NIWA
Taihoro Nukurangi

Trait-based Climate Change Vulnerability Assessment of Aotearoa New Zealand's Marine Taxa

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Executive summary

In Aotearoa New Zealand, the Department of Conservation Te Papa Atawhai (DOC) are tasked with managing biodiversity in marine and terrestrial ecosystems for conservation purposes. The DOC Climate Change Adaptation Action Plan 2020-2025 outlines the actions DOC is taking to reduce the risks posed by climate change impacts. There is particular urgency to conduct climate change vulnerability assessments (CCVAs) to understand which species and ecosystems are the most vulnerable to climate related environmental change in order to prioritise them for research, management and adaptation planning.

This report outlines a framework to conduct CCVAs for functional and taxonomic groups of marine benthic taxa. The framework adapts a terrestrial trait-based CCVA approach developed by DOC to be suitable for the marine environment. Traits and vulnerability thresholds were tailored for marine benthic taxa, with input from taxonomic and ecological experts. Experts for Bryozoans, Corals, Crustaceans, Echinoderms, Macroalgae, Molluscs and Sponges developed functional and taxonomic groups (taxon groups) to be assessed for climate vulnerability. For each CCVA taxon group, traits were categorised as 'higher' or 'lower' vulnerability by an initial assessor (a relevant taxon expert), with each assessment checked by a secondary expert reviewer. Each trait was assigned within a vulnerability dimension (Sensitivity, Exposure, Adaptive capacity). If any of the traits within the dimension received a 'higher' score, the respective dimension was categorised as 'higher' vulnerability. Species were categorised as 'Highly Vulnerable' if all three of the dimensions received a 'higher' score. Two approaches were taken to analyse the assessments (1) an Optimistic approach, where 'unknown' scores were considered as Low Vulnerability, and (2) a Pessimistic approach where 'unknown' scores were considered as High Vulnerability.

In total CCVAs were carried out for 83 groups considering 33 traits, including exposure traits for predicted environmental change across two climate change scenarios SSP2 (4.5) and SSP3 (7.0) for two time periods (2050 and 2100). The taxon groupings included: 8 Bryozoans, 18 Corals, 10 Crustaceans, 12 Echinoderms, 17 Macroalgaes, 10 Molluscs and 8 Sponges.

- A total of 47 taxon groups scored Highly Vulnerable (with Vulnerable scores across all three dimensions) for the Optimistic approach. And a total of 72 groups scored Highly Vulnerable for the Pessimistic approach.
- The scores did not differ considerably between climate change scenarios and time periods.
- In general, Bryozoans, Macroalgae, Sponges and Corals scored high vulnerabilities across both approaches.
- A high proportion of taxon groups were found to have knowledge deficiencies, especially for the Adaptive capacity traits. CCVAs for knowledge deficient groups may not be informative, highlighting the need for targeted research in these areas.

In general, the experts involved in this work felt that the CCVA method provided a good framework for expert-driven assessments of climate change vulnerability for marine species. The report presents a range of suggestions on limitations and future recommendations for the marine CCVA approach.

1 Introduction

Anthropogenic climate change poses a significant threat to marine species (Doney et al. 2012). Elevated temperatures can exceed optimal environmental conditions for species' growth, reproduction and survival, resulting in individual mortalities, population-wide effects and ultimately localised extinctions (Pinsky et al. 2019). This can have knock-on ecosystem effects, with losses of species' interactions (e.g., predator-prey) affecting populations across multiple trophic levels (Chapman et al. 2020). Globally, there have been observed climate-induced losses of unique species and biodiversity, with local extinctions and irreversible ecosystem shifts (Pinsky et al. 2020; Worm and Lotze 2021). Aotearoa New Zealand is a global biodiversity hotspot with over 17,000 known marine species, around 19% of which are endemic (Gordon et al. 2010). Waters around northern Aotearoa New Zealand are warming 3-4 times faster than the global average (Sutton and Bowen 2019), and there have been multiple severe national marine heatwave events in the past decade (Salinger et al. 2023). Such long-term warming, and short-term climate related extreme events are expected to increase in the future (Lundquist et al. 2011; Behrens et al. 2022). Marine species around Aotearoa New Zealand are becoming increasingly threatened by climate change impacts, yet such impacts are likely to differ between geographic regions (Montie et al. 2023), species, and taxa, with some taxa likely to be more vulnerable to stressors (Foden et al. 2019). Thus, effective management strategies need to be developed appropriately to manage marine biodiversity under global change.

In Aotearoa New Zealand, the Department of Conservation Te Papa Atawhai (DOC) are tasked with managing biodiversity for conservation purposes in marine and terrestrial ecosystems. The DOC Climate Change Adaptation Action Plan 2020-2025 (CCAAP) outlines the actions DOC is taking to reduce the risks posed by climate change impacts (Department of Conservation 2020). The purpose of the CCAAP is to guide DOC's strategic planning and management activities for increased resilience to climate change impacts. Two of the first main steps DOC needs to take over the next five years is to: 1) identify and rectify important climate change information gaps; and 2) to develop and implement consistent risk assessments on priority species, regions and assets. DOC has identified 139 actions to implement the CCAAP, outlined in the updated CCAAP Action Tables (Department of Conservation 2023). The work outlined in this report specifically aims to address the marine aspects of Biodiversity Action BIO1a – to undertake climate change vulnerability assessments (CCVAs) to identify aquatic threatened species and ecosystems at risk and prioritise them for research and adaptation. The results of this work will inform Action BIO2a – to undertake detailed vulnerability analysis of marine taxa for prioritised aquatic threatened species and ecosystems at risk from climate change, ultimately helping to inform Action BIO3f – to assess the continued effectiveness of biodiversity management tools and techniques considering climate change (Department of Conservation 2023).

DOC is in the process of conducting Aotearoa New Zealand's first large-scale CCVA of terrestrial species and developing 'how to' guidelines to assist with expanding the CCVAs to other terrestrial taxon groups and to marine and freshwater species (Brumby et al. 2024). Vulnerability refers here to the extent to which a species is susceptible to or unable to cope with the adverse effects of climate change (adapted from the IPCC, 2007).The CCVA of terrestrial species utilises a widely used trait-based framework and expert elicitation methods developed by Foden et al. (2013). The CCVA outputs are relative ranks of vulnerability to climate change, based on the assessment of species traits under three vulnerability dimensions (Sensitivity, Exposure and Adaptive capacity) under different climate change emissions scenarios and time periods. The methods were designed to be used as a high-level rapid assessment tool for terrestrial taxon groups (Brumby et al. 2024). DOC now seeks to test the modified framework in a marine context, and in so doing update the 'how to' guidelines to provide assurance that this approach is fit-for-purpose to aquatic contexts and can be used at a functional group level.

1.1 Aims

The aims of this work were to:

1. Adapt the terrestrial trait-based CCVA approach developed by DOC (Brumby et al. 2024) so that it can be applied to functional groups of benthic marine invertebrates. Marine taxa are highly diverse, so conducting CCVAs for functional groups allows for enhanced taxonomic coverage of assessments.
2. Apply the adapted marine framework to identify the relative vulnerability of groups of benthic marine organisms to prioritise further research to support their management.
3. Gather feedback during the marine CCVA process and recommend changes to the terrestrial trait-based CCVA approach developed by DOC to progress and enhance CCVA approaches across marine, freshwater, and terrestrial environments.

2 Methods

2.1 Adaptation of past CCVA approaches

CCVAs evaluate three dimensions of vulnerability: Sensitivity, Exposure and Adaptive capacity. Definitions of the dimensions are summarised from Foden,Young (2016):

- **Sensitivity** is the degree to which a species, habitat or ecosystem is or is likely to be affected by- or respond- to environmental change. Sensitivity is mediated by a range of characteristics that influence the fitness of individuals and recovery of populations comprising a species. These characteristics include physiological, behavioural and life history traits that influence: 1) the degree to which species are buffered from exposure to sub-optimal conditions; 2) their ability to tolerate changes in environmental conditions and cues, as well as in interspecific interactions; and 3) their ability to regenerate and recover following impacts. The characteristics also include within- and across-generation plastic responses and genetic variability in traits that facilitate regeneration and recovery.
- **Exposure** describes the nature, magnitude and rate of change experienced by a species, and includes change in both direct climatic variables (e.g., temperature,) and associated factors (e.g., sea level rise and ocean acidification). Measures of future climate exposure are typically informed by scenario projections derived from General Circulation Models (GCMs).
- **Adaptive capacity** describes the degree to which a species, habitat or ecosystem can reduce or avoid the adverse effects of climate change through dispersal to- and colonisation of- more climatically suitable areas, plastic ecological responses, and/or evolutionary responses.

Species that are exposed to large or rapid changes in environmental conditions, are sensitive to those changes and have low capacity to adapt (i.e., they are vulnerable in all three dimensions) are considered highly vulnerable (Foden et al. 2013; Foden and Young 2016). These vulnerabilities can be assessed in three ways (or a combination of approaches); correlative (e.g., Araújo et al. (2011)), mechanistic (e.g., Kearney,Porter (2009)) and trait-based (e.g., Foden et al. (2013)). Trait-based assessments are typically used to inform the prioritisation of species for conservation interventions. They are increasingly used by conservation organisations and management agencies as they allow for relatively rapid assessments for multiple species, do not require modelling expertise, and have easily understood methods which promotes buy-in (Foden and Young 2016). Biological knowledge of the focal taxonomic group is required to parameterise relevant traits and vulnerability categories, but such knowledge can be qualitative, allowing for expert-driven assessments without the requirement for detailed literature (Foden and Young 2016). Thus, trait-based assessments are applicable to most species, even those without detailed ecological information. This makes them particularly suited for marine species, which are known to have data gaps.

Trait-based CCVAs have been conducted in Aotearoa New Zealand for freshwater taonga species (Egan et al. 2020) using numerical scores that result in a ranked index of vulnerability, and for over 1000 terrestrial species including birds and herpetofauna (Brumby et al. 2024) using the conservative approach following Foden et al. (2013).

For the terrestrial approach, species traits were categorised as ‘higher’ or ‘lower’ vulnerability for each species by relevant species experts. Each trait was assigned within a dimension (Sensitivity, Exposure, (Low) Adaptive capacity), and if any of the traits within the dimension received a ‘higher’ score, the respective dimension was categorised as ‘higher’. Species were categorised as ‘Highly Vulnerable’ if all three of the dimensions received a ‘higher’ score. Species with one or two vulnerability dimensions triggered (i.e., receiving a ‘higher’ score) were classified with lower vulnerabilities with different risk scores (Table 2-1) (Brumby et al. 2024).

The benthic marine CCVA carried out in this report adapted the terrestrial approach described by Brumby et al. (2024), to be suitable for the marine environment, and to be applicable to functional groups of benthic marine taxa. The adaptation of the approach by Brumby et al. (2024) involved an expert elicitation process to identify which additional traits to include (described in Section 2.2, and Section 2.4) and to develop appropriate functional and taxonomic groups for analyses. The CCVAs were conducted for functional and taxonomic groups to optimise taxonomic coverage (Section 2.3), helping to target further research (and potentially species level assessments) for the groups identified as most vulnerable. The experts who carried out the assessments also attended a final workshop to provide feedback on the CCVA approach (Section 2.7).

Table 2-1: CCVA vulnerability categories ordered from highest to lowest vulnerability. Taxa with high Sensitivity, high Exposure and low Adaptive capacity are scored ‘higher’ vulnerability. H= 'higher' vulnerability and L = 'lower' vulnerability scored for the vulnerability dimension (Sensitivity, Exposure, Adaptive capacity). Adapted from Foden et al. (2013) and Brumby et al. (2024).

Vulnerability Category	Sensitivity	Exposure	(Low) Adaptive capacity
Highly Vulnerable	H	H	H
Potential Adaptors	H	H	L
Potential Persisters	L	H	H
Latent Risk	H	L	H
Sensitive Only	H	L	L
Exposed Only	L	H	L
Low Adaptive Capacity Only	L	L	H
Low Vulnerability	L	L	L

2.2 Initial expert workshop

CCVAs for marine benthic taxa were conducted for seven wider taxonomic groups: Bryozoans, Corals and other cnidaria (referred to as Corals throughout this report), Crustaceans, Echinoderms, Macroalgae, Molluscs and Sponges. Marine benthic taxa were chosen for assessments due to the availability of expertise within NIWA across a diverse range of groups. An initial online workshop was organised with experts with taxonomic expertise relevant to the wider taxonomic groups, and broader ecological expertise in the marine benthic space. An overview of the CCVA approach was presented, along with case studies that have been conducted in the terrestrial and freshwater space, both globally and in Aotearoa New Zealand. A particular focus was taken describing the terrestrial CCVA approach conducted in Aotearoa New Zealand (Brumby et al. 2024), as this methodology would form the basis for the marine benthic CCVAs.

Each of the traits, definitions, vulnerability thresholds and categorisations of vulnerabilities used in the terrestrial approach (Brumby et al. 2024) were presented, with the omission of traits which were less relevant to the marine space (e.g., traits associated with precipitation change). Some of the definitions and thresholds were adapted using marine terminology, e.g., temperature extremes were described as marine heatwaves. Additional traits thought to be relevant to marine climate vulnerabilities were suggested for inclusion. These traits were 'heightened sensitivity to cumulative stressors' and 'extent of species range exposed to changes in pH'. Experts were given the opportunity to comment on additional traits that were thought to be important for marine climate vulnerability.

During the workshop, experts were also asked to group lists of benthic marine Aotearoa New Zealand taxa into functional or taxonomic groups to which the CCVAs could be applied. Initial taxa lists were provided of 293 taxa with spatially modelled distribution (habitat suitability) maps, developed for the Atlas of Seafloor Biodiversity (Stephenson et al. 2023a). Models were previously developed for these taxa based on data availability at the time, with the mapped taxa a subset of overall biodiversity (e.g., 86 species of macroalgae compared to >1000 species known to be found in Aotearoa New Zealand (Nelson et al. 2023)). Thus, experts were also asked to identify missing taxa of high cultural, economic and recreational importance (e.g., kaimoana species) so that they could be included in the CCVA process. The developed CCVA taxon groups, along with more details of the development process is described in Section 2.3.

Finally, an outline of the specific CCVA expert elicitation process was presented, including an overview of the CCVA materials and resources which are described in Section 2.5.

2.3 Taxon group development

Aotearoa New Zealand's marine environment is highly diverse, with over 17 000 known species (Gordon et al. 2010). Conducting CCVAs at a species level would require a significant investment in resources to achieve broad taxonomic coverage. Adapting CCVAs for grouped species enhances taxonomic coverage, and groups identified as vulnerable can be targeted for further management actions, such as conducting CCVAs for within-group species. Functional and taxonomic groups (hereby 'CCVA taxon groups' or 'taxon groups') of benthic marine taxa were identified by experts for Bryozoans, Corals, Crustaceans, Echinoderms, Macroalgae, Molluscs and Sponges. Experts were asked to group a subset of taxa from the Atlas of Seafloor Biodiversity (Stephenson et al. 2023a) (hereafter referred to as the 'SDM atlas') into functional groups, where the taxa had shared functional attributes, or taxonomic groups at a taxonomic level that the expert deemed appropriate. The experts were informed that: 1) the taxa within the groups did not need to have known shared climate vulnerabilities, 2) the groups did not need to be perceived vulnerable to climate change to be included in the CCVA, 3) the groups could be split geographically or by depth to appropriately capture differences in exposure, and 4) taxonomically and functionally unique taxa did not need to be grouped, and could be included in the CCVA as an individual taxon. Additionally, experts were asked to identify key species, genera, or taxon groups that they thought were missing from the SDM atlas species that should be included for the CCVAs. The number of groupings was left open-ended for the experts to determine.

As the criteria for the taxon groupings was not strictly defined, the grouping criteria differed slightly between wider taxonomic groups (i.e., Bryozoans, Corals, Crustaceans, Echinoderms, Macroalgae, Molluscs and Sponges). For Macroalgae and Echinoderms, taxa were categorised according to defined values for a suite of morphological and environmental traits and taxonomic attributes. For Macroalgae, the categories were scored 'yes' or 'no' for: Intertidal/upper subtidal only, Deeper, Filamentous/skein, Northern large browns, Southern large browns, Algal meadows, Individually (if it was a unique species that should not be grouped), Fucales, Laminariales, Greens, Browns, Red. Species with unique combinations of these categories were developed into taxon groups. Similarly, Echinoderms were assigned taxon groups according to their Geographic range, Depth, Habitat and feeding strategy, with an additional category for whether the taxon should be included as a unique species.

Similar functional and taxonomic attributes were taken into consideration when grouping the Bryozoans, Corals, Crustaceans and Sponges, but the attributes were not definitively categorised, with the overall categorisations being largely expert driven. A detailed list of the CCVA taxon groups and constituting taxa is available in Table B-1, with a summary list in Table 2-2. An additional nine taxon groups of echinoderms were identified, but CCVAs were not conducted for them due to budgetary constraints.

For Molluscs, the expert was provided the same instructions for developing groups, but advised that there would be little value in grouping taxa as the traits and associated climate vulnerabilities would be highly variable within the groups. The expert advised that species-level assessments would be more appropriate. Thus, for the Molluscs, ten species were selected for assessment. These species were selected as they were 1) relatively common and widespread with adequate data for CCVAs, 2) spread across a mixture of habitats (reefs, sand, mud, as well as inshore and offshore) and 3) a mix of commercially harvested and non-commercial species.

Table 2-2: List of functional and taxonomic groups that were used for the climate change vulnerability assessments. Experts chose to include some taxa without grouping them, and the reason for keeping these taxa ungrouped is summarised.

Wider taxonomic group	CCVA taxon grouping	Reason for not grouping (for individual species/ genera)
Bryozoans	Algal associated (*Disporella sp.*)	
Bryozoans	Coral like bryozoan	
Bryozoans	*Fenestrulina (Thyreophora)* (genus)	Functionally unique
Bryozoans	Southern fixed erect	
Bryozoans	*Telopora* (genus)	Functionally unique
Bryozoans	Widespread encrustor	
Bryozoans	Widespread fixed erect	
Bryozoans	Widespread flexible erect	
Macroalgae	*Corallina aff ferreyrae*	Ecologically important

Wider taxonomic group	CCVA taxon grouping	Reason for not grouping (for individual species/ genera)
Macroalgae	*Durvillaea antarctica* and *poha*	Ecologically important
Macroalgae	*Ecklonia radiata*	Ecologically important
Macroalgae	Filamentous brown algae	
Macroalgae	Filamentous green algae	
Macroalgae	Fucales	
Macroalgae	Intertidal/ shallow brown algae	
Macroalgae	Intertidal/ shallow green algae	
Macroalgae	Intertidal/ shallow red algae	
Macroalgae	*Macrocystis pyrifera*	Ecologically important
Macroalgae	Meadow formers (green algae)	
Macroalgae	Meadow formers (red algae)	
Macroalgae	Northen large brown	
Macroalgae	Southern large brown	
Macroalgae	Subtidal brown alage	
Macroalgae	Subtidal green algae	
Macroalgae	Subtidal red algae	
Corals and other Cnidaria	Anemones	
Corals and other Cnidaria	Bamboo coral	
Corals and other Cnidaria	Black corals	
Corals and other Cnidaria	Branching coral	
Corals and other Cnidaria	Bubblegum coral	
Corals and other Cnidaria	Deadmans Fingers	
Corals and other Cnidaria	Golden coral	
Corals and other Cnidaria	Goniocorella	
Corals and other Cnidaria	Hard substrate cup coral	
Corals and other Cnidaria	Hydrocorals	
Corals and other Cnidaria	Mushroom corals	

Wider taxonomic group	CCVA taxon grouping	Reason for not grouping (for individual species/ genera)
Corals and other Cnidaria	Precious corals	
Corals and other Cnidaria	Primnoids	
Corals and other Cnidaria	Sea fans	
Corals and other Cnidaria	Sea pen	
Corals and other Cnidaria	Soft sediment cup coral	
Corals and other Cnidaria	*Taiaroa*	Functionally unique
Corals and other Cnidaria	Zoanthid	
Crustaceans	Blind lobsters	
Crustaceans	Chirostylid squat lobster	
Crustaceans	*Jasus* cray	Economically important
Crustaceans	Large predator/scavenger crabs	
Crustaceans	Large shrimp and prawns	
Crustaceans	Metanephrops scampi	Economically important
Crustaceans	Ibacus slipper lobster	Functionally unique
Crustaceans	Small soft sediment crabs	
Crustaceans	Squat lobster and hermit crabs	
Crustaceans	Swimming crabs	
Molluscs	*Alcithoe arabica*	Ecologically important, culturally important, common and widespread
Molluscs	*Austrovenus stutchburyi*	Functionally unique, economically important, ecologically important, culturally important
Molluscs	*Haliotis iris*	Functionally unique, economically important, ecologically important, culturally important
Molluscs	*Lima zelandica*	Functionally unique, ecologically important
Molluscs	*Maurea selecta*	Common and widespread

Wider taxonomic group	CCVA taxon grouping	Reason for not grouping (for individual species/ genera)
Molluscs	*Pecten novaezelandiae*	Functionally unique, economically important, ecologically important, culturally important
Molluscs	*Pratullum pulchellum*	Functionally unique, ecologically important
Molluscs	*Provocator mirabilis*	Ecologically important, common and widespread
Molluscs	*Tawera spissa*	Functionally unique, economically important, ecologically important,
Molluscs	*Zyglochlamys delicatula*	Functionally unique, economically important, ecologically important
Sponges	Bleaching fan sponges	
Sponges	Calcareous sponges	
Sponges	Finger sponges	
Sponges	Fragile coral garden sponges	
Sponges	Lithistid sponges	
Sponges	Massive, tough sponges	
Sponges	Mobile substrate sponges	
Sponges	Shallow water glass water sponges	
Echinoderms	*Australostichopus*	Ecologically important
Echinoderms	*Centrostephanus*	Ecologically important
Echinoderms	Deep scavenger	
Echinoderms	Deep soft sediment deposit feeder	
Echinoderms	Deep soft sediment scavenger	
Echinoderms	*Evechinus*	Culturally and ecologically important
Echinoderms	Hard substrate scavenger	
Echinoderms	Infaunal deposit feeder	
Echinoderms	Shallow scavenger	

Wider taxonomic group	CCVA taxon grouping	Reason for not grouping (for individual species/ genera)
Echinoderms	Soft sediment deposit feeder	
Echinoderms	Deep infaunal deposit feeder	
Echinoderms	Widespread scavenger	

2.4 CCVA traits

Following the initial expert workshop, 33 traits were finalised to be included in the marine CCVA process. The traits were largely the same as those used in the terrestrial CCVA (Brumby et al. 2024), with the omission of traits not strictly relevant in the marine space (e.g., Exposure to changes in precipitation), and the addition of traits relevant to the marine space (e.g., Exposure to changes in pH) (see Table A-1 for trait comparisons). Each trait was assigned a vulnerability dimension, and thresholds for higher or lower vulnerability were developed to better represent marine ecosystems. The traits, associated definitions and thresholds for higher and lower vulnerabilities are listed below for Sensitivity (Table 2-3), Exposure (Table 2-4), and Adaptive capacity (Table 2-5).

2.4.1 Sensitivity Traits

Table 2-3: List of Sensitivity traits used for the climate change vulnerability assessment, trait definitions, and thresholds for Higher and Lower vulnerability scores.

Trait	Definition	Lower vulnerability threshold	Higher vulnerability threshold
1. Habitat specialisation	Generalist taxa that are less tightly coupled to specific habitats are likely to be more resilient to climate change because they will have a wider range of habitat options available to them. For example, taxa that occupy rocky shoreline, sandy shoreline and muddy shoreline intertidal habitats are likely less sensitive than specialist rocky shoreline taxa. The trait 'habitat specialisation' is based on the number of habitats listed at the secondary classification level in the IUCN Red List (2009) (n = up to 34) as of major importance to the species. Habitats are defined as (1) the habitat(s) in which the taxon occurs regularly or (2) any habitat that is important for the survival of the taxon because it has an absolute requirement for the habitat at some point in its life cycle (e.g., for spawning). For species with an IUCN red listing these habitats are classified as 'suitable' and 'of major importance' in the Habitat and Ecology section of the species accounts. Any other habitat where the taxon occurs irregularly or infrequently, as a vagrant, or where only a small proportion of individuals are found will be considered marginal habitats, not primary habitats.	Taxon group primarily occurs in more than two habitats	Taxon group primarily occurs in two or fewer habitats

Trait	Definition	Lower vulnerability threshold	Higher vulnerability threshold
2. Dependence on a particular microhabitat or single location	This trait addresses the risks to taxa that can have small or large populations but are confined to small or specific areas or microhabitat types, which put the taxa that are reliant on them at a higher risk of extinction. Microhabitat dependency is defined as where a taxon is (1) restricted to a specific limited or patchy habitat type within a more extensive primary habitat (e.g., associated with a specific shelly substrate which is patchily distributed across a broader sandy shoreline), (2) is found in only a small proportion of what may be a more extensive habitat, (3) is found at a single location even if the habitat is present in other locations or (4) is confined to the rarest and most-restricted threatened ecosystem types (<10,000 ha; Holdaway et al. 2012) Sensitivity is increased if a taxon has several life stages, each with different microhabitat requirements (e.g., for spawning), or if it requires a microhabitat that is particularly vulnerable to climate change impacts. This trait could apply to (but is not restricted to) species within taxon groups that have a 'One Location' qualifier in the NZTCS; defined as one geographically or ecologically distinct area of less than 1000 km^2 (100,000 ha) (Townsend et al. 2008). Single locations are vulnerable to a single event (e.g., a predator irruption) that could easily affect all individuals of the taxon.	No microhabitat or single location dependency known	Has one or more microhabitat dependencies and/or occurs in a single location
3. Narrow temperature tolerance	Taxa with narrow tolerance are those for which projected changes in temperature (including both increases and decreases) are likely to exceed physiological thresholds (e.g., taxa that have life history characteristics dependent on narrow temperature ranges). Medium tolerance taxa will primarily remain within physiological thresholds. Some stress may limit functions or reproductive requirements. Broad tolerance taxa will tolerate very broad ranges in temperature.	Taxa with 'Broad' or 'Medium' temperature tolerances for all, or at critical parts, of the life cycle	Taxa with 'Narrow' temperature tolerances for all, or at critical parts, of the life cycle
4. Narrow pH tolerance	Taxa with narrow tolerance are those for which projected changes in ocean pH (including both increases and decreases) are likely to exceed physiological thresholds (e.g., taxa that have life history characteristics dependent on narrow pH ranges). Medium tolerance taxa will primarily remain within physiological thresholds. Some stress may limit functions or breeding requirements. Broad tolerance taxa will tolerate very broad ranges in pH.	Taxa with 'Broad' or 'Medium' pH tolerances for all, or at critical parts, of the life cycle	Taxa with 'Narrow' pH tolerances for all, or at critical parts, of the life cycle

Trait	Definition	Lower vulnerability threshold	Higher vulnerability threshold
5. Interactions with other species/taxa	Taxa dependent on functional interspecific interactions. Climate change driven alterations in species' ranges, phenologies and relative abundances may affect their interspecific and ecological interactions (e.g., with prey, hosts, and symbionts). Taxa are likely to be particularly sensitive to climate change if, for example, they are highly dependent on one or few specific resource species and are unlikely to be able to substitute these for other species. Taxa could also be sensitive to the impacts of range extending species, e.g. some macroalgal species may be highly sensitive to predation from range extending tropical urchins.	No known interspecific interactions	One or more known interspecific interactions
6. Rarity	The inherent vulnerability of small populations to Allee effects and catastrophic events, as well as their generally reduced capacity to recover quickly following local extinction events, suggest that many rare species will face greater impacts from climate change than more common and/or widespread species. Rare taxa can include those that are geographically isolated or those that are naturally uncommon within broad areas. The thresholds developed for this trait cover both these scenarios with taxa being considered rare if they occur in a single bioregion (using the new Aotearoa New Zealand seafloor bioregionalization (Stephenson et al. 2023b)) or if they are known from less than 10 occurrence records throughout Aotearoa New Zealand waters. This second threshold aligns with that used for informing key ecological areas.	Taxon group occurs across multiple bioregions OR is known from more than 10 records.	Taxon group occurs in a single bioregion OR is known from less than 10 records.
7. Heightened sensitivity to sedimentation	With future predicted increases in storm surge and erosion under climate change, some areas may experience regular high-volume influxes of sediment, with long term sedimentation and increases in turbidity. Taxa that have certain feeding strategies such as photosynthesising, filter feeding and using visual cues to hunt may be highly sensitive to reduced food availability due decreased water clarity from suspended sediment. Sediment deposited on the benthos can smother slow-growing non-mobile taxa. This trait should apply to taxa with known sensitives to sedimentation and turbidity.	Taxon group are known or thought to live in highly turbid areas, or are known to survive regular, seasonal or stochastic influxes of sediment	Taxon group are known or thought to require high water clarity, and are sensitive to influxes of sediment, and long term sedimentation

Trait	Definition	Lower vulnerability threshold	Higher vulnerability threshold
8. Heightened sensitivity to cumulative stressors	Anthropogenic stressors do not exist in isolation and many marine taxa are faced with multiple and interacting impacts. This trait acknowledges that taxa that are already facing multiple stressors that may not be directly related to climate change, are likely more sensitive to climate change impacts due to having less capacity to absorb additional stressors. For example, taxa that reside in habitats degraded by sedimentation or fisheries may have reduced physiological tolerances (e.g., resilience to ocean acidification) due to already persisting in a stressed state. The threshold for this trait is based on whether there are known and demonstrated impacts of multiple stressors (>1) (other than those directly related to climate change) for a given taxon group.	Taxon group has no demonstrated sensitivity to stressors that are unrelated to climate change	Taxon group has demonstrated sensitivity to multiple stressors that are not directly related to climate change

2.4.2 Exposure traits

Table 2-4: List of Exposure traits used for the climate change vulnerability assessment, trait definitions, and thresholds for Higher and Lower vulnerability scores.

Trait	Definition	Lower vulnerability threshold	Higher vulnerability threshold
9. Habitat types exposed to sea level inundation and increased storm surges	Sea level around New Zealand is expected to continue to rise by an additional 0.2–0.3 m by 2040 and 0.4–0.9 m by 2090, depending on which emission scenario is used. Thus, some habitat types exposed to sea level inundation will be lost through flooding depending on local topography. In addition, predicted increases in the frequency and magnitude of storm surges are likely to significantly shorelines. Vulnerable habitats include intertidal and shallow sub-tidal (<20m) areas, especially mangroves, intertidal rocky shores and flats, estuaries, brackish or saline lakes and lagoons, coastal caves, some sea cliffs, some coastal turfs, low-lying rocky offshore islands. Taxa are considered to have high exposure if they occur largely in, or are dependent on, one or more of these vulnerable habitats for any critical parts of their life cycle.	Taxon group does not occur largely in inundation or storm-surge exposed coastal habitats	Taxon group occurs largely in inundation or storm-surge exposed coastal habitats

Trait	Definition	Lower vulnerability threshold	Higher vulnerability threshold
10, 11, 12, 13. Extent of taxon group's geographic range exposed to changes in temperature	The greater the amount of a taxon group range that is exposed to substantially increased temperatures, the greater the potential vulnerability. Taxon groups with HIGH exposure are those exposed to substantial (>x°C) changes in mean seawater temperature across >75% of their range. Projected exposure evaluated for two scenarios of mean seawater temperature changes (SSP2 (4.5) 'moderate scenario' and SSP3 (7.0) 'high emissions scenario') and for two future time periods, mid-century (2050) and late-century 2100. x = Known threshold for temperature tolerance or highest 25% temperature variability	No substantial changes (>x°C) in mean temperature projected across >75% of taxon group range	Substantial changes (>x°C) in mean temperature projected across >75% of taxon group range
14, 15, 16, 17. Extent of taxon group's range exposed to marine heatwaves	The greatest impact of climate change is likely to be experienced first by changes in extremes rather than by changes in mean conditions. Taxon groups with HIGH exposure are those exposed to substantial changes in frequency, duration and intensity of extreme heat events across most (>75%) of the group range, which lead to stress affecting productivity and survival especially if they are cold-adapted species. Marine heatwaves are defined as sea water temperature above the 90th percentile of mean local conditions (25 yr. average) for more than five consecutive days. Projected exposure evaluated for two scenarios of marine heatwave predictions (SSP2 (4.5) 'moderate scenario' and SSP3 (7.0) 'high emissions scenario') and for two future time periods, mid-century (2050) and late-century 2100. 'Substantial' increases in heatwave events are defined as areas with >150 days of heatwave events predicted, although it is noted that MHW events may also become more frequent and intense.	No substantial projected increases in substantial marine heatwaves across >75% of the taxon group range	Substantial projected increases in substantial marine heatwaves across >75% of the taxon group range
18,19,20,21. Extent of taxon group's range exposed to changes in pH (ocean acidification)	The greater the amount of a taxon group range that is exposed to substantially altered pH, the greater the potential vulnerability. Groups with HIGH exposure are those exposed to substantial (>x pH) changes in mean seawater pH at the seafloor within the majority (>75%) of the group range. Projected exposure evaluated for two scenarios of mean pH changes (SSP2 (4.5) 'moderate scenario' and SSP3 (7.0) 'high emissions scenario') and for two future time periods, mid-century (2050) and late-century 2100. 'Substantial' decrease in pH are areas with the top 25% of the difference in pH between present and future conditions	No substantial changes (x) in pH projected across >75% of taxon group range	Substantial changes (x) pH projected across >75% of taxon group range

Trait	Definition	Lower vulnerability threshold	Higher vulnerability threshold
22, 23, 24, 25. Extent of taxon group's range exposed to changes in aragonite	Aragonite is a form of calcium carbonate that some organisms require to build their skeletons and shells. The lower the saturation level, the more difficult it is for organisms to build and maintain their protective skeletons and shells. The greater the amount of a taxon group range that is exposed to substantially reduced aragonite saturation, the greater the potential vulnerability. Groups with high exposure are those where >75% of group range overlaps with areas with substantial reductions in mean seawater aragonite saturation at the seafloor. Projected exposure evaluated for two scenarios of mean aragonite saturation change (SSP2 (4.5) 'moderate scenario' and SSP3 (7.0) 'high emissions scenario') and for two future time periods, mid-century (2050) and late-century 2100. 'Substantial' is defined as the areas with the top 25% of reductions in aragonite saturation between present and future conditions	No substantial changes (x) in aragonite saturation projected across >75% of taxon group range	Substantial changes (x) aragonite saturation projected across >75% of taxon group range
26, 27 ,28, 29. Extent of taxon groups range exposed to changes in calcite	Calcite is a form of calcium carbonate that some organisms require to build their skeletons and shells. The lower the saturation level, the more difficult it is for organisms to build and maintain their protective skeletons and shells. The greater the amount of a taxon group range that is exposed to substantially reduced calcite saturation, the greater the potential vulnerability. Groups with high exposure are those where >75% of group range overlaps with areas with substantial reductions in mean seawater calcite saturation at the seafloor. Projected exposure evaluated for two scenarios of mean calcite change (SSP2 (4.5) 'moderate scenario' and SSP3 (7.0) 'high emissions scenario') and for two future time periods, mid-century (2050) and late-century 2100. 'Substantial' is defined as the areas with the top 25% of reductions in calcite saturation between present and future conditions	No substantial changes (x) in calcite saturation projected across >75% of taxon group range	Substantial changes (x) calcite saturation projected across >75% of taxon group range

2.4.3 Adaptive capacity traits

Table 2-5: List of Adaptive capacity traits used for the climate change vulnerability assessment, trait definitions, and thresholds for Higher and Lower vulnerability scores.

Trait	Definition	Lower vulnerability threshold	Higher vulnerability threshold
30. Limitations to dispersal	Factors that limit dispersal will impede the ability of species to keep up with a shifting climate envelope (e.g., moving to from low to high latitudes) or move to alternative habitats if their current range becomes unsuitable (e.g., moving into deepwater habitats). Limitations include low dispersal rates or intrinsic or extrinsic barriers. Intrinsic barriers include behavioural traits such as very high site fidelity and larval dispersal. Extrinsic barriers may be geographic features such as unsuitable oceanographic conditions (e.g., currents, fronts), or other impassable habitat types (e.g., fronts, eddies, seafloor geomorphology).	No known limitations to dispersal for taxa	Limitations to dispersal for taxa
31. Low genetic diversity	Taxa potential for rapid genetic change will determine whether evolutionary adaptation can occur at a rate sufficient to keep up with climate change driven changes to their environments. Taxa with low genetic diversity, potentially resulting from recent bottlenecks in population numbers, generally exhibit lower ranges of both phenotypic and genotypic variation. As a result, such taxa tend to have fewer novel characteristics that could facilitate adaptation to the new climatic conditions.	No evidence of low genetic diversity or known genetic bottleneck in taxa	Evidence of low genetic diversity or known genetic bottleneck in taxa
32. Slow turnover of generations	Evidence suggests that evolutionary adaptation is possible in relatively short timeframes (e.g., 5 to 30 generations) but for most species with long generation lengths, this is likely to be too slow to have any serious minimising effect on climate change impacts (generation time refers to the length of time from birth/hatching to reproductive maturity). Species with shorter generation times have more potential to express changes at a population level. Species with lower adaptive capacity (therefore higher potential vulnerability) are defined as those with generation length ≥x years (based on definition from Townsend, 2008: Age of maturity * 2.5).	Generation length <x years	Generation length ≥x years
33. Low reproductive capacity	Low productivity has consequences for adaptability because fewer young are produced, further reducing potential for opportunities for genetic adaptation for a species (e.g., reduced rate at which advantageous novel genotypes could accumulate in populations and species). Taxon groups with higher potential vulnerability are defined as those that produce low number of offspring relative to number of offspring of closely related taxa (≤x offspring). Limitations to this trait measurement include not knowing the recruitment into the breeding population etc.	>x offspring on average over a one-year period	≤x offspring on average over a one-year period

2.5 Expert CCVA process

Two taxonomic experts (an assessor and a reviewer) were identified for each wider taxonomic group (Table 2-6). For some wider taxonomic groups (e.g., Corals, Macroalgae, Crustaceans) both the assessor and the reviewer were experts for the taxonomic group, whereas for Bryozoans and Molluscs the initial assessor was a taxonomic expert, and the reviewer was a taxonomist with a good understanding of the taxon in general, as well as a good understanding of benthic marine ecology. For Echinoderms, both expert and reviewers were parataxonomists with a good understanding of Echinoderms in general (with regular identification of specimens) but did not consider themselves specialised echinoderm taxonomists. Additionally, the reviewer suggested by the Sponge expert assessor did not feel they had enough specific knowledge to provide a review, and an alternative reviewer could not be identified due to there being a limited number of experts with the specialist knowledge required, and time constraints.

The expert assessors listed in Table 2-6 were sent an email containing resources required to conduct CCVAs (the scoring sheet and map resources described in detail below). The email included a brief outline of the resources, and instructed experts to provide scores for all traits, even those that may not be relevant to the wider taxonomic group, to allow for comparisons of vulnerabilities between the wider taxonomic groups (e.g., comparing Macroalgae CCVAs with Coral CCVAs). Additionally, experts were reminded that CCVAs have been designed to be relatively rapid, so they should mainly rely upon their expert knowledge and resources they were already aware of, without the need to spend time extensively searching the literature. Experts were asked to return the assessments by a given date (ca. two weeks). Experts were also informed that the project team were available for questions via email or video chat, and the project team could assist by running through the assessments (or part of the assessments) via video call.

A scoring sheet was developed which included all 33 traits to be assessed. The scoring sheet was sent to experts in Microsoft Excel (.xlsx) format. It included instructions required to complete and review the CCVAs (e.g., how and where to record the scores, when the CCVAs needed to be completed by, who to return the scoring sheet to), information on the CCVA taxon groups to be assessed (species and genera within each group), and definitions and databases for each trait (definition, thresholds for lower and higher vulnerability).

The scoring sheet allowed for each trait to be assigned vulnerability categories using dropdown boxes. Depending on the trait, the scoring categories differed, for example the trait ‘Dependence on a particular microhabitat or single location’ was scored with ‘Yes’ (categorised as ‘Higher’ vulnerability), ‘No’ and ‘Unknown’, but the trait ‘Narrow temperature tolerance’ was scored with ‘Narrow’ (categorised as ‘Higher’ vulnerability), ‘Medium’, ‘Broad’ and ‘Unknown’. Each of the traits was also scored ‘Unknown’, ‘Low’, ‘Medium’ and ‘High’ for Information adequacy. The definitions for Information adequacy categories are as follows:

- Unknown = There are no data available to help predict how this trait might influence vulnerability (trait scored as 'Unknown')
- Low = We have little data or relevant ecological knowledge to predict how this trait might influence vulnerability
- Medium = We have some good quality data but with knowledge gaps limiting how we predict this trait might influence vulnerability

- High = We have good quality data and understanding of species ecology to predict how this trait might influence vulnerability

The scoring sheet also provided opportunity for additional information and commentary should the expert see fit (e.g., comments such as the score was only specific to a certain life stage, or the scoring was mainly conducted with one particular species in mind).

A map resources document was also developed to be shared alongside the scoring sheet. This document contained 21 maps to be used when assessing Trait 6 – Rarity, and the Exposure traits (Traits 10-29), Changes in temperature, Changes in marine heatwave exposure, Changes in pH, Changes in aragonite saturation and Changes in calcite saturation. These maps were developed for two Shared Socio-economic Pathway (SSP) climate change scenarios, SSP2 (4.5) 'moderate scenario' and SSP3 (7.0) 'high emissions scenario', for two time periods 2050 and 2100. To develop the maps, the environmental change was predicted across the New Zealand exclusive economic zone (EEZ) for the four scenarios for each environmental variable. The areas with the top 25% of change (increases or decreases) were then outlined (Appendix C). For Changes in temperature, the areas with the top 25% of increases (i.e., areas where the temperature would increase the most) were outlined (see Figure 2-1 for an example map of Bottom temperature changes). For changes in pH, aragonite saturation and calcite saturation, the areas with the top 25% decreases were outlined (as decreases in these variables are known limit growth and survival). The marine heatwaves maps predicted number or marine heatwave days per year (banded between 0 and 365), thus areas predicted to have over 150 marine heatwave days per year were included in the outlined areas. Currently, there are no clear definitions on how many marine heatwave days per year constitutes a severe heatwave event, but the Tasman 2017/2018 marine heatwave that had recorded ecological impacts in Aotearoa New Zealand was 147 days long (Salinger et al. 2019). For each trait, experts were instructed to assess if the outlined areas overlapped with >75% of the taxon group's range.

Once the initial assessor completed the scoring sheet, the filled-out scoring sheet, map resources and instructions were sent to the reviewer (Table 2-6). Reviewers were instructed not to change any scores, but to comment on scores if they disagreed with the initial assessment. The initial assessor was then contacted again, the comments were discussed, and the scores were altered accordingly.

Table 2-6: List of expert assessors and reviewers who conducted the climate change vulnerability assessments for each wider taxonomic group.

Wider taxonomic group	Initial assessor	Reviewer
Bryozoans	Dr Dennis Gordon (NIWA)	Dr Michelle Kelly (NIWA)
Corals	Di Tracey (NIWA)	Dr Jaret Bilewitch (NIWA)
Crustaceans	Dr Kareen Schnabel (NIWA)	Dr Rachael Peart (NIWA)
Echinoderms	Kate Neill (NIWA)	Sadie Mills (NIWA)
Molluscs	Kerry Walton (Te Papa)	Sadie Mills (NIWA)
Macroalgae	Kate Neill (NIWA)	Dr Maren Preuss (NIWA)
Sponges	Dr Michelle Kelly (NIWA)	*NA*

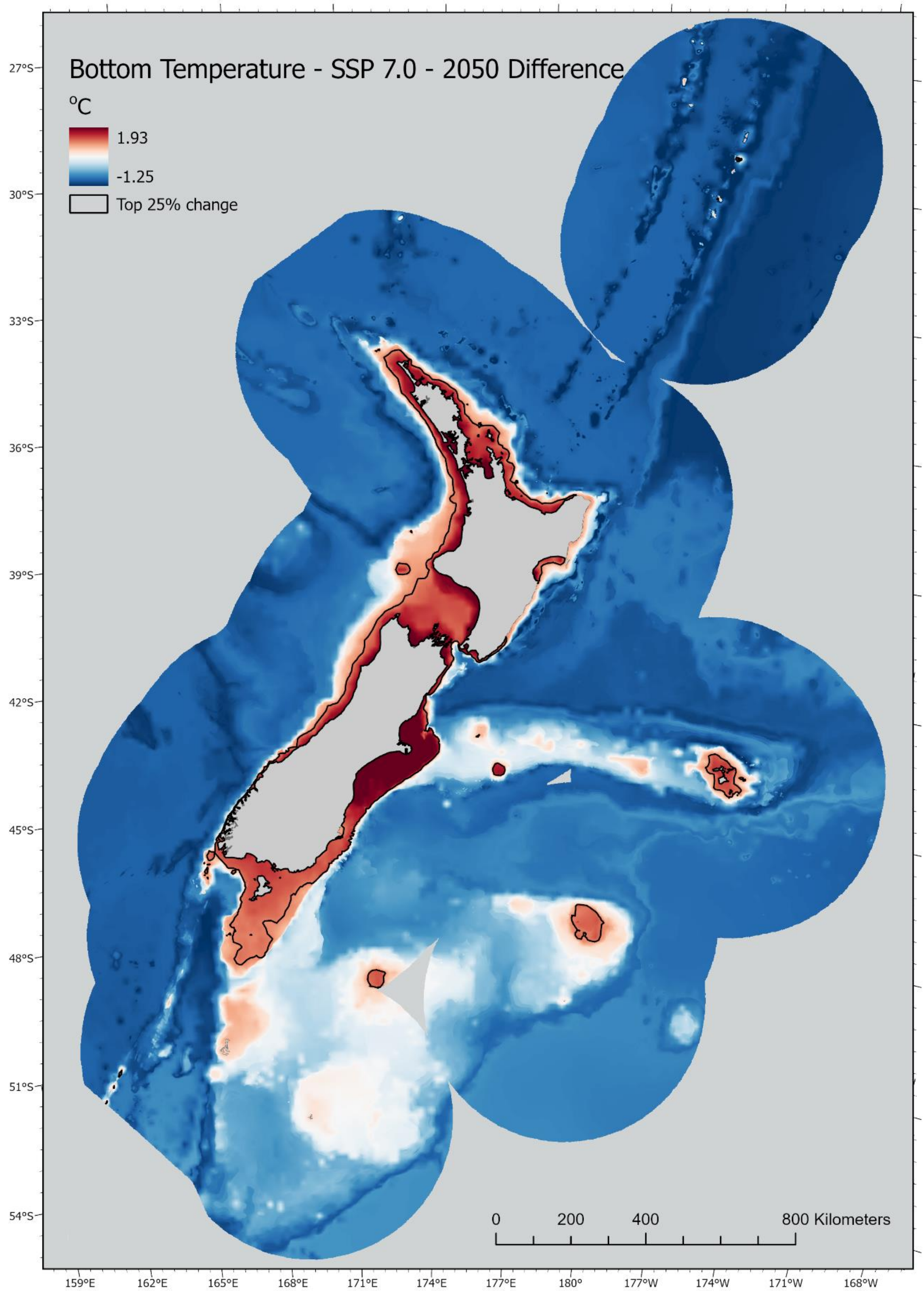

Figure 2-1: Change in bottom temperature between now and 2050 for SSP3 (7.0) climate scenario, predicted using the New Zealand Earth Systems Model. Red areas inside the black line indicate areas with the top 25% of predicted temperature increases.

2.6 Compilation of assessments and analyses

Scoring sheets were exported into R (R Core Team 2021) for data analyses and visualisation. Each of the wider taxonomic groups were analysed independently, but overall summary figures were produced to compare between the wider taxonomic groups. To allow for more detailed taxon group comparisons, two numeric approaches adapted from (Foden et al. 2013) were taken:

1. Optimistic assessment method: High vulnerability categories were converted to '1', and Medium, Low and Unknown vulnerability categories were converted to '0'. Mean numeric scores were calculated for each dimension for each taxon group.

2. Pessimistic assessment method: High vulnerability categories were converted to '1', Unknown scores were converted to a '1', and Medium scores were converted to '0.5. Mean scores were calculated for each dimension for each taxon group.

Analyses were conducted for each climate change scenario and time period, and species were assigned vulnerability categories as per Table 2-1. Total numeric vulnerability scores for each taxon group were calculated by summing the mean numeric scores for each dimension (considering all climate scenarios and time periods in one overall analyses). One overall numerical analysis was conducted as it took into account different time periods and scenarios but allowed for clearer visual comparisons between taxon groups. This calculation could be easily disaggregated for individual time periods or scenarios to understand variability in vulnerability. Additionally for each wider taxon group (e.g., Corals), mean numeric vulnerability scores were plotted for each taxon group by dimension, allowing for more detailed comparisons of vulnerabilities across groups. For each taxon group, the percentage of traits with Low', Medium and High information adequacy was also plotted for each vulnerability dimension, to visualise knowledge deficiencies across groups.

2.7 Lessons learnt workshop

After completing CCVAs, an in-person workshop was held with experts who participated in the process to identify potential drawbacks with the approach, as well as avenues for future improvement. Experts were presented the results of the CCVAs, including the mean overall vulnerability scores for each taxon group for each dimension, and mean Information adequacy scores for each taxon group for each dimension. They were given the opportunity to discuss the expectedness of the results, the scoring process, the traits selected, and overall general commentary of how the process could be improved or developed for future assessments.

At the completion of the project, the results were presented at a joint meeting of the Aquatic Environment Working Group (AEWG) and Biodiversity Research Advisory Group (BRAG) to facilitate further discussion and feedback on the projects outputs. Considerations from AEWG/BRAG members are synthesised along with those from the lessons learnt workshop in section 5.

3 Results

3.1 Comparisons across wider taxonomic groups

A total of 83 assessments were conducted for CCVA taxon groups across Bryozoans (8 groups), Corals (18 groups), Crustaceans (10 groups), Echinoderms (12 groups), Macroalgae (17 groups), Molluscs (10 groups) and Sponges (8 groups). For the Optimistic approach where Unknown scores were considered as low risk, Bryozoans and Macroalgae were the taxa with the highest overall risk, as all groups were assigned to be Highly Vulnerable, followed by Corals where 14 of the 18 groups were assigned to be Highly Vulnerable, and Sponges, where 6 of the 8 groups were assigned to be Highly Vulnerable (Table 3-1). Of the 10 crustacean groups, only two were found to be Highly Vulnerable, and no Echinoderms and Molluscs were found to be Highly Vulnerable. Generally, groups that were not assigned Highly Vulnerable were assigned Potential Adaptors (Table 3-1). When assessing the mean scores for each dimension across the wider taxonomic groups, Macroalgae had the highest mean vulnerability scores for the Sensitivity dimension, and Sponges had the highest mean vulnerability scores for the Exposure and Adaptive capacity dimensions (Figure 3-1).

When summing vulnerability scores across dimensions for the Optimistic approach, the highest scoring taxon group (i.e., the most vulnerable) was Shallow water glass sponges (Table 3-2). Six of the top 10 highest scoring taxon groups were also sponges, with three Coral taxon groups (*Goniocorrella*, Hydrocorals and Soft sediment cup corals), and one Bryozoan group (Southern fixed erect) (Table 3-2).

For the Pessimistic approach, the number of groups assigned Highly Vulnerable increased significantly for Corals, Echinoderms and Molluscs, with a slight increase for Sponge groups. Across both Optimistic and Pessimistic scenarios, no groups were assigned Latent Risk, Sensitive Only, Low Adaptive Capacity Only, or Low Vulnerability (Table 3-1). When assessing the mean scores for each dimension across the wider taxonomic groups, Macroalgae had the highest mean vulnerability scores for the Sensitivity dimension, Sponges had the highest mean vulnerability scores for the Exposure dimension, and Macroalgae and Echinoderms had the highest mean vulnerability for the Adaptive capacity dimension (Figure 3-2).

When summing vulnerability scores across dimensions for the Pessimistic approach, the highest scoring taxon group was Deadman's fingers coral (Table 3-3). Seven of the top 10 highest scoring taxon groups were Macroalgae, with one Sponge (Shallow water glass sponges), and one Echinoderm group (*Evechinus*) with the highest overall vulnerability (Table 3-3).

Table 3-1: Number of CCVA taxon groups within the wider taxonomic groups assigned climate change vulnerability categories for Optimistic (green shade) and Pessimistic (red shade) assessment approaches, considering both time periods and climate scenarios.

Taxa	Number of taxon groups	Highly Vulnerable		Potential Adaptors		Potential Persisters		Latent Risk		Sensitive Only		Exposed Only		Low Adaptive Capacity only		Low Vulnerability	
Bryozoans	8	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corals	18	14	18	3	0	0	0	0	0	0	0	1	0	0	0	0	0
Crustaceans	10	2	2	8	8	0	0	0	0	0	0	0	0	0	0	0	0
Echinoderms	12	0	12	2	0	0	0	0	0	0	0	10	0	0	0	0	0
Macroalgae	17	17	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Molluscs	10	0	7	8	3	2	0	0	0	0	0	0	0	0	0	0	0
Sponges	8	6	8	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Total	**83**	**47**	**72**	**21**	**11**	**4**	**0**	**0**	**0**	**0**	**0**	**11**	**0**	**0**	**0**	**0**	**0**

Table 3-2: Top 10 CCVA taxon groups with the highest vulnerability scores for the Optimistic approach across the Sensitivity, Adaptive Capacity and Exposure dimensions (considering all climate scenarios and time periods). Mean vulnerability scores for each dimension were summed to determine overall scores.

Rank	Wider taxonomic group	CCVA Taxon group	Score
1	Sponges	Shallow water glass water sponges	2.18
2	Sponges	Fragile coral garden sponges	1.95
3	Sponges	Lithistid sponges	1.90
4	Corals	*Goniocorella*	1.83
5	Sponges	Bleaching fan sponges	1.82
6	Sponges	Calcareous sponges	1.70
7	Sponges	Massive, tough sponges	1.70
8	Corals	Hydrocorals	1.68
9	Corals	Soft sediment cup coral	1.60
10	Bryozoans	Southern fixed erect	1.60

Table 3-3: Top 10 CCVA taxon groups with the highest vulnerability scores for the Pessimistic approach across the Sensitivity, Adaptive Capacity and Exposure dimensions (considering all climate scenarios and time periods). Mean vulnerability scores for each dimension were summed to determine overall scores.

Rank	Wider taxonomic group	CCVA Taxon group	Score
1	Corals	Deadmans Fingers	2.45
2	Macroalgae	*Corallina aff ferreyrae*	2.29
3	Macroalgae	Northen large brown	2.27
4	Sponges	Shallow water glass water sponges	2.25
5	Echinoderms	*Evechinus*	2.24
6	Macroalgae	Intertidal/ shallow brown algae	2.23
7	Macroalgae	Intertidal/ shallow green algae	2.23
8	Macroalgae	Intertidal/ shallow red algae	2.23
9	Macroalgae	Meadow formers (green algae)	2.23
10	Macroalgae	Southern large brown	2.23

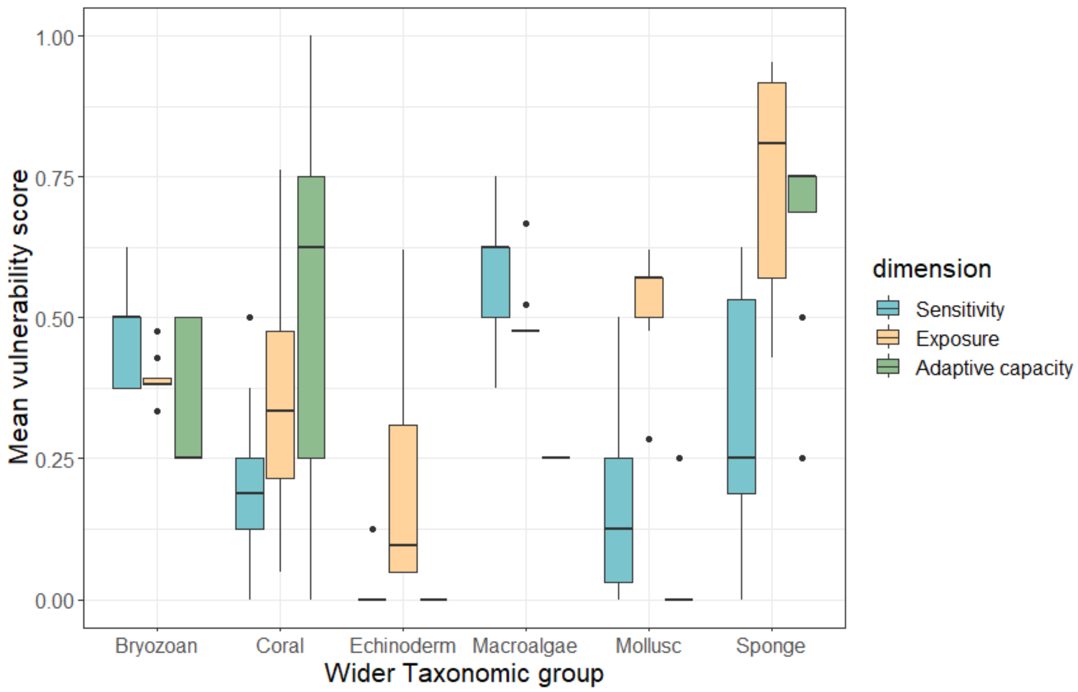

Figure 3-1: Boxplot of mean vulnerability scores considering all climate change scenarios and time periods for each dimension across the wider taxonomic groups, analysed using the Optimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability. Mean vulnerability scores range from 0 (low vulnerability) to 1 (high vulnerability) for each dimension.

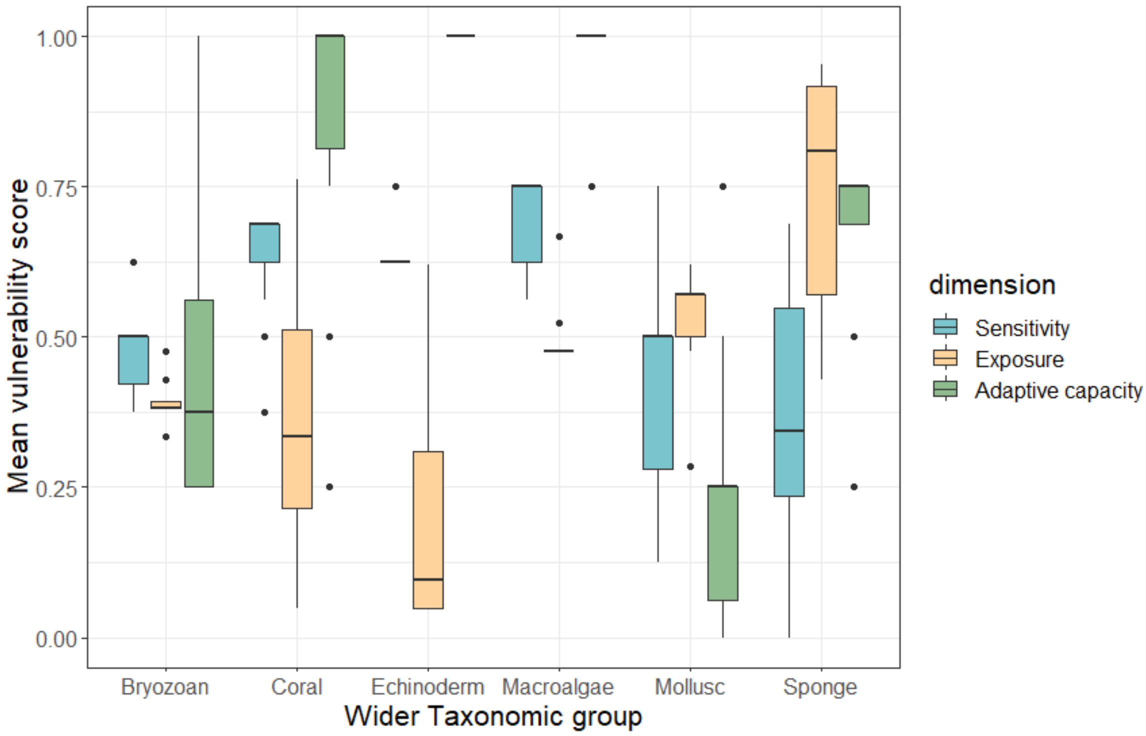

Figure 3-2: Boxplot of mean vulnerability scores considering all climate change scenarios and time periods for each dimension across the wider taxonomic groups, analysed using the Pessimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability. Mean vulnerability scores range from 0 (low vulnerability) to 1 (high vulnerability) for each dimension.

3.2 Bryozoans

When comparing vulnerabilities between the climate scenarios and time periods, all eight of the assessed Bryozoan groups were scored Highly Vulnerable, with High scores across all three dimensions (Sensitivity, Exposure, Adaptive Capacity). The results were the same for both the Optimistic and Pessimistic approaches (Table 3-4,

Table **3-5**, Figure D-1) and when considering all climate scenarios and time periods in one overall assessment (Figure 3-3, Figure 3-4).

When considering the numeric vulnerability scores, the Southern fixed erect grouping had the highest score for both Optimistic and Pessimistic approaches (Figure 3-3, Figure 3-4). Coral like Bryozoans, and *Telopora* also had relatively high numeric vulnerability scores for both approaches.

Information adequacy was highest for the Sensitivity dimension traits, with >75% of traits scoring High Information adequacy. The Information adequacy for the Exposure traits was consistent across groups, with over 50% of the traits scoring Medium Information adequacy, except for the Southern fixed erect group which had Higher Information adequacy. On the contrary, the Southern fixed erect group had the lowest Information adequacy for the Adaptive capacity dimension, with all traits being assigned a Low score. Adaptive capacity had the most inconsistent information adequacy scores, and the most variation in scores between groups.

Table 3-4: Climate change vulnerability assessment results for the Bryozoan taxon groups for the Optimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Algal associated	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Coral like	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Fenestrulina	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Southern fixed erect	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Telopora	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Widespread encrustor	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Widespread fixed erect	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Widespread flexible erect	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable

Table 3-5: Climate change vulnerability assessment results for the Bryozoan taxon groups for the Pessimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Algal associated	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Coral like	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Fenestrulina	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Southern fixed erect	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Telopora	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Widespread encrustor	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Widespread fixed erect	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Widespread flexible erect	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable

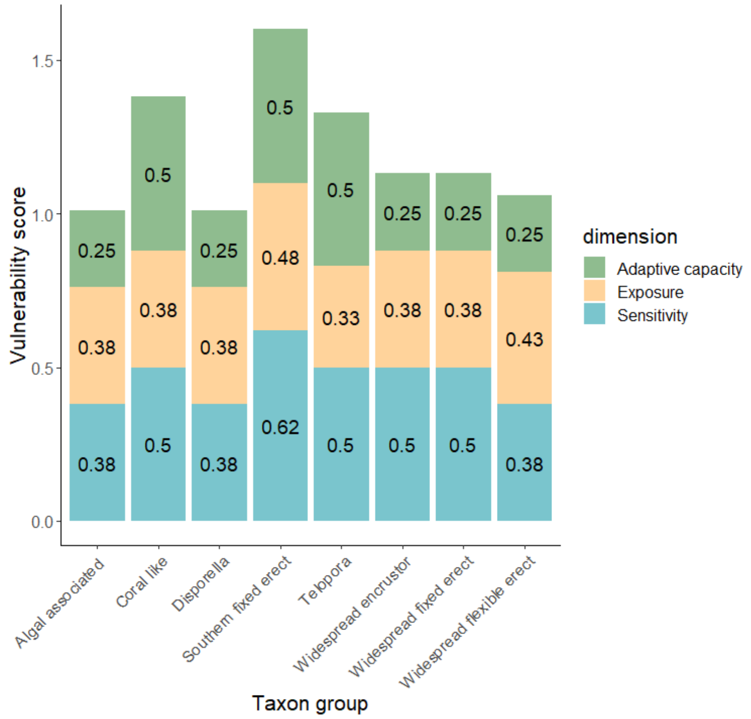

Figure 3-3: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Bryozoan taxon groups, calculated using the Optimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

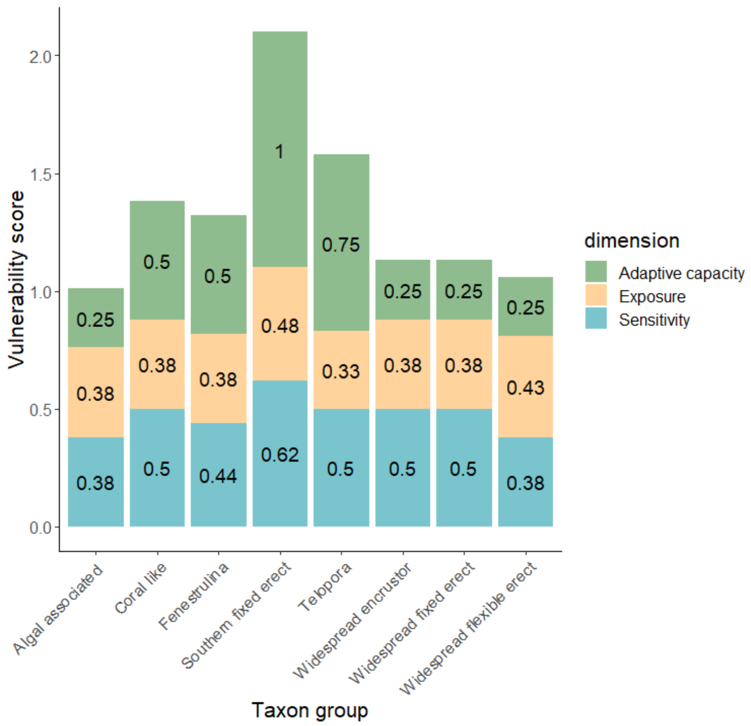

Figure 3-4: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Bryozoan taxon groups, calculated using the Pessimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

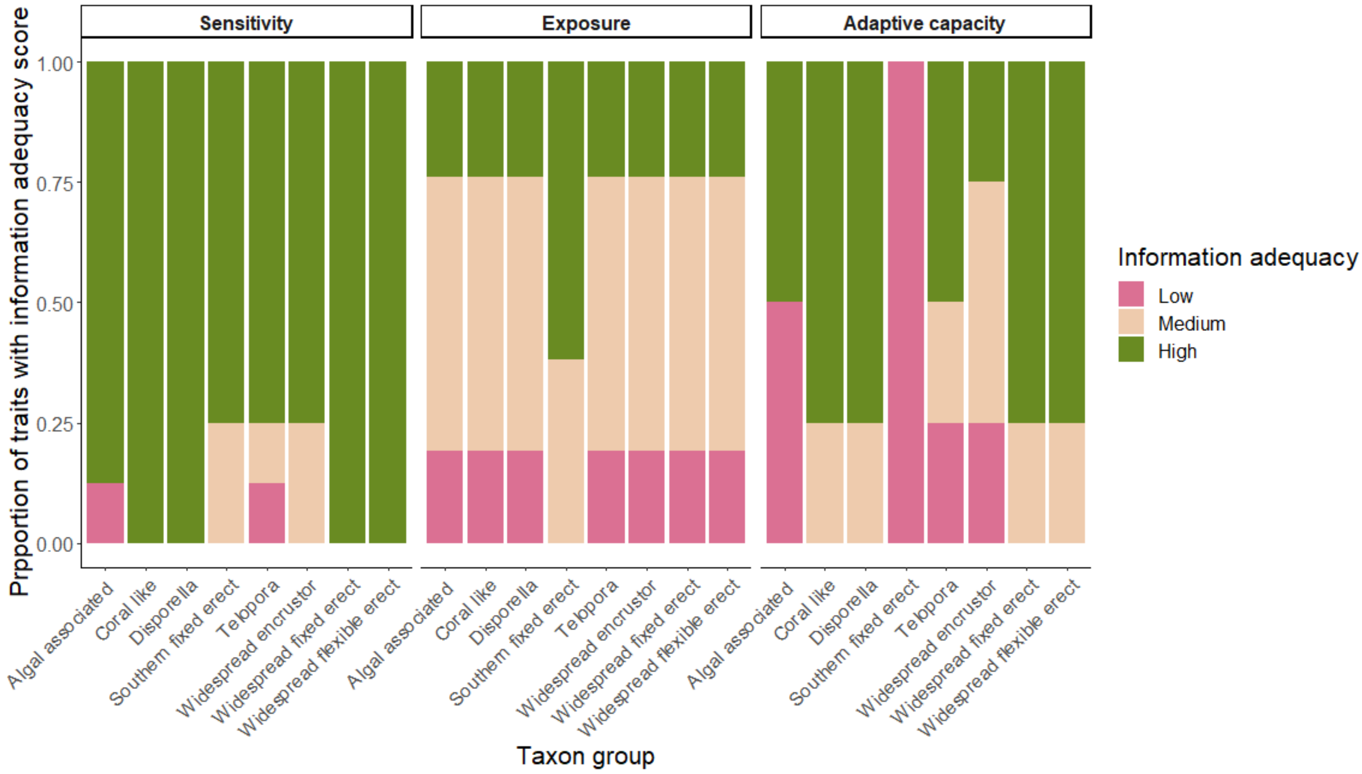

Figure 3-5: Proportion of traits with Low, Medium and High information adequacy scores for Bryozoan taxon groups across the Sensitivity, Exposure and Adaptive capacity climate change vulnerability dimensions.

3.3 Corals

When comparing vulnerabilities between the climate scenarios and time periods for the Optimistic approach, the scores did not change between the 2050 and 2100 time periods for the SSP2 (4.5), with 12/18 taxon groups being scored Highly Vulnerable (Table 3-6, Figure D-2). The groups were slightly less vulnerable for SSP3 (7.0) 2050, with 9/18 groups scoring Highly Vulnerable. Overall vulnerability was highest for the SSP3 (7.0) 2100 time period, with 14/18 taxon groups scoring Highly Vulnerable (Table 3-6). Vulnerabilities increased significantly for the Pessimistic approach, with 13/18 taxon groups scoring Highly Vulnerable for all time periods and scenarios, and all 18 taxon groups scoring Highly Vulnerable for SSP3 (7.0) 2100 (Table 3-6, Figure D-2).

When considering all climate scenarios and time periods in one assessment, for the Optimistic approach, 14 of the 18 assessed coral groups were scored Highly Vulnerable (Figure 3-6) and for the Pessimistic approach, all 18 taxon groups scored Highly Vulnerable (Figure 3-7). When considering the numeric vulnerability scorings, *Goniocorella* had the highest score across dimensions for the Optimistic approach, whereas Deadman's Fingers had the highest score for the Pessimistic approach. approaches.

Information adequacy was highest for the Exposure dimension traits, with 100% of traits scoring Medium Information adequacy (Figure 3-8). Information adequacy scores for the Sensitivity traits were relatively low, with 13 of the taxon groups scoring Low Information adequacy scores for 50% or more of the traits. For the Adaptive Capacity traits, all taxon groups had Low Information adequacy scores for at least 50% of the traits, with seven taxon groups scoring Low Information adequacy scores for 100% of the traits. Deadman's Fingers and Mushroom corals taxon groups had lowest overall Information adequacy scores, with 75% of the Sensitivity traits, and 100% of the Adaptive capacity traits scoring Low respectively (Figure 3-8).

Table 3-6: Climate change vulnerability assessment results for the Coral taxon groups for the Optimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Anemones	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Bamboo coral	Highly Vulnerable	Highly Vulnerable	Latent Risk	Highly Vulnerable
Black corals	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Branching coral	Highly Vulnerable	Highly Vulnerable	Latent Risk	Highly Vulnerable
Bubblegum coral	Latent Risk	Latent Risk	Latent Risk	Highly Vulnerable
Deadmans Fingers	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Golden coral	Latent Risk	Latent Risk	Latent Risk	Highly Vulnerable
Goniocorella	Highly Vulnerable	Highly Vulnerable	Latent Risk	Highly Vulnerable
Hard substrate cup coral	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Hydrocorals	Highly Vulnerable	Highly Vulnerable	Highly vulnerable	Highly Vulnerable
Mushroom corals	Exposed Only	Exposed Only	Exposed Only	Exposed Only
Precious corals	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Primnoids	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Sea fans	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Sea pen	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Soft sediment cup coral	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Taiaroa	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Zoanthids	Potential Adaptors	Potential Adaptors	Sensitive Only	Potential Adaptors

Table 3-7: Climate change vulnerability assessment results for the Coral taxon groups for the Pessimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Anemones	Highly Vulnerable	Highly vulnerable	Highly vulnerable	Highly vulnerable
Bamboo coral	Highly Vulnerable	Highly vulnerable	Latent Risk	Highly vulnerable
Black corals	Highly Vulnerable	Highly vulnerable	Highly vulnerable	Highly vulnerable
Branching coral	Highly Vulnerable	Highly vulnerable	Latent Risk	Highly vulnerable
Bubblegum coral	Latent Risk	Latent Risk	Latent Risk	Highly Vulnerable
Deadmans Fingers	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Golden coral	Latent Risk	Latent Risk	Latent Risk	Highly Vulnerable
Goniocorella	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Hard substrate cup coral	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly vulnerable
Hydrocorals	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly vulnerable
Mushroom corals	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Precious corals	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly vulnerable
Primnoids	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly vulnerable
Sea fans	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly vulnerable
Sea pen	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly vulnerable
Soft sediment cup coral	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly vulnerable
Taiaroa	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Zoanthids	Highly Vulnerable	Highly Vulnerable	Latent Risk	Highly vulnerable

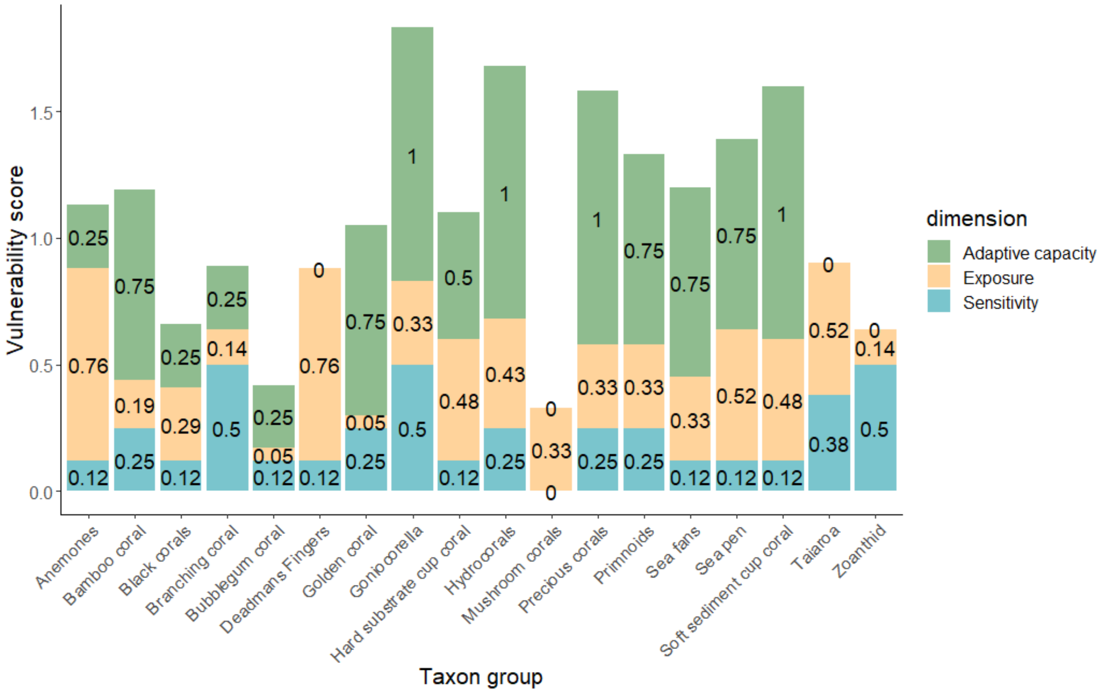

Figure 3-6: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Coral taxon groups, calculated using the Optimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

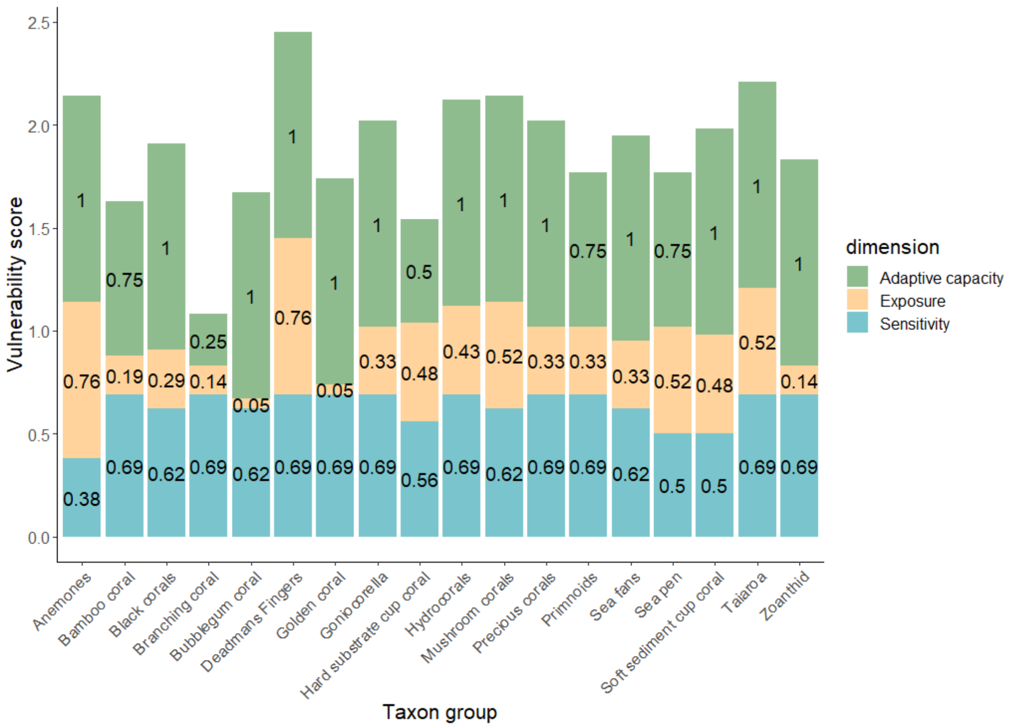

Figure 3-7: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Coral taxon groups, calculated using the Pessimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

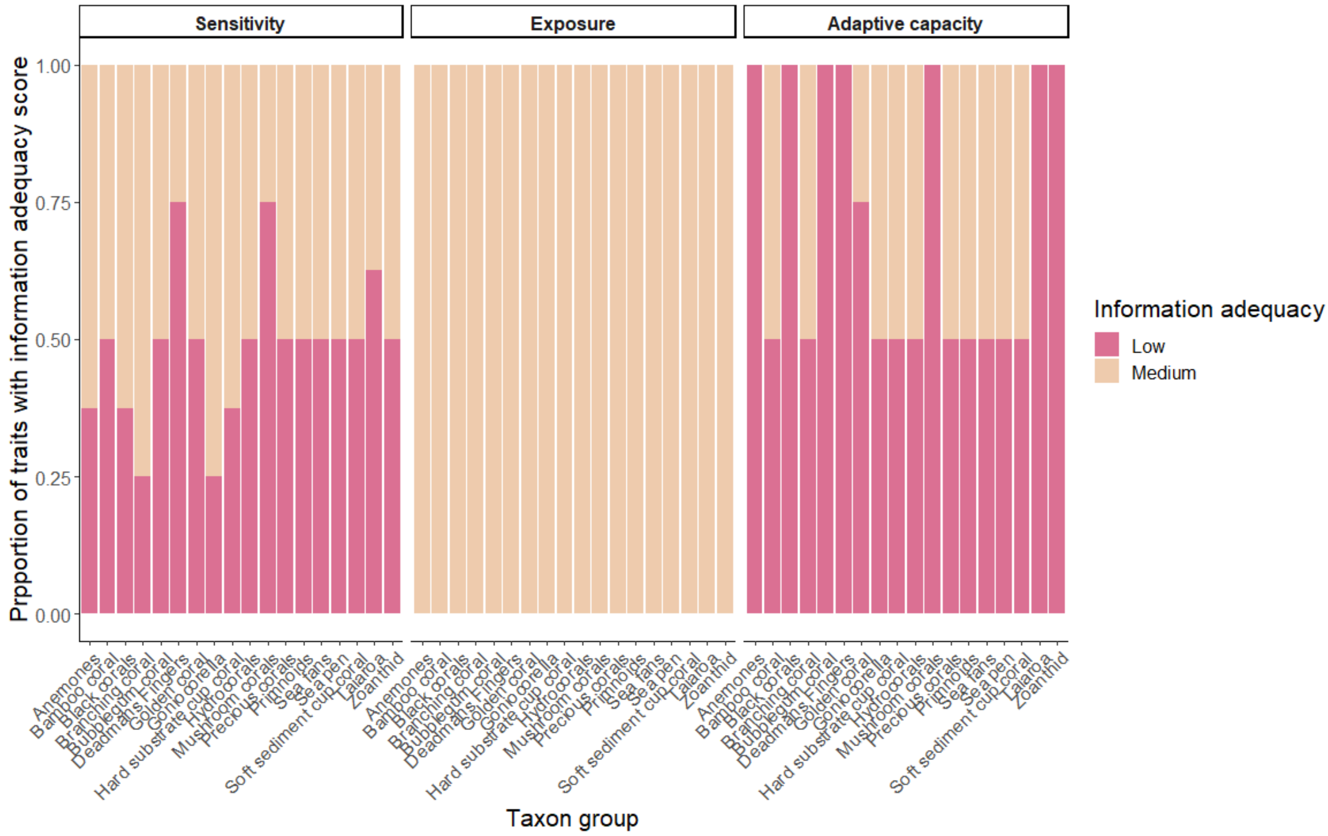

Figure 3-8: Proportion of traits with Low, Medium and High information adequacy scores for Coral taxon groups across the Sensitivity, Exposure and Adaptive capacity climate change vulnerability dimensions.

3.4 Crustaceans

When comparing vulnerabilities between the climate scenarios and time periods for the Optimistic and Pessimistic approaches the scores did not change (Table 3-8, Table 3-9, Figure D-3). Two of the taxon groups (*Chriostylid* squat lobster and *Jasus* cray) scored Highly Vulnerable, with all other groups scored as Potential Adaptors. Thus, the results did not change when considering all climate scenarios and time periods in one assessment for the Optimistic and Pessimistic approaches (Figure 3-9, Figure 3-10). When considering the numeric vulnerability scorings, the *Jasus* cray taxon group had the highest score, followed by the *Chriostylid* squat lobster taxon group. Squat lobster and hermit crabs, Small soft sediment crabs and Swimming crabs also had relatively high numeric scores, despite not being scored vulnerable within the Adaptive capacity dimension (Figure 3-9, Figure 3-10). Information adequacy was highest for the Exposure dimension traits, with all traits scoring either Medium or High Information adequacy (Figure 3-11). Information adequacy scores were relatively consistent between taxon groups and dimensions, with the exception of the *Jasus* Cray taxon group, which had relatively higher information adequacy across all three dimensions. The Adaptive capacity dimension had the lowest overall information adequacy, with all groups being scored Low for 50% of the traits (Figure 3-11).

Table 3-8: Climate change vulnerability assessment results for the Crustacean taxon groups for the Optimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Blind lobsters	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
***Chriostylid* squat lobster**	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
***Ibacus* slipper lobster**	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
***Jasus* cray**	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Large predator/scavenger crabs	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Large shrimp and prawns	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
***Metanephrops* scampi**	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Small soft sediment crabs	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Squat lobster and hermit crabs	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Swimming crabs	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors

Table 3-9: Climate change vulnerability assessment results for the Crustacean taxon groups for the Pessimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Blind lobsters	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
***Chriostylid* squat lobster**	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
***Ibacus* slipper lobster**	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
***Jasus* cray**	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Large predator/scavenger crabs	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Large shrimp and prawns	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
***Metanephrops* scampi**	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Small soft sediment crabs	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Squat lobster and hermit crabs	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Swimming crabs	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors

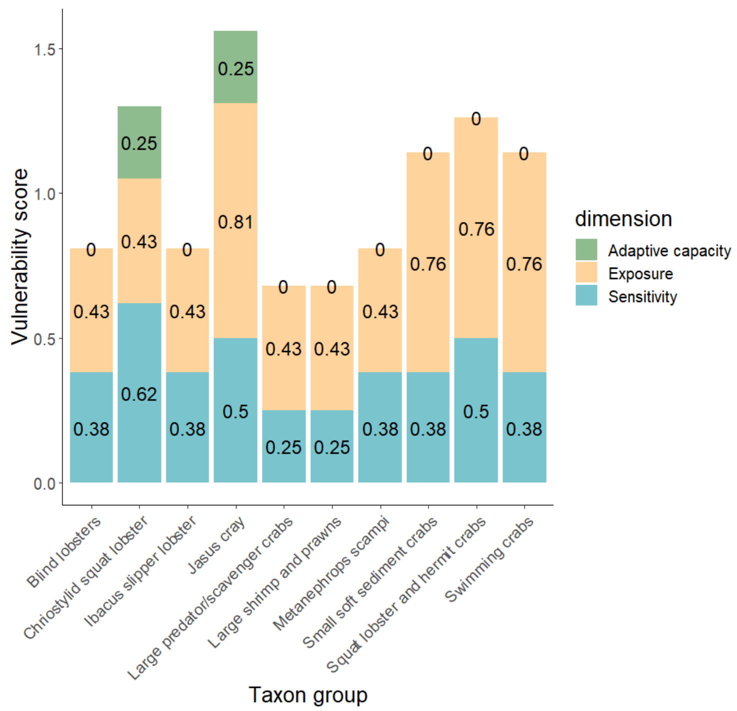

Figure 3-9: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Crustacean taxon groups, calculated using the Optimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

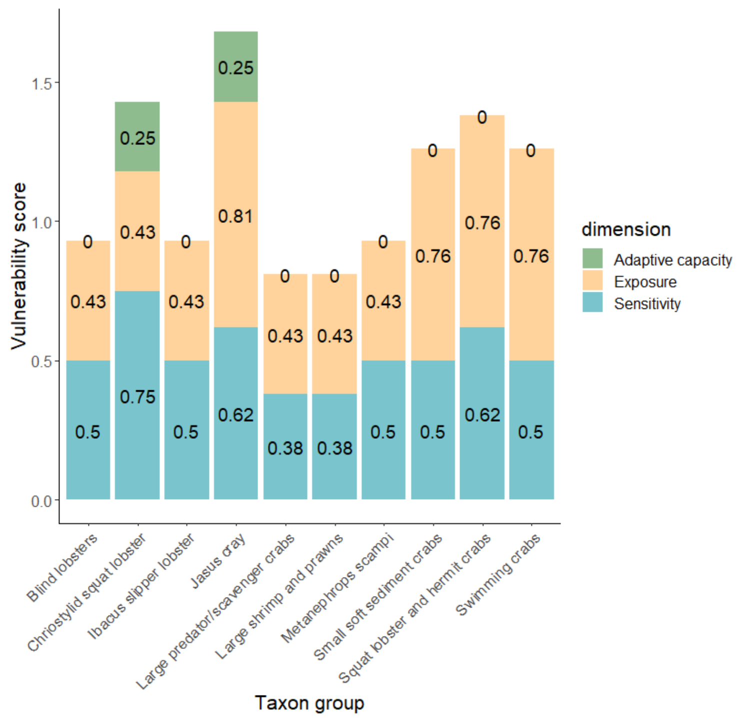

Figure 3-10: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Crustacean taxon groups, calculated using the Pessimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

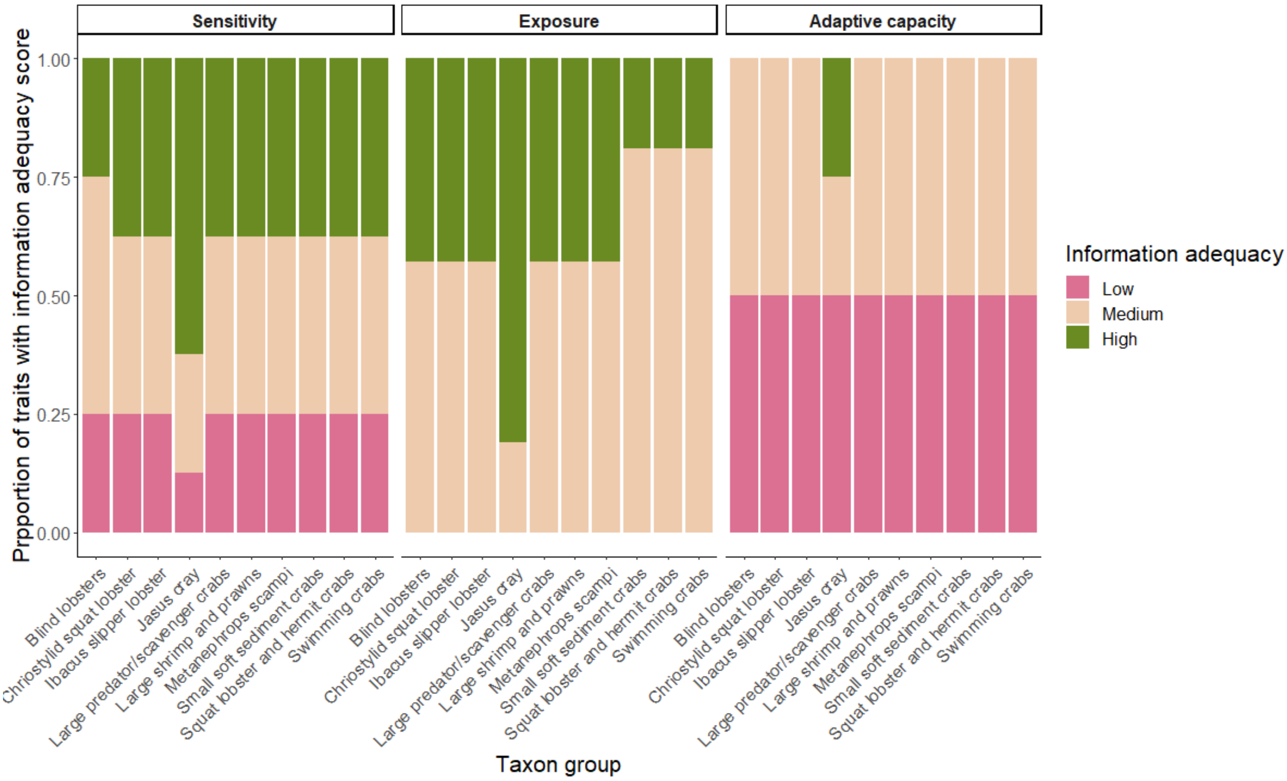

Figure 3-11: Proportion of traits with Low, Medium and High information adequacy scores for Crustacean taxon groups across the Sensitivity, Exposure and Adaptive capacity climate change vulnerability dimensions.

3.5 Echinoderms

When comparing vulnerabilities between the climate scenarios and time periods for the Optimistic approach, the Echinoderms had relatively low vulnerability across groups, with no Highly Vulnerable scores (Table 3-10, Figure D-4). The scores stayed stable for all groups across all scenarios, except for Deep soft sediment scavengers, where the vulnerability increased from Sensitive Only for both the SSP2 (4.5) scenarios, and the SSP3 (7.0) 2050 scenario, to Potential Adaptors for the SSP3 (7.0) 2100 scenario (Table 3-10). Vulnerabilities increased significantly for the Pessimistic approach, with 8/12 taxon groups scoring Highly Vulnerable for all time periods and scenarios except SSP3 (7.0) 2100, where all 12 taxon groups scored Highly Vulnerable (Table 3-11, Figure C 4).

When considering all climate scenarios and time periods in one assessment, for the Optimistic approach, no groups scored Highly Vulnerable (Figure 3-12), with Deep sediment scavengers and *Evechinus* being the only two groups to receive vulnerable scores across two dimensions (Sensitivity and Exposure). All other groups only scored vulnerability scores for the Exposure dimension. Comparing the numeric scorings, *Evechinus, Centrostephanus* and Shallow scavengers had the highest Exposure scores (Figure 3-12). For the Pessimistic approach, all 12 taxon groups scored Highly Vulnerable (Figure 3-13). *Centrostephanus, Evechinus* and Shallow scavengers had the highest numeric scores (Figure 3-13).

Information adequacy was highest for the Sensitivity dimension traits, with some traits scoring High Information adequacy (Figure 3-14). Overall Information Adequacy was low, with the majority of the Exposure traits, and 100% of the Adaptive Capacity traits scorning Low Information Adequacy (Figure 3-14).

Table 3-10: Climate change vulnerability assessment results for the Echinoderm taxon groups for the Optimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Australostichopus	Exposed Only	Exposed Only	Exposed Only	Exposed Only
Centrostephanus	Exposed Only	Exposed Only	Exposed Only	Exposed Only
Deep infaunal deposit feeder	Low Vulnerability	Low Vulnerability	Low Vulnerability	Exposed Only
Deep scavenger	Low Vulnerability	Low Vulnerability	Low Vulnerability	Exposed Only
Deep soft sediment deposit feeder	Low Vulnerability	Low Vulnerability	Low Vulnerability	Exposed Only
Deep soft sediment scavenger	Sensitive Only	Sensitive Only	Sensitive Only	Potential Adaptors
Evechinus	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Hard substrate scavenger	Exposed Only	Exposed Only	Exposed Only	Exposed Only
Infaunal deposit feeder	Exposed Only	Exposed Only	Exposed Only	Exposed Only
Shallow scavenger	Exposed Only	Exposed Only	Exposed Only	Exposed Only
Soft sediment deposit feeder	Exposed Only	Exposed Only	Exposed Only	Exposed Only
Widespread scavenger	Exposed Only	Exposed Only	Exposed Only	Exposed Only

Table 3-11: Climate change vulnerability assessment results for the Echinoderm taxon groups for the Pessimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Australostichopus	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Centrostephanus	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Deep infaunal deposit feeder	Latent Risk	Latent Risk	Latent Risk	Highly Vulnerable
Deep scavenger	Latent Risk	Latent Risk	Latent Risk	Highly Vulnerable
Deep soft sediment deposit feeder	Latent Risk	Latent Risk	Latent Risk	Highly Vulnerable
Deep soft sediment scavenger	Latent Risk	Latent Risk	Latent Risk	Highly Vulnerable
Evechinus	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Hard substrate scavenger	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Infaunal deposit feeder	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Shallow scavenger	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Soft sediment deposit feeder	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Widespread scavenger	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable

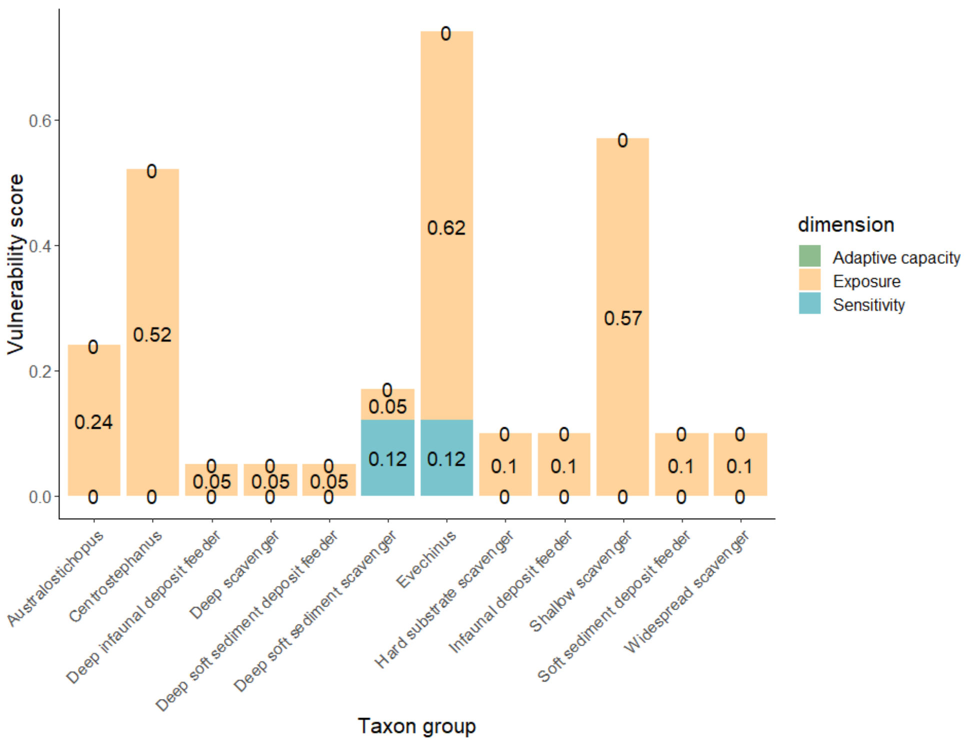

Figure 3-12: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Echinoderm taxon groups, calculated using the Optimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

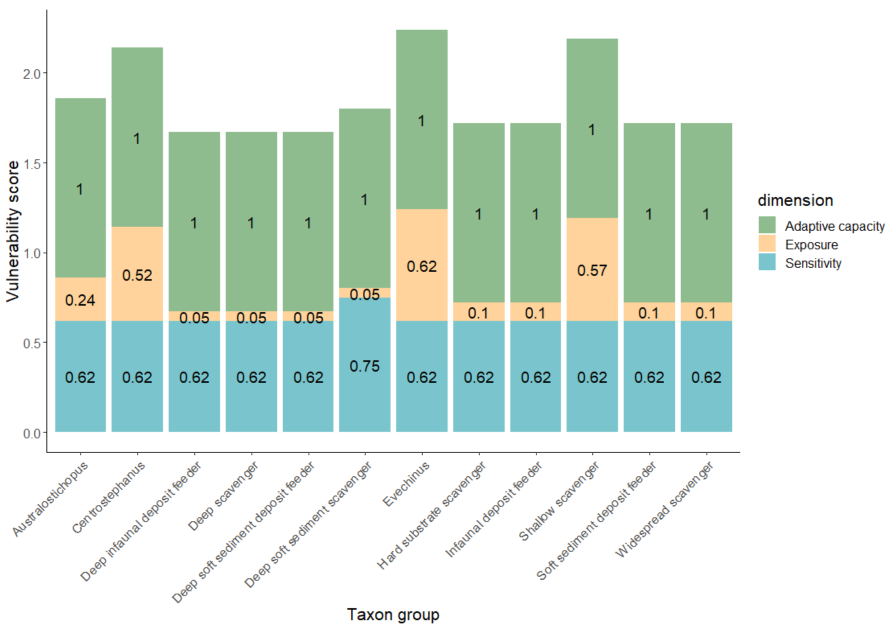

Figure 3-13: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Echinoderm taxon groups, calculated using the Pessimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

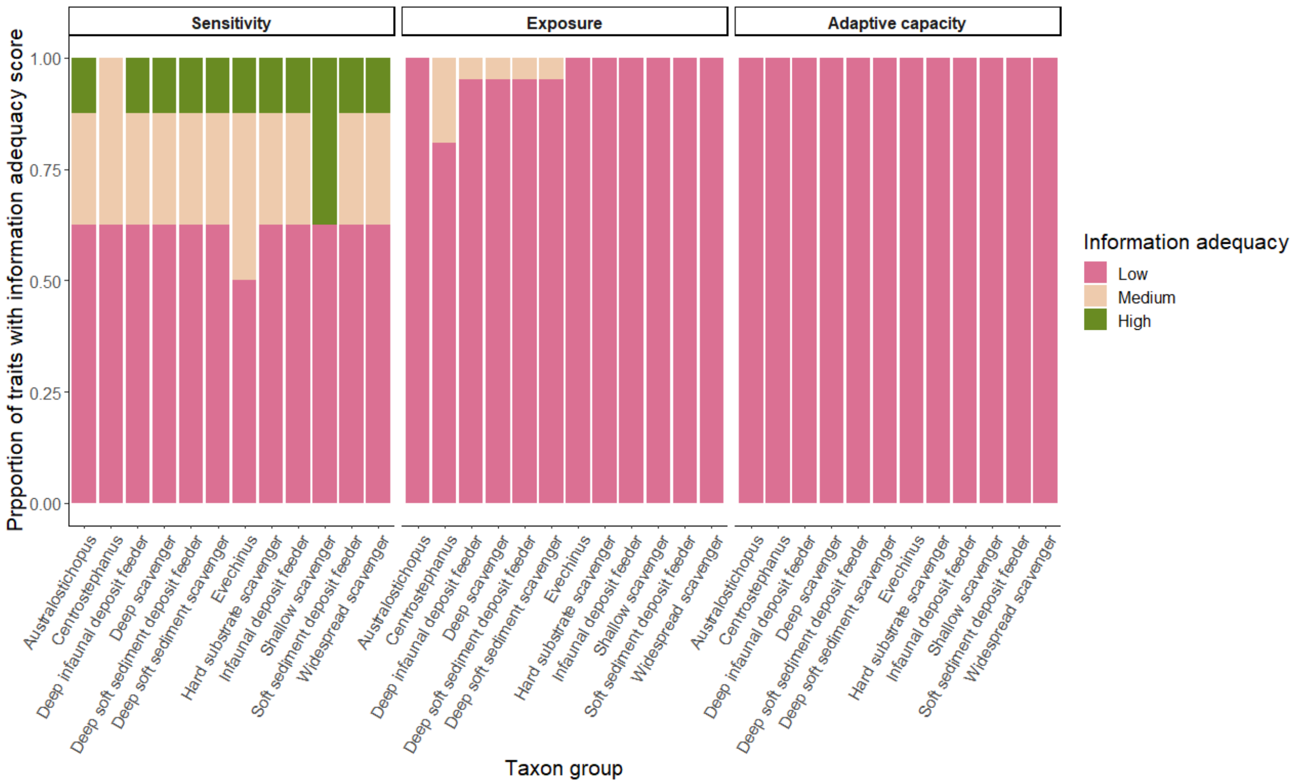

Figure 3-14: Proportion of traits with Low, Medium and High information adequacy scores for Echinoderm taxon groups across the Sensitivity, Exposure and Adaptive capacity climate change vulnerability dimensions.

3.6 Macroalgae

Across the Optimistic and Pessimistic approaches for all climate scenarios and time periods, all Macroalgae taxon groups scored Highly Vulnerable (Table 3-12, Table 3-13, Figure D-5). When considering all time periods and climate scenarios in one assessment, the numeric scores, and thus vulnerability, was higher for the Pessimistic scenario, although all groups still scored Highly Vulnerable (Figure 3-15, Figure 3-16). For the Optimistic scenario, *Ecklonia radiata* had the highest overall score, followed by *Corallina aff ferreyra*e and the Northern Large Browns, with a high proportion of these scores being attributed to Sensitivity traits. *Corallina aff ferreyrae* had the highest score for the pessimistic approach, with the scores being generally more consistent across the taxon groups (Figure 3-15, Figure 3-16).

The Sensitivity dimension had the highest Information Adequacy, with 12% of traits having High Information Adequacy scores for 11 of the 17 taxon groups (Figure 3-17). In general, Information Adequacy was scored Low across all dimensions. For the Exposure dimension, 8 of the 17 taxon groups scored Low Information Adequacy for 100% of the traits and for the Adaptive Capacity dimension, 14 of the 17 taxon groups scored Low Information Adequacy for 100% of the traits (Figure 3-17).

Table 3-12: Climate change vulnerability assessment results for the Macroalgae taxon groups for the Optimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Corallina aff ferreyrae	High Vulnerability	High Vulnerability	High Vulnerability	High Vulnerability
Durvillaea antarctica* and *Durvillaea poha	High Vulnerability	High Vulnerability	High Vulnerability	High Vulnerability
Ecklonia radiata	High Vulnerability	High Vulnerability	High Vulnerability	High Vulnerability
Filamentous brown algae	High Vulnerability	High Vulnerability	High Vulnerability	High Vulnerability
Filamentous green algae	High Vulnerability	High Vulnerability	High Vulnerability	High Vulnerability
Fucales	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Intertidal/ shallow brown algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Intertidal/ shallow green algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Intertidal/ shallow red algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Macrocystis pyrifera	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Meadow formers (green algae)	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Meadow formers (red algae)	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Northen large brown	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Southern large brown	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Subtidal brown algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Subtidal green algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Subtidal red algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable

Table 3-13: Climate change vulnerability assessment results for the Macroalgae taxon groups for the Pessimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Corallina aff ferreyrae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Durvillaea antarctica* and *Durvillaea poha	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Ecklonia radiata	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Filamentous brown algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Filamentous green algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Fucales	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Intertidal/ shallow brown algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Intertidal/ shallow green algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Intertidal/ shallow red algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Macrocystis pyrifera	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Meadow formers (green algae)	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Meadow formers (red algae)	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Northen large brown	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Southern large brown	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Subtidal brown algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Subtidal green algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Subtidal red algae	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable

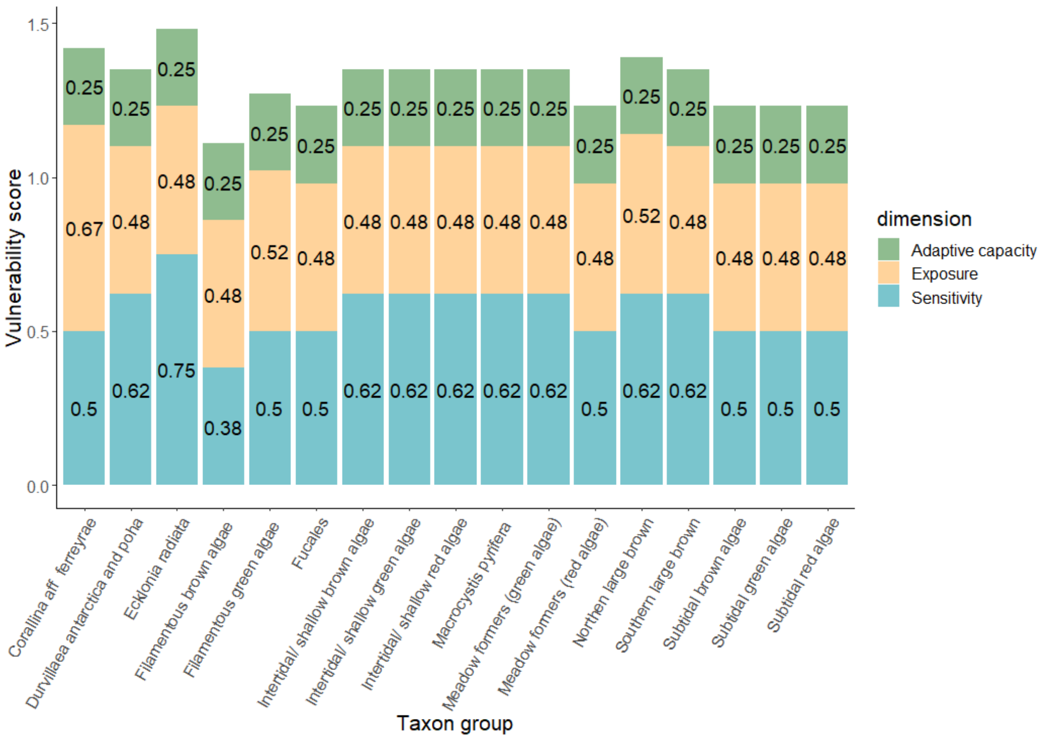

Figure 3-15: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Macroalgae taxon groups, calculated using the Optimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

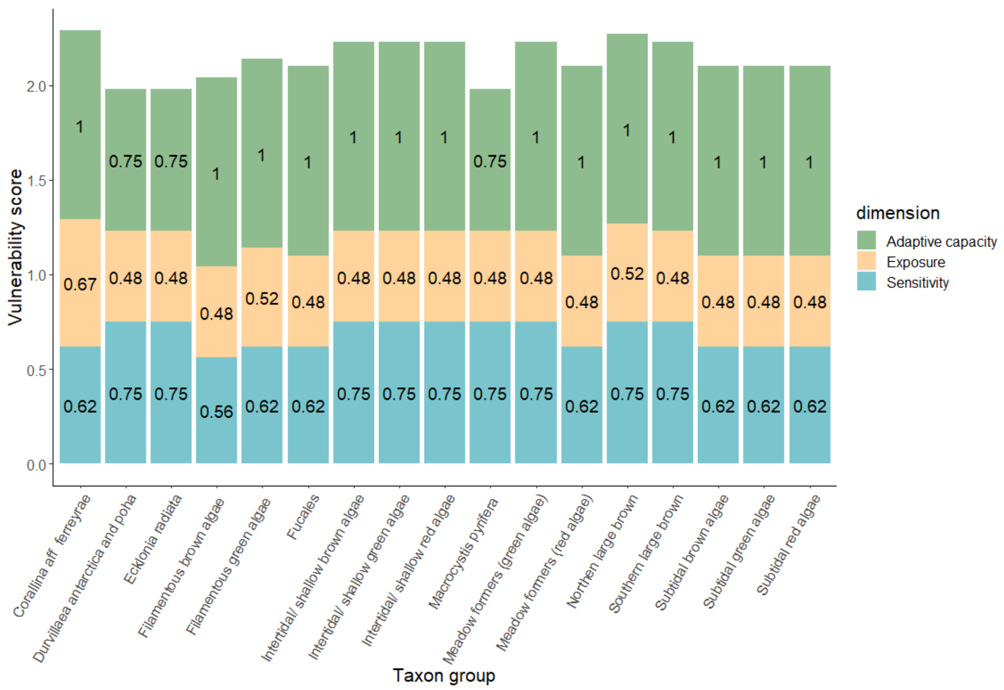

Figure 3-16: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Macroalgae taxon groups, calculated using the Pessimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

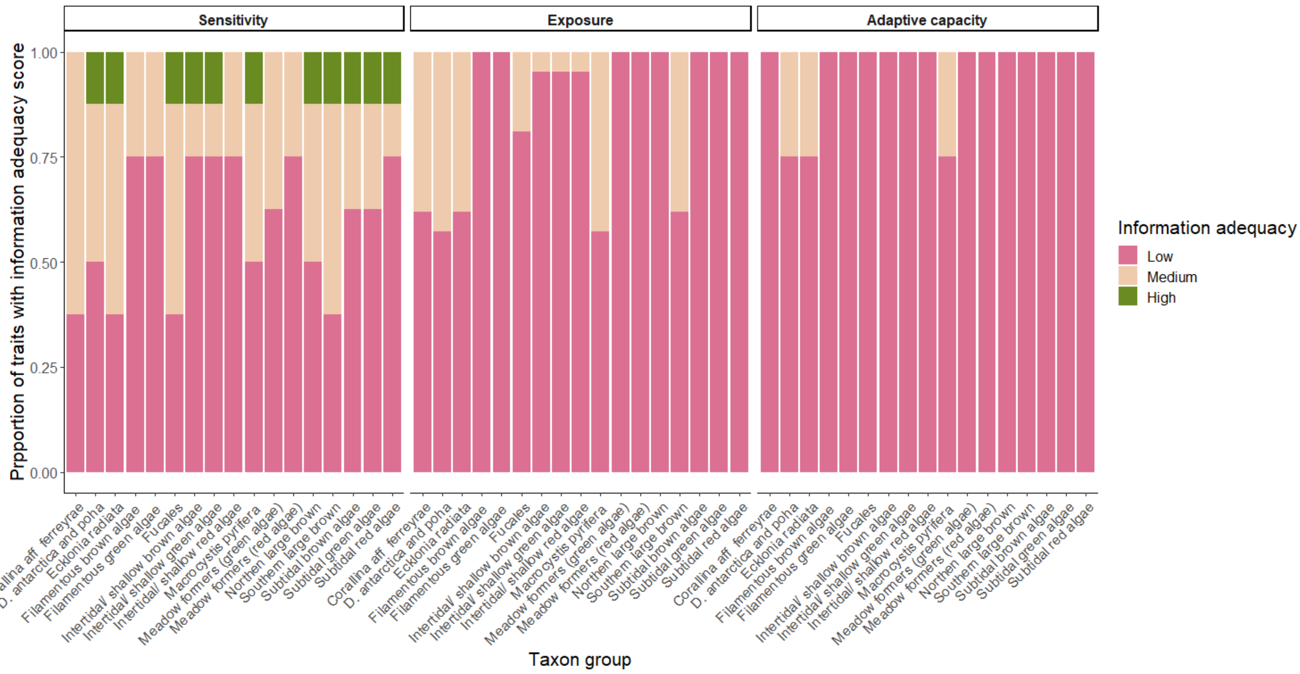

Figure 3-17: Proportion of traits with Low, Medium and High information adequacy scores for Macroalgae taxon groups across the Sensitivity, Exposure and Adaptive capacity climate change vulnerability dimensions.

3.7 Molluscs

There was no change in Mollusc vulnerability between climate scenarios and time periods, but vulnerabilities increased between the Optimistic and Pessimistic approaches (Table 3-14, Table 3-15, Figure D-6). For the Optimistic approach, no taxon groups were scored Highly Vulnerable, with 7 of the 10 groups scoring Potential Adaptors. *Maurea selecta* was the least vulnerable, scoring Exposed Only (Table 3-14). For the Pessimistic approach, 7 of the 10 taxon groups scored Highly Vulnerable, with the remainder scoring Potential Adaptors (Table 3-14, Table 3-15). Although no taxon groups scored Highly Vulnerable, when comparing numeric vulnerability scores, the Potential adaptors *Haliotis iris*, *Austrovenus stutchburyi* and *Pecten novaezelandiae* had the highest overall scores for the Optimistic approach (Figure 3-18). For the Pessimistic approach, *Zyglochlamys delicatula* and *Maurea selecta* had the highest mean vulnerability scores (Figure 3-19).

The Sensitivity dimension had the highest Information adequacy, with 5 of the 10 groups having 50% or more of the traits scoring High Information adequacy. For eight taxon groups, Information adequacy was scored High for 25% of the Adaptive Capacity traits. Information adequacy was lowest for the Exposure dimension, with all taxon groups scoring Low Information adequacy for over 50% of the traits.

Table 3-14: Climate change vulnerability assessment results for the Mollusc taxon groups for the Optimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Alcithoe arabica	Potential Persitors	Potential Persitors	Potential Persitors	Potential Persitors
Austrovenus stutchburyi	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Haliotis iris	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Lima zelandica	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Maurea selecta	Exposed Only	Exposed Only	Exposed Only	Exposed Only
Pecten novaezelandiae	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Pratullum pulchellum	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Provocator mirabilis	Potential Persitors	Potential Persitors	Potential Persitors	Potential Persitors
Tawera spissa	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Zyglochlamys delicatula	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors

Table 3-15: Climate change vulnerability assessment results for the Mollusc taxon groups for the Pessimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Alcithoe arabica	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Austrovenus stutchburyi	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Haliotis iris	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Lima zelandica	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Maurea selecta	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Pecten novaezelandiae	Potential Adaptors	Potential Adaptors	Potential Adaptors	Potential Adaptors
Pratullum pulchellum	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Provocator mirabilis	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Tawera spissa	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Zyglochlamys delicatula	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable

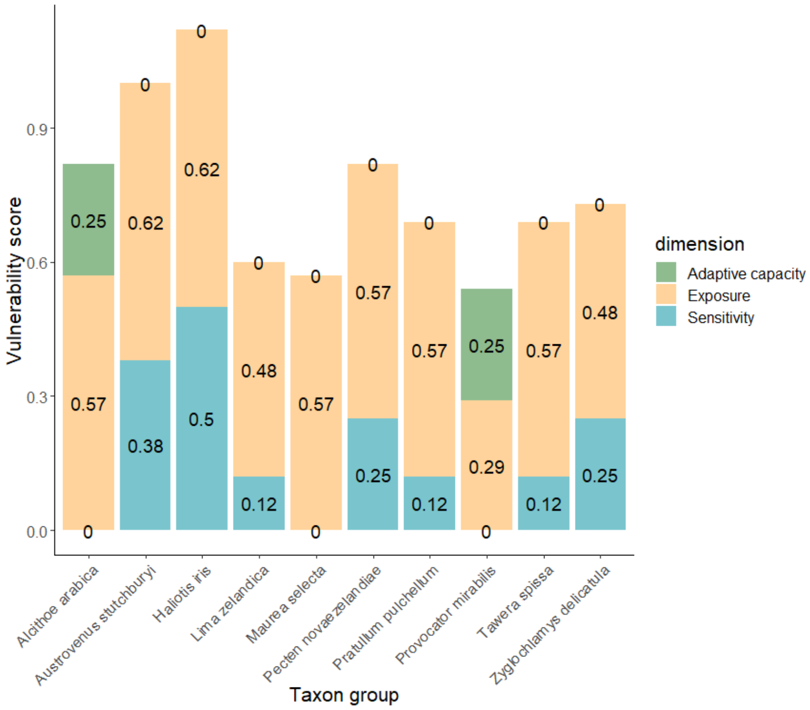

Figure 3-18: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Mollusc taxon groups, calculated using the Optimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

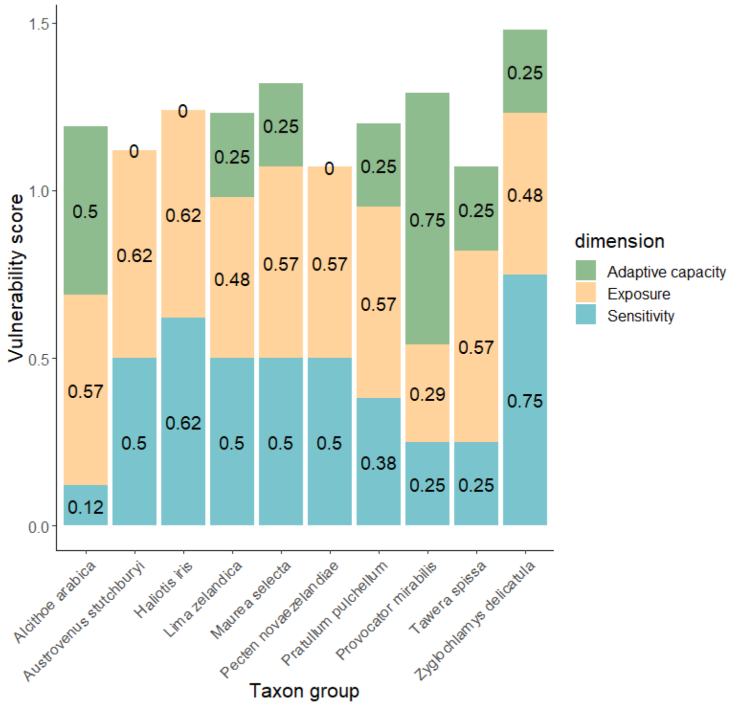

Figure 3-19: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Mollusc taxon groups, calculated using the Pessimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

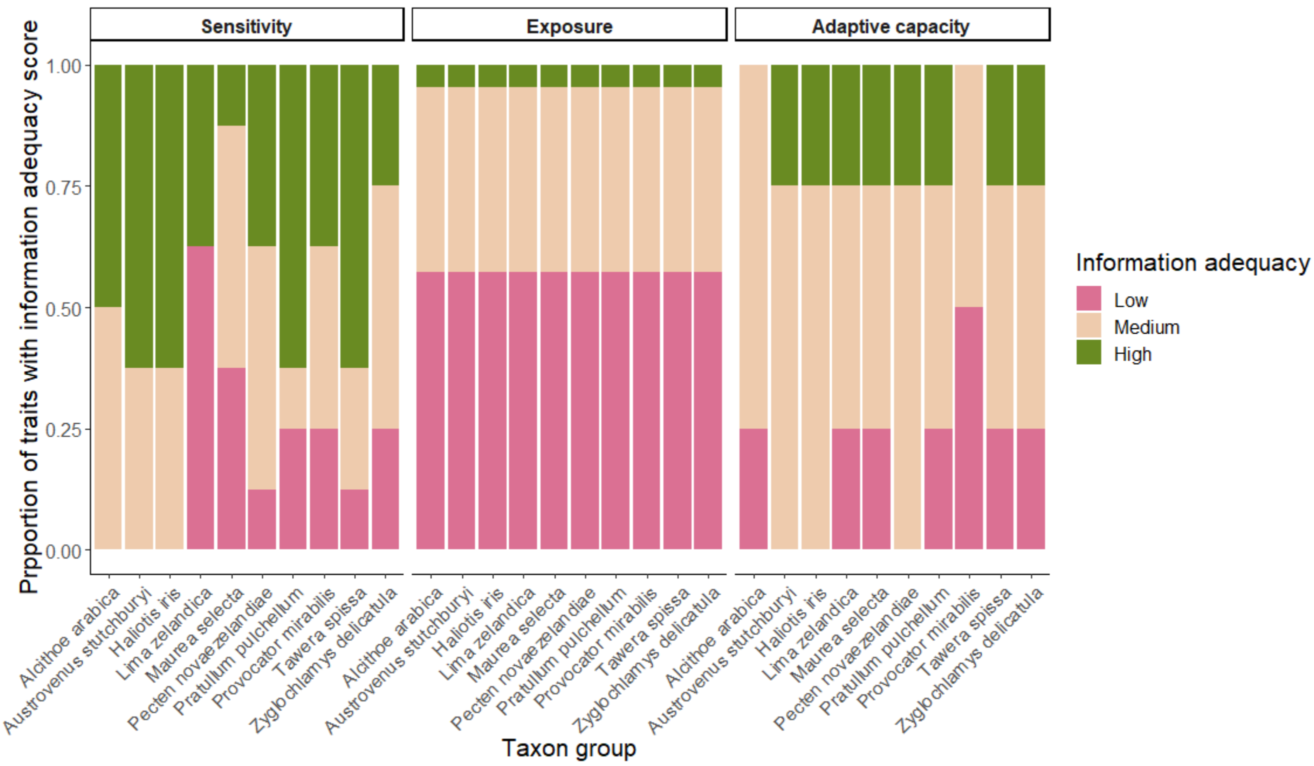

Figure 3-20: Proportion of traits with Low, Medium and High information adequacy scores for Mollusc taxon groups across the Sensitivity, Exposure and Adaptive capacity climate change vulnerability dimensions.

3.8 Sponges

The vulnerability of Sponges did not differ between climate scenarios, time periods, or between the Optimistic and Pessimistic approaches (Table 3-16, , Figure D-7). Six of the eight Sponge groups scored Highly Vulnerable, with Finger sponges and Massive, tough sponges scoring Potential Persisters. The numeric scores only differed slightly between the Optimistic and Pessimistic approaches, with Shallow water glass sponges, Fragile coral garden sponges and Lithistid sponges being assigned the highest vulnerability scores (Figure 3-21, Figure 3-22).

The Exposure traits had the highest Information adequacy scores, with all groups scoring High Information adequacy for 75% of traits, except for Calcareous sponges, where over 50% of the traits scored High Information Adequacy (Figure 3-23). Information adequacy was consistent across taxon groups for the Sensitivity traits, with ~30% of the traits scoring High Information adequacy, and the remainder scoring Medium Information adequacy. The Adaptive capacity dimension had the lowest Information adequacy, with 50% of traits scoring Low Information adequacy for all groups, and the remainder scoring Medium Information adequacy (Figure 3-23).

Table 3-16: Climate change vulnerability assessment results for the Sponge taxon groups for the optimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Bleaching fan sponges	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Calcareous sponges	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Finger sponges	Potential Persisters	Potential Persisters	Potential Persisters	Potential Persisters
Fragile coral garden sponges	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Lithistid sponges	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Massive, tough sponges	Potential Persisters	Potential Persisters	Potential Persisters	Potential Persisters
Mobile substrate sponges	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Shallow water glass water sponges	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable

Table 3-17: Climate change vulnerability assessment results for the Sponge taxon groups for the pessimistic approach across SSP2 (4.5) and SSP3 (7.0) climate change scenarios for 2050 and 2100.

CCVA taxon group	SSP2 (4.5) 2050	SSP2 (4.5) 2100	SSP3 (7.0) 2050	SSP3 (7.0) 2100
Bleaching fan sponges	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Calcareous sponges	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Finger sponges	Potential Persisters	Potential Persisters	Potential Persisters	Potential Persisters
Fragile coral garden sponges	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Lithistid sponges	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Massive, tough sponges	Potential Persisters	Potential Persisters	Potential Persisters	Potential Persisters
Mobile substrate sponges	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Shallow water glass water sponges	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable

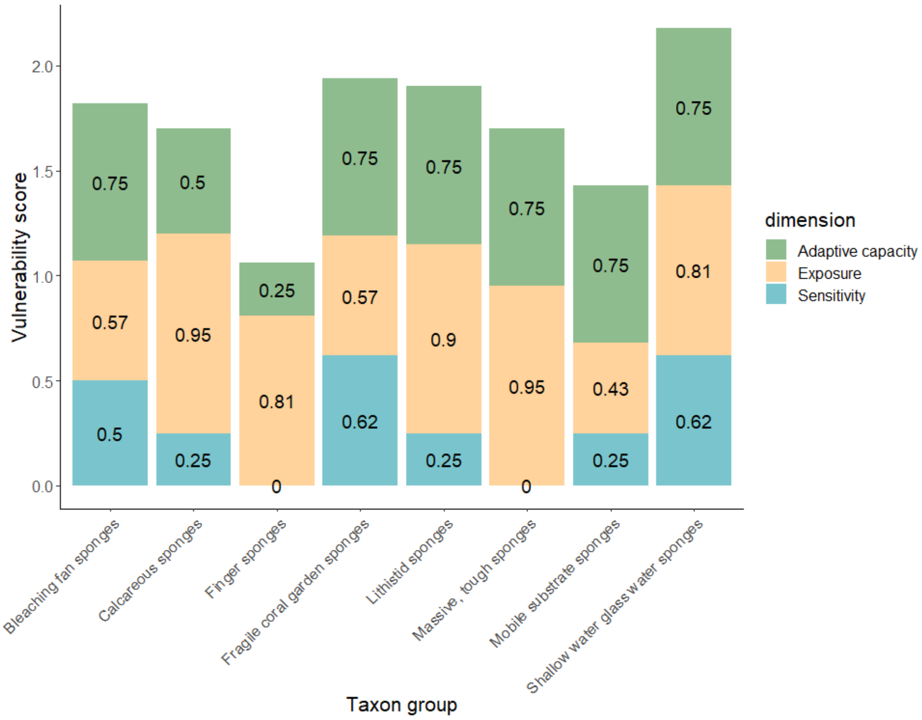

Figure 3-21: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Sponge taxon groups, calculated using the Optimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

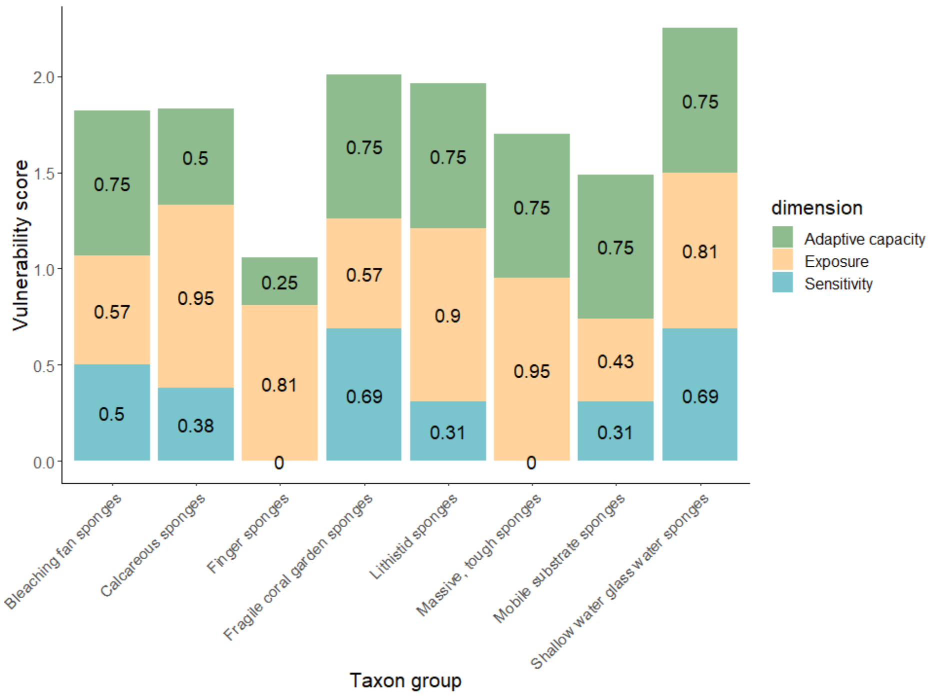

Figure 3-22: Mean vulnerability scores within each of the three climate change vulnerability dimensions for Sponge taxon groups, calculated using the Pessimistic approach. Taxa with high sensitivity, high exposure and low adaptive capacity are scored as having higher vulnerability, with mean vulnerability scores within each dimension ranging from 0 (low vulnerability) to 1 (high vulnerability).

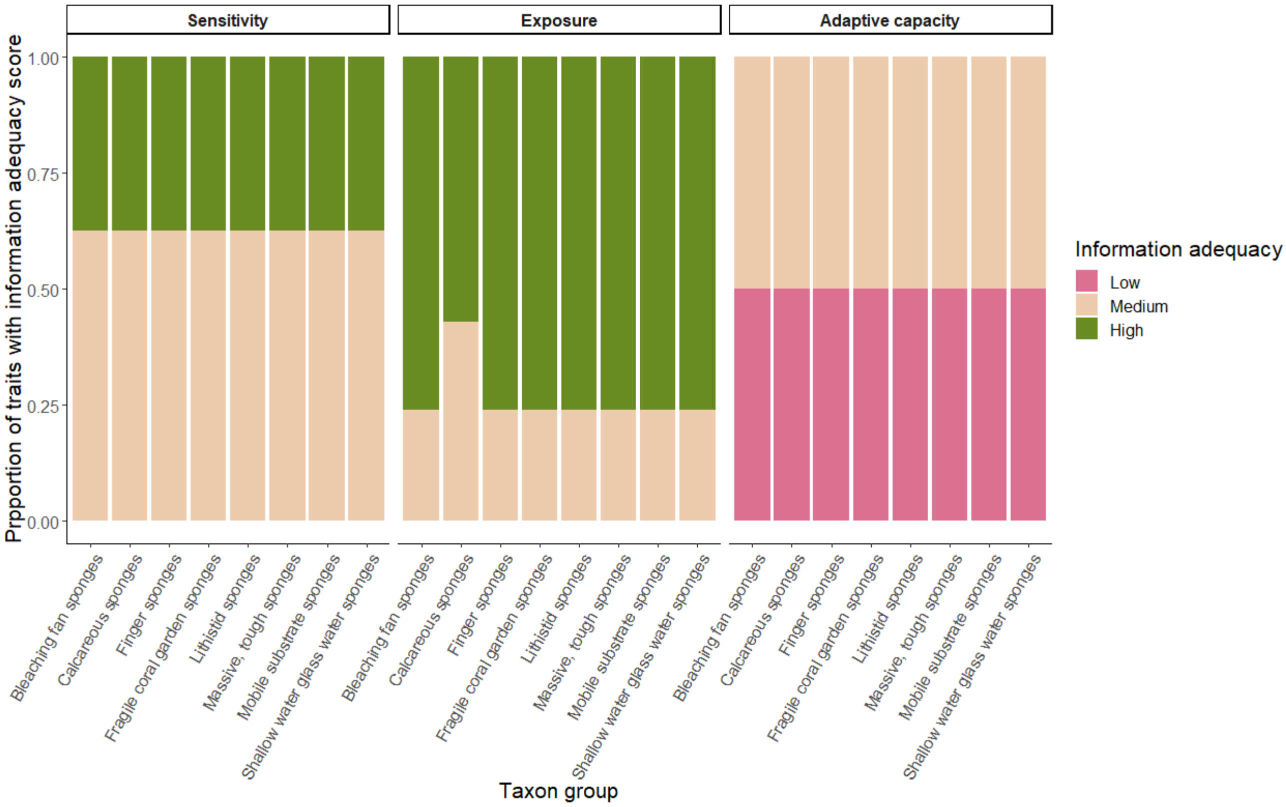

Figure 3-23: Proportion of traits with Low, Medium and High information adequacy scores for Sponge taxon groups across the Sensitivity, Exposure and Adaptive capacity climate change vulnerability dimensions.

3.9 Variability between assessors and reviewers

Generally, the reviewers agreed with scores from the initial assessments. For Crustaceans, Echinoderms and Molluscs, the reviewers did not suggest any proposed changes. For the Corals, the reviewer suggested for six of the taxon groups (including soft corals, sea pens and gorgonians) that the pH tolerance trait score be changed from Narrow to Medium, and a reduction from Medium to Low for the Information adequacy score across most of the Coral taxon groups for the pH tolerance trait. These changes were discussed with the initial assessor, who agreed to edit the scores. For the Macroalgae, the reviewer identified a few changes throughout the scoring sheet, mainly editing the Information adequacy scores (increasing and decreasing these scores across multiple traits), and altering seven of the scores across four of the traits. The reviewer discussed these changes with the initial assessor, who agreed to accept the changes. The reviewer for the Bryozoan assessments identified a few scores (mainly relating to the Exposure and Adaptive capacity traits for a few select taxon groups) to edit or to discuss with the initial assessor. After discussions with the initial assessor, including reasoning for the scorings, the majority of the scores were kept the same, with the exception of one Adaptive capacity trait score.

4 Discussion

4.1 Knowledge deficiencies for benthic marine taxa

The marine CCVA approach identified 47 Highly Vulnerable groups using the Optimistic approach, and 72 Highly Vulnerable groups using the Pessimistic approach. Of these Highly Vulnerable groups, coastal and shallow water groups (Macroalgae, Bryozoan) generally featured more strongly, as well as sessile groups known to be sensitive to biochemical changes such as pH change (Corals and Sponges). Coastal foundation species are known to be declining globally due to environmental change (Van Woesik et al. 2022; Smith et al. 2024), with losses of macroalgae coverage (Thomsen et al. 2019), and sponge tissue necrosis (Bell et al. 2023) attributed to climate change and marine heatwaves in Aotearoa New Zealand. However, the differing Optimistic and Pessimistic approaches taken to considering the Unknown trait scores significantly altered the results. For example, for the Echinoderms across both climate scenarios and time periods, no taxon groups were scored Highly Vulnerable for the Optimistic approach, whereas for the Pessimistic approach all taxon groups were considered Highly Vulnerable (Table 3-10, Table 3-11). *Centrostephus* echinoderms are known to have increased in Northern Aotearoa New Zealand (Balemi and Shears 2023), but scored one of the highest vulnerabilities for the Echinoderms with the CCVA approach (Figure 3-12, Figure 3-13). This suggests that CCVAs for such knowledge deficient taxon groups may not be informative, highlighting the need for targeted research in these areas.

For most taxon groups, the traits for the Adaptive capacity dimension had Low Information adequacy, with many Unknown scores. Thus, for the Optimistic approach, there was a high number of Potential Adaptors. However, in the final workshop, experts agreed that classifying groups with mostly Unknown scores, and Low information adequacy (such as all the Echinoderm taxon groups) is inappropriate as these groups could be potentially vulnerable groups but get assigned Low Vulnerability. In general, the species level groups recommended by experts (e.g., *Evechinus* for Echinoderms, *Jasus edwardsii* for Crustaceans) had higher vulnerability levels when assessing the numeric scores. Individually assessed species also had generally higher Information adequacy scores than their grouped counterparts. This is unsurprising considering many of these species were not grouped due to their commercial and ecological importance and are thus more well studied species. Yet, such results infer that the taxon group CCVA scorings may be driven by data/knowledge availability. .

The knowledge deficiencies across the CCVA traits suggest that the Vulnerability scores should be interpreted with caution. Given that results across groups are likely to change with further information, we suggest assessments are not appropriate for informing Action BIO2a from the CCAP (to undertake detailed vulnerability analyses to prioritise threatened species and ecosystems at risk from climate change) (Department of Conservation 2023). However, even considering the knowledge deficiencies, for the taxon groups identified as having higher vulnerability using the Optimistic approach, CCVAs could be carried out for within-group species. Where information is available, such species level assessments may more appropriately inform Action BIO2a. Additionally, taxon groups identified as having high vulnerability using the pessimistic approach, but low Information adequacy could be prioritised for further ecological research to better inform climate risks. Thus, the CCVA results should help to inform CCAP Action BIO1a (to undertake climate change risk assessments to identify threatened species and ecosystems to prioritise them for further research) (Department of Conservation 2023).

4.2 Limitations of the approach

Various limitations of the CCVA approach were identified by assessors and reviewers whilst conducting the assessments, as well as at the lessons learnt workshop. Some of these limitations were common across all benthic marine taxa, whilst some were specific to the taxon group being assessed.

- For all wider taxonomic groups, identified assessors and reviewers were taxonomic experts. However, some experts identified gaps in their ecological knowledge, and suggested that ecologists may be better suited to score certain traits. For example, for the Macroalgae and Echinoderms, the experts highlighted limitations in their ecological knowledge regarding the Adaptive capacity traits. Such limitations are reflected in the number of Unknown trait scores for these taxa (and thus the significant differences between the Optimistic and Pessimistic approach), and also the Low Information adequacy scores across all traits. Thus, the experts suggested that CCVAs should be carried out by one taxonomic expert and one ecological expert. However, such ecological expertise (i.e., specialised knowledge on physiology and life history traits for specific taxa) may not be available within Aotearoa New Zealand, and therefore may require the inclusion of international experts to conduct CCVAs.
- Although some of the taxonomists suggested that their knowledge of the taxon group's ecology was limited, it is also likely that information for the traits for many taxon groups (and constituent taxa) is knowledge deficient, and inclusions of additional/international experts may not result in significant changes to the results. Such deficiencies are particularly likely for deep sea species which are regularly identified from fisheries bycatch and in research trawl surveys, but very little is known about their ecology and biology due to the difficulty of *in-situ* research. Trait values extrapolated from well-studied and common species may not be transferable to such taxa, especially for taxa endemic to Aotearoa New Zealand, or to functionally unique taxa which may respond differently to climate change.
- The initial taxa lists provided to experts for grouping taxonomic and functional groups were based on the SDM Atlas taxa (Stephenson et al. 2023a). These species were selected due to the availability of occurrence data, i.e., enough records for the development of habitat suitability (HSI) species distribution models. The occurrence data used for these models were sourced from fisheries bycatch, museum records and research trawls, with biases towards species that inhabit depths targeted by commercial fishing. Thus, many common coastal species were excluded from the initial species list. Although experts were asked to identify missing taxa or taxa groupings that have functional, ecological or economic importance for inclusion in the CCVAs, the CCVA taxon groupings are unlikely to be representative of overall biodiversity. There may be a skew towards deep water taxa which are potentially sheltered from more adverse environmental effects. Thus, the results from the benthic marine CCVAs are likely not representative of the vulnerabilities of the wider taxonomic groups, or of other species not included in the assessments.
- Despite the consistent approach used across wider taxonomic groups, with defined categories and thresholds for vulnerability scores, the expert-led approach could still be considered subjective. Experts who are passionate about certain groups could

unconsciously score taxa to be more vulnerable (unconscious bias). Additionally, some experts were more confident in their ability to provide scores for the grouping and were comfortable using their expertise to extrapolate information across taxa. For example, for the Exposure dimension, some experts were comfortable inferring the taxon group range from their general knowledge of the within group taxa distributions. However, other experts spatially plotted within group occurrence records to infer group distributions, potentially biasing results as records are more likely to be collected from areas that are commercially fished, accessible, or have been the focus of research voyages. This could lead to inconsistences in comparing vulnerabilities across wider taxon groups. If possible, future assessments could provide consistent group distribution maps.

- Comparisons across wider taxonomic groups are also challenging, due to the expertise available for the wider taxonomic groups. For example, CCVAs for Corals were carried out by Coral taxonomic and ecological specialists, yet the Echinoderm CCVAs were carried out by parataxonomists with specific expertise for some classes of Echinoderm. A delphi style approach as used in Bennion et al. (2024) would allow for the inclusion of an expert 'self-assessment of knowledge' or 'confidence' score, which could be incorporated into the analyses. Additionally, comparing between groups with different levels of Information adequacy is challenging. A weighted mean approach could be used to weight vulnerability scores by Information adequacy to allow for further comparability (Bennion et al. 2024).

- Although the Optimistic and Pessimistic approaches highlighted the importance of the Unknown scores, the overall percentage of traits with Unknown scores was not considered in the final results of each approach. A threshold could be introduced where taxon groups with too many Unknown scores are not assessed for climate vulnerability due to data/knowledge deficiencies, or vulnerabilities are presented with an additional cautionary note. This threshold could be percentage based, e.g., >50% of Unknown scores across all traits, or >50% of Unknown scores for traits in any dimension.

5 Lessons learnt

In general, the experts involved as assessors and reviewers in this project felt that the CCVA method provided a good framework for expert-driven assessments of climate change vulnerability for marine species. However, during the lessons learnt workshop there were a range of suggestions on how the process could be improved for future applications.

5.1 General feedback

Availability of expertise. For some groups, there was a limited amount of expertise available within NIWA, and experts were forced to rely heavily on the 'Unknown' vulnerability category and to score Information adequacy as Low. For future applications, it is recommended that the project receives a higher level of funding to enable subcontracting of experts from across Aotearoa New Zealand, and potentially internationally. In this project, we did reach out to several non-NIWA experts, but most were unavailable. It was also suggested that the CCVA assessment requires assessors to have good knowledge on detailed species characteristics (e.g., taxonomic expertise) as well as a good understanding of species ecology. Experts often do not have expertise across both areas. It was suggested that the most accurate assessments would likely be undertaken by experts that have thorough knowledge across both taxonomic and ecological disciplines, or a team of two experts with discipline-specific knowledge.

Biases in available knowledge. Experts stated that, for some taxonomic groups, the knowledge on component species' distributions and general ecology is skewed due to the sources of data available that underpin experts' knowledge. This was particularly true for taxa that are most well-known due to fisheries bycatch (e.g., corals and other biogenic habitat forming species). Experts attempted to account for this in the information adequacy score but felt that some ability to provide comment around information adequacy would be worthwhile.

Lethal vs sub-lethal impacts. It was suggested that there needs to be better differentiation of vulnerabilities between lethal and sub-lethal impacts. For example, the accumulation of multiple sub-lethal climate vulnerabilities is likely to cause taxa to be more vulnerable than those that may have a small number of lethal impacts across traits due to cumulative impacts. It was suggested that having some ability to provide context on traits that have sub lethal vs lethal vulnerabilities would be very useful.

Large number of traits. Some experts felt that the large number of traits, particularly under the exposure dimension caused the process to be unduly time consuming – departing from the 'rapid assessment' methodology. While the need to incorporate multiple time periods and climate change emission scenarios (SSPs), a high-level overview might be better undertaken using a 'worst case scenario', and then determining more nuanced vulnerabilities for those groups that are characterised as highly vulnerable.

Regional scale application. Members of the AEWG/BRAG meeting raised questions around the utility of applying the CCVA framework at the regional scale, given the likelihood of species/group vulnerabilities varying among regions and the opportunities for management (i.e., regional councils) to respond to regional-level threats. While the existing framework is likely to apply for regional level CCVAs, the availability of regional-level information may limit the number of taxa for which assessments may be undertaken, and some additional thought may be required for appraising the exposure dimension (e.g., would overlap with the highest 25% of stressor variability within a region still be an appropriate measure for appraising vulnerability). Comparison of assessment of the same taxa at both regional and national scale may shed some light on the applicability of the framework for regional level assessment.

5.2 Feedback on results

It was agreed that the results of the CCVA appraisal generally made sense when considering within and among group relative vulnerabilities. However, some caveats to the results were discussed that merit consideration. These include:

1. 'Unknown' trait coding. It was evident that for some taxa (e.g., Echinoderms), how 'Unknown' responses are used to calculate the scores are the key component that influence whether groups are designated highly vulnerable, or not. Our initial approach followed DOC's Optimistic approach for the terrestrial CCVA application and treated 'Unknowns' as 0 (i.e., not vulnerable). However, the Pessimistic approach, treating 'Unknowns' as 1 (i.e., vulnerable) made more sense to experts as a precautionary measure (see Results section), or weighting calculation of scores by the Information adequacy values. Further, it was suggested that 'Unknown' coding of traits could be given more dimensionality to cater for situations where experts could infer a trait score from closely related species/groups, both within Aotearoa New Zealand and internationally. It was suggested that such 'unknowns' should be treated differently from 'unknowns' where the information is so scarce that meaningful inference from other species/groups is not available.

3. Species-level comparisons. If group-level assessments are going to become the established method for CCVA in the marine environment, it was suggested that some species-level assessments be undertaken and compared to the results of group-wise assessments. This would provide some detail on the degree of variability among species within groups and determine the utility of group-wise assessments.

5.3 Grouping of species for assessment

While the reasoning behind grouping species into broader functional and taxonomic groups was well accepted, experts found that this approach presented several challenges. These included:

1. Variability within groups. In some cases, the high variability of species within a group made assessment challenging, with assessors needing to generalise an 'average' vulnerability score across species which masks any high vulnerabilities within groups. It was suggested that grouping based on shared vulnerabilities would address this issue. Species could then be aggregated into functional groups for management, or to explore within-group vulnerabilities. Grouping based on shared vulnerabilities across each dimension was discussed at the project introduction workshop, but functional groupings were preferred due to a perception that pre-grouping based on vulnerability would lead to predetermination of the results.

   AEWG/BRAG members suggested that undertaking assessments at the species level would likely facilitate greater specificity around the traits used for coding vulnerabilities. For example, the calcification strategy used by calcifying organisms would have significant implications for climate change vulnerability and sensitivity to changes in aragonite or calcite in particular. Such species/group specific traits would likely be best incorporated into species-level assessments planned under future work under BIO2a of DOC's CCAAP.

2. Functional vs. distributional grouping. In some cases, groupings did not have the required spatial distribution qualifiers. For example, some groups had 'southern' or 'northern' qualifiers attached to the functional grouping (e.g., North/Southern large brown Macroalgae) or 'shallow' or 'deepwater' qualifiers to specify depth distribution. The use of these qualifiers was not, however, consistently applied across the assessment classes. Thus, for some groups there is a generalisation of vulnerability across taxon group that may include species with very different distributions, which would have implications particularly for Exposure traits.

3. Spatial distribution information. Experts found it difficult to approximate the spatial distribution of an entire CCVA taxon group to appraise the Exposure traits. It was suggested that having a map with the approximate distribution of the functional group would have been highly useful. Distribution maps were provided for DOC's terrestrial assessment. However, as this project pooled species into taxon groups, existing species-level distributional maps (e.g., from the Aotearoa New Zealand Atlas of Seafloor Biodiversity (Stephenson et al. 2023a)) would not have been relevant. Further, the CCVAs included other species/species groups that were not included in the SDM atlas. Experts discussed that a spatial representation of taxon-group distribution would have been helpful to map the Exposure traits. Experts suggested such maps could be developed by collectively mapping all occurrence records of species within the CCVA taxon groups, noting the biases associated with using such data as a proxy for distribution.

5.4 Trait assessments

Generally, it was found that the traits captured most of the vulnerabilities that benthic marine taxa face in the context of climate change. However, there were recommendations for the consideration of additional traits or updating existing trait definitions to provide more context and specificity for particular impacts. Suggestions include:

1. Life history stages. The available traits provided limited ability to account for difference among life history stages in terms of specific vulnerabilities to climate change impacts. Mention of life history stages occurs in the 'Habitat specialisation' and 'Dependence on microhabitat' traits, but the vulnerabilities of key life-histories should be considered across all dimensions, particularly as many species have very difference requirements/distributions at the larval compared to adult stages.

2. Range shifts. The trait (Dispersal ability) under the Adaptive capacity dimension was intended to capture vulnerabilities associated with taxa's inability to move in response to climate change. However, experts suggested this should be better integrated into the Exposure dimension. For example, if a species has limited ability to disperse AND its currently available habitat is facing considerable future changes in suitability, it should have higher vulnerability. Members of the AEWG/BRAG also noted the link between the ability to disperse and the sensitivity/availability of suitable habitat within the dispersal range of a species or group. The trait on dispersal ability could be updated to include a lack of new habitat availability to species as a contributing factor to vulnerability.

3. Sensitivity to other stressors. During the preliminary workshop, two additional traits were added to the Sensitivity to dimension to account for 1) sensitivity to sedimentation and 2) sensitivity to cumulative stressors. Experts suggested that, while sedimentation is a key stressor for benthic taxa, it does not require specific mention above other important stressors. In particular, sensitivity to the impacts of commercial fishing is a key trait that was missing. Rather than having a trait for each key stressor to benthic species, it would be better to have a trait designed to capture key vulnerabilities to any of the other major (excluding climate change) stressors on the marine environment and thus a full range of human impacts (e.g., sedimentation, commercial fishing, invasive species, disease would be included under a single trait). Generally, experts found it difficult to consider group-specific vulnerabilities without the context of all the other impacts facing a group and the current status of populations.

4. Interaction with other species. The interactions with other species/taxa trait under the sensitivity dimension provides the ability to score taxa as more vulnerable if they are dependent on other species/taxa (i.e., presence on interspecific associations). The definitions of this trait were considered too vague – as every taxa has interspecific associations as prey, predator, symbionts, for habitat etc. It was suggested that it would be better phrased to explicitly capture whether the known associations are likely to be threatened by climate change impacts, and to differentiate between the degradation of associations that are positive for the assessed taxa (e.g., habitat provision) vs those that are negative that may come about due to climate change (e.g., higher predator/competitor density). Further feedback related to this trait was provided at the joint AEWG/BRAG meeting where members suggested there should be capacity to include the potential impacts of the introduction of new species (i.e., invasive species) under climate change, and the potential for negative interactions with native species. This additional cumulative effect of climate change could be accounting for by modifying the interaction sensitivity trait to specify vulnerability due to risks to positive interactions and vulnerability due to the emergence of negative interactions from potential invasive species.

5. Habitat specialisation. It was found that the habitat classification used to determine the 'habitat specialisation' traits was difficult to apply, particularly in the context of the functional groupings where component species had diverse habitat requirements. It was suggested that allowing experts to make their own suggestions as to specialisation to a particular habitat would be more appropriate. However, not providing a consistent level of classification for reporting specialisation would challenge comparisons among groups. A habitat classification better tailored to the Aotearoa New Zealand marine environment would also likely improve the assessment on this trait.

6. Exposure traits. Maps for the exposure dimension were sometimes difficult to interpret in terms of understanding the area under appraisal (i.e., the top 25% of change). While taxa specific thresholds were not available in any case (hence the top 25% area being used), it would have been worthwhile to work with experts to characterise the extent of this area for each broad taxonomic group given the high variability in the distribution of broad groups. For example, all macroalgae overlap with

the area of greatest change in temperature because they are all coastal. Potentially, differentiating the top 25% within the available habitat for a broad taxonomic group would be more appropriate for future assessments.

AEWG/BRAG members also noted that there is often some uncertainty related to model-based representation of current and future environmental conditions. In this project the best available data on future conditions were sourced from the NZ earth systems model, yet it should be noted that predictions from such models are being continuously updated with new information. For example, future incorporation of data from significant sampling campaigns such as that undertaken by the moana project are likely to result in more accurate and precise predictions of future conditions.

Additionally, it was noted that the appraisal of the exposure dimension considered stressors related to physical changes in ocean conditions (i.e., temperature, pH), but not variation in ecological processes such as primary productivity or detrital flux. The NZ earth systems model generates biogeochemical outputs that can be used to explore variability in ecological processes, however experts would also need to consider the sensitivity of species/groups to such changes, with the evidence of such sensitivity likely being more poorly known that sensitivity to physical changes in the environment.

7. Adaptive capacity. Experts felt that this dimension was very difficult to assess due to substantial knowledge gaps across most species/taxon groups

5.5 Recommendations for adapting the terrestrial approach

- The CCVA traits should be adapted to be suitable for grouped species, and include the additional marine-specific traits scored in this analyses (Table 2-3). Experts suggested the inclusion of further traits and relevant considerations (e.g., a trait that specifically addresses vulnerabilities at life history stages). Suggestions are listed in Section 5.4 .
- The averaged trait values of within-group species are likely to mask any high vulnerabilities. Thus, CCVAs should be carried out for grouped species with shared climate vulnerabilities across all vulnerability dimensions. CCVAs should additionally be carried out for some within-group species to determine if the groups are accurately representing the species' vulnerabilities.
- The vulnerability classification approach used by Foden et al. (2013) requires adequate information across all three vulnerability dimensions. Yet, substantial knowledge gaps for the Adaptive capacity dimension mean that the vulnerabilities may be underestimated for the Optimistic approach and overestimated for the Pessimistic approach. Vulnerability scores could be more informative if they incorporate the information adequacy of the scores (e.g., through using a weighted mean approach).
- Taxon groups with a high amount of Unknown trait values (e.g., >50% of traits being scoring Unknown for any dimension) should not be considered when comparing relative vulnerabilities.
- Experts should be provided with distributional range maps for the taxa being assessed.
- CCVA of higher trophic levels (e.g., fish, megafauna) will have increased uncertainties due to the large numbers of interspecific associations and dependencies upon lower

trophic levels that have their own, unique vulnerabilities to climate change. Such uncertainties may be better characterised by assessments of species within particular ecosystems/communities where relationships between trophic levels are well known.

6 Acknowledgements

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Appendix A Terrestrial and marine CCVA trait comparisons

Table A-1: Comparison between the CCVA traits used in the terrestrial approach (Brumby et al. 2023), and the marine approach for benthic invertebrate taxon groups presented in this report.

Trait	Vulnerability dimension	Included in terrestrial CCVA	Included in marine CCVA
Habitat specialisation	Sensitivity	Yes	Yes
Dependence on a particular microhabitat or single location	Sensitivity	Yes	Yes
Narrow temperature tolerance	Sensitivity	Yes	Yes
Narrow precipitation tolerance	Sensitivity	Yes	No
Narrow pH tolerance	Sensitivity	No	Yes
Interactions with other species/taxa	Sensitivity	Yes	Yes
Small population size	Sensitivity	Yes	No
Small population size and heightened sensitivity to threatening processes	Sensitivity	Yes	No
Rarity (bioregions)	Sensitivity	No	Yes
Heightened sensitivity to sedimentation	Sensitivity	No	Yes
Heightened sensitivity to cumulative stressors	Sensitivity	No	Yes
Habitat types exposed to sea level inundation and increased storm surges	Exposure	Yes	Yes
Extent of geographic range exposed to changes in temperature	Exposure	Yes	Yes
Extent of taxon group's range exposed to temperature extremes (reworded to marine heatwaves)	Exposure	Yes	Yes
Extent of exposure to changes in precipitation	Exposure	Yes	No
Extent of species range exposed to precipitation extremes	Exposure	Yes	No

Trait	Vulnerability dimension	Included in terrestrial CCVA	Included in marine CCVA
Extent of taxon group's range exposed to changes in pH (ocean acidification)	Exposure	No	Yes
Extent of taxon group's range exposed to changes in aragonite	Exposure	No	Yes
Extent of taxon groups range exposed to changes in calcite	Exposure	No	Yes
Limitations to dispersal	Adaptive capacity	Yes	Yes
Low genetic diversity	Adaptive capacity	Yes	Yes
Slow turnover of generations	Adaptive capacity	Yes	Yes
Low reproductive capacity	Adaptive capacity	Yes	Yes

Appendix B Functional and taxonomic groups

Table B-1: List of taxon groups and constituting taxa that were included in the climate change vulnerability assessments (CCVAs).

Wider taxonomic group	Common name	Order	Family	Genus (some taxa to species level)	CCVA taxon group
Bryozoan	Bryozoan	Cheilostomatida	Fenestrulinidae	*Fenestrulina*	Algal associated
Bryozoan	Bryozoan	Cyclostomatida	Lichenoporidae	*Disporella*	Algal associated
Bryozoan	Bryozoan	Cheilostomatida	Smittinidae	*Smittoidea*	Coral like
Bryozoan	Bryozoan	Cheilostomatida	Celleporidae	*Celleporaria*	Coral like
Bryozoan	Bryozoan	Cyclostomatida	Cinctiporidae	*Cinctipora*	Southern fixed errect
Bryozoan	Bryozoan	Cheilostomatida	Adeonidae	*Adeonellopsis*	Southern fixed errect
Bryozoan	Bryozoan	Cyclostomatida	Hastingsiidae	*Telopora*	Telopora
Bryozoan	Bryozoan	Cheilostomatida	Microporidae	*Micropora*	Widespread encrustor
Bryozoan	Bryozoan	Cyclostomatida	Lichenoporidae	*Disporella*	Widespread encrustor
Bryozoan	Bryozoan	Cheilostomatida	Celleporidae	*Galeopsis*	Widespread fixed errect
Bryozoan	Bryozoan	Cheilostomatida	Celleporidae	*Galeopsis*	Widespread fixed errect
Bryozoan	Bryozoan	Cheilostomatida	Candidae	*Caberea*	Widespread flexible errect
Bryozoan	Bryozoan	Cheilostomatida	Candidae	*Caberea*	Widespread flexible errect
Bryozoan	Bryozoan	Cheilostomatida	Cellariidae	*Cellaria*	Widespread flexible errect
Bryozoan	Bryozoan	Cheilostomatida	Cellariidae	*Cellaria*	Widespread flexible errect
Bryozoan	Bryozoan	Cheilostomatida	Catenicellidae	*Paracribricellina*	Widespread flexible errect
Coral	Warty anemone	Actiniaria	Hormathiidae	*NA*	Anemones
Coral	Smooth anemone	Actiniaria	Actinostolidae	*NA*	Anemones
Coral	Sea anemone	Actiniaria	Actiniidae	*Bolocera*	Anemones
Coral	Bamboo coral	Scleralcyonacea	Keratoisididae	*Keratoisis*	Bamboo coral

Wider taxonomic group	Common name	Order	Family	Genus (some taxa to species level)	CCVA taxon group
Coral	Bamboo coral	Scleralcyonacea	Keratoisididae	*Acanella*	Bamboo coral
Coral	Black coral	Antipatharia	Schizopathidae	*Bathypathes*	Black corals
Coral	Black coral	Antipatharia	Schizopathidae	*Leiopathes*	Black corals
Coral	Branching coral	Scleractinia	Oculinidae	*Madrepora*	Branching coral
Coral	Branching coral	Scleractinia	Caryophylliidae	*Solenosmilia*	Branching coral
Coral	Branching coral	Scleractinia	Dendrophylliidae	*Enallopsammia*	Branching coral
Coral	Bubblegum coral	Scleralcyonacea	Coralliidae	*Paragorgia*	Bubblegum coral
Coral	Soft coral/Deadman's Fingers	Malacalcyonacea	Alcyoniidae	*Ushanaia*	Deadmans Fingers
Coral	Soft coral/Deadman's Fingers	Malacalcyonacea	Alcyoniidae	*Kotatea*	Deadmans Fingers
Coral	Gorgonian sea fan	Scleralcyonacea	Chrysogorgiidae	*Chrysogorgia*	Golden coral
Coral	Branching coral	Scleractinia	Caryophylliidae	*Goniocorella*	Goniocorella
Coral	Cup coral	Scleractinia	Caryophylliidae	*Caryophyllia*	Hard substrate cup coral
Coral	Cup coral	Scleractinia	Caryophylliidae	*Desmophyllum*	Hard substrate cup coral
Coral	White hydrocoral	Anthoathecata	Stylasteridae	*Conopora*	Hydrocorals
Coral	Red hydrocoral	Anthoathecata	Stylasteridae	*Errina*	Hydrocorals
Coral	White hydrocoral	Anthoathecata	Stylasteridae	*Stylaster*	Hydrocorals
Coral	Soft coral	Scleralcyonacea	Coralliidae	*Anthomastus*	Mushroom corals
Coral	Soft coral	Scleralcyonacea	Coralliidae	*Heteropolypus*	Mushroom corals
Coral	Precious corals	Scleralcyonacea	Coralliidae	*Corallium*	Precious corals
Coral	Precious corals	Scleralcyonacea	Coralliidae	*Hemicorallium*	Precious corals
Coral	Gorgonian sea fan	Scleralcyonacea	Primnoidae	*Metafannyella*	Primnoids

Wider taxonomic group	Common name	Order	Family	Genus (some taxa to species level)	CCVA taxon group
Coral	Gorgonian sea fan	Scleralcyonacea	Primnoidae	*Narella*	Primnoids
Coral	Gorgonian sea fan	Scleralcyonacea	Primnoidae	*Thouarella*	Primnoids
Coral	Gorgonian sea fan	Malacalcyonacea	Paramuriceidae	*Acanthogorgia*	Sea fans
Coral	Sea pen	Superfamily Pennatuloidea	Anthoptilidae	*Funiculina*	Sea pen
Coral	Sea pen	Superfamily Pennatuloidea	Anthoptilidae	*Anthoptilum*	Sea pen
Coral	Cup coral	Scleractinia	Flabellidae	*Flabellum*	Soft sediment cup coral
Coral	Cup coral	Scleractinia	Flabellidae	*Monomyces*	Soft sediment cup coral
Coral	Cup coral	Scleractinia	Caryophylliidae	*Stephanocyathus*	Soft sediment cup coral
Coral	Soft coral	Malacalcyonacea	Taiaroidae	*Taiaroa*	*Taiaroa*
Coral	Zoanthid	Zoantharia	Epizoanthidae	*Epizoanthus*	Zoanthid
Crustaceans	Blind lobster	Decapoda	Polychelidae	*Polycheles*	Blind lobsters
Crustaceans	Blind lobster	Decapoda	Polychelidae	*Stereomastis*	Blind lobsters
Crustaceans	Squat lobster	Decapoda	Chirostylidae	*Uroptychus*	Chirostylid squat lobster
Crustaceans	Spiny lobster	Decapoda	Palinuridae	*Jasus*	Jasus cray
Crustaceans	Carrier crab	Decapoda	Homolidae	*Dagnaudus*	Large predator/scavenger crabs
Crustaceans	Crab	Decapoda	Inachidae	*Vitjazmaia*	Large predator/scavenger crabs
Crustaceans	King crab	Decapoda	Lithodidae	*Paralomis*	Large predator/scavenger crabs
Crustaceans	King crab	Decapoda	Lithodidae	*Neolithodes*	Large predator/scavenger crabs
Crustaceans	King crab	Decapoda	Lithodidae	*Lithodes*	Large predator/scavenger crabs

Wider taxonomic group	Common name	Order	Family	Genus (some taxa to species level)	CCVA taxon group
Crustaceans	Crab	Decapoda	Majidae	*Leptomithrax*	Large predator/scavenger crabs
Crustaceans	Crab	Decapoda	Majidae	*Teratomaia*	Large predator/scavenger crabs
Crustaceans	Crab	Decapoda	Majidae	*Jacquinotia*	Large predator/scavenger crabs
Crustaceans	Shrimp	Decapoda	Acanthephyridae	*Acanthephyra*	Large shrimp and prawns
Crustaceans	Shrimp	Decapoda	Aristeidae	*Aristeus*	Large shrimp and prawns
Crustaceans	prawn	Decapoda	Aristeidae	*Aristaeomorpha*	Large shrimp and prawns
Crustaceans	Shrimp	Decapoda	Aristeidae	*Aristaeopsis*	Large shrimp and prawns
Crustaceans	Shrimp	Decapoda	Campylonotidae	*Campylonotus*	Large shrimp and prawns
Crustaceans	Shrimp	Lophogastrida	Gnathophausiidae	*Gnathophausia*	Large shrimp and prawns
Crustaceans	Shrimp	Decapoda	Lipkiidae	*Lipkius*	Large shrimp and prawns
Crustaceans	prawn	Decapoda	Nematocarcinidae	*Nematocarcinus*	Large shrimp and prawns
Crustaceans	Shrimp	Decapoda	Oplophoridae	*Oplophorus*	Large shrimp and prawns
Crustaceans	Shrimp	Decapoda	Pandalidae	*Notopandalus*	Large shrimp and prawns
Crustaceans	Shrimp	Decapoda	Pandalidae	*Plesionika*	Large shrimp and prawns
Crustaceans	Shrimp	Decapoda	Pasiphaeidae	*Pasiphaea*	Large shrimp and prawns
Crustaceans	Prawn	Decapoda	Sergestidae	*Sergestes*	Large shrimp and prawns
Crustaceans	Shrimp	Decapoda	Solenoceridae	*Haliporoides*	Large shrimp and prawns
Crustaceans	Lobster	Decapoda	Nephropidae	*Metanephrops*	Metanephrops scampi
Crustaceans	Slipper lobster	Decapoda	Scyllaridae	*Ibacus*	Ibacus slipper lobster

Wider taxonomic group	Common name	Order	Family	Genus (some taxa to species level)	CCVA taxon group
Crustaceans	Crab	Decapoda	Goneplacidae	*Pycnoplax*	Small soft sediment crabs
Crustaceans	Crab	Decapoda	Leucosiidae	*Dittosa (now Bellidilia)*	Small soft sediment crabs
Crustaceans	Crab	Decapoda	Raninidae	*Lyreidus*	Small soft sediment crabs
Crustaceans	Crab	Decapoda	Trichopeltariidae	*Trichopeltarion*	Small soft sediment crabs
Crustaceans	Squat lobster	Decapoda	Galatheidae	*Phylladiorhynchus*	Squat lobster and hermit crabs
Crustaceans	Squat lobster	Decapoda	Munididae	*Munida*	Squat lobster and hermit crabs
Crustaceans	Squat lobster	Decapoda	Munidopsidae	*Munidopsis*	Squat lobster and hermit crabs
Crustaceans	Hermit crab	Decapoda	Paguridae	*Diacanthurus*	Squat lobster and hermit crabs
Crustaceans	Hermit crab	Decapoda	Paguridae	*Lophopagurus*	Squat lobster and hermit crabs
Crustaceans	Hermit crab	Decapoda	Parapaguridae	*Sympagurus*	Squat lobster and hermit crabs
Crustaceans	Crab	Decapoda	Ovalipidae	*Nectocarcinus*	Swimming crabs
Crustaceans	Crab	Decapoda	Ovalipidae	*Ovalipes*	Swimming crabs
Echinoderm	Sea cucumber	Synallactida	Stichopodidae	*Australostichopus*	Australostichopus
Echinoderm	Sea urchin	Diadematoida	Diadematidae	*Centrostephanus rodgersii*	Centrostephanus
Echinoderm	Sea urchin	Spatangoida	Brissidae	*Brissopsis*	Deep infaunal deposit feeder
Echinoderm	Sea star	Forcipulatida	Zoroasteridae	*Zoroaster*	Deep scavenger
Echinoderm	Sea star	Forcipulatida	Stichasteridae	*Cosmasterias*	Deep scavenger
Echinoderm	Sea star	Valvatida	Solasteridae	*Solaster*	Deep scavenger
Echinoderm	Sea star	Valvatida	Solasteridae	*Crossaster*	Deep scavenger
Echinoderm	Sea star	Valvatida	Goniasteridae	*Hippasteria*	Deep scavenger
Echinoderm	Brittle star	Amphilepidida	Amphiuridae	*Amphioplus*	Deep scavenger
Echinoderm	Brittle star	Amphilepidida	Hemieuryalidae	*Ophiozonella*	Deep scavenger
Echinoderms	Brittle star	Ophiacanthida	Ophiacanthidae	*Ophiophthalmus*	Deep scavenger

Wider taxonomic group	Common name	Order	Family	Genus (some taxa to species level)	CCVA taxon group
Echinoderms	Basket starfish	Euryalida	Gorgonocephalidae	*Gorgonocephalus*	Deep scavenger
Echinoderms	Sea urchin	Camarodonta	Echinidae	*Echinus*	Deep scavenger
Echinoderms	Sea urchin	Echinothurioida	Echinothuriidae	*Araeosoma*	Deep scavenger
Echinoderms	Sea urchin	Pedinoida	Pedinidae	*Caenopedina*	Deep scavenger
Echinoderms	Sea star	Paxillosida	Astropectinidae	*Dipsacaster*	Deep soft sediment deposit feeder
Echinoderms	Sea star	Paxillosida	Astropectinidae	*Plutonaster*	Deep soft sediment deposit feeder
Echinoderms	Sea cucumber	Elasipodida	Laetmogonidae	*Laetmogone*	Deep soft sediment deposit feeder
Echinoderms	Sea cucumber	Elasipodida	Laetmogonidae	*Pannychia*	Deep soft sediment deposit feeder
Echinoderms	Sea cucumber	Persiculida	Pseudostichopodidae	*Pseudostichopus*	Deep soft sediment deposit feeder
Echinoderms	Brittle star	Ophiurida	Ophiomusaidae	*Ophiomusa*	Deep soft sediment scavenger
Echinoderms	Sea urchin	Cidaroida	Cidaridae	*Ogmocidaris*	Deep soft sediment scavenger
Echinoderms	Sea urchin	Echinothurioida	Phormosomatidae	*Phormosoma*	Deep soft sediment scavenger
Echinoderms	Sea urchin	Echinothurioida	Echinothuriidae	*Hygrosoma*	Deep soft sediment scavenger
Echinoderms	Sea urchin	Camarodonta	Echinometridae	*Evechinus*	*Evechinus*
Echinoderms	Brittle star	Euryalida	Euryalidae	*Ophiocreas*	Hard substrate scavenger
Echinoderms	Brittle star	Ophiacanthida	Ophiodermatidae	*Ophiopsammus*	Hard substrate scavenger
Echinoderms	Brittle star	Ophiacanthida	Ophiomyxidae	*Ophiomyxa*	Hard substrate scavenger
Echinoderms	Brittle star	Ophiurida	Ophiopyrgidae	*Amphiophiura*	Hard substrate scavenger
Echinoderms	Sea urchin	Spatangoida	Spatangidae	*Spatangus*	Infaunal deposit feeder
Echinoderms	Sea cucumber	Dendrochirotida	Heterothyonidae	*Heterothyone*	Infaunal deposit feeder
Echinoderms	Sea cucumber	Molpadida	Molpadiidae	*Heteromolpadia*	Infaunal deposit feeder

Wider taxonomic group	Common name	Order	Family	Genus (some taxa to species level)	CCVA taxon group
Echinoderms	Sea cucumber	Molpadida	Caudinidae	*Paracaudina*	Infaunal deposit feeder
Echinoderms	Sea star	Valvatida	Asterinidae	*Patiriella/Meridiastra*	Shallow scavenger
Echinoderms	Sea star	Forcipulatida	Asteriidae	*Coscinasterias*	Shallow scavenger
Echinoderms	Sea star	Forcipulatida	Asteriidae	*Astrostole*	Shallow scavenger
Echinoderms	Sea star	Forcipulatida	Stichasteridae	*Stichaster*	Shallow scavenger
Echinoderms	Sea star	Paxillosida	Astropectinidae	*Proserpinaster*	Soft sediment deposit feeder
Echinoderms	Sea star	Paxillosida	Astropectinidae	*Psilaster*	Soft sediment deposit feeder
Echinoderms	Sea star	Paxillosida	Luidiidae	*Luidia*	Soft sediment deposit feeder
Echinoderms	Sea star	Paxillosida	Pseudarchasteridae	*Pseudarchaster*	Soft sediment deposit feeder
Echinoderms	Sea cucumber	Synallactida	Synallactidae	*Bathyplotes*	Soft sediment deposit feeder
Echinoderms	Sea star	Paxillosida	Astropectinidae	*Astromesites*	Soft sediment deposit feeder
Echinoderms	Sea star	Forcipulatida	Asteriidae	*Sclerasterias*	Widespread scavenger
Echinoderms	Sea star	Valvatida	Odontasteridae	*Odontaster*	Widespread scavenger
Echinoderms	Brittle star	Amphilepidida	Amphiuridae	*Amphiura*	Widespread scavenger
Echinoderms	Brittle star	Ophiacanthidae	Ophiacanthidae	*Ophiacantha*	Widespread scavenger
Echinoderms	Brittle star	Ophiurida	Ophiuridae	*Ophiura*	Widespread scavenger
Echinoderms	Sea urchin	Camarodonta	Temnopleuridae	*Pseudechinus*	Widespread scavenger
Macroalages	Coralline algae	Corallinales	Corallinaceae	*Corallina aff ferreyrae*	*Corallina aff ferreyrae*
Macroalages	Bull kelp	Fucales	Durvillaeaceae	*Durvillaea antarctica (spp)*	*Durvillaea antarctica* and *poha*
Macroalages	Kelp	Laminariales	Lessoniaceae	*Ecklonia radiata*	Ecklonia radiata
Macroalages	Filamentous brown algae	Scytothamnales	Bachelotiaceae	*Bachelotia antillarum*	Filamentous brown algae

Wider taxonomic group	Common name	Order	Family	Genus (some taxa to species level)	CCVA taxon group
Macroalages	Filamentous brown algae	Ectocarpales	Ectocarpaceae	*Ectocarpus siliculosus*	Filamentous brown algae
Macroalages	Filamentous green algae	Cladophorales	Cladophoraceae	*Lychaete herpestica*	Filamentous green algae
Macroalages	Brown seaweed	Fucales	Sargassaceae	*Carpophyllum flexuosum*	Fucales
Macroalages	Brown seaweed	Fucales	Sargassaceae	*Carpophyllum maschalocarpum*	Fucales
Macroalages	Brown seaweed	Fucales	Sargassaceae	*Cystophora retroflexa*	Fucales
Macroalages	Brown seaweed	Fucales	Sargassaceae	*Cystophora scalaris*	Fucales
Macroalages	Brown seaweed	Fucales	Sargassaceae	*Cystophora torulosa*	Fucales
Macroalages	Brown seaweed	Fucales	Sargassaceae	*Landsburgia quercifolia*	Fucales
Macroalages	Brown seaweed	Fucales	Sargassaceae	*Sargassum sinclairii*	Fucales
Macroalages	Brown seaweed	Ectocarpales	Adenocystaceae	*Adenocystis utricularis*	Intertidal/ shallow brown algae
Macroalages	Brown seaweed	Ectocarpales	Scytosiphonaceae	*Petalonia binghamiae*	Intertidal/ shallow brown algae
Macroalages	Brown seaweed	Sphacelariales	Stypocaulaceae	*Halopteris virgata*	Intertidal/ shallow brown algae
Macroalages	Brown seaweed	Ectocarpales	Chordariaceae	*Myriogloea intestinalis*	Intertidal/ shallow brown algae
Macroalages	Brown seaweed	Ectocarpales	Scytosiphonaceae	*Scytosiphon lomentaria*	Intertidal/ shallow brown algae
Macroalages	Brown seaweed	Fucales	Xiphophoraceae	*Xiphophora chondrophylla*	Intertidal/ shallow brown algae
Macroalages	Green seaweed	Cladophorales	Cladophoraceae	*Chaetomorpha aerea*	Intertidal/ shallow green algae
Macroalages	Green seaweed	Bryopsidales	Codiaceae	*Codium convolutum*	Intertidal/ shallow green algae
Macroalages	Green seaweed	Cladophorales Sip	Siphonocladus clade	*Microdictyon mutabile*	Intertidal/ shallow green algae
Macroalages	Red seaweed	Gracilariales	Gracilariaceae	*Gracilaria transtasmanica*	Intertidal/ shallow red algae

Wider taxonomic group	Common name	Order	Family	Genus (some taxa to species level)	CCVA taxon group
Macroalages	Red seaweed	Gigartinales	Gigartinaceae	*"Sarcothalia" decipiens*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Gelidiales	Gelidiaceae	*Capreolia implexa*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Gigartinales	Caulacanthaceae	*Caulacanthus ustulatus*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Rhodymeniales	Champiaceae	*Champia novae-zelandiae*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Bangiales	Bangiaceae	*Clymene coleana*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Gelidiales	Gelidiaceae	*Gelidium caulacantheum*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Gigartinales	Gigartinaceae	*Gigartina macrocarpa*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Halymeniales	Halymeniaceae	*Grateloupia urvilleana*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Gigartinales	Phyllophoraceae	*Gymnogongrus furcatus*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Gigartinales	Phyllophoraceae	*Gymnogongrus torulosus*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Ceramiales	Wrangeliaceae	*Lophothamnion hirtum*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Halymeniales	Halymeniaceae	*Pachymenia dichotoma*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Halymeniales	Halymeniaceae	*Pachymenia lusoria*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Gigartinales	Gigartinaceae	*Psilophycus alveatus*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Gelidiales	Gelidiaceae	*Pterocladiella capillacea*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Bangiales	Bangiaceae	*Pyropia plicata*	Intertidal/ shallow red algae
Macroalages	Red seaweed	Ceramiales	Ceramiaceae	*Centroceras clavulatum*	Intertidal/ shallow red algae
Macroalages	Giant kelp	Laminariales L	Laminariaceae	*Macrocystis pyrifera*	*Macrocystis pyrifera*
Macroalages	Sea Rimu	Bryopsidales	Caulerpaceae	*Caulerpa brownii*	Meadow formers (green algae)

Wider taxonomic group	Common name	Order	Family	Genus (some taxa to species level)	CCVA taxon group
Macroalages	Dead Man's Fingers	Bryopsidales	Codiaceae	*Codium fragile*	Meadow formers (green algae)
Macroalages	Fern Caulerpa	Bryopsidales	Caulerpaceae	*Caulerpa flexilis*	Meadow formers (green algae)
Macroalages	Harpoon weed	Bonnemaisoniales	Bonnemaisoniaceae	*Asparagopsis armata*	Meadow formers (red algae)
Macroalages	Red seaweed	Gracilariales	Gracilariaceae	*Gracilaria truncata*	Meadow formers (red algae)
Macroalages	Red seaweed	Gigartinales	Phyllophoraceae	*Stenogramma interruptum*	Meadow formers (red algae)
Macroalages	Brown seaweed	Fucales	Sargassaceae	*Carpophyllum angustifolium*	Northen large brown
Macroalages	Featherweed	Fucales	Sargassaceae	*Carpophyllum plumosum*	Northen large brown
Macroalages	Sawtoothed comb	Fucales	Seirococcaceae	*Marginariella boryana*	Southern large brown
Macroalages	Brown seaweed	Fucales	Seirococcaceae	*Marginariella urvilliana*	Southern large brown
Macroalages	Flattened acid kelp	Desmarestiales	Desmarestiaceae	*Desmarestia ligulata*	Subtidal brown algae
Macroalages	Brown seaweed	Sphacelariales	Stypocaulaceae	*Halopteris funicularis*	Subtidal brown algae
Macroalages	Brown seaweed	Sporochnales	Sporochnaceae	*Carpomitra costata*	Subtidal brown algae
Macroalages	Sinuous ballweed	Ectocarpales	Scytosiphonaceae	*Colpomenia sinuosa*	Subtidal brown algae
Macroalages	Brown seaweed	Syringodermatales	Syringodermataceae	*Microzonia velutina*	Subtidal brown algae
Macroalages	Brown seaweed	Fucales	Xiphophoraceae	*Xiphophora gladiata*	Subtidal brown algae
Macroalages	Brown seaweed	Dictyotales	Dictyotaceae	*Zonaria turneriana*	Subtidal brown algae
Macroalages	Green seaweed	Bryopsidales	Caulerpaceae	*Caulerpa geminata*	Subtidal green algae
Macroalages	Green seaweed	Bryopsidales	Codiaceae	*Codium gracile*	Subtidal green algae
Macroalages	Red seaweed	Gigartinales	Gigartinaceae	*"Gigartina" atropurpurea*	Subtidal red algae

Wider taxonomic group	Common name	Order	Family	Genus (some taxa to species level)	CCVA taxon group
Macroalages	Red seaweed	Halymeniales	Halymeniaceae	*Aeodes nitidissima*	Subtidal red algae
Macroalages	Red seaweed	Ceramiales	Wrangeliaceae	*Anotrichium crinitum*	Subtidal red algae
Macroalages	Red seaweed	Balliales	Balliaceae	*Ballia callitricha*	Subtidal red algae
Macroalages	Red seaweed	Gigartinales	Gigartinaceae	*Chondracanthus chapmanii*	Subtidal red algae
Macroalages	Red seaweed	Ceramiales	Rhodomelaceae	*Chondria macrocarpa*	Subtidal red algae
Macroalages	Red seaweed	Ceramiales	Rhodomelaceae	*Cladhymenia oblongifolia*	Subtidal red algae
Macroalages	Red seaweed	Ceramiales	Rhodomelaceae	*Dasyclonium incisum*	Subtidal red algae
Macroalages	Red seaweed	Ceramiales	Callithamniaceae	*Euptilota formosissima*	Subtidal red algae
Macroalages	Red seaweed	Ceramiales	Delesseriaceae	*Haraldiophyllum crispatum*	Subtidal red algae
Macroalages	Red seaweed	Ceramiales	Delesseriaceae	*Hymenena variolosa*	Subtidal red algae
Macroalages	Red seaweed	Ceramiales	Rhodomelaceae	*Laurencia distichophylla*	Subtidal red algae
Macroalages	Red seaweed	Ceramiales	Rhodomelaceae	*Laurencia thyrsifera*	Subtidal red algae
Macroalages	Red seaweed	Ceramiales	Rhodomelaceae	*L. pauciramulosa*	Subtidal red algae
Macroalages	Red seaweed	Gracilariales	Gracilariaceae	*Melanthalia abscissa*	Subtidal red algae
Macroalages	Red seaweed	Plocamiales	Plocamiaceae	*Plocamium angustum*	Subtidal red algae
Macroalages	Red seaweed	Plocamiales	Plocamiaceae	*Plocamium cartilagineum*	Subtidal red algae
Macroalages	Red seaweed	Plocamiales	Plocamiaceae	*Plocamium cirrhosum*	Subtidal red algae
Macroalages	Red seaweed	Gigartinales	Kallymeniaceae	*Psaromenia berggrenii*	Subtidal red algae
Macroalages	Red seaweed	Gigartinales	Cystocloniaceae	*Rhodophyllis membranacea*	Subtidal red algae
Macroalages	Red seaweed	Ceramiales	Delesseriaceae	*Schizoseris dichotoma*	Subtidal red algae
Macroalages	Red seaweed	Ceramiales	Rhodomelaceae	*Vidalia colensoi*	Subtidal red algae

Wider taxonomic group	Common name	Order	Family	Genus (some taxa to species level)	CCVA taxon group
Molluscs	Arabic volute	Neogastropoda	Volutidae	*Alcithoe*	*Alcithoe arabica*
Molluscs	Cockle/ tuangi	Venerida	Veneridae	*Austrovenus*	*Austrovenus stutchburyi*
Molluscs	Pāua	Lepetellida	Haliotidae	*Haliotis iris*	*Haliotis iris*
Molluscs	Bivalve	Limida	Limidae	*Lima zelandica*	*Lima zelandica*
Molluscs	Gastropod	Trochida	Calliostomatidae	*Maurea selecta*	*Maurea selecta*
Molluscs	Scallop	Pectinida	Pectinidae	*Pecten novaezelandiae*	*Pecten novaezelandiae*
Molluscs	Cockle	Cardiida	Cardiidae	*Pratulum pulchellum*	*Pratulum pulchellum*
Molluscs	Golden volute	Neogastropoda	Volutidae	*Provocator mirabilis*	*Provocator mirabilis*
Molluscs	Morning star shell	Venerida	Veneridae	*Tawera spissa*	*Tawera spissa*
Molluscs	Queen scallop	Pectinida	Pectinidae	*Zyglochlamys*	*Zyglochlamys delicatula*
Sponges	Sponge	Axinellida	Axinellidae	*Cymbastela lamellata*	Bleaching fan sponges
Sponges	Sponge	Clathrinida	Leucaltidae	*Leucettusa lancifer*	Calcareous sponges
Sponges	Sponge	Haplosclerida	Callyspongiidae	*Callyspongia*	Finger sponges
Sponges	Sponge	Haplosclerida	Callyspongiidae	*Dactylia*	Finger sponges
Sponges	Sponge	Haplosclerida	Chalinidae	*Haliclona*	Finger sponges
Sponges	Sponge	Sceptrulophora	Aphrocallistidae	*Aphrocallistes*	Fragile coral garden sponges
Sponges	Sponge	Sceptrulophora	Farreidae	*Farrea*	Fragile coral garden sponges
Sponges	Sponge	Tetractinellida	Vulcanellidae	*Poecillastra*	Fragile coral garden sponges
Sponges	Lithistid sponges	NA	NA	NA	Lithistid sponges
Sponges	Sponge	Tetractinellida	Ancorinidae	*Ecionemia*	Massive, tough sponges
Sponges	Sponge	Tetractinellida	Ancorinidae	*Stelletta*	Massive, tough sponges
Sponges	Sponge	Tetractinellida	Geodiidae	*Geodia*	Massive, tough sponges

Wider taxonomic group	Common name	Order	Family	Genus (some taxa to species level)	CCVA taxon group
Sponges	Sponge	Lyssacinosida	Rossellidae	*Hyalascus*	Mobile substrate sponges
Sponges	Sponge	Poecilosclerida	Coelosphaeridae	*Lissodendoryx bifacialis*	Mobile substrate sponges
Sponges	Sponge	Suberitida	Suberitidae	*Suberites*	Mobile substrate sponges
Sponges	Glass sponge	Lyssacinosida	Rossellidae	*Symplectella rowi*	Shallow water glass sponges
Sponges	Glass sponge	Lyssacinosida	Rossellidae	*Rossella ijimai*	Shallow water glass sponges

Appendix C Map resources

This appendix contains 21 maps used during the climate change vulnerability assessments (CCVAs).

These maps relate to:

Sensivity

- Trait 6 – Rarity. We included the New Zealand Seafloor Bioregionalisation map (Stephenson et al. 2023b). Experts were instructed to assess how many bioregions the taxon group's range overlaps with.

Exposure

We provided maps for the exposure traits that show the environmental change predicted using New Zealand Earth Systems Model (NZESM) for temperature, marine heatwaves, pH, argagonite and calcite saturations between current conditions and two time periods (2050 and 2100). Predictions use two shared socio-economic pathway (SSP) climate change scenarios; SSP2 (4.5) 'moderate scenario' and SSP3 (7.0) 'high emissions scenario'. Thus, there are four maps for each environmental variable. The areas with the top 25% of change (increases or decreases) are outlined in black. Experts were instructed to assess if these areas overlap with >75% of the taxon group's range. For some exposure variables, some of the outlined 'top change' areas hug the coastline, so experts were instructed to pay close attention to these areas.

- Trait 10-13 – Changes in temperature (increases)
- Trait 14-17 – Changes in marine heatwave exposure (increases)
- Trait 18-21 – Changes in pH (decreases)
- Trait 22-25 – Changes in aragonite saturation (decreases)
- Trait 26-29 – Changes in calcite (decreases)

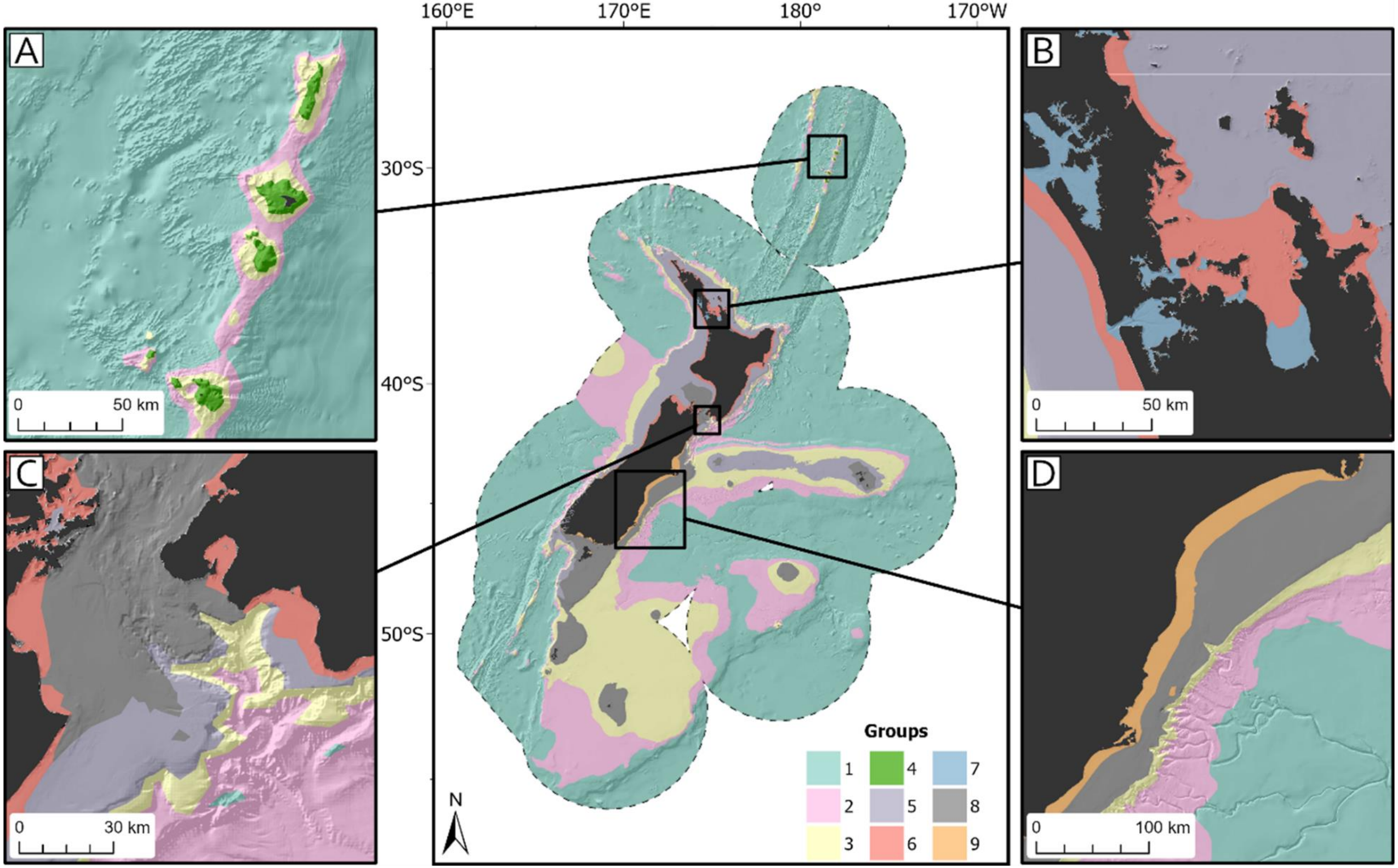

Figure C-1: Trait 6 - Rarity, New Zealand Seafloor Bioregionalisation (Stephenson et al. 2023).

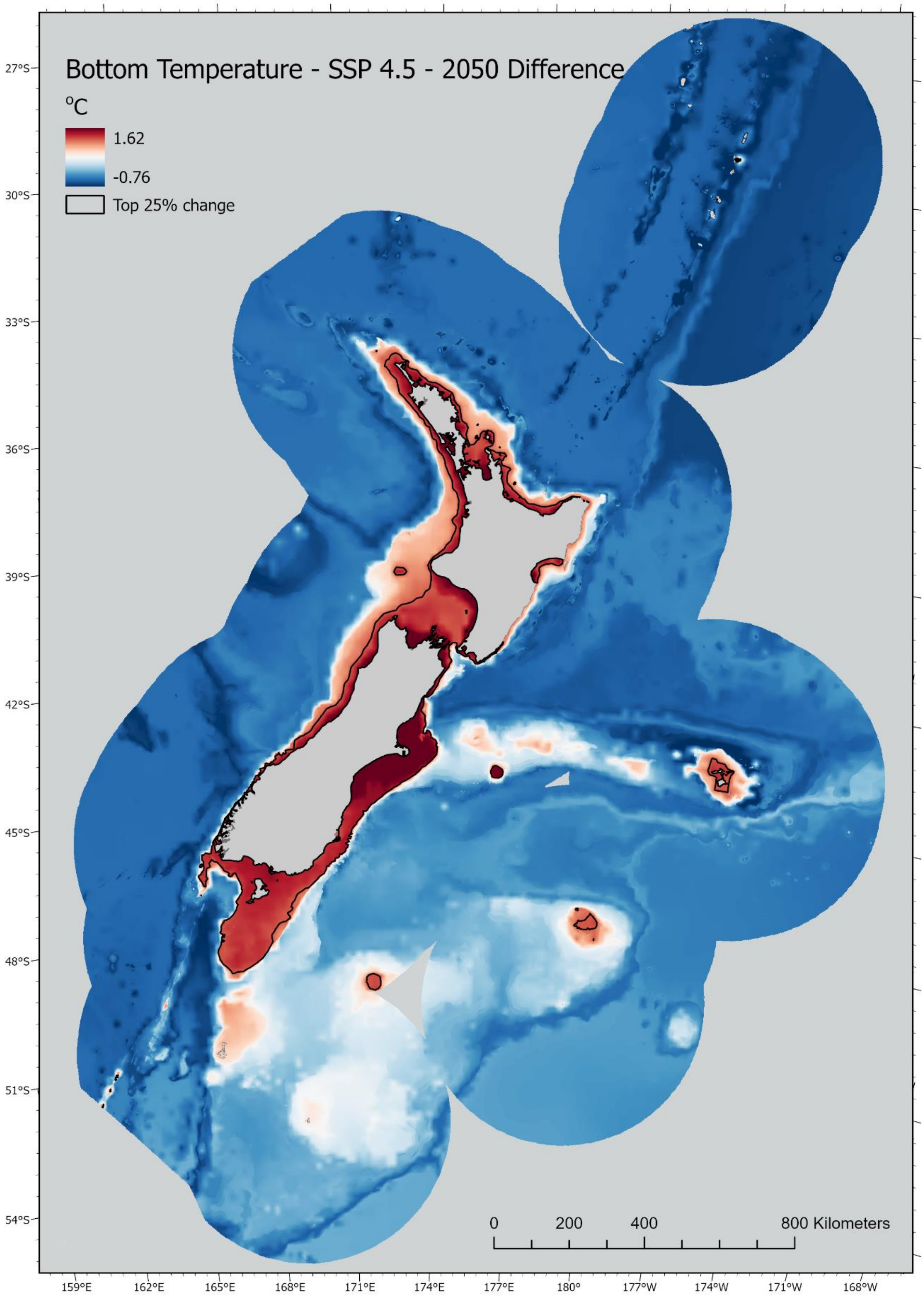

Figure C-2: Trait 10 – Changes in temperature at depth SSP2 (4.5) 2050.

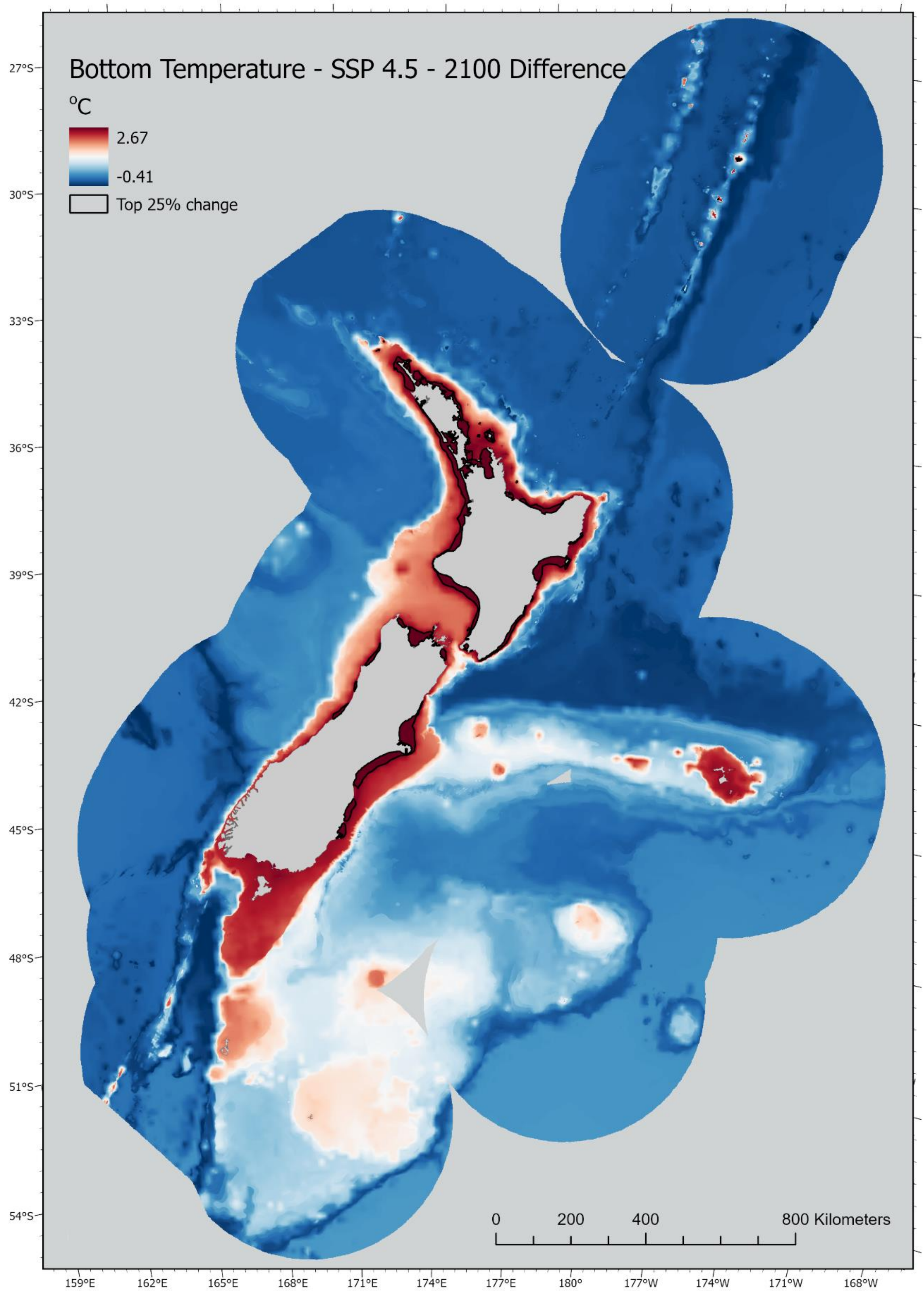

Figure C-3: Trait 11 – Changes in temperature at depth SSP2 (4.5) 2100.

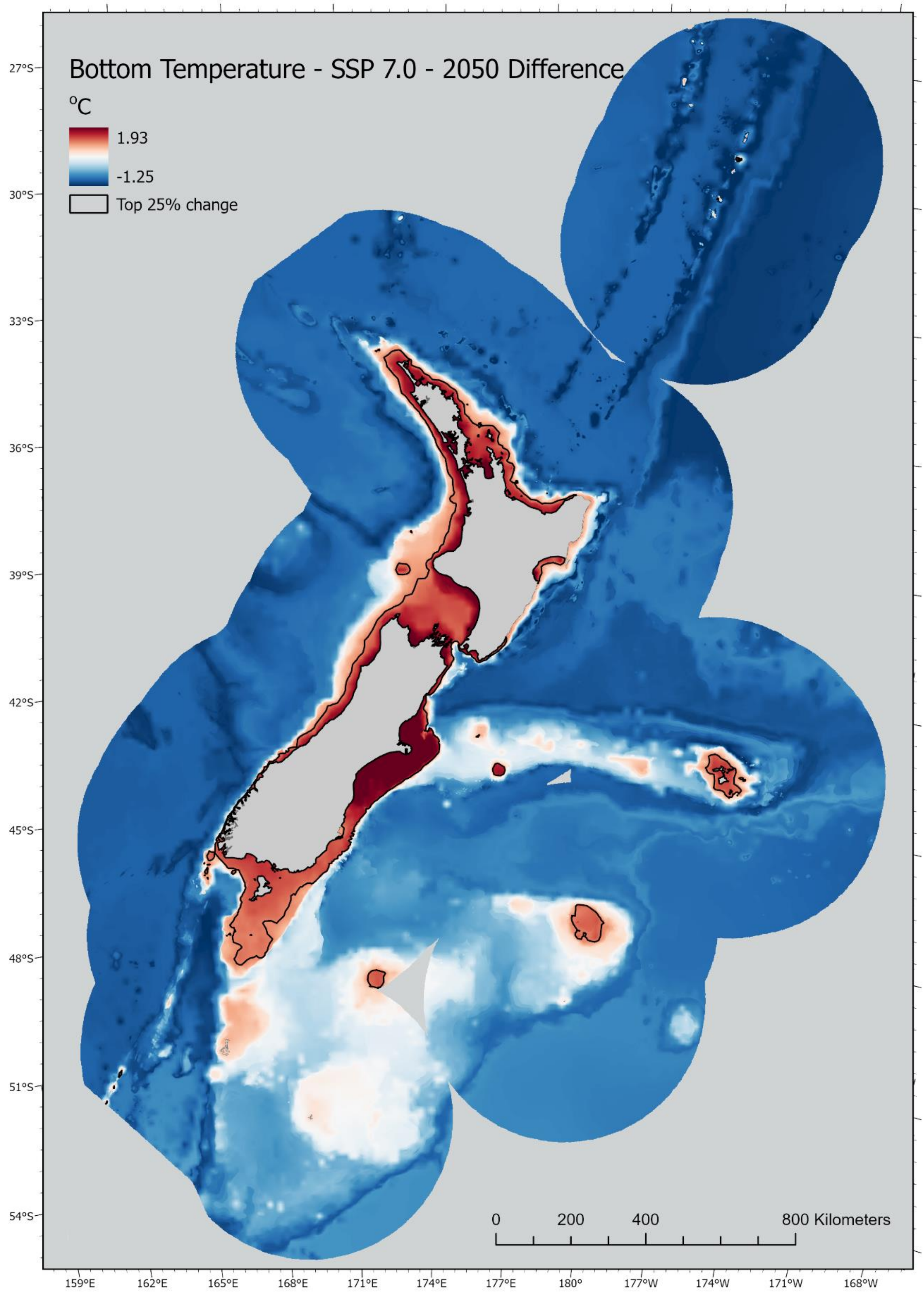

Figure C-4: Trait 12 – Changes in temperature at depth SSP3 (7.0) 2050.

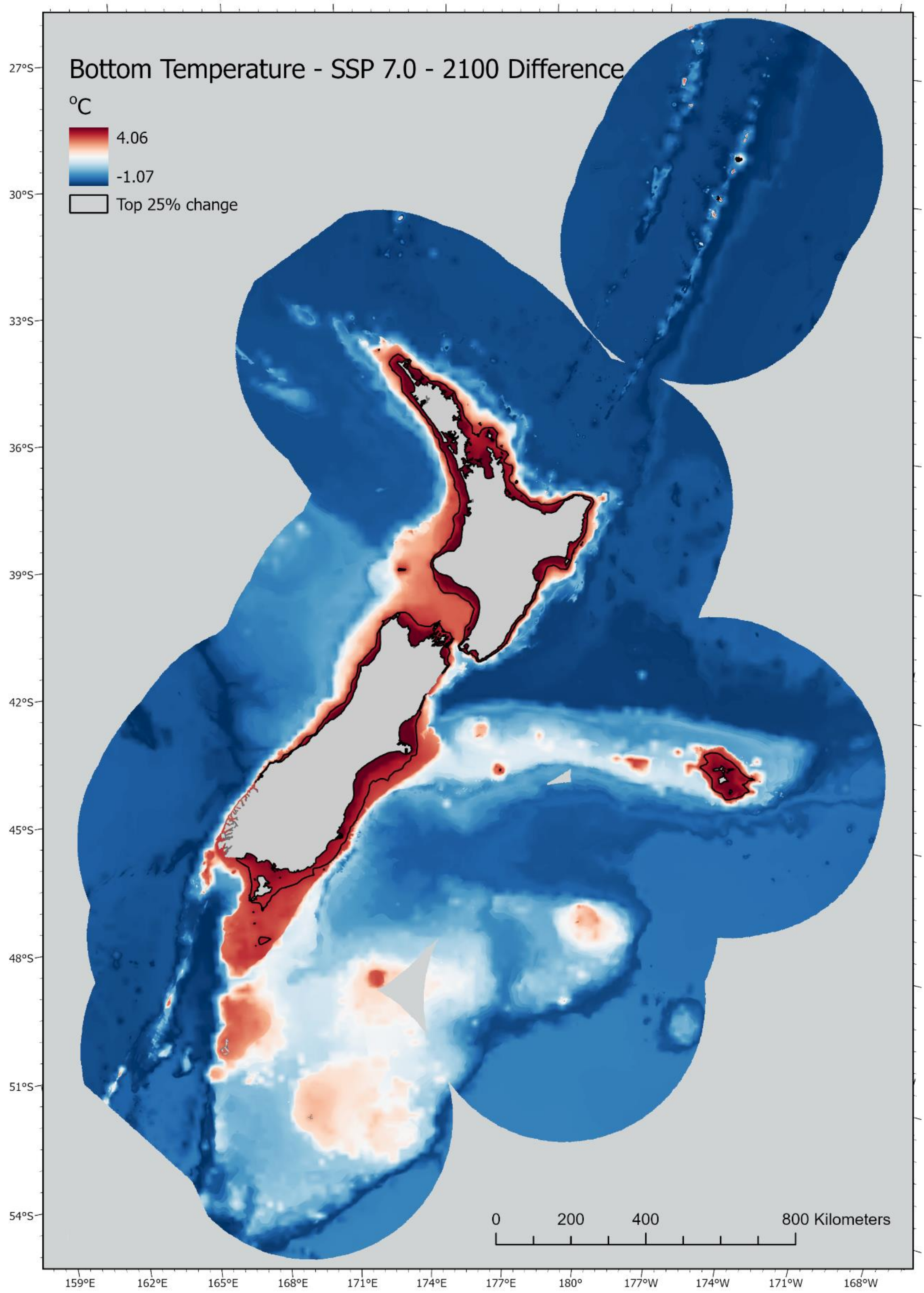

Figure C-5: Trait 13 – Changes in temperature at depth SSP3 (7.0) 2100.

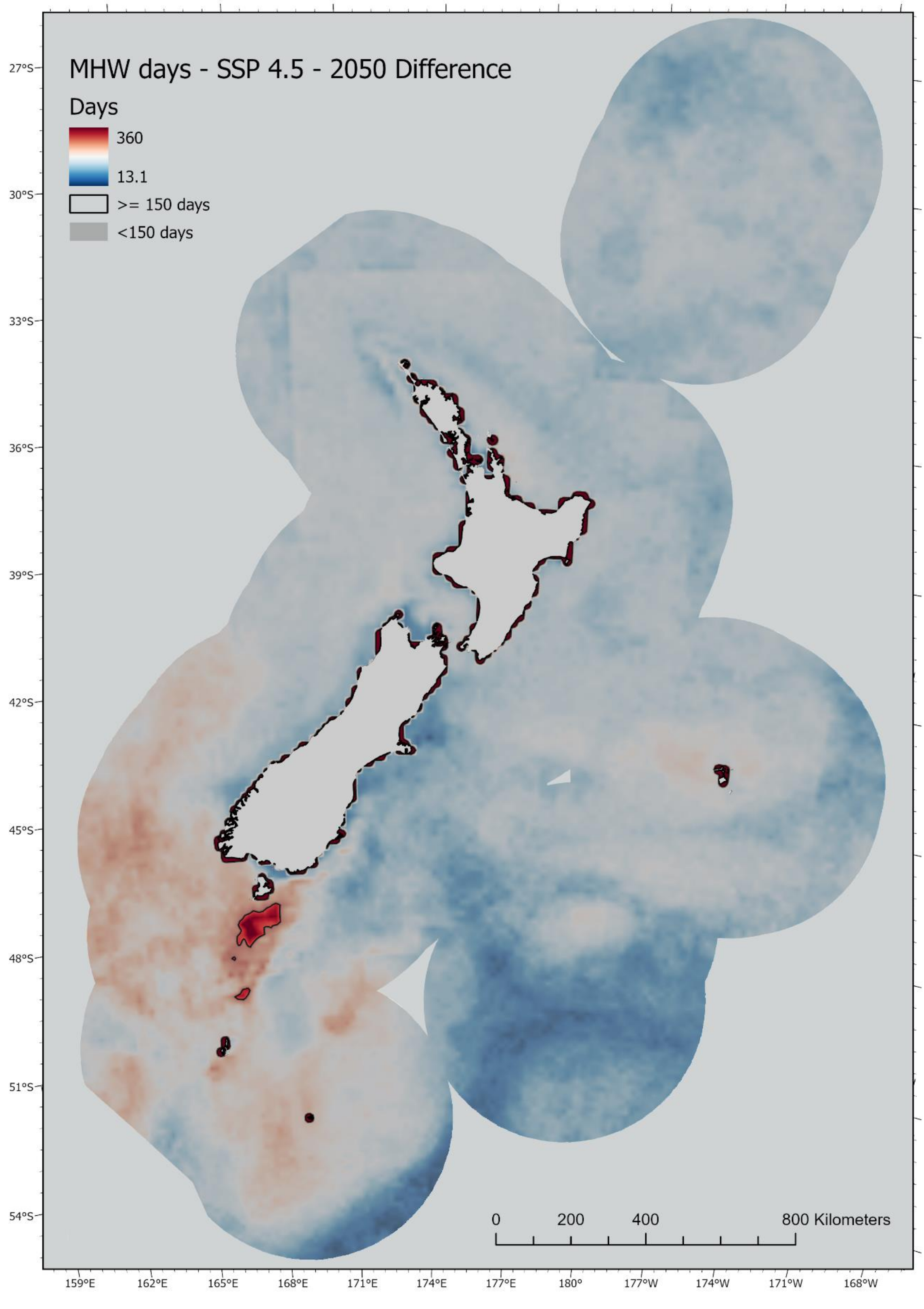

Figure C-6: Trait 14 -Changes in marine heatwave exposure SSP2 (4.5) 2050.

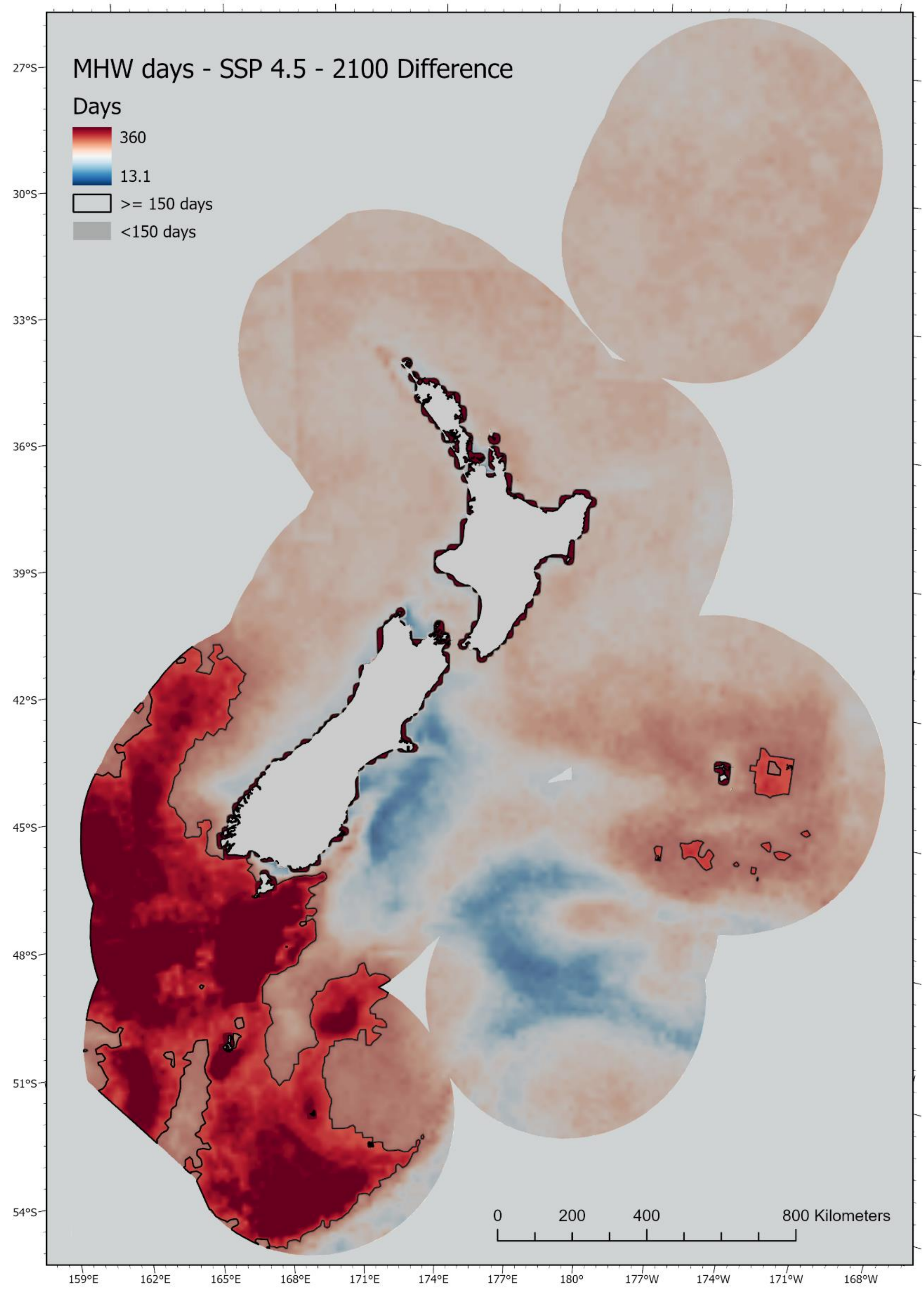

Figure C-7: Trait 15 -Changes in marine heatwave exposure SSP2 (4.5) 2100.

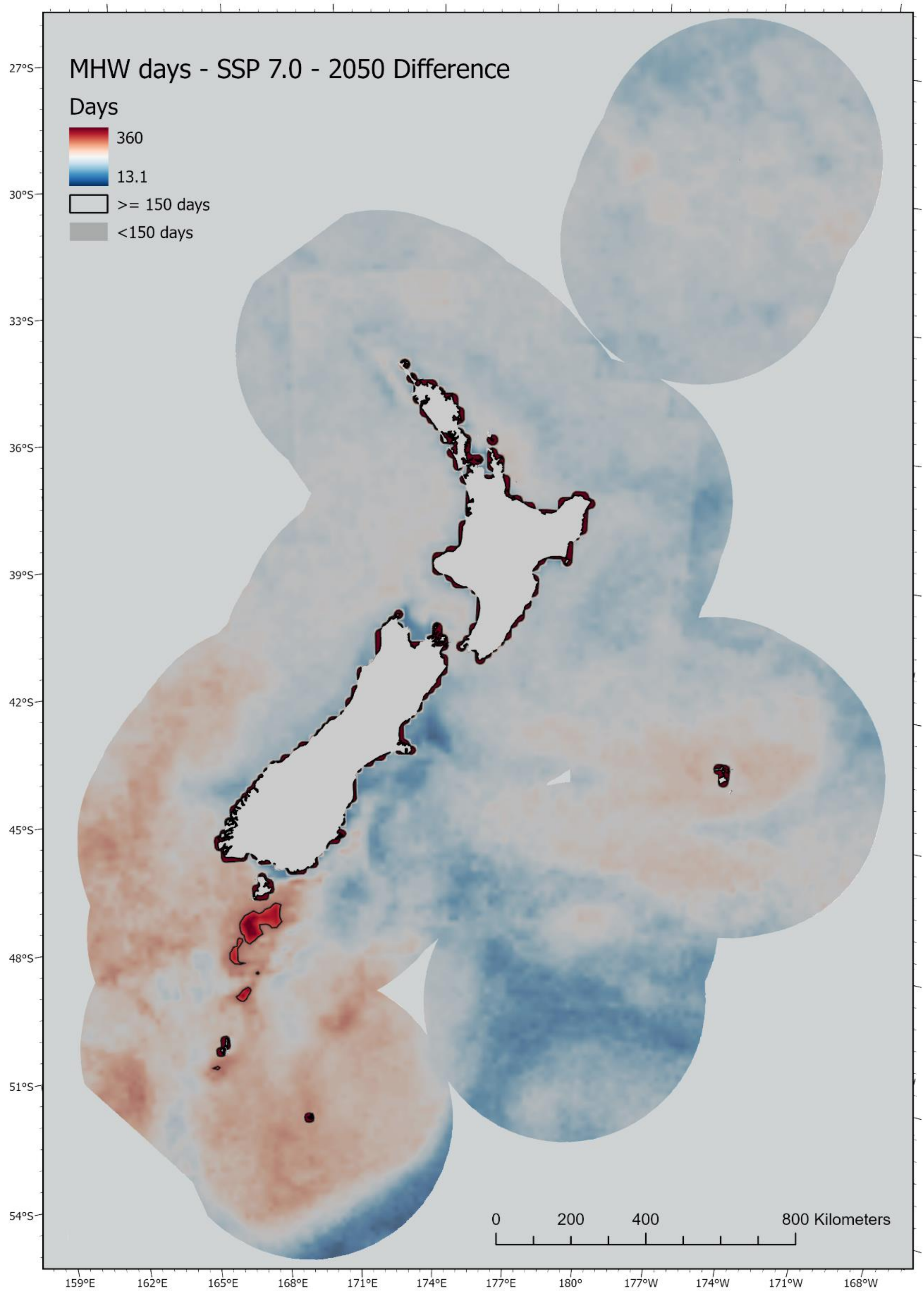

Figure C-8: Trait 16 – Changes in marine heatwave exposure SSP3 (7.0) 2050.

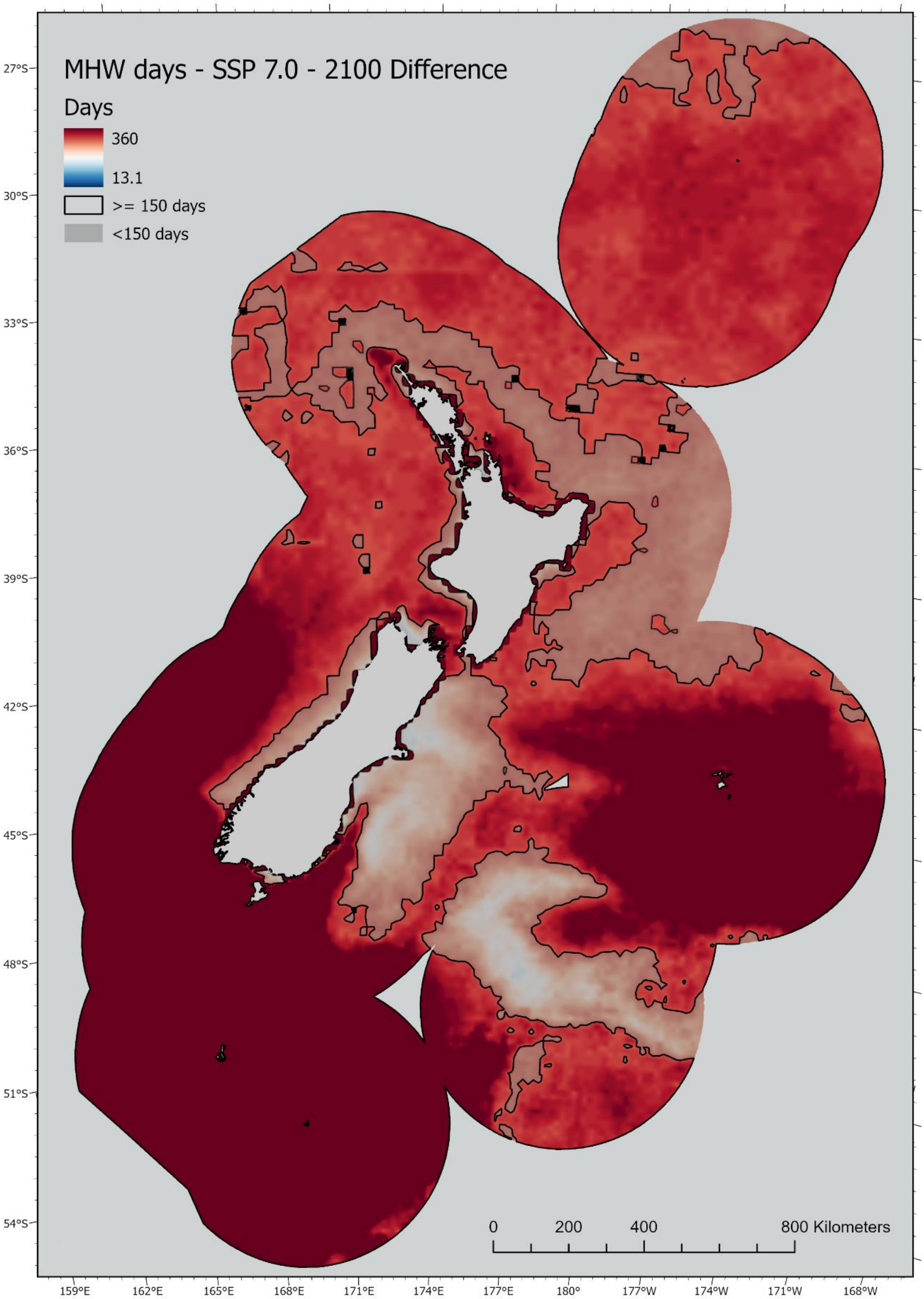

Figure C-9: Trait 17 – Changes in marine heatwave exposure SSP3 (7.0) 2100.

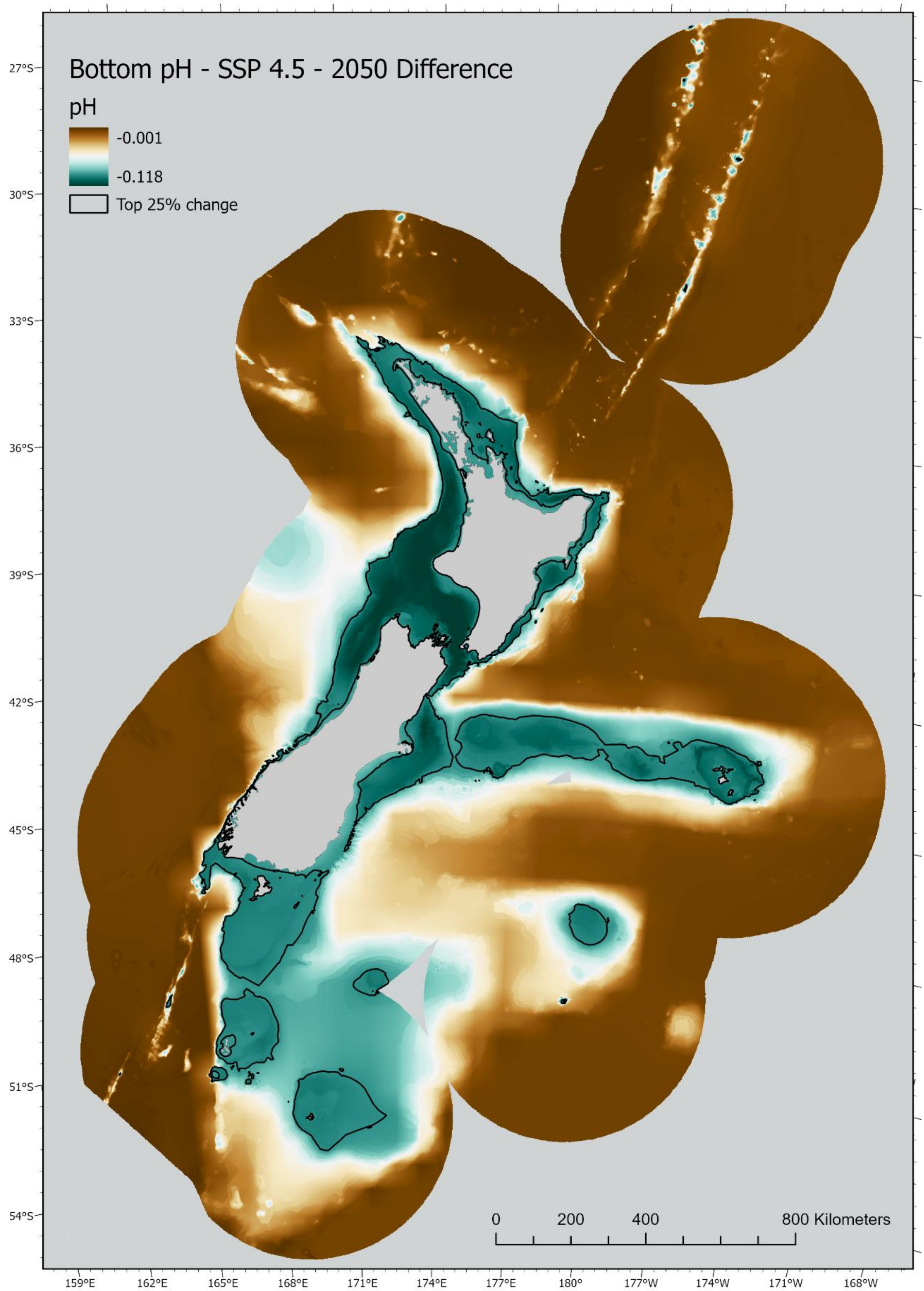

Figure C-10: Trait 18 – Changes in pH SSP2 (4.5) 2050.

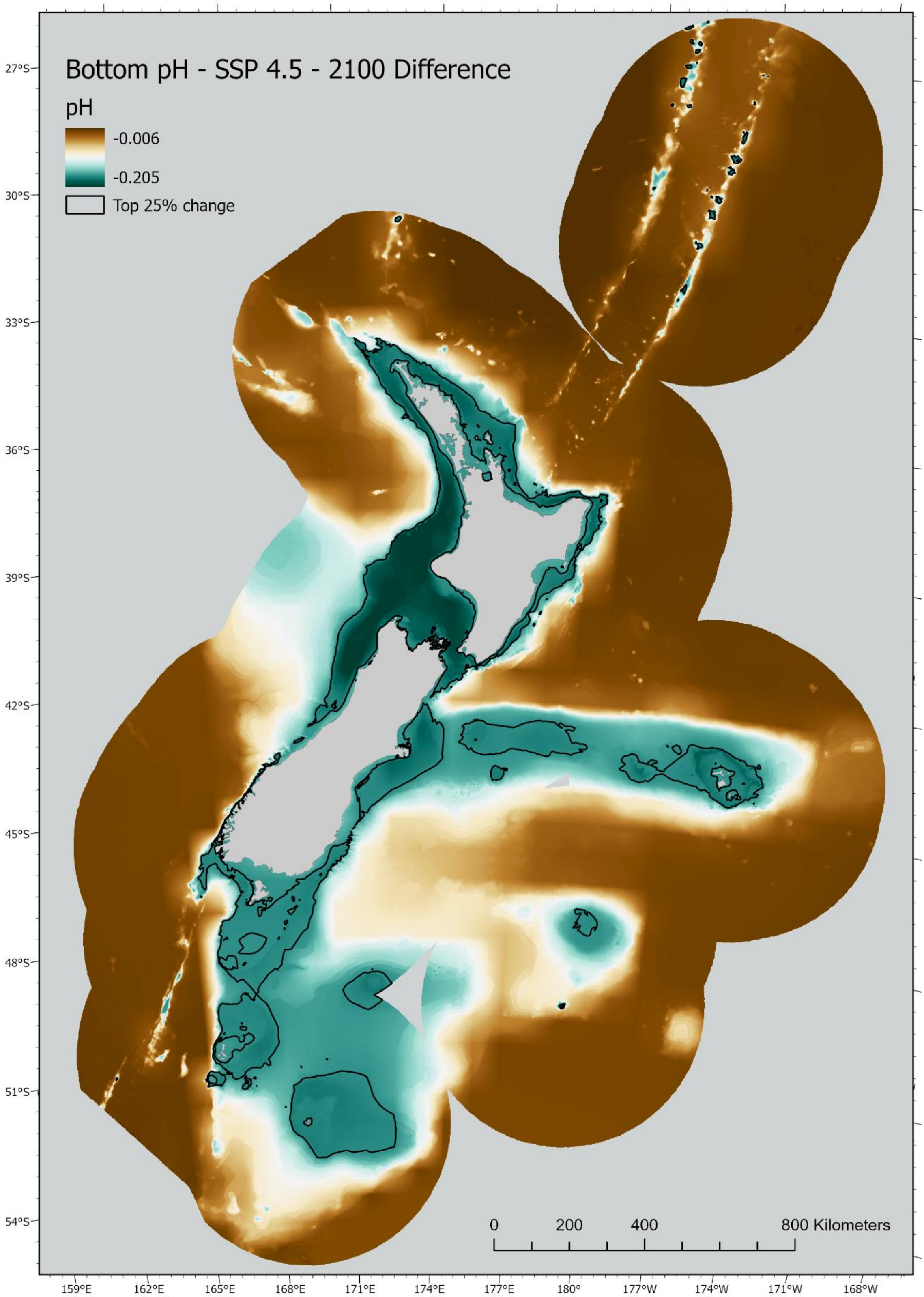

Figure C-11: Trait 19 - Changes in pH SSP2 (4.5) 2100.

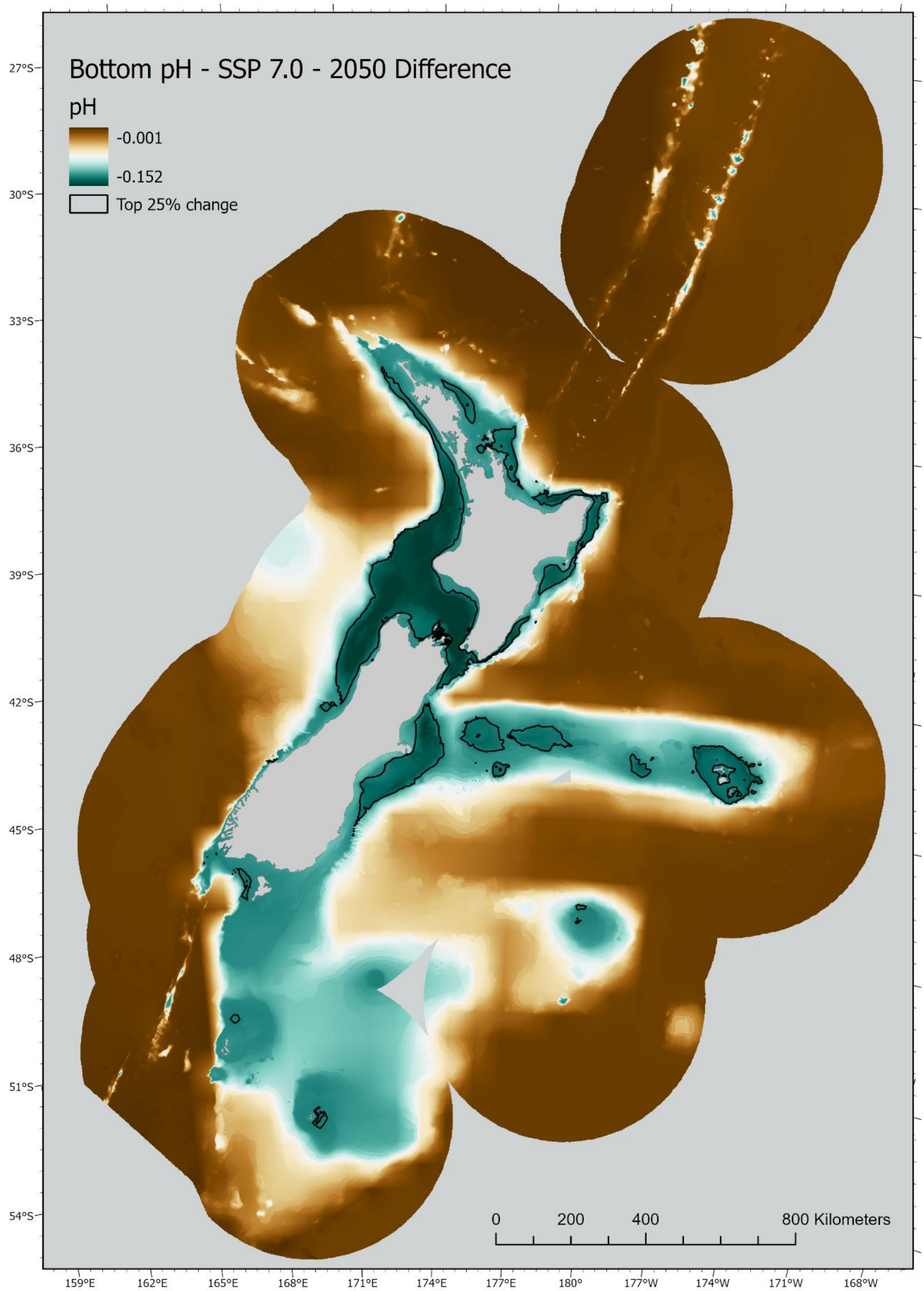

Figure C-12: Trait 20 - Changes in pH SSP3 (7.0) 2050.

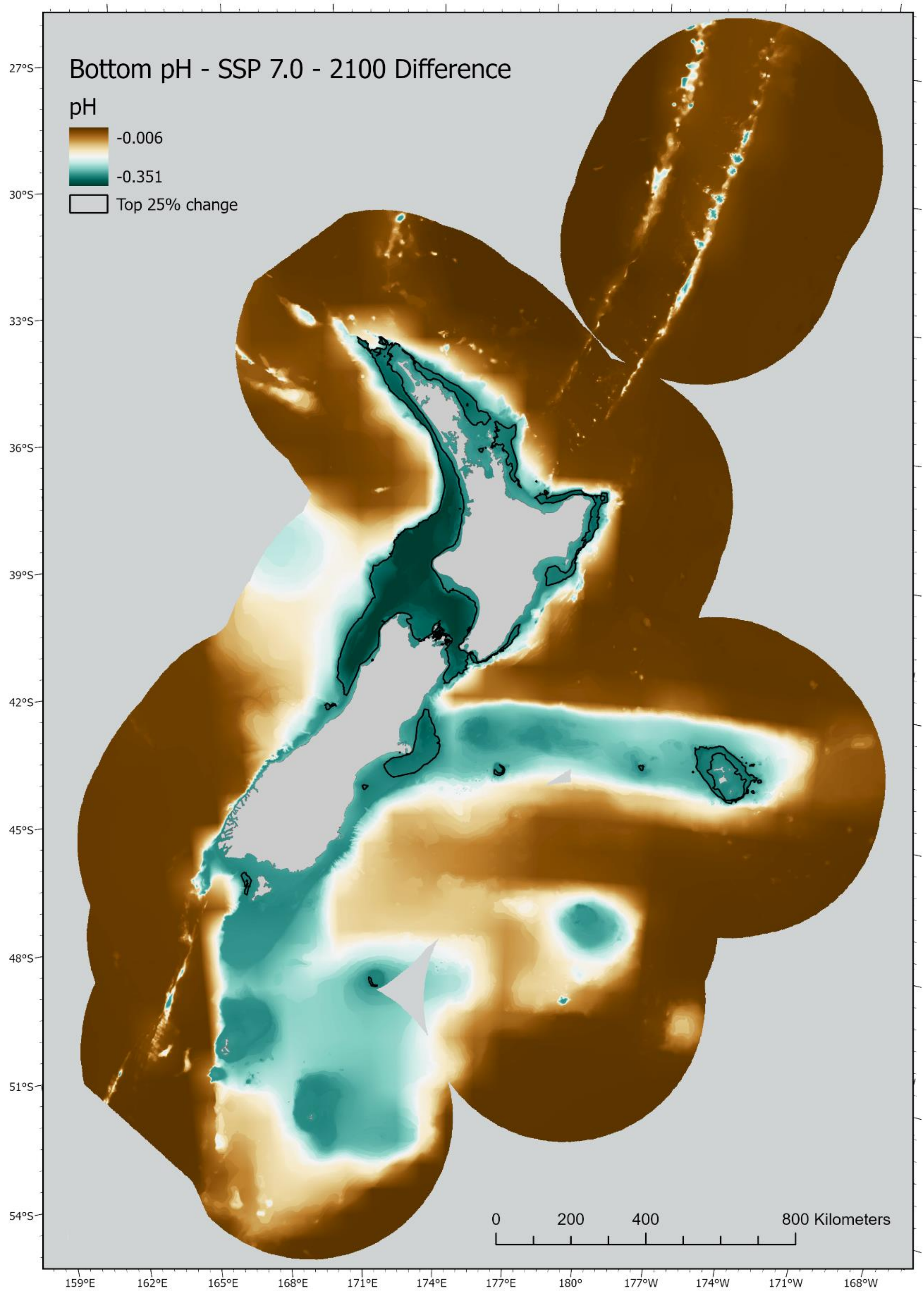

Figure C-13: Trait 20 - Changes in pH SSP3 (7.0) 2050.

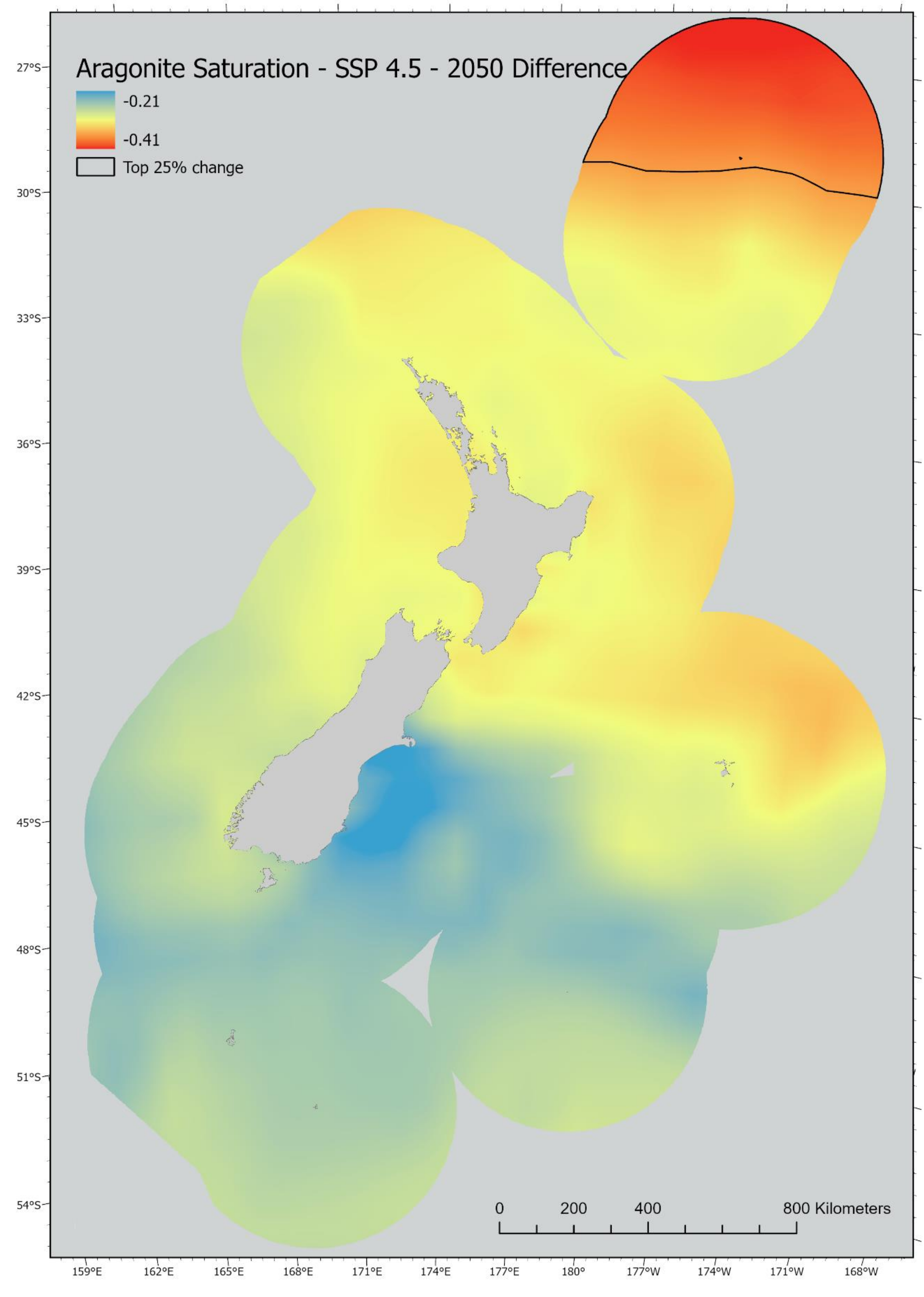

Figure C-14: Trait 22 – Changes in aragonite saturation SSP2 (4.5) 2050.

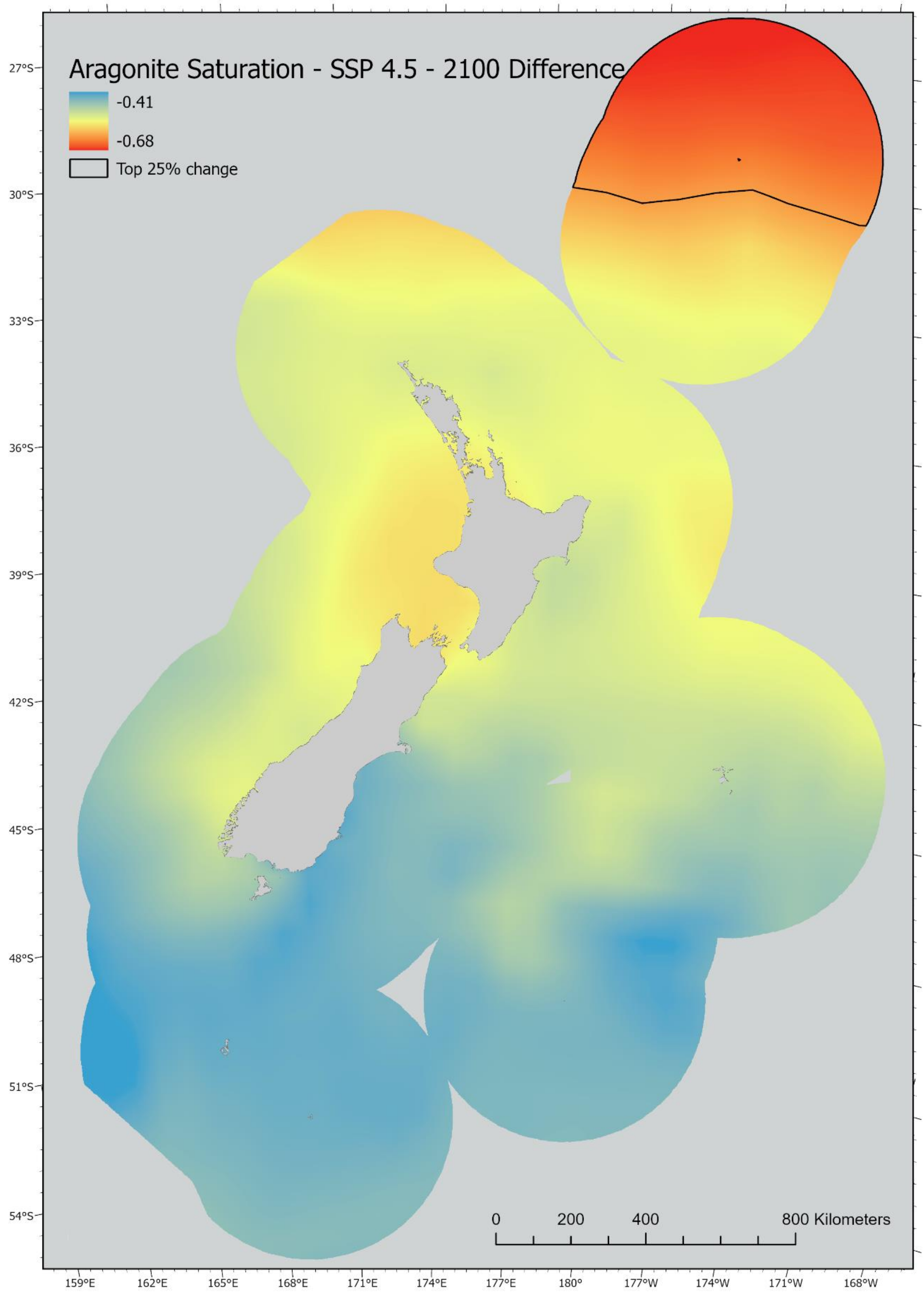

Figure C-15: Trait 23 – Changes in aragonite saturation SSP2 (4.5) 2100.

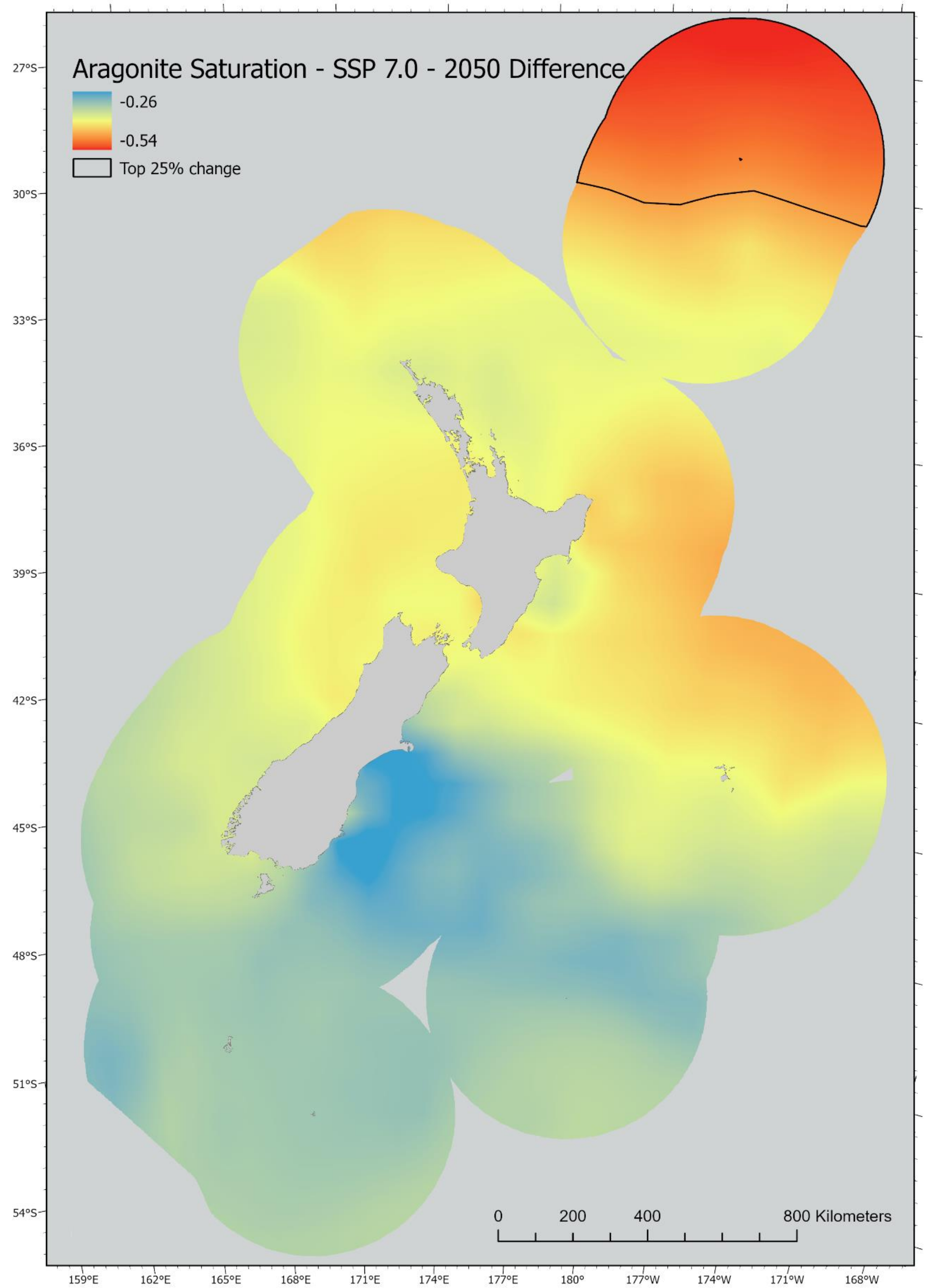

Figure C-16: Trait 24 - Changes in aragonite saturation SSP3 (7.0) 2050.

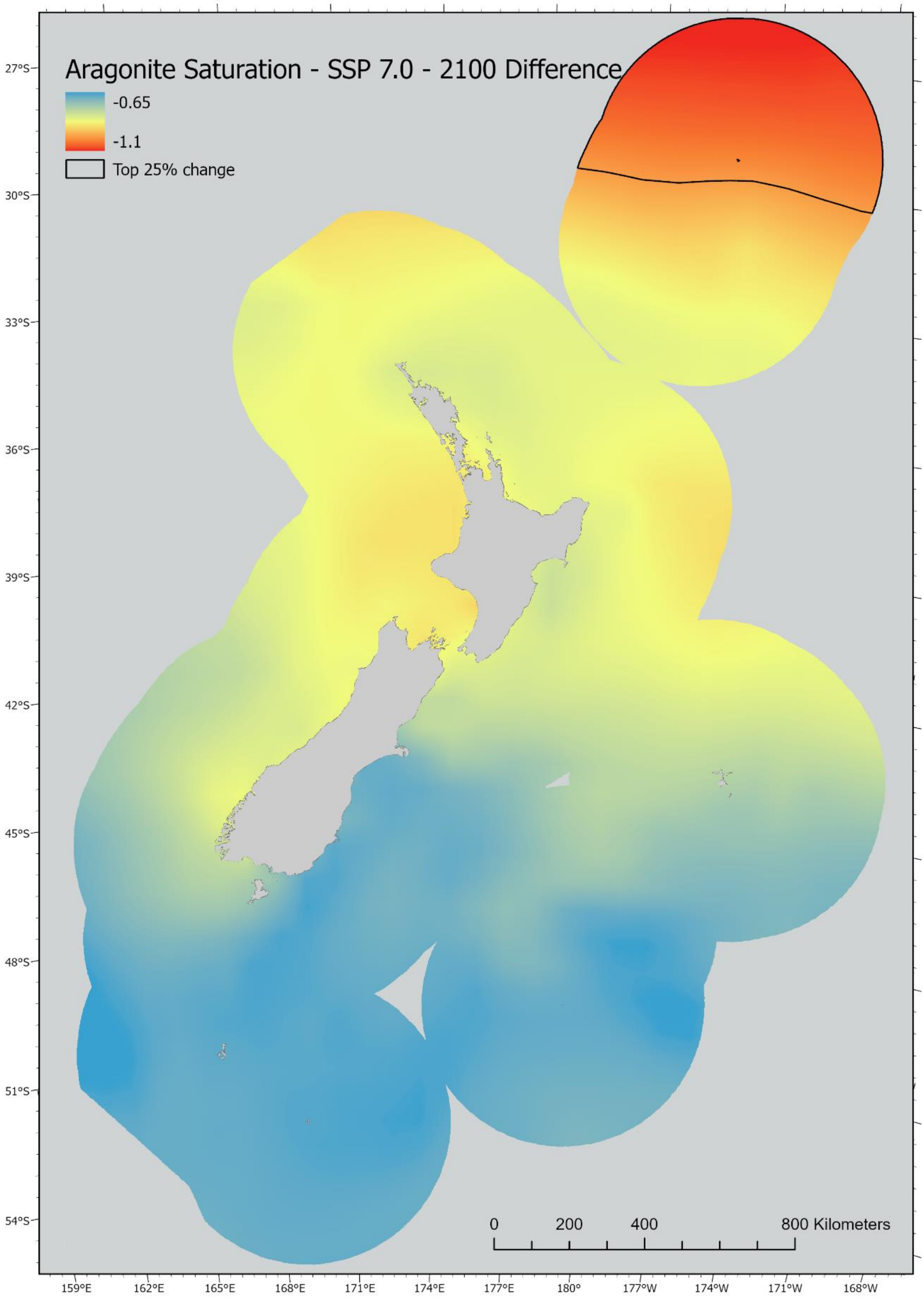

Figure C-17: Trait 24 - Changes in aragonite saturation SSP3 (7.0) 2050.

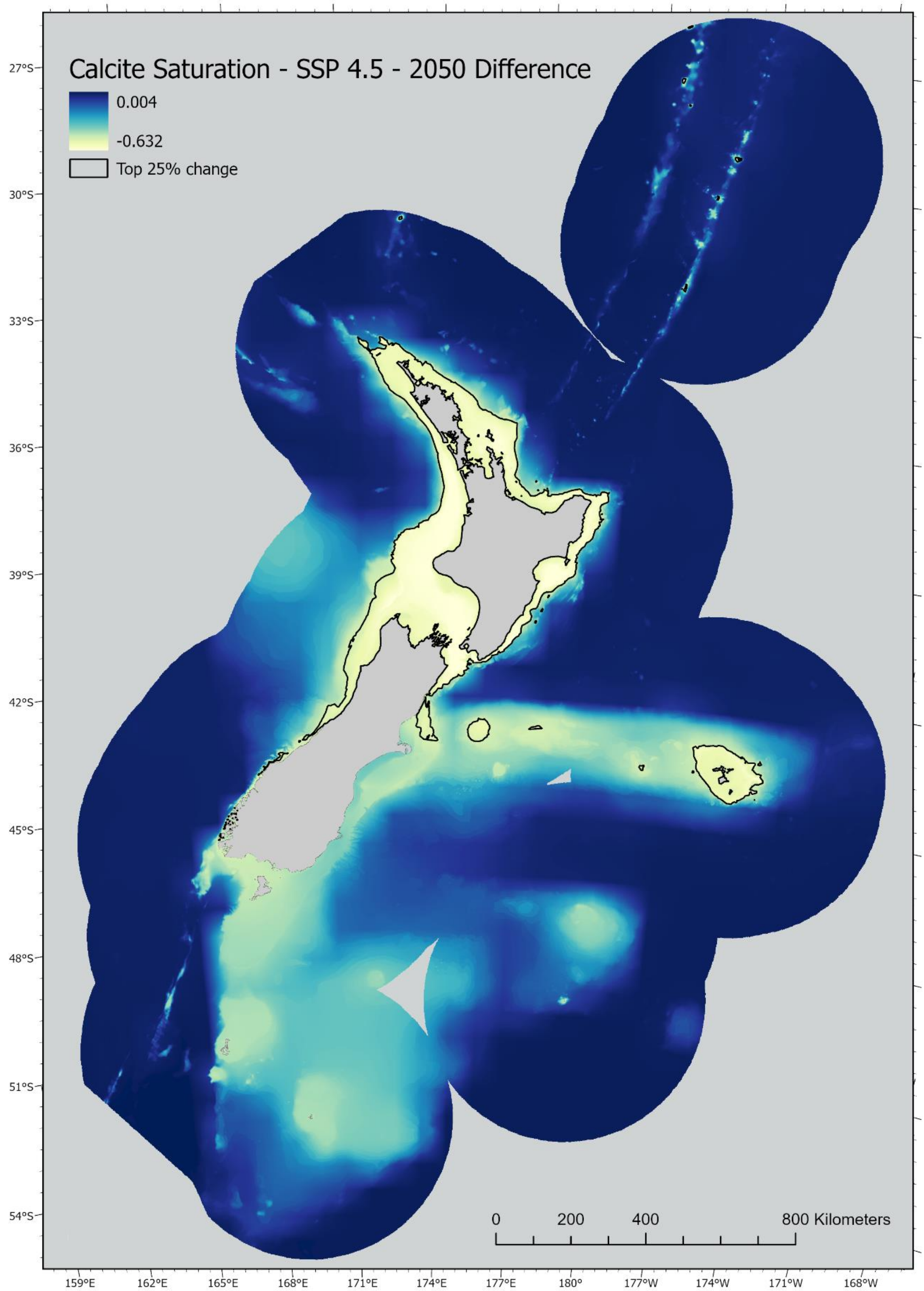

Figure C-18: Trait 26 - Changes in calcite saturation SSP2 (4.5) 2050 .

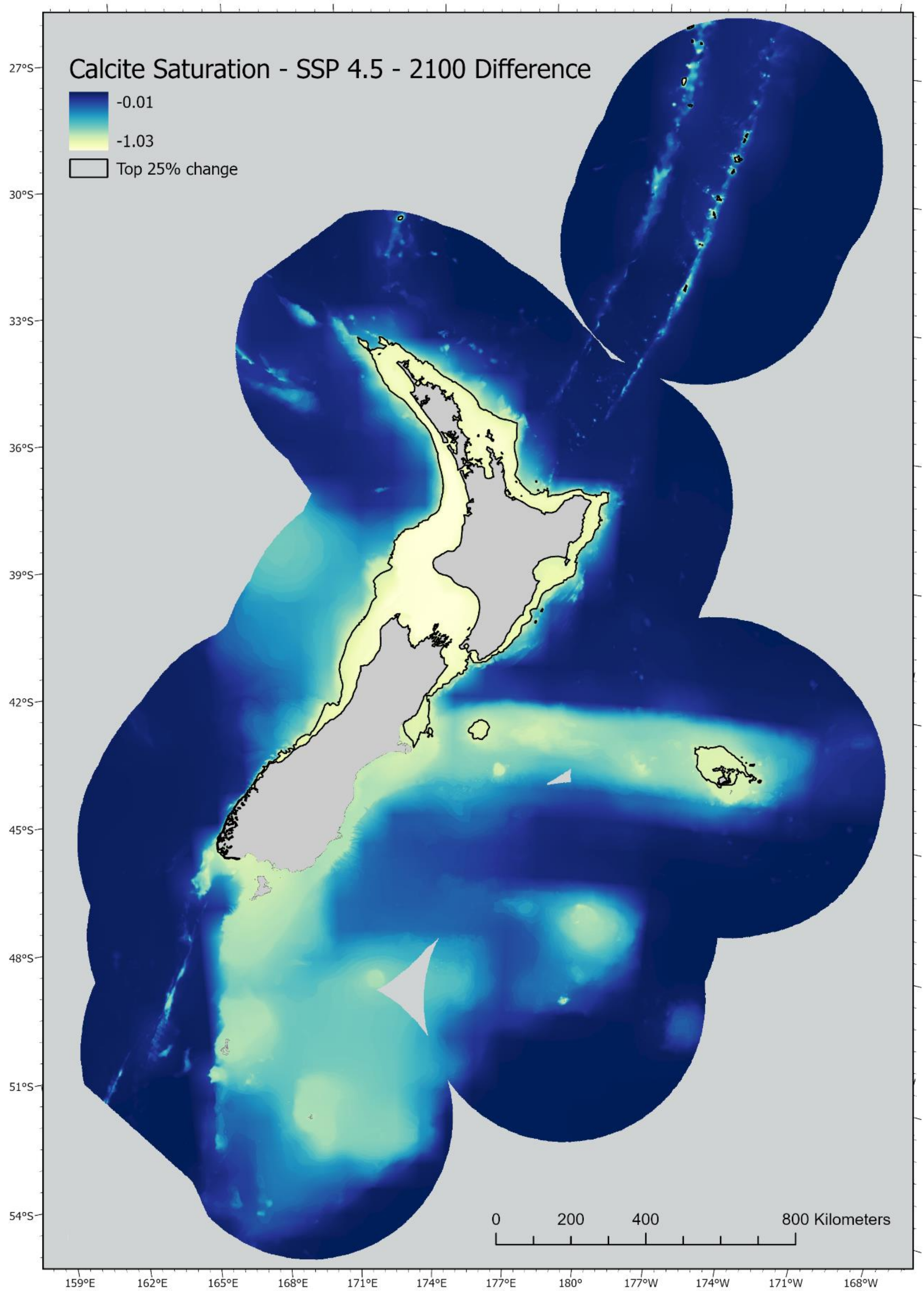

Figure C-19: Trait 27 - Changes in calcite saturation SSP2 (4.5) 2100.

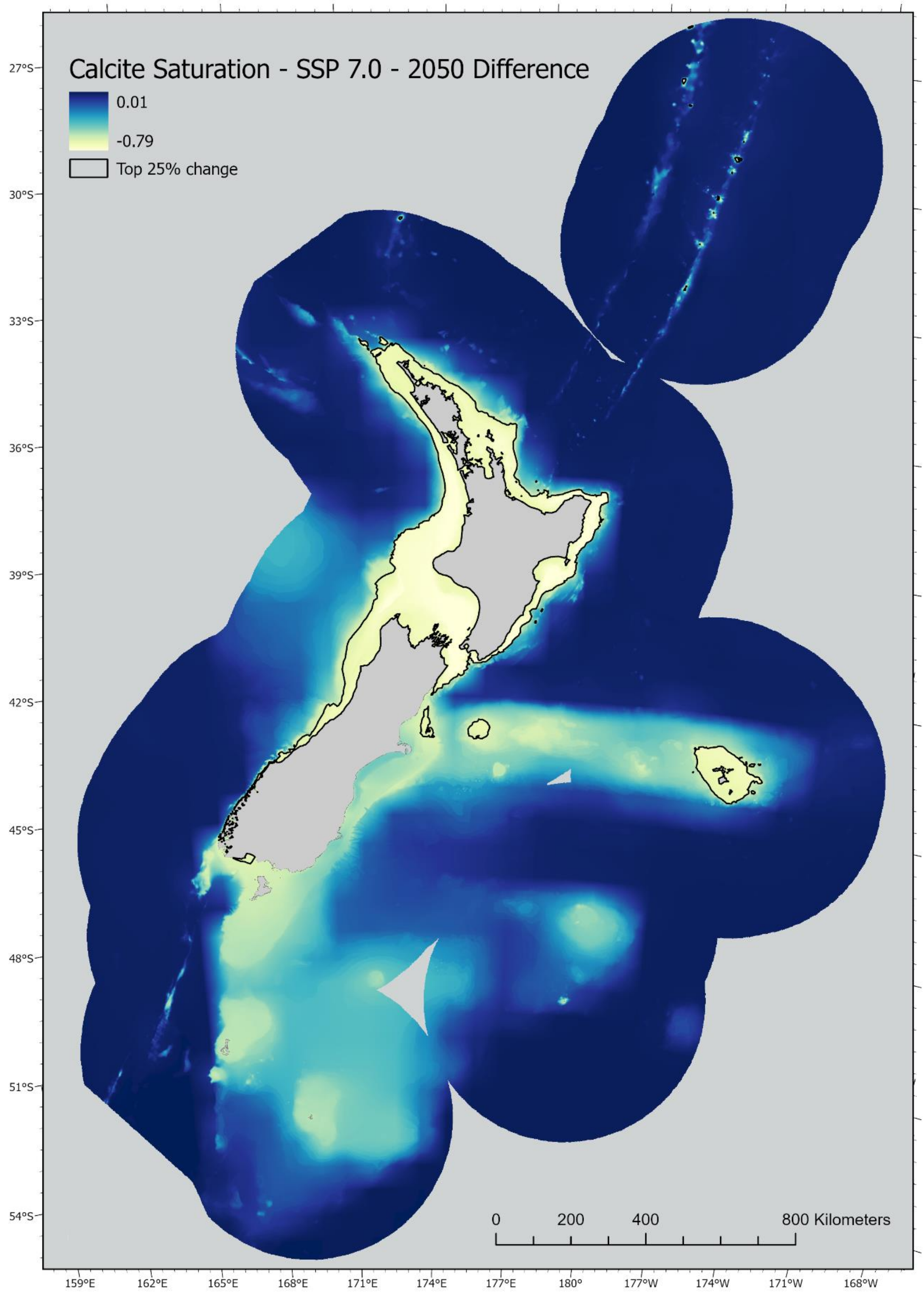

Figure C-20: Trait 28 – Changes in calcite saturation SSP3 (7.0) 2050.

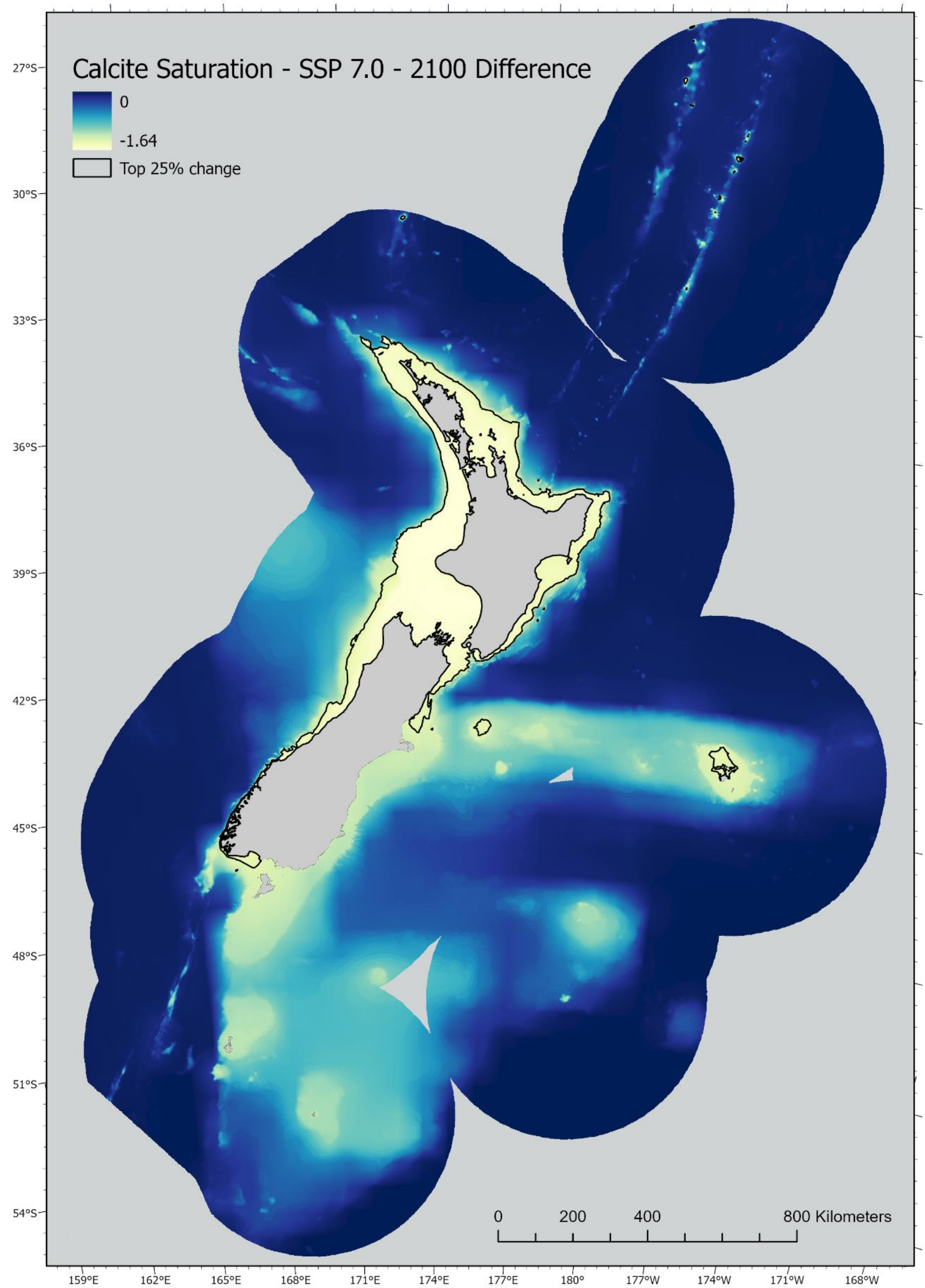

Figure C-21: Trait 29 – Changes in calcite saturation SSP3 (7.0) 2100.

Appendix D Comparisons between climate scenarios and time periods

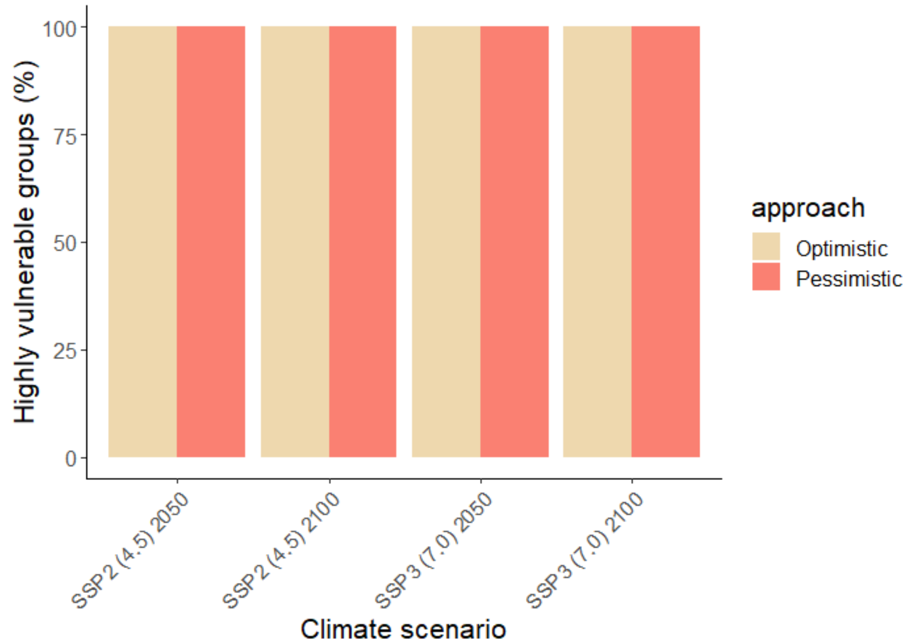

Figure D-1: Percentage of Bryozoan taxon groups assigned Highly Vulnerable for two climate scenarios SSP2 (4.5), and SSP3 (7.0) and two time periods 2050 and 2100.

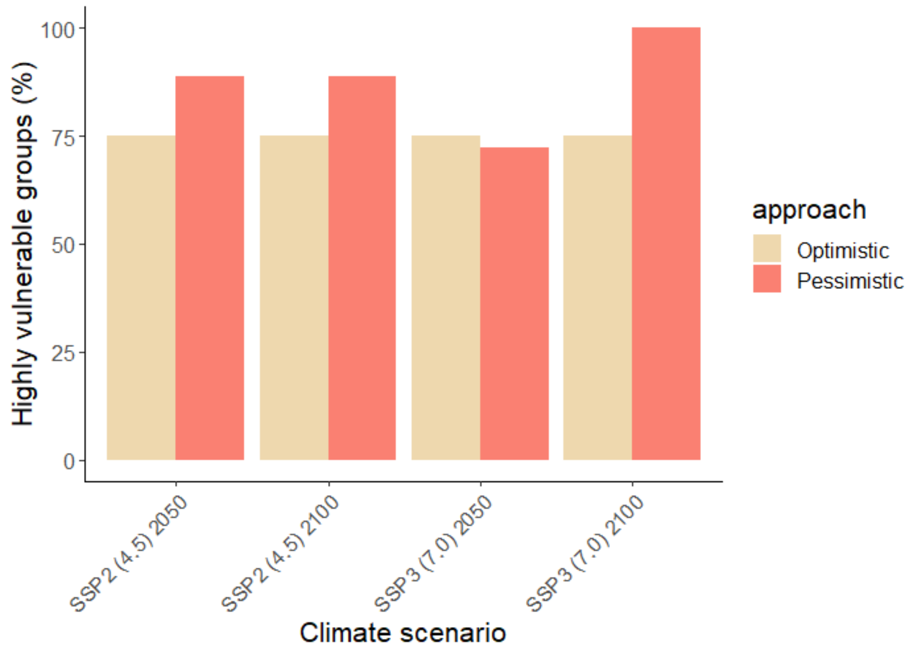

Figure D-2: Percentage of Coral taxon groups assigned Highly Vulnerable for two climate scenarios SSP2 (4.5), and SSP3 (7.0) and two time periods 2050 and 2100.

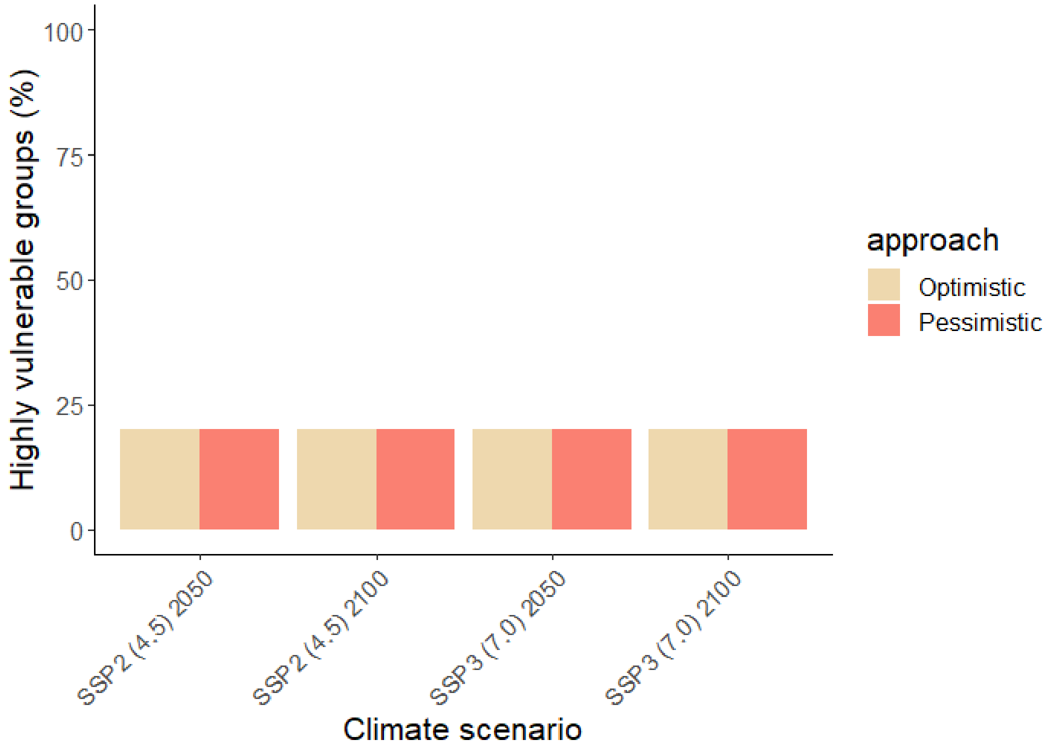

Figure D-3: Percentage of Crustacean taxon groups assigned Highly Vulnerable for two climate scenarios SSP2 (4.5), and SSP3 (7.0) and two time periods 2050 and 2100.

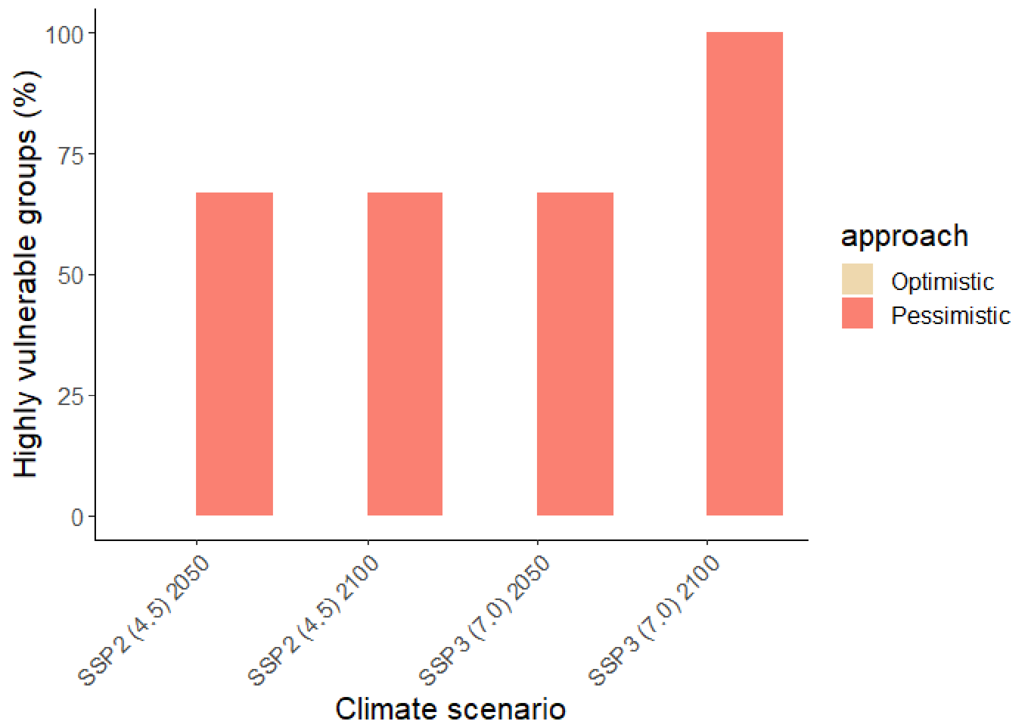

Figure D-4: Percentage of Echinoderm taxon groups assigned Highly Vulnerable for two climate scenarios SSP2 (4.5), and SSP3 (7.0) and two time periods 2050 and 2100. No groups were assigned Highly Vulnerable for the Optimistic approach.

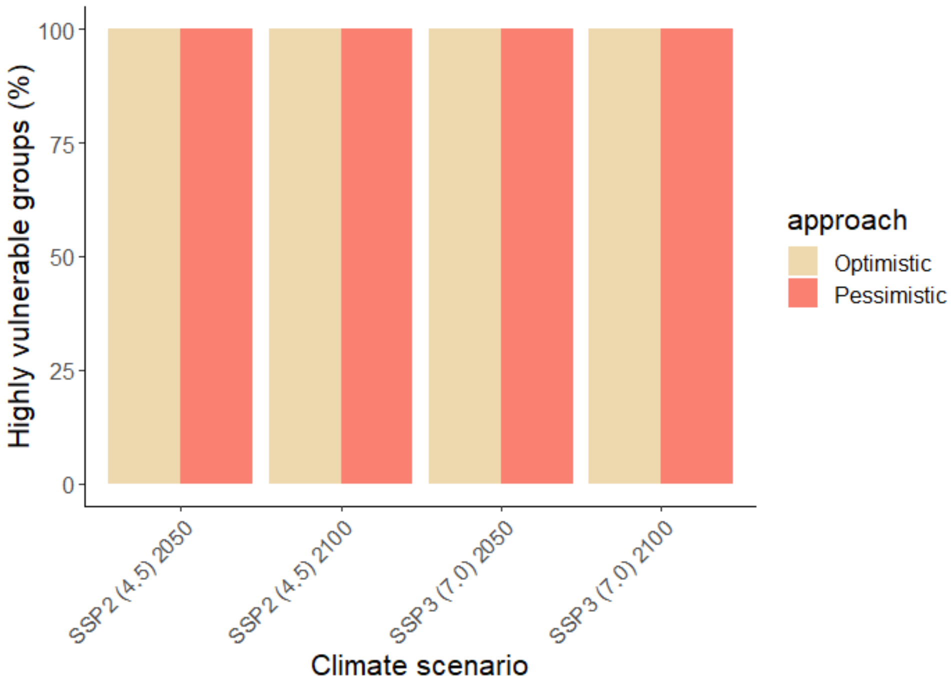

Figure D-5: Percentage of Macroalgae taxon groups assigned Highly Vulnerable for two climate scenarios SSP2 (4.5), and SSP3 (7.0) and two time periods 2050 and 2100.

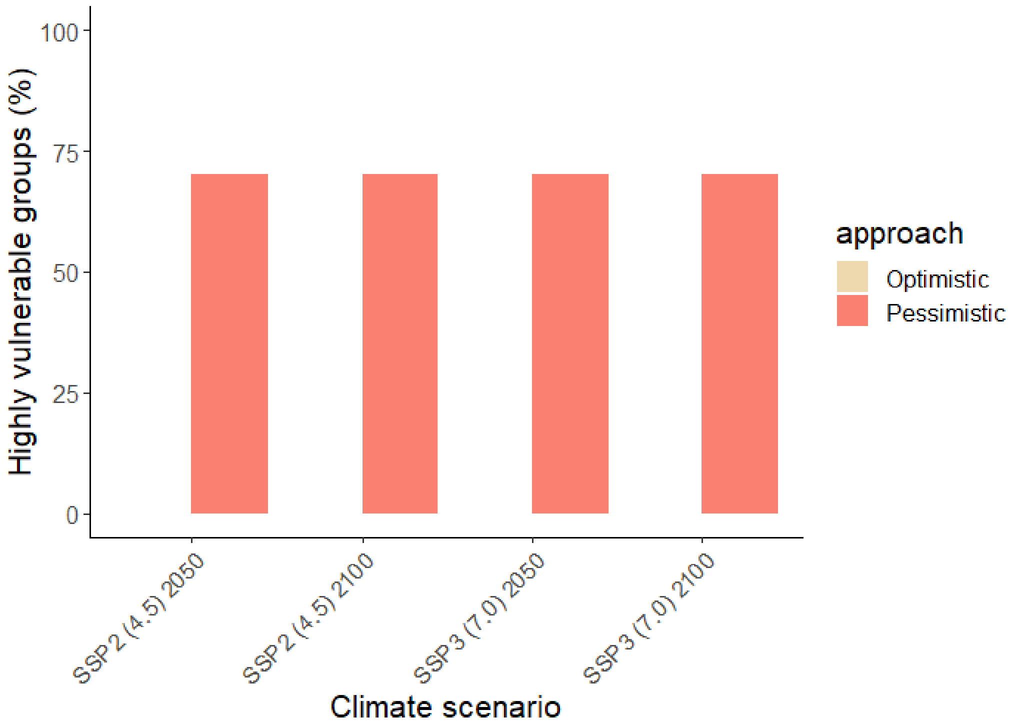

Figure D-6: Percentage of Mollusc taxon groups assigned Highly Vulnerable for two climate scenarios SSP2 (4.5), and SSP3 (7.0) and two time periods 2050 and 2100. No groups were assigned Highly Vulnerable for the Optimistic approach.

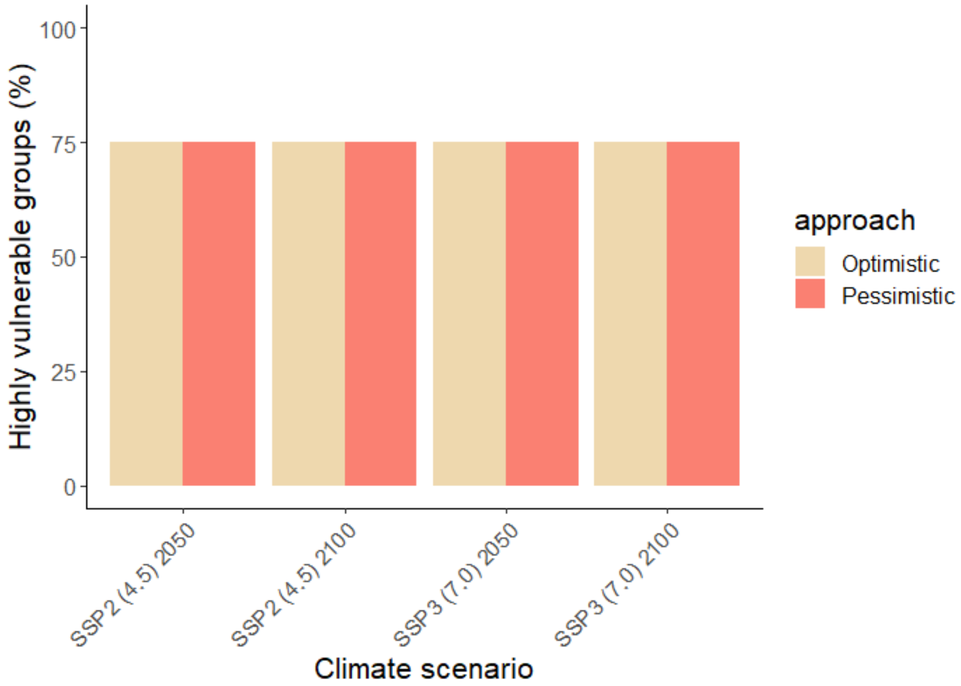

Figure D-7: Percentage of Sponge taxon groups assigned Highly Vulnerable for two climate scenarios SSP2 (4.5), and SSP3 (7.0) and two time periods 2050 and 2100.