# Climate Change Vulnerability Assessment of Selected Taonga Species

Technical Report

**MARCH 2020** 







# Climate Change Vulnerability Assessment of selected taonga freshwater species

Technical report

Prepared for Te Wai Māori Trust

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# Summary

#### Background

To respond to and prepare for changes in climate, and the effects of those changes on our fresh water and oceans, decision-makers need information on species vulnerability to climate change. Te Wai Māori Trust recognises that observed and/or predicted impacts of climate change on taonga freshwater species needs to be factored in to effectively manage, enhance and conserve taonga species in Aotearoa-New Zealand both now and in the future.

Climate Change Vulnerability Assessments (CCVAs) are a structured, transparent and reproducible methodology that can be used to assess species' vulnerability to climate change. CCVAs are used internationally to rapidly identify species that are most vulnerable to climate change but have seldomly been used in Aotearoa-New Zealand. This report presents an assessment of the vulnerability of 10 freshwater taonga species (eight fish and two invertebrates) using the CCVA methodology. To complete the CCVAs, we drew on:

- Available published literature Where information was not available from Aotearoa-New Zealand-based studies, we accessed the international literature. This was particularly useful for species that we have in common with Australia;
- Projections of relevant environmental/exposure variables, or desktop assessments where projections were not available – Projections were made for two Representative Concentration Pathway scenarios (4.5 and 8.5) and two timeframes, 35 years from now (2046–2065) and 70 years from now (2081–2100);
- Workshops Where individuals ("expert species assessors ") with expertise in the relevant freshwater taonga species biology and ecology ranked the sensitivity attributes and exposure variables of that species.

#### Climate Change Vulnerability Assessment: Method overview

The CCVAs involved six key stages:

- First, the spatial scale of the assessment for each species (i.e., individual catchments, regions or nationally) was determined. We decided to complete a national scale CCVA as a first step considering that significant data gaps exist in our understanding of taonga species ecology and life histories at the regional and/or catchment scale.
- 2. We created species profiles so that all expert assessors were provided with the available background information in a standardised format for the CCVAs. The species profiles covered 12 topics concerning basic biology and ecology (life cycle, demographics, recruitment, habitat requirements, diet and predation, ecosystem level interactions), fisheries data (where appropriate) and any relevant national/international literature on the effects of climate change, and their sensitivity and resilience to environmental change.
- 3. Twelve sensitivity attributes were chosen for the CCVA based on information synthesised in the species profiles and a summary of relevant international literature (Figure 1-1). Sensitivity attributes include biological or ecological variables that predict the potential vulnerability of each species to climate change. For example, a species that



has low reproductive output may be more sensitive to climate change compared to a species with high reproductive output.

# Figure 1-1: Sensitivity attributes scored for each freshwater taonga species as part of the Climate Change Vulnerability Assessment.

- 4. Climate exposure variables were selected based on: (1) environmental parameters known to affect the freshwater taonga species being assessed, and (2) data availability.
  - Four exposure variables were considered relevant to the freshwater life phase of taonga species: air temperature, precipitation, wind, and potential evaporation deficit (as a proxy for drought intensity). The exposure variables were sub-divided into annual and seasonal timescales (spring, summer, autumn and winter) because of the seasonally-dependent movements and life histories of the species being assessed (see Figure 1-2). Extremes in air temperature and precipitation were also used as exposure variables in the CCVAs (Figure 1-2);
  - Projections of temperature, precipitation, air wind, and potential evapotranspiration deficit (as a proxy for drought intensity) were prepared using six-model dynamically downscaled Global Climate Model averages. Projections were made for two greenhouse gas scenarios herein referred to as Representative Concentration Pathways (RCP). The RCP scenarios used for the exposure variables were 4.5 and 8.5. RCP 8.5 is the high-concentration scenario (atmospheric CO<sub>2</sub> of 936 ppm in 2100) that assumes little or no stabilisation of greenhouse gas concentrations (i.e., a "business as usual scenario") by 2100. RCP 4.5 (CO<sub>2</sub> concentrations of 538 ppm by 2100) represents a moderate-concentration scenario and requires stabilisation of greenhouse gas concentrations during the twenty-first century. For each RCP scenario, the projected magnitude of change for each exposure variable was also mapped at two projection timelines: mid-century (2046–2065) and late-century (2081–2100);



**Figure 1-2:** Exposure variables chosen for the Climate Change Vulnerability Assessment. These are the variables with projection maps available for the two timelines (2046–2065 and 2081–2100) and RCP scenarios (4.5 and 8.5)<sup>1</sup>.

- Exposure variables relevant to the marine life phase of taonga species (i.e., eels, whitebait species and lamprey) were sea surface temperature, ocean currents and sea-level rise. Projected changes in sea surface temperature were derived at the annual scale for RCP 8.5 for 2081–2100 (Figure 1-2). Descriptions of sea level rise and changes in near-shore ocean currents were synthesised from recent publications and reports;
- We also synthesised information about the Western Pacific Ocean from the literature especially changes to the speed and direction of the East Australian Current which is a Western Boundary Current system. The Western Pacific Ocean is the perceived location of longfin and shortfin eel spawning grounds and may be a migration route for lamprey. Any predicted changes to the oceanography of the Western Pacific Ocean may therefore affect these taonga species.
- 5. To complete the CCVAs, a series of workshops were held with individuals with the appropriate expertise in the relevant taonga species biology and ecology. A scoring system was applied<sup>2</sup> for the sensitivity attributes (i.e., dispersal, habitat specificity; Figure 1-1) and exposure variables. The scores for the sensitivity and exposure attributes were then combined to derive a relative climate change vulnerability ranking for each species being assessed. Data quality were scored by the expert assessors for the sensitivity attributes.

<sup>&</sup>lt;sup>1</sup> Note: sea surface temperature predictive maps were only available for the timeframe 2081–2100 and RCP 8.5.

<sup>&</sup>lt;sup>2</sup> As per Morrison et al. (2015)

#### Literature review: Summary of results

We identified five climatic factors from the national/international literature broadly affecting taonga species. These were: drought, temperature (indirect [air temperature] and direct [water temperature]), El Niño/La Niña cycles, sea level rise, and extreme events (i.e., storms).

The 2019 International Union for Conservation of Nature (IUCN) threat ranking assessments indicate that climate change, especially drought, temperature and severe weather, are key threats to three taonga species: longfin eel/tuna, shortfin eel/tuna and kōaro. Studies in Australia indicate that droughts and increased air temperatures affect shortfin eels. However, in an analysis of 15 freshwater species resistance and resilience to drought, shortfin eels were ranked as one of the most resistant and resilient species to drought conditions in Australia while īnanga had medium resistance and resilience. Yellow-eye mullet habitat availability and juvenile feeding opportunities are affected by drought conditions.

In Australia, predictive models show that temperature increases may reduce lamprey distributions. On the contrary, the predictive models indicate there will be no effect of increased temperatures on the probability of capture of īnanga or kōaro, while yellow-eye mullet populations are anticipated to increase in response to increased temperatures in Australia.

A recent (2018) global CCVA on freshwater crayfish included kõura (*Paranephrops planifrons*) in their assessment<sup>3</sup>. The assessors found that kõura are likely to be vulnerable to climate change by 2070 under two different climate (RCP) scenarios, however, the specific exposure variable linked to their vulnerability was not made clear in the assessment. Kõura are thought to be sensitive to disturbances associated with flooding and increases in severe weather events due to changes in climatic change. There is some evidence that El Niño/La Niña cycles may affect glass eel recruitment.

In summary, our literature review revealed substantial knowledge gaps regarding the effects of climate change on Aotearoa-New Zealand's freshwater taonga species. Further, it is apparent from the literature that the climatic factors identified above are unlikely to affect our taonga species in isolation, potentially compounding impacts on species and their populations.

#### **Climate Change Vulnerability Assessment: Summary of results**

We completed CCVAs for ten Aotearoa-New Zealand taonga freshwater species: longfin eel (Anguilla dieffenbachii); shortfin eel (Anguilla australis); īnanga (Galaxias maculatus); banded kōkopu (Galaxias fasciatus); giant kōkopu (Galaxias argenteus); kōaro (Galaxias brevipinnis); pouched lamprey (Geotria australis); yellow-eye mullet (Aldrichetta forsteri); freshwater crayfish (kōura; P. planifrons); and freshwater mussel (Echyridella menziesii).

CCVAs could not be completed for seven species. This was due to inadequate information, particularly concerning the ecology and life histories of: shortjaw kōkopu (*Galaxias postvectis*); grey mullet (*Mugil cephalus*); common smelt (*Retropinna retropinna*); black flounder (*Rhombosolea retiarii*); the freshwater crayfish (*Paranephrops zealandicus*) and two freshwater mussel (kākahi) species (*Echyridella onekaka* and *Echyridella aucklandica*).

Using the combined scores for the vulnerability attributes and exposure variables, our CCVA found that longfin eels and lamprey are very highly vulnerable to climate change. Three galaxiid species (īnanga [*G. maculatus*], kōaro [*G. brevipinnis*] and banded kōkopu [*G. fasciatus*]), together with shortfin eel (*A.* 

<sup>&</sup>lt;sup>3</sup> Hossain et al. (2018)

*australis*) and the freshwater mussel (*E. menziesii*) were ranked as highly vulnerable. Giant kōkopu (*G. argenteus*) and the freshwater crayfish (*P. planifrons*) were ranked as moderately vulnerable, while yellow-eye mullet (*A. forsteri*) was ranked as having low vulnerability (Figure 1-3).



# Figure 1-3: Climate change vulnerability ranking of the freshwater taonga species assessed during this study.

Reproductive complexity and exposure to other pressures were the two sensitivity attributes with the highest overall mean scores. This indicates that these two sensitivity attributes contributed the most to the overall vulnerability rankings of freshwater taonga species assessed. Species-specific differences in the sensitivity attributes scores were apparent (i.e., dispersal or dependence on interspecific interactions) and reflect the diversity of taonga species life histories and ecology. Analysis of data quality for the sensitivity attributes suggests that a large proportion of the scores relied on expert judgement and there was little or no data for many sensitivity attributes. Research into freshwater taonga species sensitivity attributes will therefore help us to better understand their sensitivity to climate change.

Five exposure variables contributed the most to taonga species climate change vulnerability. These exposure variables at the respective time frames and RCP scenarios were:

Change (%) in mean annual precipitation (mm); timeframe 2081–2100; RCP 8.5;

- Change (%) in mean autumn precipitation (mm); timeframe 2081–2100; RCP 8.5;
- Change (%) in mean winter precipitation (mm); timeframe 2046–2065; RCP 8.5; 2081–2100; RCP 4.5 and 8.5;
- Autumn mean air temperature change (°C); timeframe 2081–2100; RCP 8.5, and
- Annual number of hot days (more than 25°C); timeframe 2081–2100; RCP 8.5.

Changes in mean winter precipitation was consistently identified as an important exposure variable across the ten species assessed. Patterns in projected changes to winter precipitation differ between the west and east coasts of Aotearoa-New Zealand, and these differences will affect species differently depending on their distributions (i.e., likelihood of being exposed). For migratory fishes, changes to river flow regimes as a result of changes in precipitation (increase and decreases) may alter migratory cues. Fishes requiring specific rainfall regimes and water-level changes are likely to have limited tolerance to climate change as the frequency, intensity, and predictability of precipitation is anticipated to change. Autumn mean air temperature change was another key exposure variable that contributed to taonga species vulnerability rankings; however, the nature and extent of these effects remain unknown.

#### Conclusions

The results from the CCVAs revealed there are emerging climate-related threats to freshwater taonga species in Aotearoa-New Zealand. The application of the CCVA methodology allowed for a diverse set of Aotearoa-New Zealand freshwater taonga species to be assessed using existing information and expert opinion in a relatively short period of time. However, it is not known if impacts of climate change on taonga species will be positive, negative or neutral as the CCVA did not incorporate a directional effect of climate change. This could be done in future assessments.

There was some agreement between species identified as highly or very highly vulnerable to climate change in the CCVA (longfin eel, lamprey, shortfin eel, banded kōkopu, īnanga and kōaro) and species identified as threatened by climate change on the IUCN Red List. For species where limited data are available, such as the freshwater mussels *E. onekaka* and *E. aucklandica*, more research is needed to enable CCVA methods to be applied.

Taonga species exposure to climate change varies nationally and therefore each species will respond to climate change differently depending on where they are located and their unique set of characteristics (e.g., spawning duration or dispersal abilities).

Our analysis indicates that climate change can be considered when assessing threats to taonga species and a CCVA provides a structured and transparent means for this to be done. Research to increase our understanding of the potential impacts of changes in (1) mean annual precipitation (mm), (2) changes in mean autumn and winter precipitation, (3) changes in autumn mean air temperature and (4) annual number of hot days (more than 25°C) on taonga species responses is required to inform the management, restoration and conservation actions needed in the coming decades.

We recommend future CCVAs incorporate more species in the assessment and that improvements could be made to the sensitivity attributes and exposure variables used (i.e., river flow projections instead of precipitation projections). In addition, we recommend the scoring of species is done by at least four experts as per other CCVAs. While there are limitations associated with CCVAs, this

assessment is considered as the first step towards increasing our understanding about potential effects of climate change on Aotearoa-New Zealand freshwater taonga species.

# 1 Introduction

# 1.1 Te Wai Māori Trust

Te Wai Māori Trust was established as part of the Māori Fisheries Settlement with the goal of advancing Māori interests in freshwater fisheries<sup>4</sup>. Te Wai Māori Trust strives to achieve this goal through a variety of pathways which include:

- Undertaking or funding priority research, development and education;
- Promoting the protection and enhancement of freshwater fisheries habitat;
- Promoting the establishment of freshwater fisheries;
- Using resources to benefit Māori in respect of their freshwater fisheries interests.

When using the terminology 'freshwater fisheries', Te Wai Māori Trust describes this as including the species, habitat, surrounding land, water column, and water quality and quantity. Protecting Māori interests in freshwater fisheries ultimately means identifying and protecting habitat, which will preserve and enhance the abundance of mahinga kai species.

The long-term outcomes that Te Wai Māori Trust are working towards include:

- Increased iwi and hapū capacity and capability in freshwater fisheries and their ability to control their freshwater fisheries;
- Fostered indigenous fisheries expertise, knowledge and understanding;
- Increased quality and range of information available to iwi and hapū on freshwater fisheries and their interests thereof;
- Assurance that indigenous fisheries are well and can be enhanced.

In 2017, NIWA were commissioned by Te Wai Māori Trust to produce a review of the current state of knowledge for 19 taonga freshwater species in Aotearoa-New Zealand. This report, titled "Understanding Taonga Freshwater Fish Populations in Aotearoa-New Zealand" (Williams et al. 2017) covered six topics for each species:

- Species life cycles;
- Aotearoa-New Zealand distribution;
- States and trends in the relative abundance of populations (if known);
- Threat status determined using the New Zealand Threat Classification System and the International Union for Conservation of Nature;
- Known pressures on freshwater taonga species and their populations;
- Fisheries management responsibilities.

<sup>&</sup>lt;sup>4</sup> <u>https://waimaori.maori.nz/</u>

Following the 2017 review, it was apparent that significant knowledge gaps exist regarding the potential effects of a changing climate on Aotearoa-New Zealand's taonga freshwater species.

# 1.2 Project scope and objectives

To provide for the health and abundance of taonga species in our waterways, Te Wai Māori Trust believes that the potential impacts of climate change need to be examined and factored into long-term habitat and fisheries management decisions. Te Wai Māori Trust requested a scoping study to better understand the potential climate change-related effects on selected taonga freshwater species by: (1) collating the existing published literature, and (2) applying the CCVA methodology. In a meeting between Te Wai Māori Trust and NIWA representatives (Friday 28<sup>th</sup> Feb 2019), Te Wai Māori Trust identified 17 species (12 fish, three bivalve and two crustacea) for inclusion in the CCVA (Table 1-1).

Common names	Scientific name	Group
Longfin eel/Tuna	Anguilla dieffenbachii	Diadromous fish
Shortfin eel/Tuna	Anguilla australis	
Īnanga/Whitebait	Galaxias maculatus	
Kōaro/Whitebait	Galaxias brevipinnis	
Banded kōkopu/Whitebait	Galaxias fasciatus	
Giant kōkopu/Whitebait	Galaxias argenteus	
Shortjaw kōkopu/Whitebait	Galaxias postvectis	
Lamprey/Piharau/Kanakana	Geotria australis	
Common smelt/Porohe	Retropinna retropinna	
Mullet/Kātaha/Aua	Aldrichetta forsteri	
	Mugil cephalus	
Black flounder/Pātiki	Rhombosolea retiaria	
Freshwater mussel/Kākahi/Kāeo	Echyridella menziesii	Bivalve
	Echyridella onekaka	
	Echyridella aucklandica	
Freshwater crayfish/Koura/Kewai	Paranephrops planifrons	Crustacean
	Paranephrops zealandicus	Clustacean

#### Table 1-1: List of freshwater taonga species identified by Te Wai Māori Trust for the CCVAs.

# 1.2.1 Outside project scope

This scoping study is the first step towards increasing our understanding about the potential climate change-related effects on our freshwater taonga species. We recognise that there are many uncertainties associated with an assessment of this nature, particularly for data deficient species and their fisheries— as is the case for **most** of New Zealand's taonga freshwater species (Williams et al. 2017).

For clarity and transparency, we describe the following caveats of the CCVA:

- We used the existing CCVA methodology largely derived from Pecl et al. (2011), Morrison et al. (2015) and Hare et al. (2016) as our standardised assessment framework. We did not explore any substantial modifications to the CCVA methodology. CCVAs account for species traits (i.e., "the fish") and climate projections and does not weave in cultural values, beliefs and practises (i.e., the "fisher" and the "socioecological system");
- We did not collate or present the extensive mātauranga Māori related to the aforementioned species, or information about historical use and management of freshwater fisheries by Māori communities;
- For some of the 17 species in (Table 1-1) there were significant knowledge gaps (e.g., relating to traits or habitat) that prevented a CCVA from being completed for some species;
- The vulnerability of species to the effects of climate change in coastal and estuarine habitats was not covered in the assessment. This is because the climate change projections for these types of habitats are poorly resolved;
- We did not consider the effects of future resource/fisheries management or restoration scenarios because these are unknown (e.g., changes in land use practices, habitat quantity or quality, and management of taonga species). We did not consider the potential effects of interactions between climate change and pressures such as harvesting/fishing activity and invasive/exotic species;
- The current distribution of freshwater taonga species, and their vulnerability to climate change at various temporal scales was considered in this analysis, but potential climatedriven changes in species-distributions were not explored;
- The effects of climate change on species and/or populations were not assessed for different habitats and/or spatial areas (i.e., each species was not assessed separately for lakes, rivers, wetlands or biogeographical regions)<sup>5</sup>.

<sup>&</sup>lt;sup>5</sup> The diversity of habitats a species occupies was considered in the CCVA using habitat specificity as a sensitivity attribute.

# 1.3 Structure of this report

This scoping study was based on a methodology used internationally to assess species climate change vulnerability and applied to an Aotearoa-New Zealand context for the first time. This report explains the detailed steps that the project team undertook to complete this assessment.

This report is divided into the following sections:

Section 2: **Literature review** – This section collates key findings from the published literature about any known existing and potential impacts of a changing climate on freshwater taonga species in Aotearoa-New Zealand. Where information was not available from New Zealand-based studies, where relevant, we accessed the international literature. This was particularly useful for species that we have in common with Australia (e.g., īnanga [*G. maculatus*], kōaro [*G. brevipinnis*], lamprey [*G. australis*], and shortfin eel [*A. australis*]).

Section 3: **Approach: Climate Change Vulnerability Assessment** – CCVAs are a structured, transparent and reproducible methodology that can be used to assess species' vulnerability to climate change. CCVAs are used internationally to identify species that are most vulnerable to climate change. In this section we explain the methodology and the information we used.

Section 4: **Results: Climate Change Vulnerability Assessment** – This section presents the results of the CCVAs for 10 freshwater taonga species.

Section 5: **Discussion** – This section elaborates on the results of the CCVAs and discusses the pathways through which climate change pressures may exert impacts on our freshwater taonga species. The report is supplemented by three appendices that present the detailed methodology and background information used to inform the CCVAs:

- Appendix 1: Species profiles Provides a profile for each of the freshwater taonga species assessed. This information, alongside Appendix 2, was provided to each assessor to inform their expert judgement and scoring of each sensitivity attribute/species in the CCVA;
- Appendix 2: Sensitivity attributes Details the definitions, justifications, links to climate change references and scoring bins for each of the 12 sensitivity attributes used to inform the CCVAs; and
- Appendix 3: Projections of exposure variables Details the projections for the climate variables included in the CCVA (air temperature, air temperature extremes, precipitation/rainfall, precipitation/rainfall extremes, wind speed, potential evapotranspiration deficit and sea surface temperatures). Descriptions of sea level rise, New Zealand oceanography and Western Pacific Oceanography are also provided here.

# 2 Literature review on climate change effects on taonga species

Our literature review revealed substantial knowledge gaps regarding the effects of climate change on Aotearoa-New Zealand's freshwater taonga species. We identified three climatic factors affecting taonga species: (1) drought, (2) El Niño/La Niña cycles, (3) temperature (indirect [air temperature] and direct [water temperature]), (4) sea level rise, and (5) extreme events (i.e., storms). Although there is less definitive information available at present, sea level rise and extreme weather events are also likely to impact taonga species in the future. It is apparent from the literature that these climatic factors interact with each other and no one factor affects taonga species in isolation.

# 2.1 Droughts

According to the 2019 IUCN Red List of threatened species, climate change and severe weather is a key stressor for three taonga species, longfin eel (Pike et al. 2019a), shortfin eel (Pike et al. 2019b) and koaro (Raadik et al. 2019).

The IUCN threat assessment indicates that droughts are a significant and ongoing threat to longfin eels, affecting 50% of the population (Pike et al. 2019a). The effects of drought are likely to increase longfin eel mortality rates (Pike et al. 2019a).

Drought was also identified as a significant ongoing threat to shortfin eels, affecting 50–90% of the population (Pike et al. 2019b). In Australia, there is evidence that drought conditions have a negative impact on the commercial eel fishery. For example, during the "Millennium Drought" in Australia (1990s-2000s), commercial shortfin eel catches declined because harvestable waters were reduced due to low lake/river levels (McKinnon 2002; VFA 2017). In Aotearoa-New Zealand, exceptionally dry summers between 2016 and 2018 reduced shortfin eel catches in the North Island (Beentjes 2019). Catches were also reduced in the North Island in 1997 and 1998, in association with droughts. In the upper Waipaoa catchment (Gisborne), it was hypothesised that eel recruitment was limited by drought conditions (Maumahara Consulting 2007). Crook et al. (2010) used expert scoring of biological attributes (various measures of physiological, biological and hydrological tolerance) that capture a species resistance and resilience to drought. They completed the assessment for 15 freshwater fishes in South-eastern Australia. Overall, shortfin eels were ranked as one of the most resistant and resilient species to drought (Crook et al. 2010). A score of medium resilience was assigned to all four measures of drought resilience (dispersal ability, distribution, abundance and reproductive capacity). Ten measures of resistance were scored: ability to withstand high temperatures, low dissolved oxygen and conductivity, ability to avoid or survive the effects of predation, parasites or disease, ability to outcompete other species for food, habitat and other resources, ability to occupy spawn and recruit over a wide range of hydrological regimes and finally longevity. All of the resistance attributes were scored medium except for conductivity which was scored high resistance.

Following several years of prolonged drought, significant eel mortalities were found in several lakes in Australia in 2006 and 2007 (Leahy et al. 2007). High evaporation rates resulted in a rapid increase in lake salinity, which in turn altered salinity levels in eel blood plasma and ultimately reached lethal concentrations. The lethal effect of increased salinity on eels was magnified when the pH was greater than nine. In Aotearoa-New Zealand, significant tuna mortalities have been observed in recent years in several locations, including Lake Tūtira<sup>6</sup> (Napier; Figure 2-1) and the Selwyn River (Canterbury). In Lake Tūtira, the pH was greater than nine, while in the Selwyn River, prolonged drought conditions and lack of winter rainfall for three consecutive years were hypothesised to be associated with eel

<sup>&</sup>lt;sup>6</sup> https://www.stuff.co.nz/environment/87628341/eel-not-be-right-mass-fish-deaths-at-lake-under-investigation

moralities<sup>7</sup>. In the Ashley River (North Canterbury) eels and many other fish species are salvaged annually and relocated to other areas because of dry conditions<sup>8</sup>. Fish salvages regularly occur throughout the country.

The IUCN assessment for lamprey indicates that climate change and drought may reduce the quality of juvenile habitat, through increases in temperatures and a reduction in dissolved oxygen (Bice et al. 2019). The effects of drought are thought to be most evident in streams with altered flow regimes (Bice et al. 2019). However, climate change is not specifically listed as a threat to lamprey in these assessments (Bice et al. 2019) and we found no evidence in the published literature about climate change effects on Aotearoa-New Zealand populations.



**Figure 2-1:** Dead eels along the shoreline of Lake Tūtira, Napier (December 2016). Source: Stevie Smith, Hawkes Bay Regional Council.

In Australia, an assessment of drought vulnerability for 43 freshwater fish species was done using 14 traits for each species (e.g., fecundity, adult size, spawning temperature; Chessman 2013). In this analysis, koaro (or climbing galaxias as they are known in Australia) were ranked as the 11<sup>th</sup> most drought vulnerable freshwater fish species (Chessman 2013), but we did not find any evidence on the impact of drought on Aotearoa-New Zealand populations.

In Australia, īnanga (or common galaxias as they are known in Australia) were ranked as the 16<sup>th</sup> most drought vulnerable species (Chessman 2013). In another Australian study, īnanga were present in unregulated streams, despite prolonged drought conditions during 2006–2010 (Chester et al. 2014). Compared with historic data, the assemblages of the streams remained essentially unchanged over a 30-year period (Chester et al. 2014) suggesting drought did not have an adverse effect on īnanga populations. Crook et al. (2010) also included īnanga in their assessment of species resistance and resilience to drought. For īnanga, a score of medium resilience was assigned to all four measures of drought resilience (dispersal ability, distribution, abundance and reproductive capacity). Resistance

Climate Change Vulnerability Assessment of selected taonga freshwater species

<sup>&</sup>lt;sup>7</sup> https://www.stuff.co.nz/environment/86992441/road-or-river-barren-selwyn-reaches-new-low-swimming-spot-stagnant

<sup>&</sup>lt;sup>8</sup> <u>https://fishandgame.org.nz/news/stranded-fish-rescued-after-the-ashley-river-dries-up/</u>

attributes (as outlined for shortfin eel) scored medium were temperature, conductivity, dissolved oxygen, occupancy and recruitment. Low scores were resistance to parasites, predation, disease, competitive ability and longevity (Crook et al. 2010). In Aotearoa-New Zealand, it is speculated that diadromous galaxiids like īnanga may be affected by drought because spawning and larval migration to the sea occurs during periods of increased drought prevalence (i.e., in the summer and autumn; McDowall 1995). During drought conditions, low flows can also result in gravel and sediment build up at river mouths and can block the inward migrations of the post-larval stages, with the effects of drought being exacerbated in regulated rivers (Mitchell and Davis-Te Mairie 1994).

The geographic range of yellow-eye mullet is influenced by salinity which is driven primarily by the magnitude of freshwater inflows. During drought and associated low freshwater inflows, hypersaline conditions reduced yellow-eye mullet habitat availability in Australia (Earl and Ferguson 2013). Furthermore, during high inflow conditions to estuaries, juvenile yellow-eye mullet consume more larval fish and amphipods compared to drought conditions indicating feeding opportunities are better during high inflows (Earl and Ferguson 2013).

# 2.2 El Niño Southern Oscillation Index

Our synthesis of the literature indicated that El Niño/La Niña cycles affects the productivity of the commercial eel fishery, eel growth rates, and glass eel recruitment.

A summary of El Niño-Southern Oscillation (ENSO) is given in Pearce et al. (2018) and is synopsised here. ENSO is a natural mode of climate variability that has wide-ranging impacts around the Pacific basin. ENSO involves the movement of warm ocean water from one side of the equatorial Pacific to the other, changing atmospheric circulation patterns in the tropics and subtropics, with corresponding shifts for rainfall across the Pacific.

During El Niño, easterly trade winds weaken and warm water 'spills' eastward across the equatorial Pacific, accompanied by higher rainfall than normal in the central-east Pacific. La Niña produces opposite effects and is typified by an intensification of easterly trade winds, and retention of warm ocean waters over the western Pacific. ENSO events occur on average 3 to 7 years apart, typically becoming established in April or May and persisting for about a year thereafter.

During El Niño events, the weakened trade winds cause Aotearoa-New Zealand to experience a stronger than normal south-westerly airflow. This generally brings lower seasonal temperatures to the country and drier than normal conditions to the north and east of Aotearoa-New Zealand, including Auckland (Salinger and Mullan 1999). During La Niña conditions, the strengthened trade winds cause Aotearoa-New Zealand to experience more north-easterly airflow than normal, higher-than-normal temperatures (especially during summer), and wetter conditions in the north and east of the North Island.

During the extreme 1997–98 El Niño event, commercial eel harvests in the North Island were severely reduced (Chisnall and Kemp 1998). High water temperatures and low rainfall meant there was a lack of freshes/floods to stimulate eel movement and therefore the probability of capture and availability to the fishery declined.

In Te Waihora, shortfin eel growth rates were related to environmental variables over a 5-year period (1995–1999; Graynoth and Jellyman 2002). Although not statistically significant, the highest growth rates were observed in the warmest summer (1995–1996) and the lowest in the coldest summer (1996–1997) suggesting temperature affects shortfin eel growth rates. However, the lack of long-term

data spanning multiple years/decades made it difficult to track changes in growth rates with respect to environmental variation and climate change. Nevertheless, the period of analysis covered by Graynoth and Jellyman (2002) coincides with the significant El Niño event in 1997–98.

In Pigeon Bay (Banks Peninsula), Horokiwi (Wellington) and Te Maari (Waikato) streams, shortfin growth rates declined by 1.4 mm per year over the period 1996 to 1998, again coinciding with an El Niño event (Graynoth and Taylor 2004). These declines were attributed to annual variation in weather and streamflow between 1996 and 1998 but were not explicitly incorporated into any statistical analysis (Graynoth and Taylor 2004).

Chisnall et al. (2002) found variations in the size and recruitment patterns of shortfin and longfin glass eels that appeared to be related to El Niño events in 1997 and 1998. There is some evidence to suggest that ENSO and associated changes to ocean conditions may influence eel recruitment in the western South Pacific Ocean (Jellyman and Bowen 2009). Between 1995 and 1998, glass eel recruitment was monitored in 13 streams on the east and west coasts of Aotearoa-New Zealand (Jellyman et al. 2002) again coinciding with the 1997–98 El Niño. Annual variation in recruitment was found to be influenced by ENSO with greater recruitment occurring in the north-west during the El Niño phase (when there are persistent westerly winds). During La Niña events, when the wind direction is typically more persistent from the north-east, greater recruitment of glass eels was observed in the north-east of the country (Jellyman et al. 2002). Furthermore, the mean length of glass eels decreased in all regions between 1997 and 1998 which was hypothesised to a result of changes in the duration of the migration from their spawning grounds (Jellyman et al. 2002).

In the Waikato River, glass eel recruitment (predominantly shortfin eels) was examined in 2004 and 2005 (Jellyman et al. 2009). Comparison of catch results from this study with previous catch data (30 years apart), found glass eel migration periods are occurring several weeks earlier and it was hypothesized that this may be due to climate change (Jellyman et al. 2009). The Antarctic Circumpolar Wave<sup>9</sup> which effects how ENSO cycles develop could also provide a further mechanism for the periodic alteration of glass eel recruitment in Aotearoa-New Zealand<sup>10</sup>.

At present, the effects of ENSO on longfin and shortfin eels are largely unknown. Long-term studies spanning multiple decades are needed to quantify the effects of environmental change and ENSO on Aotearoa-New Zealand tuna populations. No literature was available about the potential effects of ENSO on other freshwater taonga species.

# 2.3 Temperature

Our synthesis of the literature indicated that temperature (both indirectly, as measured by air temperature, and directly as measured by water temperature) affects the productivity of the commercial eel fishery and taonga species distributions.

Commercial eel catches are greatly influenced by water temperature, flood events (increased catches) and drought conditions (reduced catches; see section 2.1) indicating that these variables interact with each other. Commercial eel catches decline in winter months (May to September), particularly in the South Island, where fishing ceases indicating a temperature effect (Beentjes 2019).

<sup>&</sup>lt;sup>9</sup> The Antarctic Circumpolar Wave is a coupled ocean/atmosphere wave that circles the Southern Ocean in approximately eight years at 6–8 cm/s.

<sup>&</sup>lt;sup>10</sup> https://fs.fish.govt.nz/Doc/21722/25 EEL 09.pdf.ashx

Bond et al. (2011) recently predicted the probability of changes to freshwater species distributions at different air temperature scenarios in south-east Australia. Fortuitously, five taonga species (shortfin eel, lamprey, kōaro, īnanga and yellow-eye mullet) were included in this analysis. These predictions indicated that by the year 2030, shortfin eel and lamprey probability of occurrence decreases (i.e., distribution contracts), while no change was predicted for kōaro and īnanga. Yellow-eye mullet increased in their probability of occurrence (i.e., distribution expands; Table 2-1). Note that climate change projections for Australia and Aotearoa-New Zealand are different so these results are not directly applicable to Aotearoa-New Zealand species.

Recent mortalities of yellow-eye mullet have been observed in Hawkes Bay. Low river levels and water temperatures close to 29°C resulted in increased infections in fish and eventually mortalities<sup>11</sup>. Future changes in water temperatures are considered a significant threat to koaro (David et al. 2014a), while temperature extremes are predicted to affect longfins more severely (Pike et al. 2019). In Australia, current lamprey (*G. australis*) populations were predicted to decrease by 50 to 70% as a result of temperature increases (Stewart et al. 2018).

Climate change and associated changes to sea surface temperature and ocean circulation patterns have been implicated in the decline of īnanga in south-west Australia (Barbee et al. 2011). For Aotearoa-New Zealand īnanga populations, changes in larval dispersal patterns in response to changes in marine conditions are currently unknown. We did not find any Aotearoa-New Zealand studies of the effects of changing ocean temperatures on taonga species.

Table 2-1:Results from Bond et al. (2011) predicting changes in species occurrence at different temperaturescenarios for rivers in South East Victoria, Australia by the year 2030. Climate scenarios corresponded to theA1T (low), A2 (median) and A1Fl (high) scenarios from the Intergovernmental Panel on Climate Change (IPCC)'sSpecial Report on Emission Scenarios<sup>12</sup> with associated temperature increases (by 2030) of +0.54°C, +0.85°C and+1.24°C, respectively.

	Species occurrence under different air temperature projections		
Species	+0.54°C (low)	+0.85°C (medium)	+1.24°C (high)
Shortfin eel	No change	20% reduction	25% reduction
Lamprey	More than 30% reduction	More than 30% reduction	More than 30% reduction
Kōaro	No change	No change	No change
Īnanga	No change	No change	No change
Yellow-eye mullet	More than 30% increase	More than 30% increase	More than 30% increase

# 2.4 Sea-level rise

We did not find Aotearoa-New Zealand based studies of the effects of sea-level rise on freshwater taonga species. However, Booth et al. (2011) indicated that īnanga may be vulnerable to sea-level rise. This is because īnanga have very particular spawning requirements, including specific timing and salinity characteristics (spawning occurring on spring tides), dependencies on riparian vegetation, and location (in freshwater, but just upstream of estuarine saline wedges). Given spawning and

<sup>&</sup>lt;sup>11</sup> https://www.nzherald.co.nz/hawkes-bay-today/news/article.cfm?c\_id=1503462&objectid=12308061

<sup>&</sup>lt;sup>12</sup> IPCC (2000) Special report on emissions scenarios: a special report of working group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

recruitment are salinity-dependent, salinity changes in freshwater habitats due to sea-level rise could contraction or fragmentation in īnanga distributions (Booth et al. 2011). Estuaries, subtidal sand/mud habitats and submerged seagrass are key habitats used by yellow–eye mullet. These habitats are likely vulnerable to increasing saltwater intrusion associated with sea–level rise.

# 2.5 Extreme weather events

In 1968, the *Wahine* storm (ex-Tropical Cyclone Giselle) was an extreme weather event that destroyed some of the macrophyte beds along the shoreline of Te Waihora (Gerbeaux 1993). Te Waihora subsequently transitioned from a clear macrophyte-dominated state to a turbid phytoplankton dominated state which subsequently altered the structure of the lake food web. Although the *Wahine* storm is not explicitly related to climate change, more intense extreme storm events are anticipated with climate change (MFE 2018), which may impact the ecosystems of shallow coastal lakes such as Te Waihora.

Research carried out by NIWA is reconstructing the growth rates of Te Waihora shortfin eels from 1962–2012. Initial results show there are some years with significantly higher (i.e., 1968) and lower growth rates (i.e., 1970; Figure 2-2). The growth rate estimates were based on analyses of the annual bands on shortfin eel otoliths collected over several decades. Environmental variables were used to predicted drivers of annual growth rate variation seen in Figure 2-2. Initial results show that increased wind speeds associated with stormier conditions may reduce shortfin eel growth rates in this system. This is one of the first studies in Aotearoa-New Zealand to explicitly investigate the relationship between eel growth rates and climate/environmental variables over multiple decades.

Severe weather events associated with climate change are thought to impact koaro by altering their habitats, according to the IUCN threat assessment (Raadik et al. 2019), however, we could not find any examples of these effects in the literature. The effects of extreme and variable weather events on postlarval whitebait recruitment variation has been observed previously (McDowall and Eldon 1980). Koura (*P. planifrons*) are thought to be sensitive to flood spates and any increases in severe weather events due to changes in climatic and weather patterns (Furse et al. 2015). Flood spates are considered an emerging threat to this species (Furse et al. 2015).



**Figure 2-2:** Time series of predicted shortfin eel annual otolith-derived growth rates (as a proxy for changes in fish length) in Te Waihora from 1962–2012. The horizontal dashed line is the model intercept and the vertical lines are the 95% confidence intervals of the predicted values. Values greater than 0 are years with good growth and values below zero are years with poor growth. Source: E. Egan (unpubl. data).

# 2.6 Summary

Based on the national/international literature climate variables such as drought, temperature (indirect [air temperature] and direct [water temperature]), El Niño/La Niña cycles, sea level rise, and extreme events (i.e., storms) have been shown to affect taonga species.

- The 2019 IUCN ranking assessments indicate that drought, temperature and severe weather, are key threats to longfin eel/tuna, shortfin eel/tuna and koaro;
- In Australia, droughts and increased air temperatures affect shortfin eels, while predictive models show that temperature increases may reduce lamprey populations. These Australian studies showed no effect of increased temperatures on the probability of capture of īnanga or koaro, while yellow-eye mullet populations increased;
- A recent global climate change vulnerability assessment found that koura are likely to be vulnerable to climate change by 2070. Koura are thought to be sensitive to disturbances associated with flooding and increases in severe weather events due to changes in climatic change;
- There is some evidence that El Niño/La Niña cycles may affect glass eel recruitment to Aotearoa-New Zealand, but this effect is speculative at present.

Our literature review revealed substantial knowledge gaps regarding the effects of climate change on Aotearoa-New Zealand's freshwater taonga species, including a lack of long-term multi-decadal datasets. Further, it is apparent from the literature that the climatic factors identified above are unlikely to affect our taonga species in isolation, potentially compounding impacts on species and their populations.

# 3 Approach

# 3.1 What is a Climate Change Vulnerability Assessment?

To respond to and prepare for changes in climate, our freshwater and oceans, decision-makers need information about what species may be most vulnerable and why (Morrison et al. 2015). Climate Change Vulnerability Assessments (CCVAs) are structured, transparent and reproducible frameworks that can be used to assess species' vulnerability to climate change. CCVAs are used internationally to rapidly identify which species may be most vulnerable to climate change. These assessments have been completed for a wide range of species including birds, reptiles, mammals, amphibians, invertebrates, and marine and freshwater fishes (Pacifici et al. 2015; Hare et al. 2016; Crozier et al. 2019). CCVAs have been used to assess the vulnerability of marine fishes that constitute important fisheries in Australia (Pecl et al. 2014), diadromous and freshwater fishes in the wider Pacific (Hare et al. 2016; Olsuyana et al. 2018), as well as alien freshwater fishes in California (Moyle et al. 2013). As far as we are aware, this is the first time CCVAs have been applied to any marine or freshwater species in Aotearoa-New Zealand. There are two key components to a CCVA. These are:

- 1. Species **sensitivity** and/or adaptability to respond to climate change based on their characteristics or attributes (e.g., number of reproductive events, habitat requirements, temperature sensitivity; Morrison et al. 2015);
- 2. Species exposure to projected environmental changes based on their current distributions (i.e., current species distribution overlaps with warming oceans or more frequent droughts; Morrison et al. 2015). An example of lamprey (*G. australis*) current distribution overlaid with projections for changes in winter rainfall (RCP 8.5; 2081–2100) and koura (*P. planifrons*) distributions overlaid with annual number of hot days (> 25°C) projections (RCP 8.5; 2081–2100) is shown in Figure 3-1.

Together, exposure and sensitivity form a species **vulnerability** score. Definitions of these terms are in section 3.1.1. The theory behind a CCVA is relatively straightforward. For a species to be affected by climate change, it must be sensitive to change, as well as be exposed to a change. For example, if a species is highly sensitive to temperature, but it is located in an area where the water temperature is not predicted to significantly increase, then this species will not be affected. Conversely, if temperature is expected to change but the species is not sensitive to temperature it also would not be affected.

CCVAs rank species vulnerability to climate change and do not measure what the effects of climate change will be (i.e., changes in species distributions, increased mortalities due to extreme temperatures). This is one of the main limitations of CCVAs. Although some CCVAs can incorporate a directional effect of climate change (i.e., positive or negative; Hare et al. 2016) we did not incorporate this step here.

The sensitivity attributes and exposure variables are scored for each species based on a pre-defined scoring system (Morrison et al. 2015). These scores are then combined across exposure variables and sensitivity attributes to derive an overall climate vulnerability score for each species being assessed. While these methods have limitations, CCVA allows for a diverse range of species to be assessed using existing information in a relatively short period of time. Where possible data is used to inform these assessments, however, in situations where no data is available, expert opinion is used.



**Figure 3-1:** An example of maps used to score species exposure. Panel A) shows current lamprey (*G. australis*) distributions overlaid with projections of changes (%) in mean winter rainfall (mm); Panel B) shows koura (*P. planifrons*) distributions overlaid with changes in annual number of hot days (> 25°C). The green dashed line delineates *P. planifrons* from *P. zealandicus*. Projections are for RCP 8.5 and late-century (2081–2100). Source: NIWA.

# 3.1.1 Terminology used in Climate Change Vulnerability Assessments

**Sensitivity attributes** are characteristics that are likely to make a species more (or less) vulnerable to climate change. Species sensitivity attributes include biological or ecological variables that predict the vulnerability to climate change. For example, a species that has low reproductive output may be more sensitive to climate change compared to a species with high reproductive output.

In this study, a species **exposure** is assessed by examining the overlap between the spatial distribution of a species and predicted changes in the environmental variable of interest (i.e., sea surface temperature; Morrison et al. 2015). Exposure variables are those climate variables included in the assessment that could impact taonga species (e.g., temperature, sea surface salinity, precipitation [as a proxy for river flow]). The exposure score includes information about the magnitude of the expected climate change, but not in relation to each species' tolerances, which are often unknown (Hare et al. 2016).

**Vulnerability** is a combination of species sensitivity to climate change (i.e., their sensitivity attributes) and their exposure to climate change.

# 3.2 Populating the Climate Change Vulnerability Assessment

There were six key stages in the CCVAs (described in more detail in sections 3.2.1 to 3.2.6):

- Define the spatial and temporal scale of the assessment (i.e., is the assessment being done at a nationwide level, in a specific region or a specific catchment and what time period are the exposure variables (i.e., environmental conditions) being examined (e.g., mid-century [2046–2065] or late-century [2081–2100]);
- 2. Create species profiles that summarise the relevant biological and ecological information;
- 3. Identify the sensitivity attributes being assessed for each species;
- 4. Identify the relevant exposure variables for the assessment;
- 5. Gather expert assessors to score the sensitivity attributes and exposure variables for each species;
- 6. Derive the final climate vulnerability ranking for each species using a combination of the sensitivity and exposure scores to interpret the data.

#### 3.2.1 Stage 1: Defining spatial and temporal scale of the assessment

CCVAs can be applied to different spatial and temporal scales. For example, Hossain et al. (2018) conducted a global assessment of freshwater crayfish vulnerability while Hare et al. (2016) focused their assessment of marine fisheries on the Northeast United States Continental Shelf.

In this study we conducted an Aotearoa-New Zealand-wide CCVA and did not refine our assessment to a specific region, catchment or ocean basin. We considered that a national scale assessment was most appropriate for several reasons, including:

 Te Wai Māori Trust requested CCVAs for 17 taonga species. These species have varying distributions across Aotearoa-New Zealand. For example, koura (*P. planifrons*) are widely distributed throughout the North Island especially in central areas and are absent along the east and south coast of the South Island. By comparison, īnanga (*G. maculatus*) are found almost exclusively in lowland coastal rivers and there are very few observations in the central North Island. Based on the variety of species distributions, it was therefore not feasible to refine the assessment to a specific region or catchment at this time.

- Projections of climate variables are more robust at a national scale than at the individual catchment scale.
- Lack of spatial information on species sensitivity attributes.

Another important aspect is to determine the most relevant temporal scale for the CCVA. Typically, climate change predictions are made over a 40-100 year time horizon because climate change signals can often only be detected for periods spanning multiple decades to remove the influence of natural inter-annual climate variability (Morrison et al. 2015). This can create a mismatch with those involved in fisheries management who, for example, typically require information over the next 1-5 years.

In this study, we assessed taonga species exposure to climate change at two "future" time frames: (1) mid-century (2046–2065); and (2) late-century (2081–2100). Thus, this CCVA indicates species vulnerability to climate change approximately 35 years and 70 years from now.

# Climate change scenarios (Representative Concentration Pathways)

Another important aspect of the CCVA is deciding which global greenhouse concentration scenarios (termed Representative Concentration Pathways [RCPs]) are used for each of the exposure variables and timeframes.

We used two RCPs (4.5 [moderate concentration scenario] and 8.5 [business as usual scenario]) for the exposure predictions. These RCPs are consistent with the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report<sup>13</sup>. The RCPs are indicative of the rate and amount of atmospheric global greenhouse gas concentrations over the coming decades, as emissions (e.g., from the burning of fossil fuels) are directly related to atmospheric concentrations and represent different climate change scenarios.

- Moderate concentration scenario: RCP 4.5 (CO<sub>2</sub> concentrations of 538 ppm by 2100) represents a moderate-concentration scenario and requires stabilisation of greenhouse gas emissions during the twenty-first century.
- Business as usual scenario: RCP 8.5 is the high-concentration scenario (atmospheric CO<sub>2</sub> of 936 ppm in 2100) that assumes little or no stabilisation of greenhouse gas emissions (i.e., "business as usual") by 2100.

NIWA's regional climate model was used to downscale six global climate models (approximately 250 km resolution) for the Aotearoa-New Zealand region. For the climate change projections used here, the six-model average (termed ensemble-average) projection was used. Ensemble means of at least three to four models are recommended for CCVAs so that uncertainty is reduced from predictions that rely solely on a single climate model (Foden et al. 2019). The regional climate model projections (27

<sup>&</sup>lt;sup>13</sup> IPCC, 2014: *Climate Change 2014: Synthesis Report.* Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

km resolution) were further reduced to approximately a 5-kilometre grid by statistical methods, and temperature and precipitation variables were bias-corrected. All projections are relative to a 1986-2005 climatology. More information about the climate modelling methodology can be found in MFE (2018).

# 3.2.2 Stage 2: Create taonga species profiles

A species profile was created for each taonga species to summarise the biological and ecological information needed to score the sensitivity attributes (see section 3.2.3, Appendix A). We consolidated information relevant to the species being assessed into a standardised format. The species profiles were based on a template adapted from several sources including Pecl et al. (2011) and Hare et al. (2016). The species profiles were collated using existing data (quantitative) and peer-reviewed literature (qualitative). Topics covered in the species profiles were:

- Habitats;
- The fishery;
- Life cycle and demographics;
- Distribution and environmental preferences;
- Diet and predation;
- Recruitment;
- Current climate impacts;
- Ecosystem level interactions;
- Additional (multiple) stressors;
- Critical data gaps and level of uncertainty.

Creating a profile for each species was an important step to ensure experts were provided with the baseline information in the same format for the assessments. The taonga species report (Williams et al. 2017) and the IUCN threat assessments<sup>14</sup> were key summary documents used to create species profiles as well as published and grey literature. The species profiles are provided in Supplementary Appendix 1<sup>15</sup>.

# 3.2.3 Stage 3: Identify sensitivity attributes

Twelve sensitivity attributes were analysed for each species in the CCVA (Figure 3-2). These attributes were chosen based on the data compiled in the species profiles as well vulnerability assessments that have been done previously on other fish, bivalves and invertebrate species (Hare et al. 2016; Pecl et al. 2014; Crozier et al. 2019). A summary of the sensitivity attributes and the description of what each attribute aims to capture is given in Table 3-2.

<sup>&</sup>lt;sup>14</sup> <u>https://www.iucnredlist.org/</u>

<sup>&</sup>lt;sup>15</sup> All of the species profiles have been provided to Te Wai Māori trust as supplementary material and are not included in the main body of this report.



Figure 3-2: The 12 sensitivity attributes used in the Climate Change Vulnerability Assessment.

# Data quality

An important consideration for CCVAs is the quality and specificity of information on which the CCVA is based. Understanding the type and quality of information used to score the sensitivity attribute allows end users to identify data gaps and areas for future research. Several species included in this assessment are considered data-poor (Williams et al. 2017). A "Data Quality" attribute was included with the sensitivity attribute scoring to help identify uncertainty and highlight information gaps in the sensitivity attributes (Morrison et al. 2015).

The data quality for each sensitivity attribute was characterised based on the type of data used. The four categories used to score data quality were: adequate data; limited data; expert judgement and no data (Table 3-1). Data quality was not scored specifically for the exposure variables because the exposure variables are model projections (see section 3.2.1).

Table 3-1:	Data quality scoring system for the sensitivity attribute scores.	Source: Adapted from Williams
et al. (2015).		

Data quality score	Description
3	Adequate Data. The score is based on data which have been observed, modelled or empirically measured for the species in question and comes from a reputable source.
2	<b>Limited Data.</b> The score is based on data which has a higher degree of uncertainty. The data used to score the attribute may be based on related or similar species, come from outside the study area, or the reliability of the source may be limited.
1	<b>Expert Judgment.</b> The attribute score reflects the expert judgment of the reviewer and is based on their general knowledge of the species, or other related species, and their relative role in the ecosystem.
0	<b>No Data.</b> No information to base an attribute score on. Very little is known about the species or related species and there is no basis for forming an expert opinion.

Sensitivity attribute	Description			
Habitat specificity	Determine, on a relative scale, if the species is a habitat generalist or a habitat specialist while incorporating information on the type and abundance of key habitats.			
Prey specificity	Determine, on a relative scale, if the species is a prey generalist or a prey specialist.			
Complexity in reproductive strategy	Determine how complex the species' reproductive strategy is and how dependent reproductive success is on specific environmental conditions.			
Dispersal of early life stages	Estimate the ability of the species to colonize new habitats when/if their current habitat becomes less suitable.			
Spawning cycle	Determine if the duration of the spawning cycle could limit the ability of the species to successfully reproduce if necessary, conditions are disrupted by climate change.			
Early life history survival and recruitment	Determine the relative importance of early life history requirements for a species.			
Adult/juvenile mobility	Ability of the species to move to a new location if their current location changes and is no longer favourable for growth and/or survival.			
Population growth rate/demographics	Estimate the relative productivity of the species.			
Sensitivity to temperature	Use species distributions as a proxy for temperature sensitivity.			
Dependence on environmental triggers	Species' dependence on natural exogenous factors during its life cycle, especially those likely to be affected by climate change			
Dependence on interspecific interactions	Dependence on another species for life cycle completion.			
Exposure to threats/other stressors	Account for conditions that could increase the stress on a species and thus decrease its ability to respond to changes.			

#### Table 3-2: Summary of species sensitivity attributes used to assess climate change vulnerability of taonga species.

#### 3.2.4 Stage 4: Identify relevant exposure variables

We chose exposure variables for the CCVAs based on three criteria:

- previous work that has shown an effect of an environmental/exposure variable on the species being examined;
- from the international literature on similar species, and
- previous CCVAs that have assessed marine and freshwater fish, freshwater invertebrates and freshwater bivalves.

Using these criteria, eight exposure variables chosen for the assessment were:

- air temperature (annual, seasonal and extreme);
- precipitation (annual, seasonal and extreme);
- wind speed (annual);
- potential evapotranspiration deficit (annual);
- sea surface temperature (annual);
- sea level rise;
- Aotearoa-New Zealand's near-shore ocean currents, and
- oceanography of the Western Pacific Ocean.

Climate change predictions were mapped for the four exposure variables: air temperature, precipitation, wind speed and potential evapotranspiration deficit (as a proxy for drought intensity<sup>16</sup>). For these climate change projections, six-model average (termed ensemble models) climate scenarios from global climate models were used. Ensemble means of at least three to four models are recommended for CCVA so that uncertainty is reduced from predictions that rely solely on a single climate model (Foden et al. 2019).

As described in section 3.2.1, these maps were derived for two representative concentration pathways (RCP) scenarios (4.5 and 8.5) and two "future" time frames (mid-century [2046–2065] and late-century [2081–2100]). Table 3-3 summarises the exposure variables, the RCP scenarios and timeframes used. Note: Sea surface temperature was only modelled for RCP 8.5 for late-century [2081–2100] time period because of constraints with data availability (Table 3-3). Figure 3-3 shows the breakdown of the exposure variables with projection maps available.

Collectively, there were 56 maps of the four exposure variables (air temperature, precipitation, wind speed and potential evapotranspiration deficit) at two RCPs (4.5 and 8.5) and two-time frames to be assessed against each species distribution maps and one predictive map for sea surface temperature changes.

Because of constraints in some of the climate change predictions for the marine environment (i.e., sea level rise, Aotearoa-New Zealand's ocean currents and the oceanography of the Western Pacific Ocean) we used descriptions of the expected changes to these exposure variables with respect to climate change. Predictive maps for each timeframe and RCP scenario were not available for these exposure variables.

<sup>&</sup>lt;sup>16</sup>Potential evapotranspiration deficit (PED) is a proxy for drought intensity. PED, in units of mm, can be thought of as the amount of missing rainfall needed in order to keep pastures growing at optimum levels. Accumulations of PED greater than 300 mm indicate very dry conditions (Pearce et al. 2018).

 Table 3-3:
 Summary of the exposure variables with predictive maps available for the exposure assessment.
 All exposure variables are mapped for representative concentration pathways 4.5 and 8.5.

Time scale	Time period	Representative concentration pathway (RCP)	Air temperature (°C)	Precipitation (mm)	Wind speed (km/hr)	Potential Evapotranspiration Deficit (PED)	Sea surface temperature (°C)
Annual	2046–2065	4.5 and 8.5	Mean temperature difference (°C)	Mean difference (%)	Mean difference (km/hr)	Accumulation (mm/yr)	-
	2081–2100	4.5 and 8.5	Mean temperature difference (°C)	Mean difference (%)	Mean difference (km/hr)	Accumulation (mm/yr)	Sea surface temperature change <sup>17</sup>
Seasonal	2046–2065	4.5 and 8.5	Mean temperature difference (°C)	Mean difference (%)	-	-	-
	2081–2100	4.5 and 8.5	Mean temperature difference (°C)	Mean difference (%)	-	-	-
Extreme	2046–2065	4.5 and 8.5	Number of days difference	Number of days per year difference	-	-	-
	2081–2100	4.5 and 8.5	> 25 C Number of days difference > 25°C	<ul> <li>&gt; 25 mm precipitation</li> <li>Number of days per year</li> <li>difference</li> <li>&gt; 25 mm precipitation</li> </ul>	-	-	-

<sup>&</sup>lt;sup>17</sup> Sea surface temperature was only measured for RCP 8.5 for late-century time period because of constraints with data availability.



# Figure 3-3: Exposure variables used in the climate change vulnerability assessment with projection maps available.

Key documents used to summarise climate change projections for each of the exposure variables were:

- Ministry for the Environment and Stats NZ (2019). New Zealand's Environmental Reporting Series: Our marine environment 2019. Available from <u>www.mfe.govt.nz</u> and <u>www.stats.govt.nz</u>.
- Ministry for the Environment (2018). Climate Change Projections for New Zealand: Atmosphere Projections Based on Simulations from the IPCC Fifth Assessment, 2nd Edition. Wellington: Ministry for the Environment. <u>https://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/Climate-change-projections-2nd-edition-final.pdf</u>
- Ministry for the Environment (2017). Coastal Hazards and Climate Change. Guidance for local Government. <u>https://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/coastal-hazardsguide-final.pdf</u>
- National maps for air temperature, precipitation, wind speed and potential evapotranspiration deficit exposure variables using climate change data developed by NIWA for the Ministry for the Environment (2018) report and NIWA's Our Future Climate New Zealand webpage. <u>https://ofcnz.niwa.co.nz/#/nationalMaps.</u>

A synopsis of these exposure variables is given in the following sections.

#### Air temperature

Air temperature was used as proxy for water temperature in lakes, rivers, streams, wetlands, estuaries and nearshore areas (Hare et al. 2016). Six measures of temperature were scored: four based on seasonal changes

in mean air temperature (autumn, winter, spring and summer), annual changes in mean air temperature, and annual number of hot days (more than 25°C; Table 3-3).

Although air temperature and sea surface temperature are likely correlated, these two exposure variables are distinct in terms of their impacts on the biology of migratory species (i.e., diadromous fish) and so were assessed independently (Hare et al. 2016).

Extreme weather events are those that are rare, severe and unseasonal and occur over a short period of time, such as heatwaves. The number of hot days, more than 25°C, was chosen as an exposure variable representing temperature extremes because the greatest impact of climate change is likely to be experienced in the first instance by changes in extremes, rather than by changes in mean conditions<sup>18</sup>.

# Precipitation

Precipitation was used as a proxy for freshwater flows (Table 3-3) instead of river flow projections. This was done to ensure that the exposure variables being used in the CCVAs were at the same resolution. This approach has also been used to develop CCVAs for other species (e.g., Hare et. al. 2016). Six measures of precipitation were scored (Table 3-3). Four were based on seasonal changes in mean precipitation change (autumn, winter, spring and summer) and one variable capturing annual changes in mean precipitation. Precipitation extremes were measured by the number of heavy rain days (more than 25 mm rainfall) and are included in our analysis to measure changes in extreme precipitation rather than by changes in mean conditions<sup>19</sup>.

#### Wind

Mean annual and seasonal changes in wind speed was used as an exposure variable in the CCVAs (Table 3-3) to capture the effects of winds on aquatic ecosystems and associated taonga species. For example, in lakes, climate-induced changes to wind (both speed and direction) may increase lake productivity. This in turn can accelerate the rate of eutrophication (Ficke et al. 2007). Furthermore, stronger winds (Hamilton et al. 2013) and subsequent increased mixing in lakes could resuspend anoxic sediments and anoxic waters resulting in fish kills (Ficke et al. 2007).

Changes in the magnitude and direction of winds, especially southerlies, can have a significant effect on the dispersal pathways of pelagic species in the marine environment, particularly along the west coast of the North Island (Salinasde-Leon et al. 2012). Furthermore, increases in wind speed could increase ocean current strength and lead to increases in eddy activity (Meridith and Hogg 2006) resulting in larvae being trapped in these features and restricting their ability to disperse. Wind direction data was not included.

# Potential Evapotranspiration Deficit (proxy for drought intensity)

Potential evaporation deficit (PED)<sup>20</sup> was included as an exposure variable in the CCVAs and was used as a proxy for drought intensity (Table 3-3). PED is measured in millimetres. Drought can be categorised as an extreme climate event that occurs over a longer time period as a result of persisting extreme dry conditions, as well as high temperatures which drive increased evapotranspiration.

# New Zealand sea surface temperature

Trends in sea surface temperatures between 1981 and 2017 show that New Zealand's waters are warming, with strongest warming east of Wairarapa and weakest between East Cape and North Cape (Sutton and

<sup>&</sup>lt;sup>18</sup> <u>https://niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios</u>

<sup>&</sup>lt;sup>19</sup> <u>https://niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios</u>

<sup>&</sup>lt;sup>20</sup> Potential evapotranspiration deficit (PED) is the cumulative sum of the difference between potential evapotranspiration (PET) and precipitation from 1 July of a calendar year to 30 June of the next year, for days of soil moisture under half of available water capacity (AWC), where an AWC of 150 millimetres for silty-loamy soils is consistent with estimates in previous studies (e.g., Mullan et al. 2005).

Bowen 2019). Temperature changes are greatest at the ocean surface and extend to  $\sim$ 200 m in the northeast and at least 850 m in the eastern Tasman (Sutton and Bowen 2019).

Mean annual change in sea surface temperature was included as an exposure variable to capture the effects of changing temperatures (Table 3-3) on migratory freshwater species (e.g., whitebait, yellow-eye mullet, lamprey and eels). Only one measure of sea surface temperature (annual for the time period 2081–2100 at RCP 8.5) was used to score exposure because of constraints on data availability (Table 3-3). Law et al. (2019) recently predicted spatial changes in sea surface temperature for Aotearoa-New Zealand's marine environment and these spatial predictions were used for the exposure scoring.

#### Sea-level rise

Spatially resolved projections of sea-level rise scenarios were not available for this assessment. Consequently, we prepared a document describing sea-level rise scenarios in Aotearoa-New Zealand from our readings of the literature. In brief, sea level in the Aotearoa-New Zealand area will rise by 5–10% more than the global average (MFE 2017). Annual average sea levels will continue to show year-to-year and decadal variability arising from natural climate cycles like El Niño Southern Oscillation and the longer 20–30 year Inter-decadal Pacific Oscillation<sup>21</sup>. Sea-level rise is predicted to increase an additional 0.5 m by 2050 and 1 m by 2090 above a 1986-2005 baseline mean sea level (MFE 2017). Across RCP scenarios, there is near certainty that by mid-century (2050) sea-level rise will lie within a narrow band of around 0.15–0.3 m. The uncertainty band widens toward the end of the century and beyond (MFE 2017; MFE 2019). RCP 8.5 was the only scenario assessed for sea-level rise for 2081–2100 similar to the SST exposure variable.

#### Oceanography of the New Zealand region

Models and predictive maps of changes to Aotearoa-New Zealand's main ocean currents were not available for this assessment because there are difficulties making projections in circulation changes. For example, Fernandez et al. (2018) recently used over 20 years of satellite altimeter observations and data to investigate the mean and variability of current transports at seasonal, interannual and decadal time scales along the east coast of New Zealand. They showed that the East Auckland Current, East Cape Current and the Subantarctic Font have their own unique properties with high inter-annual variability and that these ocean currents show little correlation with each other or with winds. This apparent lack of correspondence poses several challenges for future climate change projections. Fernandez et al. (2018) indicated that in order to have some predictive capability in New Zealand's regional ocean climate, a better understanding of the ocean dynamics of New Zealand and the connection to the winds over the South Pacific are needed.

Although large scale changes in ocean currents are possible to predict, it is recognised that small scale changes in ocean currents are often be recognised from global climate models (Hare et al. 2016; Oliver et al. 2015). Analyses of species potential exposure to ocean currents (speed and direction) was therefore derived from a synthesis of the literature and descriptions of New Zealand's nearshore oceanography (Figure 3-4). Stevens et al. (2019) recent overview of New Zealand's shelf seas and coastal currents was a key document used to describe New Zealand oceanography.

We follow the rationale by Hare et al. (2016) regards the scoring system used for species exposure to potential changes in ocean currents. Although the overlap between a species distribution and the magnitude of change in near-shore ocean currents would be the preferred means to rank species exposure (Hare et al. 2016), little is known about the marine life of New Zealand taonga species (Williams et al. 2017). Instead, expert knowledge of a species' distribution was used to determine where overlap with ocean currents occurs. Descriptions of low (1) and high (4) exposure were considered as bookends of a continuum and were as follows:

<sup>&</sup>lt;sup>21</sup> https://niwa.co.nz/natural-hazards/hazards/sea-levels-and-sea-level-rise

Climate Change Vulnerability Assessment of selected taonga freshwater species
- Species were scored "low" exposure to changes in near shore ocean currents if their distributions overlap almost exclusively with currents that are expected to have a low magnitude of change such as estuarine circulation, nearshore density and wind driven currents, and/or eddies;
- Species were scored in the "high" exposure category if their distributions overlap almost exclusively with large boundary currents.



**Figure 3-4:** New Zealand at the shelf seas scale showing coastal currents, plateaus and features. Features include the Tasman Front, East Auckland Current (EAUC), Wairarapa Coastal Current (WCXC) and Eddy (WE), Westland (WC) and Southland Currents (SC), Hikurangi Bay (HE), Mernoo Saddle (MS) and the d'Urville Current (dUC). Regions less than 250 m are shaded and the 500 and 1000 m isobaths are shown. Source: Stevens et al. (2019).

# Western Pacific Oceanography

The oceanography (speed and direction of currents) of the Western Pacific Ocean (Figure 3-5) and any ongoing or predicted changes associated with climate change are important to understand in the context of longfin eel, shortfin eel and lamprey movements and migrations. The Western Pacific Ocean is where the spawning grounds of eels are believed to be located (Figure 3-6) while lamprey likely use tropical waters for part of their life cycle (Dr Cindy Baker, pers. comm.).

A summary of likely changes to the speed and direction of key ocean currents (namely the South Equatorial Current [SEC], the East Australian Current [EAU] and the Tasman Sea and Tasman Front [TF]) was prepared. Key documents used were the predictions and summaries by van Gennip et al. (2017)<sup>22</sup>, Cetina-Heredia et al. (2014), Ganachaud et al. (2014) and Hu et al. (2015). In brief, climate-driven ocean circulation changes are not well revolved for the South Equatorial Current. The location where the SEC splits shows significant inter-annual variability, however, between the 1950s and 2010 the SEC has split at increasingly lower latitudes (Hu et al. 2015).



**Figure 3-5:** Southwest Pacific topography with dominant surface ocean currents. Depths less than 2000 m are shown in yellow-orange colour. SEC denotes South Equatorial Current; EAC East Australian Current and the Tasman Front (TF). EAUC is the East Auckland Current. Source: Ganachaud et al. (2014).

<sup>&</sup>lt;sup>22</sup> Descriptions of changes in the Western Pacific Ocean oceanography is supplied in Appendix 3.



**Figure 3-6: Proposed spawning areas of shortfin and longfin eel in the Western Pacific Ocean.** The purple stars show locations where shortfin eel larvae have been observed and the ovals are the proposed spawning areas. The potential spawning areas of longfin eel are shown in green. Source: NIWA.

At present, the characteristics of the EAC are undoing rapid change. Globally, the ocean warming rate over the path of western boundary currents such as the EAC is two to three times faster than the global mean surface ocean warming rate (Wu et al. 2012). The multi-decadal strengthening of ocean boundary current system such as the EAC is primarily driven by large scale wind patterns associated with the dominant modes of climate variability and climate change (Feng et al. 2016). Recent modelling<sup>23</sup> by van Gennip et al. (2018) for RCP scenario 8.5 for 2090-2099 shows that there will be strong changes in the intensity and position of western boundary currents such as the EAC and that significant projected changes in ocean circulation will occur in the future.

For the Tasman Sea and Outflow, recent modelling by van Gennip et al. (2018) for RCP scenario 8.5 (2090–2099) shows that the weakening of the TF will reduce the connectivity between the coastal shelves of the New Zealand and East Australia with connectivity on six-month timescale being lost between the two shelves. Projected changes in the formation of mesoscale eddies through to 2060 were modelled by Oliver et al. (2015) using high-resolution dynamically downscaled climate change simulations. They showed that a higher proportion of anticyclonic eddies form in the EAC regions and that these eddies are longer lived and more stable. As a result, eddy-related southward temperature transport in the upper 200 m of the Tasman Sea occurs within concomitant increases in the prevalence of marine heat waves (Oliver et al. 2015).

# 3.2.5 Stage 5: Score sensitivity attributes and exposure variables

A series of workshops were held with expert assessors to complete the CCVAs. The expert assessors that contributed to the CCVAs were from NIWA, the Department of Conservation and the University of Canterbury (listed in Table B-1). Where possible, the sensitivity attributes and exposure variables for any given species were ranked by different people ensuring a mix of assessor expertise was incorporated.

There were four steps involved in scoring the sensitivity attributes and exposure variables. The scoring system was adapted from Morrison et al. (2015). The steps were:

<sup>&</sup>lt;sup>23</sup> The NEMO model was used for 1975-2099 under RCP 8.5 to project changes in ocean current speed and the deviation of decadal average speeds for the period 2090–2099 from the period 2000–2009.

- Assigning scores to the sensitivity attributes and the data quality used to score each of the attributes;
- Assigning scores to the exposure attributes;
- Weighting the sensitivity and exposure attribute scores using a formula that determines the relative importance of an single attribute/variable to the overall species vulnerability;
- Combining the weighted sensitivity and exposure scores to produce a composite score. This score was then compared to a series of thresholds to decide on the final climate change vulnerability ranking.

In the following section we explain each of these steps in detail and provide a working example of the method being applied.

# Assign initial sensitivity attribute scores

A detailed description of the 12 sensitivity attributes was given to each assessor<sup>24</sup>. This was done so each assessor understood the background context for including these attributes in the assessment and their interpretation (summarised in Table 3-4).

To score the 12 sensitivity attributes for each species, we adapted the scoring system used in previous CCVAs (Pecl et al. 2011; Morrison et al. 2015; Hare et al. 2016; Crozier et al. 2019). In brief:

- Each assessor had five tallies which could be distributed amongst four bins (low; moderate, high and very high);
- The scoring bins for low and very high are shown in Table 3-4 to give examples how to interpret
  a low score compared to a very high score for each sensitivity attribute;
- Experts used the species profiles (see section 3.2.2) and the 12 sensitivity attribute descriptions as common baseline knowledge for the assessment;
- Expert opinion was encouraged and incorporated into scoring each of the sensitivity attributes when necessary;
- Experts who were certain about a score could place all five tallies in one bin (e.g., all five tallies can be placed in the very high bin). Conversely, experts who are unsure about a score could spread all five tallies across the relevant bins (for example, they can put two tallies in the high bin, and three in the very high bin).

<sup>&</sup>lt;sup>24</sup> This document is provided as supplementary material.

Sensitivity attribute	Low Score	Very High Score
Habitat specificity	Habitat generalist with abundant habitat available	Habitat specialist with limited habitat availability
Prey specificity	Generalist – eats a diversity of prey	Specialist – reliance on a specific type of prey
Complexity in reproductive strategy	Low complexity: broadcast spawning; broad environmental cues needed (i.e., not a specific environment threshold)	Species has five characteristics to suggest complexity (e.g., aggregate spawning, specific environmental cues needed, migration to distant spawning grounds, sex-specific migration times, temperature-dependent sex differentiation)
Dispersal of early life stages	Highly dispersed eggs and larvae. Duration of planktonic eggs and larvae greater than 8 weeks and/or larvae are dispersed more than 100 km from spawning locations	Minimal larval dispersal. Benthic eggs and larvae or little to no planktonic early life stages
Spawning cycle	Spawning occurs year-round	Spawning occurs once per year (i.e. in a single season)
Early life history survival and recruitment	Larval requirements are relatively resistant to environmental change; consistent recruitment events	Larval requirements are specific and likely to be impacted by environmental change, highly episodic recruitment events
Adult/juvenile mobility	High mobility, more than 1,000 km	Low mobility, less than 10 km
Population growth rate	High productivity (i.e., small body size, high fecundity, low age at maturity)	Low productivity (i.e., slow growing, large maximum body size, low fecundity).
Sensitivity to temperature	Species found in wide temperature range or has a distribution across wide latitudinal/altitudinal range and depths	Species found in limited temperature range or has a limited distribution across latitude/altitude and depths
	More than 20° latitude distribution	Less than 5° latitude distribution
Dependence on environmental triggers	No apparent correlation to environmental variable	Strong correlation with environmental variable
Dependence on interspecific interactions	No obligate interactions required with another species to completion of life history.	Interspecific interactions are obligate and highly specialised for completion of life history.
Exposure to threats/other stressors	Threats are relatively minor at present, and anticipated potential threats are likely to be alleviated by management actions. Experiencing no more than one known stressor	Must include some climate-interacting threats. Threats are present in multiple categories, including anthropogenic factors that affect temperature or flow constraints, some of which are severe

#### Table 3-4: Scoring system for sensitivity attributes showing criteria used to inform what is a low or a very high score.

#### Worked example 1:

An example of the scores assigned to the sensitivity attributes "reproductive complexity" and "prey specificity" are given in Table 3-5 for longfin eel and koura. For the sensitivity attribute "reproductive complexity", the expert assessor placed their five tallies into the very high category (Table 3-5) indicating that that reproduction of longfin eels is highly complex. Reproduction in koura was considered less complex and the expert assessor assigned four scores to the low category but also put one score into the medium category (Table 3-5).

Sensitivity attribute	Species	Low	Moderate	High	Very high
Reproductive complexity	Longfin eel	0	0	0	5
	Kōura	4	1	0	0
Prey specificity	Longfin eel	4	0	1	0
	Kōura	4	1	0	0

Table 3-5:	Example of scores assigned to the sensitivity attributes "reproductive complexity" and "pr	rey
specificity".		

The distribution of these scores fits with our understanding of reproduction in longfin eel and koura. According to the scoring system summarised in Table 3-4, for reproductive complexity to be categorised as very high, the species must have at least five characteristics that create complexity. Longfin eels have more than five characteristics that make their reproduction complex and so a score of five in the very high bin is warranted. These longfin eel characteristics are:

- Migrate more than 1,000 km to their marine spawning grounds in the Western Pacific Ocean;
- Reproduction occurs in large aggregations;
- Sex determination in eels is affected by water temperature;
- Females typically migrate later than males; and
- Need specific environmental cues for migration.

By comparison, koura reproduction is less complex and therefore the five tallies are assigned between the low and moderate bins. The rational is that:

- Koura can reproduce in their adult habitat and do not need to migrate (unlike longfin eels),
- Fewer individuals are needed for reproduction to be successful;
- The sex of koura is not determined by a specific environmental variable.

#### Score exposure variables

Detailed descriptions of the exposure variables and their ecological and biological relevance were given to each assessor during the workshops<sup>25</sup>. Exposure was assessed by examining the overlap between a species distribution (using the species distribution maps in the species profiles) with maps showing the predicted

<sup>&</sup>lt;sup>25</sup> This document is provided as supplementary material.

changes for each of the eight exposure variables, both time periods (2041–2065 and 2081–100) and both RCP (4.5 and 8.5) scenarios.

The scoring bins for the exposure variables use a measure of the magnitude of change (i.e., mean difference) as a function of past climate variability. Examples of low and very high scores are shown in Table 3-7 for each of the exposure variables. Each assessor had five tallies which could be distributed amongst four bins (low, moderate, high and very high). If the magnitude of exposure varies across species distribution, the assessor scoring exposure can spread their five tallies appropriately.

#### Worked example 2:

In panel A of Figure 3-7, the distribution of giant kōkopu is compared with the predicted change in mean spring rainfall for the period 2081–2100 at RCP 8.5. In panel B Figure 3-7, banded kōkopu distribution is compared with the same exposure variables (mean spring rainfall change for the period 2081–2100 at RCP 8.5). The scores assigned by the assessor for these species are shown in Table 3-6.

Table 3-6:Example of exposure scores assigned to giant kōkopu and banded kōkopu for mean spring precipitationchange (%). RCP 8.5 for time period 2081–2100.

			Score				
Exposure variable	Timeframe	RCP	Species	Low	Moderate	High	Very high
Moon onling rainfall change (0()	2081 2100	0 5	Giant kōkopu	0	2	1	2
mean spring raintail change (%)	2081-2100	8.5	Banded kōkopu	0	1	3	1

The distribution maps show that giant kōkopu has a more restricted distribution compared to banded kōkopu (Figure 3-7). The largest number of giant kōkopu records are from the west coast of the South Island. This species is also found in Southland, Wellington, Taranaki and Waikato with fewer records in Auckland and the Bay of Plenty (Panel A Figure 3-7). By comparison, banded kōkopu are found in all regions of Aotearoa-New Zealand including the east coast of the North and South Islands where giant kōkopu are largely absent (Panel B Figure 3-7).

The projection maps of mean spring rainfall change show that the west coast of the South Island (from Greymouth south) and large parts of Southland are likely to experience more than 15% increase in spring rainfall (Figure 3-7). The remainder of the South Island may see a 0–10% increase with some pockets along the east coast showing a 5% reduction (denoted by light green). Most of the North Island will likely experience reduced mean spring rainfall, with a greater than 15% reduction in Northland. The exception is the south west coast of the North Island where there may be no change or slight increases (more than 5%). The tallies assigned to each species in Table 3-6 are therefore representative of their likely exposure to mean spring rainfall change.

Table 3-7:	System for	scoring	exposure	variables.
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Exposure variable	Time period	Low score	Very high score
Mean air temperature (°C) change	Annual Seasonal	0–1°C increase in mean annual/seasonal air temperature	3.1°C to more than 4°C increase in mean annual/seasonal air temperature
Daily temperature extremes: hot days (more than 25°C)	Annual	Increase of between 0.5 and 5 days per year	Increase of more than 75 days per year
Mean precipitation change (%)	Annual Seasonal	Negligible exposure to changes in precipitation (i.e., no change)	More than 20% increase in precipitation
Daily precipitation extremes: very wet days (more than 25 mm rainfall)	Annual	No change in wet days	More than 10 day increase in wet days
Extreme wind speeds	Annual	Decreased exposure to wind speed (more than -7.5 km/h change)	More than 10 km/h increase in wind speed
Potential Evaporation deficit (Drought intensity index <sup>26</sup> )	Annual	Species is exposed to negligible change in PED	Species are exposed more than 100 mm change in PED
Sea surface temperature	Annual	No change in sea surface temperature is expected	More than 3°C increase in sea surface temperatures
Sea level rise	Annual	No reliance on coastal/near-shore habitats	Species are dependent on coastal habitats to complete part of their life cycle.
			Regional sea level within species range is expected to increase more than 7 mm yr $^{\rm 1}$ by 2050
Near shore ocean currents (Aotearoa-New Zealand)	Annual	Distributions overlap almost exclusively with ocean currents that are expected to have a low magnitude of change such as estuarine circulation, nearshore density and wind driven currents	Distributions overlap almost exclusively with ocean currents that are expected to have a high magnitude of change
Western Pacific Ocean oceanography	Annual	Distributions overlap almost exclusively with ocean currents that are expected to have a low magnitude of change	Distributions overlap almost exclusively with currents that are expected to have a high magnitude of change

<sup>&</sup>lt;sup>26</sup> Measured as potential evaporation deficit (PED)



Figure 3-7: Panel A) shows giant kōkopu distribution with projected changes in mean spring precipitation (%). Panel B) shows banded kōkopu distribution with projected changes in mean spring precipitation (%). Projections are plotted for RCP 8.5 and timeline 2081–2100. Source: NIWA.

#### Deriving sensitivity and exposure weighted mean scores

Next, the scores for the sensitivity attributes and the exposure variable scores for each species were weighted. To do this, the scoring categories (low, moderate, high and very high) were converted into a numerical system whereby low = 1, moderate = 2, high = 3 and very high = 4. The tallies assigned to the sensitivity attributes and exposure variables (as per Table 3-5 and Table 3-6) were then multiplied by the numerical scores for each category to derive a weighted score for each sensitivity attribute and exposure variable.

These weighted scores were then summed for each sensitivity attribute and exposure variable for each species and were divided by five (total number of tallies available to each assessor) to get the final mean score for each sensitivity attribute and exposure variable.

#### Worked example 3:

A worked example of scoring banded kokopu sensitivity attributes is given in Table 3-8. The initial tallies scored by the assessors are show in the green column and the weighted scores in the orange column (Table 3-8). The final score for this stage of the process, the mean score, is shown in the grey column (Table 3-8). The mean values for each of the sensitivity attribute and exposure variables are then used in the next stage.

 Table 3-8:
 Example of a worked scoring system for banded kokopu sensitivity attributes.
 The final score which is the mean score for each sensitivity attribute is shown in the last column (grey shading, far right).

		Initia	l score by spe	cies ass	essor	Numerical score assigned to categories			Weighted scores				Tallies	Mean score		
Species	Sensitivity attribute	Low	Moderate	High	Very High	Low	Moderate	High	Very High	Low	Moderate	High	Very High	Sum of weighted scores	Sum of tallies	Sum of weighted scores/Sum of tallies
	Habitat specificity	0	2	3	0	1	2	3	4	0	4	9	0	13	5	2.6
	Prey specificity	2	3	0	0	1	2	3	4	2	6	0	0	8	5	1.6
	Complexity in reproduction	0	0	1	4	1	2	3	4	0	0	3	16	19	5	3.8
	Dispersal of early life stages	1	3	1	0	1	2	3	4	1	6	3	0	10	5	2.0
	Spawning cycle	0	0	3	2	1	2	3	4	0	0	9	8	17	5	3.4
	Early life history	0	1	4	0	1	2	3	4	0	2	12	0	14	5	2.8
	Adult mobility	0	1	4	0	1	2	3	4	0	2	12	0	14	5	2.8
Banded kōkopu	Population growth rate/demographics	3	2	0	0	1	2	3	4	3	4	0	0	7	5	1.4
	Temperature sensitivity	0	2	3	0	1	2	3	4	0	4	9	0	13	5	2.6
	Dependence on environmental triggers	0	0	3	2	1	2	3	4	0	0	9	8	17	5	3.4
	Dependence on interspecific interactions	0	4	1	0	1	2	3	4	0	8	3	0	11	5	2.2
	Exposure to other pressures	0	0	2	3	1	2	3	4	0	0	6	12	18	5	3.6

## Threshold for defining vulnerability using a logic rule

Following on from the rationale of Morrison et al. (2015), we used logic rules rather than averages to assign vulnerability scores. Morrison et al. (2015) state that "averaging tends to minimize the importance of high scoring sensitivity attributes or exposure factors". The logic rule system can "pull out those species with multiple risks (i.e., they will experience large changes in multiple environmental parameters, or they have specific life history requirements where environmental change could impact productivity through multiple mechanisms)" (Morrison et al. 2015).

For each sensitivity attribute or exposure variable to be considered in the "very high" category, 3 or more individual sensitivity attributes or exposure variables need to score more than 3.5. The cut-offs for receiving a "high" and "moderate" component scores follow similar but less strict criteria. A "high" component score requires at least two sensitivity attributes or climate factors receive a "high" attribute or factor mean (more than 3.0). Similarly, a "moderate" component score requires at least two sensitivity attribute or factor mean more than 2.5. Any species that does not meet or exceed the criteria for moderate will receive a "low" score (see Table 3-9).

# Table 3-9:Scoring system used to derive final climate change vulnerability ranks. Adapted from Morrison et al.(2015).

Vulnerability score	Rank category
Very High	3 or more mean sensitivity attribute or exposure variable scores $\ge$ 3.5
High	2 or more mean sensitivity attributes or exposure variable scores $\ge$ 3.0
Moderate	2 or more mean sensitivity attribute or exposure variable scores $\ge$ 2.5
Low	Do not meet any of the above criteria

#### Worked example 3 (continued):

The mean scores in Table 3-8 (grey column, far right) are inspected. The number of scores greater than 3.5 are counted to decipher how many sensitivity attributes fall into the "very high" category as per Table 3-9. Only two sensitivity attributes "complexity in reproduction" and "exposure to other pressures" had scores  $\geq$  3.5 meaning banded kōkopu does not meet the threshold for being assigned to the "very high" vulnerability score (see Table 3-9). There were at least three sensitivity attributes with scores  $\geq$  3 ("high"; Table 3-8) meaning the sensitivity attributes are assigned an overall score of high. This process is repeated for the exposure variables.

#### 3.2.6 Stage 6: Determining the overall climate change vulnerability rank

The score for the sensitivity attributes and exposure variables derived in section 3.2.5 are then combined across exposure variables and sensitivity attributes to derive a relative climate vulnerability score for each species being assessed.

The overall vulnerability rank was determined by multiplying the exposure and sensitivity scores. Low, moderate, high and very high component scores are assigned 1, 2, 3, and 4 respectively. The results were then classified where final scores with:

- 1-3 results in a low vulnerability rank;
- 4-6 a moderate vulnerability rank;
- 8-9 a high vulnerability rank, and
- 12-16 a very high vulnerability rank.

#### Scoring data quality of the sensitivity attributes

To score the data quality for the sensitivity attributes, experts had five "tallies" for each sensitivity attribute which they distributed among the four scoring bins depending on their confidence in the score. Experts who are certain about a score may have placed all five tallies in one bin (e.g., all five tallies can be placed in the very high bin, i.e., adequate data). Conversely, experts who are unsure about a score may have spread all five tallies across the relevant bins (for example, they can put two tallies in the high bin, and three in the very high bin). Distributing five tallies across four bins forces the expert to choose one bin as the most likely. This is a transparent method that clearly shows the expert's uncertainty about each score. This information was used to characterise the uncertainty in the sensitivity attributes.

We summarised data quality scores by identifying the number of data quality scores with tallies  $\geq$  3.0. We used this information to compare available information among species. Together, the data quality score and the distribution of the tallies that make up the sensitivity attribute are useful in characterizing the uncertainty in the overall vulnerability.

# 4 Results

# 4.1 Overall climate vulnerability ranking

Using the combined scores for the vulnerability attributes and exposure variables, our analysis found that longfin eels (*A. dieffenbachii*) and lamprey (*G. australis*) were ranked highly vulnerable to climate change (Figure 4-1). Three galaxiid species, īnanga, kōaro and banded kōkopu had a high vulnerabiltiy rankings, as did shortfin eel and the freshwater mussel *E. menziesii* (Figure 4-1**Error! Reference source not found.**). Giant k ōkopu (*G. argenteus*) and freshwater crayfish (*P. planifrons*) were ranked as moderately vulnerable to climate change while yellow-eye mullet was the least vulnerable (Figure 4-1).



#### Figure 4-1: Overall climate change vulnerability ranking for selected freshwater taonga species.

CCVAs could not be done for seven species (shortjaw kōkopu [*G. postvectis*], grey mullet [*M. cephalus*], common smelt [*R. retropinna*], black flounder [*R. retiarii*], southern kōura [*P. zealandicus*] and two freshwater mussel (kākahi) species [*E. onekaka and E. aucklandica*]). This was because of significant knowledge gaps regarding their ecology and life histories. These high levels of data uncertainty would undermine a robust CCVA for these species.

The vulnerability rankings for the 10 taonga species assessed were largely consistent across timeframes (midcentury and late century) and RCP scenarios (4.5 and 8.5). However, for koura (*P. planifrons*), vulnerability increased to "high" for 2081–2100 and RCP 8.5 as a result of changes to this species exposure rankings. This was due to predicted increased exposure to annual number of hot days more than 25°C and autumn mean air temperature change (see section 4.3 for more discussion). Giant kokopu also showed increased vulnerability for the period 2081–2100 and RCP 8.5. However, this change in vulnerability did not change the overall ranking, and giant kōkopu remained in the moderate category (Figure 4-1).

# 4.2 Species sensitivity attribute scores

The average scores for each of the sensitivity attributes are shown in Figure 4-2. Across the 10 taonga species assessed, "reproductive complexity" and "exposure to other pressures" were the two sensitivity traits with mean scores more than 3.0 (Figure 4-2). These results indicate that these attributes contributed the most to taonga species' climate change vulnerability. The sensitivity attributes with the lowest scores (i.e.,  $\leq$  2.0, low vulnerability) were "dependence on interspecific interactions", "prey specificity" and "temperature sensitivity". On average, these attributes did not contribute to taonga species climate change vulnerability.



Sensitivity attribute score

**Figure 4-2:** Boxplot showing mean scores for each of the sensitivity attributes. The thick centre line is the mean score, the width of the box is the standard deviation and the horizontal black lines are the maximum and minimum values. The purple circles show the scores for individual species. The orange dashed line separates low and medium scores (less than 3.0) from high and very high ( $\geq$ 3.0).

# 4.2.1 Reproductive complexity

The reproductive strategies of the freshwater taonga species assessed are diverse. The more complex the reproductive strategy, the more specific the environmental conditions may need to be for successful reproduction, and thus the more vulnerable the species may be to environmental change.

The reproductive characteristics of the most freshwater taonga species can be considered complex, increasing their vulnerability to climate change. Only three species scored less than 3 ("high"; Figure 4-2) for this attribute: yellow-eye mullet, koura (*P. planifrons*) and koaro. To summarise, the characteristics that influence reproductive complexity in freshwater taonga species include:

Large scale migrations to spawning grounds;

- Large aggregations of males and females needed for reproduction (Figure 4-3);
- Repeated spawning in the same location within and among years (Figure 4-3);
- Temperature dependent sex differentiation (i.e., longfin and shortfin eels), and;
- Reproductive success requires the use of vulnerable habitats (freshwater, estuaries)) for spawning or rearing of young (i.e., riparian spawning habitats of giant kokopu; Figure 4-3).



**Figure 4-3:** The spawning grounds of giant kōkopu (*Galaxias argenteus*) in an urban stream in Hamilton. Giant kōkopu spawning has been located here in five consecutive years, aggregations of males and females are needed for reproduction and spawning occur on bankside grasses. Source: NIWA.

#### 4.2.2 Exposure to other pressures

In Aotearoa-New Zealand, several freshwater taonga species are already facing multiple threats that are impacting on populations (see Figure 4-4 as an example). These pressures can impair a species' inherent ability to respond to changing climate conditions as they are already stressed. Yellow-eye mullet scored "low" (less than 2.5) for this attribute as the threats facing this species are considered much lower than those for other taonga species.

# 4.2.3 Species differences in sensitivity attribute rankings

Although reproductive complexity and exposure to other pressures were the two sensitivity attributes with the highest overall mean score and contributed the most to the overall vulnerability rankings, it is clear from Figure 4-2 that other sensitivity attributes were more important for some species. In the following section we give examples of these attributes to highlight where there are clear differences between species. It is not possible to detail all the differences and similarities between species here, but we have pulled out the most significant patterns to help illustrate some of this variation.

#### Dispersal (movement) of early life stages

In general, greater larval dispersal corresponds with a better ability to respond to climate change. This is because widely distributed eggs and larvae have a greater ability to colonise new habitats in areas that are

suitable for survival. Conversely, if a species has limited larval dispersal and their larval environment is affected by climate change, they are then more likely to be negatively affected by climate change.

In our analysis, dispersal of early life stages was on average scored "moderate" vulnerability to climate change. However, for some species, dispersal was ranked in the "very high" category (score  $\geq$  3.5; Figure 4-2). Koura (*P. planifrons*) and lamprey were two species with limited dispersal of the larvae and juveniles and their scores were in the "very high" category. For koura, once the eggs are hatched, the juveniles are carried by the mother for several weeks (Figure 4-5) and genetic studies show that koura dispersal capability is limited (Smith and Smith 2009). Larval lamprey can remain in their nest for at least two weeks before dispersal, as opposed to dispersing immediately post hatching (Baker et al. 2017).



Figure 4-4: Example of pressures on longfin and shortfin eel/tuna populations in Aotearoa-New Zealand. Source: Williams et al. (2017).



**Figure 4-5:** Koura, freshwater crayfish (*Paranephrops planifrons*) showing the female carrying the juveniles until they are mature. Source: Ian Kusabs, Karen Thompson.

#### Dependence on interspecific interactions

Dependence on interspecific interactions was overall one of the lowest scored sensitivity attributes. However, the purple dots (Figure 4-1) show two species scored "very high" ( $\geq$ 3.5) for this attribute – lamprey and kākahi (*E. menziesii*). For example, freshwater mussels have an obligate host-dependent stage in their life cycle (Figure 4-6) are therefore not only limited but their own environmental tolerances but also by those of their host species. This means kākahi may be indirectly and adversely affected by climate change because of this close relationship with other fish species. The same holds true for lamprey as during their marine life they must find another host fish species to parasitize for feeding.

#### 4.2.4 Data quality

The assessors scored data quality for each of the sensitivity attributes into four categories: adequate data, limited data, expert judgement, and no data. Overall, the results indicate that only a handful of species had data categorised as adequate for the relevant sensitivity attributes (Table 4-1). Yellow-eye mullet was the species with the greatest number of tallies distributed in the adequate data category (Table 4-1) while four species (giant kōkopu, banded kōkopu, kōaro and shortfin eel) did not meet the criteria for  $\geq$ 3 tallies in the adequate data bin.

There were 28 scores in the expert judgement category with tallies  $\geq$  3.0, while there were 19 scores in the no data category (see Table C-1) highlighting the degree of expert opinion needed to do the CCVAs.

# Eggs

The eggs are fertilised in the gill pouch of the female where they develop into larvae. The female releases them into the water when they are mature possibly in response to the presence of a fish

#### Adult kākahi

Once juveniles have reached about 25 mm length, they move into the same locations as adult mussels.

At about four years of age (approximately 40mm long) they mature and are then able to reproduce with neighbouring kākahi. Males release their sperm into the water and nearby females collect it while filtering to fertilise their eggs.



Life cycle of kākahi/freshwater mussel Echyridella menziesii. Life cycle completion depends on the larvae (glochidia) attaching to a fish host species. Source: NIWA. Figure 4-6:

Sensitivity attribute	Species	No. of tallies
Adult mobility	Kōura	4
Addit mobility	Lamprey	3
Complexity in reproduction	Īnanga	3
Dependence on environmental triggers	Lamprey	3
Dependence on interspecific interactions	Kākahi	5
Dispersal of early life stages	Longfin eel	3
Early life history survival and recruitment	Yellow-eye mullet	3
Exposure to other pressures	Yellow-eye mullet	5
	Īnanga	3
nabitat specificity	Yellow-eye mullet	5
Population growth rate/demographics	Longfin eel	4
Prey specificity	Yellow-eye mullet	5
Spawning cycle	Lamprey	5
	Lamprey	3
Temperature sensitivity	Longfin eel	5
	Yellow-eye mullet	5

#### Table 4-1: Data quality scores for the sensitivity attributes with adequate data.

# 4.3 Climate change exposure rankings

Overall, five exposure variables had a mean score  $\geq$  3.0 (i.e., high vulnerability ranking) across the ten freshwater taonga species assessed. These exposure variables were:

- Change (%) mean annual precipitation (mm),
- Change (%) mean autumn precipitation (mm),
- Change (%) mean winter precipitation (mm),
- Autumn mean air temperature change (°C), and
- Annual number of hot days (more than 25°C).

These results showed that overall, freshwater taonga species will likely be exposed to changes in annual mean precipitation and autumn mean precipitation by the late century (2081-2100) under the more extreme climate scenario (RCP 8.5; Table 4-2). Taonga species will likely be exposed to changes in winter precipitation patterns in the mid-century (2046-2065) at RCP 8.5, but by the late century (2081-2100) will likely be exposed to these changes at both RCP 4.5 and RCP 8.5 scenarios (Table 4-2). Finally, by the late century (2081-2100) under the highest RCP scenario (8.5), taonga species will likely be exposed to changes in mean autumn air temperatures and extreme air temperatures, defined as the number of days with air temperatures  $\ge 25^{\circ}C$ .

Exposure variable	Time period	Representative concentration pathway	Mean Score	Standard deviation	Vulnerability ranking
Change (%) mean annual precipitation (mm)	2081–2100	8.5	3.0	0.22	
Change (%) mean Autumn precipitation (mm)	2081–2100	8.5	3.0	0.21	
	2046–2065	8.5	3.3	0.13	
Change (%) mean Winter precipitation (mm)	2081–2100	4.5	3.2	0.16	Hign (mean score ≥ 3.0)
		8.5	3.3	0.17	
Autumn mean air temperature change (°C)	2081–2100	8.5	3.1	0.44	
Annual no. of hot days (more than 25°C)	2081–2100	8.5	3.1	0.36	

Table 4-2: Exposure variables with scores ≥3. These exposure variables contributed to the "high" vulnerability ranking of the freshwater taonga species assessed during this study.

# 4.3.1 Mean winter precipitation change (%)

All species were "highly" (exposure score  $\geq$ 3.0) or "very highly" (exposure score more than 3.5) exposed to changes in mean winter precipitation for the two time periods and two RCP scenarios (RCP 4.5 and 8.5). Figure 4-7 shows the projected changes in mean winter rainfall for 2045–2065 and 2081–2100. For the period 2045–2065, the west coast of the South Island is likely to experience a 20% increase in mean winter precipitation. These changes are predicted to increase in the 2081–2100 period, with the east coast of the North Island and Northland experiencing greater reductions in winter rainfall while most of the South Island will see greater increases in mean winter precipitation (Figure 4-7). These differences between the west and east coasts indicate the effects of changes to winter precipitation (either an increase or decrease) will affect species differently depending on their location.

#### 4.3.2 Species differences in exposure rankings

When the exposure scores were inspected for individual species, time periods (2046–2065 and 2081–2100) and RCP scenarios (4.5. and 8.5), substantial differences among species were evident. In this section, we discuss species with relatively high exposure scores for each exposure attribute.

#### Temperature extremes (annual number of hot days more than 25°C)

The annual number of days with air temperatures higher than 25°C was identified as a key exposure variable that increased the vulnerability of freshwater taonga species for the period 2081–2100 under RCP 8.5. Figure 4-8 shows that a large proportion of the North Island and the central South Island along the Southern Alps will experience at least 50 more days with air temperatures more than 25°C (denoted by orange-red colour). Longfin eels, shortfin eels, banded kōkopu, īnanga, yellow-eye mullet, giant kōkopu and kōura had exposure scores  $\geq$ 3.0 for this attribute. Conversely, kōaro, kākahi and lamprey attained exposure scores in the moderate (less than 3, but  $\geq$ 2.5) category. These species will therefore be lesser exposed to increased numbers of hot days.



Figure 4-7: Projected changes in mean winter precipitation for 2045–2065 and 2081–2100 for RCP 8.5 scenario. Source: NIWA.



Change in Number of Annual Hot Days Between 1995 and 2090



#### Potential Evapotranspiration Deficit (as a proxy for drought intensity)

Species with high exposure to changes in PED for the period 2081–2100 under the most extreme climate change scenario (RCP 8.5) were longfin eels, banded kōkopu, kākahi (*E. menziesii*), kōaro, kōura (*P. planifrons*) and yellow-eye mullet. Drought conditions are projected to increase in most of the North Island, the central South Island along the Southern Alps and the east coast of the South Island (Figure 4-9). Species with large populations along the west coast of the South Island and Southland such as īnanga, giant kōkopu and lamprey are less exposed to drought conditions as a whole, and their rankings for drought exposure were in the moderate category.



#### Annual Potential Evapotranspiration Deficit Accumulation Change Between 1995 and 2090



#### Sea-level rise

Only īnanga and yellow-eye mullet scored high ( $\geq$ 3.0) vulnerability to sea level rise. Īnanga spawning requirements are specific in terms of timing and salinity characteristics, with spawning occurring on spring tides, amongst littoral vegetation and in freshwater but just upstream of estuarine saline wedges<sup>7</sup>. Given spawning and recruitment are salinity-dependent, salinity changes associated with climate change may contract or fragment īnanga distributions (Booth et al. 2011).

New Zealand has a wide diversity of coastal habitats (Hume et al. 2016) that taonga species use. These include beach streams, coastal lagoons (for example Te Waihora/Lake Ellesmere), hāpua, coastal

embayment's, tidal lagoons and tidal river mouths (Hume et al. 2016). These habitats are vulnerable to saltwater intrusion and SLR. However, there are few direct links in New Zealand and globally regards habitat changes due to SLR and fish populations (Fulford et al. 2014).

#### Changes in the speed and direction of ocean currents in the Western Pacific Ocean

Exposure to changes in marine conditions, particularly changes in ocean currents in the Western Pacific Ocean were observed for migratory fish species. Our analysis indicated that longfin eels, shortfin eels and lamprey were "very highly" exposed (score ≥3.5) to changes in the Western Pacific Ocean especially western boundary currents. Some of the main ocean currents longfin and shortfin eels are thought to use to reach their spawning grounds in the Western Pacific Ocean are undergoing rapid environmental change, especially the East Australian Current (EAC). The EAC is a western boundary current<sup>27</sup> that is formed from the westward flow of the South Equatorial current as it crosses the Coral Sea and reaches the Australian coast (Figure 3-5). The main branch of the EAC flow separates from the Australian coast at latitudes 30°S–34°S and flows eastward as the Tasman Front to reach the top of the North Island in Aotearoa-New Zealand.

Globally, the ocean warming rate over the path of western boundary currents (such as the EAC) is two to three times faster than the global mean sea surface ocean warming rate (Wu et al. 2012). Strong changes in the intensity and position of western boundary currents such as the EAC are observed and there are significant projected changes in ocean circulation for the future (van Gennip et al. 2018; Figure 4-10). These projections indicate the EAC will penetrate further south towards Tasmania, that connectivity with the north-eastern part of Aotearoa-New Zealand will be reduced, and the speed of ocean currents will decline (see grey squiggles in Figure 3-5). Changes in the range of species across a number of marine species have been related to changes in our understanding of the marine life stages of the taonga species assessed, together with uncertainty in the predictions to changes in ocean currents (elaborated on in Section 5).

<sup>&</sup>lt;sup>27</sup> Western boundary currents are strong, persistent currents along the western boundaries of the world's major ocean basins that are responsible for the transport of warm tropical water to the mid latitudes.





The projected intensification of the southern branch of the East Australian Current leads to both an increase in the maximum poleward displacement (+14°; from +7°to +21°) and to changes in the connectivity with the Australian shelf (from the south to the northeast coast). In contrast, the projected weakening of the Tasman Front decreases the maximum poleward displacement (-9°; from +10° to +1°) with a disruption in connectivity between the Australian and New Zealand shelves on the 6-month timescale shown. The present model NEMO<sup>28</sup> runs from 1975–2099 under RCP 8.5 shows projections for ocean current speed (panel b) and the deviation of decadal average speeds for the period 2090–2099 from 2000–2009 (panel d). Source: van Gennip et al. (2018).

#### Sea surface temperature

Freshwater taonga species that spend part of their life in the marine environment (i.e., galaxiids, longfin and shortfin eels, lamprey and yellow-eye mullet) were "highly" exposed to sea surface temperature changes in New Zealand's waters for RCP 8.5 for the end-century (2081–2100)<sup>29</sup>. By 2100, mean sea surface temperature will likely increase in Aotearoa-New Zealand's waters by +2.5°C (Law et al. 2019). However, the sea surface temperature predictions show regional variability. For example, there is a tongue of water with a 4°C increase extending eastwards along the Canterbury and Otago coastlines (subregions 6 and 7; Figure 4-11). There is also a broad band of sea surface temperature changes more than 3°C extending across the Tasman Sea (Figure 4-11; Law et al. 2019). Species such as īnanga and yellow-eye mullet are widely distributed and therefore will be exposed to these increases in sea surface temperature throughout much of their range.

<sup>&</sup>lt;sup>28</sup> NEMO is an abbreviation for the Nucleus for European Modelling of the Ocean.

<sup>&</sup>lt;sup>29</sup> Note sea surface temperature predictions were only available for RCP 8.5 and time period 2081–2100.





<sup>&</sup>lt;sup>30</sup> According to ecosystem model 2 used by Law et al. (2019).

# 5 Discussion

This study is the first application of CCVAs to freshwater taonga species in Aotearoa-New Zealand. The results from the CCVAs revealed emerging climate-related threats to selected freshwater taonga species in Aotearoa-New Zealand. Two species were ranked as very highly vulnerable (longfin eel and lamprey), five species were ranked as highly vulnerable (shortfin eel, banded kōkopu; īnanga; kōaro and the freshwater mussel [*E. menziesii*]), two species were ranked as moderately vulnerable (giant kōkopu and kōura), and yellow-eye mullet had a low vulnerability ranking. These vulnerability ranks were largely consistent between two timeframes (mid-century and late century) and two RCP scenarios (4.5 and 8.5). However, for kōura (*P. planifrons*), vulnerability increased to "high" for 2081–2100 and RCP 8.5 as a result of increased exposure to annual number of hot days more than 25°C.

Although longfin eel, lamprey, shortfin eel, banded kōkopu; īnanga and kōaro had vulnerability rankings of "very high" or "high", it is not known if the impacts of climate change on these species will be positive or negative. Figure 5-1 highlights that when species are exposed to climate change pressures there can be negative and/or positive impacts on populations. For example, although īnanga were ranked as highly vulnerable to climate change based on the combination of their sensitivity attributes and their exposure to environmental change (Figure 4-1), this species is genetically very diverse (Waters et al. 2000). This genetic diversity may increase their ability to adapt to future climate change scenarios and so the impacts of climate change on īnanga may be negligible. CCVAs simply rank species vulnerability to climate change and do not measure what the effects will be (i.e., changes in distributions, increased mortalities due to extreme temperatures). This is one of the main limitations of CCVAs. Although some CCVAs can incorporate a directional effect of climate change (i.e., positive or negative; Hare et al. 2016) we did not incorporate this step here. This could be done in another workshop with species experts, but additional data gathering would be needed.



**Figure 5-1:** Mechanisms that describe the pathways through which climate change pressures may exert impacts on species. These impacts may have positive and/or negative impacts on the species and are mitigated or exasperated by species individual sensitivities and adaptive capacities. Source: Foden et al. (2019).

# 5.1 Sensitivity attributes

Two sensitivity attributes contributed consistently to the climate change vulnerability rankings. These were (1) complexity in reproduction, and (2) exposure to other pressures. Species-specific differences in the sensitivity attributes that contributed to the overall score were also apparent (i.e., dispersal or dependence on interspecific interactions) reflecting the diversity of taonga species life histories and ecology included in the CCVA.

The reproductive characteristics of freshwater taonga species included in this assessment are diverse and complex. The reproductive success of many taonga species requires the use of multiple habitats (i.e., freshwater and estuaries), interspecific interactions with other species (i.e., freshwater mussels), environmental cues for reproduction and large aggregations. Indeed, reproductive complexity is regarded as one of the key attributes that may increase species vulnerability to climate change (Koehn et al. 2011; Foden et al. 2019). Taonga species will be exposed to various combinations of changes in seasonal, annual and extreme temperatures and precipitation (see sections 4.3 and 5.2) which are likely to affect reproduction but the direction of this effect is not known.

Species that are already facing multiple threats are considered to be more vulnerable to climate change (Jarić et al. 2019). For example, Pearson et al. (2014) found that decreasing population size and/or occupied area, as well as increasing range fragmentation, were associated with higher extinction risk under climate change. The taonga species assessed in this study face multitude pressures including fishing/harvesting, in-stream structures that are impediments to their movements and migrations, water abstraction, pollution and non-native/invasive species (Williams et al. 2017; see Appendix 1). According to the Department of Conservations' threat rankings, lamprey are ranked as 'Threatened – Nationally Vulnerable', five taonga species are ranked as At Risk - Declining (longfin eel, inanga, koaro, giant kokopu and the freshwater mussel (E. menziesii), and four are 'Not Threatened' (shortfin eel, banded kokopu, yellow-eye mullet and koura [P. planiforns]; Dunn et al. 2018; Appendix D). It might be expected therefore, that species ranked as very highly and highly vulnerable to climate change, together with threat rankings of Threatened – Nationally Vulnerable and At Risk – Declining, will be the most affected by climate change. These species are the longfin eel, lamprey, īnanga and koaro. CCVAs are increasingly being used alongside threat assessments including the IUCN assessments as they are a transparent and structured means to assess species vulnerability to climate change (Foden et al. 2019; Jarić et al. 2019).

Habitat specificity was incorporated as a sensitivity attribute in the CCVAs (Hare et al. 2016) because climate change is expected to alter the habitats that freshwater fish, invertebrates and bivalves use. As environmental changes occur, species that depend on habitats that are abundant and wide ranging are less likely to be impacted by changes associated with climate change (Foden et al. 2019) and are likely to be more resilient (Clavel et al. 2011) because they will have a wider range of habitat and microhabitat options available to them. On the contrary, sensitivity to climate change is increased for species with several life stages, where each requires different habitats or microhabitats. For example, giant kōkopu require riparian (and possibly in-stream gravel) habitat for egg development, pelagic habitat for larval development, coastal/estuarine habitat for post-larval development and lowland coastal freshwaters/lacustrine habiats for adult development. Species that use biological habitats (i.e., macrophytes, riparian vegetation) are more likely to be impacted by climate change than those that only use physical habitats (i.e., gravels, sand, mud).

To derive habitat specificity, the habitats of taonga species were extracted from IUCN red list assessments<sup>31</sup> as this is a globally relevant database with standardised habitat terminology across the species assessed (Hossain et al. 2018). However, notable discrepancies in the habitats listed by IUCN for similar species were found. For example, īnanga (David et al. 2014c) and banded kōkopu (West et al. 2014) were listed as being found in marine neritic pelagic habitats, but kōaro (David et al. 2014a) and giant kōkopu (David et al. 2014b) were not. These discrepancies are not merely due to the IUCN assessments being a global assessment and therefore being populated from information overseas because banded kōkopu and giant kōkopu are only found in Aotearoa-New Zealand and so New Zealand specific data informs these assessments. In this CVVA, the expert assessors highlighted discrepancies in the IUCN species habitat types and suggested that the sensitivity attribute habitat specificity should be broken down by life stage in any future CCVAs or modifications to the methodology.

The analysis of data quality used in the CCVAs suggests that a large proportion of the scores relied on expert judgement and there was little or no data for many sensitivity attributes. For example, complexity in reproduction was highlighted as one of the sensitivity attributes whereby the species assessors used expert judgment/opinion for their scoring of this attribute. This highlights significant data gaps with respect to freshwater taonga species reproduction. Research into freshwater taonga species reproduction will therefore help us to better understand their sensitivity to climate change. Data gaps were also highlighted in the individual species assessment profiles (Supplementary Appendix 1). Dispersal and early life history/recruitment were emphasised as data-poor areas, along with population demographics and spawning cycle. Generally, there was a greater understanding of the biology of adult life stages for our freshwater taonga species.

# 5.2 Exposure variables

Changes in mean winter precipitation was consistently identified as an important exposure variable across the ten species assessed. Patterns in changes to winter precipitation differ between the west and east coasts of Aotearoa-New Zealand, and these differences will affect species differently depending on their location. For migratory fishes, changes to river flow regimes (i.e., reductions in overall discharge and altered seasonality) may alter migratory cues, especially given winter is a key time for the inward migration of whitebait, lamprey and glass eels to rivers (McDowall et al. 1995). Fishes requiring specific rainfall regimes and water level changes are likely to have limited tolerance to climate change as the frequency, intensity, and predictability of precipitation is anticipated to change. Predictable periodicity in rainfall is a very important trigger for reproduction in freshwater species during the winter such as giant kōkopu (Franklin et al. 2015). A change in hydrological regime that alters precipitation patterns may therefore affect the egg incubation stage especially for species that spawn in-stream in gravels. Egg incubation can also be threatened by elevated flows and intense precipitation or can result in increased egg mortalities indirectly via sediment deposition (Hickford and Schiel 2011). Large scale climate change could therefore have a greater impact on species that have specific early life history and recruitment requirements.

Autumn mean air temperature change was another key exposure variable that contributed to freshwater taonga species vulnerability rankings. Many species have known thermal preferences, and these can differ between environments and among life stages, with early life-history stages and reproductive adults being especially sensitive (Koehn et al. 2011). Seasonal increases in temperatures cue reproductive development in spring-spawning species, and falling temperatures stimulate

<sup>&</sup>lt;sup>31</sup> https://www.iucnredlist.org/

reproduction in autumn-spawners. Elevated temperatures typically truncate spring spawning, and delay autumn spawning (Pankhurst and Munday 2011). Exposure to changes in autumn mean air temperature may alter timing of reproduction, reduce spawning and reproductive output, reduce egg size, size at hatching, developmental and feeding rates, number and quality of offspring, and swimming performances (especially for larvae), with wide ranging impacts on population dynamics (see Koehn et al. 2011 and references therein). While temperature changes are likely to affect reproduction in freshwater taonga species, the nature and extent of these effects remain unknown.

Although the CCVA results suggest that longfin and shortfin eels are exposed to changes in large scale ocean currents, there is a large degree of uncertainty around the likelihood of longfin and shortfin eel exposure to changes given the scarcity of predictive models of climate-driven changes in ocean currents. Furthermore, the migratory routes of adult and larval eels are poorly known. Both species may use several ocean currents and do not solely rely on the EAC to transport them to Aotearoa-New Zealand. For example, longfin eels may take a short-cut to their spawning grounds and follow the Kermadec Trench to the North-East of Aotearoa-New Zealand (Jellyman and Bowen 2009); if so, these eels are not exposed to changes in the EAC. Until a better understanding of the marine life of eels, lamprey and galaxiid species is attained, we cannot predict the consequences of climate-driven changes in the marine environment for these species.

A recent vulnerability assessment by Foley et al. (2019) for the Auckland region suggested that banded kōkopu, kōaro and smelt are the most vulnerable freshwater taonga species to warming associated with climate change. Our CCVA results suggested that banded kōkopu will be highly exposed to extreme air temperatures by late-century (2081–2100) under RCP 8.5, while kōaro will be exposed to seasonal (autumn, spring and summer) changes in mean air temperature for the 2081–2100 period under RCP 8.5. Based on the exposure projections for extreme and seasonal (autumn, spring and summer) air temperatures, the north-west of the North Island especially Northland and Auckland are two areas where temperatures will increase. These regions have large populations of banded kōkopu which therefore may be affected by climate change, but the nature of these effects cannot be derived from the CCVA methodology alone. Future work applying region-specific CCVAs will increase our understanding of the vulnerability of regional populations of freshwater taonga species, but this can only occur when region-specific data on the sensitivity attributes (such as spawning cycle) are available for the species of interest.

There was some agreement between the environmental variables affecting taonga species identified in the literature review and the exposure variables identified in the CCVAs. For example, the IUCN assessment predicted that drought will affect longfin eels (Pike et al. 2019a) and the CCVAs indicated that longfin eels will be exposed to changes in drought intensity (2081–2100: RCP 8.5). However, there were also some disagreements. For example, shortfin eels were not ranked high or very highly exposed to drought intensity in our assessment but there was more evidence in the literature for droughts impacting on shortfin eels than there was for longfins (see section 2.1).

There was some agreement between species identified as highly or very highly vulnerable to climate change in the CCVAs (longfin eel, lamprey, shortfin eel, banded kōkopu, īnanga and kōaro) and species identified as threatened by climate change on the IUCN Red Lists. For example, our literature review revealed that longfin eel (Pike et al. 2019a), shortfin eel (Pike et al. 2019b) and kōaro (Raadik et al. 2019) all had climate change listed as a threat according to the IUCN Red List, but lamprey (Bice et al. 2019), īnanga (Bice et al. 2019b) and banded kōkopu (West et al. 2014) did not.

# 5.3 Future research and data needs

This scoping study demonstrates that climate change can be considered when assessing threats to taonga species and that CCVAs provide a structured and transparent means for this to be done. However, for species where key aspects of their ecology and life histories are poorly described, such as the freshwater mussels *E. onekaka* and *E. aucklandica*, greater data collection efforts are needed to enable the application of CCVA methods (Foden et al. 2019; Hare et al. 2019). Other species that should be considered for assessment using CCVA methods include significant prey species like the common bully (*Gobiomorphus cotidianus*), for which there is anecdotal evidence that annual fluctuations in populations have negative impacts on eel growth rates. It would also be prudent to assess non-native/exotic/pest fishes using CCVAs, to better understand their vulnerability to a changing climate relative to our taonga species.

This CCVA largely adopted the methods by Pecl et al. (2011), Morrison et al. (2015) and Hare et al. (2016). A wide range of species were included in the CCVAs by the aforementioned authors, which include fish and invertebrates. The sensitivity attributes used in CCVAs must therefore be broad enough to cover a wide range of species and need to account for the extent of existing information pertaining to the sensitivity attributes. While some CCVAs use very specific sensitivity attributes such as temperature tolerances at the egg/larval stages or correlations between marine survival and climate (Crozier et al. 2019) this was not possible here because of substantial data deficiencies for many taonga species (Williams et al. 2017). Furthermore, we did not have the capacity to make substantial changes to the CCVA methodology for this initial scoping study. We recommend future CCVA incorporate more species in the assessment and that improvements could be made to the sensitivity attributes and exposure variables used (i.e., river flow projections instead of precipitation projections). In addition, we recommend the scoring of species is done by at least four experts as per other CCVAs (Hare et al. 2016).

Regional climate change projections have been prepared for Aotearoa-New Zealand (i.e., Auckland; Pearce et al. 2018) and so a potential next step could be to **conduct CCVAs for a specific region**. However, this would require targeted surveys in specific regions and catchments to **address critical knowledge gaps** for our freshwater taonga species. Attempts have been made previously to compile a national species traits database for freshwater fishes. However, the dearth of spatial data, minimal number of observations for key traits such as egg size or longevity, and difficulty accessing data (such as in unpublished reports) make compiling a database challenging (Dr Richard White, pers. comm.). It would be prudent to **develop an open-source database** so that researchers can access the data required to develop region-specific CCVAs.

Species exposure to climate change varies nationally and freshwater taonga species will likely respond to climate change differently based on their unique set of characteristics and distributions. It is expected that species with more restricted distributions will be more likely to show high climate change vulnerability than widespread species (Lee et al. 2015). We view these freshwater taonga species CCVAs as the first step towards accelerating research on taonga species vulnerability to climate change. Although our assessment looked at species exposure approximately 30 years from now (2046– 2065) and 70 years from now (2081–2100), our assessment suggests that **understanding the impacts of changes in mean annual precipitation (mm), changes in mean autumn and winter precipitation, changes in autumn mean air temperature and the annual number of hot days (more than 25°C) will increase our understanding of taonga species responses (positive, negative or neutral) to the environmental conditions they are most likely to be exposed to in the coming decades.**  One of the key limitations of CCVAs is that the results do not provide any information around what management actions should be taken and how these actions should be prioritised for species (Lee et al. 2015; Butt et al. 2016). However, CCVAs can help direct research priorities for a species and/or a region and can be used as a management decision-support tool.

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#### 8 Glossary of abbreviations and terms

Antarctic Circumpolar Wave	The Antarctic Circumpolar Wave is a coupled ocean/atmosphere wave that circles the Southern Ocean in approximately eight years at 6-8 cm/s.				
AWC	Available Water Capacity.				
CCVA	Climate Change Vulnerability Assessment.				
cm/s	Centimetres per second.				
Diadromous	Diadromous species can be split into three categories:				
	<ul> <li>Catadromous species (e.g., tuna and īnanga) – live in freshwater, but migrate to sea to spawn, with larvae returning on ocean currents and enter freshwater as juveniles (e.g., glass eels and whitebait).</li> </ul>				
	<ul> <li>Anadromous species (e.g., piharau/kanakana) – where adults live at sea and then migrate upstream from the sea to spawn in fresh water. For these species, the larvae rear in fresh water before migrating out to sea as juveniles.</li> </ul>				
	<ul> <li>Amphidromous species (e.g., large galaxiids and common smelt) undertake a migration between fresh and saltwater for a purpose other than breeding. In general, adults breed in the freshwater environment, with larvae rearing at sea, and then migrating upstream into freshwater as juveniles several months later for growth to adulthood. Although a large proportion of common smelt populations are amphidromous, they also form anadromous populations, where larvae and juveniles rear in marine or estuarine waters and adults migrate into freshwater to spawn.</li> </ul>				
	Several diadromous species have also formed <b>land-locked</b> populations overtime (e.g., due to man-made barriers and/or translocations) – where no marine phase is required (e.g., common smelt and kōaro).				
EAC	East Australian Current.				
Ecosystem regime shift	In ecology, <b>regime shifts</b> are large, abrupt, persistent changes in the structure and function of a system.				
El Niño	An irregularly occurring and complex series of climatic changes affecting the equatorial Pacific region and beyond every few years, characterised by the appearance of unusually warm, nutrient-poor water off northern Peru and Ecuador, typically in late December. The effects of El Niño include reversal of wind patterns across the Pacific, drought in Australasia, and unseasonal heavy rain in South America.				
ENSO	El Niño-Southern Oscillation.				

Exposure	Species <b>exposure</b> is assessed by examining the overlap between the spatial distribution of a species alongside predicted changes in the environmental variable of interest (i.e., sea surface temperature; Morrison et al. 2015). Exposure variables are those climate variables included in the assessment that could impact taonga species (e.g., temperature, sea surface salinity, precipitation [as a proxy for river flow]). The exposure score includes information about the magnitude of the expected climate change, but not in relation to each species' tolerances, which are often unknown (Hare et al. 2016).
IPCC	Intergovernmental Panel on Climate Change ( <u>www.ipcc.ch</u> )
IUCN	International Union for the Conservation of Nature ( <u>www.iucn.org</u> )
IUCN Red List	Is an inventory of the global conversation status of plants and animals.
La Niña	A cooling of the water in the equatorial Pacific, which occurs at irregular intervals, and is associated with widespread changes in weather patterns complementary to those of El Niño, but less extensive and damaging in their effects.
NEMO	Nucleus for European Modelling of the Ocean.
Otolith	Fish ear bone made of calcium carbonate. Otoliths are used to age fish and measure annual growth rates.

Phermones

Representative Concentration Pathway (RCP)		A <b>Representative Concentration Pathway</b> (RCP) is a greenhouse gas concentration (not emissions) trajectory adopted by the IPCC for its Fifth Assessment Report (AR5) in 2014.
		RCP 4.5 (CO <sub>2</sub> concentrations of 538 ppm by 2100) represents a moderate-emission scenario and requires stabilisation of greenhouse gas emissions during the twenty-first century.
		RCP 8.5 is the high-emission scenario (atmospheric $CO_2$ of 936 ppm in 2100) that assumes little or no. stabilisation of greenhouse gas emissions (i.e., a "business as usual scenario") by 2100.
Sensitivity		Sensitivity attributes are characteristics that are likely to make a species more (or less) vulnerable to climate change. Species sensitivity attributes include biological or ecological variables that predict the vulnerability to climate change. For example, a species that has low reproductive output may be more sensitive to climate change compared to a species with high reproductive output.

Taonga speciesWe have used the phrase "taonga species" to collectively refer to species of<br/>importance to Māori, as defined by Māori. The representative species included in<br/>this report were chosen by Te Wai Māori. This list was then reduced further due to<br/>the lack of information/research focus on taonga species of importance to Māori.<br/>We recognise that whānau and hapū across Aotearoa-New Zealand have an<br/>extensive range of names for their freshwater taonga species. In this report we have<br/>drawn on the most commonly used names.

### Appendix A Summary of information sources used for the species profiles

The type and number of habitats used by each species was derived from the IUCN Red List assessments and was also adopted by Hossain et al. (2018). Stock assessment information was used where species are commercially fished (i.e., longfin and shortfin eels; Beentjes 2019) to provide information on the fishery.

Demographic parameters were derived for each species form the literature. These were:

- Maximum body size (mm),
- Minimum size sexual maturity (mm),
- Age at sexual maturity (years),
- Longevity (years),
- Growth parameter (K),
- Fecundity,
- Larval size at hatching (mm),
- Egg size (mean), and
- Generation length (years).

Species distribution maps were derived from the "Freshwater taonga species report" (Williams et al. 2017) to provide the necessary background information to each assessor. These maps were also used to score species exposure to each of the climate variables (section 4.3). Information about taonga species environmental preferences was extracted from Leathwick et al. (2008). The authors used statistical models to determine the main environmental correlates of species' distributions in New Zealand, and to establish the environmental conditions preferred by each species (Leathwick et al. 2008). Environmental variables that explained greater than 5% of a species distribution were presented here. Information on the temperature tolerances of taonga species was derived from a comprehensive review by Olsen et al. (2012) on the water temperature criteria for native fish and invertebrates. Multiple metrics of water temperature criteria were assessed by Olsen et al. (2012) and include species:

- Critical thermal maximum;
- Thermal preferences;
- Upper incipient lethal temperature; and
- Behavioural/developmental effects.

Information on diet and predation, recruitment and current impacts of climate change was largely drawn from the literature. Taonga species are affected by numerous stressors not directly related to climate but that potentially reduce their ability to cope with climate change. The types of threats that taonga species are currently affected by was derived from the IUCN assessments and was used to populate information on 'additional multiple stressors'.

## Appendix B Expert assessors of the sensitivity and exposure attributes for taonga species

Table B-1:Individuals that assessed the sensitivity attributes of selected taonga species during theworkshops.Note: All exposure attributes were scored by Dr Eimear Egan, except for kākahi (*E. menziesii*) andgiant kōkopu (*G. argenteus*) which were scored by Dr Thomas Drinan.

Name	Organisation	Species
Dr Cindy Baker	NIWA	Pouched lamprey
Dr Erica Williams	NIWA	Shortfin eel
Dr Shannan Crow	NIWA	Longfin eel
Dr Eimear Egan	NIWA	Giant kōkopu
Mark Fenwick	NIWA	Kākahi; Yellow-eye mullet
Dr Michael Hickford	University of Canterbury	Īnanga; Banded kōkopu
Dr Richard White	University of Canterbury	Kōaro
Dr Thomas Drinan	Department of Conservation	Kōura

# Appendix C Data quality scores for sensitivity attributes in the low (no data) and medium (expert judgement) categories

Attribute	Species	Category	Score
	Banded kōkopu	Low	3
Adult mobility	Kākahi	Medium	4
	Kōaro	Low	4
	Banded kōkopu	Low	3
	Giant kōkopu	Medium	3
Complexity in reproduction	Kākahi	Medium	3
	Kōaro	Low	3
	Lamprey	Medium	3
	Īnanga	Medium	3
	Kākahi	Medium	3
Dependence on environmental triggers	Kōaro	Low	4
	Kōura	Medium	3
	Yellow-eye mullet	Medium	3
	Banded kōkopu	Low	3
Dependence on interspecific interactions	Kōaro	Low	4
	Banded kōkopu	Low	4
	Kākahi	Medium	3
Dispersal of early life stages	Kōaro	Low	3
	Yellow-eye mullet	Medium	5
	Banded kōkopu	Low	3
	Giant kōkopu	Low	3
Early life history survival and recruitment	Kōaro	Low	4
	Lamprey	Medium	4

Table C-1:Distribution of tallies for low and medium quality data for each sensitivity attribute and<br/>species.Only tallies  $\geq$ 3 are shown.

#### Table C-2: Continued.

Attribute	Species	Category	Score
	Banded kōkopu	Low	3
Exposure to other pressures	Kākahi	Medium	3
	Lamprey	Medium	4
Habitat specificity	Kōaro	Medium	3
	Lamprey	Medium	3
	Giant kōkopu	Low	3
	Kākahi	Medium	3
Population growth rate/domographics	Kōaro	Low	4
Population growth rate/demographics	Kōura	Medium	3
	Lamprey	Medium	4
	Yellow-eye mullet	Medium	3
	Banded kōkopu	Medium	3
	Kākahi	Medium	3
Prey specificity	Kōaro	Medium	3
	Kōura	Medium	3
	Lamprey	Medium	3
	Banded kōkopu	Low	3
	Giant kōkopu	Low	3
Showning cyclo	Kākahi	Low	3
Spawning Cycle	Kōaro	Low	4
	Longfin eel	Medium	3
	Yellow-eye mullet	Medium	3
Tamparatura consitivity	Kōura	Medium	3
	Shortfin eel	Medium	5

#### Appendix D Taonga species threat rankings

Common name	Species	Threat status	Long term population trend	Total area of occupancy (ha)	Current population size
Longfin eel/Tuna	Anguilla australis	At risk declining	Decreasing 10-70% (Low confidence)	Area > 10 000 (High confidence)	
Shortfin eel/Tuna	Anguilla dieffenbachii	Not threatened	Increasing > 10% (High confidence)		Mature individuals > 100,000 (High confidence)
Īnanga/Whitebait	Galaxias maculatus	At risk declining	Decreasing 10-70% (Medium confidence)		Mature individuals > 100,000 (High confidence)
Kōaro/Whitebait	Galaxias brevipinnis	At risk declining	Decreasing 10-70% (High confidence)		Mature individuals > 100,000 (High confidence)
Banded kõkopu/Whitebait	Galaxias fasciatus	Not Threatened	Stable +/-10% (Medium confidence)		Mature individuals > 100,000 (High confidence)
Giant kōkopu/Whitebait	Galaxias argenteus	At risk declining	Decreasing 10-50% (Medium confidence)		Mature individuals = 20,000 – 100,000 (Medium confidence)
Lamprey/Piharau/Kanakana	Geotria australis	Threatened – Nationally Vulnerable	Decreasing 10-30% (Low confidence)	Area <= 100 (High confidence)	
Yellow-eye Mullet/Kātahi/Aua	Aldrichetta forsteri	Not Threatened	Stable +/-10% (Low confidence)		Mature individuals > 100,000 (High confidence)
Freshwater mussel/Kākahi/Kāeo	Echyridella menziesii	At risk declining	Decreasing 10-70% (High confidence)	Area > 10000 (Medium confidence)	

 Table D-1:
 Taonga species threat rankings according to the Department of Conservation threat ranking system (Dunn et al. 2018). Grey shading denotes no data.

Common name	Species	Threat status	Long term population trend	Total area of occupancy (ha)	Current population size
Freshwater crayfish/Kōura/Kēwai	Paranephrops planifrons	Not Threatened	Stable +/-10% (Medium confidence)		Mature individuals > 100,000 (High confidence)



