NIWA
Taihoro Nukurangi

Te Wai Māori

Contents

We recognise that whānau and hapū across Aotearoa have an extensive range of names for their freshwater taonga species. In this resource we have drawn on the most commonly used names, but please check with your local hapū for the te reo that is relevant to your area.

Introduction

To respond to and prepare for changes in our climate, and the effects of those changes on taonga species, we need a better understanding of taonga species' vulnerability to climate change. This information is needed so that decision makers such as Te Wai Māori Trust can make informed decisions regards taonga species conservation and management.

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).

This document summarises the results of a Climate Change Vulnerability Assessment (CCVA) done for 10 freshwater taonga species (eight fish and two invertebrates). The CCVA methodology is used internationally and has been completed for a wide range of species including birds, reptiles, mammals, amphibians, invertebrates, marine and freshwater fishes. This study is the first application of CCVAs to freshwater taonga species in Aotearoa–New Zealand.

The theory behind a CCVA is relatively straightforward. For a species to be affected by climate change, it must be exposed to a change, as well as be sensitive to change.

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.
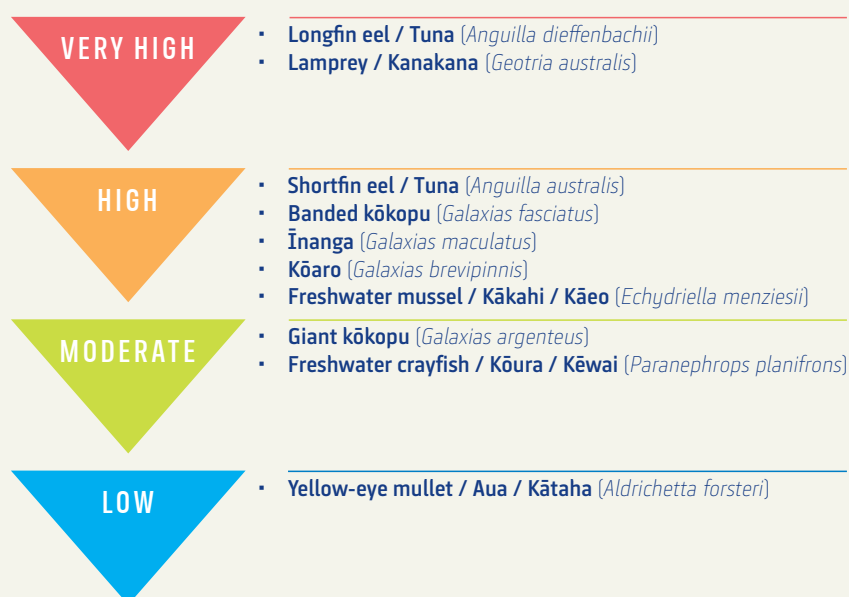
However, CCVAs can help direct research priorities for a species and/or a region and can be used as a management decision-support tool when specific data on species responses to climate change is lacking. Importantly the CCVA results may change in time as better data is gathered about taonga species.

Our findings

The results from the CCVAs revealed there are emerging climate-related threats to freshwater taonga species in Aotearoa–New Zealand over the remainder of the 21st century.

Climate Change Vulnerability Assessment ranking

CCVAs 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. Using the combined scores for the sensitivity attributes and exposure variables, the climate change vulnerability scores for 10 freshwater taonga species were:

VERY HIGH
- **Longfin eel / Tuna** (*Anguilla dieffenbachii*)
- **Lamprey / Kanakana** (*Geotria australis*)

HIGH
- **Shortfin eel / Tuna** (*Anguilla australis*)
- **Banded kōkopu** (*Galaxias fasciatus*)
- **Īnanga** (*Galaxias maculatus*)
- **Kōaro** (*Galaxias brevipinnis*)
- **Freshwater mussel / Kākahi / Kāeo** (*Echydriella menziesii*)

MODERATE
- **Giant kōkopu** (*Galaxias argenteus*)
- **Freshwater crayfish / Kōura / Kēwai** (*Paranephrops planifrons*)

LOW
- **Yellow-eye mullet / Aua / Kātaha** (*Aldrichetta forsteri*)

Find out more about each species' CCVA results on pages 9-49.

Due to a lack of basic life history and ecological information, CCVAs could not be completed at this time for: shortjaw kōkopu (*Galaxias postvectis*); grey mullet (*Mugil cephalus*); common smelt (*Retropinna retropinna*); black flounder (*Rhombosolea retiarii*); kōura (*Paranephrops zealandicus*) and two freshwater mussel species (*Echyridella onekaka* and *Echyridella aucklandica*).

More research is needed to fill critical knowledge gaps for data-deficient species (See *Future research* section on page 50).

Methodology

What is a Climate Change Vulnerability Assessment?

CCVAs identify which species may be most vulnerable to climate change in the future based on:

(1) their exposure to predicted changes in the environment (e.g., warming oceans or more frequent droughts), and

(2) their sensitivity or ability to cope with changes in their environment based on their unique characteristics.

Together, exposure and sensitivity form a species' climate change vulnerability score which are ranked as very high, high, moderate and low.

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 for the sensitivity attributes and exposure variables (see methodology page 5). The scores for the sensitivity and exposure attributes were then combined to derive a relative climate change vulnerability ranking for each taonga species being assessed.

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.

SENSITIVITY

+

EXPOSURE

=

CCVA SCORE

VERY HIGH

HIGH

MODERATE

LOW

SENSITIVITY

How were sensitivity attributes and scoring assessed?

Sensitivity attributes are characteristics that are likely to make a species more (or less) vulnerable to climate change. The sensitivity attributes we assessed are in table 1.

Experts had five "tallies" for each sensitivity attribute which they distributed among four bins (low, medium, high and very high) depending on their confidence in the score. Experts who were certain about a score were able to place all five tallies

in one bin (e.g., all five tallies can be placed in the very high bin). Conversely, experts who were unsure about a score were able to spread all five tallies across the relevant bins (for example, they could put two tallies in the high bin, and three in the very high bin). Distributing five tallies across four bins forced the expert to choose one bin as the most likely. This is a transparent method to show where there was uncertainty in a score.

		Goal of the CCVA assessment
Distribution	Habitat specificity	*Determine, on a relative scale, if the population/species is a habitat generalist or a habitat specialist while incorporating information on the type and abundance of key habitats.*
	Dispersal of early life stages	*Estimate the ability of the population/species to disperse and colonise new habitats when/if their current habitat becomes less suitable.*
	Adult 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.*
	Temperature sensitivity	*Using known temperature requirements and/or the altitudinal/latitudinal distribution of species as a proxy for its sensitivity to temperature.*
	Dependence on interspecific interactions	*Determine potential changes in interspecific interactions with a changing climate.*
Abundance	Prey specificity	*Determine, on a relative scale, if the population/species is a prey generalist or a prey specialist.*
	Complexity in reproduction	*Determine how complex the population's/species' reproductive strategy is and how dependent reproductive success is on specific environmental conditions.*
	Early life history survival and recruitment	*Determine the relative importance of early life history requirements for a species.*
	Demographics	*Estimate the relative productivity of the population/species.*
	Exposure to threats/other stressors	*Account for conditions that could increase the stress on a population/species and thus decrease its ability to respond to changes.*
Phenology	Dependence on environmental triggers	*Assessing the dependence of a species on specific environmental triggers or cues over its life cycle (e.g., temperature, freshwater flows, ocean currents etc).*
	Spawning duration	*Determine if the duration of the spawning cycle could limit the ability of the population/species to successfully reproduce if necessary, conditions are disrupted by climate change.*

Table 1. Twelve sensitivity attributes were used to inform CCVAs for 10 freshwater taonga species

EXPOSURE

How was exposure to climate change assessed?

Species exposure to climate change was assessed using maps of species distributions across Aotearoa–New Zealand alongside predicted changes in environmental conditions that could impact taonga species.

The scoring system for the exposure variables was similar to the sensitivity scoring.

Representative Concentration Pathways (RCP)

Projections were made for two greenhouse gas scenarios (referred to as Representative Concentration Pathways (RCP)):
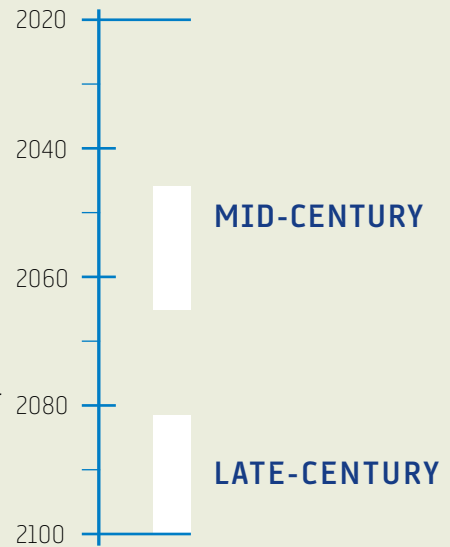
RCP 8.5 is the high-concentration scenario that assumes little or no stabilisation of greenhouse gas concentrations by 2100.

RCP 4.5 is a moderate-concentration scenario and requires stabilisation of greenhouse gas concentrations during the twenty-first century.

Maps for each of these environmental variables (see table 2) were produced for two future timeframes:

- mid-century [2046–2065] and
- late-century [2081–2100].

2020

2040

MID-CENTURY

2060

2080

LATE-CENTURY

2100

Exposure variable	Low score	Very high score
Mean air temperature (°C) change	*0°C – 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)	*Increase of between 0.5 and 5 days per year*	*Increase of more than 75 days per year*
Mean precipitation change (%)	*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)	*No change in wet days*	*More than 10 day increase in wet days*
Extreme wind speeds	*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)	*Species is exposed to negligible change in PED*	*Species are exposed more than 100 mm change in PED*
Sea surface temperature	*No change in sea surface temperature is expected*	*More than 3°C increase in sea surface temperatures*
Sea level rise	*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-1 by 2050*
Near shore ocean currents (Aotearoa-New Zealand)	*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	*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*

Table 2. Scoring system for the exposure variables

Summary

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.

Our literature review revealed substantial knowledge gaps regarding the effects of climate change on Aotearoa-New Zealand's freshwate taonga species. However, we identified five climatic factors from the national/international literature that broadly affect taonga species.

These were:

- drought
- temperature (indirect [air temperature] direct [water temperature])
- El Niño/La Niña cycles
- sea level rise
- extreme events (e.g., storms).

It is apparent from the literature that these climatic factors interact with each other and no one factor affects taonga species in isolation.

Sensitivity attributes

Reproductive complexity and **exposure to other pressures** were the sensitivity attributes that contributed the most to the overall vulnerability rankings of the freshwater taonga species assessed.

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. Targeted research to help us understand the sensitivity of our freshwater taonga species to climate change is needed to inform the strategies and actions needed to help our freshwater taonga species/populations prepare for a changing climate.

Exposure variables

Five exposure variables contributed the most to taonga species climate change vulnerability.

These exposure variables 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 (ºC); timeframe 2081–2100; RCP 8.5**
- **annual number of hot days (more than 25ºC); 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.

Climate Change Vulnerability Assessment by species

Tuna
(Longfin eel)
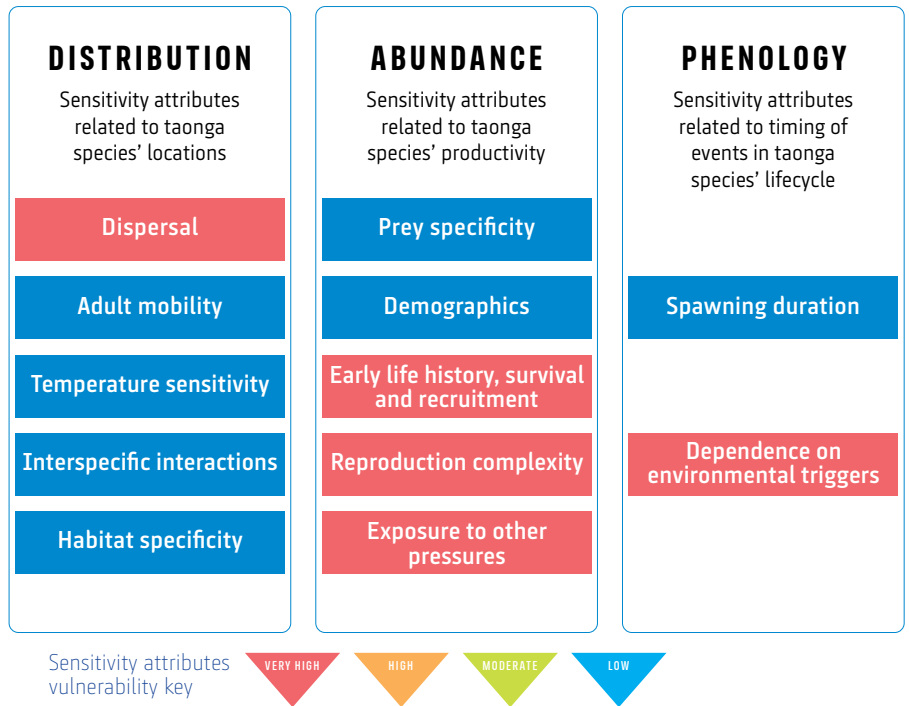Species: *Anguilla dieffenbachii*

SENSITIVITY + EXPOSURE = **VERY HIGH**

SENSITIVITY

Longfin eels have a complex lifecycle. Most of their life is spent in freshwater, followed by migration to the marine environment for reproduction.

DISTRIBUTION
Sensitivity attributes related to taonga species' locations

Dispersal

Adult mobility

Temperature sensitivity

Interspecific interactions

Habitat specificity

ABUNDANCE
Sensitivity attributes related to taonga species' productivity

Prey specificity

Demographics

Early life history, survival and recruitment

Reproduction complexity

Exposure to other pressures

PHENOLOGY
Sensitivity attributes related to timing of events in taonga species' lifecycle

Spawning duration

Dependence on environmental triggers

Sensitivity attributes vulnerability key

VERY HIGH | HIGH | MODERATE | LOW

Subset of the sensitivity attributes that contributed to longfin eel CCVA scores

Demographics

Longfins are one of the largest, slowest growing and longest–lived eel species in the world. Females can live for over a century, meaning they may be exposed to the impacts of environmental changes over multiple decades and climate change over their lifetime. Large eels play an important role in determining the population structure and these large eels affect species composition, sex ratios and size distribution. Longfin eels breed once in their life and die after spawning. They can produce millions of eggs and larger females are more fecund than smaller females.

Exposure to multiple pressures

Species that are already facing multiple threats are often considered more vulnerable to climate change. Longfin eel are ranked as 'At-Risk Declining' by the Department of Conservation and 'endangered' by the International Union for Conservation of Nature. Pressures on longfin eels include the commercial eel fishery, in-stream barriers to upstream and downstream migrations, and mortality at hydro-structures. Roughly one-third of the available longfin habitat is currently commercially fished and approximately 40% of the longfin eel habitat is estimated to be impacted by both hydroelectric dams and commercial fishing. Drought is recognised as a significant ongoing threat to longfin eel, potentially affecting 50% of the population in New Zealand.

Tuna (Longfin eel)

Complexity in reproduction

Longfin eels have several characteristics that likely increase their vulnerability to climate change. Longfin eels migrate from fresh water to the Pacific Ocean to spawn, a spawning migration that spans thousands of kilometres. Sex-specific differences in migration times are known with males generally migrating to sea during April, and longfin females during late April and May. The adult migration to the spawning grounds takes approximately 6–9 months. Females that do reach the spawning area must encounter males and spawn and they reproduce in large aggregations. However, the location of their spawning ground is unknown and therefore spawning behaviour has never been observed. Gender is thought to be determined principally by environmental factors, particular temperature, meaning sex ratios are vulnerable to changes in temperature. Longfin eels are semelparous meaning they die after reproduction.

Tuna have an unusual life cycle which sees them traveling between the sea, estuaries and fresh waters.

EXPOSURE

Longfin eels are only found in Aotearoa–New Zealand. They can travel up to 300 km inland, are distributed from sea level up to 1,150 metres elevation. This species can be found in many high–country lakes and rivers. Although the adults are highly mobile, they have a narrow home range with an average of just 10 metres.

Subset of the exposure variables that will likely increase the vulnerability of longfin eels to climate change

Drought intensity

Longfin eels will likely be highly exposed to changes in drought intensity (indicated by changes to potential evapotranspiration deficit) for mid-century (2081–2100), under the "extreme" scenario (RCP 8.5). Most of the North Island, the central South Island along the Southern Alps, and the east coast of the South Island will experience increases in drought conditions. Populations on the west coast of the South Island are projected to be the least exposed to changes in drought intensity.

Increased stress associated with changes in drought intensity may reduce longfin eel habitat availability, alter prey availability, interfere with environmental triggers, and increase mortality rates. However, like shortfin eels, longfin eels may be resistant and resilient to drought conditions.

Temperature extremes

Longfin eels will likely be exposed to changes in extreme annual air temperatures for the time period 2081–2100 for RCP 8.5. The number of hot days ranges from 0 to 60 for the annual baseline (time period 1986–2005) with more hot days along the east coast of both North and South Islands. The projections show a large proportion of the North Island and the central South Island along the Southern Alps will experience an increase in the number of hot days (at least 50 more days per year).

Because longfin eels penetrate further inland than shortfins, and live in higher altitude environments, they may be more exposed to changes in temperature extremes. Adult longfin eels have an upper thermal limit of 37.3°C. Increased stress associated with changes in temperature extremes may skew longfin eel sex ratios and reduce reproductive success.

Western Pacific Ocean circulation changes

Longfin eels will likely be highly exposed to projected changes in Western Boundary Currents by late century (2081–2100) for RCP 8.5. Recent modelling shows that there will be strong changes in the intensity and position of the East Australian Current and that significant projected changes in ocean circulation will occur in the future. Connectivity between Australia and New Zealand will reduce, meaning larval transport to northern New Zealand may be affected. Projected changes in the size and temporal extent of eddies might be beneficial for longfin eel larvae as they can obtain more food and potentially grow faster, thereby enhancing larval survival rates.
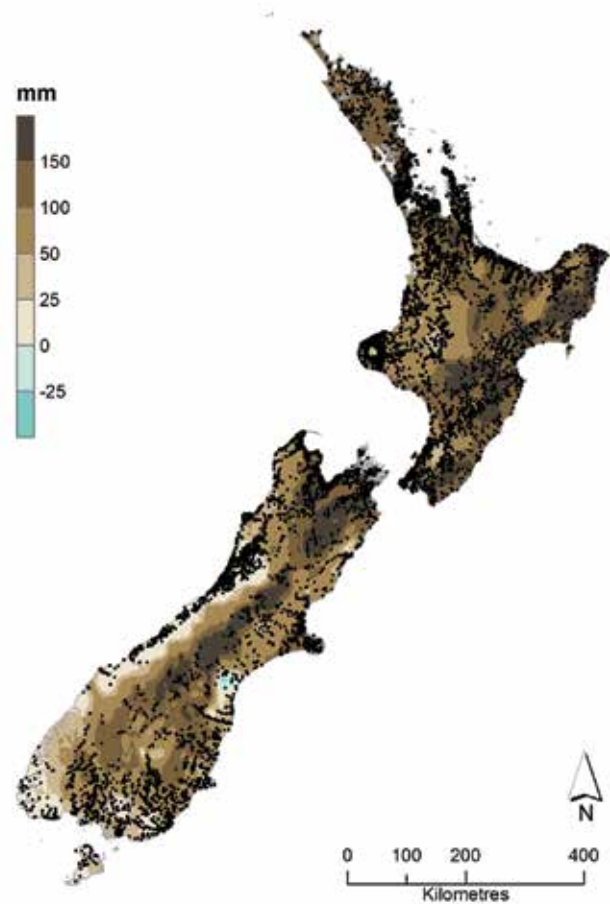
Current longfin eel distribution (dark circles) mapped with projected changes in mean annual drought intensity indicated by changes to annual potential evapotranspiration deficit accumulation (for time period 2081–2100 under RCP 8.5).

The migratory routes of adult and larval longfin eels are poorly known and it is not clear if the East Australian Current is a major migratory pathway. The spawning period of longfin eels extends from August to December indicating winter, spring and summer spawning events. The extensive spawning indicates that a portion of the population may encounter favourable transport conditions, while another portion may encounter unfavourable larval transport conditions.

Longfins may use several ocean currents to and from their spawning grounds. Until we better understand the needs of longfin eels during their marine life stage, we cannot accurately predict what the consequences of a changing marine environment on longfin eel populations.

Piharau / Kanakana
(Pouched lamprey)
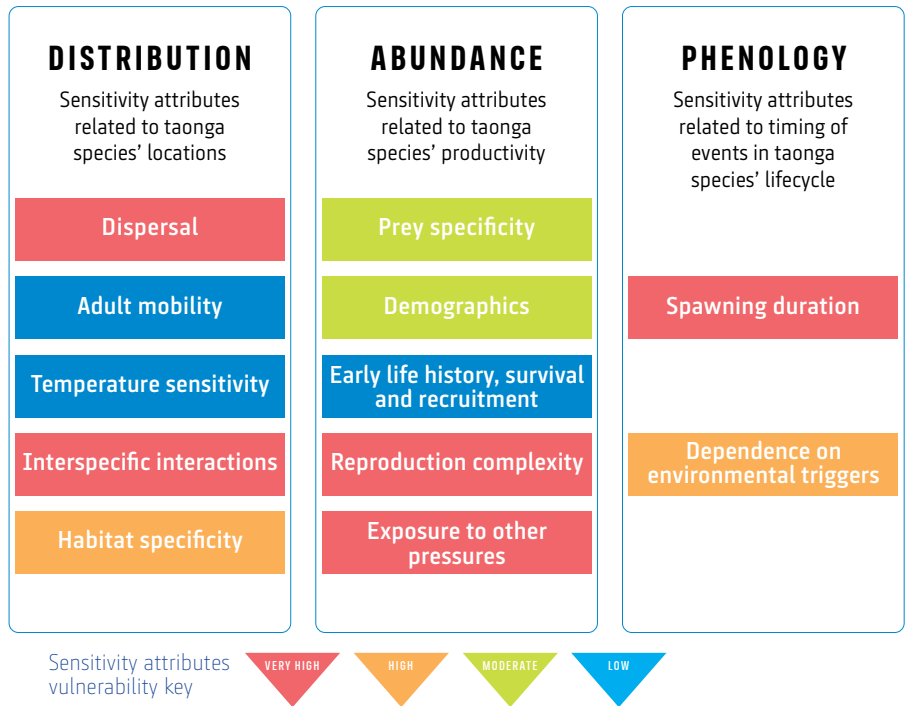Species: *Geotria australis*

SENSITIVITY + EXPOSURE = VERY HIGH

SENSITIVITY

Lamprey/kanakana use marine, estuarine and freshwater habitats to complete their life cycle. Lamprey migrate from the sea into freshwaters to spawn. Adult lamprey are attracted to pheromones (chemicals) released by juveniles. Length of the marine stage is not known but it is suggested to range between two and four years.

DISTRIBUTION
Sensitivity attributes related to taonga species' locations

- Dispersal
- Adult mobility
- Temperature sensitivity
- Interspecific interactions
- Habitat specificity

ABUNDANCE
Sensitivity attributes related to taonga species' productivity

- Prey specificity
- Demographics
- Early life history, survival and recruitment
- Reproduction complexity
- Exposure to other pressures

PHENOLOGY
Sensitivity attributes related to timing of events in taonga species' lifecycle

- Spawning duration
- Dependence on environmental triggers

Sensitivity attributes vulnerability key

VERY HIGH   HIGH   MODERATE   LOW

Subset of the sensitivity attributes that contributed to lamprey/kanakana CCVA scores

Dispersal of early life stages

In general, greater larval dispersal corresponds with a better ability to respond to climate change. The dispersal of larval lamprey is limited. Lamprey lay their eggs under boulders in freshwater and so are benthic spawners. Once the eggs hatch, larval lamprey remain in the nest for at least 2 weeks. After this period, they are then believed to disperse away from the nest, but the extent of this dispersal is limited. The weak dispersal of larval lamprey in freshwater means they cannot readily escape changes in their environment and colonise new habitats.

Dependence on interspecific interactions

Species are likely to be particularly sensitive to climate change if, for example, they are highly dependent on beneficial interaction(s) with one or few particular species. During the marine life stage, lamprey feed parasitically on other fish (and potentially marine mammals) meaning they rely on another species to complete their life cycle. The marine migration routes of lamprey are likely determined by those of their unknown host species. This means that if climate change affects the marine migration route of their host, then lamprey will be indirectly affected.

Exposure to multiple pressures

Lamprey were ranked as 'Nationally Vulnerable' by the Department of Conservation in 2017 and 'data deficient' by the International Union for Conservation of Nature in 2019. River regulation and construction of instream barriers have affected the abundance and distribution of lamprey. Hydropower development is a specific threat in Aotearoa–New Zealand, and poorly designed instream barriers like culverts, weirs and fords can impact the upstream migration of adult fish. Changes to river flow regimes have likely altered migratory cues (presence of juvenile pheromones) and the quality of juvenile nursery habitats. As a result of land use change, adults now likely have to travel greater distances to find suitable spawning habitat which may impact adult condition, whilst the overall area of suitable spawning habitat has likely decreased. Lamprey Reddening Syndrome was observed in 2011 resulting in mass mortalities of pre-reproductive adults.

Piharau / Kanakana (Pouched lamprey)

Complexity in reproduction

Lamprey have several reproductive characteristics that likely increase their vulnerability to climate change. Lamprey likely use the same spawning sites in fresh water within and between years. However, considering their spawning sites are only known from a handful of sites throughout the country, their fidelity for a specific spawning area is not well known. Adult lamprey are attracted to pheromones released by juveniles and it is believed that this helps adults locate suitable spawning and rearing habitats.

Lamprey reproduce in pairs unlike other fish species that spawn in large mixed groups of males and females. Male lamprey care for the eggs and help with hatching of the larvae. This is one of few examples of paternal care for New Zealand's freshwater fish species. Lamprey only reproduce once in their lifetime and they die about three months after reproduction.

EXPOSURE
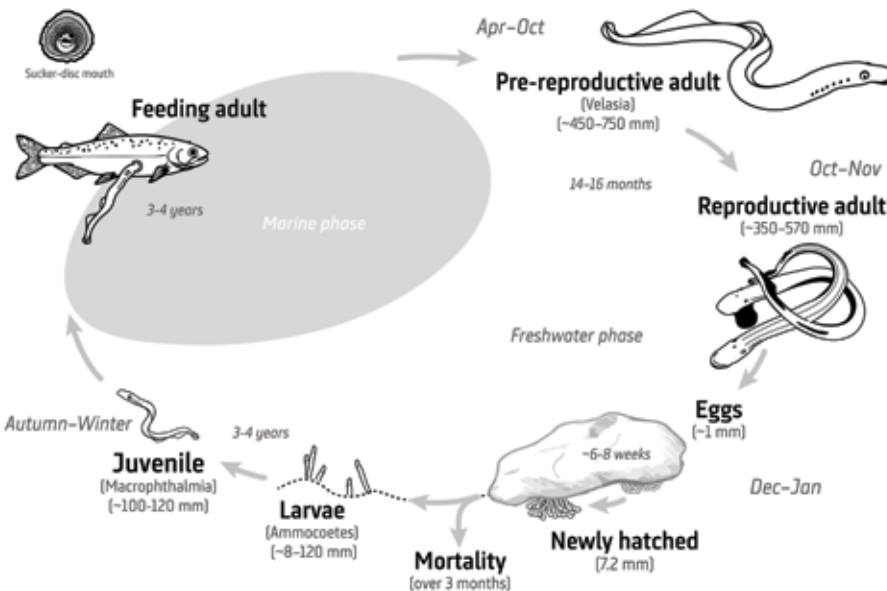
Lamprey are found throughout the Southern Hemisphere's temperate waters. In Aotearoa–New Zealand they are relatively common in Taranaki, Wellington, Banks Peninsula, and the south–eastern corner of the South Island. They can travel substantial distances inland (up to 200 km and can climb over 300 m in elevation).

Subset of the exposure variables that will likely increase the vulnerability of lamprey to climate change

Rainfall (annual, autumn and winter)

Lamprey will likely to be highly or very highly exposed to changes in mean annual and seasonal (autumn and winter) rainfall for the two time periods (mid–century [2046–2065] and late century [2081–2100]) and RCPs [4.5 and 8.5]. Winter rainfall projections show clear differences throughout Aotearoa-New Zealand: precipitation increases by >=20% for many parts of the South Island while the North Island and part of the north-east coast of the South Island will see negligible changes or even decreases.

Adult lamprey return to freshwaters during late autumn, throughout winter and into early spring. Their upstream migrations are stimulated by large flow events. This may benefit the upstream migrations of lamprey. Conversely, large flood events can delay upstream movement and may displace some lamprey downstream.

Autumn air temperatures

By 2081–2100 under RCP 8.5 conditions, lamprey will likely be highly exposed to autumn mean air temperature changes. Juvenile lamprey typically migrate downstream in autumn. Therefore, increased autumn air temperatures could potentially increase lamprey metabolic rates and their swimming speeds so that downstream migration to the marine environment occurs at a faster rate. Migrations of lamprey from the marine environment into freshwater occur in autumn and are usually the most intense between 12°C and 14.5°C. If mean autumn air temperatures increase beyond this range, then migration to spawning sites may be reduced and/or inhibited.

In Australia, projected temperature increases could result in a 30% reduction in pouched lamprey distributions. Furthermore, lamprey are predicted to lose between 50% and 70% of their current population size in Australia, as a result of temperature increases. Data does not exist for Aotearoa–New Zealand populations, however, the CCVA suggests a better understanding the effects of changes in autumn air temperature on lamprey populations is needed.
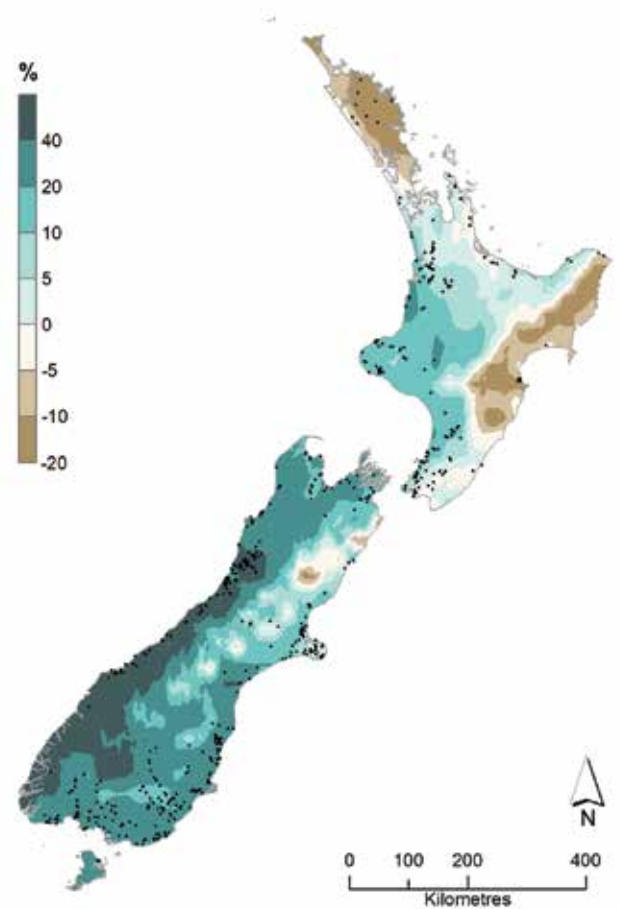
Current lamprey distribution (dark circles) mapped with projected changes in winter precipitation (for time period 2081–2100 under RCP 8.5).

Western Pacific Ocean circulation changes

Lamprey will likely be highly exposed to projected changes in Western Boundary Currents by late century (2081–2100) for RCP 8.5 which makes lamprey highly vulnerable to climate change. Although the marine migratory routes of lamprey are poorly known, recent research suggests this species uses tropical waters during its marine life. There is significant uncertainty about the likelihood of lamprey exposure to changes in oceanic conditions. Until a better understanding of the marine life of lamprey is attained, we cannot predict what the consequences of a changing marine environment may have on this taonga species.

Īnanga / Inaka
(Whitebait)
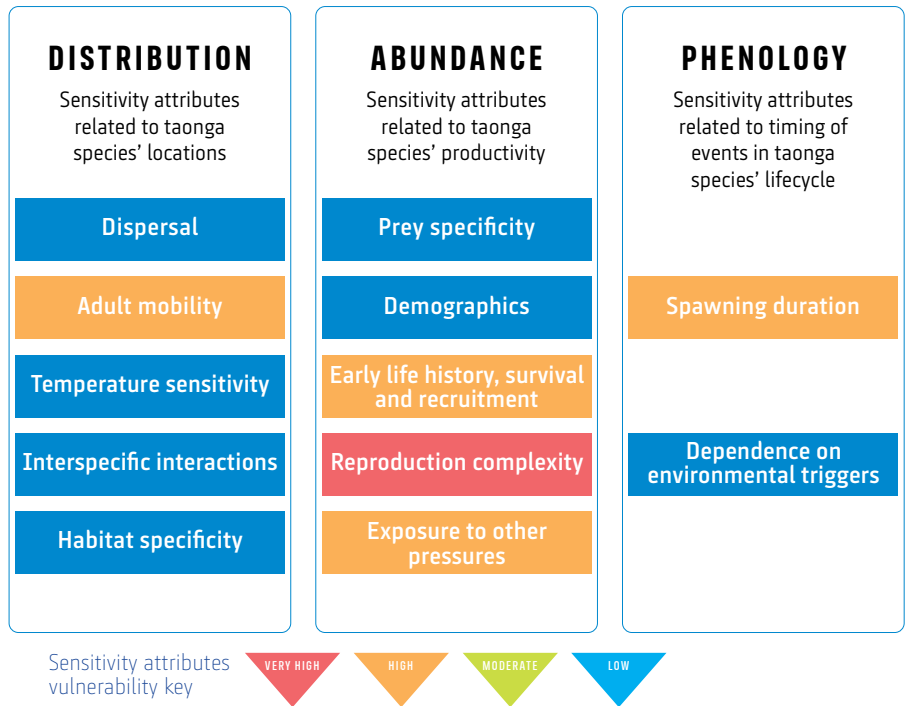Species: *Galaxias maculatus*

Rob Suisted

SENSITIVITY + EXPOSURE = HIGH

SENSITIVITY

Īnanga have an amphidromous life cycle that typically involves downstream larval transport, dispersal and development in the marine environment followed by inward migration of post-larvae (whitebait) to freshwater where most feeding and growth occurs.

DISTRIBUTION
Sensitivity attributes related to taonga species' locations

- Dispersal
- Adult mobility
- Temperature sensitivity
- Interspecific interactions
- Habitat specificity

ABUNDANCE
Sensitivity attributes related to taonga species' productivity

- Prey specificity
- Demographics
- Early life history, survival and recruitment
- Reproduction complexity
- Exposure to other pressures

PHENOLOGY
Sensitivity attributes related to timing of events in taonga species' lifecycle

- Spawning duration
- Dependence on environmental triggers

Sensitivity attributes vulnerability key: VERY HIGH | HIGH | MODERATE | LOW

Subset of the sensitivity attributes that contributed to īnanga CCVA scores

Complexity in reproduction

The complex reproduction of īnanga likely increases their vulnerability to climate change. Īnanga are one of only a handful of species worldwide that use grasses growing on river banks for reproduction. Īnanga can use several species of grasses to deposit their eggs but water levels must be sufficient to inundate the grasses at the correct height for the eggs to hatch. Īnanga require a specific set of environmental cues (salinity, lunar and tidal) for reproduction and the timing of their reproduction is highly predictable. Īnanga usually migrate downstream to their spawning habitats and reproduction occurs in large groups. The same spawning areas are used within and between years. Individuals typically live for one year – although some individuals can survive for two years. Each individual typically reproduces once in their lifetime but a few individuals may lay eggs several times in a year.

Dispersal

The dispersal of īnanga larvae likely reduces their vulnerability to climate change. Once īnanga eggs hatch into larvae (approximately 7 mm long) they rapidly disperse downstream, through estuaries and out to the marine environment, where larvae from multiple sources may mix. However, some īnanga larvae can remain in freshwater meaning that īnanga dispersal abilities are varied which may help this species respond to a changing climate. Studies show īnanga are genetically very diverse and surface ocean currents are likely an important factor in promoting long distance larval dispersal and thus gene flow over a wide geographic scale.

Īnanga / Inaka (Whitebait)

Temperature sensitivity

A species' sensitivity to temperature can be a good predictor of how it will respond to climate change. Species that experience a wide range of temperature regimes (i.e., broad latitudinal distribution) are more likely to persist in warming freshwater/marine environments than those with narrow latitudinal distributions. For species that lack specifics on temperature requirements, their altitudinal/latitudinal species distributions can be used as proxy for temperature tolerance. Aotearoa–New Zealand, īnanga distribution spans 12 degrees latitude indicating this species can tolerate a wide range of temperatures.

Although īnanga populations may be experiencing localised declines in specific areas throughout their range, this species is widespread and abundant throughout the southern hemisphere. Īnanga can be found in temperate zones (usually at low elevations up to 230 m) except for South Africa. These areas include south eastern and south western Australia (east and south of the Great Dividing Range from Brisbane, Queensland (28ºS) to Albany, Western Australia (117ºS, 50ºE) and from Flinders Island and King Island, Bass Strait), Tasmania, and the southern tip of South America including Chile (from 35ºS to 55ºS), Patagonia, Argentina and the Falkland Islands.
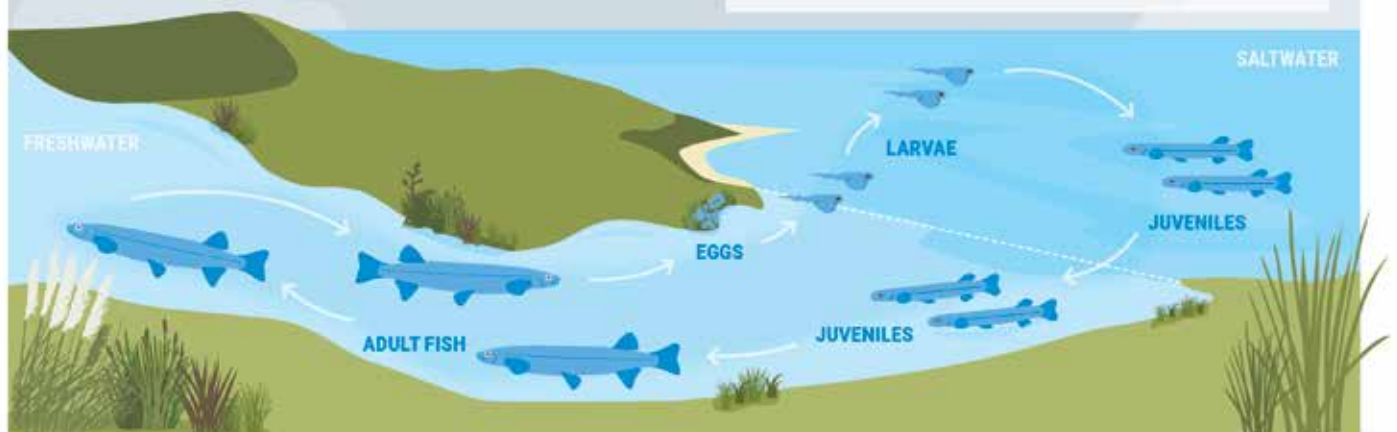
EXPOSURE

Īnanga are considered the most widely distributed freshwater fish species in the world and are abundant in the Southern Hemisphere. In Aotearoa–New Zealand, they are found throughout the country, usually close to the coast. There are a few landlocked populations, particularly in the North Island.

ĪNANGA LIFE CYCLE

Īnanga have a diadromous life cycle meaning they use the marine and freshwater environment to complete their development.

Spawning occurs in freshwater and the larvae develop in the marine environment. This specific type of diadromy is called amphidromy. Once īnanga reach maturity in freshwater, they move downstream to their spawning sites. Spawning occurs on bankside grasses where the saltwater wedge penetrates fresh waters at high tides. The eggs are laid during high spring tides in the intertidal vegetation and develop out of water for 2-4 weeks. The vegetation protects the eggs from drying out but also protects them from predators. The following spring tide stimulates the eggs to hatch and larvae are carried to the sea to feed and grow. After about six months, juvenile īnanga (whitebait) migrate back into freshwater as juveniles. They remain in the lower parts of rivers while they adapt to their new freshwater environment and change into the adult form. They then move further upstream in search of suitable adult habitat.

FRESHWATER   SALTWATER   LARVAE   EGGS   JUVENILES   JUVENILES   ADULT FISH

Subset of the exposure variables that will likely increase the vulnerability of īnanga to climate change

### Rainfall (annual, autumn, winter, spring, summer)

For the two time periods (mid–century [2046–2065] and late century [2081–2100]) and RCPs (4.5 and 8.5), īnanga will likely be moderately to highly exposed to changes in mean annual and seasonal (spring, summer autumn and winter) rainfall.

The early life history stages are likely to be the most sensitive to changes in rainfall. This is because seasonal cues from increased rainfall stimulate the inward migration of post–larvae (whitebait) from the marine environment to freshwater. If rainfall is reduced, particularly during winter and spring, then whitebait recruitment may be episodic, which in turn may impact on the whitebait fishery. Hydrological cues are needed to stimulate spawning in the non–migratory (i.e., landlocked) component of populations.

Sea surface temperature

For RCP 8.5, īnanga will likely be exposed to changes in mean annual sea surface temperatures. By 2100, Aotearoa–New Zealand's mean sea surface temperature is projected to increase by +2.5°C. These projections show regional variability with the greatest increases along the east coast of the South Island. There will also be a broad band of sea surface temperature changes more than 3°C extending across the Tasman Sea.

During larval life, īnanga grow faster in the summer and slower in winter months presumably due to seasonal variation in sea surface temperatures. The peak swimming ability of larval īnanga is at 15–20°C, with swimming ability declining markedly at temperatures above 20°C. Larval īnanga may therefore be more susceptible to predation in warmer conditions. Climate change and associated changes to sea surface temperatures and ocean circulation patterns have been implicated in the decline of īnanga in south–west Australia, but this is not yet known for Aotearoa–New Zealand populations.
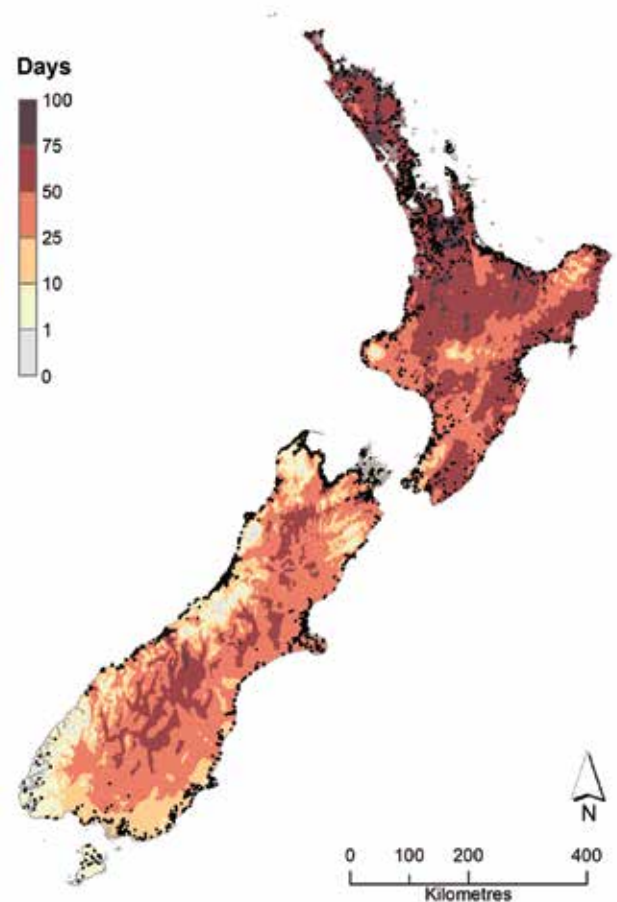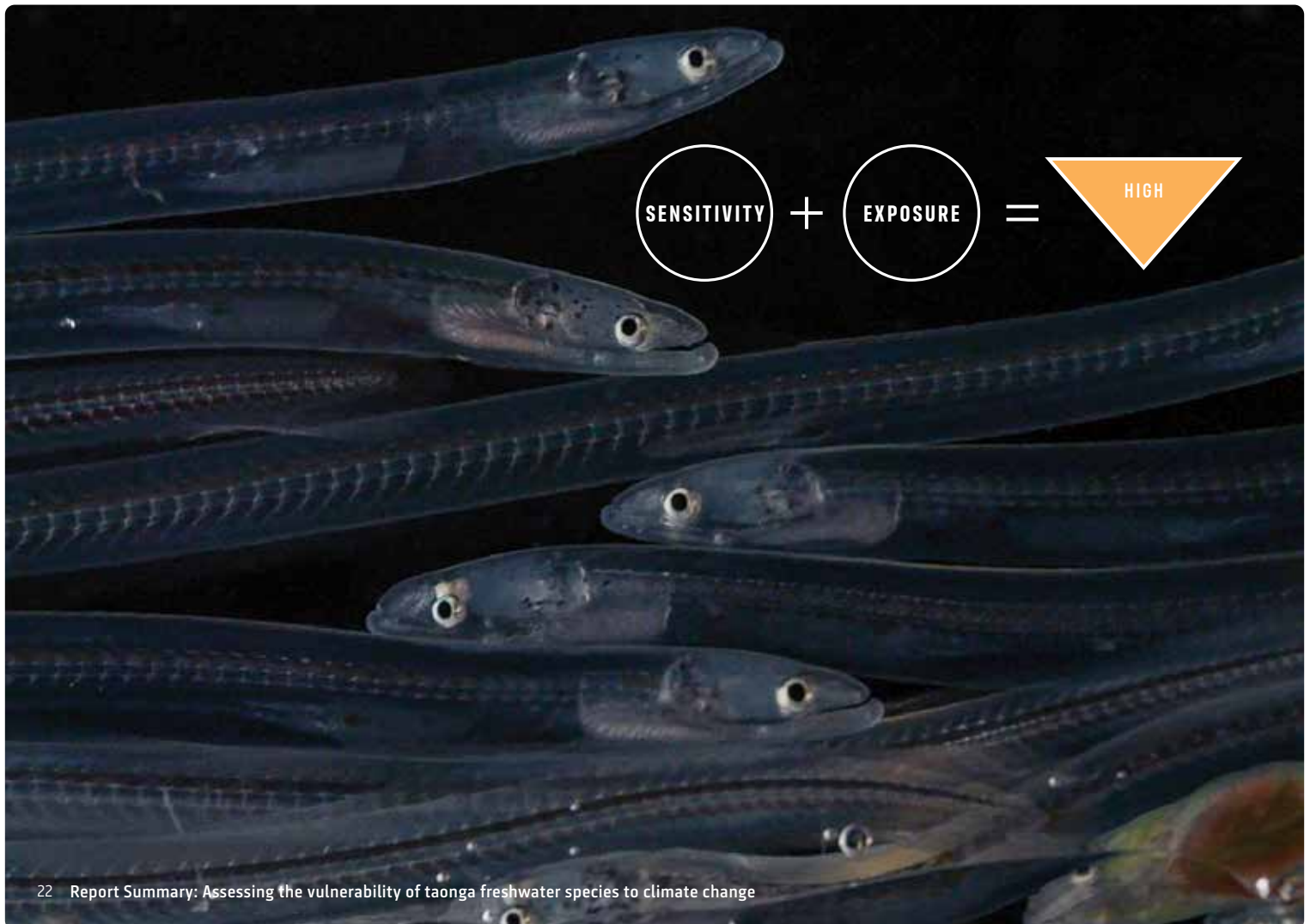

Current īnanga distribution (dark circles) mapped with projected changes in annual number of hot days (maximum temperature >25°C) (for time period 2081–2100 under RCP 8.5).
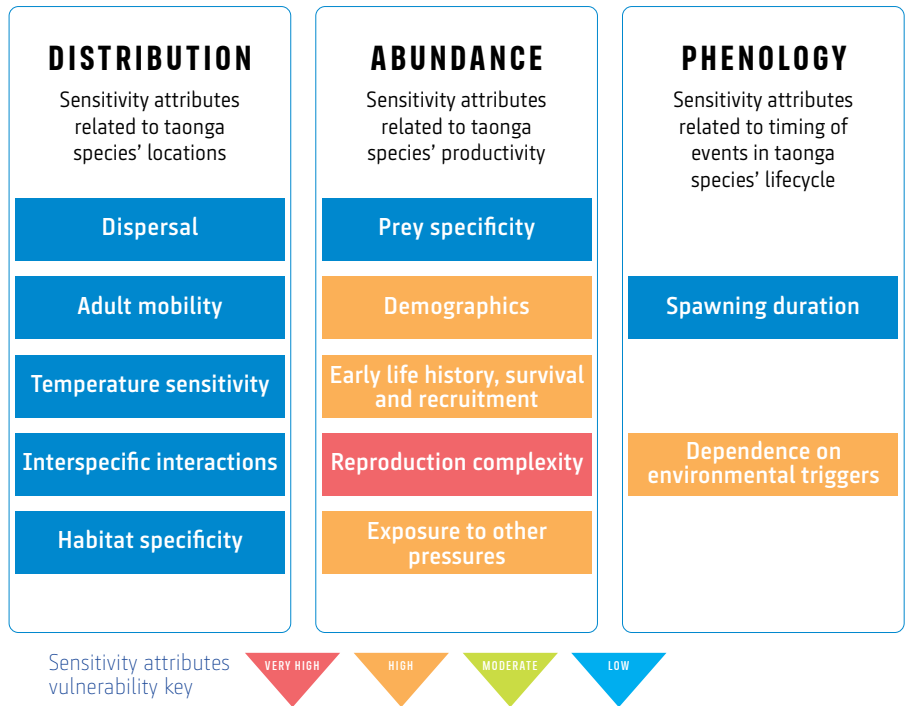
Tuna
(Shortfin eel)
Species: *Anguilla australis*

Rod Morris/www.rodmorris.co.nz

SENSITIVITY + EXPOSURE = HIGH

SENSITIVITY

Shortfin eels have a complex lifecycle. Most of their life is spent in freshwater, followed by migration to the marine environment for reproduction. Some individuals do not reach maturity until they are 50 years old.

DISTRIBUTION
Sensitivity attributes related to taonga species' locations

- Dispersal
- Adult mobility
- Temperature sensitivity
- Interspecific interactions
- Habitat specificity

ABUNDANCE
Sensitivity attributes related to taonga species' productivity

- Prey specificity
- Demographics
- Early life history, survival and recruitment
- Reproduction complexity
- Exposure to other pressures

PHENOLOGY
Sensitivity attributes related to timing of events in taonga species' lifecycle

- Spawning duration
- Dependence on environmental triggers

Sensitivity attributes vulnerability key

VERY HIGH   HIGH   MODERATE   LOW

Subset of the sensitivity attributes that contributed to shortfin eel CCVA scores

Complexity in reproduction

Shortfin eels have several reproductive characteristics that likely increase their vulnerability to climate change. Shortfin eels migrate from fresh water to the Pacific Ocean to spawn. The adult migration to the spawning grounds takes approximately 6–9 months. The characteristics of these migrations are not well-known. Females that reach the spawning area must encounter males and spawn. The location of their spawning ground is not well-described. They may use environmental markers (e.g., salinity fronts) and geographic markers (e.g., seamounts) to locate their spawning habitats. A critical knowledge gap is that it is unknown if a minimum number of eels are required to reach the spawning grounds to achieve successful spawning and recruitment. Eels have sex-specific life-history strategies and gender is thought to be determined principally by environmental factors, in particular temperature.

Exposure to multiple pressures

Species that are already facing multiple threats are considered more vulnerable to climate change. Shortfin eels are exposed to multiple pressures including harvest pressure from the commercial eel fishery, in-stream barriers to upstream and downstream migrations, and mortality at hydro-structures. Drought is recognised as a significant ongoing threat to shortfin eels that may affect 50% of the population. Shortfin eel were ranked as 'Not Threatened' by the Department of Conservation in 2017 and 'Near Threatened' by the International Union for Conservation of Nature in 2020.

Tuna (Shortfin eel)

Dispersal

The widespread dispersal of shortfin eels' larvae in the marine enviroment likely makes them less vulnerable to climate change. Shortfin eels are approximately 7–8 months old when they arrive at our coastline. Like freshwater eels worldwide, the New Zealand species are assumed to be panmictic (i.e., they consist of single genetic stock despite occupying broad geographic ranges). Shortfins from Australia and New Zealand show small but significant differences in morphology, but genetic homogeneity, at least at the glass eel stage. Whether these small morphological differences are a result of spawning in separate areas is unknown, but on the weight of current evidence this would seem unlikely, meaning that the species should be recognised and managed as a single trans-Tasman one.
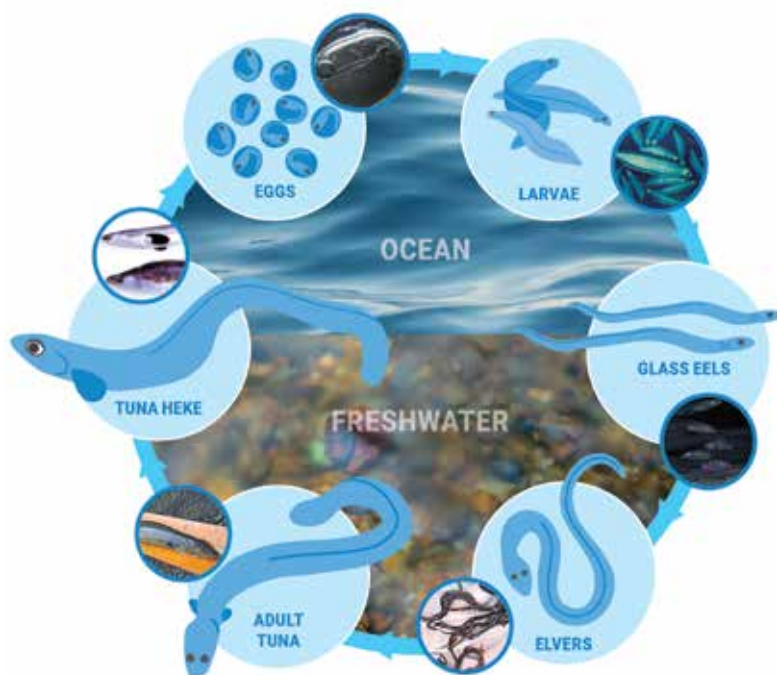
EXPOSURE

Shortfin eels are widely distributed throughout the Southern Hemisphere. They are found in both Australia and Aotearoa–New Zealand but we do not yet know if these stocks spawn in different places in the Western Pacific Ocean. In Aotearoa–New Zealand they are principally found in lowland habitats such as lowland lakes, estuaries and the lower reaches of rivers. Their upper elevation limit is 700 m. The adults have a narrow home range with an average of just 30 metres meaning they are highly site-attached.

Subset of the exposure variables that will likely increase the vulnerability of shortfin eels to climate change
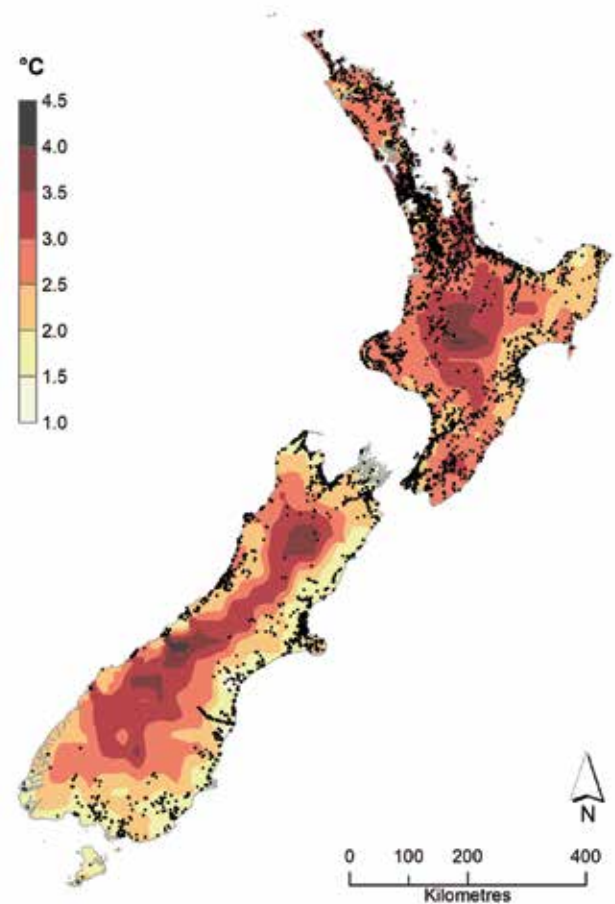
Autumn air temperature

For the late century (2081–2100) time period and RCP 8.5, shortfin eels will likely be highly exposed to changes in autumn mean air temperatures. The relationship between eel movement, growth rates and water temperature is not fully resolved so the effects of increased water temperatures are unknown. However, it is known that water temperature affects the length of the growing season and indirectly affects eels' foraging and feeding activity. Summer is considered the peak growing period but in warmer autumns, the growing period may be extended which would likely be beneficial for shortfins. Water temperatures more than 12.4ºC promote growth rates for shortfins in some rivers. Shortfins are usually inactive when water temperatures are less than 12ºC. When they exceed 12ºC, shortfin feeding activity increases.

Glass eel catches are strongly and inversely related to water temperature, with 99% of catch in the two years studied occurring at temperatures between 12.6 and 13.1ºC.

Winter precipitation

For the two time periods and RCPs (4.5 and 8.5), shortfin eels will likely be highly (mid–century [2046–2065] or very highly late century [2081–2100]) exposed to changes in mean winter precipitation. The projections for the west and east coasts of Aotearoa–New Zealand show different patterns in changes to winter precipitation, indicating that shortfin eels will be affected differently depending on their location. Increased winter precipitation may stimulate the migrations of glass eels to freshwater and facilitate better recruitment. The migration of mature adults out to sea for reproduction can occur in the winter months. Changes to the magnitude, frequency and predictability of winter rainfall may therefore affect shortfin eel migrations. However, in catchments that are highly regulated for hydro-generation, the relationship between winter rainfall and downstream eel migration will likely be unclear.

A lack of winter rainfall for three consecutive years was hypothesised to be associated with eel mortalities in Canterbury rivers. Shortfins are generally considered more responsive to changing water levels than longfin eels, because they predominantly occupy the main stem of rivers rather than the tributaries.

Current shortfin eel distribution (dark circles) mapped with projected changes in mean autumn air temperatures (for time period 2081–2100 under RCP 8.5).

Circulation change in the Western Pacific Ocean

For the late century (2081–2100) and RCP 8.5, shortfin eels will likely be highly exposed to projected changes in Western Boundary Currents. The migratory routes of adult and larval shortfin eels are poorly known. Until a better understanding of the marine life of eels is achieved, we cannot predict what the consequences of a changing marine environment on shortfin eels may be.

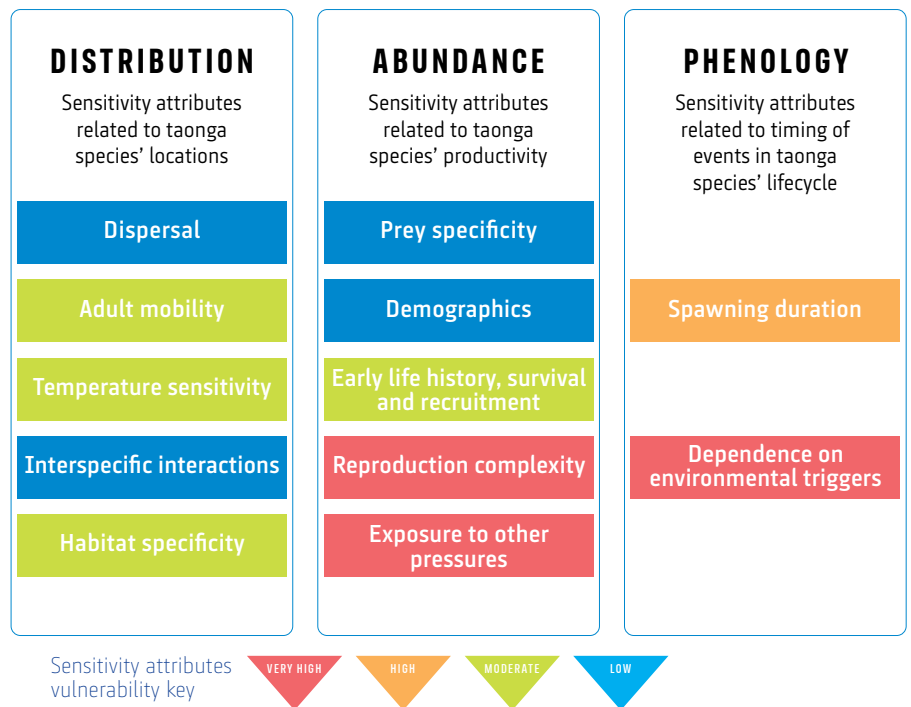# Banded kōkopu
(Whitebait)
Species: *Galaxias fasciatus*

Rob Suisted

(SENSITIVITY) + (EXPOSURE) = ▽ HIGH

Rob Suisted

SENSITIVITY

Banded kōkopu are a large galaxiid that migrate between freshwater and the marine environment to complete their lifecycle. They can also form land–locked populations in lakes. Adults are commonly found up to 200 mm.

DISTRIBUTION	ABUNDANCE	PHENOLOGY
Sensitivity attributes related to taonga species' locations	Sensitivity attributes related to taonga species' productivity	Sensitivity attributes related to timing of events in taonga species' lifecycle
Dispersal	Prey specificity	
Adult mobility	Demographics	Spawning duration
Temperature sensitivity	Early life history, survival and recruitment	
Interspecific interactions	Reproduction complexity	Dependence on environmental triggers
Habitat specificity	Exposure to other pressures	

Sensitivity attributes vulnerability key

▼ VERY HIGH ▼ HIGH ▼ MODERATE ▼ LOW

Subset of the sensitivity attributes that contributed to banded kōkopu CCVA scores

Complexity in reproduction

Banded kōkopu usually migrate downstream to their spawning habitats (in lakes and rivers) and reproduction occurs in aggregations. Spawning occurs from autumn/early winter close to typical adult habitats. Variation in spawning times among years has been observed in some catchments. The same spawning areas are used within and between years indicating banded kōkopu have a fidelity to their spawning sites. They can lay their eggs within the stream in gravels or on bankside grasses, although the suite of plant species they use is unknown. Eggs have been observed to be deposited terrestrially during high water events, hatching after re-inundation. Larvae rear in estuaries or at sea and return to fresh water after 4–6 months as whitebait. Olfactory cues from other migratory galaxiids help post–larvae to select a river to return to.

Dependence on environmental triggers

Banded kōkopu require hydrological cues for reproduction. Spawning occurs from autumn/early winter close to typical adult habitats. Eggs have been observed to be deposited terrestrially during high water events, hatching after re-inundation. 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 rainfall is anticipated to change.

Little is known about the cues banded kōkopu use for inward migration to freshwaters, but migration is likely trigged by seasonal changes in water temperature and day length along with flood flows. It is presumed that upstream migration rate is influenced by water clarity and stream flows as well as temperature.
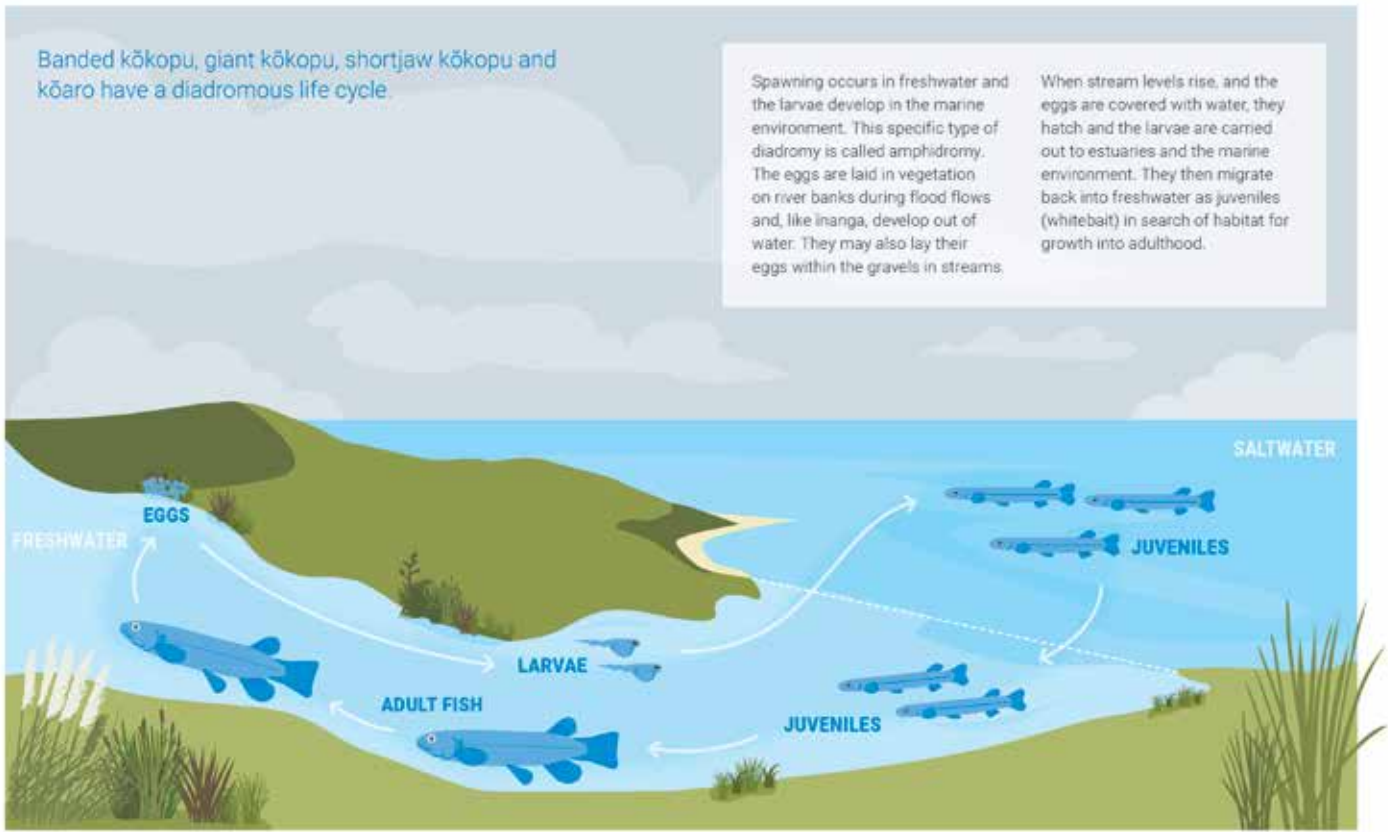
Banded kōkopu (Whitebait)

Exposure to multiple pressures

Species that are already facing multiple threats are likely to be more vulnerable to climate change. Banded kōkopu are exposed to multiple pressures including harvesting of the juvenile whitebait stage in New Zealand, artificial barriers to migration, habitat destruction, pollution of waterways, changes in catchment land use and the impacts of introduced species. Natural pollutants such as ammonia, which occurs in livestock waste and poorly treated wastewater, can adversely affect fish populations through displacement and, at high concentrations, death.

EXPOSURE

Banded kōkopu are only found in Aotearoa–New Zealand. They are found in the North and South Islands, Stewart, Chatham and many offshore islands around the main islands, but not the sub–Antarctic islands. Banded kōkopu have a coastally restricted distribution, similar to īnanga, but are not as widely spread throughout the country.

Banded kōkopu, giant kōkopu, shortjaw kōkopu and kōaro have a diadromous life cycle.

Spawning occurs in freshwater and the larvae develop in the marine environment. This specific type of diadromy is called amphidromy. The eggs are laid in vegetation on river banks during flood flows and, like īnanga, develop out of water. They may also lay their eggs within the gravels in streams.

When stream levels rise, and the eggs are covered with water, they hatch and the larvae are carried out to estuaries and the marine environment. They then migrate back into freshwater as juveniles (whitebait) in search of habitat for growth into adulthood.

SALTWATER

FRESHWATER

EGGS

LARVAE

ADULT FISH

JUVENILES

JUVENILES

Subset of the exposure variables that will likely increase the vulnerability of banded kōkopu to climate change

Winter precipitation

For the two time periods (mid–century [2046–2065] and late century [2081–2100]) and RCP 4.5 and 8.5, banded kōkopu will likely be highly exposed to projected changes in mean winter rainfall. Predictable periodicity in rainfall is an important environmental trigger for banded kōkopu reproduction which occurs mostly during the winter although reproduction timing is only know from a few locations around the country. Changes in the frequency, timing and magnitude of flood events that are predicted to occur with climate change may alter the reproductive cues used by banded kōkopu. Extreme precipitation especially during the spawning season could result in egg mortalities either in the gravels or in riparian vegetation that banded kōkopu use. Little is known about the cues banded kōkopu use for inward migration to freshwaters, but migration is likely trigged by seasonal changes in water temperature and day length along with flood flows.

Drought intensity

For the time period 2081–2100, under the "extreme" scenario (RCP 8.5), banded kōkopu will likely be highly exposed to changes in the potential evapotranspiration deficit (as proxy for drought intensity). It is speculated that diadromous galaxiids may be affected by drought conditions because spawning and larval migration to the sea occurs during periods of increased drought prevalence (i.e., in the summer and autumn). During drought conditions, low flows can 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 exacerbated in regulated rivers. Variable and extreme weather conditions such as droughts likely affect spawning and recruitment, but these effects have not been measured in Aotearoa–New Zealand.

Sea surface temperature

For the late century (2081–2100) time period and RCP 8.5, banded kōkopu will likely be highly vulnerable to projected changes in sea surface temperatures. Banded kōkopu larvae typically rear in estuaries or at sea, and the post-larvae (whitebait) return to freshwater after 4–6 months. Their marine phase is important for growth and to facilitate connectivity of populations from multiple rivers. Changes in sea surface temperatures may affect the dispersal of the larvae and increase or decrease population connectivity. If sea surface temperatures are warmer the larvae may grow quicker and return to freshwater earlier. However, conditions in freshwater may not be favourable for juvenile growth.
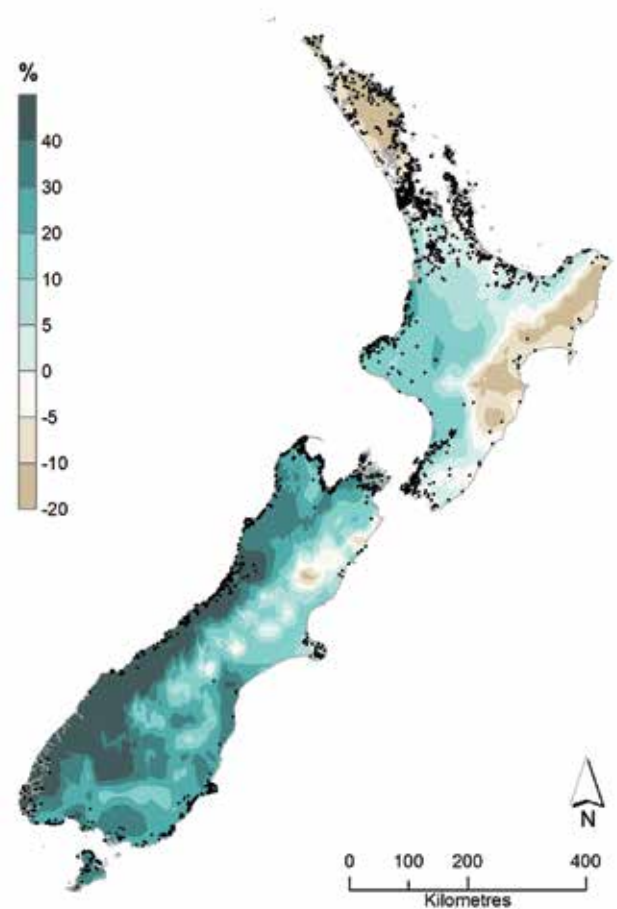
Current banded kōkopu distribution (dark circles) with projected changes in mean winter rainfall (for time period 2081–2100 under RCP 8.5).

Kōaro
(Whitebait)
Species: *Galaxias brevipinnis*
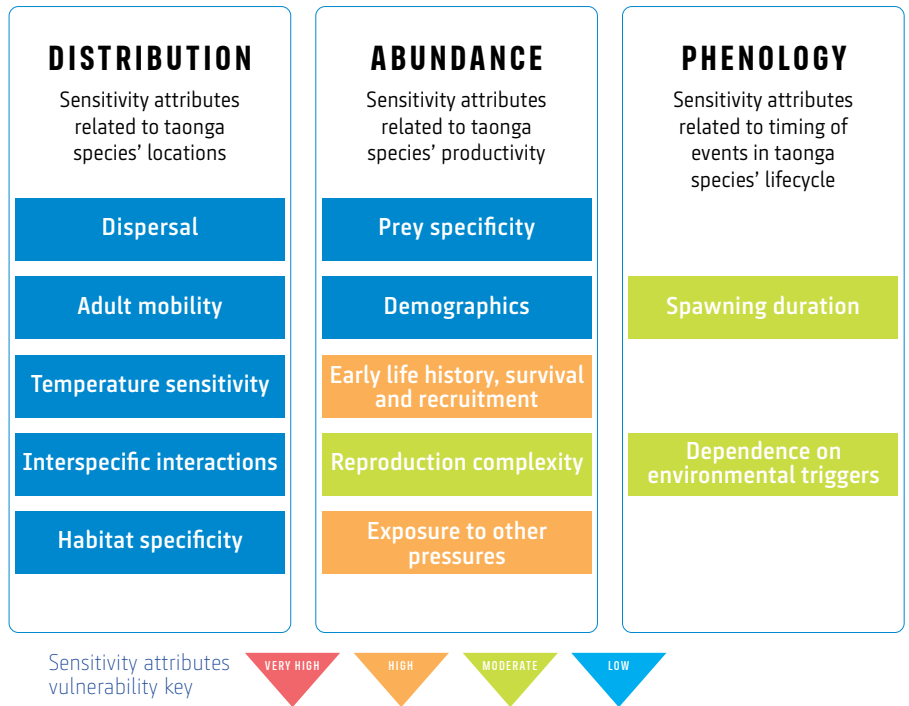
Rob Suisted

SENSITIVITY + EXPOSURE = HIGH

SENSITIVITY

Kōaro migrate between freshwater and the sea to complete their lifecycle but can also form land-locked populations in lakes. Kōaro are a relatively long-lived species (~15 years) that can reproduce every year from about three years of age, with a generation length of eight years.

DISTRIBUTION
Sensitivity attributes related to taonga species' locations

- Dispersal
- Adult mobility
- Temperature sensitivity
- Interspecific interactions
- Habitat specificity

ABUNDANCE
Sensitivity attributes related to taonga species' productivity

- Prey specificity
- Demographics
- Early life history, survival and recruitment
- Reproduction complexity
- Exposure to other pressures

PHENOLOGY
Sensitivity attributes related to timing of events in taonga species' lifecycle

- Spawning duration
- Dependence on environmental triggers

Sensitivity attributes vulnerability key: VERY HIGH · HIGH · MODERATE · LOW

Subset of the sensitivity attributes that contributed to kōaro CCVA scores

Early life history survival and recruitment

Kōaro deposit their eggs amongst gravels and leaf litter during periods of elevated stream flow. Spawning has also been found on macrophytes. Kōaro larvae hatch typically 3–4 weeks later if the eggs are re-inundated during high flow events. The newly hatched larvae disperse to the marine environment to feed and grow for about 17–20 weeks. Once sufficient growth has been attained, the whitebait stage enters fresh waters and migrates upstream usually in early spring. In Aotearoa–New Zealand, spawning habitats have rarely been observed with the only known spawning site occurring at the edge of riffle habitat. No specific information on the distribution of kōaro larvae during marine development exists. Little is known about the cues kōaro use for inward migration to freshwaters, but migration is likely trigged by seasonal changes in water temperature and day length along with flood flows. Kōaro whitebait select streams to enter based on that adult pheromones, which may also be used as a migration cue by this species.

Exposure to multiple pressures

Kōaro are exposed to multiple pressures. These pressures include harvesting of the juvenile whitebait stage, artificial barriers to migration, habitat destruction, pollution of waterways, changes in catchment land use and the impacts of introduced species. Localised extinctions of kōaro have occurred in Lake Rotopounamu and are attributed to the introduction of smelt (*Retropinna retropinna*) and changes in the food web structure.
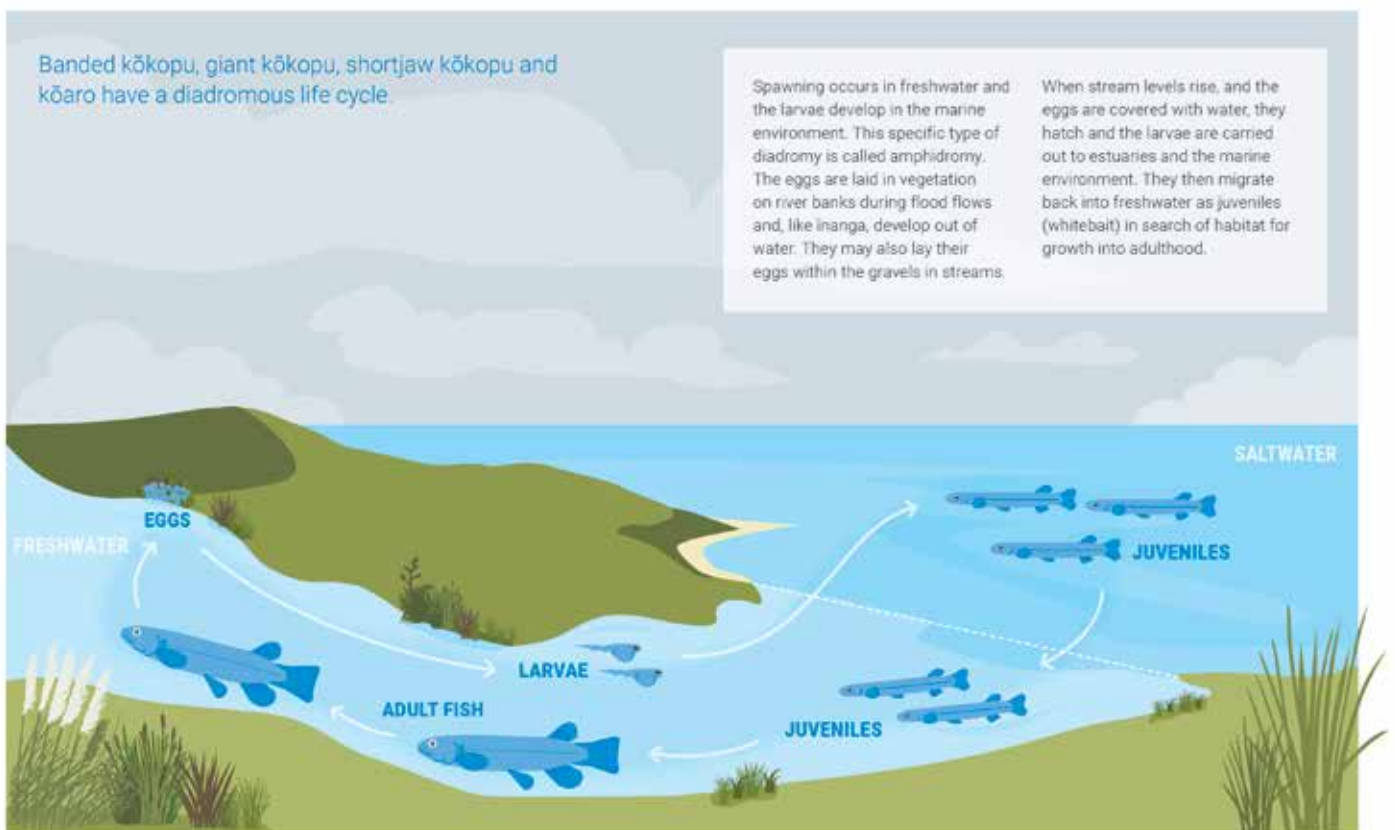
Kōaro (Whitebait)

Prey specificity

Understanding how reliant a species is on specific prey species could predict its ability to persist as the climate changes. Species that are considered specialists (i.e., they have specific prey requirements) are likely to be more vulnerable to climate change because their survival is dependent on their own response to climate change, but also on their preferred prey type. A diverse diet likely reduces the vulnerability of kōaro to climate change. Like other large galaxiids, kōaro feed opportunistically on a variety of aquatic and terrestrial invertebrates. Kōaro can be found in lakes, rivers and high altitude environments meaning they encouter a varied invertebrate community. They are also piscivourous meaing they can feed on other fish species.

EXPOSURE

Kōaro are found in New Zealand and Australia. They are noted climbers with corrugated fins to help them climb. They are often found in the headwaters of many catchments. Kōaro are less common on the east coast of the South Island but can easily be found in areas of suitable habitats and are usually at higher altitudes.

Banded kōkopu, giant kōkopu, shortjaw kōkopu and kōaro have a diadromous life cycle.

Spawning occurs in freshwater and the larvae develop in the marine environment. This specific type of diadromy is called amphidromy. The eggs are laid in vegetation on river banks during flood flows and, like īnanga, develop out of water. They may also lay their eggs within the gravels in streams.

When stream levels rise, and the eggs are covered with water, they hatch and the larvae are carried out to estuaries and the marine environment. They then migrate back into freshwater as juveniles (whitebait) in search of habitat for growth into adulthood.

SALTWATER

FRESHWATER

EGGS

LARVAE

ADULT FISH

JUVENILES

JUVENILES

Subset of the exposure variables that will likely increase the vulnerability of kōaro to climate change

Autumn air temperature

For the late century (2081–2100) and RCP 8.5, kōaro will likely be highly exposed to projected changes in autumn mean air temperature. Changes in water temperatures are already considered a significant threat to kōaro populations according to the International Union of Conservation threat rankings.

In the South Island, high altitude environments show the largest predicted increases in autumn air temperature (>3ºC). Large populations of kōaro are found in these high altitude environments meaning this portion of the population will likely be the most exposed to changes in autumn air temeprature. Landlocked kōaro move into lake tributaries during autumn prior to spawning, meaning spawning adults may be the most affected by potential changes in autumn air temperatures.

Kōaro are thought to form landlocked populations in colder, less productive lakes, indicating that larvae could be limited by temperature, but this could also be associated with productivity and food abundance (also linked to temperature). A recent vulnerability assessment for the Auckland region suggests that kōaro are one of three native fish species that are likely to be the most vulnerable to warming associated with climate change in this region.

Winter precipitation

For the two time periods (mid–century [2046–2065] and late century [2081–2100]) and RCP 8.5, kōaro highly exposed to projected changes in mean winter rainfall. Winter rainfall is projected to increase by up to 40% along the west coast of the South Island while the east coast of the North Island will likely experience up to 20% reduction.

Winter is a peak migration time for the post-larvae (whitebait) life stage. Juvenile galaxiids prefer low velocity waters for migration (less than 0.1 m s⁻¹) and fish often move upstream in the low velocity surface waters (less than 1.0 m deep) along riverbank margins. Increases in winter rainfall may affect the upstream migrations of kōaro however data specific for kōaro is needed.

Most populations in the montane environments of the central South Island are landlocked and non-migratory. Winter is the key spawning period for these populations. These populations will likely experience less pronounced changes in winter rainfall. In riverine populations, kōaro spawning occurs during autumn/winter. However, for landlocked populations, reproductive development and spawning is more protracted.
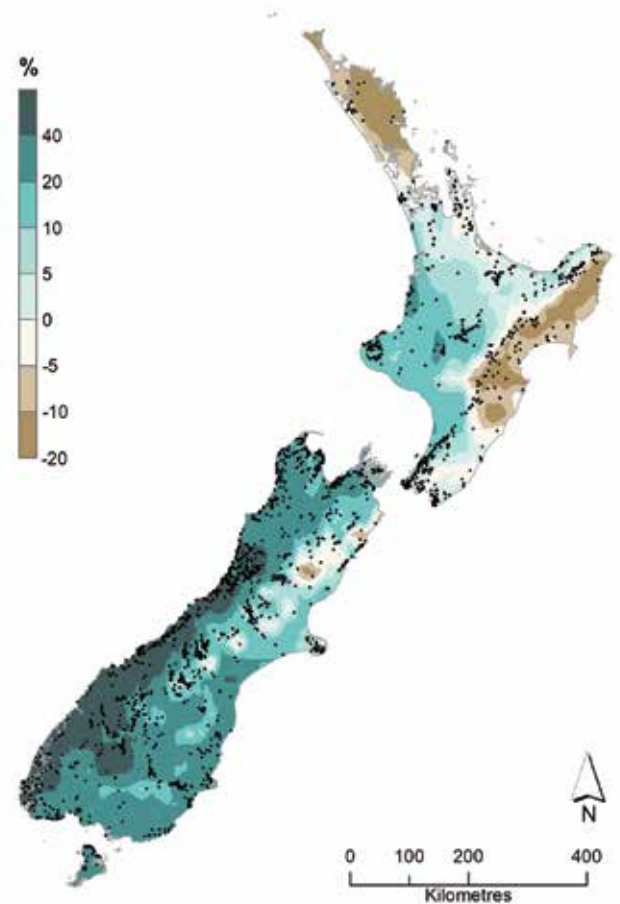
Current kōaro distribution (dark circles) mapped with projected changes in mean winter rainfall (for time period 2081–2100 under RCP 8.5)

Changes in the frequency, timing and magnitude of winter flood events may alter the reproductive cues used by kōaro. Recent studies show that kōaro larvae in lakes display strong signals to flows meaning that the dispersal of larvae and thereby population connectivity, is likely influenced by flows. However, at present, these potential effects are not well understood.

Drought intensity

For the late century (2081–2100) time period and RCP 8.5, kōaro will likely be highly exposed to projected changes in potential evapotranspiration deficit (as proxy for drought intensity). The vulnerability of 43 freshwater fish species in Australia was done using 14 traits for each species (e.g., fecundity, adult size, spawning temperature). In the analysis, kōaro were ranked as the 11th most drought vulnerable freshwater fish species. The effects of drought on kōaro populations in Aotearoa–New Zealand are unknown.

Kākahi / Kāeo
(Freshwater mussels)
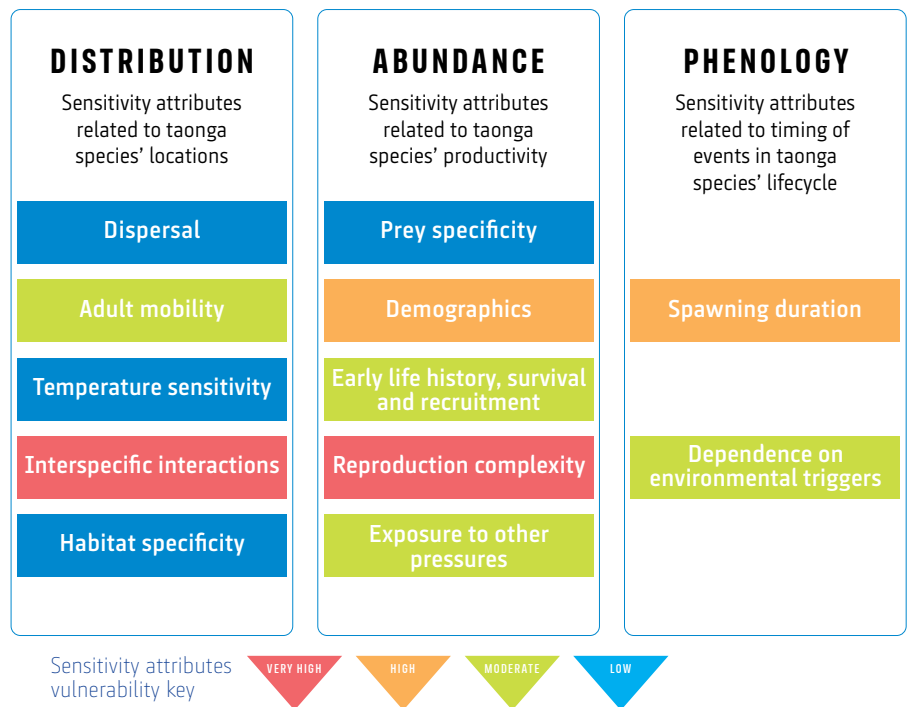Species: *Echydriella menziesii*

SENSITIVITY + EXPOSURE = HIGH

SENSITIVITY

Kākahi are a long-lived species with relatively restricted movements as adults. They are found in both rivers and lakes.

DISTRIBUTION
Sensitivity attributes related to taonga species' locations

- Dispersal
- Adult mobility
- Temperature sensitivity
- Interspecific interactions
- Habitat specificity

ABUNDANCE
Sensitivity attributes related to taonga species' productivity

- Prey specificity
- Demographics
- Early life history, survival and recruitment
- Reproduction complexity
- Exposure to other pressures

PHENOLOGY
Sensitivity attributes related to timing of events in taonga species' lifecycle

- Spawning duration
- Dependence on environmental triggers

Sensitivity attributes vulnerability key

VERY HIGH   HIGH   MODERATE   LOW

Subset of the sensitivity attributes that contributed to kākahi CCVA scores

Complexity in reproduction

To successfully complete their life cycle, freshwater mussels are dependent on a fish host species (including kōaro, tuna, bullies, banded kōkopu). Males release their sperm into the water in spring. The females then grab the sperm and use it to fertilise their eggs which are located in a special brood pouch in the gill. The eggs develop into larvae known as glochidia which are released into the water column in spring and summer, possibly when the female senses the presence of a suitable fish host. The glochidia parasitise a fish host until they transform into a juvenile mussel. After about two or three weeks the juveniles detach from the fish host to develop further.

Dependence on interspecific interactions for lifecycle completion

Freshwater mussels have an obligate host-dependent stage in their life cycle and 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 their close relationship with other fish species.

Juvenile kākahi attach to a host fish and are transported away from the release site. Barriers to fish movement, stopping recruitment upstream pose a localised threat. This means kākahi may be indirectly and adversely affected by climate change because of this close relationship with other fish species. *E. menziesii* and *E. aucklandica* often occur together (side-by-side in the sediment) which may indicate that their ecological relationship is more complex than is currently understood.

Kākahi / Kāeo (Freshwater mussels)

Demographics

Life history traits such as long generation length and slow growth rate are associated with a heightened vulnerability to climate change.

The freshwater mussel *E. menziesii* is a long-lived species, with some individuals reaching at least 50 years of age. *E. menziesii* with a shell length longer than 30 mm (and therefore older individuals) often dominate populations, and it is rare to find juvenile mussels indicating recruitment failure.

Skewed sex ratios are found in some populations. For example, in Lake Horowhenua, there is a 67:33 ratio of female:male mussels in the lake. It is not known if sex is determined by an environmental variable.

Although there may be reasonable populations of adult mussels in lakes and rivers, there are many example where these populations are not viable, because of low reproduction and juvenile survival. These populations are called "geriatric" populations and are at risk of local extinction which might be increased by climate change.

EXPOSURE

Kākahi (*E. menziesii*) are only found in Aotearoa–New Zealand. They are widespread throughout the North and South Islands and are locally common in some places. They can be found in streams, rivers and lakes.
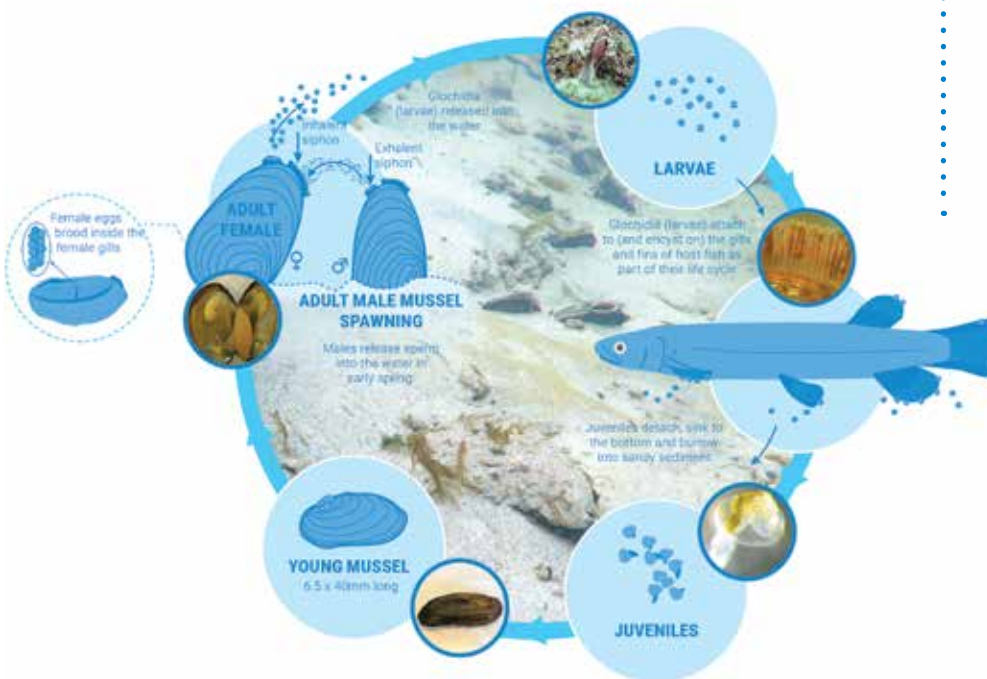
Subset of the exposure variables that will likely increase the vulnerability of kākahi to climate change

Autumn air temperature

For the late century (2081–2100) and RCP 8.5, kākahi will likely be highly exposed to projected changes in autumn mean air temperatures. The thermal tolerances for Aotearoa–New Zealand freshwater mussel species (and the various life stages) are not well known. Kākahi have a very broad range of depth distribution in warm well-mixed lakes indicating they tolerate a wide range of temperatures. However, in highly productive lakes, their distribution is much more restricted and is defined by the thermocline (abrupt changes in water temperature). This indicates that in increasingly degraded habitats, their thermal window may be more restricted. Adult freshwater mussel mobility is relatively restricted and localised, and they must be able to tolerate local environmental conditions including temperature changes to survive.

Kākahi reproduction may be affected by changes in temperatures. Peak glochidia release occurrs in summer (February) when average monthly water temperatures are >18.8ºC. In the North Island, ripe female mussels brooding glochidia have been routinely collected from November to March. Planktonic glochidia were found in Lake Taupō when seasonal water temperature increased from 14ºC (November) up to 20ºC. Changes in autumn air temperatures may affect glochidia release. Freshwater mussels are not only limited by their own thermal tolerances, but also by those of their host fish which increase their vulnerability to environmental change.

Winter precipitation

For the two time periods (mid–century [2046–2065] and late century [2081–2100]) and RCPs (4.5 and 8.5), kākahi will likely be highly exposed to changes in mean winter rainfall. Winter rainfall is projected to increase by up to 40% along the west coast of the South Island while the east coast of the North Island will likely experience up to 20% reduction.

Kākahi brood in the wintertime. Increases in winter rainfall may result in large floods and disturbance events that could dislocate adult mussels that are brooding, resulting in changes in their distributions.

The seasonal movements of fish over winter may affect the dispersal of mussels. However, some mussel species may have multiple broods or use multiple reproductive strategies, including host overwintering (glochidia being attached to fish over winter) which could lead to large-scale dispersal.
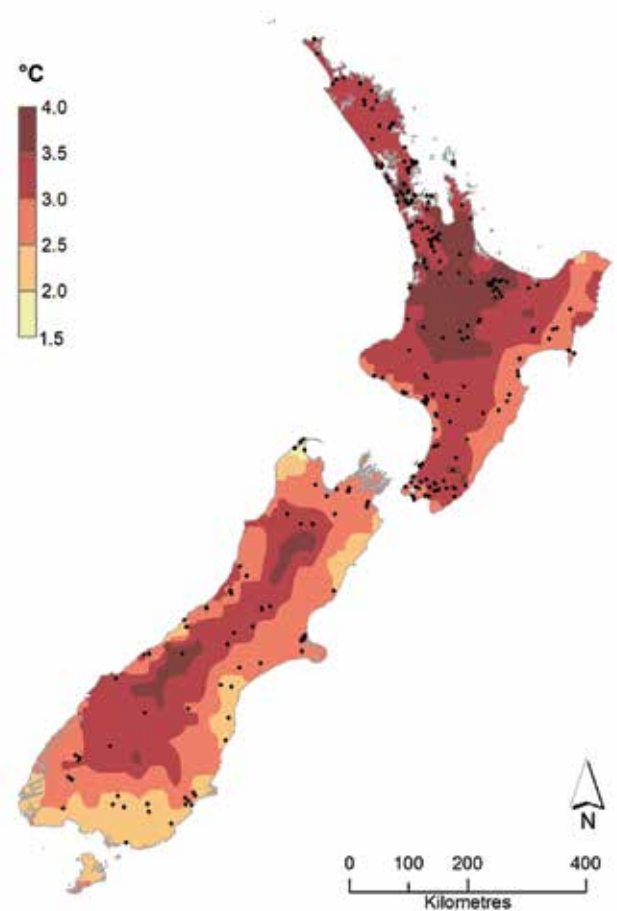
Current kākahi distribution (dark circles) mapped with projected changes in mean autumn air temperature (for 2081–2100 under RCP 8.5).

Drought intensity

For the late century (2081–2100) time period and RCP 8.5, kākahi will likely be highly exposed to projected changes in potential evapotranspiration deficit (as proxy for drought intensity). Internationally, freshwater mussels are experiencing increased mass mortality events linked to hydrologic drought, with mussel loss associated with drought severity, location within the river network, and species–specific drought tolerances. Little is known about the effect of drought on kākahi in New Zealand. In streams with degraded riparian vegetation, mussels may be more vulnerable to drought conditions as there is little shading provided by overhead canopy. Mussels can bury indicating they could avoid harsh conditions but they need suitable substrate conditions to do this.
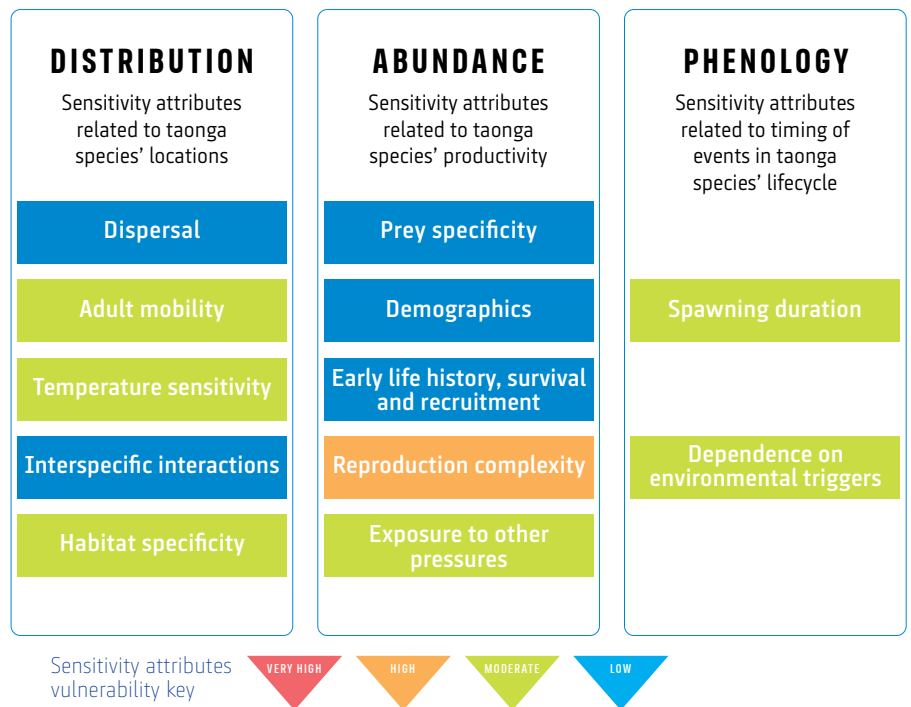
Giant kōkopu
(Whitebait)
Species: *Galaxias argenteus*

SENSITIVITY + EXPOSURE = MODERATE

SENSITIVITY

Giant kōkopu migrate between freshwater and the sea to complete their lifecycle but can also form land–locked populations in lakes. Spawning is known to occur from late April to late June, but it possibly extends later to July and August. Average age at maturity is 10 years.

DISTRIBUTION
Sensitivity attributes related to taonga species' locations

- Dispersal
- Adult mobility
- Temperature sensitivity
- Interspecific interactions
- Habitat specificity

ABUNDANCE
Sensitivity attributes related to taonga species' productivity

- Prey specificity
- Demographics
- Early life history, survival and recruitment
- Reproduction complexity
- Exposure to other pressures

PHENOLOGY
Sensitivity attributes related to timing of events in taonga species' lifecycle

- Spawning duration
- Dependence on environmental triggers

Sensitivity attributes vulnerability key

VERY HIGH   HIGH   MODERATE   LOW

Subset of the sensitivity attributes that contributed to giant kōkopu CCVA scores

Complexity in reproduction

Giant kōkopu are on average 10 years at sexual maturity. Medium-large aggregations of males and females are needed for reproduction. This species repeatedly spawns in the same location within and among years although spawning has only been recorded from two sites in New Zealand, an urban stream in Hamilton and the Awaawaroa Wetland on Waiheke Island.

Spawning occurs adjacent to adult habitat on low–gradient banks amongst riparian vegetation inundated when water flows are elevated. Eggs develop terrestrially before hatching 3–6 weeks later when re–inundated by high flows. Reproductive success requires the use of vulnerable habitats (freshwater, estuaries) for spawning and rearing of young (i.e., riparian spawning habitats).

Habitat specificity

Giant kōkopu are found in three different habitat types over their life cycle. They are primarily a coastal species that does not usually penetrate very far inland. Giant kōkopu are mainly found in low altitude areas close to the south and west coasts of both main islands. Preferred habitat includes small-medium size, slow-flowing streams, although it can also occur in non-flowing aquatic habitats such as wetlands, ponds and lake margins. Their preferred microhabitats are associated with good cover from overhanging vegetation, undercut banks, logs or debris clusters. Because giant kōkopu have more specific adult habitat requirements, this increases their vulnerability to climate change.
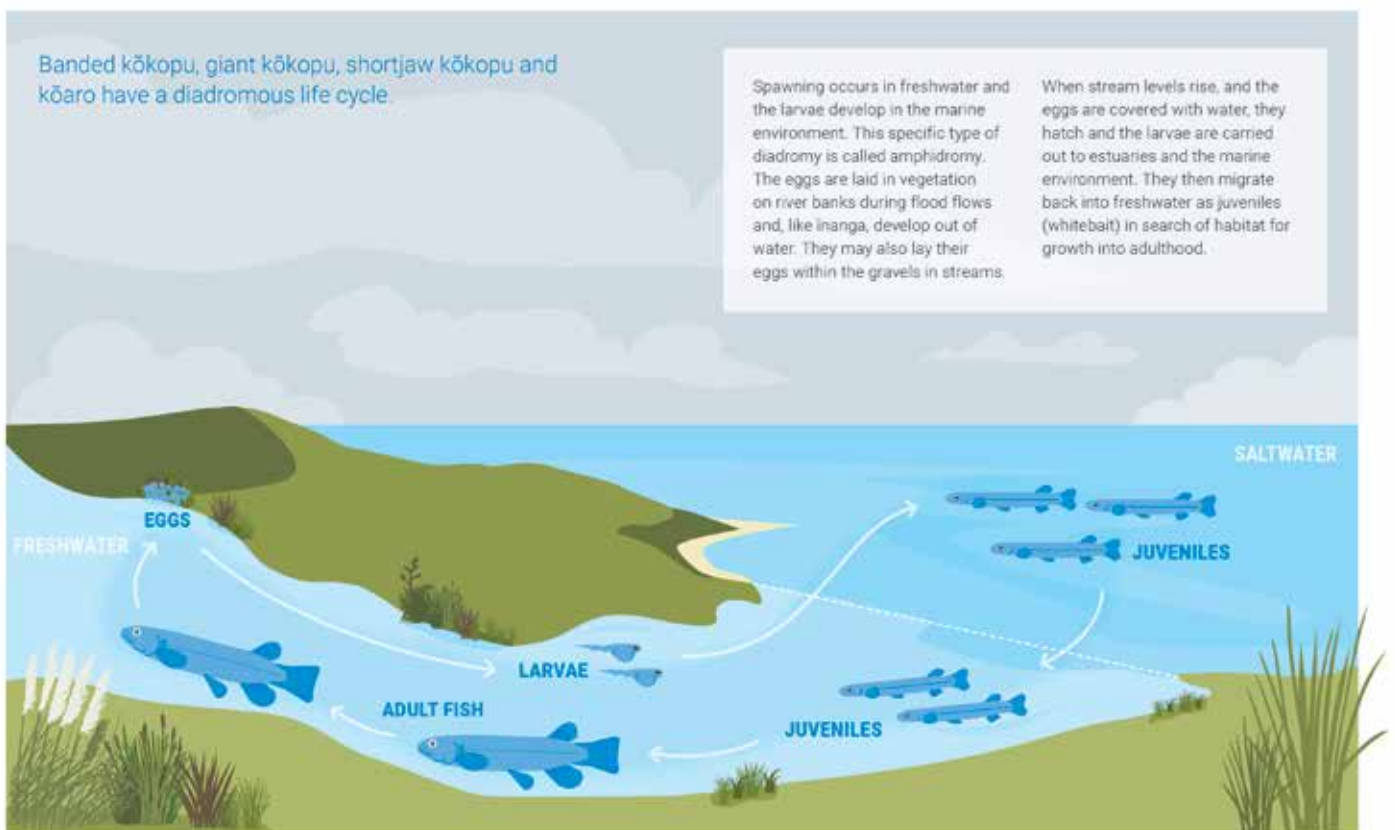
Giant kōkopu (Whitebait)

Exposure to multiple pressures

Giant kōkopu are currently exposed to multiple pressures including harvesting of the juvenile whitebait stage in New Zealand, artificial barriers to migration, habitat degradation and destruction, and the impacts of introduced species. The loss of and degradation of habitat through activities such as drainage of wetlands and straightening of river channel systems are the biggest threat to this species. Approximately 85% to 90% of New Zealand's wetlands have been lost in the last 100 years which has severely impacted on the abundance and distribution of this species. Mechanical clearance of drains causes direct mortality, and on-going drain management is continually suppressing the potential for these areas to be recolonised.

EXPOSURE

Giant kōkopu are only found in Aotearoa–New Zealand. They are a coastal species with a patchy distribution. Giant kōkopu are predominantly absent around Fiordland and the East Coast of both North and South Islands. Their patchy distributions mean they are more exposed to environmental change in specific parts of the country.

Banded kōkopu, giant kōkopu, shortjaw kōkopu and kōaro have a diadromous life cycle.

Spawning occurs in freshwater and the larvae develop in the marine environment. This specific type of diadromy is called amphidromy. The eggs are laid in vegetation on river banks during flood flows and, like īnanga, develop out of water. They may also lay their eggs within the gravels in streams.

When stream levels rise, and the eggs are covered with water, they hatch and the larvae are carried out to estuaries and the marine environment. They then migrate back into freshwater as juveniles (whitebait) in search of habitat for growth into adulthood.

Subset of the exposure variables that will likely increase the vulnerability of giant kōkopu to climate change

Autumn air temperature

For the late century (2081–2100) time period and RCP 8.5, giant kōkopu are likely to be highly exposed to changes in autumn mean air temperature.

Giant kōkopu spawning occurs in autumn from late April to late June. At present, the specific temperature triggers for spawning are not well known. Optimum egg hatching occurs at 10°C. Baseline autumn air temperatures (1986-2005) range 2°C to 18°C with mean autumn air temperatures in the North Island mostly >12°C. This means that an additional projected increase of >3°C during autumn may affect successful egg development and egg survival for giant kōkopu. However, the microhabitat conditions of their spawning habitats may buffer any projected changes in autumn air temperatures. Furthermore, spawning is known to occur in the winter (July and August) meaning some populations will avoid these projected temperature increases.

Winter precipitation

Giant kōkopu are likely to be highly exposed to projected changes in mean winter rainfall for mid–century (2046–2065) and late century (2081–2100) under RCP 8.5. Predictable periodicity in rainfall is an important trigger for reproduction in giant kōkopu and it is believed that the winter hydrograph triggers reproduction. In an urban stream in Hamilton, low spawning success was observed in a dry winter indicating changes in the frequency, timing and magnitude of flood events that are predicted with climate change may alter the reproductive cues used by giant kōkopu. In catchments with high intensity rain events that occur with moderate frequency, giant kōkopu are mostly migratory (i.e., complete larval development in marine/estuarine environments). Any changes to rainfall patterns may therefore affect diadromy in giant kōkopu.

Temperature extremes

For the late century (2081–2100) and RCP 8.5, giant kōkopu will likely be highly exposed to projected increases in the annual number of hot days. Giant kōkopu are found in temperatures between 11 and 15°C, however, their temperature preferences are not apparent. Although giant kōkopu may be encountered more frequently in cooler water, this may be biased by maps of their known geographical distribution because there are substantially more records from Westland and Southland regions than from warmer northern regions.
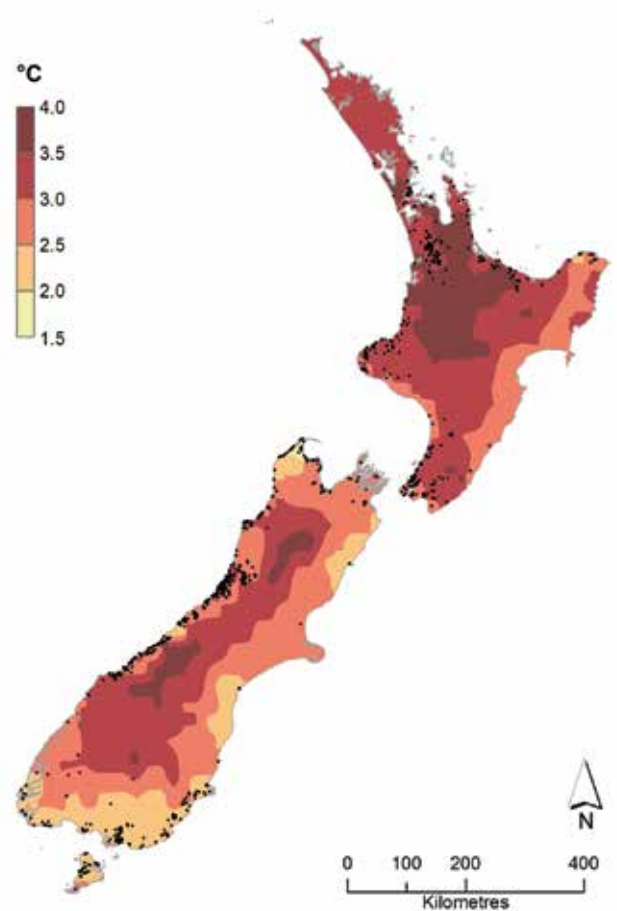
Current giant kōkopu distribution (dark circles) mapped with projected changes in mean autumn temperature (for time period 2081–2100 under RCP 8.5).
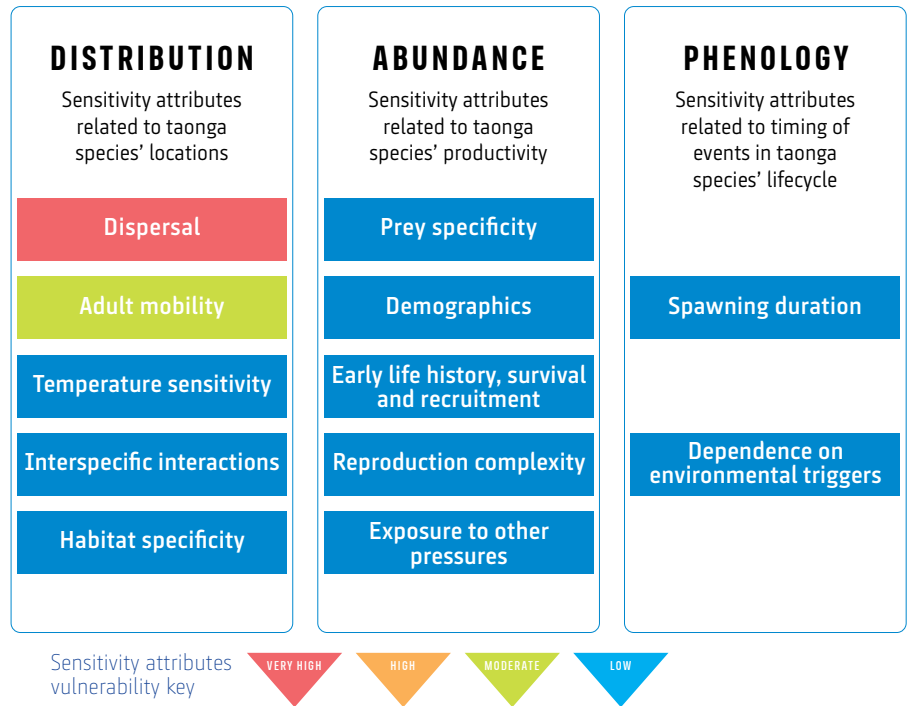
Kōura / kēwai
(Freshwater crayfish)
Species: *Paranephrops planifrons*

(SENSITIVITY) **+** (EXPOSURE) **=** MODERATE

SENSITIVITY

Kōura complete their life cycle in freshwater. Females carry their young for 1 month. Adult kōura usually reach maturity at 2 years' age in streams and 3 years in lakes.

DISTRIBUTION
Sensitivity attributes related to taonga species' locations

Dispersal
Adult mobility
Temperature sensitivity
Interspecific interactions
Habitat specificity

ABUNDANCE
Sensitivity attributes related to taonga species' productivity

Prey specificity
Demographics
Early life history, survival and recruitment
Reproduction complexity
Exposure to other pressures

PHENOLOGY
Sensitivity attributes related to timing of events in taonga species' lifecycle

Spawning duration
Dependence on environmental triggers

Sensitivity attributes vulnerability key — VERY HIGH — HIGH — MODERATE — LOW

Subset of the sensitivity attributes that contributed to kōura CCVA scores

Dispersal of early life stages

The dispersal of kōura early life stages is highly restricted which likely increases their vulnerability to climate change. Once kōura eggs hatch into juveniles, they are carried by the mother for up to three weeks and undergo two moults before they become independent. Genetic studies confirm that kōura dispersal is limited because there is strong genetic structuring among neighbouring catchments. The weak dispersal of kōura in freshwater means they likely cannot readily escape changes in their environment and colonise new habitats if climate changes impact their environments.

Adult mobility

A species can survive changes in habitat if they can emigrate from unsuitable habitat and find new, suitable habitat. Kōura are considered a relatively mobile species but it is unlikely they can move substantial distances. Within lakes, kōura undertake daily movements between the shallow and deeper waters to feed and avoid predators. In rivers, there is little inter-catchment exchange of kōura, except where there are downstream freshwater connections. Translocation of populations is required to restore areas given their restricted adult movements.

Exposure to multiple pressures

Pressures on kōura populations include habitat loss (wetland drainage, deforestation), land management practises (drain clearance), water management practises (e.g., water abstraction, controlled flows), pollution and predation (particularly by introduced salmonids and pest fish species). In the most recent threat rankings by the Department of Conservation (2018), *P. planifrons* are ranked as least concern. The International Union for the Conservation of Nature indicates kōura populations are declining but globally, this species is also ranked as "least concern" although this assessment was done over a decade ago.

Kōura / Kēwai (Freshwater crayfish)

Complexity in reproduction

Kōura reproduction is relatively simple which likely decreases their vulnerability to climate change compared to other taonga species such as eels. Kōura can reproduce in their adult habitat and do not need to migrate for successful reproduction. Reproduction does not need to occur in large aggregations for it to be successful. Furthermore, the sex of kōura is not determined by a specific environmental variable and so sex ratios are less likely to be skewed towards males or females if a change in the environment occurs. They do not depend on another species to successfully complete their lifecycle.
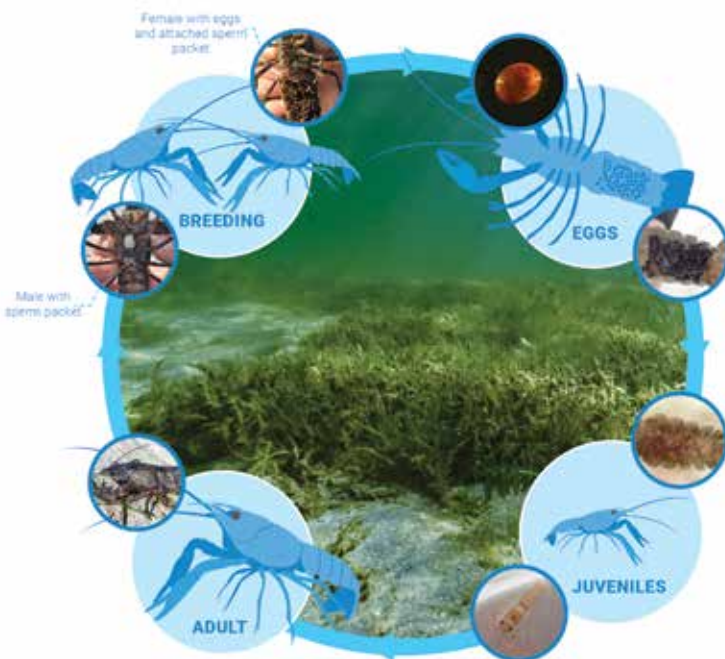
EXPOSURE

The kōura species *P. planifrons* are only found in Aotearoa–New Zealand. They are widely distributed throughout the North Island and the West Coast region of the South Island.

Subset of the exposure variables that will likely increase the vulnerability of kōura to climate change

Annual and autumn air temperature

For the late century (2081–2100) time period and RCP 8.5, kōura will likely be very highly exposed to projected changes in mean autumn air temperatures and highly exposed to changes in annual air temperatures.

P. planifrons are considered a cool water species, and in the central North Island inhabits areas where water temperatures fluctuates seasonally from ~6-18°C in native forest habitat and ~5-25°C in pastoral habitats. Peak reproduction occurs in late autumn/early winter but can occur in spring and summer also. Populations spawning in autumn will therefore likely be the most exposed to changes in autumn temperatures. Autumn air temperatures are projected to increase up to 4°C with the greatest increases in the central North Island which is regarded as a population stronghold for this species. Temperature is considered the primary determinant of growth in *P. planifrons* and influences time to maturity and their mobility.

Temperature extremes

For the late century (2081–2100) time period and RCP 8.5, kōura will likely be highly exposed to projected changes in temperature extremes. *P. planifrons* can tolerate higher temperatures than the southern species (*P. zealandicus*), but optimum temperatures are likely to be less than 23°C. In an experiment to simulate exposure to high temperatures in pasture streams, 100% of crayfish exposed to 26.2°C survived after 24 hours compared to 5–10% at 28.9°C and 0% at 32.4°C. When hypoxia stress was added to five days of exposure to 26.2°C (to simulate deoxygenation in eutrophic lowland streams and as a multiple stressor) survival decreased to 40%, compared to 95% in crayfish held at 19°C. In habitats that are already degraded, kōura are therefore most likely to be negatively impacted by temperature increases. However, they can tolerate temperatures at 35°C but only for brief periods.

Winter precipitation

For the two time periods (mid–century [2046–2065] and late century [2081–2100]) and RCP 8.5, kōura will likely be highly exposed to projected changes in mean winter rainfall. Kōura are thought to be sensitive to flood spates and any increases in severe weather events due to changes in climatic and weather patterns. Flood spates are considered an emerging threat to this species. In the central North Island, egg-bearing or "berried" kōura occur throughout the year but are most numerous in winter, meaning changes in winter rainfall may disproportionately affect reproductive individuals.
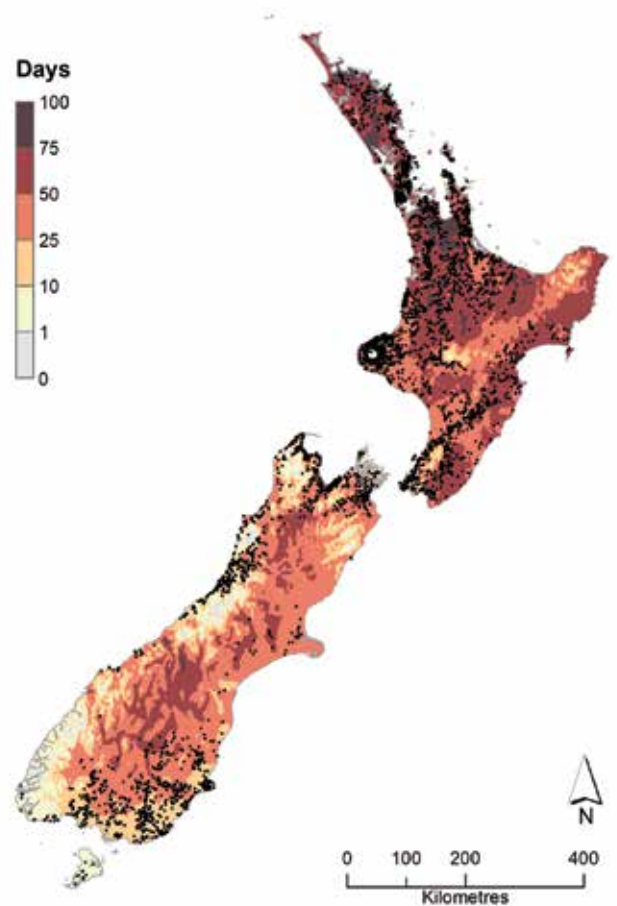
Current kōura distribution (dark circles) mapped with projected changes in annual number of hot days (for time period 2081–2100 under RCP 8.5).
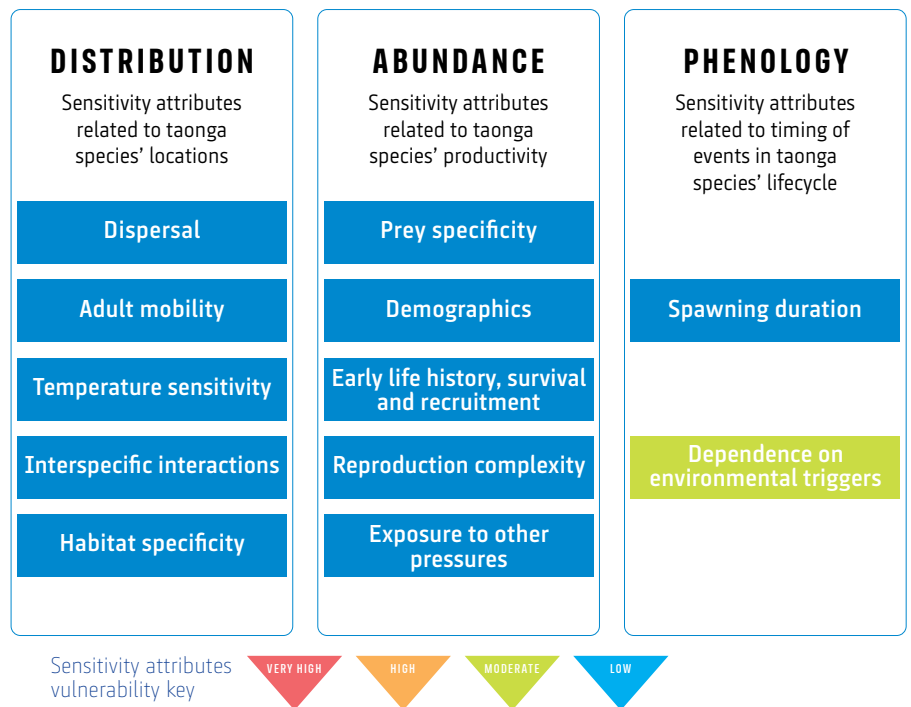
Aua / kātaha
(Yellow-eye mullet)
Species: *Aldrichetta forsteri*

LOW
VULNERABILITY

SENSITIVITY + EXPOSURE = LOW

SENSITIVITY

Yellow-eye mullet are a small, rapidly maturing, short-lived species. They commonly reach 300 mm length but can be as large as 500 mm and a maximum age of 7 years. Yellow-eye mullet spawning takes place in the sea and the juveniles use estuaries for rearing.

DISTRIBUTION
Sensitivity attributes related to taonga species' locations

- Dispersal
- Adult mobility
- Temperature sensitivity
- Interspecific interactions
- Habitat specificity

ABUNDANCE
Sensitivity attributes related to taonga species' productivity

- Prey specificity
- Demographics
- Early life history, survival and recruitment
- Reproduction complexity
- Exposure to other pressures

PHENOLOGY
Sensitivity attributes related to timing of events in taonga species' lifecycle

- Spawning duration
- Dependence on environmental triggers

Sensitivity attributes vulnerability key: VERY HIGH | HIGH | MODERATE | LOW

Subset of the sensitivity attributes that contributed to yellow-eye mullet CCVA scores

Environmental triggers

Little is known about the specific environmental triggers associated with yellow-eye mullet spawning, recruitment and movements. Juveniles are known to move into estuaries when inflows are low. Environmental triggers for spawning are not well-known. Offshore winds may trigger their seaward spawning migrations. The speed and direction of surface ocean currents may be an important factor in promoting long distance larval dispersal and thus gene flow.

Complexity in reproduction

Yellow-eye mullet reproduction is relatively simple which likely reduces their vulnerability to climate change relative to other taonga species. Spawning occurs at sea and there is some evidence that biennial spawning occurs, with peaks in winter and summer. Yellow–eyed mullet produce several hundred thousand eggs, which float in the surface waters of the sea up to 33 km offshore. Egg development usually begins in July and maturity occurs by late December. For both sexes, first maturity is reached at 220–230 mm (total length) and age at sexual maturity is typically 2-3 years.

Adult mobility

A species can better survive changes in their habitat if they can leave that habitat in search of a new one. Yellow-eye mullet have a large geographic range and the adults are considered highly mobile. Large aggregations of adults have been observed over open coastal reefs suggesting that this species can migrate considerable distances from their original nursery grounds. Large scale movements occur prior to the spawning period.

In several estuaries throughout Aotearoa–New Zealand, the growth rates of yellow-eye mullet show significant spatial differences. These differences might be indicative of stock structure and more restricted adult movements. In Australia, otolith (fish ear bone) chemistry shows spatial variation among neighbouring estuaries. However, some locations show similar otolith chemistry meaning there is connectivity between populations.

Aua / Kātaha (Yellow-eye mullet)

EXPOSURE

Yellow–eye mullet occur throughout Aotearoa–New Zealand, they are also found in western and eastern Australia. They are considered locally abundant throughout coastal areas.

Subset of the exposure variables that will likely increase the vulnerability of yellow-eyed mullet to climate change

Rainfall

Yellow-eye mullet will likely be highly exposed to changes in mean annual and seasonal (autumn and winter) rainfall for the two time periods (mid–century [2046–2065] and late century [2081–2100]) and RCP scenarios 4.5 and 8.5. Changes in seasonal rainfall patterns may affect the estuarine habitats yellow-eye mullet use via increased or reduced inflows of freshwater to estuaries. However, the effects of changes to inflows likely depends on the type of estuarine habitat yellow-eye mullet use in Aotearoa–New Zealand.

Yellow-eye mullet mostly use estuaries for juvenile rearing indicating changes in freshwater inflows will largely affect the juvenile life stage. In parts of Aotearoa–New Zealand with lower projected rainfall (such as the east coast of the North Island), water quality may be reduced which might affect juvenile survival. Increased inflows to estuaries and associated increases in turbidity may also affect yellow-eye mullet swimming performance, movements and feeding.

Variability in freshwater inflows to estuaries affects yellow-eye mullet recruitment. In Australia, years with high annual freshwater inflows are associated with low yellow-eye mullet catches. During high estuarine inflow, juvenile fish consume more larval fish and amphipods compared to low inflows during drought conditions. This indicates that feeding opportunities are better for yellow-eye mullet during high inflows and may facilitate greater recruitment success.

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 can reduce yellow-eye mullet habitat availability. Recent mortalities of yellow-eye mullet have been observed in Hawke's Bay as a result of low freshwater flows and water temperatures close to 29ºC. There was an increased prevalence of diseased fish which resulted in mortalities.

Sea–level rise

Yellow-eye mullet will likely be highly exposed to sea-level rise. Across Aotearoa–New Zealand, sea-level rise is predicted to increase by an additional 0.5 metres by 2050 and 1 metre by 2090. 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.

Sea-level rise will likely alter estuarine hydrodynamics, but this is dependent on the shape and characteristics of individual estuaries. Nevertheless, changes to estuarine hydrodynamics as a result of sea-level rise may alter the habitats of yellow-eye mullet especially for juveniles. However, there are few direct links in Aotearoa–New Zealand and globally regards habitat changes due to sea-level rise and fish populations and no data exists for yellow-eye mullet.

Sea surface temperature

For the late century (2081–2100) and RCP 8.5, yellow-eye mullet will likely be highly exposed to changes in sea surface temperatures. Yellow-eye mullet are found in Western and Southern Australia and throughout much of Aotearoa–New Zealand indicating they can tolerate a wide range of temperatures. The preferred temperature range of yellow-eye mullet is 13.5–20.2°C, with a mean of 17.1°C. Species distribution modelling shows that yellow-eye mullet distributions are predicted to increase in Australia at lower (+0.54°C), median (+0.85°C) and upper (+1.24°C) temperature scenarios but no data exists for Aotearoa–New Zealand. Yellow-eye mullet have a large aerobic scope suggesting physiological adaptation to the highly variable temperatures found in coastal environments. However, recruitment surveys along the west and south coasts of Australia during 2011 and 2012 indicated a marked decline of the "cool temperate" yellow-eye mullet on both coasts which may be a result of a marine heatwave during that time. The effects of marine heatwaves on Aotearoa-New Zealand populations of yellow-eye mullet are unknown.
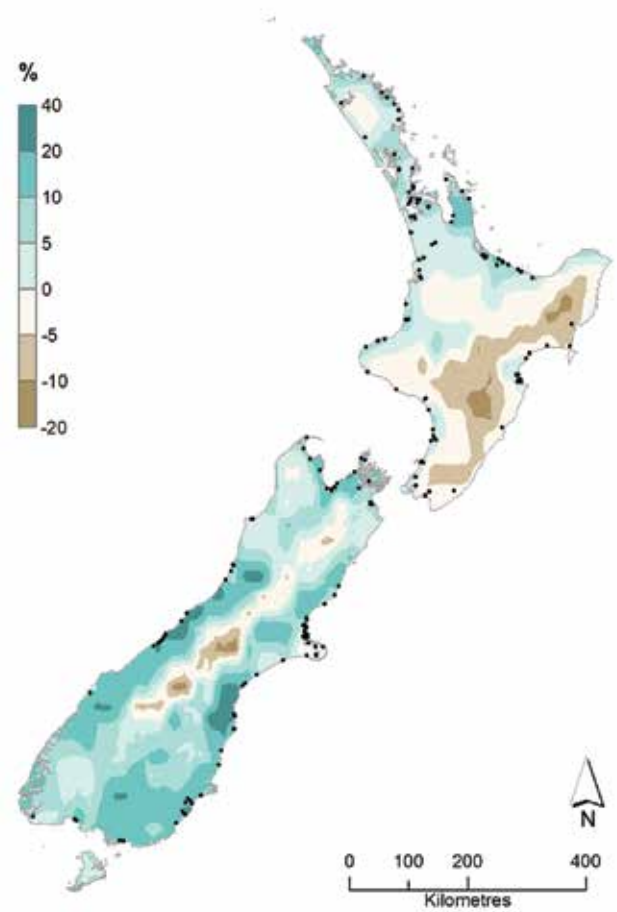
Current yellow–eye mullet distribution (dark circles) mapped with projected changes in mean autumn rainfall (for time period 2081–2100 under RCP 8.5).

Future research

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),**
- **mean autumn and winter precipitation;**
- **autumn mean air temperature;**
- **annual number of hot days (more than 25ºC)**

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.

We recommend future CCVAs incorporate more species in the assessment (e.g., significant prey species or invasive/non-native species) and that improvements could be made to the sensitivity attributes and exposure variables used (e.g., 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.

A potential next step could be to conduct CCVAs for a specific region in Aotearoa–New Zealand. However, this would require targeted surveys in specific regions and catchments to address critical knowledge gaps for our freshwater taonga species.

Acknowledgements

For more on this project or to view the full report visit
www.niwa.co.nz/te-kuwaha/CCVA

NIWA
Taihoro Nukurangi

Te Wai Māori