Te Mana o Taiari - Matatū ki te Taiao Hui Rautaki

Shane Orchard

Prepared for

Department of Conservation
June 2022

Cover image: Waipōuri (Waipori) River
Back cover: Lake Waipōuri
Photo: S. Orchard

Waterlink Ltd
CONSERVATION PLANNING • RESOURCE MANAGEMENT
439 Marine Parade, Christchurch 8062
Aotearoa / New Zealand
T: +64-3-388 8281 | M: +64-21-318548

Document revision and status

Revision	Date	Status	Approved by	Issued by
v1	10/07/2022	Draft for review	S. Orchard	S. Orchard
vFinal	04/08/2022	Final	C. Kavazos	S. Orchard

Te Mana o Taiari - Matatū ki te Taiao Hui Rautaki

Shane Orchard

Prepared for

Department of Conservation
July 2022

Report WL22071 for Department of Conservation

CONTENTS

Executive summary

The development of Matatū ki te Taiao - a climate resilience strategy - has been identified as a central component of the Te Mana o Taiari Ngā Awa river restoration programme co-led by mana whenua, the Department of Conservation Te Papa Atawhai and Otago Regional Council for the Taiari catchment.

Te Mana o Taiari aims to improve the mauri of the Taiari awa by:

- Restoring ecological processes
- Enhancing native species diversity
- Increasing resilience to climate change

This report provides a summary of the initial hui rautaki (strategy workshop) held on 11 June 2022 at Te Nohoaka o Tukiauau / Sinclair Wetlands. The report consists of two main parts and supporting appendices.

Part 1 provides a set of notes and overarching principles for the development of Natural Environment Resilience Planning for climate change. This approach recognises the critical need to incorporate natural environment values within climate resilience strategies and action plans.

The material covered in this section summarises a selection of topics that were discussed at the strategy workshop that draw upon a considerable international literature on resilience in relation to natural resource management and climate change. It is important to note that this section does not attempt to provide a comprehensive review of those topics and only a few key references are included in citations. The objective is to document the concepts and themes discussed at the hui prior to the strategy session.

Part 2 provides a summary of outputs and notes from the rautaki (strategy) session attended by representatives from Te Rūnaka o Ōtākou, Kāti Huirapa Rūnaka ki Puketeraki, Department of Conservation, Otago Regional Council staff and Councillors, Te Nukuroa o Matamata staff, and the local community.

Appendix 1 provides more detailed information captured during the strategy session.

Appendix 2 provides a set of worked examples of ecological impact and scenario analysis that were used to support the hui. These studies are based on the investigation of sea-level changes in an environment similar to the lower Taiari catchment. Although they have a focus on ecohydrological changes in a coastal environment, the same general approach to identifying and characterising values, vulnerabilities and adaptation options is transferable to other natural environments and resources at a variety of scales.

PART 1 Te Mana o Taiari - Matatū ki te Taiao

This section provides a set of notes and overarching principles that were discussed at the hui rautaki (strategy workshop). This material draws upon a considerable international literature on resilience in relation to natural resource management, conservation and climate change. It is important to note that this section does not attempt to provide a comprehensive review of those topics and only a few key references are included in citations herein. Rather, the main objective is to document the concepts and themes discussed at the hui prior to the strategy session for the benefit of the workshop participants and also other interested persons who were unable to attend.

He mihi

Climate change
Food security
Mahika kai

I orea te tuatara ka patu ki waho

A problem is solved by continuing to find solutions

Nāu te rourou, nāku te rourou, ka ora ai te iwi

With your food basket and my food basket the people will thrive

Matatū ki te Taiao

Te Mana o Taiari is a catchment restoration project co-led by mana whenua, the Department of Conservation Te Papa Atawhai and Otago Regional Council.

It aims to improve the mauri of the Taiari awa by:

- Restoring ecological processes
- Enhancing native species diversity
- Increasing resilience to climate change

Te Mana o Taiari is part of the national Ngā Awa river restoration programme. It is applying a collaborative ki uta ki tai (mountains-to-sea) approach to restore river environments through the identification, planning and implementation of new partnership and co-management models (Department of Conservation 2021).

The need for Matatū ki te Taiao - a climate resilience strategy – has emerged from initial work between the project partners. It will help to identify strategic restoration and protection needs for the natural environment of the Taiari.

Horopaki / Context

Risk-based approaches to change

Hazards refer to events that have the potential to cause loss or harm. They include physical processes that we associate with natural hazards, natural disasters and other pervasive landscape change. Because climate change can affect both incremental changes and the frequency and magnitude of extreme events, it is a key concern for the management of hazards and associated risks (sometime referred to as 'hazard risks'). Some examples of hazards that are associated with risks to aquatic systems and land-water interface environments such as those such as those found in the Taiari are shown in Box 1.

BOX 1 Climate-related drivers of change associated with natural hazards in aquatic systems and land-water interface environments

- Water quantity changes
- Water level and changes
- Salinity changes
- Temperature changes
- Wind-storms and wind patterns
- Extreme or slow-change processes affecting erosion & deposition trends

The concept of risk relates to the potential for negative outcomes such as the loss of life, assets or values, as the result of exposure to hazards. Risk is often expressed as an interaction between the consequence and likelihood of these negative outcomes becoming manifested over time (Box 2). It follows that a risk-based approach will involve strategies to avoid, reduce or mitigate negative outcomes by various means.

BOX 2 Risk-based approach

Risk is often measured as the interaction between the consequence and likelihood of events with the potential to cause harm

It can be applied to both natural and built environments and the values they sustain

In the field of climate risk assessment much of the literature has a tendency to focus on the consequences of specific hazard scenarios. This methodological approach for risk assessment is consistent with risk concepts based on consequence and likelihood so long as the 'likelihood' component is explicitly recognised in the choice of climate change scenario(s) and their associated uncertainties. For example, these considerations can be explicitly incorporated within the hazard exposure term in the climate risk assessments framework recommended in IPCC (2014).

It is also important to recognise that many climate change vulnerabilities are interconnected. This is clearly seen in the consideration of 'adaptive capacity' which is a key component of vulnerability concepts in climate change analyses (IPCC 2014), and wider sustainability science, and typically involves both natural and anthropogenic influences (Turner et al. 2003). The adaptive capacity of a system is also related to the concept of resilience, which refers to the ability of system components to withstand disturbance events and longer-term change. Resilience theory also recognises that this need not involve a return to the exact same system state (Gunderson & Holling 2001). In this way social-ecological systems may evolve incrementally while retaining their essential character, functionality and resources over time.

Human aspects of disaster and climate risk

Climate change intersects with risks caused by natural events and also those exacerbated by human actions, or inactions, in the sense of man-made disaster events (Turner & Pidgeon 1997). There is now a considerable focus on preventing 'maladaptation' which refers to poorly planned climate responses that may cause unnecessary loss and harm due to deficiencies in their design (Macintosh 2013). These are especially likely where adaptation actions designed for one type of value involve a trade-off with other values for which the level of risk increases to the same (or other) hazards. This is relevant to the topic of Natural Environment Resilience Planning and the role of Nature-based Solutions which seek climate change responses that avoid undesirable trade-offs and ensure that natural environment values are maintained (Orchard 2022a). It also illustrates the role that human interventions can play, either intentionally or unintentionally, in critical aspects of a risk-based approach.

These concepts are incorporated within New Zealand's first National Climate Change Risk Assessment (Ministry for the Environment 2020), but there remains an urgent need for more specific conceptualisation and working examples across a range of biogeographical and social-ecological settings. Te Mana o Taiari and the wider Ngā Awa programme are important opportunities for thought leadership in this space. The Ngā Awa kaupapa is well-aligned with many of these concepts and has considerable potential to help investigate and solve Aotearoa's climate challenges in new and innovative ways. Alongside its primary role as place-based resilience strategy Te Mana o Taiari - Matatū ki te Taiao can provide important contributions to regional initiatives such as the Otago Climate Change Risk Assessment (Tonkin & Taylor 2021), and future iterations of the National Climate Change Risk Assessment and related work.

Natural Environment Resilience Planning

It is becoming increasingly important that climate resilience and adaptation strategies incorporate natural environments and ecosystems to safeguard the diversity of life and planetary life support systems alongside other goals. These objectives are supported by an understanding of values and objectives for natural environments and resources, particularly those of established cultural importance in Aotearoa New Zealand. This is relevant, for example, to the current New Zealand guidance on coastal hazard management in which an understanding of values underpins climate change response strategies based on adaptive planning cycles (Bell et al. 2017). It is also reflected in the 'value domains' adopted in the National Climate Change Risk Assessment for Aotearoa New Zealand (Ministry for the Environment 2020).

Key aspects of an adaptive planning process for climate change include:

- Iterative cycles of decision-making
- Adaptation pathways and scenario-based analyses for decision support
- The critical role of community engagement throughout (Figure 1).

Figure 1 Positioning of the understanding of values and objectives for natural environments and resources within an iterative decision cycle for responding to coastal hazards and climate change. Adapted from Bell et al. (2017).

Te Mana o Taiari - Matatū ki te Taiao recognises the need to address climate risk and resilience in an integrated way.

Some of the key points of focus include:

- Natural ecosystem values being considerable and diverse
- The many interdependencies between cultural values and natural values
- The need to integrate built & natural environment resilience to climate change

These aspects can be supported by holistic frameworks such as those embodied in the Ngā Awa programme and internationally through a family of approaches known as "Nature-based Solutions (Figure 2). Moving in this direction requires a paradigm shift from business-as-usual but is ultimately achievable if we take actions without delay (Orchard 2022a; Seddon et al. 2021).

Figure 2 The 'Nature-based Solutions' concept works with nature to solve societal challenges such as food security, natural hazards and climate change. Image courtesy of IUCN (Cohen-Shacham et al. 2016).

Some of the most powerful frameworks for assessments and decision-making fall within the scope of 'Nature-based Solutions' but differentiate themselves according to specific aspects such as the type of activities involved or the main objectives that are sought. Examples include Ecosystem-based Adaptation (EbA), Ecosystem-based Disaster Risk Reduction (EcoDRR), Natural Climate Solutions (NCS), Nature-based climate adaptation and mitigation, ecological engineering, green infrastructure, blue-green infrastructure and more. It is important to note that there are many overlaps between these terms and the same intervention can be an example of more than one of these concepts. For example, the conservation of coastal wetlands can contribute to EbA for existing wetland values, EcoDRR where the wetlands also provide protective defence functions, and NCS / Nature-based climate mitigation if additional carbon can be sequestered as a result.

It is also important to recognise the central role of mātauranga & holistic worldviews which may incorporate different ways of valuing nature and ecosystem services (IPBES 2022). This diversity of values and perspectives is also represented in integrative concepts such as 'ecological resilience' (Holling 1973) and 'social-ecological systems' (McGinnis & Ostrom 2014). Together, these knowledge frameworks provide powerful ways of thinking about interdependencies and environmental change. Improving the acceptance and mainstreaming of these concepts can therefore help to create the enabling conditions for holistic approaches to climate change. They also suggest that education and community engagement activities will have important roles to play.

Key role of Protected Areas in climate change

Addressing the role of Protected Areas is a key concern for climate change. For example, our current network of Protected Areas has been designed to protect important values … but what if those values move?

Protected Areas are a cornerstone of conservation efforts worldwide and can be defined according to the scope and level of protection they provide (Dudley 2008). In New Zealand, many environment types, such as lowland floodplains, are under-represented in the National Park system but can be protected under other forms of Protected Areas enabled through legislation such as the Resource Management Act 1991 (and reforms), Conservation Act 1987, Reserves Act 1977 and Wildlife Act 1953, and tenure-based protections such as covenants. The recognition of important values and areas for protection is also a component of statutory policy and plans prepared by local and regional councils in accordance with the legislative requirements they have responsibilities for.

Protected Area design and management is already challenging in dynamic environments. For example, many characteristic ecosystems have evolved to occupy transition zones and extremes that are too harsh for others to thrive, yet these same transition zones are often sensitive to change and may also be spatially confined. Improving the climate resilience of Protected Area networks will require increased attention to the mobility of natural environments and include the need to accommodate assembly / reassembly processes following disturbance events. Moreover, this brief discussion highlights the need for a specific focus on the effectiveness of Protected Area networks as an essential aspect of resilience to climate change.

PART 2 Hui Rautaki

Workshop overview

The initial hui rautaki was held on 11 June 2022 at the Te Nohoaka o Tukiauau / Sinclair Wetlands. Participants included representatives from Te Rūnaka o Ōtākou, Kāti Huirapa Rūnaka ki Puketeraki, Department of Conservation, Otago Regional Council staff and Councillors, Te Nukuroa o Matamata staff, and the local community. The workshop format followed a full-day session facilitated in three parts (Table 1).

Table 1 Hui Rautaki workshop format

Hui Rautaki
He mīhi (greetings)
Horopaki (context) • Resilience concepts • Values and risk identification
Whakatauira (examples) • Wildlife movement • Climate displacement • Coastal squeeze
Rautaki (strategy session) • Whāika rongoā (potential solutions) • Ara urutauka (adaptation pathways) • He ara ki mua? Where to from here?)

The horopaki / context session considered information on the context for climate change adaptation and resilience strategies, including the material shown in Part 1 of this report. A preliminary values and risk identification exercise was also completed to help set the scene for Te Mana o Taiari - Matatū ki te Taiao.

The whakatauira / examples session considered a set of worked examples of climate resilience studies based on the investigation of sea-level changes in an environment similar to the lower Taiari catchment. These examples were drawn from studies of vertical land movement caused by the Canterbury earthquakes that produced a natural experiment in sea-level change with similarities to climate change. Although these studies have a focus on ecohydrological changes involving water levels and salinity, the same general approach to characterising current values, vulnerabilities and adaptation opportunities is transferable to other natural environments and resources at a variety of scales.

The rautaki / strategy session consisted of a series of small group and plenary exercises to consider and document important aspects of a climate resilience strategy for Te Mana o Taiari.

The following sections provide a summary of notes and outputs recorded during these sessions.

Values and climate risk

Table 2 summarises the combined workshop results from the values identification exercise based on documentation captured by each small-group team. In the collated results the assignment of perceived sensitivity of the value reflects the highest sensitivity for that value recorded across the three groups. See Appendix 1 Table A1 for individual group results.

Table 2 Values identification exercise

Identified values	Climate change sensitivity (assigned by group)

Tikaka maori
• Wāhi tīpuna
• Wāhi taoka
• Spiritual connection to the awa
• Spiritual connection to places
• Understanding/ knowledge of the awa and the catchment
• Whānau/memories
• Restoring our names
Water health
• Water quantity
• Water flows
• Water quality (e.g., drinking)
• Water yield
Species and mahika kai
• Native fish
    • Tuna
    • Kanakana
    • Kōkopu
    • Non-migratory galaxiids
    • Bullies
• Manu
    • Kererū
    • Weka
    • Kākāpō
    • Kākā
    • Kārearea
• Aquatic invertebrates
    • Kōura
    • Kākahi
• Other animals
    • Other invertebrates (e.g., wētā)
    • Geckos
• Plants
    • Rākau
    • Taramea
    • Podocarps
Natural environment
• Healthy/functioning ecosystems
    • Mauri of te Taiari
    • Wetlands/Repo
    • Mahere
    • Mauka
    • Plants supporting mahika kai
    • Soil health/integrity
    • Native fish spawning grounds
    • Habitat connectivity
Human activities/Usage
• Water usage
	High

Human activities/Usage • Linking communities along the river • Recreational use of waterways • Access to mahika kai • Access to the awa • Access to the mountains • Walking Natural environment • Vegetation processes • Landscape • Harakeke	Medium

Table 3 summarises the combined workshop results from climate risk documentation captured by the small-group teams. These climate-related hazards and associated risks were considered after the values identification exercise and are partly informed by the perceived exposure and sensitivities of those values to various drivers of changes. See Appendix 1 Table A2 for individual group results.

Table 3 Climate risk identification exercise

Type of risk	Climate-related hazards and associated risks
Extreme events	• Storms • Droughts • Floods • Sedimentation events (resulting from floods) • Fires • Heatwaves
Slow changes	• Temperatures • Sea level • Salinity • Water levels/baseline flows • Seasonal cycles • Sedimentation • Water usage • Other catchment usage (e.g., grazed floodbanks) • Infrastructure development/adaptation • Shifts in species distributions • Disturbances in foodwebs and ecological processes • Invasive species behaviours/ecology • Pathogens/parasites • Political/legislative landscape for conservation (inertia) • Shifting baselines of knowledge • Shifting baselines of human attitudes/ behaviours in response to crisis

Whāika rongoā

Whāika rongoā (potential solutions) for climate resilience include the identification and creation of ara aratauka (adaptation pathways).

Perspectives on these topics were shared by workshop participants and form a preliminary set of components for the development of Te Mana o Taiari - Matatū ki te Taiao (Table 4).

Table 4 Whāika rongoā – components of resilience strategy

Components of resilience strategy
- How to define "resilience"? • Improve understanding of concepts and terms • Educational / outreach aspects - How to guide restoration efforts? • Vulnerability assessments drive restoration • Leverage opportunities, especially coordination between agencies – eg. LIDAR flights over the catchment might get more coverage if every stakeholder informed/involved. • Establishing baseline o Use of remote sensing / in situ data loggers o Cultural health assessment: upskilling hapū (e.g. Cultural Health Indicators, State of the Takiwā) o More detailed methods to be chosen when values are identified/honed in - How does restoration work link with future-proofing the awa? • Focus on recovery from extreme events as part of a resilience strategy • Opportunities for integrating climate change mitigation and adaptation – e.g., carbon sinks o Create new ones – e.g., blue carbon o Protect existing ones, including risks from extreme events - How to think holistically at the catchment scale. • A full understanding of linkages is difficult and can be frustrating and overwhelming • Grass-root movements at the catchment scale are more effective than piecemeal or isolated actions • Tuna and other migratory fish could be a good story-telling device – focus on catchment connections and needs • Do we have sufficient information for projection/planning? - Change thinking around food/food basket: the way we currently envision food is very westernised, is there a way to go back to thinking of food as something provided in the environment? • The legal/societal system can be difficult to navigate • Current legislation does not really give space to cultural and biodiversity values o Lack of flexibility o Lack of adaptability to conditions at site o Overcoming inertia to change • Legacy issues affect land use opportunities and the potential rate of change • It is necessary to start with identifying values – it is a prerequisite for activating several existing legal protection mechanisms and is essential for developing new mechanisms and strategies that will be effective against climate change - We (people) are part of the natural system – how do we stop thinking of ourselves as separate from it? • Should "protecting" an area mean excluding people from it? Are "outdoor zoos" conservation? • Weaving stories • Some creativity is needed when imagining how to protect ecosystems • Changing thought is intergenerational • Values can lead change ahead of policy and legislation - How to ensure equity? • Currently, some are paying for consequences of others' actions/activities/benefits

He ara ki mua

This final workshop session had a focus on identifying some shorter-term objectives as a focus for developing the next stages of Te Mana o Taiari - Matatū ki te Taiao. A summary of the ideas captured is shown in Table 5.

One of these components involves the establishment of a participatory salinity monitoring project as a collaboration between Te Mana o Taiari project partners and Te Nukuroa o Matamata staff. Results from an initial pilot study and monitoring framework to support the salinity monitoring project are available in a separate report (see Orchard 2022b).

Table 5 He ara ki mua – next steps

Perspectives on next steps

- Baseline conceptualisation and measurement
  • start thinking about what you want to measure as baselines for the values present
  • situate baseline measures in a coherent framework
  • 'ecological librarian' task to find existing information on baselines
  • ' gap analysis' to inform remaining measurement needs
    ○ opportunities for innovation to address data collection needs (e.g., new technologies, citizen science)
- Ground elevation data
  • investigate LIDAR for as much of the catchment as possible
  • coordinate between agencies
  • potential use of drones
- Oral history project
- Historical land use change project
- Creation of a common repository and shop-front window /data sharing website
- Training in cultural health assessment
- Sharing knowledge with whānau to reignite relationship with the awa
- Citizen science opportunity for monitoring
- Discrete current/future projects
  • eDNA surveys
  • kanaka critical habitats
  • īnaka spawning sites
  • characterisation/monitoring of giant kōkopu populations
  • tuna project
  • main drain project/creation of artificial wetland?
  • review of floodbank bylaws re: planting/revegetating
    ○ avenues to increase ecological values (e.g., provide fish habitat)
- Salinity monitoring project
  • collaboration with Te Nukuroa o Matamata
  • opportunities for training/upskilling
    ○ include deployment & result analysis
- Other projects underway in Te Nukuroa o Matamata
  • weed control/site preparation for planting
  • relationship building with people and organisations to assist project delivery
  • plant nursery development
  • project-level gearing up (e.g., need for a boat)
  • ideas to progress:
    ○ how to respond to interest from landowners who are keen on restoration
    ○ methods to share information across organisations/agencies
  • opportunity for Te Nukuroa o Matamata to provide operational capacity longer-term

References

Bell, R., Lawrence, J., Allan, S., Blackett, P., & Stephens, S. (2017). *Coastal hazards and climate change: Guidance for local government*. Wellington: Ministry for the Environment. 279pp.

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. e. (2016). *Nature-based Solutions to address global societal challenges*. Gland, Switzerland: IUCN. xiii + 97pp.

Department of Conservation. (2021). *Ngā Awa programme engagement report 2020/2021*. Department of Conservation.

Dudley, N. (2008). *Guidelines for applying protected area management categories*. IUCN: Gland, Switzerland. 86pp.

Gunderson, L. H., & Holling, C. S. (2001). *Panarchy: understanding transformations in human and natural systems*. Washington: Island Press.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics, 4*(1), 1-23. doi:10.1146/annurev.es.04.110173.000245

IPBES. (2022). *Summary for policymakers of the methodological assessment of the diverse values and valuation of nature of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. U. Pascual, P. Balvanera, M. Christie, B. Baptiste, D. González-Jiménez, C.B. Anderson, S. Athayde, R. Chaplin-Kramer, S. Jacobs, E. Kelemen, R. Kumar, E. Lazos, A. Martin, T.H. Mwampamba, B. Nakangu, P. O'Farrell, C.M. Raymond, S.M. Subramanian, M. Termansen, M. Van Noordwijk, A. Vatn (eds.). IPBES secretariat, Bonn, Germany. 37pp. https://doi.org/10.5281/zenodo.6522392.

IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)].* Geneva, Switzerland: IPCC. 151pp.

Macintosh, A. (2013). Coastal climate hazards and urban planning: how planning responses can lead to maladaptation. *Mitigation and Adaptation Strategies for Global Change, 18*(7), 1035-1055. doi:10.1007/s11027-012-9406-2

McGinnis, M. D., & Ostrom, E. (2014). Social-ecological system framework: initial changes and continuing challenges. *Ecology and Society, 19*(2). doi:10.5751/ES-06387-190230

Ministry for the Environment. (2020). *National Climate Change Risk Assessment for Aotearoa New Zealand: Main report – Arotakenga Tūraru mō te Huringa Āhuarangi o Āotearoa: Pūrongo whakatōpū*. Wellington: Ministry for the Environment. 133pp.

Orchard, S. (2022a). Defining nature-based solutions for coastal climate change in New Zealand. *Coastal News, 78*, 3-5.

Orchard, S. (2022b). *Te Mana o Taiari salinity monitoring*. Report prepared for Department of Conservation. 16pp.

Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., . . . Turner, B. (2021). Getting the message right on nature-based solutions to climate change. *Global Change Biology, 27*(8), 1518-1546. doi:10.1111/gcb.15513

Tonkin & Taylor. (2021). *Otago Climate Change Risk Assessment*. Report prepared for Otago Regional Council. 226pp. + App.

Turner, B. A., & Pidgeon, N. F. (1997). *Man-made disasters* (2nd ed.). Boston: Butterworth-Heinemann.

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., . . . Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences, 100*(14), 8074-8079. doi:10.1073/pnas.1231335100

Appendix 1. Data from workshop sessions

Table A1 Values identification exercise

Climate change sensitivity (assigned by group)	Values		
	Group 1	**Group 2**	**Group 3**
High	More water in the river Podocarps Mauri of the Taiari Habitat connectivity Wetlands Galaxiids Tuna Kōura Native bullies Native fish spawning grounds Our level of understanding of the Taiari catchment Geckos Wētā Kārearea	Plants supporting mahika kai Non migratory galaxiids Water flow Water quantity Water quality Water yield Water usage Tuna Kanakana Inaka Kōkopu Manu, e.g., kererū, weka, kākāpō, Kākā Taramea Rākau Invertebrates Mauka Mahere Raupō	Water flow Drinking water Mahika kai Healthy ecosystems Soil health/integrity Whānau/memories Function of the wetlands Function of the forest Wāhi tīpuna Wāhi taoka Native fish Restoration Restoration of our names Knowledge Spiritual connection Tuna Understanding
Medium	Linking communities along the river	Recreational use of waterways Wāhi tīpuna	Vegetation processes Landscape Recreation
Low	Harakeke Access to the awa Access to the mountains	Access to mahika kai Restoring traditional names	Walking

Table A2 Climate risk identification exercise

Type of risk	Climate related hazards and associated risks		
	Group 1	**Group 2**	**Group 3**
Extreme events	• Fire • Drought • Storms	• Droughts • Floods • Heatwaves • Fires	• Storms • Droughts • Floods • Sedimentation events (resulting from floods) • Fires
Slow changes	• Temperatures • Salinity • Water levels • Invasive species	• Water usage • Invasive species • Pathogens/ parasites • Sedimentation • Sea level rise • Changes in salinity • Species distribution shifts • Disturbance in food webs • Shifting baselines of knowledge • Shifting baselines of human attitudes/ behaviours in response to crisis	• Temperature change • Sea level rise • Salinity change • Weed species • Pest species breeding • Seasonal cycles • Infrastructure development • Creation of floodbanks • Politics/ conservation inertia

Appendix 2 Whakatauira / Example of sea-level change in a shallow coastal lagoon

Introduction

Establishing relationships between degrees of physical change and the magnitude of impacts on values and resources can help to inform the identification of climate impacts and their distribution across the landscape. This assists the development of resilience strategies that address undesirable effects and may include opportunities to secure gains. In the following sections these topics are explored in relation to ecohydrological changes in coastal lagoon systems. These environments are among the highest priorities for progressing climate change adaptation strategies in Aotearoa (and elsewhere) because of their exposure to sea-level rise and prevalence of anthropogenic land uses that may present constraints to natural system dynamics in the areas concerned.

These issues are exemplified in the lower Taiari catchment which is characterised by extensive lowland wetlands and floodplains, many of which are already within the intertidal zone. These lowland areas are a key concern for climate resilience - while also noting that there may be other climate impacts to address higher in the catchment and the likelihood of interactions between the land-uses and waterways involved (e.g., due to water abstraction and other effects on water availability and flows).

Studies from the 'Resilient Shorelines' project (www.resilientshorelines.nz) provide an example that may be helpful in conceptualising the role and design of vulnerability assessments for the lower Taiari. In these examples, vertical land movement caused by the Canterbury earthquakes produced a natural experiment in altered sea-levels with similarities to climate change (Figure A1). The following sections provide details of the methodology used in these studies together with an example of ecological impact and climate vulnerability assessment for īnaka (*Galaxias maculatus*) spawning grounds.

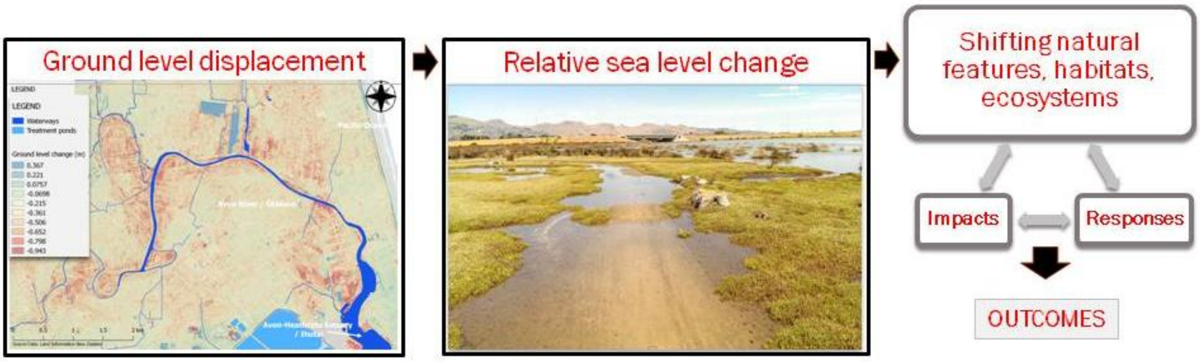

Figure A1 A natural experiment in sea-level change in Ōtautahi Christchurch caused by the Canterbury earthquakes created a unique opportunity to study resilience in coastal hydrosystems exposed to sea-level rise (Orchard et al. 2020a).

Ecological impact assessment

To characterise changes in the biophysical environment, the Resilient Shorelines studies used an impact assessment framework that combined field surveys, remote sensing and numerical models (Figure A2). The field surveys included distribution mapping for key habitats and vegetation types, and the collection of ground-truthing data for the development of numerical models. The remote-sensing used mainly LiDAR data to assess landscape changes over relatively large scales. Geospatial and hydrodynamics models were used to gain a better understanding of the altered landscape under conditions additional to those that were directly observed (e.g., under the influence of different combinations of tidal heights and river flows) (Figure A2). This same basic framework was applied to three types of natural hazard; coastal inundation, coastline retreat, and salinity changes (Orchard et al. 2020a; Orchard et al. 2020b; Orchard & Schiel 2021). All of these were affected by vertical land movement in relation to sea level and will similarly be affected by climate change.

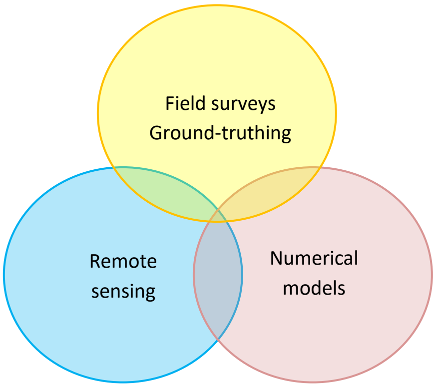

Figure A2 Impact assessment framework combining remote-sensed, field survey and numerical model results to evaluate habitat shifts driven by ecohydrological changes.

Vulnerability assessment approach

The impacts of future events on social-ecological systems can be investigated using scenario analysis (Peterson et al. 2003). One methodological approach for developing future scenarios involves the use of process models that link physical changes (e.g., Figure A2) to associated biological changes at relevant scales. The linked models are then used to simulate the effect of a given set of physical parameter changes associated with a future scenario. The response variables are biological values or indicators of interest, and further linkages with social and cultural dimensions can also be explored (Figure A3).

In developing linked process models (as above), the nature of the biological response is based on the best knowledge of relevant biophysical relationships at the time. This knowledge may reflect mātauranga, hypothesis-based experiments, field surveys or trials, and exploratory data analyses (e.g., mining of existing data), and combinations thereof. Examples include process models based on empirical relationships established through field surveys and experiments (e.g., as used in the īnaka spawning ground studies) and bioclimatic envelope models of species or habitat distributions that are parameterised from distribution data using statistical routines (Anderson et al. 2009; Jeschke & Strayer 2008). The biological changes may be further linked to social and cultural values and associated indicators of progress using a wide range of methods including traditional knowledge systems and social science techniques (Figure A3).

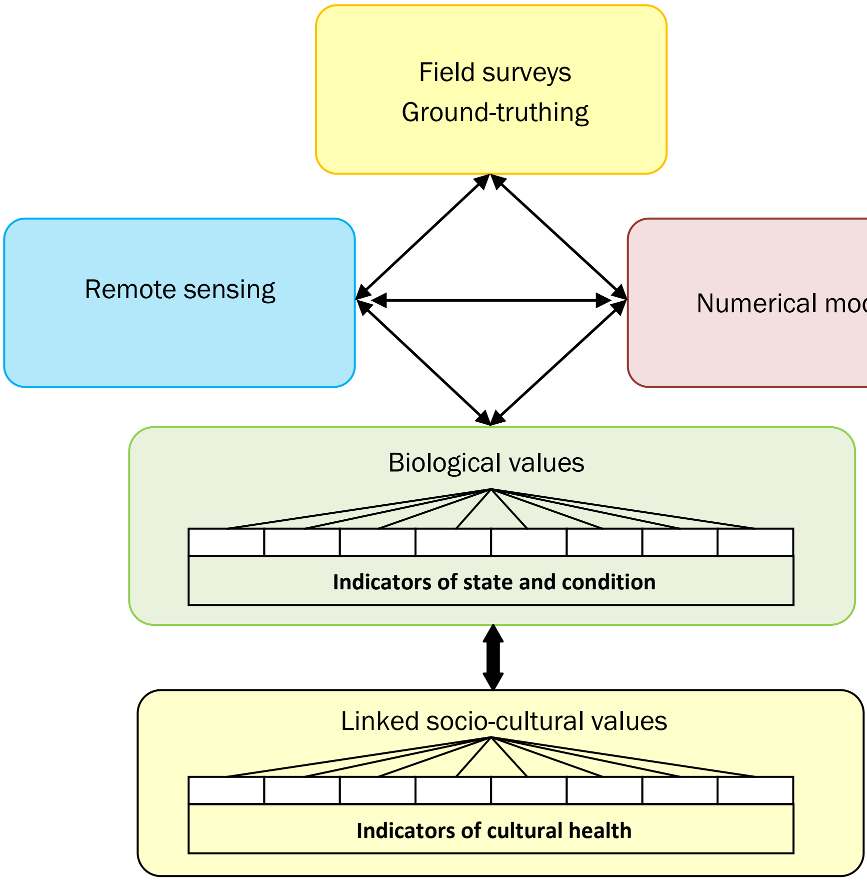

Figure A3 Linked process model framework impact and vulnerability assessment in social-ecological systems.

For the purpose of climate vulnerability assessments, linked process models are ideally parameterised with variables for which climate projections are available. They can then be used to investigate the vulnerabilities of system components to plausible scenarios of climate change. The exploration of many such scenarios can also help to illustrate the range of potential outcomes, thereby helping to overcome the high level of uncertainty associated with climate change (Haasnoot et al. 2013). Furthermore, each such scenario may consider either single or multi-hazard effects such as combinations of higher water levels and salinity changes, or higher water levels and coastline retreat. These scenarios may be established through a range of methods including the extrapolation of past trends, historical reference points, process models of physical changes and stakeholder-generated perspectives on potential change.

Vulnerabilities can be assessed in absolute terms by considering the magnitude of potential impacts in a given scenario, or in risk-based terms by incorporating an expression of the assumed likelihood of the scenario and its outcomes. It is important to note that there are many variables that may be of interest, and this gives rise to many potential variations and degrees of complexity when developing vulnerability assessments. Spatial and temporal connectivity aspects are particularly important to consider alongside trends in overall gain and loss. For example, they can have pronounced effects on some ecological entities (e.g., migratory species), and may also affect social and cultural values such as access to resources that have been historically used.

Some of these principles are exemplified in the following case study on wildlife movement and habitat migration that was triggered by salinity changes in a coastal waterway.

CASE STUDY: Īnaka spawning grounds

Connectivity conservation context

This case study exemplifies the challenges of wildlife movement and connectivity conservation in situations where physical processes (i.e., hazards) cause large-scale landscape changes. In this case, major earthquakes caused vertical displacements (both uplift and subsidence) of a coastal landscape, and these in turn caused hydrological alterations (Hughes et al. 2015; Quigley et al. 2016). The hydrological changes had major impacts on natural environments and resources (Orchard et al. 2020a), as was also the case in a more recent sea-level change example caused by the Kaikōura earthquake (Orchard et al. 2021; Schiel et al. 2019; Schiel et al. 2021).

The investigations mentioned in this case study were designed to investigate one particular aspect of sea-level change that involved alterations to the salinity environment. The following sections provide only brief details of the various studies but more information can be found in the references provided. As these studies are ongoing, some of the findings are available in recent publications while others will be including in future publications.

Establishing the drivers of change

As mentioned above, characterising the drivers of change, such as inundation patterns and salinity, is essential for the building of scenario models to investigate climate change. Ideally, models of key relationships are also validated using ground-truthed data to establish the veracity of model outputs and gauge associated uncertainties. This highlights the essential need for empirical data on the distribution of the species, habitats or resources of interest, and their relationships with other factors. In this regard, the īnaka spawning ground case involved a learning opportunity that was presented by the Canterbury earthquakes. Its focus was the relationship between salinity changes and the distribution and potential movement of spawning habitat within a catchment. It also shows how natural experiments generated from relatively rare events can be harnessed to gain new insights into fundamental processes that are otherwise difficult to study.

In this case, investigating the hypothesis of salinity-induced changes provided the starting point for the studies mentioned below. The approaches used are set out in two parts using the same format to highlight analogies between the assessment of ecological impacts from the earthquake event (Part A), and vulnerability to future climate change (Part B). This format is also transferable to other ecological impact and climate change vulnerability studies. It consists of four main steps that are underpinned by baseline measurements of the values of interest, quantitative measures or models of impacts, and the evaluation of management implications to inform the development of potential adaptation pathways (Figure A4).

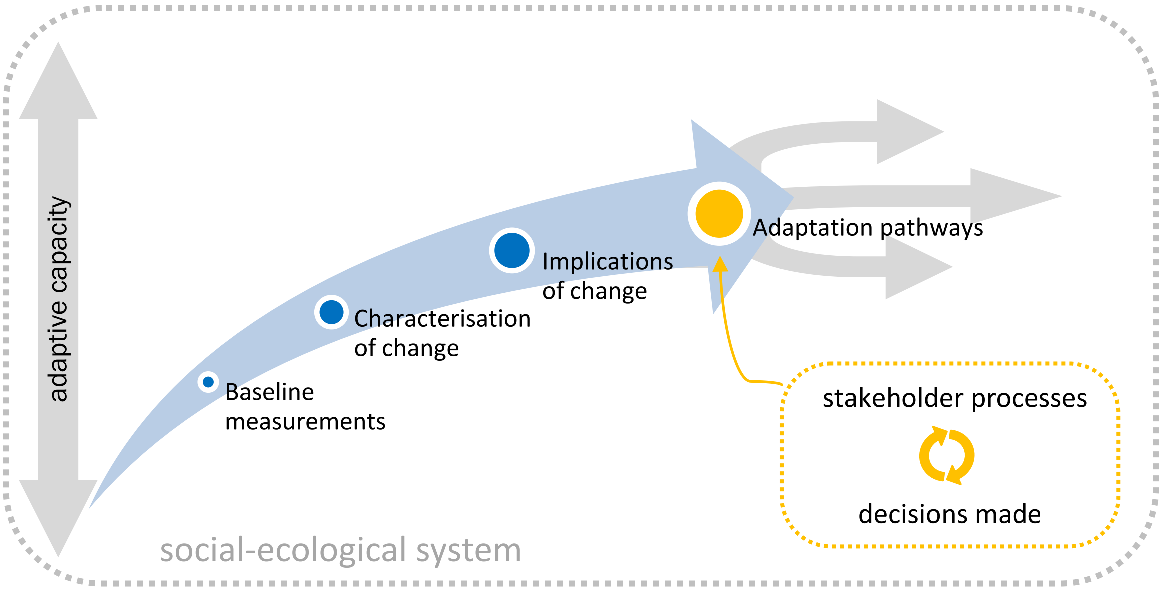

Figure A4 Generalised format for climate change vulnerability and social-ecological impact assessments to support adaptive pathway planning (Haasnoot et al. 2013; Lawrence et al. 2019). Vulnerability and impact assessments rely on robust baseline assessments to inform the characterisation of actual or potential changes and their implications for desirable outcomes, from which appropriate responses (i.e., adaptation pathways) can be designed. Adaptive capacity is a whole-system property that includes interactions between social and ecological elements regardless of how the systems boundaries are construed. It is best incorporated explicitly as a cross-cutting consideration that affects all of the steps, including, for example, the scope of considerations in each assessment and conceptualisation of baseline measurement needs. All of the steps can be iterated as needed and will ideally include the updating of baseline measurements at strategic points in time.

Part A: Ecological impact assessment

Baseline measurements

Īnaka (*Galaxias maculatus*) spawning grounds are found on the margins of tidal waterways.
To investigate the hypothesis of substantial habitat shifts following the Canterbury earthquakes it was important to have baseline information. Fortunately, the study catchments are among the best studied of all river systems in New Zealand for īnaka spawning with surveys having being completed periodically for over two decades. In this case, results from these pre-earthquake surveys were compiled into a common format using spatial ecology metrics suitable for comparative analyses (e.g., extent of occurrence, area of occupancy) (Orchard 2016).

Characterisation of change

To assess impacts of the natural disaster, the characterisation of change was concerned with detecting and quantifying of actual effects. To address this, comprehensive surveys were used to detect and quantify differences from the historical (pre-earthquake) pattern at a whole-catchment scale. Major displacement effects were found. For example, spawning grounds in the Ōpāwaho / Heathcote catchment had moved over 2 km downstream from all known records (Orchard & Hickford 2016, 2018; Orchard et al. 2018a).

Management implications

Although the main previously-known spawning location was protected under existing management arrangements, most of the spawning grounds and the majority of egg production had moved to unprotected locations in the post-earthquake landscape. These spawning grounds were also vulnerable to various combinations of threats from incompatible land uses associated with reserves maintenance and flood management activities. In general terms, these vulnerabilities could be established through considering the exposure, sensitivity and adaptive capacity of the spawning grounds to these man-made hazards (Orchard et al. 2016; Orchard et al. 2018b). The results helped to identify a range of management needs including the updating of the Protected Area designations in relevant statutory (and non-statutory) plans (Orchard & Hickford 2020), and practical steps to change management practices in the areas concerned (Orchard et al. 2018b).

Adaptation pathways

Addressing the management needs identified above is analogous to the concept of 'adaptation pathways' for climate change but in this case happened to involve adaptation to a natural disaster event with similarities to climate change (i.e., in relation to sea-level rise). Completion of this step involves the preferences and initiatives of the wider community. It can, however, be usefully informed by studies such as those mentioned above which help to detect and quantify actual or potential impacts, and can be further assisted by studies that explicitly link science and policy objectives.

In this case, science-policy linkages were explored and evaluated in relation to Protected Area implications, and also practical opportunities for management changes that might be effective in protecting natural environment values while also being acceptable within the social context. Over time these studies have included options evaluations to inform longer-term adaptive management strategies and plans. They include, for example, new approaches to managing vegetation on the riverbanks (Orchard 2017), restoration strategies for maintaining and enhancing spawning habitat in parks and reserves (Orchard 2019), and low-impact approaches for flood management needs (Orchard 2021).

Although the above studies are specific to the earthquake-affected area and community context in Ōtautahi Christchurch, the same general approach is applicable to impact and vulnerability assessments for īnaka spawning grounds at other locations and scales. As discussed further below, the same drivers of change (i.e., water levels and salinity) are among these most pervasive hazards associated with coastal climate change in this case. Additionally, these same drivers can also be expected to affect a wide range of values associated with coastal environments and resources (i.e. not just īnaka spawning grounds). With this in mind, a similar approach to that outlined below is broadly transferable to a range of climate vulnerability and adaptation challenges in coastal lowland environments and also to other ecohydrological changes further upstream (e.g., involving floodplains and wetlands). However, it is noted that the specific effects of erosion (and similarly, deposition) are not explicitly considered in this example. Addressing this is likely to be important in many aquatic environments wherever appreciable landscape change can be expected (e.g., involving river alignments or coastline configuration) due to influences on spatial aspects and interactions with hydrological aspects. Therefore, the scenarios mentioned in the examples below assume a base-case of current topography and bathymetry, and the potential for other configurations would need to be assessed in terms of additional scenarios.

Part B: Climate change vulnerability assessment

The following brief notes illustrate a quantitative approach to climate change vulnerability assessment (CCVA) that builds on the above impact assessment work.

Baseline measurements

For the consideration of future change the post-earthquake studies effectively provide a 'new baseline' against which climate change vulnerability can be evaluated. This also illustrates the need to undertake periodic monitoring of key values, especially after conditions change. The updated baseline information can then be used as an input for vulnerability assessments that consider climatic drivers of change. In the above case, the climatic drivers of change happen to involve the same key hazards that were involved in the natural disaster event (i.e., water level and salinity changes).

Characterisation of change

For the purposes of CCVA the characterisation of change is concerned with assessing the potential impacts of climate change as informed by plausible future scenarios. In current work on the īnaka spawning ground example, climate change vulnerability is being assessed for sea-level rise with a focus on the impacts of salinity changes while also considering the effects of water level changes. , In These two factors are also likely to be among the most pervasive influences on the location of spawning grounds based on current understanding of īnaka spawning biogeography in tidal waterways (Orchard et al. 2018c). This both enables and somewhat simplifies the consideration of climate change vulnerability versus situations, for example, where a wider suite of drivers of change might need to be considered to create fit-for-purpose scenarios.

For the īnaka spawning grounds case, future scenarios of the hydrological environment can be developed using a hydrodynamics models calibrated for salinity (Orchard & Measures 2016, 2017). These models are able to simultaneously consider different sea-level heights and river flows (along with other model inputs) thereby accounting for two of the most relevant influences on the physical parameters of interest. These physical change scenarios are related to the biological values of interest (īnaka spawning grounds) using a linked process modelling approach as shown in Figure A3. The combined approach facilitates the quantitative assessment of various combinations of sea-level height and river flows, and the impacts of these on the location and extent of īnaka spawning grounds.

Management implications

To date, a CCVA for īnaka spawning grounds has not been formally completed for the Ōtautahi Christchurch waterways but significant groundwork has been laid in developing the above methodologies and example scenarios. Initial modelling results include 15 discrete climate change scenarios representing combinations of three sea-level heights (up to 1 m sea-level rise) and five river flows (Figure A5) (Orchard & Measures 2017). The next step in the CCVA process involves evaluating the management implications of these scenarios (and potentially others) as shown in Figure A4. Similar approaches could be readily developed in other catchments provided that hydrodynamics models were available.

Adaptation pathways

As with the disaster impact assessment context, identifying the management implications of environmental change informs the development of adaptation pathways and involves the preferences and initiatives of the wider community. At the current point in time, progressing towards this step is urgently needed for many natural environments and resources in Aotearoa New Zealand. It could, however, be readily accomplished using various combinations of the approaches discussed in this report.

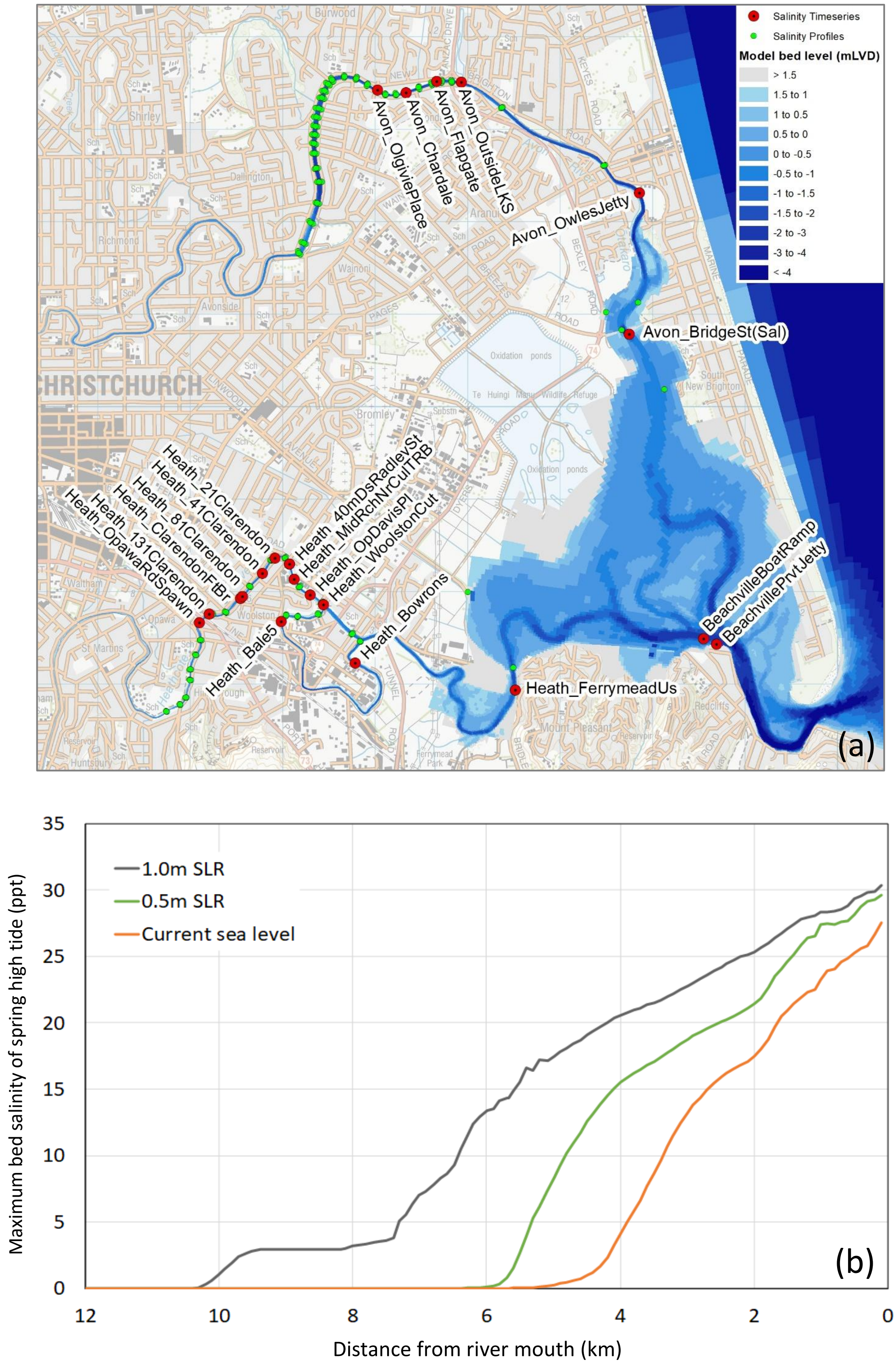

Figure A5 (a) Example of a hydrodynamics model built for the Ihutai catchment in Ōtautahi Christchurch showing a portion of the model extent and salinity sampling sites used for model calibration and validation (Measures & Bind 2013; Orchard & Measures 2016). (b) Example of scenario analyses using the calibrated model showing the effect of sea-level rise on peak bed salinity in the Ōtākaro / Avon River with a river flow of 2.07 m^3/s. This represents the flow exceeded 20% of the time under current conditions

Key points and transferable aspects

Some of the most important and transferable features of the material discussed in this report are itemised below (Box 3). All of these points should be regarded as essential for the development of assessments that are robust and specific enough to support effective action on climate change.

BOX 3 Key principles for climate change vulnerability and risk assessments in linked social-ecological systems.

- The assessment is place-based at a scale that is relevant to the values of interest.
- The assessment is specific to the values of interest but able to accommodate and evaluate the influence of wide range of interacting risk factors from across the social-ecological spectrum. This is an essential aspect of a comprehensive vulnerability and risk assessment for natural environment (and other) values.
- Climate risk aspects can be investigated through extension of the vulnerability assessment framework to consider a suite of climate change projections and the different futures they would generate.
- The climate risk aspects (and similarly, each specific vulnerability scenario) can be re-evaluated at any point in time to respond to, for example, updated information on the nature of the values at stake or the nature of the hazards to which they are exposed. This iterative approach produces an adaptable and progressive assessment framework and is a useful attribute for decision support in climate change adaptation planning given that such processes are likely to involve lengthy time frames. Indeed they may be best conceptualised as an ongoing human endeavour.
- The iterative aspects discussed above provide opportunities for stakeholders to investigate any alternative or additional scenarios that are important to them, for example in relation to different perspectives on relevance of uncertainties in climate projections, or the degree of acceptable risk to key values as signified by thresholds or trigger levels in relevant indicators.

Case study references

Anderson, B. J., Akçakaya, H. R., Araújo, M. B., Fordham, D. A., Martinez-Meyer, E., Thuiller, W., & Brook, B. W. (2009). Dynamics of range margins for metapopulations under climate change. *Proceedings of the Royal Society B: Biological Sciences, 276*(1661), 1415-1420. doi:10.1098/rspb.2008.1681

Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change, 23*(2), 485-498. doi:10.1016/j.gloenvcha.2012.12.006

Hughes, M. W., Quigley, M. C., van Ballegooy, S., Deam, B. L., Bradley, B. A., Hart, D. E., & Measures, R. (2015). The sinking city: earthquakes increase flood hazard in Christchurch, New Zealand. *GSA Today, 25*(3-4), 4-10. doi:10.1130/GSATG221A.1

Jeschke, J. M., & Strayer, D. L. (2008). Usefulness of bioclimatic models for studying climate change and invasive species. *Annals of the New York Academy of Sciences, 1134*(1), 1-24. doi:10.1196/annals.1439.002

Lawrence, J., Haasnoot, M., McKim, L., Atapattu, D., Campbell, G., & Stroombergen, A. (2019). Dynamic Adaptive Policy Pathways (DAPP): From Theory to Practice. In V. A. W. J. Marchau, W. E. Walker, P. J. T. M. Bloemen, & S. W. Popper (Eds.), *Decision Making under Deep Uncertainty: From Theory to Practice* (pp. 187-199). Cham: Springer International Publishing.

Measures, R., & Bind, J. (2013). *Hydrodynamic model of the Avon Heathcote Estuary: Model build and calibration, NIWA Client Report CHC2013-116.* Christchurch: NIWA. 29pp.

Orchard, S. (2016). *Identifying īnanga spawning sites in plans: options for addressing post-quake spawning in Ōtautahi Christchurch.* Report prepared for Christchurch City Council and Environment Canterbury. Christchurch: University of Canterbury. 14pp.

Orchard, S., Hickford, M., & Schiel, D. (2016). *Planning for whitebait: applying vulnerability assessment to īnanga spawning sites*. Paper presented at the Joint conference of New Zealand Marine Sciences Society and Australian Marine Science Association, Wellington, New Zealand, 4-7 July, 2016.

Orchard, S., & Hickford, M. J. H. (2016). *Spatial effects of the Canterbury earthquakes on īnanga spawning habitat and implications for waterways management*. Report prepared for IPENZ Rivers Group and Ngāi Tahu Research Centre. Waterways Centre for Freshwater Management and Marine Ecology Research Group. Christchurch: University of Canterbury. 37pp.

Orchard, S., & Measures, R. (2016). *Development of a fine-scale salinity model for the Avon Heathcote Estuary Ihutai*. Report prepared for Brian Mason Scientific & Technical Trust. Christchurch: University of Canterbury & NIWA. 22pp.

Orchard, S. (2017). *Response of īnanga spawning habitat to riparian vegetation management in the Avon & Heathcote catchments*. Report prepared for Christchurch City Council. 35pp.

Orchard, S., & Measures, R. (2017). *Sea level rise impacts in the Avon Heathcote Estuary Ihutai. Salinity intrusion and īnanga spawning scenarios*. Report prepared for Christchurch City Council. 56pp.

Orchard, S., & Hickford, M. J. H. (2018). Census survey approach to quantifying īnanga spawning habitat for conservation and management. *New Zealand Journal of Marine and Freshwater Research, 52*(2), 284-294. doi:10.1080/00288330.2017.1392990.

Orchard, S., Hickford, M. J. H., & Schiel, D. R. (2018a). Use of artificial habitats to detect spawning sites for the conservation of *Galaxias maculatus*, a riparian-spawning fish. *Ecological Indicators, 91*, 617-625. doi:10.1016/j.ecolind.2018.03.061

Orchard, S., Hickford, M. J. H., & Schiel, D. R. (2018b). Earthquake-induced habitat migration in a riparian spawning fish has implications for conservation management. *Aquatic Conservation: Marine and Freshwater Ecosystems, 28*(3), 702-712. doi:10.1002/aqc.2898

Orchard, S., Hickford, M. J. H., & Schiel, D. R. (2018c). *Conservation biology insights from an extreme event: a new understanding of whitebait habitat following earthquake-induced landscape change*. Paper presented at the Oceania Congress for Conservation Biology, Te Papa Tongarewa, Wellington, New Zealand, July 2-6, 2018.

Orchard, S. (2019). *River restoration opportunities in Amelia Rogers Reserve*. Report prepared for Christchurch City Council, April 2019. 12pp. .

Orchard, S., & Hickford, M. J. H. (2020). Protected area effectiveness for fish spawning habitat in relation to earthquake-induced landscape change. In R. Maiti, H. G. Rodríguez, C. A. Kumari,

D. Mandal, & N. C. Sarkar (Eds.), *Sustainable bioresource management: Climate change mitigation and natural resource conservation. (Chpt 22)*: Apple Academic Press. 526pp.

Orchard, S., Hughey, K. F. D., Measures, R., & Schiel, D. R. (2020a). Coastal tectonics and habitat squeeze: response of a tidal lagoon to co-seismic sea-level change. *Natural Hazards, 103*(3), 3609-3631. doi:10.1007/s11069-020-04147-w

Orchard, S., Hughey, K. F. D., & Schiel, D. R. (2020b). Risk factors for the conservation of saltmarsh vegetation and blue carbon revealed by earthquake-induced sea-level rise. *Science of the Total Environment, 746*, 141241. doi:10.1016/j.scitotenv.2020.141241

Orchard, S. (2021). *Flood management that protects whitebait spawning grounds: channel dredging outcomes in the Ōpāwaho Heathcote River*. Report prepared for Christchurch City Council. 28pp.

Orchard, S., Fischman, H. S., Gerrity, S., Alestra, T., Dunmore, R., & Schiel, D. R. (2021). Threshold effects of relative sea-level change in intertidal ecosystems: empirical evidence from earthquake-induced uplift on a rocky coast. *GeoHazards, 2*(4), 302-320. doi:10.3390/geohazards2040016

Orchard, S., & Schiel, D. R. (2021). Enabling nature-based solutions for climate change on a peri-urban sandspit in Christchurch, New Zealand. *Regional Environmental Change, 21*(3), 66. doi:10.1007/s10113-021-01791-1

Peterson, G. D., Cumming, G. S., & Carpenter, S. R. (2003). Scenario planning: A tool for conservation in an uncertain world. *Conservation Biology, 17*(2), 358-366. doi:10.1046/j.1523-1739.2003.01491.x

Quigley, M. C., Hughes, M. W., Bradley, B. A., van Ballegooy, S., Reid, C., Morgenroth, J., . . . Pettinga, J. R. (2016). The 2010–2011 Canterbury Earthquake Sequence: Environmental effects, seismic triggering thresholds and geologic legacy. *Tectonophysics, 672-673*, 228-274. doi:10.1016/j.tecto.2016.01.044

Schiel, D. R., Alestra, T., Gerrity, S., Orchard, S., Dunmore, R., Pirker, J., . . . Thomsen, M. (2019). The Kaikōura earthquake in southern New Zealand: loss of connectivity of marine communities and the necessity of a cross-ecosystem perspective. *Aquatic Conservation: Marine and Freshwater Ecosystems, 29*(9), 1520-1534. doi:10.1002/aqc.3122

Schiel, D. R., Gerrity, S., Orchard, S., Alestra, T., Dunmore, R. A., Falconer, T., . . . Tait, L. W. (2021). Cataclysmic disturbances to an intertidal ecosystem: loss of ecological infrastructure slows recovery of biogenic habitats and diversity. *Frontiers in Ecology and Evolution, 9*(827). doi:10.3389/fevo.2021.767548