agriculture, fishing and tourism (King et al. 2010).

There may also be displacement and migration within Aotearoa, accompanied by immigration into the country, particularly from neighbouring Pacific islands most severely affected by sea level rise. Housing, employment, access to services, and food and water security will all be affected. Health inequities will be increased, with increased risk of injury and disease, and associated increased mortality. Regions of Aotearoa where socioeconomic and health inequities are already present, such as Northland and East Cape, are likely to be amongst the communities most vulnerable to climate change. Food security, nutrition, and housing all affect health, with climate change acting as a stressor. For instance, heatwaves will disproportionately affect individuals living in housing lacking adequate mitigations such as well-designed ventilation/cooling and insulation. How do we alleviate the harms and mitigate the risks? What can we do to support our most vulnerable communities?

T8. Eco-anxiety about climate change and other global crises exacerbates existing mental health crisis

The New Zealand Health Navigator website defines climate change anxiety, or anipā o te huringa āhuarangi, as 'a sense of fear, worry or tension linked to climate change'. This anxiety, also known as 'eco-anxiety', can come from 'the pressure to take individual action while seeing societal inaction' (Health Navigator New Zealand 2023). Globally, mental health risks – including anxiety, stress, post-traumatic stress disorder (PTSD) and even suicide – are predicted to increase as temperatures continue to rise and people experience more extreme weather events (Pörtner et al. 2022).

Any increase in mental health risk in Aotearoa will challenge a mental health system that is already in crisis. Aotearoa is known for having the highest youth suicide rate in the OECD despite much-heralded government efforts to fund and reform the mental health system and prioritise national wellbeing (McClure 2021), with an ongoing shortage of mental health professionals, leading to descriptions of a service in 'crisis point' (Spence 2022). Urgent action is needed if a system already in a 'crisis' is not to head towards catastrophe.

T9. Global pandemics derail efforts to address excessive emissions

The COVID-19 pandemic can be seen as both an opportunity and a threat to climate action. On one hand, the fast behaviour change and reduction in emissions from travel provided evidence that such global-scale actions are possible. On the other hand, the pandemic served to create a new focus, which was more urgent and therefore seen to be more important to respond to than the climate crisis, which is unfolding over a considerably longer timeframe.

Lockdowns and restrictions on in-person meetings slowed down progress on climate change, for example, by delaying the United Nations climate change conference, COP 26 (Filho et al. 2022). Climate distraction was also noted in the International Energy Agency report which noted that the pandemic reduced investment and associated growth of clean energy technologies (IEA 2020).

The parallels between COVID-19 and climate change, as ‘global public bads’ mean that there is an opportunity to apply insights from the COVID-19 response to climate change. Examples include the potential for establishing new political processes (Schmidt 2021) and transforming the global economy (Stern et al. 2021). The pandemic also demonstrated that stimulating new behaviours occurred most easily when they were ‘personal and actionable’ (Bernstein 2020). This approach would encourage identification, framing and investment in activities that have co-benefits with climate action, for example investment in sectors that have both environmental and economic benefits (Stern et al. 2021).

T10. Aotearoa is seen as a strategic asset for our (relatively) liveable land

Climate change has been identified as having the potential to lead to food shortages causing unrest, fights between countries over water, and increased competition for fish, minerals and other resources (Flavelle et al. 2021). Aotearoa stands out as a possible haven – a stable democracy with a low population density, abundant agricultural land, and a relatively mild climate. This makes Aotearoa an attractive location for those with the resources to escape their home countries.

King and Jones (2021) identified Aotearoa as top of the five best countries to live after climate change, identified as a ‘collapse lifeboat’ and ‘node of persisting complexity’ in a world affected by a global ‘decomplexification’ (collapse) event. The New Zealand Ministry of Defence defence assessment identified climate change as one of two principal challenges to Aotearoa’s defence interests, citing possible ‘violence from mismanaged adaptation or migration’ and ‘land disputes’ (Ministry of Defense 2021). In early 2020, some billionaires enacted just such a plan, choosing to ride out the COVID-19 pandemic in safety in Aotearoa (Carville 2020).

Throughout history, more powerful countries have invaded less powerful countries. If we end up with the ‘best country in the world’ in a future affected by climate change, then invasion (possibly framed as ‘liberation’) – whether by a national army, a well-armed militia, or wealthy individuals – is a very real threat. In a future affected by climate change, our Pacific neighbours might be among the most in need but will we get to decide on our own terms whom we share our country with?

Discussion

Our horizon scan highlights how the global effects of climate change play out in distinctive ways in Aotearoa. Opportunities emerge for Aotearoa in areas where it has a capacity for change. Conversely, threats represent points where it is not clear that Aotearoa has an ability to change. The threats and opportunities emphasise particular attributes of Aotearoa as a diverse and changing culture in a geographically distinct region. We observed that recognition of both opportunities and threats could be impeded by traditional disciplinary boundaries. Once opportunities and threats have been identified, the mobilisation of responses may be limited by relationships between research and societal institutions, including policy agencies and industry bodies, and favour the accumulated economic, social, and political status quo over needed change. It is our hope that using an established systematic process to identify points of change can improve societal responsiveness to climate change, and serve as a blueprint for many other regions of the world with unique and diverse issues posed by climate change. While papers such as Lawrence et al. (2023) provide a framework for adaptation across sectors, the horizon scan approach is better suited for highlighting emerging issues or those that need more attention and we provide a synthesis of our opportunities and threats below.

Aotearoa's culture and geography has several distinctive features, which can be leveraged into opportunities. For example, Aotearoa's economy has emphasised small-scale technological innovations (O1). Just this type of innovation is needed to implement existing climate change solutions such as carbon credit farming (O5), food futuring (O3, O4), and the realignment of investment in the face of more realistic financial disclosures (O2). These opportunities for economic reorganisation sit atop deeper facets of Aotearoa's culture, which may lend themselves to responses to climate change. In particular, responses to climate change require changes in perspective, including an honest assessment of the risks we face and the social cohesion to act in accordance with these risks (O8). The particularities of Aotearoa's culture provides tools that are unavailable in other regions. Several of our pieces highlight how Māori culture interacts with this (O6, O7). Other facets of Aotearoa's culture lend themselves to this transition. For example, Aotearoa has an intense history and mythology surrounding agriculture and food production. This leads to world leading research on soils (O9) and underexploited perspectives that may be deployed to make agriculture more resilient and less carbon intensive (O10). These diverse opportunities are difficult to picture simultaneously, but many of these ideas have long been themes in Aotearoa culture. See for example Rita Angus's painting 'A Goddess of Mercy' (Figure 4).

The threats we highlight represent barriers that are likely to impede Aotearoa's ability to enact positive change. In particular, the adoption of mitigation strategies will require clear communication and prediction about the likely effects of climate change. Some facets of Aotearoa's geography will impede these efforts. Aotearoa's geography has made it prone to extreme events (T2). Heatwaves represent one salient example of an extreme event (T3). The consequences of individual extreme events may be exacerbated by feedbacks that emerge as a result of interactions among seemingly distinct problems caused by climate change. This includes combined effects of high winds and flooding (T4), and unpredictable novel threats such as new diseases (T5). Our ability to respond to these natural phenomena will be threatened by social dimensions of climate change in Aotearoa. In particular, a number of pre-existing threats are likely to exacerbate climate change's effects. These include eco-anxiety (T7), social inequality (T8), and residual conflicts due to the coronavirus pandemic (T9). Aotearoa's potential

Figure 4. Rita Angus, Goddess of Mercy Oil on canvas. Collection of Christchurch Art Gallery, Te Puna o Waiwhetū; Purchased 1956. The opportunities presented in response to climate change draw on deep themes in Aotearoa's culture and geography. Many of these facets can be found in artworks such as Rita Angus's 'A Goddess of mercy' (painted 1945-1947). A key element of the painting is the misfit between styles from other parts of the world (discussed in T1), this mismatch is evident in how the figure is portrayed in the style of Renaissance art with an anomalous background of Canterbury high country. The painting depicts diverse crops in the mid ground (discussed in O3 and O5). The value of soils is highlighted through the tilled field and the agricultural crops (O9). Angus is visually emphasising women as an underrepresented group in the landscape (O10). Painted at the end of World War Two, the painting highlights the opportunities to fulfil Angus's pacifist ideals.

role as a strategic asset (T10) stands apart as a pre-existing social problem whose effects could be large and difficult to address.

Some of the opportunities we identify warrant urgent action. For example, the benefits of deploying technological solutions (O1) deserves investment not just for the immediate benefits, but also for the longer-term economic growth. Similarly, better financial disclosure (O2) aligns with narrow financial disclosure legislation that came into effect in January 2023, but which can be broadened over time. Progress was underway on the development of indicators for intergeneration wellbeing (O6) but is not yet included in updates to the dashboard supporting policy and legislation evaluation. Some threats also engender actions, such as heatwaves (T3) and increased support for mental health (T8).

We acknowledge that our top ten opportunities and threats were strongly influenced by our individual and collective expertise (Table S1). Horizon scan approaches are usually carried out by groups with a tighter collective expertise (e.g. Sutherland et al. 2011; Stanley et al. 2015), so scoring is more consistent across the group and consensus quickly forms. When the horizon scan method is used by a group with a broad range of disciplines, the score difference between items that do or do not make the top ten is likely to be much smaller, reflecting different perspectives of individuals within the group. Despite this, the process was an effective way to identify some under-studied threats and opportunities. While a different group of researchers will have undoubtedly selected a different collection of threats and opportunities for their top ten, the process is still useful for highlighting some areas that need research, policy action and community preparation.

This horizon scanning exercise is useful for Aotearoa as an idiosyncratic place with problems that are distinct from those in large centralised powers in other parts of the world. This effort to re-think problems related to climate change neatly mimics efforts to reduce Aotearoa's carbon footprint. When explaining Aotearoa's obligations to mitigate climate change, Chair of the Climate Change Commission, Rod Carr speaks of '100 small countries that look like us [Aotearoa]', from this point of view the world is full of many distinctive regions, where the threats and opportunities of climate change must be re-thought to reflect local realities. Addressing the diverse requirements of the opportunities and threats identified herein potentially provides a tangible test of the nation's ability to address climate change as a complex, interconnected multidisciplinary challenge. To do so, it must be able to support new ideas, and better embrace the 'weird' opportunities that have reached significant scales in recent years. Doing so may also benefit from an improved understanding of success and barriers in the networks that deliver innovation to society, industry, and policy.

Notes

1. https://www.projectkainga.co.nz/
2. https://www.youtube.com/watch?app=desktop&v=h4y1yquH2fQ&t=766s

Acknowledgements

We thank Te Pūnaha Matatini for funding the workshop that stimulated this mahi. Thanks to Inga Smith and Mubashir Qasim for discussions on the paper and the wider TPM community who contributed to the original list of threats and opportunities. We thank three anonymous reviewers who provided detailed and thoughtful comments on a draft of the manuscript.

Disclosure statement

Shaun Hendy declares that he is a co-founder and employee of Toha, a New Zealand-based company that builds digital marketplaces for environmental action. Sandra J. Velarde was a staff at the New Zealand Climate Change Commission during most of the writing period. She is currently staff at WSP, an international consultancy company. Her Primary Industries team advises government and private sector on rural infrastructure, water resources, sustainable land and climate change adaptation and mitigation. All other authors do not have any conflicts of interest to declare.

Funding

This work was supported by Te Pūnaha Matatini.

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