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What is the role of biodiversity in mediating the effects of climate change on New Zealand's future agroecosystems?

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ABSTRACT

Climate change will have far-reaching negative impacts on all aspects of Earth's state and functions, including ongoing biodiversity decline and threats to agricultural production. These effects will be dependent on geographic location; for example, parts of New Zealand are predicted to have increased flooding, drought and wildfires, depending on the local environmental context. Effects of climate change on agricultural production will be both direct, such as crop losses due to flooding, and indirect, such as increased invasive pest insect and weed pressure on horticultural production or decline in water capture capacity in pastoral South Island High Country tussock grasslands due to increased fire frequency combined with grazing. It is crucial to understand the complex, interactive effects of climate change on agroecosystems, mediated by biodiversity, if human interventions, such as land management, are to be developed and effectively applied to mitigate negative consequences. Even better is if those interventions can be used to address the biodiversity crisis. Nature-based Solutions is a framework that offers such solutions; however, improved scientific understanding of these interacting processes within agroecosystems is required at multiple temporal and spatial scales to justify sector investment for changes in agricultural land management practices that enhance production and native biodiversity.

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The challenge of climate change for New Zealand agroecosystems: interactions with biodiversity

New Zealand primary production regions have already begun to be impacted by more extreme weather and climate patterns induced by global climate change processes. More prevalent and intense drought conditions, extreme rainfall events, increases in temperature, and modifications in seasonality patterns (e.g. warmer, wetter winters) are projected to make many areas of the country more vulnerable to climate change related risks (The Royal Society of New Zealand, 2016). Some of these risks are direct and obvious; for instance, more prevalent and severe droughts, flood events, and wildfires are already having clear consequences for production lands, related infrastructure, and rural communities (Pomeroy, 2011). In highly modified agricultural ecosystems, landscape biodiversity and the habitats encompassed in non-production vegetation features (e.g. remnant bush, riparian zones, shrublands) and in soils are foundational to agroecosystem function and resilience to climate change impacts (Case et al., 2020). However, the relationships among agricultural production,

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biodiversity, and agroecosystem function and resilience are complex; while the effects of climate change on agroecosystems and production are mediated via biodiversity, so too is biodiversity itself at risk from the effects of a changing climate.

Agroecosystem biodiversity is the total phylogenetic diversity (diversity of all organisms as generated by evolutionary processes) within an agroecosystem, including both production species and non-production species. Production species comprise crops, pasture grasses, important insects (e.g. honeybees), and stock animals; in Aotearoa New Zealand, nearly all these species have been introduced and are exotic to the country. Non-production species can comprise either indigenous species, such as native forest patches on farms and the native birds and invertebrates that inhabit them, or exotic species, including weed plants such as thistle and hawkweeds and pest animals such as feral cats, goats and the Australian brushtail possum. From an ecological point of view, indigenous biodiversity conservation and restoration is of utmost importance in agroecosystems since it is this component of biodiversity that has been most heavily lost or modified due to human impacts over the last century and is also the component that gives Aotearoa New Zealand its unique ecological identity. However, agroecosystems are 'novel' (sensu Hobbs et al., 2014), in that contemporary ecosystem functioning relies on contributions from both indigenous and exotic species and their complex interactions, of which our understanding is poor. Climate change exacerbates this already poor understanding, by potentially introducing additional novelty in terms of ecological outcomes for different agroecosystem contexts. Below, we illustrate two scenarios and agroecosystem contexts in terms of the interplay between biodiversity and potential climate change impacts.

Indigenous grasslands and impacts of increased wildfire and weed invasion under climate change

Indigenous grassland ecosystems, comprising about 13% of New Zealand's land mass, dominate some of the country's most iconic landscapes, and are of significant conservation value; many of these areas continue to be used for agricultural production, particularly in high-country zones. Biodiversity values held within these grasslands are under threat from agricultural intensification, degradation due to over-grazing, wildfires, and invasive species (Emson, 2022). As New Zealand's climate continues to warm, wildfire activity is projected to increase across many grassland areas (Pearce et al., 2011), potentially generating both abrupt and long-term shifts in plant communities and associated biodiversity. For example, while indigenous tall tussock species can survive and resprout rapidly after fire, they can take over a decade to recover; some fire effects, including a reduction in the sizes of tussock plants, is observable more than a decade post-fire (Gitay et al., 1991). The loss of vegetation cover and modification of soil conditions after fire often generate favourable conditions for quick establishment of invasive plant species (Emson, 2022). The invasion of exotic pine species ('wilding pines') into indigenous grasslands is especially problematic: increasing wilding pine numbers, for instance, ultimately raise the overall flammability of these landscapes, likely facilitating a greater prevalence of future wildfires. Further, the water storage potential of production grasslands in New Zealand is at least twice that of forests in areas between 600-1000 mm annual rainfall, and between three and ten times more in native snow tussock (*Chionochloa* spp.) grasslands (Dymond, Ausseil, Ekanayake, & Kirschbaum, 2012). Thus, the ability of indigenous tall tussock grasslands to capture and secure water is highly valuable to enhancing the resilience of high-country catchments under climate change. These brief examples suggest changes in vegetation, particularly native plant diversity, with increasing occurrence of fire under a warming climate, will impact on a range of functional and biodiversity benefits provided by indigenous grasslands.

Soil microbial communities and the effects of climate-induced warming

Belowground microbial diversity is critical to agroecosystem function under a future climate. Soil microbes have crucial roles in biogeochemical cycles, regulate bioavailability of these nutrients and elements, interact with plants to affect their growth and shape the composition of soil's organic matter (Chernov & Semenov, 2021). Thus, microbial communities are key determinants of the productivity of agricultural activities. Given that soil microbial community composition and diversity is strongly driven by environmental conditions, it is no surprise that they are impacted by global change factors, including temperature increases (Hendershot, Read, Henning, Sanders, & Classen, 2017). However, the magnitude, and direction of those changes is wildly inconsistent between different studies; for example, while some may report increased diversity with temperature, others report decreased diversity (Hendershot et al., 2017). This makes it difficult to ascertain what microbial communities will look like under the climate conditions expected in the future. Some clarification could come from focussing on particularly biogeochemical processes. For example, changes in carbon cycling dynamics observed over almost three decades of soil warming suggest that microbial mediated changes could have adverse outcomes for soil sustainability through soil carbon losses (Melillo et al., 2017). Likewise, focussing on relevant groups of organisms can help us understand the roles of microorganisms under climate change. Increased temperatures, along with elevated CO2 levels and periods of drought impact beneficial plant-associated microorganisms, and these microbes may be crucial for helping plants cope with environmental stressors brought about by climate change (Compant, Van Der Heijden, & Sessitsch, 2010). Overall, given the importance of soil microbes to the health and productivity of soils, how the diversity and structure of these communities shifts in response to climate change will be an important factor that determines the response of agroecosystems.

Human-mediated solutions: how can nature-based solutions be used to mitigate these potential future scenarios?

Climate change poses risks to natural processes, which in turn pose risks to agricultural production. However, the reintegration of natural processes into agricultural systems provides opportunities to enhance production, contribute to landscape resilience, and create long-term value through other relevant functions. Incorporating these risks and opportunities into the design of regulation and markets is critical for future-proofing the agricultural sector in a heating world.

Regulatory oversight of biodiversity sits primarily with Department of Conservation, especially through Te Mana o te Taiao – Aotearoa New Zealand Biodiversity Strategy, which articulates the risks to local biodiversity by climate change. Meanwhile, companies are under increasing pressure to understand climate and nature-related risks through new reporting and disclosure frameworks. New Zealand was the first country in the world to introduce information-based regulation which makes climate-related risk disclosures mandatory for large, listed companies (i.e. market capitalisation of more than $60 million), large financial market participants (i.e. more than $1 billion in assets), and some Crown financial institutions. It is based on international guidance developed by the Taskforce for Climate-related Financial Disclosures, established by the Financial Stability Board. Several agricultural companies fall directly under this compliance regime, which means that disclosures must be prepared for accounting periods that start on or after 1 January 2023. Other smaller agricultural companies are likely to prepare climate risk disclosures voluntarily to meet market expectations, or to address heightened scrutiny from banks, insurers and other financial service providers. Understanding the materiality of the aforementioned climate-related impacts on agroecological systems will be critical to high-integrity disclosures.

Internationally, momentum is also gathering to illuminate risks related to nature and biodiversity. The Taskforce for Nature-related Financial Disclosures is currently preparing a parallel set of recommendations to improve management of nature-related impacts in company activities and supply chains. For a country so reliant on its primary sector, these risks are substantial. According to Swiss Re's new Biodiversity and Ecosystem Services (BES) Index – which will inform re/insurance decision-making and provide BES-related benchmarks – 36% of New Zealand's GDP is dependent on biodiversity (Swiss Re Institute, 2020). Other companies are turning to a range of biodiversity assessment and management tools, such as the Integrated Biodiversity Assessment Tool and Science Based

Targets for Nature, to analyse supply chains and investment portfolios for nature-related risks. Local taxonomies, such as the Sustainable Agriculture Finance Initiative (SAFI), also set standards for the purposes of guiding investment and financial support. However, biodiversity and natural processes are not only a source of risk, but also an opportunity for risk reduction.

Nature-based Solutions (NbS) are actions that work with, or mimic, nature to address societal challenges, such as climate change, biodiversity loss, and landscape resilience (Seddon et al. 2020). NbS actions include the protection, restoration, management and creation of forests, wetlands, grasslands, peatlands, riparian ecosystems, and coastal and marine ecosystems. In agricultural settings, NbS contributes to (Simelton et al., 2021): sustainable practices that enhance production (e.g. via nutrient management), natural infrastructure (e.g. water regulation and erosion mitigation), biological amelioration (e.g. phytoremediation, riparian buffer establishment), and biodiversity enhancement and conservation.

Currently the policy system is significantly weighted toward climate mitigation, which monetises carbon sequestration for large forests (i.e. over 1 ha, wider than 30 m) via the New Zealand Emissions Trading Scheme. Yet there is no equivalent economic instrument for biodiversity, except for ad hoc and often indirect support through schemes like the Erosion Control Funding Programme, direct landowner grants under One Billion Trees, and Jobs for Nature. A challenge for policy makers is to enable and incentivise a wider suite of NbS to increase their contribution to other policy objectives, including biodiversity and climate adaptation. The inclusion of NbS as a key lever in the National Adaptation Plan, as well as the Emissions Reduction Plan, is an important acknowledgement of their dual contribution to both objectives. However, this intent needs to translate into policy instruments, for which two objectives are critical: (i) the development of a monitoring, verification, and reporting (MVR) protocol for biodiversity and/or adaptation alignment, which might act like greenhouse gas accounting as the basis for economic instruments; (ii) the implementation of a payment scheme for the benefits of NbS (e.g. biodiversity improvement, adaptation alignment) which incentivises and enables farmers to participate in the restoration economy. Efficiency, effectiveness, political feasibility and distributional impacts are among the considerations for instrument choice, which might include grants or subsidies, tax and transfer schemes, pay-for-performance, offsetting mechanisms, or voluntary or compliance markets (e.g. Hall, 2022).

Conclusions

We have briefly outlined the types of expected consequences of climate change within agroecosystems in New Zealand and how ongoing climate warming might interact with indigenous biodiversity in these systems to generate novel and/or complex outcomes. Given that land management practices over the last century or more has already significantly degraded indigenous biodiversity across New Zealand's agricultural landscapes, it is imperative that we now mobilise efforts to understand the additional and potentially confounding impacts being imposed by accelerating climatic changes. We also advocate for economic mechanisms and land use policies that facilitate the reintegration of indigenous biodiversity into New Zealand agroecosystems in a strategic and targeted manner (e.g. Case et al., 2023). Such Nature-based Solutions approaches will enhance the resilience of these ecosystems against inevitable climate change impacts.

Further research on the relationship between biodiversity and climate risk management is urgently needed, both to understand risks to nature as well as the potential for nature to mitigate those risks. In regard to the latter, the growing appreciation of climate risk as financial risk will increase demand for aligned research. For example, modelling the flood mitigation impacts of NbS in hydrological catchments can guide effective investment and policy support for activities that currently are not incentivised by carbon markets, such as improving soil health, small-scale afforestation, riparian planting, wetland restoration and more. This would help to address some of the many significant knowledge gaps of climate adaptation in Aotearoa New Zealand.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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