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PRACTICE BRIDGE

Principles and process for developing participatory adaptation pathways in the primary industries

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Adaptation pathways is an approach to identify, assess, and sequence climate change adaptation options over time, linking decisions to critical signals and triggers derived from scenarios of future conditions. However, conceptual differences in their development can hinder methodological advance and create a disconnect between those applying pathways approaches and the wider community of practitioners undertaking vulnerability, impacts, and adaptation assessments. Here, we contribute to close these gaps, advancing principles, and processes that may be used to guide the trajectory for adaptation pathways, without having to rely on data-rich or resource-intensive methods. To achieve this, concepts and practices from the broad pathways literature is combined with our own experience in developing adaptation pathways for primary industries facing the combined impacts of climate change and other, nonclimatic stressors. Each stage is guided by a goal and tools to facilitate discussions and produce feasible pathways. We illustrate the process with a case study from Hawke's Bay, New Zealand, involving multiple data sources and methods in two catchments. Resulting guidelines and empirical examples are consistent with principles of adaptive management and planning and can provide a template for developing local-, regional- or issue-specific pathways elsewhere and enrich the diversity of vulnerability, impacts, and adaptation assessment practice.

Keywords: Climate change, Global warming, Multiple stressors, Resilience, Social-ecological systems, Vulnerability

1. Introduction

Primary economic activities such as pastoral farming, arable cropping, horticulture, and viticulture are exposed and sensitive to changes in climate, variability, and extremes (Meinke et al., 2009; Cradock-Henry, 2017; Marshall et al., 2018). Management strategies, in many cases, are currently designed to cope with variable conditions around a long-term mean. Departure from that mean and any climate change then will likely have widespread environmental, economic, and social implications for communities and individuals. Just as production of agricultural commodities is sensitive to climatic conditions, it might be anticipated that so too are those communities and regions that depend on agriculture uniquely susceptible in turn to climate change impacts and implications. Higher temperatures, declining rainfall, and more frequent droughts will be felt through declining yields and rising production costs, with implications for economic development, food security, rural livelihoods, and well-being (Tanner et al., 2015). Furthermore, these changes are likely to occur in conjunction with other socioeconomic and global changes such as trade liberalization or protectionism, water availability, and conflicts over land use (Hammond et al., 2013; Cradock-Henry et al., 2018).

As climate change increasingly confounds primary production practices through the accelerating scale, intensity and variability of severe weather events, slow onset changes, and shifting seasonal trends, the consequent impact on the infrastructure and social fabric of rural communities also increases (Spector et al., 2019; Paulik et al., 2021). These changes, however, do not happen in isolation. Rural communities also have to contend with social and economic changes such as demographic transitions, shifts in market requirements for agricultural products, competition for natural resources, and increasingly the impacts of pandemics (Dombroski et al., 2020). In

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turn, this requires primary industries to change management practices, increase adaptive capacity, and reduce the risks of long-term trends (Meinke et al., 2009).

To ensure a sustainable long-term future for primary industries, adaptation will be required. Adaptation requires adjusting practices, processes, capital, and infrastructure in response to actual or anticipated climate change impacts (Nelson et al., 2010; Kiem and Austin, 2013; Cradock-Henry, 2017). For primary industries, this involves a range of strategies at different scales, from within the farm to local- and regional-scales, and within and across specific land uses or sectors to minimize risk and reduce exposure. Adaptation also calls for responses in the decision environment, such as changes in social and institutional structures or new technical options that can affect the potential for these actions to be realized (Bizikova et al., 2012; Neset et al., 2018; Fedele et al., 2019).

For land managers, local and territorial authorities, resource-dependent rural communities and others, adaptation to climate change involves multiple potential responses, in a complex and fast changing decision context (Westerhoff and Smit, 2009; Nicholas and Durham, 2012; Hammond et al., 2013; Cradock-Henry, 2017). Not only is climate change often not the most urgent stressor to which stakeholders might need to respond, it may only be one of several, including the need to manage desirable outcomes for freshwater or other natural resources, maintain social license to operate and buffer themselves against market and financial shocks (Nicholas and Durham, 2012; Castellanos et al., 2013; Kalaugher et al., 2013). Given this complexity and uncertainty, identifying and prioritizing adaptation actions presents significant methodological and practical challenges (Hardaker et al., 2015; Antle et al., 2018; Cradock-Henry et al., 2018; Ausseil et al., 2019; Cradock-Henry and Frame, 2021a).

A number of different tools and processes are now used to work uncertainty in adaptation planning and decision making including scenarios, real options, adaptive management, and robust decision making. Collectively, these and other approaches acknowledge the dynamics of adaptation contexts, the limitations of foresight, and the need to ensure decisions and actions realize desired outcomes regardless of how the future unfolds (Hallegatte, 2009; Lempert, 2019). These tools and approaches draw on an extensive diverse literature not exclusive to climate change and have been applied through empirical case study analysis in different contexts (Butler et al., 2016; Campos et al., 2016; Zandvoort et al., 2017; Jacobs et al., 2019; Costa et al., 2020; McNicol, 2020).

"Adaptation pathways" is one such approach and is a novel method for identifying how best to adapt to future climate change. There are several different interpretations of adaptation pathways (Werners et al., 2021). In some studies, pathways are used to better understand the process of adaptation, how and why change has occurred, the variability of response, and the influence of context and power relations (Fazey et al., 2015). In this article, we use adaptation pathways as a tool to facilitate engagement, build local capability and capacity, and explore potential adaptation practices (Butler et al., 2016; Bosomworth and Gaillard, 2019; Cradock-Henry et al., 2020a). This applied approach considers multiple possible futures ("pathways") and anticipates adjustments to plans as conditions change and new information is gathered (Haasnoot et al., 2013; Barnett et al., 2014; Cradock-Henry et al., 2018).

Adaptation pathways have been developed and applied internationally, particularly for coastal regions characterized by slow-onset hazards such as sea-level rise and flooding (Barnett et al., 2014; Bloemen et al., 2018; Hall et al., 2019). In many cases, pathways have been part of formal planning processes, with significant data and resource requirements, linking critical management decisions to signals and triggers derived from probabilistic modeling (Barnett et al., 2014; Kench et al., 2018; Lawrence et al., 2019). There are, however, a growing number of examples of how to develop and apply pathways at the local and regional scale, in the context of multiple, interacting stressors, using inclusive, participatory approaches (Bosomworth and Gaillard, 2019). These cases range from biodiversity and conservation (Jacobs et al., 2019), freshwater and marine management (Costa et al., 2020; Skrimizea and Parra, 2020), climate change, and more (Butler et al., 2016; Campos et al., 2016; Prober et al., 2017; Zandvoort et al., 2019; McNicol, 2020).

In this practice bridge, we address two specific objectives. First, we present practical guidance to enable government policy makers, resource managers, industry practitioners, and local communities to apply adaptation pathways processes in multiple contexts and at local scales. It is important to note that while climate change is a global phenomenon, its impacts and implications cross scales. At the local level, communities, households, and individuals must manage the effects of higher temperatures, changes in precipitation, and more frequent extremes. Adaptation therefore is necessarily local and context-dependent. These principles for guiding the development of adaptation pathways therefore are intended to support a place-based, participatory process with an emphasis on primary industries and rural communities but are also flexible enough to enable stakeholders to produce adaptation plans that are useful, usable and used, and bridge the gaps between scientific knowledge and the needs of stakeholders in ways that increase the likelihood of implementation (Cash et al., 2003; Marshall et al., 2017; Cvitanovic et al., 2019).

Second, we apply the guidance to a case study in New Zealand. New Zealand provides a unique opportunity to report on the development and application of adaptation pathways for primary industries. The primary sector is a significant economic driver in New Zealand and is fundamentally important to many local and regional economies (Patterson et al., 2006), contributing to 7% of GDP and 79% of export earnings (Statistics New Zealand, 2018). Nearly half the land base is in productive pasture and arable cropping. Weather-related risks pose a significant challenge to producers (Kenny, 2011). Furthermore, the primary sector is already exposed to several risks and stressors, as demonstrated by recent experience with earthquakes, biosecurity incursions, and fluctuations in commodity prices (Burton and Peoples, 2014; Harrington et al., 2014; Cradock-Henry et al., 2019b; Spector et al., 2019). Climate change will challenge management systems in the primary sector with implications across the New Zealand economy and society (Stroombergen et al., 2006). Importantly, adaptation pathways are also being promoted and incorporated in planning frameworks in New Zealand, specifically as an approach for managing coastal hazards (Kench et al., 2018; Lawrence et al., 2019), prompting growing interest in participatory adaptation processes, able to accommodate local complexity (Cradock-Henry and Frame, 2021a). Drawing insights from the empirical case study, we provide lessons and recommendations for the design and implementation of similar processes elsewhere.

2. Principles and process for participatory adaptation pathways

In this section, we present our synthesis of the extensive literature on adaptation pathway planning and existing practical guidelines to elaborate a set of principles and practical tools that can be adapted to local circumstances. We emphasize, however, that the principles and processes described are intended to provide insight that can be adapted to specific situations. While the authors have found them useful in the New Zealand context, they are not intended as a "recipe book" for practitioners. It will be through a process of relevant, credible, and legitimate co-development with stakeholders in the system of interest that their value in guiding and driving change will be most effective as discussed elsewhere (Cradock-Henry and Frame, 2021a).

2.1. Process

Developing adaptation pathways requires in-depth understanding of the complex interdependencies between different primary industries, including reliance on irrigation and land-use restrictions (e.g., Westerhoff and Smit, 2009; Milestad et al., 2011; Cradock-Henry, 2017). Contextual information is needed, covering industry-specific insights, regionally based options, and pathways that capture specific geographical and social settings. Consequently, adaptation pathways require integrated socioeconomic, policy, and climate change scenarios to engage stakeholders in thinking about multiple futures and making decisions despite uncertainty (e.g., Milestad et al., 2014; Nilsson et al., 2017; Cradock-Henry and Frame, 2021b). This is an extensive topic within the literature on pathway planning which is potentially daunting for those seeking to develop adaptation pathways from a practical perspective.

To support stakeholders, we combined our reading of the literature with existing practical guidelines and our experiences to curate a set of principles and tools that could be adapted for local circumstances without requiring extensive operational budgets from local decision makers. It is stressed that these are, in themselves, not new but are built on extensive case studies from which we have extracted examples of good practice.

2.2. Principles

Climate change and societal responses need to be considered as components of a multiscale social-ecological system where humans and our activities are both part of and actively shaping the ecosystems required for sustainable development (e.g., Deppisch and Hasibovic, 2013; Baird et al., 2014a; Folke et al., 2016). For rural regions and primary industries, this means climate adaptation within the context of long-term issues that influence rural communities and their livelihoods, and the limitations created by the complex sociopolitical dynamics that shape adaptation decisions (Bennett et al., 2016; Cradock-Henry et al., 2018; Cradock-Henry et al., 2019b). Authentic and in-depth engagement with affected communities, stakeholders, scientists, and, where relevant, indigenous knowledge holders is central to pathways planning. Such engagement is, essentially, a political process (Bosomworth et al., 2017), and the ability to reach some form of consensus at each stage needs to be transparent across regional and temporal scales (Bloemen et al., 2018).

New Zealand (Aotearoa), for example, is a bicultural nation, and Māori (the indigenous people) have *kaitiakitanga* (guardianship or responsibility) for large areas of land and commercial and farming interests. Iwi and hapū (Māori tribes) are increasingly exercising their mandate to manage climate-related risks and meet outcomes for well-being. Māori concepts of knowledge, knowing, and management priorities take a much longer (i.e., 1,000-year) perspective than Western approaches. *Kaupapa* is the set of values, principles, and plans that have been agreed as the basis for decisions. Increasingly, close attention is being paid to the way in which research involving or affecting Māori needs to be cognizant of Māori values, aspirations, and knowledge systems and of any attempt at representation or speaking for Māori (Smith, 2012).

To do so, requires true partnership and collaboration, which does not privilege scientific rather incorporates diverse knowledge (quantitative, qualitative, expert, local, and indigenous), and can adequately account for interacting drivers and feedback mechanisms in coupled social-ecological or agroecological, complex adaptive systems (Mistry et al., 2014; Oteros-Rozas et al., 2019; Cradock-Henry, 2021).

The prevailing reductionist approach to much climate change research limits integration between natural and social sciences and reduces the scope for potential solutions to narrowly defined technological solutions (Rigg and Mason, 2018). In most pathways literature, too, the sociopolitical challenges to reaching consensus are under-explained, which tends to imply that goals are agreed upon and the actions to achieve them are largely technical and uncontested (Bosomworth et al., 2017). These authors note that there has been little to guide decision makers when engaging with contested goals and values or with knowledge uncertainties. Similarly, Câmpeanu and Fazey (2014) suggest that there has been less emphasis on the human dimensions (practices, beliefs, and decision-making processes) that shape adaptation pathways.

Adaptive capacity is contextual (O'Brien et al., 2007; Bierbaum, 2013; Owen et al., 2019), varying between systems, sectors, and regions (Yohe and Tol, 2002). For example, Zandvoort et al. (2017) compared between applications of pathways to institutional diversity, planning culture, framing of goals and uncertainties, while Carstens et al. (2019) looked at constraints of adaptive pathways in municipal policy making. A common strand is that adaptation requires local and potentially sector-specific approaches involving sector-specific business bodies and institutional support (e.g., local and central government). Regional (and sometimes national) adaptation strategies must be developed with the business sector (e.g., Kenny, 2011; Hammond et al., 2013; Cradock-Henry et al., 2019b) to avoid maladaptation, realize synergies, and optimize cross-sectoral adaptive capacity and regional resilience. Narrowly focused actions may not create an adaptive sector (if they do not account for opportunities, challenges, and preferred adaptations elsewhere; e.g., Barnett and O'Neill, 2010; Neset et al., 2018). For example, water-use adaptation at the farm scale will be underpinned by sound regional policy and strategies, which in turn are enabled by national guidance and policy. Without this coordination across governance scales and over time, individuals, industries, and regions could compete for scarce resources in a detrimental way.

The empirical evidence and our experience suggest the value of using adaptation pathways processes to build capability and capacity, enhance learning, and develop a shared understanding of climate change adaptation issues with diverse stakeholders (e.g., Barnett et al., 2014; Câmpeanu and Fazey, 2014; Maru et al., 2014; Butler et al., 2016; Bosomworth and Gaillard, 2019).

Following are some broad principles based on our synthesis of the literature and the authors' experiences in developing long-term planning for primary industries:

- *Economic resilience and sustainability*: Adaptation planning may assume that individuals and organizations in primary industries are better able to adapt when they are both sustainable *and* profitable (Darnhofer, 2021). Maintaining economic resilience while acknowledging and operating within, environmentally or ecologically sustainable limits, therefore is important to achieving lasting social and environmental adaptation (Alston et al., 2018; Cradock-Henry, 2021).
- *Readiness not repair*: Anticipatory investment in adaptation and mitigation actions rather than repairing damage once the impacts of climate change are experienced will be more effective and efficient. Productive (e.g., livestock) and capital (e.g., structures) assets are exposed to climate-related hazards (Paulik et al., 2021). *Ex ante* risk assessment can enhance preparedness, by identifying critical vulnerabilities, and ensuring response and recovery plans are suitably robust (Abid et al., 2020).
- *Shared understanding of risks and responsibilities*: The necessary regulatory and legal to reduce greenhouse gas emissions are most often formulated through multilateral and international agreements. Adaptation to location- and context-specific impacts of climate change, however, is local and regional. Developing a collective understanding of shared risks and opportunities, how these interact, and potentially cascade between systems can provide insight into the need for joint responsibility for adaptation (Cradock-Henry et al., 2020b). Enhancing flood protection measures, for example, may require substantial investment with benefits accruing to diverse stakeholders (Lawrence et al., 2020). Future adaptation therefore may need to consider the interactions between different primary industry sectors and how these affect the individual and collective responses of the region.
- *Individual agency*: Ultimately, adaptation is a function of individual farmers, households, and land managers who will make decisions and act in response to risks and opportunities associated with climate change. Understanding mechanisms and potential pathways for coping, incremental or transformative changes, identifying the extent to which these decisions are shaped by individuals' values, knowledge, rules, and technology can inform adaptation responses at the regional and national policy-making levels (Gorddard et al., 2016; Fedele et al., 2019). Furthermore, acknowledging the limits to individual agency—and where a collective response (e.g., large-scale water storage)—may be required (Preston et al., 2015; Boda and Jerneck, 2019).

These principles support the synthesized guidelines, and it is anticipated that these will be applicable elsewhere subject to the assessment of their match with local contexts.

2.3. Guidelines

Climate change adaptation—like other persistent socio-economic and environmental challenges—defies conventional management, presenting as complex, multiscalar problems with multiple stakeholders with no clear solution (Moser et al., 2012). Several approaches to develop and test potential solutions have been advanced and applied in the literature. Our approach is largely consistent with Holling's principles of adaptive management (1978) though with a pathway focus. That is, adaptive management takes an iterative approach to problem solving, responding and changing to circumstance in response to learning. Managers typically set a goal for environmental management; propose solutions based on anticipated events; make a series of successive adjustments to a policy or management action over time in response to unfolding experience; and maintain ongoing flexibility in response to change, new information, goals, or objectives. Adaptive management begins, therefore, with problem identification and goal(s), followed by the development of policy or solution, implementation, and monitoring and evaluation (e.g., Stringer et al., 2006; Butler et al., 2016). The adaptation pathways literature draws on many of these principles and processes, as well as elements of adaptive planning, to identify a problem, describe the system, determine impacts and implications, assess adaptation options, implement, monitor, and evaluate (notably Haasnoot et al., 2013; Lawrence et al., 2019).

While other examples and guidance materials are available (e.g., for coastal hazards in New Zealand; Ministry for the Environment, 2017), we modified the process to suit a rural context in which there is fragmented and distributed responsibility for decision making, multiple drivers of change, and diverse adaptation options grounded in the local context and physical environment. Accordingly, emphasis is placed on eliciting local community perspectives by using participatory, nontechnical methods that focus on vulnerability analysis and adaptation planning for multiple socioeconomic and biophysical stressors. This provides a pragmatic process for those involved within a short time frame and a limited budget that could be replicated with appropriate modifications in similar situations anywhere.

The participatory adaptation pathways process described consists of five stages as shown in **Figure 1**. Each stage is guided by key questions, and various activities (both participatory and desk-based) used to facilitate discussion and meaningful pathways, as described below.

2.3.1. Stage 1: Define objectives and desired outcomes

Purpose

Put simply, why adapt? The initial stage sets the scene, by determining who may be required to undertake adaptation planning and implementation. The ability to act on decisions (agency) is required to implement preferred pathways (i.e.; McLaughlin and Dietz, 2008; Preston et al., 2015; Gorddard et al., 2016). In short, there needs to be clarity about adaptation: *of what, by whom, and why?* (Frame and O'Connor, 2011; Tanner et al., 2015). There also needs to be clarity on the time frame of interest, which can range from 5 to 100 years. However, 5 years is too short for climate change impacts and 100 years—notionally four generations—is too far away for many to envisage (Inayatullah, 2013; Kingsborough et al., 2017; Avram et al., 2019; Nilsson et al., 2019). Potentially a period of 25–50 years, in our experience, can offer an useful balance but must include implications prioritized by the stakeholders (Nilsson et al., 2017; Lacher et al., 2019).

Tools

This stage is likely to involve local authorities, business groups, NGOs, and community interests, including clarification of supporting funds, and the expectations of those providing such funds (Baird et al., 2014b). The response to the questions needs to ensure the scope of the pathways' development process can be defined, and everyone held to account for its implementation. Inclusion of indigenous groups and minority interests and issues of equity are also likely to feature greatly (Abel et al., 2016; Butler et al., 2016).

Critical is the project's overall "voice" and the extent to which it is perceived as top-down/bottom-up and its perceived level of inclusivity/exclusivity by stakeholders. It can involve the analysis and synthesis of similarities, differences, and patterns in a way that produces knowledge that helps to answer causal questions such as how and why particular programs or policies work (or not). This can combine qualitative and quantitative methods to create an understanding of how context influences the success of an intervention and how best to tailor the intervention.

2.3.2. Stage 2: Explore current system and situation

Purpose

What are the likely changes in local environmental variables under various climate change scenarios? How will the change in local climate affect the biophysical conditions and what will that mean for production systems, including those that might replace existing ones?

Tools

Ideally the local climate system model would cascade down from highly integrated national models, but in practice, it is more likely to require a synthesis of outputs from highly quantitative models that are not integrated and further rely on qualitative interpretation through experts. **Table 1** shows a simple example of what this might look like. This stage will involve desk-based activities across disciplines including:

Climate modeling: Downscaled climate data summarize anticipated changes in key climate variables and enable identification of suitable adaptation options. Of particular relevance to the agricultural sector are large scale estimates which are then downscaled to produce local projections for environmental variables such as temperature, precipitation, evaporation, and wind (Cradock-Henry, 2017; Kebede et al., 2018; Tait et al., 2018; Wreford and Topp, 2020).

Biophysical and crop modeling: Downscaled climate projections can be complemented with biophysical crop modeling for more targeted assessments of crop yield or environmental indicators (Lieffering et al., 2016). While no single model might exist for local agricultural systems, models are in constant development.

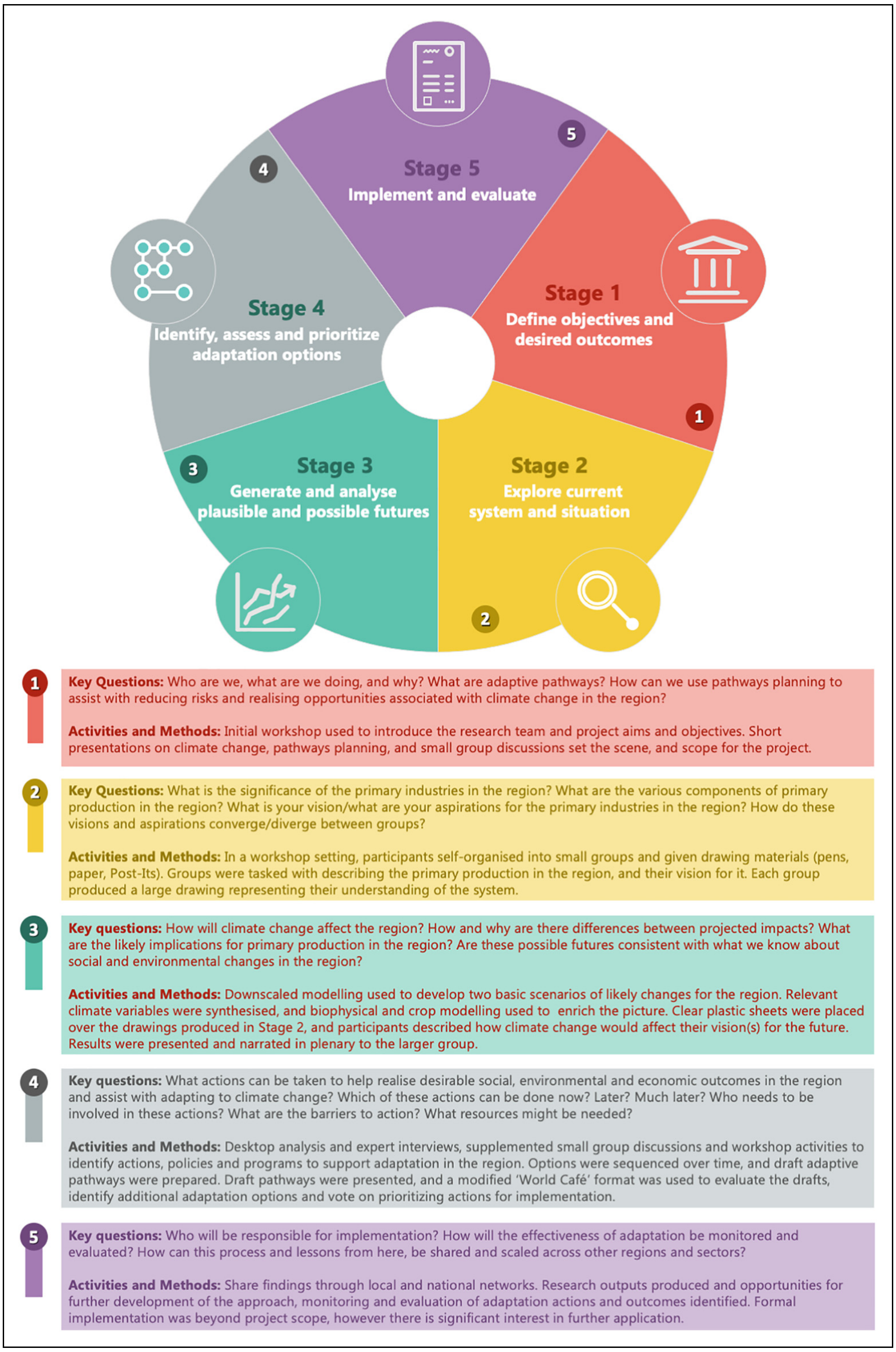

Figure 1. Five steps approach to participatory adaptation for primary industries, with key questions, methods, and activities to guide development and application. DOI: https://doi.org/10.1525/elementa.2020.00175.f1

A tiered approach is recommended to identify key climate attributes for changes in average seasonal patterns and extreme weather events (e.g., floods and droughts). This can draw on climate projections, expert interviews, and stakeholder consultation (Westerhoff and Smit, 2009; Kenny, 2011; Hammond et al., 2013; Cradock-Henry, 2017).

2.3.3. Stage 3: Generate and analyze plausible and possible futures

Purpose

Given what has been learned about the climate and the biophysical systems, what multiple versions of the future emerge are credible, relevant, and legitimate (Cash et al., 2003; Cradock-Henry et al., 2018; Lacher et al., 2019)? Are there multiple scenarios that can be organized in some loose structure?

Table 1. Values and priorities to inform key decision areas. DOI: https://doi.org/10.1525/elementa.2020.00175.t1

Domain	Values and Priorities
Community resilience and well-being	Vibrant regional economy
	Safe communities
	Sustainable, engaged community, with diverse vibrant population
	Community can affect policy outcomes
	Affordable living
	Desirable lifestyle
Agriculture	Diverse and profitable primary industries
	Local employment/entrepreneurial opportunities
	Natural capital maintained (or improved)
	Confidence in biosecurity measures
	Access to labor
Infrastructure	Connections to regional and national systems/assets
	Safe location of critical assets
	Secure, reliable, and resilient services
Water	Protected healthy freshwater systems (rivers, lakes, and aquifers)
	Enough water for everyone
	Efficient use
	Fair and equitable access

Tools

This complex and unpredictable stage requires careful external facilitation, most probably over multiple sessions (Nilsson et al., 2017; Kebede et al., 2018; Lacher et al., 2019). It is important that the scenarios developed include political, economic, social, technological, legal, and environmental dimensions. Conflict resolution can be required especially with the introduction of unanticipated outcomes (sometimes called wild cards or black swan events; Reed et al., 2013; Duckett et al., 2017) with two options commonly used.

Stakeholder workshops: Multiple workshops are likely at each case site. An initial workshop can develop shared understanding of local values and how stakeholders perceive these to be affected by climate change. Participants can develop a rich local picture that emphasizes primary industries, including ecosystem services, human capital, and infrastructure; challenges to production; and the various inputs along the value chain from farm to market. Participants can then consider how the productive sector might be affected by climate change. Subsequent workshops (at least one and potentially more) can produce collaboratively draft pathways diagrams to identify adaptation options with participants thinking beyond incremental, short-term changes toward transformational adaptations and long-term strategic options. Options may be clustered and sequenced over an agreed time frame as noted earlier, in line with the infrastructure and planning time frames of local government.

Expert interviews: Insight into the significance of changes and the potential for sectors to adapt can be gained through interviews with industry experts. These interviews can further inform the selection of adaptation pathway options.

2.3.4. Stage 4: Identify, assess, and prioritize adaptation options

Purpose

From the multiple scenarios developed in Stage 3, what are the risks and opportunities? How can the most relevant, credible, and legitimate pathways be identified? Relevance, credibility, and legitimacy is a heuristic (or "rule of thumb") used extensively in the literature on adaptation

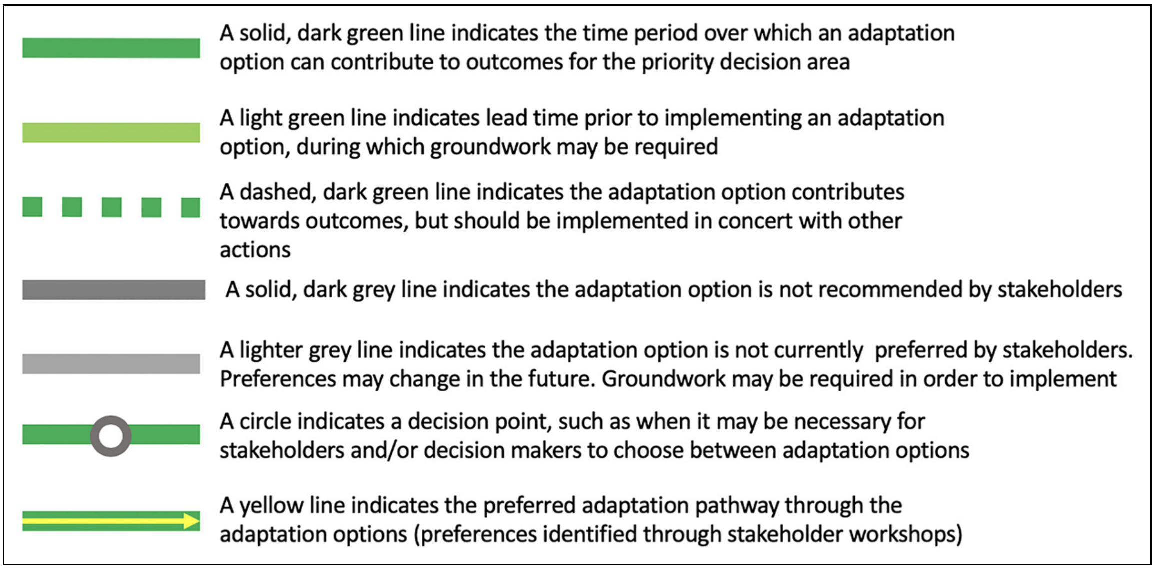

Figure 2. Key for reading adaptation pathways diagrams. Lines represent different adaptation options over time. Color scheme adapted after Siebentritt and Stafford Smith (2016). DOI: https://doi.org/10.1525/elementa.2020.00175.f2

as well as the interface between science and policy more generally (Cash et al., 2006; Cash and Belloy, 2020; Nalau et al., 2021). It describes the extent to which information generated by research is useful to policy makers and other end users (Dannevig and Hovelsrud, 2016; Cash and Belloy, 2020). Relevance refers to the importance or significance of the research in relation to the problem context. Credibility means that the research findings are robust and the sources of knowledge are dependable. In generating adaptation pathways, using participatory approaches, legitimacy encompasses the extent to which the process is perceived as fair and ethical and broadly representative and inclusive of diverse participants, values, interests, and perspectives (Cradock-Henry and Frame, 2021b).

Tools

These require a skilful mix of qualitative and quantitative tools tuned to the site specifics. There are many possible tools available:

System dynamics modeling: Climate change will compound existing vulnerabilities by creating new ones, making decision making more complex (Meinke et al., 2009). The capacity for identifying, evaluating, and comparing adaptation options can be limited by poor integration of social and economic studies with biophysical impact assessments and an emphasis on individuals' adaptive strategies. Consequently, systems dynamics modeling (either qualitative diagrams or quantitative simulation modeling) can be used to bring together insights sourced from the stakeholder workshops and present them in an accessible and relevant manner to multiple audiences (Lieffering et al., 2016; Gray et al., 2018; Cradock-Henry et al., 2020b). The value of using systems thinking is that system boundaries are flexible and can be set at a scale that is appropriate to the question of interest. Boundaries may be drawn to include factors that influence the function of primary industries, broadly defined in terms of inputs and outputs through a systems model. The resulting systems diagram can represent all types of infrastructure for all the climate impacts considered. A systems map, also known as a causal loop diagram, can be developed to show dependencies and interdependencies between various forms of capital.

Desk-based analysis of adaptation options: The options arising from local and regional workshops may be considered alongside relevant project reports and literature to identify additional adaptation options not identified in the workshops (Cradock-Henry et al., 2019c).

Local adaptation pathways: To maximize impact, these can be illustrated graphically (see **Figure 2** and **Figures 5–8** for the case study examples). The use of such graphic tools is a powerful means of increasing the learning impact and as an aid to collaboration and should be tailored to the local circumstances. The horizontal axis should show both timescale and expected changes to the climate relevant to the decision area, with the range of adaptation options listed on the left-hand side. Each option on the left should relate to a pathway on the right to indicate the:

- contribution of the adaptation option to the relevant key question—whether it fully or partly addresses the issue at stake,
- favorability of the adaptation option,
- time over which the adaptation option is likely to be effective,
- time before an adaptation option is implemented, during which preparatory work may be required (e.g., cost-benefit analysis),
- decision points where decision makers need to choose between adaptation options, and
- preferred pathway through the options listed.

A vertical line through a "decision point" circle identifies a time at which a decision needs to be made between options. The timing is indicative only, relative to the *x*-axis timeline. This assumes that, as the climate changes, some options will become less suitable as adaptation measures and new ones will be required. For each pathway, "no changes" is the first listed option. This relates to all aspects of the current approach being taken to the decision area (e.g., management and maintenance regimes). The length of the adjacent line shows how long the current approach with no changes can be expected to effectively address the area of decision making. The preferred pathway (yellow lines) identifies which options may be progressed now and into the future, based on currently available information, including information provided by relevant experts and affected stakeholders. The preferred pathway does not preclude current actions that contribute to future adaptation from continuing. Pathways can be reviewed regularly, every, say, 5 years, at which time new information may suggest that the preferred pathway may take a different course through potential options.

Regional adaptation pathways: While local adaptation pathways are relevant to decision making at the catchment scale, regional-scale pathways may differ considerably for primary industries and in identifying regional adaptation priorities. Regional adaptation pathways are likely to accommodate how decisions taken in one domain or sector could affect others and how the region might prioritize action, and this may require skilful facilitation of what is, potentially, a politicized process. In the short term, adaptation actions may well continue best practices that prepare for climate change through incremental change.

Such actions are likely to include risk assessment across regional value chains, promoting awareness of climate change adaptation, risks, and opportunities, support for research on the potential for transformational changes, and selective breeding for agriculture. These can be drafted by the research team but need to be verified at a workshop of stakeholders and experts to determine those that are

- relevant at a regional scale,
- cross-sectoral (i.e., common to more than one key decision area),
- able to deliver multiple benefits, and
- implementable through a coordinated, regional response across key regional stakeholders including sector bodies, community interests, and government.

Sector-specific adaptation pathways: Sector-specific adaptation strategies (e.g., for dairy, forestry, or wine industries) can be developed for multiple scales, including individual farms or at a national level, for an industry. The identification of preferred adaptation options can, in turn, lead to identification and consideration of synergies and trade-offs.

2.3.5. Stage 5: Implement and evaluate

Purpose

How will the pathways be reviewed as new information becomes available, as climatic conditions change, and as adaptive capacity grows? What processes are in place to increase the adaptive capacity of the stakeholders and those they represent? What lessons can be learned about the process that is specific to the locality or relevant to other jurisdictions?

Tools

Adaptation depends on learning and responding effectively to lessons learnt as well as experience, changing circumstances, and new knowledge (Baird et al., 2014a; Hermans et al., 2017; Murti et al., 2019). Monitoring and evaluation are therefore needed for effective adaptation over time. Monitoring of key indicators of systems change (e.g., tipping, turning, and trigger points) underpins decision making about adjustments to strategies, operational plans, and implementation practices. This includes monitoring biophysical, social, economic, and political dimensions of the system. Adaptation indicators can be used to determine whether adaptation activities are leading to desired outcomes. Evaluation can support the ongoing management of adaptation interventions by assessing progress and pointing out needs for adjustments and providing accountability by demonstrating and reporting on results. Documenting adaptation lessons and experience can help make successes reproducible and make the strengths and weaknesses of different forms of activity, intervention, and investment explicit. Formal lessons about what did and did not work through implementation can be shared through case studies, field days, and sector networks. This information can also be linked back to higher level strategies and policies through good governance across local, regional, and national scales, as well as providing information for provisions of global agreements.

The principles and process of adaptation pathways described are now illustrated with a case study from Hawke's Bay, New Zealand.

3. Case study: Participatory adaptation pathways in New Zealand's primary industries

3.1. Case study context: Hawke's Bay, New Zealand

New Zealand is actively working on the development and application of climate change adaptation pathways for agriculture, due to the industry's social and economic significance (e.g., Kenny, 2011; Kalaugher et al., 2013; Tait et al., 2018; Ausseil et al., 2019; Cradock-Henry et al., 2019a; Cradock-Henry et al., 2019c). The country also has experience over many decades of developing scenarios and taking long-term future perspectives (Frame, 2018). New Zealand has a mixed economy, notably primary production, tourism, and energy that depend heavily on the state of natural resource capital. Its small size, relative geographical isolation, and strong reliance on trade and migration make its economy particularly vulnerable to the world's prevailing economic situation (Reisinger et al., 2014). Socioeconomic developments thus cannot be captured appropriately by simply downscaling global scenarios. New Zealand's particular approach to managing natural resources, and the great weight given to environmental considerations, may critically influence the impacts of climate-related changes in land and water resources on its society and ecosystems. As a result, tools are being developed by researchers in partnership with government to help decision makers identify potential adverse outcomes, weigh adaptation options, and promote foresight, particularly in relation to coastal hazards (Lawrence and Haasnoot, 2017; Lawrence et al., 2019, 2020).

The case studies applied a participatory approach to adaptation pathways with rural and agricultural stakeholders in Hawke's Bay on the east coast of New Zealand's North Island (Cradock-Henry and Frame, 2021b). The land base comprises broad, fertile floodplains, and steeper hill country, supporting diverse agricultural activities, including extensive horticulture and viticulture, dairy, sheep and beef, and forestry. Of the region's 165,000 plus residents, approximately 80% live in a major urban area. Hawke's Bay has higher levels of social inequality than the national average, and nearly a quarter of the population identify as Māori (the indigenous people of Aotearoa/New Zealand). Hawke's Bay has a Mediterranean climate, with conditions typically drier and warmer than the New Zealand average. Mean annual rainfall is 1,000 mm and droughts are not uncommon. Irrigation is used primarily from groundwater resources with some surface abstraction.

3.2. Case study activities

Each stage of the process from the guidelines is now described in brief.

3.2.1. Stage 1: Define objectives and outcomes

The case studies were developed as part of a project on regional adaptation planning, with funding from the New Zealand national government and the local regional authority Hawke's Bay Regional Council (HBRC). HBRC—which is responsible for land and water management and regional economic development—identified climate adaptation as a priority in its strategy, to "support natural resource users to identify and proactively manage business risks and opportunities arising from a changing climate" (2016). The lead author had conducted previous research in the area on collaborative processes for freshwater governance (Cradock-Henry, 2017) and was well connected with local stakeholders actively involved in adaptation issues. The urgency of adaptation in the region had also been identified in a recent review of national needs and priorities for primary industries (Cradock-Henry et al., 2019b).

Two catchments (Wairoa and Karamu) were selected for the participatory adaptation pathways process in consultation with representatives from HBRC. The catchments differ in their land management and primary industries while also being broadly representative of issues facing rural communities in New Zealand. The Wairoa catchment (264,500 ha) is remote, hilly, and erosion-prone, with land use largely focused on livestock (sheep and beef) and forestry. The Karamu catchment (52,000 ha) is flat with land uses primarily for high-value horticulture and viticulture. Both face interrelated challenges including climate change adaptation, soil erosion, drought, water availability, and social and economic vulnerability.

The first step involved stakeholders identifying values and priorities for management, from which decision areas of focus for adaptation were derived. These "key areas of decision making" included soliciting information from stakeholders regarding management objectives, values, and rationale for adaptation.

To do so, we used a combination of expert interviews (farmers, growers, and consultants) and workshop activities to develop a rich picture of the complex interactions between different elements of the regional agricultural system. The systems perspective considered regional agricultural production as part of a whole/complex social-ecological system, comprised not only of the mix of land-uses and activities but also the enabling structures and processes (such as infrastructure) and social and human elements (such as communities and livelihoods).

Interviewees and workshop participants were first asked to describe and/or draw their system (in this case, land management at the catchment scale) and how they thought it might be affected by climate change. To prompt thinking and discussion, we suggested participants reflect on the features or attributes of local productive landscapes that they valued; any specific management or adaptation objectives they may which to realise, and the reasons why adaptation may be needed.

For Hawke's Bay primary industries, two major categories of impacts and implications were identified: the influence of climatic stresses on production systems, including the effects of higher temperatures and declining rainfall, and the indirect and flow-on effects for production, as well as supporting and enabling subsystems such as processing infrastructure, and freshwater. These were summarized as four key areas of decision making: community, infrastructure, agriculture, and freshwater and were used to guide the pathways development process (**Table 1**).

3.2.2. Stage 2: Explore current system and situation

Climate modeling

Downscaled climate data provided a basis for identifying and assessing suitable adaptation options (**Table 2**; National Institute of Water and Atmospheric Research, 2017) and with multiple scenario combinations. In other case studies, authors have used multiple scenarios in discussions with stakeholders, focusing on different combinations of drivers to quantify and evaluate management options (Lino et al., 2019; Reimann et al., 2021). In our experience, trying to test multiple possible worlds in a workshop setting can require more time to explore each scenario than is available as participants can struggle to accommodate several scenarios in a short time. Furthermore, differences between the futures were not sufficiently sensitive to reveal major differences relative to the impact of other non-climate-related changes. By "bookending" the evaluations with scenarios at either end of a continuum, it was considered sufficient range for sensitivity to reflect the long-term changes (Lawrence et al., 2020).

As a result, the case studies were based on two emissions pathways: RCP4.5, a low to mid-range emissions "stabilization" scenario, where radiative forcing stabilizes by 2,100, and RCP8.5, a scenario with high greenhouse gas emissions, where radiative forcing continues to increase beyond 2,100.

The climate change scenarios used climate model data from the Intergovernmental Panel on Climate Change Fifth Assessment (2014) to update climate change scenarios for New Zealand, through a dynamic regional climate model (Mullan et al., 2016). The results describe possible

Table 2. Summary of climatic impacts in the two case study catchments. DOI: https://doi.org/10.1525/elementa.2020.00175.t2

Case Study Catchment	Climate Scenarios	
	Moderate	**Extreme**
Karamu	0.75°C warmer, mostly in summer/autumn	2.5°C warmer, mostly in autumn
	15 additional "hot days" per year	60 additional "hot days" per year
	5 fewer "cold nights" per year (i.e., frosts)	10 fewer "cold nights" per year (i.e., frosts)
	5% less rainfall annually, mostly in spring	10% less rainfall annually, mostly in spring
	5% more extreme rainfall	10% more extreme rainfall
	120 mm increase in PED deficit (drought proneness)	160 mm increase in PED deficit (drought proneness)
	+ increase in extreme winds and storms is uncertain	++ increase in extreme winds and storms is uncertain
Wairoa	0.75°C warmer, mostly in summer/autumn	2.75°C warmer, mostly in autumn
	30 additional "hot days" per year	60 additional "hot days" per year
	5 fewer "cold nights" per year (i.e., frosts)	5 fewer "cold nights" per year (i.e., frosts)
	5% less rainfall annually, mostly in spring	5% less rainfall annually, mostly in spring
	5% more extreme rainfall	15% more extreme rainfall
	100 mm increase in PED deficit (drought proneness)	140 mm increase in PED deficit (drought proneness)
	+ increase in extreme winds and storms is uncertain	++ increase in extreme winds and storms is uncertain

Hot days: the number of days per year with maximum temperature >25°C. Cold nights/frosts: the number of nights per year with minimum temperature <0°C. Extreme rainfall: 1% top highest rainfall events. Drought proneness (PED = potential evapotranspiration deficit): the cumulative difference between potential evapotranspiration and rainfall from July 1 of a calendar year to June 30 of the next year, for days of soil moisture under half of available water capacity (AWC), using an AWC of 150 mm for silty-loamy soils. +, ++: (very) positive change.

Adapted from downscaled projections (National Institute of Water and Atmospheric Research, 2017).

climate change impacts but do not address mitigation. The summary (**Table 1**) was discussed with industry-specific experts in semistructured interviews to assess anticipated production impacts and adaptations for the dominant sector. The list of anticipated impacts was then used in workshops with stakeholders to identify challenges in their region, along with potential adaptation options.

Biophysical and crop modeling

In the case study, simulation results from the Agricultural Production Systems Simulator (Holzworth et al., 2014) model were used to illustrate possible responses from pastures and crops under future climatic conditions (Ausseil et al., 2019). For the horticultural sector, regional trends were informed by bioclimatic indices at a national scale owing to resource and model limitations. The findings from various model runs quantitatively illustrated impacts on specific crops for the two scenarios to enrich discussions with stakeholders and help for assessing the suitability of adaptation options.

3.2.3. Stage 3: Generate and analyze possible futures

Stakeholder workshops, expert interviews, and regional workshop

Two stakeholder workshops were held in each catchment. At the initial workshop, participants developed a rich picture of the local environment, including the function of the primary production sector and ecosystem services. The second workshop produced draft pathways diagrams that identified adaptation options for key challenges and opportunities (**Figure 3**). These were peer reviewed through 13 interviews with farmers, growers, and consultants. Each interview was between 35 and 60 min with the two draft scenarios provided in advance. Analysis of the interviews helped determine the adaptation pathways options, which were, in turn, reviewed at a regional workshop of experts.

3.2.4. Stage 4: Identify, assess, and prioritize adaptation options

Systems dynamics modeling

The aim was to formalize stakeholders' tacit knowledge, perceptions of key drivers of change, and relationships between various components of primary industries' activities. The systems map represents infrastructure for all the climate impacts considered and the various dependencies and interdependencies (**Figure 3**). The relationships (arrows) link to various capital stocks as described in the Living Standards Framework (New Zealand Treasury, 2018) to align the systems map with other New Zealand initiatives.

The map shows activities that seek a return on investment from a particular type of land use within the natural capital constraints. This land use spurs investment in, and is constrained by, the levels of financial and physical, human, and social capital. Climate change is also shown

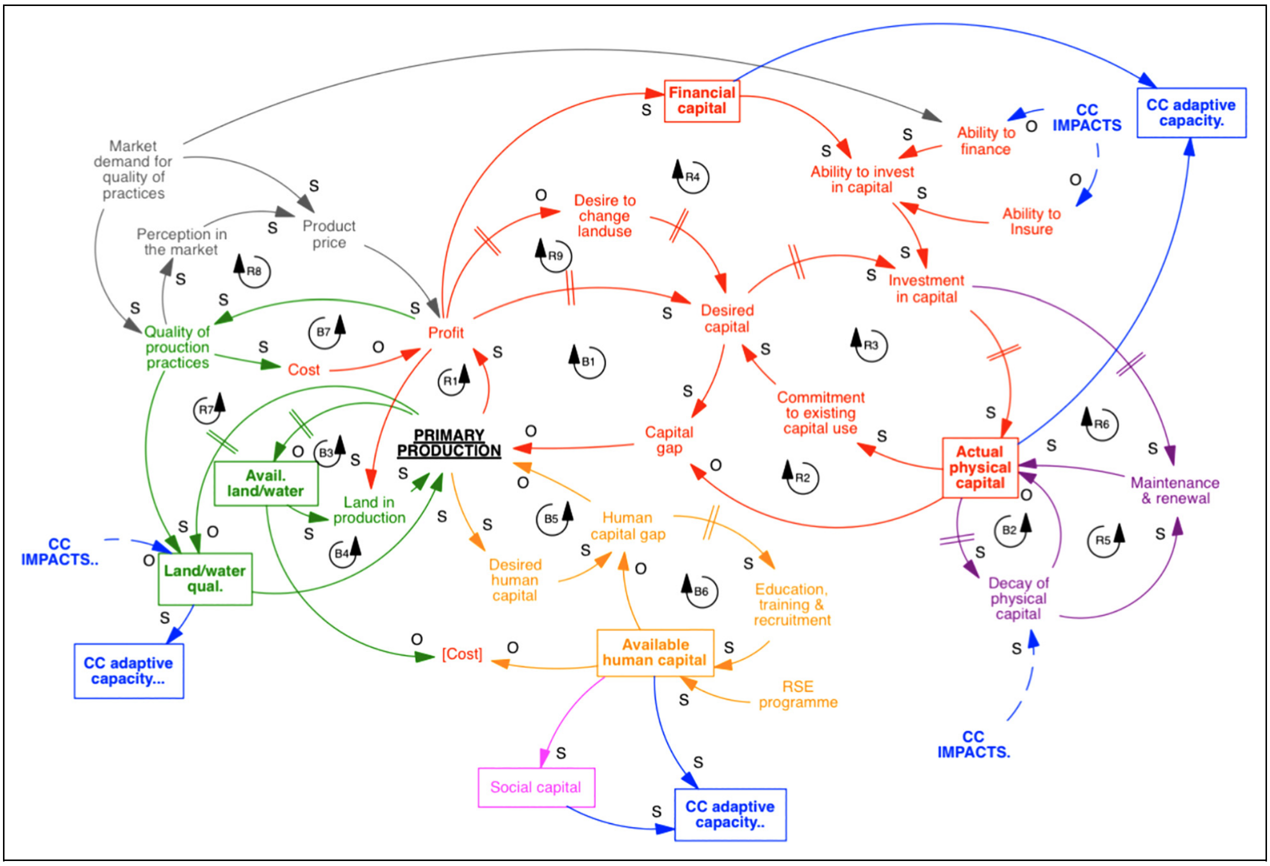

Figure 3. System map (causal loop diagram) based on workshop findings in response to "How will climate change affect primary industries in Hawke's Bay, New Zealand?" DOI: https://doi.org/10.1525/elementa.2020.00175.f3

as a stressor that would affect capitals directly through higher temperatures, climate variability, and extremes and indirectly through relationships with other parts of the system. These impacts are mediated through adaptive capacity and adjustments made to moderate potential damage, take advantage of opportunities, or cope with consequences.

Financial and physical capital is shown in red. The arrows articulate the relationships between primary production and profit fuelling more productive land, increased desire for capital, and the subsequent investment this encourages. Natural capital—including land and soil, water, plants, and animals—is shown in green and represents available land and water. Human capital is the shown in yellow and includes the things that enable individuals to participate fully in society. This includes their skills, their knowledge, and their mental and physical health. The human capital that was considered most relevant to primary production is predominantly the skills and knowledge required to work in that industry. While not fully explored, social capital (light blue) is also shown, representing the social and cultural (including Māori) norms and values that underpin society (e.g., law, government, indigenous worldviews). The map also illustrates where climate change (dark blue) is expected to affect primary production, affecting the quantity and quality of physical capital through increased storm events, for example. Natural capital is also likely to be affected. Direct impacts on land (e.g., increased rates of soil erosion) or water may be experienced, along with declining quality of natural capital. Climate change will also affect financial capital, in particular producers' ability to finance and ability to insure. The final addition to the summary system map is adaptive capacity, also shown in blue. Adaptive capacity is depicted as a function of the four major capitals: financial and physical capital, natural capital, human capital, and social capital.

Desktop analysis of adaptation options

To supplement adaptation options, the results of other studies were included (Fowler et al., 2013; Kalaugher et al., 2013; Cradock-Henry et al., 2019b). The desktop analysis identified project reports and literature focused on Hawke's Bay and primary industries (e.g., horticulture, viticulture, dairy).

Local participatory adaptation pathways

The adaptation pathways for the decision areas (community resilience, infrastructure, water, and primary industries) were developed from the information sources, as shown in **Figures 4–8. Each is now described in more detail.**

Community resilience: In the face of growing environmental change, socioeconomic inequality, and urbanization (**Figure 4**),

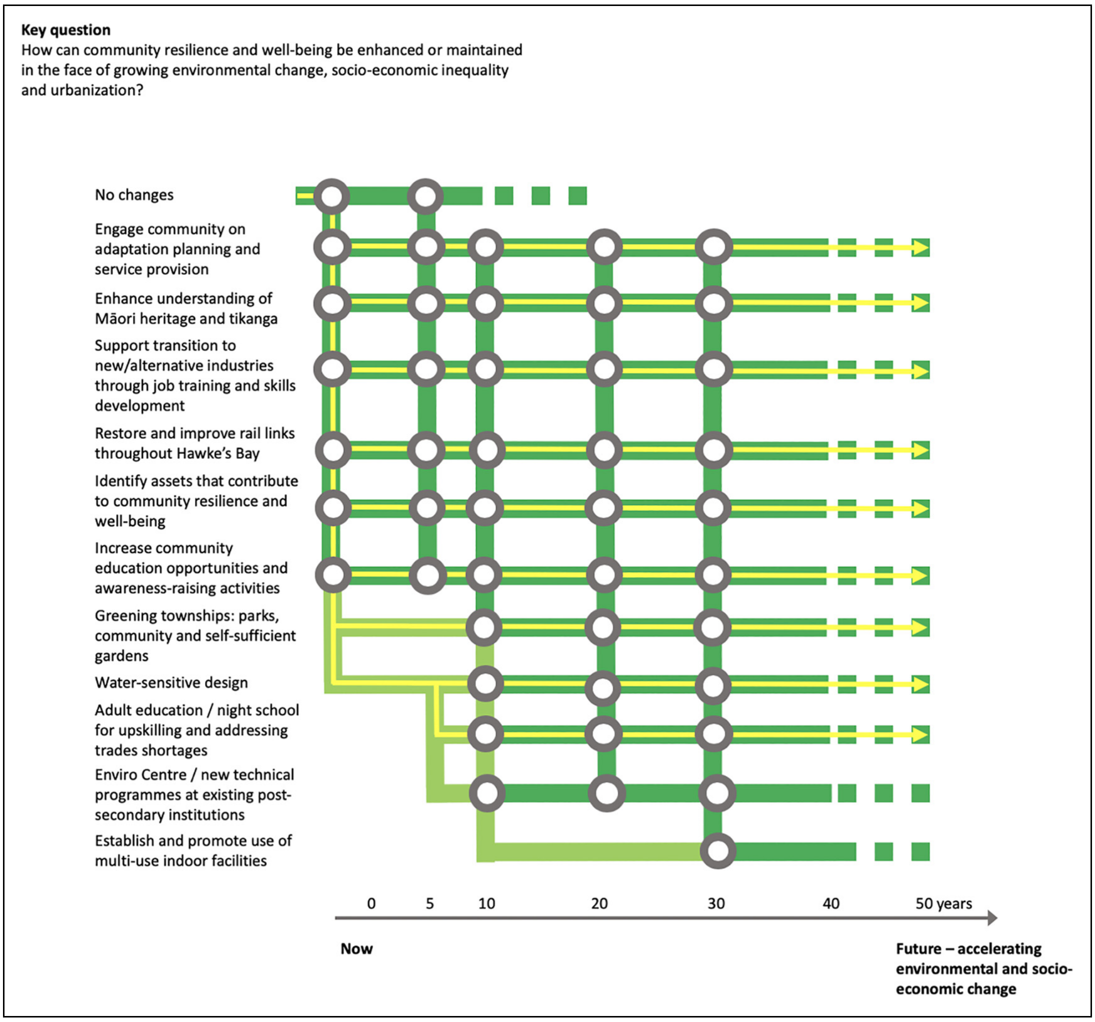

Figure 4. Adaptation pathway for community resilience and well-being. DOI: https://doi.org/10.1525/elementa.2020.00175.f4

resilience of rural communities is a critical component of their capacity to cope with and adapt to climate-related stressors and disturbances. To support community resilience and well-being, the immediate priorities for adaptation are educating and raising awareness of climate change impacts and the implications, options, and actions for Hawke's Bay. Participatory processes in local communities can be used to enhance adaptive capacity and to explore needs and options, including realizing educational opportunities. For example, the reopening of rail transport in 2019 was important in enhancing resilience by improving connectivity and creating opportunities for economic development. Other investments in infrastructure and the built environment may be required, and a shift toward water-sensitive urban design and enhancement of green spaces is anticipated. Long-term opportunities include the development of technical programs and multipurpose community facilities.

Infrastructure: Here, decision making requires improved management of transportation, processing, and distribution infrastructure to provide increased resilience to more frequent storms, sea-level rise, and possible disruption (**Figure 5**). In the immediate short term, adaptation needs to focus on risk assessment, education, and engagement that considers current and future vulnerability of critical infrastructure and lifelines. This adaptation option has been identified as a high priority by key stakeholders. In the longer term, accelerating the transition toward a circular economy and infrastructure investment to support new opportunities from the primary sector is likely to be required.

Water: In this case, decision making requires security of supply for agriculture, given a possible reduction in water availability,

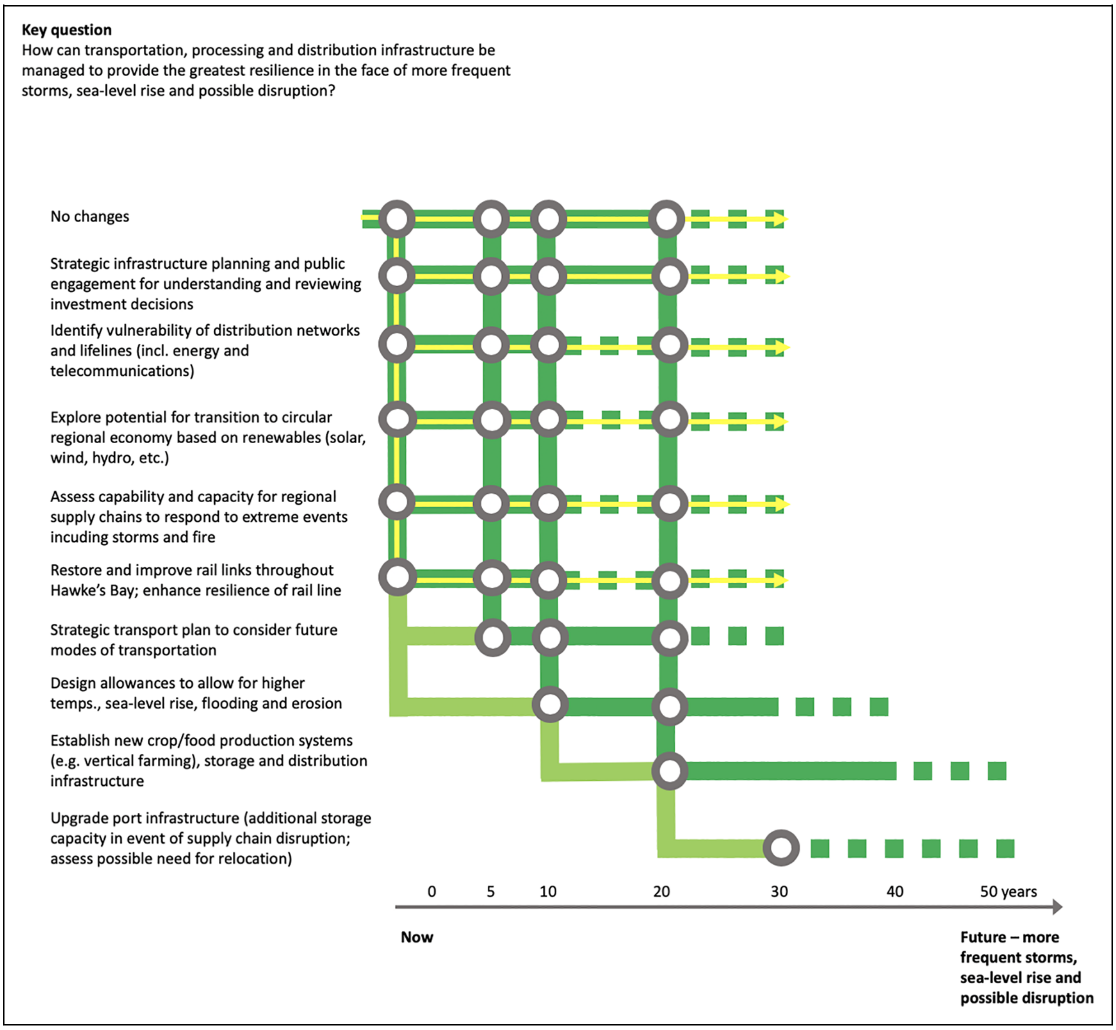

Figure 5. Adaptation pathway for infrastructure. DOI: https://doi.org/10.1525/elementa.2020.00175.f5

either because of climate-change-induced rainfall decline or reduced access from groundwater for irrigation (**Figure 6**). The need to sustainably manage freshwater resources was recognized as an essential part of climate change adaptation for Hawke's Bay primary industries. Options were identified for prioritization, including focusing on realizing efficiencies, improved education, and extension opportunities that promote best practice. The emphasis was on effective management of known resources rather than accessing or developing additional resources.

Primary industries: This involves the transition to more viable agricultural practices, including consideration of future land use for warmer and drier conditions (**Figure 7**). While current innovations in agricultural practices will provide some measure of adaptation over 10–20 years, long-term adaptation may require more transformational responses, such as the adoption of advanced breeding techniques, which will require advance planning. Transformational adaptation can be considered, including a detailed assessment of regional and sectoral capacity for widespread, systemic change including an understanding of the drivers and inhibitors of transformational adaptation.

Regional participatory adaptation pathways

Eight adaptation priorities were identified (**Figure 8**). Three that would accelerate current practice through incremental change (current best practice, strategic planning, and increased learning opportunities) were recommended for immediate implementation, while two others (changes in varietals/crops, land-use change, and transitions) could be delivered within 5 years to build resilience for specific key decision sectors. Options for delivery over a longer time frame (notionally 10–30 years) would support a transition to lower water use and support more transformational changes (climate-sensitive design and new technologies). These were recognized as not being the only adaptation actions required, nor would they be

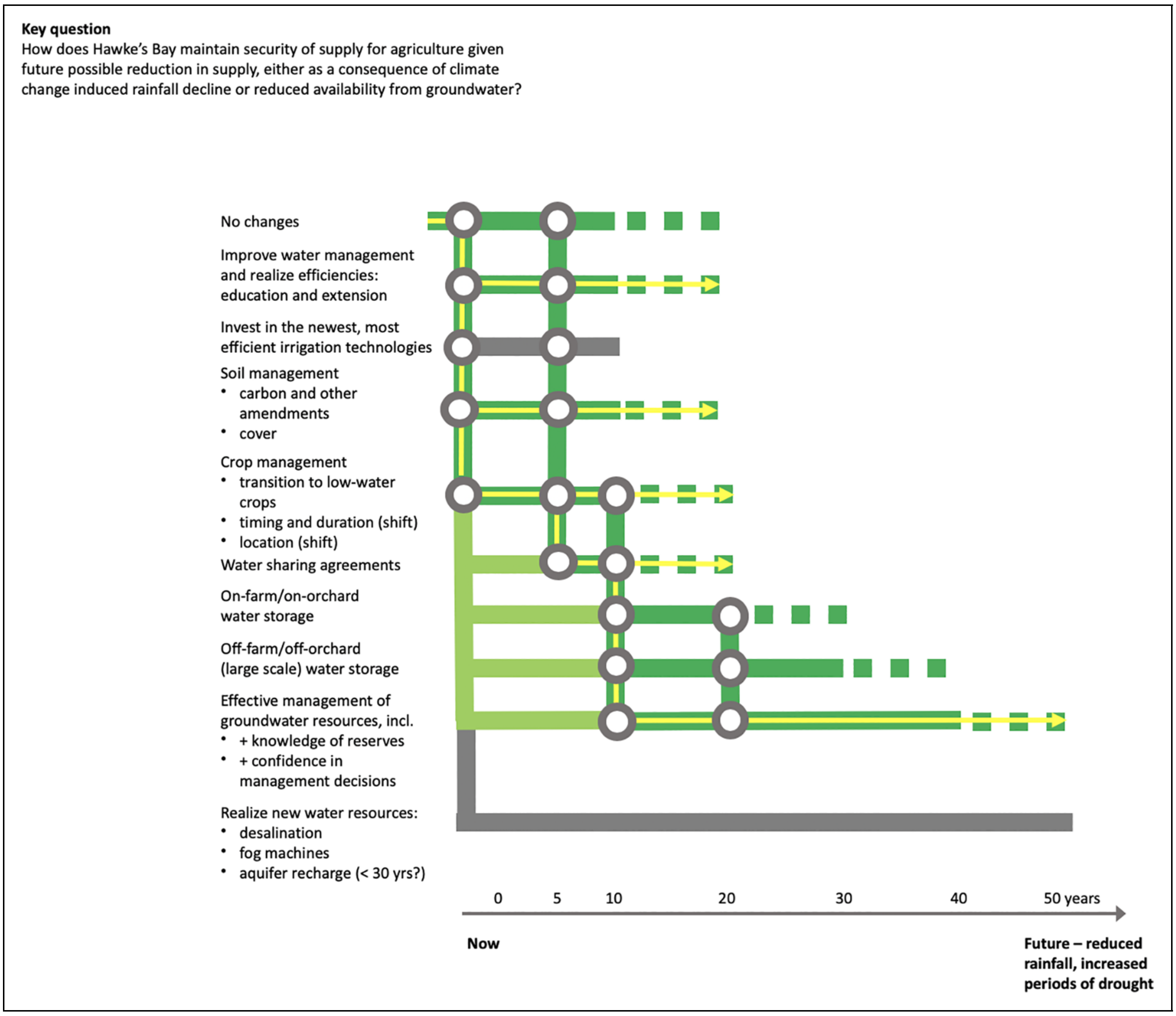

Figure 6. Adaptation pathway for freshwater. DOI: https://doi.org/10.1525/elementa.2020.00175.f6

transferable to other regions. They were solely intended as a basis for regional, cross-sectoral action. The remaining preferred options were considered critical to ensuring the resilience of primary industries, to enable the region to adapt and thrive in the face of climate change.

3.2.5. Stage 5: Implement and evaluate

Much of the current focus of adaptation planning in the region is on priority impacts and adaptation options, which require enabling conditions. For example, proposed actions need to align with community values and need to be achievable within regional policies and governance arrangements. More specifically, future adaptation requires consideration of:

- regional governance that provides for continuation of a collaborative approach to adaptation planning;
- development of a business case for regional action on climate change;
- improved awareness of climate change issues within sectors, undertaken by sector leaders, with the support of local government, sector and industry bodies, and central government;
- improved engagement with Māori peoples in adaptation planning;
- development of a vision for the regional economy that considers the impact of climate change on key sectors and plans for a "low carbon, low water" future;
- funding to address knowledge gaps for the primary sector and enhance and maintain recent progress on adaptation research to improve adaptive planning;
- support and training for the next generation of industry and community leaders to participate in adaptation planning processes; and
- greater adaptation research capability and capacity.

Across the four adaptation pathways, greater participation by stakeholders and enhancing opportunities for learning were identified as priorities for adaptation

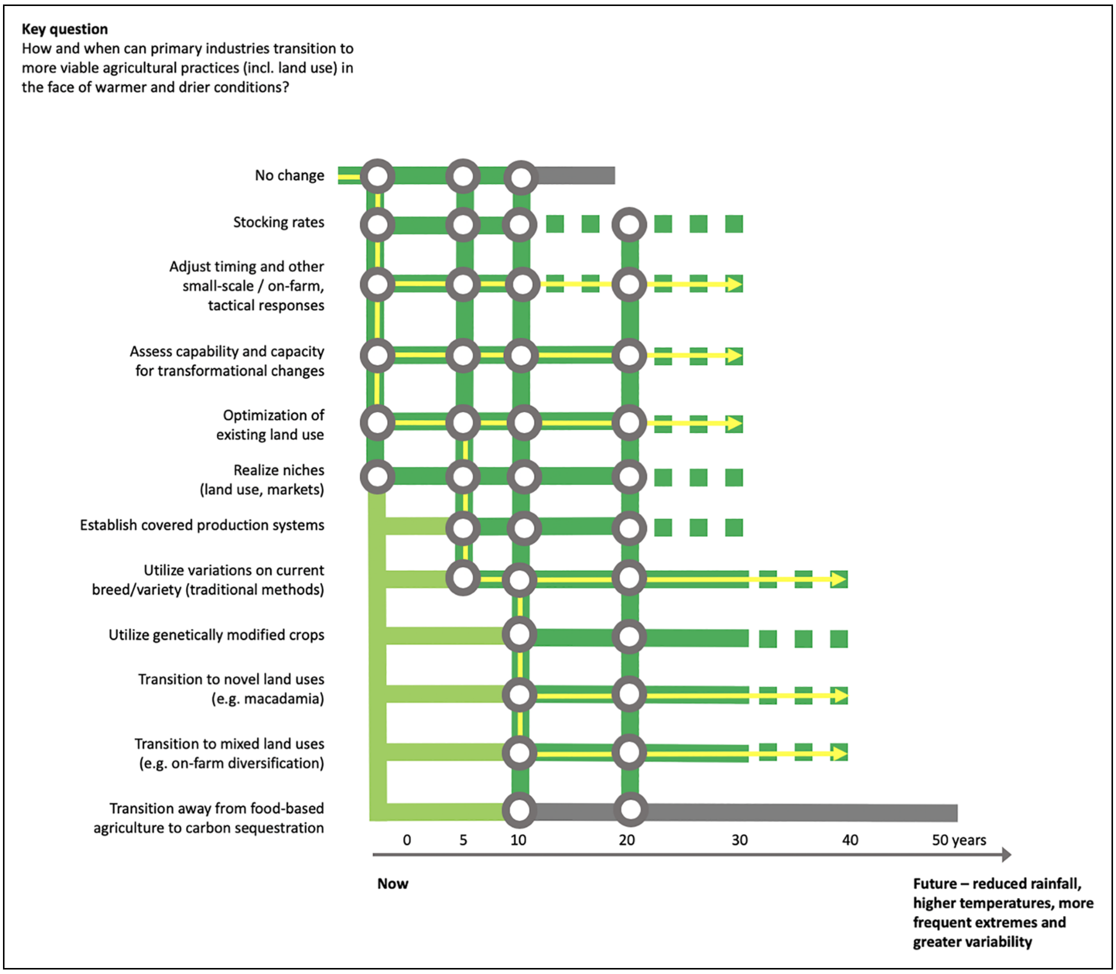

Figure 7. Adaptation pathway for primary industries. DOI: https://doi.org/10.1525/elementa.2020.00175.f7

action. These would involve a renewed focus on climate change adaptation through farm extension programs to share practices on adaptation-related topics including water and irrigation efficiencies and crop and soil management (Hermans et al., 2017; Murti et al., 2019). It would also involve development and promotion of new methods of engagement to increase learning, such as novel technologies and "serious games" (Edwards et al., 2019).

Greater attention will be needed for infrastructure initiatives to accommodate climate change impacts. Ensuring the resilience of transportation infrastructure and processing capacity (including storage and distribution facilities) will be crucial, particularly if there are widespread changes in land use. Upgrades may be required to road and rail, along with emergency preparedness to minimize disruptions and restore functionality quickly following major logistics disturbances. Within two to three decades, more of the region's adaptation actions will need to focus on maintaining and enhancing critical value chains, protecting assets, and undertaking preparatory actions for transformational change. Major emerging actions could be large-scale land-use change or the establishment of novel or genetically modified crops. In the longer term, adaptation may require the relocation of some activities and further transformation within key areas of decision making. Notably, planning work for these medium- and long-term actions needs to commence soon.

4. Evaluation and lessons

From our use of the guidelines, and through discussions with participants, important learnings have arisen and these are now described in turn.

Adaptation pathways can help generate an array of management options. The process of systematically identifying impacts and implications, and the suitability of different adaptation options with respect to different futures, helps decision makers to understand how and when to change their management practices to minimize risks and realize opportunities.

Local adaptation to climate change pathways needs to accommodate a wide range of social, cultural, economic, and environmental drivers that are transparent and accessible to nonspecialists in a short period of time. This requires a rich mix of local understanding, expert advice, and systems modeling of climate impacts and adaptation options to unpack the complexities of adaptation planning for the multiple stakeholders in primary industries. This can take place across various scales and the process needs to be tailored to the specific and in partnership with an appropriately comprehensive set of participants.

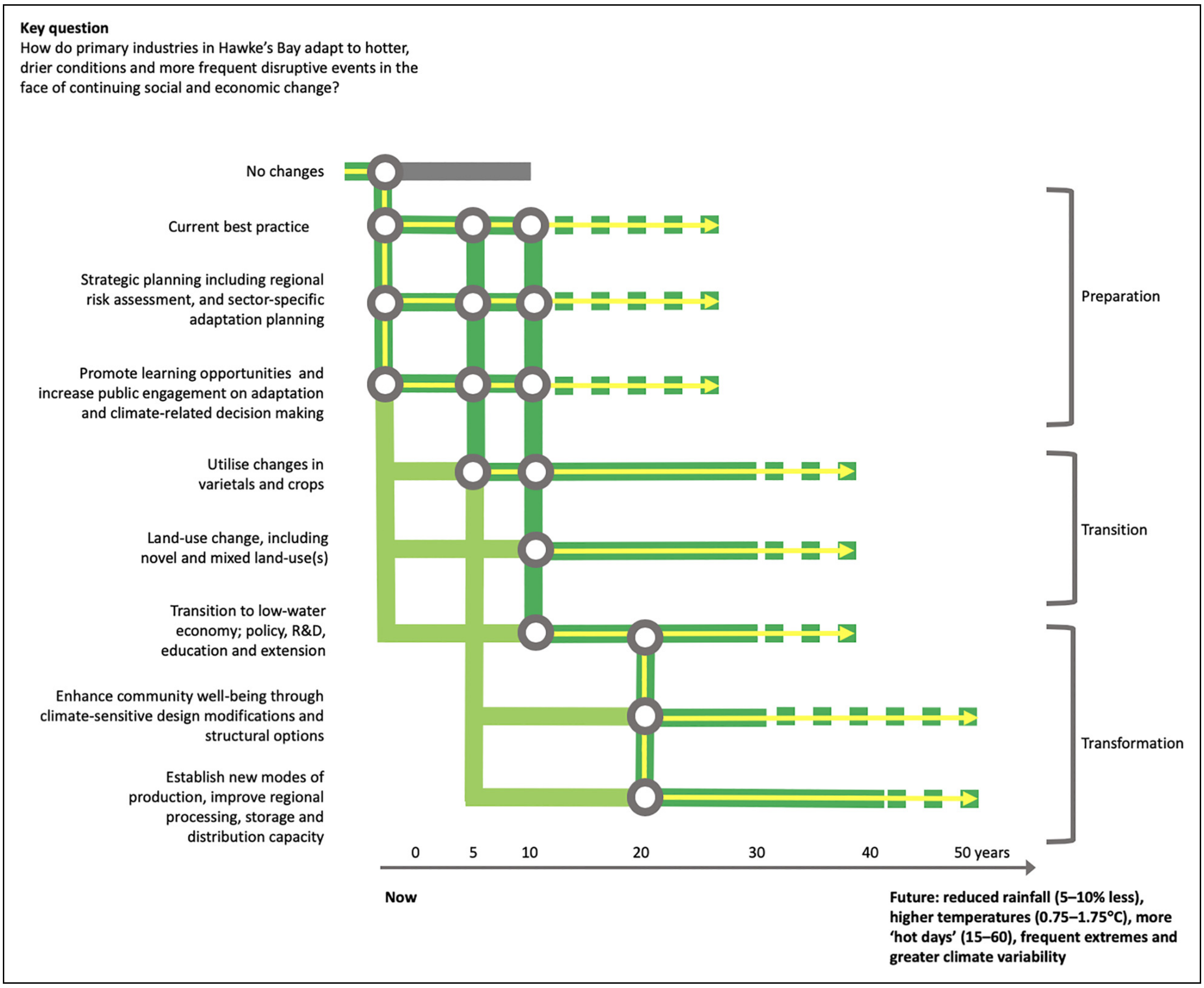

Figure 8. Regional adaptation pathway for Hawke's Bay, New Zealand. DOI: https://doi.org/10.1525/elementa.2020.00175.f8

Carefully facilitated and curated this should create potential pathways that are considered as relevant, credible, and legitimate and which prove to effective in practice, especially in an increasingly complex global environment as noted by Cash and Bolloy (2020) and by Cradock-Henry and Frame (2021a). Key to this is an approach that maximizes synergies between participants, and which enables trade-offs among adaptation options.

Pathways can visually display the temporal ordering of adaptation options, from those that can be taken now to ones that may be taken later. This provides two important benefits. First, the graphic process is, as noted earlier, an important means of communicating contextual complexity and maintaining engagement. Second, the diagrams themselves become artifacts of the process and, as such, provide a useful boundary object and practical tool for stakeholder planning as noted by Cash et al. (2003) and Cash et al. (2006).

It is important, as has been stressed throughout, to ensure that the principles and guidelines of engagement are context specific with an appropriately comprehensive group of participants. There is also the need to constantly review and accommodate location-specific conditions. There will, inevitably, be tensions between competing interest groups for which there is an existing literature available from which possible solutions can be considered (Baird et al., 2014b; Faysse et al., 2014; Cvitanovic et al., 2019).

5. Conclusion

The accelerating pace of climate change impacts and implications, and improving our understanding of the future vulnerability of human and mixed human-natural systems by including greater consideration of socioeconomic dimensions, has long been recognized. Adaptation to climate change, especially for primary industries and rural communities, will not occur in isolation but rather be influenced by complex interactions between multiple climatic and non-climatic stressors (Meinke et al., 2009; Cradock-Henry et al., 2019c). Adaptation strategies, moreover, take place in a rapidly evolving decision context, shaped and influenced by values, rules, and knowledge, structural and nonstructural constraints, and enablers that can support coping, incremental, or transformative change (Gorddard et al., 2016; Fedele et al., 2019; Wilson et al., 2020).

Primary industries globally are being faced with very complex adaptation issues as producers seek to provide goods and services essential to social well-being while also being faced with accelerating climate change. Given that there is a huge range of issues at play not just at the national level but at the local and catchment scales that are both contextually unique but operationally highly complex. Of the many tools and processes being developed, adaptation pathways using participatory processes is generally considered a supportive and accessible mechanism. Methods such as these need to be clearly identified and widely disseminated to encourage the imagination of possible futures and enable greater consideration of the need for accelerating transformative change.

This study provides support for researchers, policy makers, and practitioners interested in participatory approaches for vulnerability, impacts, and adaptation. By providing a simplified set of guidelines (**Figure 1**), we answer the call for transparent, accessible, and participatory approaches to adaptation planning. Furthermore, they provide a potential opportunity to help empower local communities for adaptation planning, and in New Zealand and elsewhere, enabling more integrated assessments of climate change impacts, adaptation, and socioeconomic risk and can assist in identifying opportunities. Such work can help those grappling with the challenges and uncertainty of climate change impacts and how to integrate multiple types of information and knowledge into adaptation plans.

Finally, extending participatory adaptation pathways processes to the local level means engaging multiple contested values including political agendas and often also with limited resources available to the organizations developing the adaptation pathways. Navigating successful and effective ways through this complex environment will require evaluation of numerous case studies across multiple jurisdictions and reflexive processes for establishing and increasing adaptive capacity, to support just and sustainable transitions toward climate-adapted futures.

Data accessibility statement

Interviews were audio-recorded and transcribed. In several cases, the written transcription omitted sections not relevant to analysis. Due to the nature of this research, participants of this study did not agree for their data to be shared publicly, so supporting data are not available. Workshop materials, including agendas, run sheets, and exercises are available upon request.

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Competing interests

The authors have declared that no competing interests exist.

Author contributions

Contributed to conception and design: NACH, BF.

Contributed to acquisition of data: NACH, PB, JC, ET, PJ, AW.

Contributed to analysis and interpretation of data: NACH, PB, JC, ET, PJ, AW.

Drafted and/or revised the article: NACH, BF, PJ, ET, AW, PB.

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