Walking into the past to explore the future: Utilizing larval densities to measure the effects of two climate change factors, temperature and salinity on Poorohe (common smelt, *Retropinna retropinna*) abundance in Te Puuaha o Waikato.

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Abstract

Poorohe (common smelt, *Retropinna retropinna*) are a highly valued kai species in Te Puuaha o Waikato (the lower 66 km of the Waikato River). Fisher whaanau have observed changes in the amount Poorohe that are harvested during annual fish harvests. Since Poorohe are particularly vulnerable to environmental changes, whaanau are particularly concerned about the how climate change might impact Poorohe populations. Climate change vulnerability assessments (CCVA) currently exist for several native New Zealand fish freshwater species; however, one does not yet exist for Poorohe. Previous larval distribution studies in the lower Waikato River only sampled as far downstream as Tuakau bridge (approximately 45km from the river mouth). These studies indicated that important spawning habitats likely existed downstream of Tuakau bridge. Temperature increases and saltwater intrusion have been identified as two climate change factors that will likely impact Poorohe in Te Puuaha o Waikato, because ambient temperatures have increased since the industrial revolution and the proximity of the study area to the ocean. A literature review was used to explore the experiences of fisher whaanau through the past, present and how the experiences will continue to change in a changing climate. The effects of temperature and saltwater intrusion on Poorohe populations were explored through replicating the methods of past research carried out in the 1980s and 2010s. Current river temperatures are in the optimal temperature range (12°C - 18°C) for Poorohe spawning. The saltwater wedge was suppressed by the high river flow during the eight-week sampling period, and it is unclear whether saltwater intrusion has an impact on Poorohe spawning. Larval densities did not significantly increase down river, which suggests large spawning habitat is not found downstream of Tuakau bridge. Furthermore, there were no decreases in larval densities in the two saltwater sites. This study has contributed to the available literature necessary to develop a CCVA for

Poorohe and explored the cultural heritage of traditionally significant practices in Te Puuaha o Waikato relating to Poorohe.

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Throughout this thesis the Waikato-Tainui dialect has been used. This dialect replaces macrons with double vowels.

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General Introduction

Climate change is a major concern for many groups, including scientists, policymakers, politicians, and the public (Nawrotzki & Kadatska, 2010). The Earth's climate has experienced natural oscillations of climate; however, deforestation and excessive greenhouse gas emissions has exacerbated the natural global temperature oscillations (Mohanty & Mohanty, 2009). Based on current temperature trends, average global temperature is expected to reach 1.5°C above pre-industrial levels between 2030 and 2052 (Diffenbaugh & Barnes, 2023) Climate change is characterised by notable shifts in climate that are persistent for extended periods and an increased frequency of extreme weather events (Lawrence et al., 2024; Nawrotzki & Kadastaka, 2010, Makondo & Thomas, 2018; Sesana et al., 2021). Furthermore, climate change has resulted in sea level rise, changes to the timing and intensity of precipitation, reduced snowfall, increased atmospheric concentration of CO_2 levels and increased air and water temperatures (Keegan et al., 2022). These changes have resulted in observable impacts to global biodiversity, which has increased the risk of extinction risk (Keegan et al., 2022). Climate change has resulted in declining ecosystem functioning by impacting the physiology of organisms and the ecological interactions among species (Keegan et al., 2022). Interactions between climate change and other environmental threats also exist, including habitat fragmentation, and the invasion of exotic species, which have created additional challenges for biodiversity (Lawrence et al., 2024; Keegan et al., 2022).

Freshwater ecosystems are particularly vulnerable to the effects of climate change because of their isolated nature, and the already severe exploitation of freshwaters for resource provisioning (Woodward et al., 2010). Physical stressors include changes to the hydrological cycle through the timing and intensity of rainfall, flow regimes, declining water quality, increased water temperature, and changes to the composition of freshwater communities through invasions of warm water tolerant species and extinction events (Aldous et al., 2011; Woodward et al., 2010; Hassan et al., 2020; Keegan et al., 2022). Additionally, the severe fluctuations of extreme flood and drought events will likely alter habitat availability and biodiversity (Death et al., 2015; Keegan et al., 2022). For example, habitat availability in low-lying rivers will be impacted by sea level rise because sea level rise is expected to shift estuarine habitats into the rivers and other low-lying freshwater ecosystems (Mohammed & Scholz, 2018). Climate change is commonly used to refer to variability of climate, however, throughout this thesis I have used climate change to refer specifically to the localised effects of sea level rise and temperature increases.

Climate Change Vulnerability Assessments (CCVAs) are an internationally used tool to assess species vulnerability to climate change. However, CCVAs have not been commonly used in Aotearoa-New Zealand. Te Wai Maaori Trust in collaboration with NIWA have used CCVA methodology to assess the climate change vulnerability of ten freshwater taonga species (Egan et al., 2020). Taonga species are culturally significant species to Maaori and are particularly important due to their role in shaping iwi and hapuu identity, Maatauranga Maaori, and whakapapa. However, as local iwi and hapuu are the determining authority, the classification of taonga species may vary regionally (Collier-Robinson et al., 2019). Te Wai Maaori Trust initially identified twelve fish, three bivalve and two crustacean species that required CCVAs; however, seven of these taonga species, including poorohe (Common smelt, *Retropinna retropinna*), could not be completed due to inadequate information existing on their ecology and life history (Egan et al., 2020).

Traditional ecological knowledge (TEK) is knowledge that is generated by indigenous communities over many generations. For a long time, the connotations surrounding traditional ecological knowledge was largely negative and it was often dismissed in lieu of western sciences (Berkes et al., 2000). In New Zealand, traditional ecological knowledge is Maatauranga Maaori, which varies across the country and reflects the environment and resources available to iwi, hapuu, and whaanau (Clapcott et al., 2018). The impacts of climate change are place-specific and can be experienced differently on regional and global scales (Schlingmann et al., 2021). Indigenous communities are considered the most vulnerable to climate change and will be disproportionately impacted through loss of important sites and resources because economic and cultural systems largely mediate the way communities are impacted by climate change (Makondo & Thomas, 2018; Schlingmann et al., 2021). The effects of colonisation have been profound on Maaori and resulted in changes to Maatauranga Maaori and associated practices. Climate change is likely to further impact practices, and the knowledge underpinning the practices, and by understanding the experience of fisher whaanau, and the changes brought about by colonisation, allows for whaanau to further protect the cultural heritage of poorohe.

The Waikato River is the longest and most economically important river in New Zealand, Because of this, the 450 km river and its 14,258 km^2 catchment are heavily managed (Chapman, 1996). The headwaters of the Waikato River originate on Mount Ruapehu and then proceed through Lake Taupoo, Huka Falls, Cambridge, Hamilton, Ngaaruawaahia and Huntly, before exiting at Port Waikato (Collier et al., 2019). The lower river is the catchment area below Karapiro dam (approximately, 300km from the mouth); however, whaanau and hapuu refer to the lower 45 km as Te Puuaha o Waikato (Fig1). Depending on the tidal cycle, the tides can influence water level as far as Rangiriri, which is approximately 63 km up the river. However, the salinity influence can extend approximately 10 km upstream from the river mouth in Port Waikato .

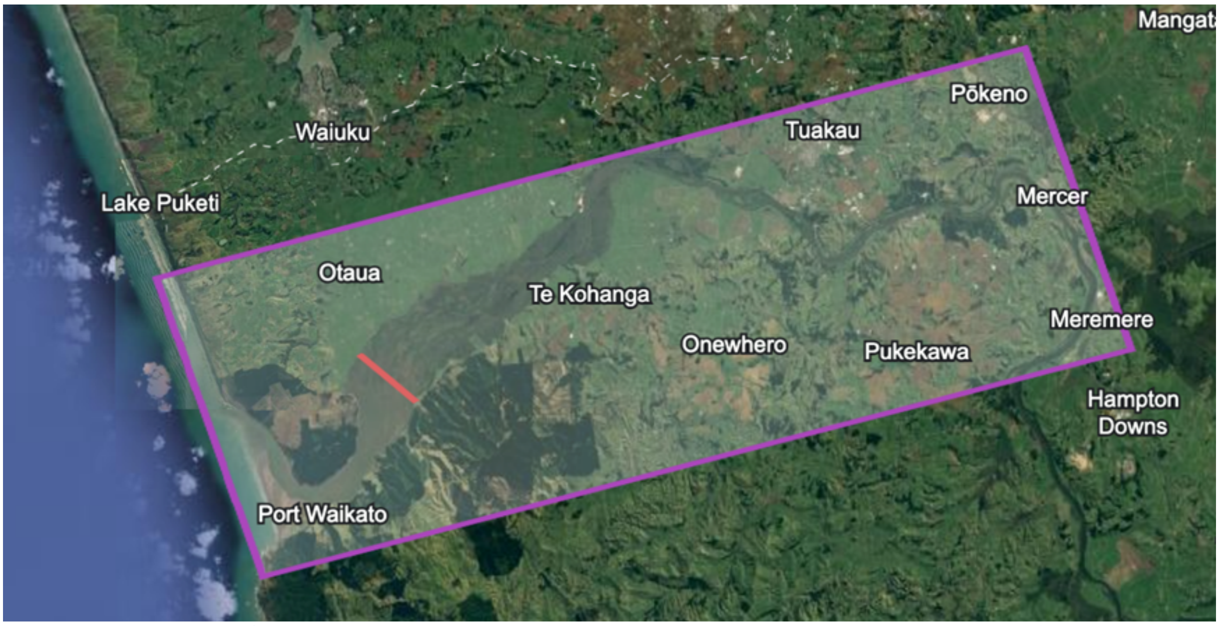


Figure 1: The area referred to as Te Puuaha o Waikato by iwi. The coastal marine boundary (CMA) is marked in red (Google Earth Maps, n.d.)

In Te Puuaha, poorohe (Common smelt, *R. retropinna*) are a culturally significant fish and valued kai species for whaanau. Poorohe are a small endemic freshwater fish species that inhabits low gradient rivers, streams and lakes (Ward et al., 2005). They inhabit a range of habitat throughout their lifecycle and during their migration back into the river, poorohe are harvested with other whitebait (Mahuta & Schravendjik-Goodman, 2024; Ward et al., 2005). In addition to being a valued kai species, poorohe are a prey item for other native species including tuna (*Anguilla dieffenbachii* and *A. australis*), and several bird species including whitefaced heron (*Egretta novahallandiae*), shag (*Phalacrocorax* sp.), and the gull species (*Larus bulleri*, *L. novaehollandiae* and *L. dominicanus*) (Ward et al., 2005). Increased temperature, declining water quality, and saltwater intrusion are some of the climate change factors that will provide novel challenges for freshwater species (Ficke et al., 2007). Poorohe are particularly vulnerable to environmental change and are likely to be impacted by these elements of climate change (Ward et al., 2005).

Whaanau in Te Puuaha are concerned with the impacts of climate change on poorohe populations because declining numbers have been caught during annual fish harvests. The extensive maatauranga and practices of the river fishing season, which includes the harvest of poorohe, and other freshwater fishes have changed through colonisation and raupatu (land confiscation) and are likely to further change under a changing climate. Poorohe have generally been overlooked by science compared to other more favourable research species because of their ‘common’ status. Exploring the experiences of fisher whaanau and the cultural heritage of the practices in Te Puuaha have demonstrated the importance of the species. Therefore, better understanding the possible implications of environmental change on poorohe and the development of tools and frameworks supports tangata whenua during planning and decision making. Furthermore, understanding the impacts of climate change on poorohe also provides whaanau with an opportunity to protect the cultural heritage of the practice.

Research Objectives

The research aim of this thesis is to provide information to develop a Climate Change Vulnerability Assessment (CCVA) for Poorohe.

This thesis aims to answer the following ecological questions:

1. **Are temperature and salinity the climate change factors that will have most impact on poorohe?**

2. **Where are poorohe spawning in the Waikato River?**

3. **Does spawning occur below the CMA (Coastal Marine Area) boundary in the estuarine environment?**

A CCVA framework does not account for the cultural beliefs, practices, and the values of fisher whaanau. However, this research aims to explore and better understand the maatauranga around poorohe. Through understanding the cultural landscape around poorohe and the experience of fisher whaanau enables the development of tools that aid tangata whenua in decision-making.

This thesis aims to answer the following questions to explore the cultural landscape of Poorohe:

a) How has the experience of the fisher whaanau in Te Puuaha changed in relation to harvesting Poorohe?

b) How might climate change, specifically the impacts of temperature increases and saltwater intrusion, further impact the maatauranga of fisher whaanau in Te Puuaha?

Chapter One: The experience of fisher whaanau through the past, present, and future

The common whakataukii, "*Ka mua, ka muri (we look to the past as we move into the future)*", implores for the use of past experiences to inform the future (Clapcott et al., 2018). This is becoming increasingly more relevant with the current climate emergency. This chapter will explore the impacts of a changing climate to the relationship tangata whenua (used to describe Maaori in both national and local contexts) with their valued kai species poorohe, through reflections on changes to practices brought about by the impacts of colonisation, and the strategies to mitigate the impacts of colonization. Furthermore, this chapter looks to the future to address potential challenges of climate change in respect to cultural heritage, barriers implicating the transmission of maatauranga, and building resilience with a changing climate. This is achieved through literature reviews, and personal communications.

Exploring the traditional relationships between Maatauranga Maaori and the past

Indigenous environmental knowledge and Maatauranga in the context of Poorohe

Traditional ecological knowledge (TEK) systems are described as a process of interactions between humans and the natural world which are shaped by the unique environments within which those peoples live (Loutit, 2014). Arising from intimate relationships between indigenous peoples and the environment, these relationships are embedded with cultural and spiritual elements that guide the level of those interactions with the natural world in a way that ensures the sustainability of resources for current and future generations (LaDuke, 1994; Loutit, 2014). These interactions are complex, diverse and context specific to the people and the location and, are closely linked to identity (Ataria, et al., 2018). Traditional ecological knowledge is a broader concept that generalises the indigenous experiences across multiple different indigenous cultures (Berkes et al., 2000). Within Te Ao Maaori (Maaori worldview), these relationships, knowledge and values are best captured within the concept of Maatauranga Maaori.

Broughton and McBreen (2015) describe maatauranga as “Maaori knowledge and all that underpins it, as well as Maaori ways of knowing” (p. 83). Maatauranga is a dynamic and holistic intergenerational collation of experience-based knowledge that emphasises whaanau relationships with their environment. This continuum of knowledge includes key principles such as whakapapa (connections and relationships, also referred to as genealogy), kaitiakitanga (the act of guardianship), and tikanga (protocols, rules and guidance) (Clapcott et al., 2018), amongst others.

Maatauranga is orally transmissible and is often shared through waiata (song), stories, whakataukii (proverbs), maramataka (lunar calendar), place names, ceremonies, dance, language (Te Reo Maaori), and teachings (Whaanga et al., 2018). Maatauranga is generated through observations of the natural world and testing hypotheses over generations (Hikuroa, 2017). This allows for innovation and evolution of maatauranga as it is being used and adapted within people’s lives (Ataria et al., 2018).

The intergenerational process of maatauranga allows for the creation of tools and processes that aid whaanau in carrying out their traditions (Ataria et al., 2018). It can be broadly used to describe knowledge generation across iwi and hapuu, but is also specific to the experiences of particular iwi, hapuu and whaanau within their environment, and therefore will express localised nuances across Aotearoa (Broughton & McBreen, 2015). As such, the context of this research is particularly relevant to the interactions of Waikato peoples with the poorohe (common smelt, *R. retropinna*).

Maatauranga of the river fishing season related to Poorohe

Poorohe (Common smelt, *R. retropinna*) are a culturally important species of the whaanau in Te Puuaha o Waikato (the catchment of the lower 66km of the Waikato River). The nature of maatauranga means that maatauranga cannot be separated out by specific species, but instead encompasses the whole river fishing season and the activities that took place on the river. In Te Puuaha, poorohe are harvested with matamata (galaxiid whitebait), glass eel (juvenile *Anguilla dieffenbachia* and *Anguilla australis*), mohimohi (the species of mohimohi is largely speculated) and Kahawai (*Arripis trutta*) (Mahuta & Schravendijk-Goodman, 2024). Overall, experience of harvesting poorohe and other freshwater fishes' pre-colonisation was positive.

Harvesting Poorohe

Maaori would travel between seasonal resources in the river, harbour, forests, and elsewhere (R. Mahuta, affiliated to Waikato iwi and Te Puuaha personal communication, October 18th, 2024). The arrival of Matariki (also recognised by other cultures as the constellation 'Pleaides') indicated the start of the river fishing season and fisher whaanau can spend months at a time on the river fishing and processing their catches (Mahuta & van Schravendijk-Goodman, 2024). However, Matariki is not the only environmental cue whanau utilised. For example, birds diving at the river mouth indicated to whaanau that fish were migrating up the river (C. van Schravendijk-Goodman, Swamp Frog Tree and Environmental Consultants, personal communication, October 8th, 2024).

During the river fishing season, children were taught about boating, weaving, whitebaiting stands and fishing. Maatauranga was shared during this time, and children were primarily taught through imitating kaumatua, and other family members (Mahuta, affiliated to Waikato iwi and Te Puuaha, personal communication, October 18th, 2024).

Traditionally, whaanau stood on wooden stands in the river and used handheld scoop nets called 'kaka' to harvest poorohe and matamata. Kaka were finely woven using muka (harakeke/New Zealand flax fibres, *Phormium tenax*) and attached to frames made from a native vine, kareao (supplejack*, Ripogonum scandens*) (Mahuta & van Schravendijk-Goodman, 2024). 'Ariari' were an additional tool used during harvests and made fish more visible to fishers. Ariari were made from stripped and dried mauku (Cabbage tree, *Cordyline australis*) pieces and were placed in the water, with the white wood making the fish more visible (Mahuta & van Schravendijk, 2024; NIWA, 2010). Branches and other shrubbery were used to stop the fish from swimming under and around the stands (Mahuta, affiliated with Waikato iwi and Te Puuaha, personal communication, October 18th, 2024). Fishing for poorohe was more difficult compared to matamata (galaxiid whitebait) because poorohe swam further out in the channel. This meant whaanau had to hold the kaka by the end of the pole and were also required to be quicker in lifting the nets because poorohe would turn once they hit the net (Mahuta, affiliated with Waikato iwi and Te Puuaha, personal communication, October 18th, 2024).

During the fishing season whaanau also collected, processed and used kiekie (*Freycinetia banksii*)*,* and harakeke for weaving. Whaanau used long lines with poorohe as bait to fish for Kahawai (Mahuta, affiliated with Waikato iwi and Te Puuaha, personal communications, 18th October 2024). Matamata, tunatuna (glass eels), and poorohe run upriver at the same time; however, when glass eels were running, whaanau would stop fishing because it would take too long to separate the glass eels from the matamata and poorohe. In Te Puuaha, tuna is a valued kai species; however, during the life stage of tunatuna, they are not eaten (Mahuta, affiliated with Waikato iwi and Te Puuaha, personal communications, 18th October 2024).

Poorohe as Kai

Poorohe are a coveted kai of people of Te Puuaha o Waikato; although the preferences of European settlers for other fish have shifted the popularity of poorohe for current generations of Maaori (McDowall, 2011). At Tauranganui Marae (a marae on the true left of the lower Waikato River), poorohe and matamata are a delicacy served during Poukai (Fig 2) (Mahuta & van Schravendijk-Goodman, 2024).

Figure 2: The location of Tauranganui marae in Te Puuaha o Waikato (Google Maps, n.d.)

The preparation and cooking of poorohe at Tauranganui has not changed since tuupuna first began cooking poorohe (Mahuta & van Schravendijk-Goodman, 2024). There are accounts from settlers that indicate poorohe was traditionally dried because of the high oil content and eaten in a similar fashion to eating potato chips (McDowall, 2011). At the Poukai held at Tauranganui, poorohe is served two ways: the first being with tiitii (tiitii most commonly refers to sooty shearwater birds (*Ardenna grisea*) but could include any shearwater birds). In this recipe, poorohe are added to the broth after the tiitii has finished cooking and are fully cooked when they lose transparency. The second method involves frying poorohe in butter until crispy (Mahuta & van Schravendijk-Goodman, 2024).

Maramataka in relation to Poorohe

Maramataka is a complex and dynamic calendar system used by Maaori, utilising lunar and celestial cycles combined with environmental and ecological calendars (Matthews, 2023). It involves an intimate understanding of the environment and guides practices like fishing, hunting, planting and harvesting crops (Palmer et al., 2023). Where the western lunar calendar describes the moon moving through eight lunar phases, maramataka describes lunar movements through approximately thirty phases. In line with local context, however, the accepted number of moon nights depends on iwi and hapuu and their environments (Roberts et al., 2006; Hikuroa; 2020).

Sourcing published information about the application of maramataka to poorohe harvest is difficult to locate, but Roberts et al. (2006) highlight two maramataka specific to the Waikato that were likely applicable to Te Puuaha (Table 1). Note that key differences between the two maramataka are the names given to the moon nights and the number of moon nights (Table 1).

Table 1: Names of moon nights of two Waikato Maramataka (Roberts et al., 2013).

Number of Moon Nights	Moon Night Names according to Waikato Maramataka 1	Moon Night Names according to Waikato Maramataka 2
(New Moon) 1	Whiro	Atarau/Pewa
2	Tireo	Ahora/Tirea
3	Hoahoata	Aurei
4	Ouenuku	Oue/Ue
5	Okoro	Akoro/Okoro

6	Tamatea tutahi	Ananga/Tamatea-tutahi
7	Tamatea turua	Ahotu/Tamatea-turua
8	Tamatea tutoru	Aio/ Tamatea-tutoru
9	Tamatea whakapapa	Kai-ariki/Tamatea-tuwha
10	Ari	Hune/Ngahuru
11	Huna	Ari
12	Ohua	Mare
13	Mawharu	Mawharu
14	Hotu	Ohua
15	Atua	Atua-mate-o-hotu
16	Maure	Oturu
17	Turu	Rakaunui
18	Rakau nui	Rakau-matohi
19	Rakau matohi	Takirau
20	Oike	Oike
21	Takirau	Korekore
22	Korekore tutahi	Korekore-ngana
23	Korekore turua	Korekore-piri
24	Kokokore piri ki nga Tangaroa	Tangaroa-mua
25	Te ngaro a mua	Tangaroa-roto
26	Te ngaro a roto	Kiokio
27	Te ngaro a kiokio	Otane
28	Aotane	Orongo-nui
29	Rongonui	Mauri
30	Mauri	Omutu-mutu-whenua
31	Mutu	

The interactions between the environment and tangata whenua are informed by maramataka. Furthermore, these interactions guide environmental management strategies (Ross, 2021). During the harvest of matamata and poorohe, maramataka can be applied to determine when fishing would be most optimal or when conditions are unfavourable. On Korekore nights, food tends to be scarce, and these nights are bad nights on the water and on shore. On these nights, fisher whaanau may need to be more cautious because conditions could be dangerous. However, Tangaroa nights following Korekore nights tend to bring favourable conditions for fishing (Hanara & Jackson, 2019).

The changing relationship

The negative implications of Raupatu, legislative changes, and the introductions of exotic species were profound experiences for fisher whaanau in Te Puuaha. Raupatu has restricted access to areas where whaanau carry out hauanga kai (also known as mahinga kai, the practices around gathering and protecting traditional kai sources), like the harvest of matamata and poorohe (Te Kauhanganui Inc (WTTKI), 2013). Legislative changes and introductions of exotic freshwater species further impacted the experience of fisher whaanau and their maatauranga. The Waikato River Settlement and Te Ture Whaimana, both described in more detail below, were designed to lessen the negative effects of colonisation on the experiences of fisher whaanau.

Impacts of colonization

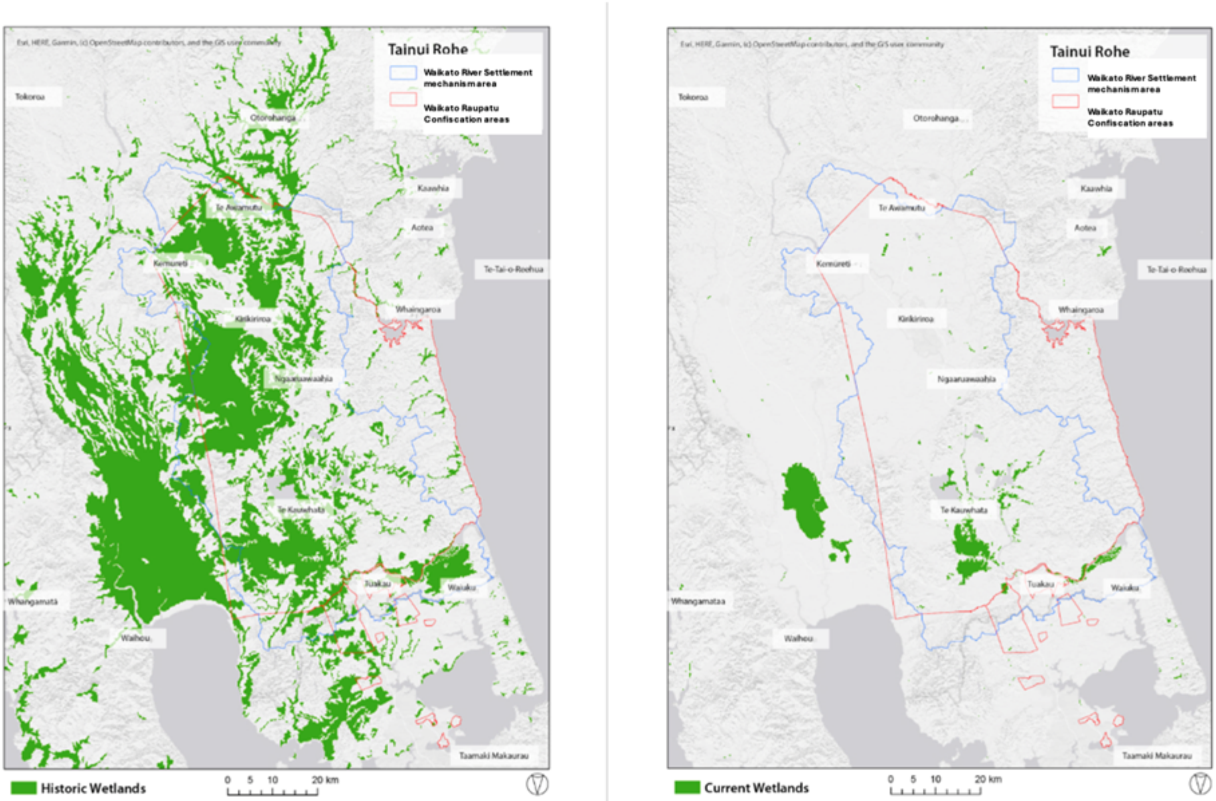
Raupatu and the impacts of Raupatu

Crown purchases under pre-emption rights, title individualization, private acquisition of land through Native Land Courts and Raupatu (confiscation) enabled by the New Zealand Settlement Act 1863, led to the diminishment of Maaori land (Thom & Grimes, 2022). This resulted in Maaori freehold land making up 5% of land mass in New Zealand (Thom & Grimes, 2022). Land loss was felt particularly acutely in Waikato under Raupatu as one million acres of Maaori owned land was confiscated (Waikato Tainui, 2013).Complex and extensive wetlands were included in the confiscated land in the Waikato (Hill, 2010).

It is important to recognize that the term ‘Raupatu’ encompasses both the confiscation of lands, and the various acts associated with the confiscation including armed invasion and killing of taangata whenua (Mahuta, 2008; Hill, 2010). Raupatu ultimately stripped Maaori of their homes, livelihoods and decision-making abilities over their whenua (land) (R. Mahuta, affiliated to Waikato iwi and Te Puuaha, personal communication, November 1, 2023). Inherent within the loss of management over whenua, was also the stripping of decision-making from tangata whenua about important species like poorohe, their habitats, and impacts of land-uses to those habitats.

The New Zealand Settlement Act 1863 outlined the Settler government’s perceived justification for Raupatu through the engagement of ‘Maaori rebellion’, primarily through movements like the Kiingitanga (Hill, 2010). The Kiingitanga (the King Movement) was formed in 1858 to unify Maaori with the objectives of ending land alienation, inter-tribal conflict, and creating a governing entity equal to the British monarchy to enable self-governance (Mahuta, 2008). Furthermore, Kiingitanga represented and provided autonomy against the sovereignty of the Crown (Mahuta, 2008; Hill, 2010).

A key example of the impacts Raupatu had on tangata whenua is the deforestation and drainage of the extensive wetlands in the Waikato region to convert this land to farmland. These wetlands were important habitat for valued freshwater species like poorohe, but also held spiritual significance and had an important role in Maaori society. Often wetlands were used as safe havens during war and to hide taonga (WTTKI, 2013.) Furthermore, in reference again to poorohe, wetlands were a kai source, and a variety of food sources were collected from these wetlands (Mahuta, personal communication, November 1, 2023) including fish, birds, fruits, other plant materials, timbers, koohatu (stones), and paru (muds) amongst other resources. In partnership with Waikato-Tainui, Manaaki Whenua – Landcare Research developed two maps that demonstrate the impacts raupatu had on wetlands in the Waikato through the conversion of land, which resulted in the diminishing of maatauranga and practices surrounding wetlands (Mahuta & van-Schravendjik-Goodman, 2024) (Fig 3).



Historic wetland coverage (c.1840) in the rohe of Waikato-Tainui. Map is presented here in line with the Waikato worldview: **Mookau ki runga, Taamaki ki raro.**

[Boundary lines supplied by Waikato-Tainui; Map built by Manaaki Whenua as part of their partnership with Waikato-Tainui, 2021]. Reproduced with permission from Waikato-Tainui Te Whakakitenga Inc. ©

Current estimated wetland coverage in the rohe of Waikato-Tainui. Map is presented here in line with the Waikato worldview: **Mookau ki runga, Taamaki ki raro.**

[Boundary lines supplied by Waikato-Tainui; Map built by Manaaki Whenua as part of their partnership with Waikato-Tainui, 2021]. Reproduced with permission from Waikato-Tainui Te Whakakitenga Inc. ©

Figure 3: Historic wetlands in the Waikato-Tainui rohe (left) and the current wetlands in the Waikato-Tainui rohe (Mahuta & van-Schravendjik-Goodman, 2024).

Legislative Impacts

Ultimately, colonisation has resulted in the fragmentation of Maaori identity and efforts to assimilate Maaori into a Paakehaa society occurred through religion, education and legislation (Anaru, 2012). Legislation like the Tohunga Suppression Act 1907 and the Resource Management Act 1991(RMA) were and/or continue to be mechanisms of colonisation that promote assimilation (Ka’ai-Mahuta, 2011). Additional legislation, like the

Conservation Act 1987, has also altered the way tangata whenua can interact with traditional practices related to their fisheries.

The Tohunga Suppression Act (1907) outlawed both the practices and the intergenerational transmission of knowledge. While the Tohunga Suppression Act specifically targeted Maaori healing and rongoaa (traditional forms of medicine) (Anaru, 2012), it also interfered with other maatauranga including knowledge revolving around weather and climate (King et al., 2008). Interference with transmission of weather and climate maatauranga is likely to have adverse effects on the collection of poorohe through impeding understanding of different environment cues associated with poorohe harvest. Furthermore, the Tohunga Suppression Act 1907 and the conversion to Christianity likely influenced the shifts in the meanings of Kaitiaki and Kaitiakitanga (Roberts et al., 1995). Traditionally, kaitiaki were non-human spiritual guardians, guides, and manifestations of Atua (gods), that were determined by whaanau, hapuu, and iwi. Kaitiaki dwell in or are manifestations of animals like tuna (eel), birds, lizards and fish (Roberts et al., 1995; Beverland, 2022; Muru-Lanning et al., 2022). However, the meaning of kaitiaki and kaitiakitanga was shifted and used to describe tangata whenua interacting with the environment and describe conservation (McDowall, 2011).

The Resource Management Act governs the use of all natural resources. As such, it also limits the way in which tangata whenua can interact with the environment. This legislation gives local government decision-making power over resources. This, in turn, enables councils to dismiss Maaori customary rights to resources (Wevers, 2013). However, it is important to recognise that RMA acknowledges tikanga through directing decision makers to acknowledge the relationship between tangata whenua and water when planning and issuing resource consents (Ruru, 2018).

The Education Ordinance Act 1847 and the Native Schools Act 1897 were legislation aimed to assimilate Maaori into Paakehaa society through education. Both acts required English to be the only language written and spoken at school and children were actively discouraged from learning Te Reo Maaori (Paul-Burke et al., 2022; Simon & Smith, 2001; Walker, 2016). These pieces of legislation contributed to the overall decline of Te Reo Maaori speakers. By the mid-1970s approximately 20% of Maaori could fluently speak Te Reo and the vast majority of speakers were above the age of 50 (Jellie, 2001). The decline in Te Reo speakers and language revitalisation initiatives have impeded the transmission of iwi specific maatauranga, because Maaori naming of species encapsulates important ecological information like habitat and life cycle (Aitken et al., 2021). For example, the name for common smelt in the Waikato is ‘poorohe’; however, in Whanganui the name ‘ngaore’ is used. Naming is further complicated in the Rotorua Te Arawa lakes, with the name for common smelt there being ‘iinanga’; however, elsewhere iinanga is the common name for *Galaxias maculatus,* which are not present in the Rotorua lakes (Phillips, 1947; Strickland, 1993; McDowall, 2011). Furthermore, the decline in ability to converse in Te Reo has impacted traditional monitoring and maatauranga frameworks (van Schravendijk-Goodman, personal communications, 12th October,2024).

Further legislation around whitebait fisheries (Whitebait Fishing Regulations, 2021) under the Conservation Act 1987 likely impacts how whaanau interact with poorohe and their harvesting. The Whitebait Fishing Regulations, 2021, do not directly impede Customary Maaori fishing rights; however, this legislation enables non-Maaori fishers to partake in the practice. Thus, creating further competition for fisher whaanau. The whitebait regulations provide Paakeeha with pseudo-rights to fishing areas and the construction of permanent structures including baches. This has further facilitated pseudo-ownership rights to customary fishing areas (Morris et al., 2013).

Introducing exotic freshwater fish species

To mimic the waterways of Europe and the British Isles, exotic fish species like Brown Trout (*Salmo trutta*) and European Perch (*Perca fluviatilis*) were introduced into New Zealand waterways in the late 19th Century. The introduction of trout was seen as a method of 'improving' New Zealand's waterways but also enabling the working class to engage in activities only the privileged of Britain could participate in (Knight, 2019). There are instances of exotic species outcompeting and even eradicating native species from freshwater systems. An example of this is the Kooaro (*Galaxias brevipinnis*) populations of Lake Taupoo and the Rotorua Lakes severely declined following the introduction of trout (Ward et al., 2005). Following this, poorohe were introduced into these lakes to sustain the trout fisheries (Ward et al., 2005). Repercussions of these introductions include increases to competition and predation on native freshwater species and have environmental impacts (Smith & Grayling, 2005; Lee, 2021).

How the river fishing practices changed because of colonisation

Colonisation initiated changes to the practice of harvesting poorohe and other river fish. Through the availability of European materials, kaka, stands and ariari were adapted and eventually became redundant tools. The traditional materials of kaka were replaced by nylon netting and aluminium frames, while ariari became painted boards or tin spouting (Mahuta & van Schravendijk-Goodman, 2024). However, modern set nets ultimately replaced the handheld kaka and ariari because the set nets resulted in a larger catch and required less effort by the fisher person (Mahuta & van Schravendijk-Goodman, 2024). Using set nets, fisher peoples can leave the net for extended periods of time following setting the net. Traditional wooden stands became floating stands which are polystyrene slabs inside a wooden frame that is attached to metal poles. This design allows for the stand to move with the tidal level (Mahuta, affiliated to Waikato iwi and Te Puuaha, personal communication, 18th October

2024). However, the design of these floating stands is non-compliant with Waikato Regional Plan rules when they are not attached to land (Morris et al., 2013). This had likely contributed to the development of baches along the lower river (Mahuta, affiliated to Waikato iwi and Te Puuaha, personal communication, 18th October 2024).

Mediating change through The Waikato River Settlement

Te Tiriti o Waitangi vs the Treaty of Waitangi

Te Tiriti o Waitangi (the Te Reo Version) differs from The Treaty of Waitangi because it was purposefully translated in a misleading manner to ensure Maaori chiefs would sign (Graham, 2015). Te Tiriti o Waitangi asserts Tino Rangatiratanga **(**ultimate authority) to Maaori as Tangata Whenua; however, the English version of the Treaty of Waitangi cedes sovereignty to the Crown (J. Baker, 2013). These differences created ambiguity around land and resource rights. During the 1970s the government experienced increased public pressures to recognise the guarantees of the Crown under Te Tiriti o Waitangi, which ultimately led to the inception of the Waitangi Tribunal. This tribunal allows for Maaori to make compensatory claims for breaches of Te Tiriti o Waitangi (Stokes, 1992).

The Waikato River Settlement

Kiingi Tawhiao’s tongikura (famous quotes/ from Maaori monarchs) is used by Waikato-Tainui to describe their aspirations for the Waikato River(Te Kauhanganui Inc (WTTKI), 2013; Waikato-Tainui Raupatu Claims (Waikato River) Settlement Act 2010, 2010). Part of this tongikura was also adopted as part of the vision for the Waikato River Authority:
“Tooku awa koiora me oona pikonga he kura tangihia o te maataamuri” (The river of life, each curve more beautiful than the last) (Waikato River Authority, 2019).

The Waikato-Tainui River Settlement is unique because it was focused on the health and wellbeing of the Waikato River, rather than ownership (Steenstra, 2008). However, a clause in section 64 allows for Waikato-Tainui to revisit ownership interests of the Waikato River (Waikato-Tainui Raupatu Claims (Waikato River) Settlement Act, 2010). This settlement is particularly important because it provides an end to the typical exclusionary paradigms through the purpose of restoring and protecting the health and wellbeing of the Waikato River (reflected through the principle of Mana o te Awa) and as defined by Waikato-Tainui in s.8 (3):

> '*The Waikato River is our tupuna (ancestor) which has mana (spiritual authority and power) and in turn represents the mana and mauri (life force) of Waikato-Tainui. The Waikato River is a single indivisible being that flows from Te Taheke Hukahuka to Te Puuaha o Waikato (the mouth) and includes its waters, banks and beds (and all minerals under them) and its streams, waterways, tributaries, lakes, aquatic fisheries, vegetation, flood plains, wetlands, islands, springs, water column, airspace, and substratum as well as its metaphysical being. Our relationship with the Waikato River, and our respect for it, gives rise to our responsibilities to protect te mana o te Awa and to exercise our mana whakahaere in accordance with long established tikanga to ensure the wellbeing of the river. Our relationship with the river and our respect for it lies at the heart of our spiritual and physical wellbeing, and our tribal identity and culture.'*.
>
> Furthermore, the River settlement also set a precedent for other river iwi to enact their own settlements Warren, 2016).

The timeline of the Waikato River Settlement

The Waikato River Settlement was settled in 2010, but the precursor to this settlement was the Waikato-Tainui Raupatu settlement in 1995. The 1995 Settlement was primarily concerned with the return and/or compensation for land confiscated under Raupatu. However, the Waikato River was excluded from the initial settlement as were outstanding claims to the West coast harbours – (south to north) Kaawhia, Aotea, Whaingaroa (Raglan) and Te Maanukanuka o Hoturoa (Manukau Harbour). The Waikato River was revisited by Waikato-Tainui in 2007 as outlined in Figure 4(below) (Te Kauhanganui Inc (WTTKI), 2013).

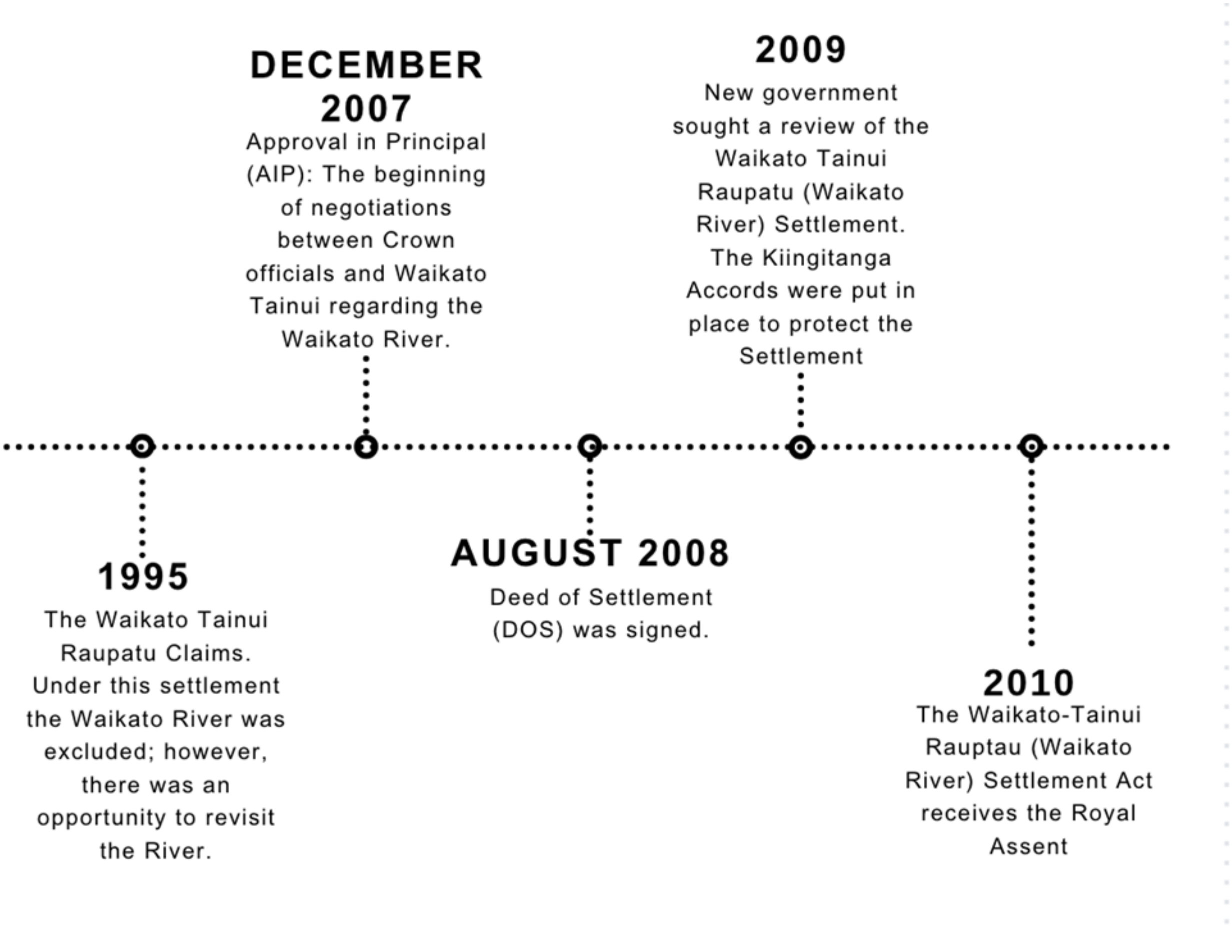


Figure 4: A timeline of the Waikato-Tainui River Settlement (Waikato-Tainui, n.d.)

The outcomes of the Waikato-Tainui Raupatu claims (Waikato River) Settlement

The Waikato River settlement was overarched by two key principles which set in place the platform from which to develop the Settlement outcomes sought by Waikato-Tainui. These principles were Te Mana o te Awa and Mana Whakahaere.

Te Mana o Te Awa uniquely puts the health and wellbeing of the Waikato River at the forefront of decision-making. Mana Whakahaere emphases the co-management and co-governance of the river_(Waikato Tainui Raupatu Claims (Waikato River) Settlement Act, 2010). Several mechanisms were also established within the Settlement to achieve the principles. Mana Whakahaere was facilitated through the development of Accords, and Joint Management Agreements (JMAS) and Te Mana o Te Awa is primarily facilitated through Te Ture Whaimana o Te Awa Waikato (the vision and strategy for the Waikato River) and the development of the co-governance entity, the Waikato River Authority (WRA) and the Clean Up Fund which is managed by the WRA (Waikato-Tainui Raupatu Claims (Waikato River) Settlement Act, 2010).

Te Ture Whaimana o Te Awa o Waikato – The vision and strategy

Te Ture Whaimana o Te Awa o Waikato (The Vision and Strategy) is a bespoke direction setting document for decision making and planning in relation to the Waikato River and including its catchment. It prevails over any inconsistencies with National Policy Statements (NPS) and/or National Environmental Statements (NES) in relation to the river (Waikato River Settlement, s. 12). There are currently 20 pieces of legislation, including the Resource Management Act (RMA), that also must factor Te Ture Whaimana into decision-making in the catchment of the Waikato River (Waikato-Tainui Raupatu Claims (Waikato River) Settlement, 2010). Additionally, Te Ture Whaimana identifies and endorses activities that support the health of the river and includes upholding rights for tangata whenua to reconnect with taonga species (Ataria et al., 2018).

Objectives of Te Ture Whaimana

Te Ture Whaimana communicates thirteen objectives for the Waikato River (Paterson-Shallard et al., 2020; Waikato-Tainui Raupatu Claims (Waikato River) Settlement Act 2010, 2010). Eight objectives are drawn directly from the Waikato-Tainui Raupatu (Waikato River)

Settlement Act and these were formally endorsed in the respective settlements of the other river iwi (Tūwharetoa, Raukawa, the Te Arawa River Iwi Waikato River Act 2010 and the Ngā Wai o Maniapoto (Waipā River) Bill) (Waikato Regional Council, 2011). The remaining five objectives of Te Ture Whaimana were decided upon through consultation led by the GEC (Waikato-Tainui Raupatu Claims (Waikato River) Settlement Act 2010, 2010). The vision objectives of Te Ture Whaimana under the Waikato River Settlement, Waikato Tainui put forth objectives A, B, E, F, G, H, and M:

A. **The restoration and protection of the health and wellbeing of the Waikato River.**

B. **The restoration and protection of the relationship of Waikato-Tainui with the Waikato River, including their economic, social, cultural, and spiritual relationships.**

C. The restoration and protection of the relationship of Waikato River Iwi according to their tikanga and kawa, with the Waikato River, including their economic, social, cultural, and spiritual relationships.

D. The restoration and protections of the Waikato Region's communities with the Waikato River including their economic, social, cultural, and spiritual relationships.

E. **The integrated, holistic, and coordinated approach to management of the natural, physical, cultural, and historic resources of the Waikato River.**

F. **The adoption of a precautionary approach towards decisions that may result in significant adverse effects on the Waikato River, and in particular those effects that threaten serious or irreversible damage to the Waikato River.**

G. **The recognition and avoidance of adverse cumulative effects, and potential cumulative effects, of activities undertaken both on the Waikato River and within its catchment on the health and wellbeing of the Waikato River.**

H. **The recognition that the Waikato River is degraded and should not be required to absorb further degradation as a result of human activities.**

I. **The protection and enhancement of significant site, fisheries, flora, and fauna.**

J. The recognition that the strategic importance of the Waikato River to New Zealand's social, cultural, environmental, and economic wellbeing requires the restoration and protection of the health and wellbeing of the Waikato River.

K. The restoration of water quality within the Waikato River so that it is safe for people to swim in and take food from over its entire length.

L. The promotion of improved access to the Waikato River to better enable sporting recreational, and cultural opportunities.

M. **The application to the above maatauranga Maaori and latest available scientific methods.**

Under the Waikato River Settlement, clauses 59 and 73 pertain to the harvest of native fish species, including poorohe. This expectation is that Waikato tribal members can continue to use and maintain traditional infrastructure in the river like whitebait stands and tuna weirs (Waikato-Tainui Raupatu Claims (Waikato River) Settlement Act 2010). Furthermore, since Te Mana o Te Awa refers to the overall health and wellbeing of the Waikato River, it should therefore encapsulate all species associated with the river. Therefore, protecting the habitat of poorohe falls under Te Mana o Te Awa (C. van Schravendijk-Goodman, personal communications, November 28, 2023), and is further supported under the definition of the Waikato River (Waikato-Tainui Raupatu Claims (Waikato River) Settlement Act 2010, section 8). The cultural practices and wellbeing of fisher whaanau in relation to the poorohe fishery also implies connection to objective B (ie., maintenance, protection and enhancement of the relationships between tribal members and their natural resources), and therefore, the principle of Mana Whakahaere.

The present and living with climate change

Whaanau in Te Puuaha are becoming increasingly concerned about Poorohe. During annual harvests, fisher whaanau have noticed they are catching less poorohe and the poorohe they are catching are smaller (Mahuta, affiliated to Waikato Iwi and Te Puuaha, personal communications, 18th October 2024).

Despite the changes brought about by colonisation, fisher whaanau in Te Puuaha have maintained their practices around the harvest of matamata and poorohe although the fishing methods have been altered following, and possibly in response to the effects of colonisation.

Climate change will exacerbate pre-existing environmental issues and create unprecedented environmental problems which may further alter harvest practices. To further explore the concerns of whaanau and enhance the maatauranga, science is being used to build tools like a Climate Change Vulnerability Assessment that can aid whaanau and environmental managers in decision-making.

Cultural heritage

What is cultural heritage?

Bouchenaki (2003) defines cultural heritage as "*synchronised relationships involving society*", which include physical (tangible) and non-physical (intangible) expressions of culture like art, monuments, languages, and religion.

More specifically, tangible cultural heritage includes the physical manifestations of culture that are interacted with like historic sites, monuments, art, and artefacts (Mortara et al., 2014). It is important to recognise that these elements can be inspired by the environment and the relationship with the environment. In Te Ao Maaori, expressions of tangible cultural heritage encompass places like marae but also practices like fishing and weaving. Comparatively, intangible cultural heritage relates to intellectual knowledge systems embedded in society like values, intergenerational knowledge, religious beliefs, and language (Mortara et al., 2014; UNESCO, 2022). Ultimately, intangible cultural heritage is reflective of inter-generational relationships between the community and environment (Mínguez García, 2020). Maatauranga and the accompanied tikanga and kaitiakitanga are expressions of Maaori intangible cultural heritage. These concepts and beliefs underpin Te Ao Maaori and traditional practices like fishing, weaving, and carving (Viriaere & Miller, 2018).

Traditionally, the safeguarding and preservation of tangible cultural heritage has taken precedence over the intangible aspects of cultural heritage. However, in 2003, United Nations Educational, Scientific, and Cultural Organisation emphasised the importance of intangible cultural heritage in the Convention for Safeguarding of Intangible Cultural Heritage of Humanity (Alivizatou-Barakou et al., 2017). This is especially important because it promotes safeguarding of both aspects of cultural heritage, which are fundamentally linked and cannot exist without each-other (Mahina-Tuai, 2006). Engaging with cultural heritage builds wellbeing and develops the identity of both individuals and communities (Orr et al., 2021). Supporting and upholding the ongoing transmission of indigenous cultural heritage across generations is also increasingly being recognised as important for monitoring and responding to environmental change (Hepi et al., 2018; Hikuroa et al., 2018; Walker et al., 2021).

Climate change and cultural heritage

Environmental changes intensified by climate change have created new risks to cultural heritage (Jigyasu, 2019). These risks have led to the development of multiple international organisations and initiatives concerned with safeguarding of cultural heritage against the impacts of climate change (Mínguez García, 2020). Tangible cultural heritage is more obviously impacted by climate change through the destruction of monuments and sites. It is typically harder to identify when intangible cultural heritage is impacted; however, forced migration caused by climate change has been linked to the destruction of intangible cultural heritage (Higgins, 2022).

Implications of losing cultural heritage

The linked nature of cultural heritage means that the loss of tangible manifestations can have dramatic impacts on expressions of intangible cultural heritage. A local historical example demonstrating the risks associated with losing cultural heritage is the giant wire rush (*Sporadanthus ferrugineus).* A Maaori name likely existed; however, the name has been lost.

This species was a wetland plant that dominated the Waikato region including Te Puuaha; however, the rapid conversion of wetlands to agricultural property following Raupatu was detrimental to this species (Williams et al., 2021). This change in land-use simultaneously led to the dramatic loss of *S. ferrugineus* and the surrounding intangible cultural heritage.

Upokororo (Grayling, *Prototroctes oxyrhynchus*) was closely related to poorohe and is another example of cultural heritage 'going to sleep'[1] with the extinction of a species. Once described as hyper-abundant, Upokororo experienced a rapid extinction following European settlement. The last confirmed sighting of Upokororo was in 1923, but unsubstantiated sightings suggest Upokororo persisted into the 1950s (Scarsbrook et al., 2023). The events that led to the extinction of Upokororo are not fully understood. It is suggested that the combination of environmental change, over-fishing, the introduction of salmonids and the amphidromous life cycle all contributed to the rapid decline (Lee & Perry, 2019). With the extinction of the Upokororo, the maatauranga also slowly declined through the generations. Similar to Upokororo, poorohe could face similar declines and challenges because of the amphidromous life cycle of poorohe and climate change. McDowall (2011) recounts the preference of early Maaori communities for poorohe over galaxiids (matamata, whitebait); however, poorohe experienced declining popularity because European settlers preferred the milder taste of the galaxiids. This shift in popularity has likely impacted the intangible cultural heritage surrounding poorohe. Furthermore, whitebait buyers in Te Puuaha called poorohe 'number two whitebait'. This further perpetuated the idea that poorohe were not as valuable as galaxiids, which has led to many fishers discarding them from their catches. Furthermore, complex climate change related issues may impact poorohe and the cultural heritage surrounding the fish. This may arise through disappearances of the fish from the

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[1] Maatauranga 'going to sleep' the preferred phrasing of Mahuta & van Schravendijk-Goodman (2024) when discussing Maatauranga being lost because Maatauranga can be recovered through whakapapa.

river and waterways, which leads to the accompanying maatauranga going to sleep along with the poorohe.

Changes to the practice of river fishing

This study was born from the maatauranga of fisher whaanau in Te Puuaha, where they observed decreases in overall size of fish being caught and the total number of poorohe being caught. The practices surrounding fishing on the river were ultimately changed by colonisation and maatauranga suggests the shift in fishing methods, from kaka to set nets, may have contributed to declining in the number of poorohe caught (Mahuta, affiliated to Waikato Iwi and Te Puuaha Personal communication, 18th October 2024). It is thought that set nets are less effective at capturing poorohe because the wings of the set net do not reach the swim path of poorohe (Personal Communication, Mahuta, 18th October 2024).

Additionally, kaka ensured fish reached rearing habitat whereas the use of set nets likely further decreases the probability of poorohe and matamata reaching this habitat because they are often set and left for long periods of time (Mahuta & van Schravendijk-Goodman, 2024). However, it is difficult to assume that this shift in methods is solely responsible for the decline in total poorohe catch.

The changing climate

The global climate is changing at unprecedented rates and the effects of climate change is not fully understood (Heino et al., 2009). Predictive climate change modelling and tools are used to estimate the effects of climate change. New Zealand's ambient temperatures are increasing with global temperature patterns (Lundquist et al., 2011). The physiology of fish are altered when water temperatures exceed their thermal niches (Ficke et al., 2007). Since poorohe have a narrow thermal niche in comparison to other native freshwater fishes, increased water temperature will likely have an impact on poorohe populations (Richardson et al., 1994). Additionally, modelling suggests sea level rise and saltwater intrusion is thought to be a prevalent concern for Te Puuaha under sea level rise (Robcke et al., 2024). This modelling predicts at 0.8 m of sea level rise the river islands of the lower river will become inundated. Furthermore, the maximum saltwater intrusion level at 0.8 m begins to reach the lower islands (Fig 6). At 1.6m sea level rise, the islands are inundated, and the saltwater intrusion begins to reach above the islands (Fig 7). Inundation of the lower islands will compromise the integrity of the fishing baches and stands throughout the lower river (van Schravendijk-Goodman, Swamp Frog Tree and Environmental Consultants, personal communications, 8th of October, 2024).It is likely that these baches and stands would become abandoned under sea level rise conditions because some of these structures have already been deserted due to damages and/or cost of maintenance (Morris et al., 2013).

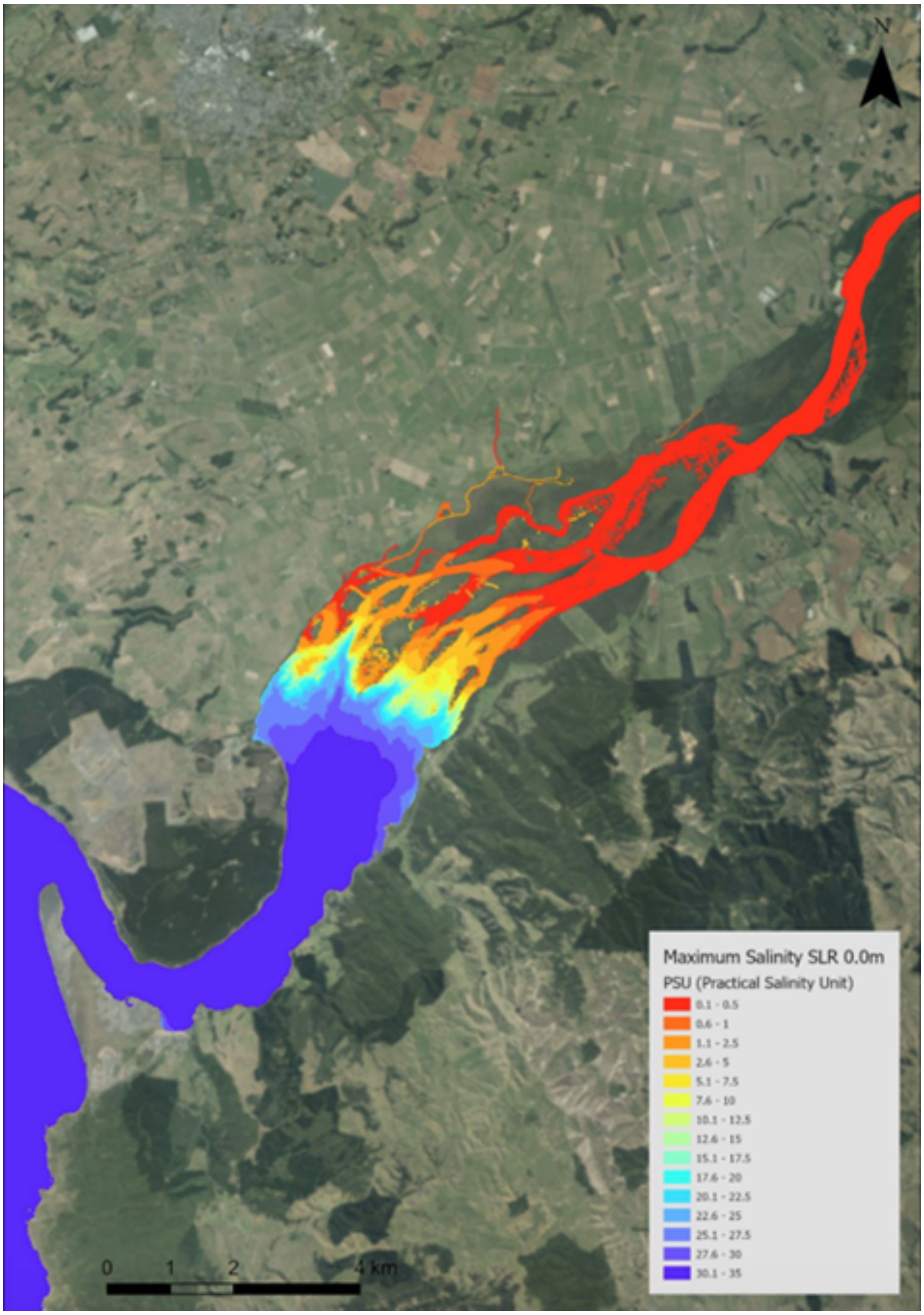

Figure 5: Sea level rise modelling, maximum saltwater intrusion (PSU) in Te Puuaha o Waikato at 0m sea level rise where red is freshwater and blue is saltwater (Wadhwa et al., 2023, ARCGIS Map).

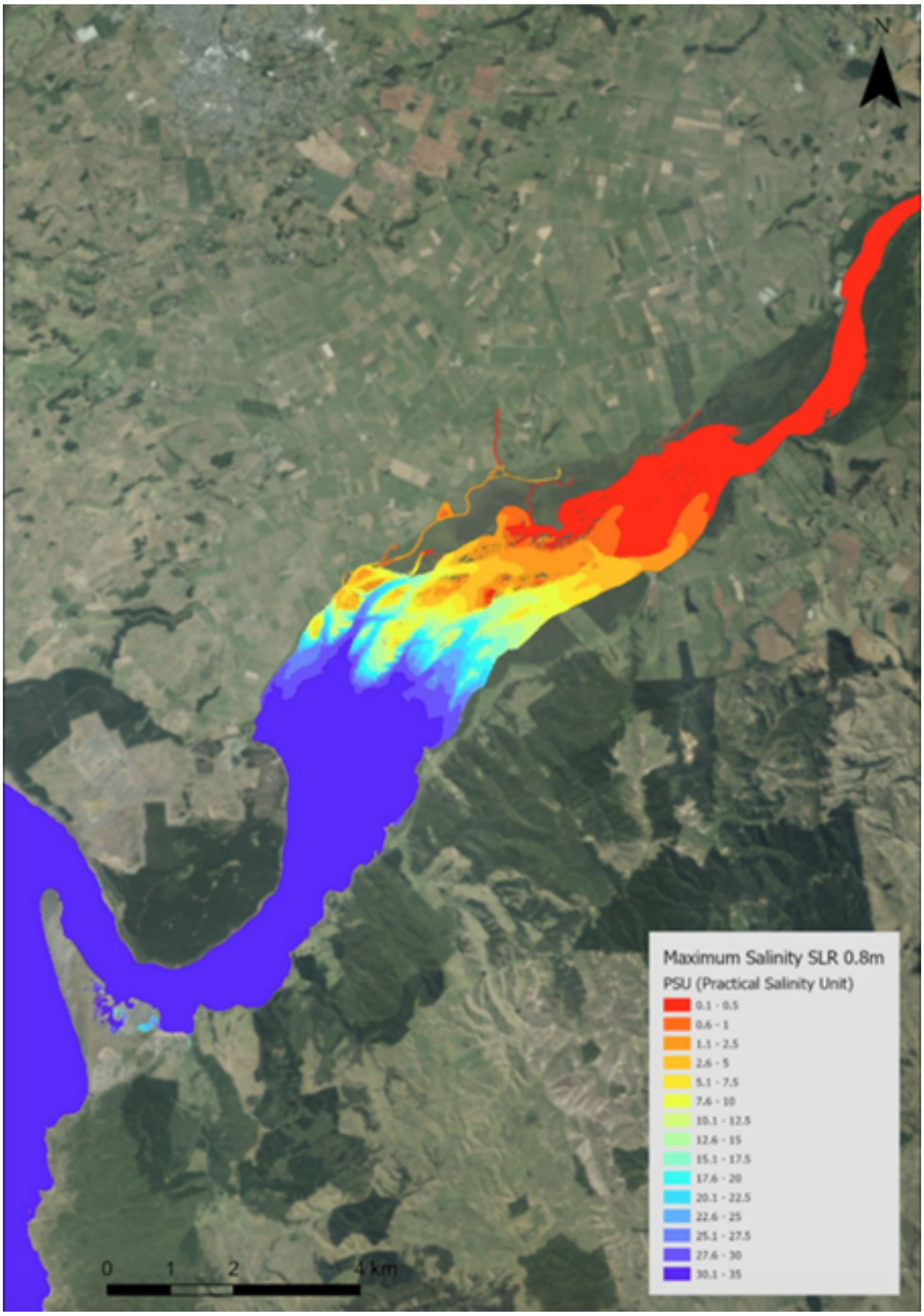

Figure 6: Sea level rise modelling scenario, maximum saltwater intrusion (PSU) under 0.8m sea level conditions in Te Puuaha o Waikato, where blue represents saltwater and red represents freshwater (Wadhwa et al., 2023, ARCGIS Map).

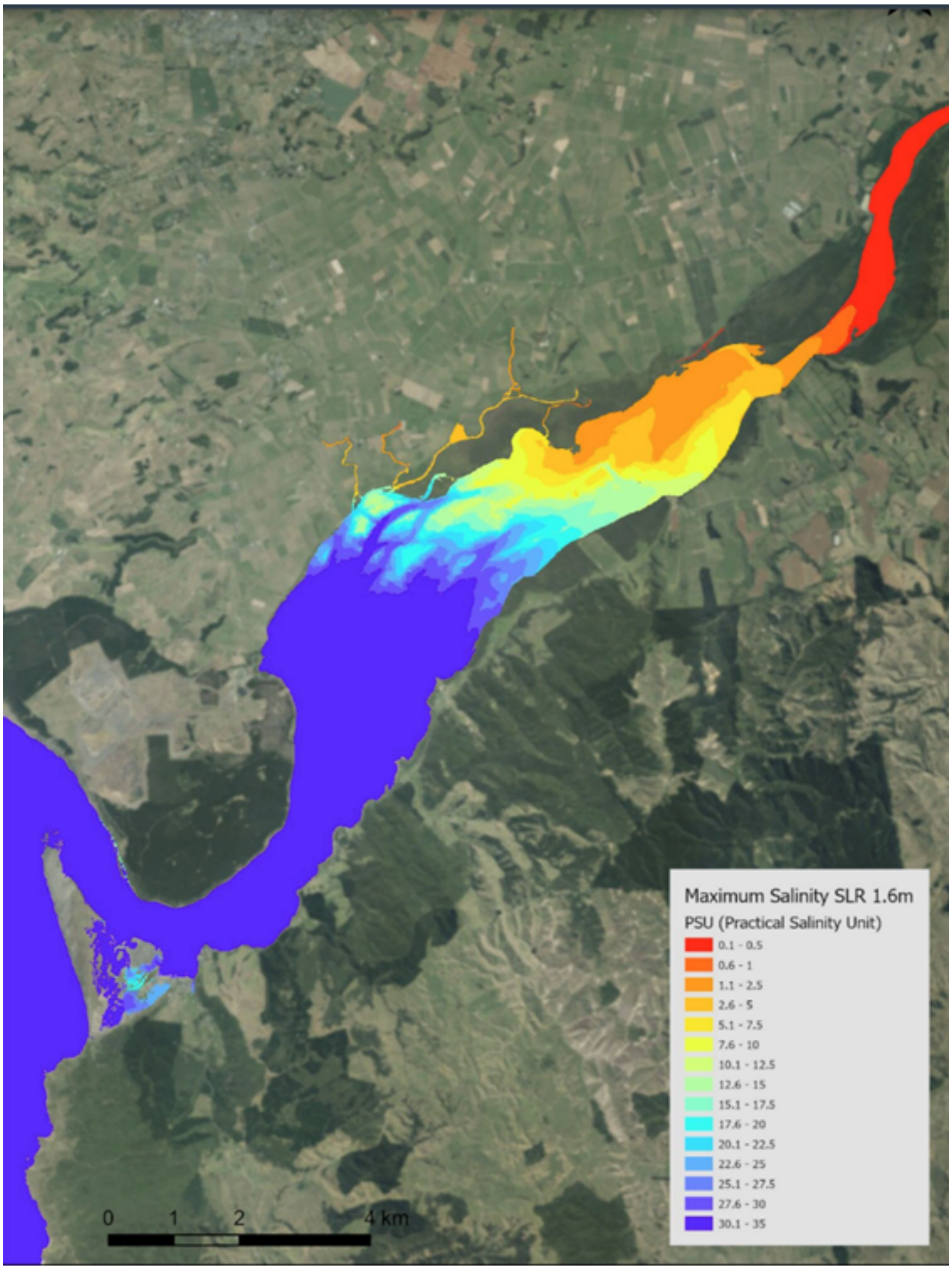

Figure 7: Sea level rise modelling in Te Puuaha o Waikato measured in PSU. Under 1.6m sea level rise conditions, where blue represents saltwater and red represents freshwater(Wadhwa et al., 2023, ARCGIS Map).

Building tools for climate change resilience

Climate change programmes largely utilise western sciences and perspectives when implementing adaptation and resilience strategies (Makondo & Thomas, 2018). However, indigenous communities are particularly vulnerable to climate change because environmental changes exacerbated by climate change will provide novel challenges for indigenous communities such as fragmentation, loss of intangible cultural heritage and ultimately loss of cultural identity (Mínguez García, 2020). Like many indigenous cultures, the relationship between tangata whenua and the environment provides an unique perspective when developing climate change adaptation strategies which allows for early detection of environmental changes (Ford et al., 2020). Furthermore, Dunlop, (2023) suggests the intergenerational nature of maatauranga contributes to the resilience of Maaori communities. The layers of generational knowledge involved in curation maatauranga and maramataka can indicate environmental changes; therefore, those who utilise maramataka may notice properties of climate change earlier than non-practitioners (Hikuroa, 2020). The relationship between Maaori and the environment will aid in building climate resilience through innovative approaches and is expressed through existing concepts like kaitiakitanga (Dunlop, 2023). Since Maaori communities and maatauranga are put at risk by climate change, it is important to consider the needs of their communities when developing adaptation strategies (Makondo & Thomas, 2018). This can be achieved through the development of tools that enable and aid whaanau in decision making, which is important because it provides autonomy over the maatauranga and practices (for example see van Schravendijjk-Goodman et al, 2023).

This research project will use science as a tool that elevates the maatauranga through exploring other factors that could influence the decline in total catch of poorohe. The two factors this research will explore is saltwater intrusion and temperature increases, because temperature is a known sensitivity of poorohe (Ward et al., 2005), and under sea level rise conditions, saltwater intrusion in Te Puuaha is inevitable. Better understanding the impacts of temperature and saltwater intrusion aids whaanau by providing tools that enable them to make decisions about their environment and customary practices. This will enable whaanau to reclaim their autonomy, which was taken during Raupatu and sustain their customary practices in a changing environment.

Conclusion

In Te Puuaha, the experiences of fisher whaanau around poorohe were once positive but this experience ultimately changed following colonisation. Colonisation and the impacts of colonisation has had profound impacts on the relationships between tangata whenua and the environment. These changes were bought about through the exclusion from ancestral lands, and limitations placed on customary practices (D. E. Johnson et al., 2021).

These changes were mediated through Treaty Settlements like the Waikato-Tainui Raupatu (Waikato River) Settlement, 2010, which has been pivotal in protecting the relationship between iwi and the Waikato River for future generations through mechanisms like Te Ture Whaimana that advocate for the restoration and protection of the river.

Further changes to the experience of fisher whaanau harvesting poorohe as hauanga kai (also referred to as mahinga kai, refers to the practices around gathering and protecting traditional kai sources) are likely to arise with the changing climate. The combination of challenges from impacts of colonisation and future environmental changes will have a detrimental effect on the cultural heritage and maatauranga around the hauanga kai practices of poorohe. Climate change will provide new environmental challenges in the Waikato River and given the proximity to the coast and tidal influence in the river mouth, saltwater intrusion is a likely change to the habitat of poorohe. Additionally, poorohe are known to have narrow thermal niches and are likely to be vulnerable to increased water temperatures (Ward et al., 2005). Understanding the influence of these two variables on poorohe populations is important because it can be used to inform a CCVA and other frameworks.

This research is intended to be used in the development of a CCVA that can further inform water quality targets for temperature and salinity levels in the Waikato River and identify important spawning habitat for poorohe. This tool can then be used by whaanau as a tool in decision-making and future planning.

Chapter Two: Larval Poorohe (Common smelt, *R. retropinna*) abundance in the lower reaches of the Waikato River: Will temperature and saltwater intrusion associated with climate change have an impact?

Introduction

Poorohe (Common smelt, *Retropinna retropinna*) are a fish species endemic to New Zealand, a member of the family Retropinnidae, that are distributed across the North, South, Stewart and Chatham Islands (McDowall, 2011). These fish are known to be poor climbers and restricted to lowland rivers with lower velocities and gradients (Ward et al., 2005). As such, the distribution of Poorohe in the more mountainous South Island is restricted to coastal areas; populations there are also primarily diadromous. In contrast, North Island populations have a more extensive inland distribution because the lowlands extend further inland than the South Island and translocations of individuals have been undertaken by Maaori and European settlers into inland lakes, including to Lake Taupoo and Te Arawa Lakes (Ward et al., 2005). The Waikato River catchment supports Poorohe populations with two distinct life histories, genetics, and morphologies. The riverine population is diadromous, whereas lacustrine populations of Poorohe are non-diadromous (Ward et al., 1989, 2005). Further, lacustrine populations have different spawning periods, fewer gill rakers, and more vertebrae in comparison to riverine populations (Ward et al., 1989). Other differences between diadromous and lacustrine populations of Poorohe include the timing of spawning, and diadromous Poorohe produce fewer but better provisioned eggs compared to their lacustrine counterparts (Ward et al., 2005; Williams et al., 2017).

Even within the diadromous populations, there are two distinct life history strategies utilised by Poorohe. The key difference between these strategies relates to their rearing habitat. In amphidromous populations, larval Poorohe undergo metamorphosis in the marine environment before returning to the riverine habitat as juveniles to mature. In contrast, in the anadromous populations juveniles mature in the marine environment, and do not migrate into the riverine habitat until they are adults, for spawning (McDowall, 2011). In the Waikato River catchment, diadromous Poorohe primarily exhibit amphidromy but the catchment does contain anadromous fish. However, other riverine populations adhere to an anadromous strategy (McDowall, 2011). Riverine Poorohe spawn in shallow sandbanks in the lower river when water temperature is between 12°C and 18°C and in the Waikato River, and the juvenile Poorohe migrate upstream during austral spring (September and October); however, this migration may continue into early summer (Ward et al., 2005).

Poorohe are known to be sensitive to a range of stressors and are commonly used to establish water quality guidelines (Williams et al., 2017). For example, various sensitivity experiments have concluded the presence of ammonia and copper, and low dissolved oxygen concentrations, have adverse impacts on Poorohe (Richardson et al., 1994; Dean & Jody, 1999; Franklin, 2013). Furthermore, Poorohe are known to have temperature sensitivity, preferring cooler waters. The optimal temperature range of Poorohe is between 15.1°C and 17.4°C; however, they have an absolute upper temperature threshold of 28.3°C when fish were acclimatised to 15 °C (Richardson et al., 1994; Ward et al., 2005). Diadromous Poorohe are known to spawn when water temperatures are between 12°C and 18°C during late autumn and early winter (Ward et al., 2005). However, when water temperatures are above 21°C, spawning events can be delayed (Mora & Boubee, 1993). Furthermore, the duration of egg incubation is increased when temperatures are below 10°C and this period is shortened in temperatures above 25°C. Eggs incubated at temperatures above 30°C are non-viable (Mora & Boubee, 1993; Ward et al., 2005). When Poorohe eggs are incubated in temperatures that are outside of their optimal temperature range (15.1°C - 17.4°C), the larval Poorohe are typically smaller, and are more likely to have larval deformities (Mora & Boubee, 1993; Ward et al., 2005). Furthermore, the high-water temperature in the rearing habitat results in decreased length of mature Poorohe. Fecundity is lowered in shorter fish because fewer eggs are produced (Baker et al., 2024). Condition and the ability for fish to grow gonads are not compromised by increased temperature (Baker et al., 2024). Catchment land-use changes, urban pollution, and hydro-electric expansions in the Waikato River, are all likely to increase the pressure exerted on Poorohe populations (Ward et al., 2005).

Two larval fish distribution studies have taken place in the lower Waikato River. Baker & Bartels (2011) replicated a study by Meredith et al. (1992), who examined the spatial distribution of Poorohe in the river, with the most upstream sampling site being at Ngaaruawaahia (approximately 90 km up-river) and the lowest site at Tuakau bridge approximately 45km up-river. Both studies found larval density to increase as sampling progressed down river and suggested that larval density would continue to increase in the approximately 30 km stretch between Tuakau bridge and the river mouth at Port Waikato. This is because highly mobile sandbanks that dominate the lower Waikato River and are the preferred spawning habitat of Poorohe, are especially abundant in the first 30 km from the sea (Fenton, 1989; Meredith et al., 1992; Baker & Bartels, 2011). Tidal height influence on water level can be observed 66 km upriver at Rangiriri and the salinity influence extends approximately 13 km from the river mouth (Whitelock-Bell, 2020). Temperature increases and a greater influence of saltwater intrusion are two likely climate change factors that will influence lower rivers and estuaries like the Waikato River. Saltwater intrusion and estuarine habitats will migrate inland with rising sea level (Swales et al., 2024). Furthermore, water temperature increases are expected as ambient temperatures increase. A Climate Change Vulnerability Assessment (CCVA) currently does not exist for Poorohe. This is a problem because Poorohe are particularly sensitive to temperature and poor water quality. By examining the distribution of larval Poorohe in Te Puuaha (the lower 30 km reaches of the river), I aim to determine whether increased water temperatures and saltwater intrusion brought about by climate change are likely to impact larval Poorohe distribution and spawning habitat. I predict that important spawning habitat is present in the stretch of river below Tuakau bridge. However, spawning will not occur in the permanently saline areas of the estuary.

Methods and Materials

Site selection

An unbroken width of the river was required for each sampling site. However, the lower reaches of the river are dominated by river islands. This is a problem because sampling around the river islands would impede the accuracy of the results as the flow is diverted which would make estimating larval density for the site incredibly difficult given the size of the river islands in Te Puuaha. Therefore, four sites were chosen between Tuakau bridge and the river mouth in Port Waikato in unbroken stretches of the river (Fig 8). Tidally influenced saltwater intrusion is dependent on the tidal height and river flow conditions. Based on these conditions, saltwater intrusion can reach between 1.05 km and 13 km upriver (Jones & Hamilton, 2014; Whitelock-Bell, 2020). Site A and B were chosen because of their salinity profiles, which were confirmed using GIS modelling of Te Puuaha (Figs 9-12) (Robcke et al., 2024). Site A was permanently salt influenced, while site B had fluctuating salinity levels based on tidal cycles. Site C is located above the river delta and does not experience any salinity changes associated with tidal influence; however, water level and flow rate are influenced by the tides there. Site C was chosen based on Baker & Bartels (2011), who suggested larval abundance would increase below Tuakau bridge, although sampling was never undertaken by them below this bridge. Site D was the lowest site sampled by Meredith et al. (1992) and Baker & Bartels (2011) and had the highest larval densities when sampled by these authors. The influence of the tide height at site D was not mentioned in either study; however, Baker & Bartels (2011) took a secondary replicate of the sampling transects in case problems arose with the with the original sample set and when flow conditions impeded sampling.

Figure 8: Sampling locations in Te Puuaha o Waikato (Google Maps, n.d.)

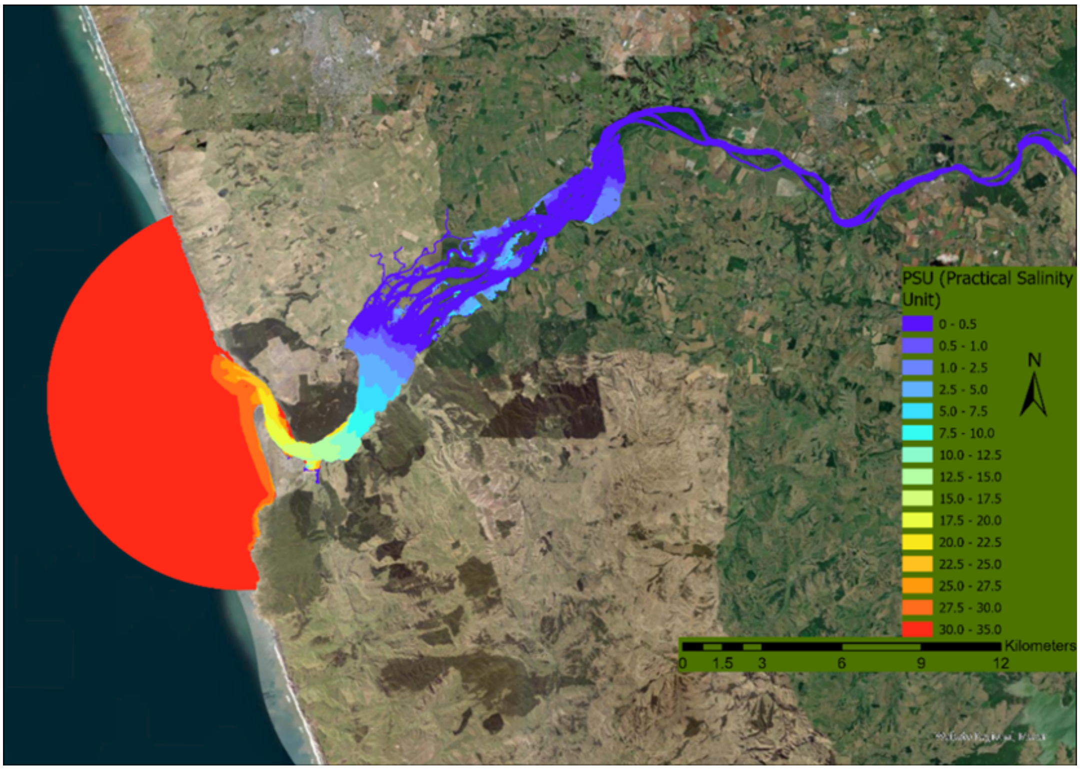

Figure 9: 3-D salinity modelling in Te Puuaha o Waikato. Scenario: Mean tide saltwater intrusion under current sea level rise conditions (Robcke et al., 2024, ARCGIS Story Map)

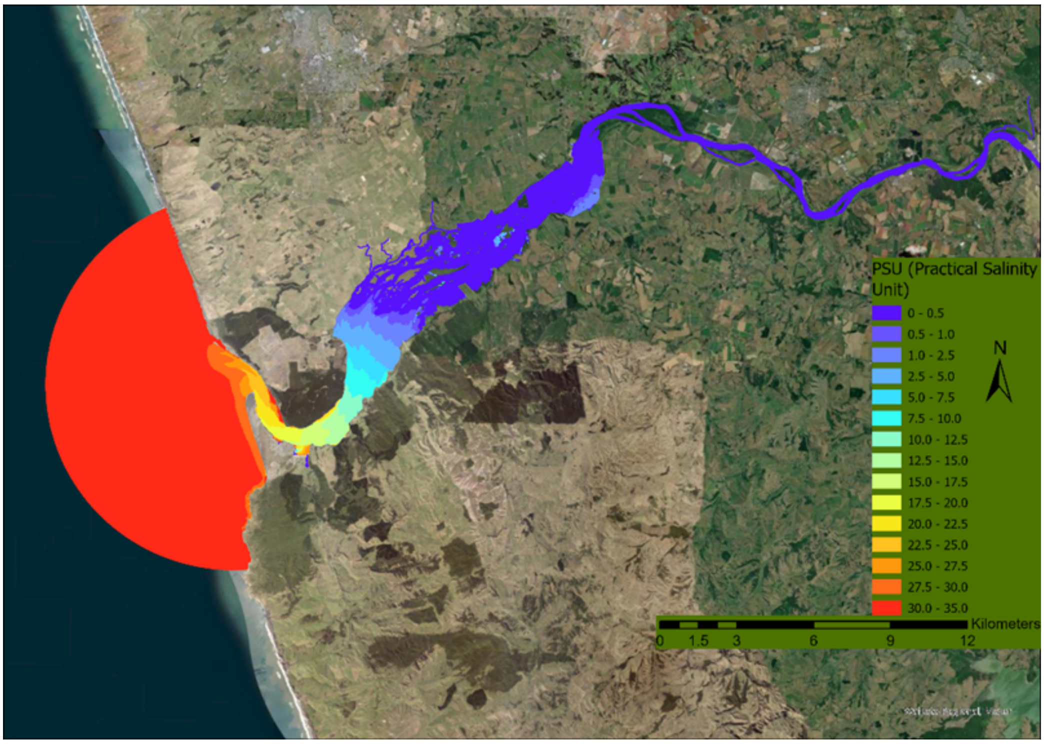

Figure 10: 3-D salinity modelling in Te Puuaha o Waikato. Scenario: Mean tide conditions with 0.4m sea level rise (Robcke et al., 2024, ARCGIS Story Map).

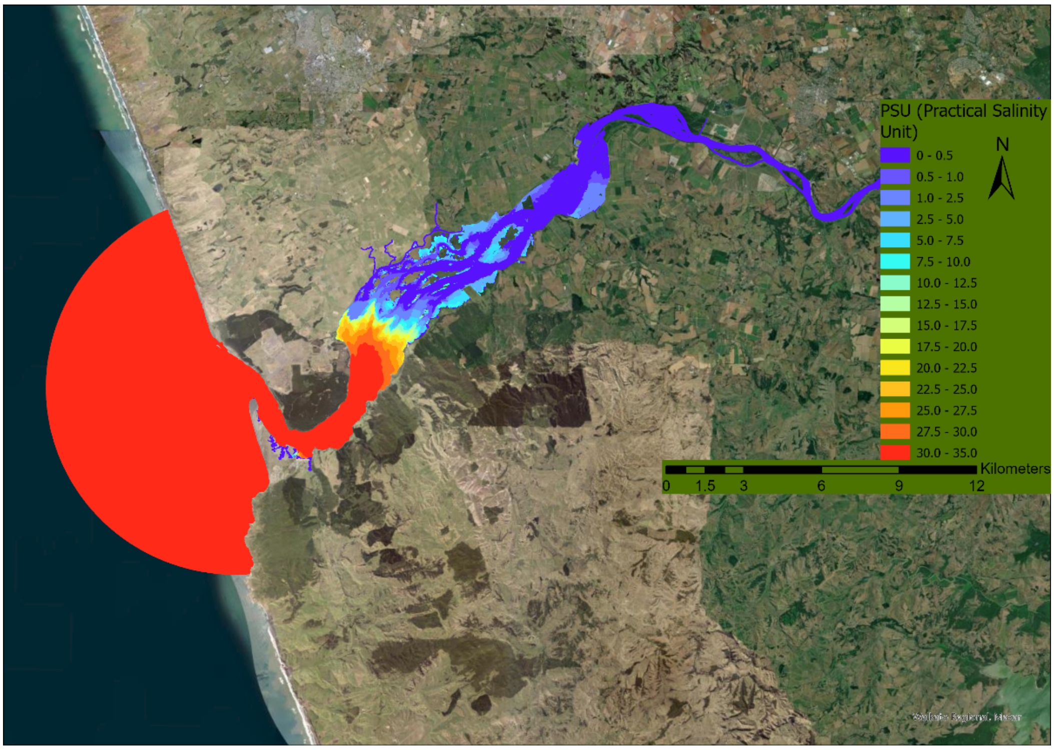

Figure 11: 3-D salinity modelling in Te Puuaha o Waikato. Scenario: Spring tide conditions at current sea level rise conditions (Robcke et al., 2024. ARCGIS Story Map).

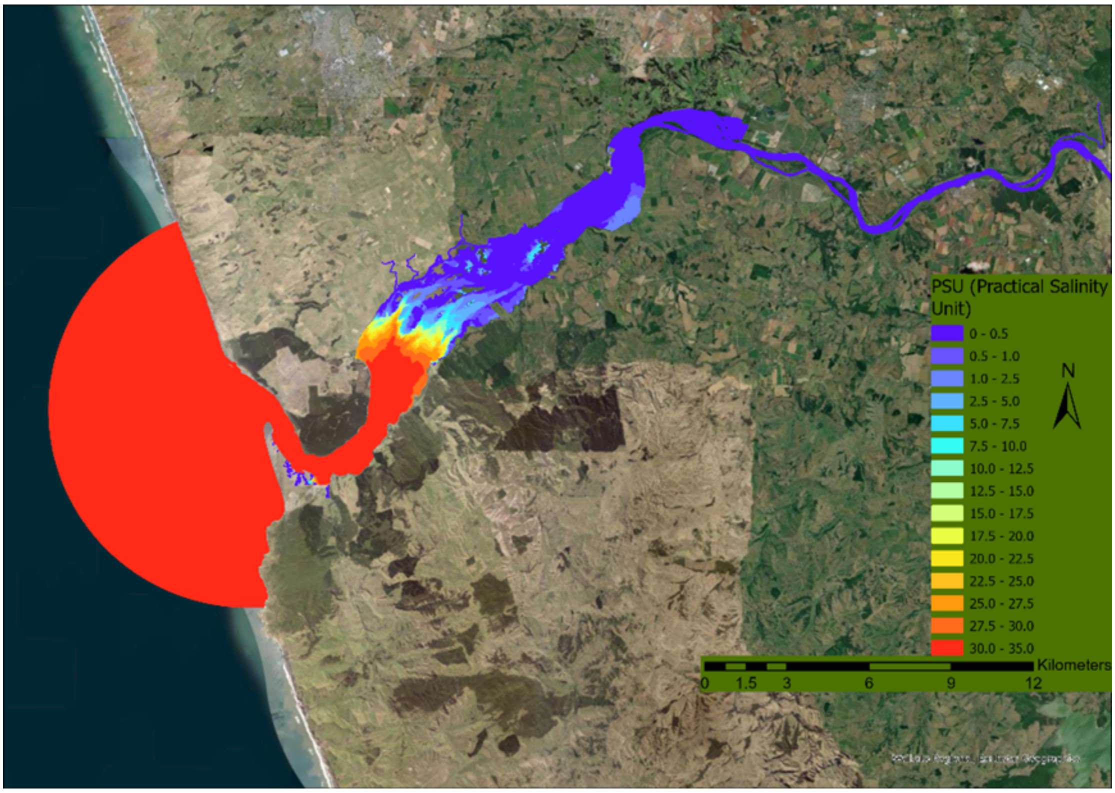

Figure 12: 3-D salinity modelling in Te Puuaha o Waikato. Scenario: Spring tide conditions under 0.4m sea level rise (Robcke et al., 2024, ARCGIS Story Map).

Sampling methods

Larval Poorohe exhibit a diel vertical migratory pattern where larvae enter the upper water column at dusk and exit the upper water column at dawn to return to the bottom of the water column (Empson et al., 1992). Furthermore, Meredith et al. (1992) and Baker and Bartels (2011) determined that highest larval Poorohe densities to occur through April and May after dusk in the upper water column. These factors influenced sampling strategy. The tidal influence at all four sites meant sampling occurred on a fortnightly basis when high tide fell between 3:00 pm and 3:30 pm, because the tide would be outgoing during the sampling period at dusk when Poorohe were in the upper waters. Sampling had to occur on an outgoing tide because this allowed for the nets to be held in their correct downstream position. Further, accurate flow readings could not be obtained during an incoming tide. Sampling took place at dusk on 1, 15, and 30 May, and 14 June 2024.

Sites A and B were sampled first to avoid re-sampling the same larval stock. Sampling at sites A and B was synchronised at 6:15 pm. Sites C and D were then sampled at 9:15 pm. Sampling in this order accounted for the approximately three-hour tidal delay experienced at sites C and D.

Sampling Equipment

The sampling methods of Meredith et al. (1987, 1989), Empson et al. (1992), Baker et al. (2007, 2021) and Baker & Bartels (2011) were replicated. These methods used 2.8 m cylinder plankton nets with 0.25 m^2 mouth openings constructed from 0.3 mm Nybolt mesh (Fig 13). A PVC cod-end with of volume of 451.39cm^3 and a small mesh window were attached to the end of the nets with male to female screw ends and the net mouth was held open with a stainless-steel hoop, which also provided attachment points for flowmeters and floats. General Oceanics 2030R flowmeters were used to measure the average water velocity of the river during the outgoing tide and volume of water filtered through each net. The net configuration was anchored in place with a Danforth sand anchor. The nets were attached to large 23.1 L marine floats. The floats were inflated an extra 10% to accommodate for sites with high flows.

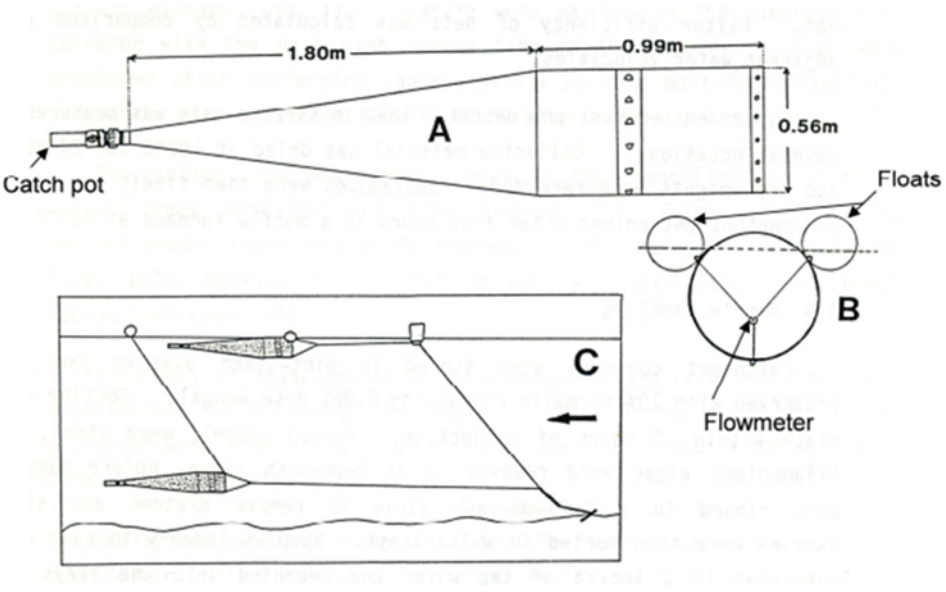

Figure 13: The set up and design of the plankton nets used in the sampling. (A) the net dimensions, (B) the front of the net showing the position of the floats on the top nets and the attachment for the flowmeters, (C) the configuration of a top and bottom net set (Baker & Bartels, 2011)

Prior to the beginning of sampling, depth profiles were taken using the sonar of the boat's depth sounder to continually measure depth across each transect. The depths were recorded both using the boat's sounder and manual recordings were taken as depths changed. The depth profiles were then used to determine the configuration of the sampling nets at each site because the riverbed varied at each site (Fig 14-17). Shallow areas were set with one net and deep areas were set with two nets. The top nets were set at the surface, and the bottom nets were set approximately 2m off the riverbed. Two small floats were attached to the outside of the mouth of top nets and a singular small float was attached to bottom nets to keep the net off the riverbed. The nets were left *in-situ* for fifteen-minute periods. The values on the flowmeters were recorded before each net was deployed and upon retrieval, the flowmeters were recorded again and the difference between the two values was used to calculate the volume of water passing through the nets.

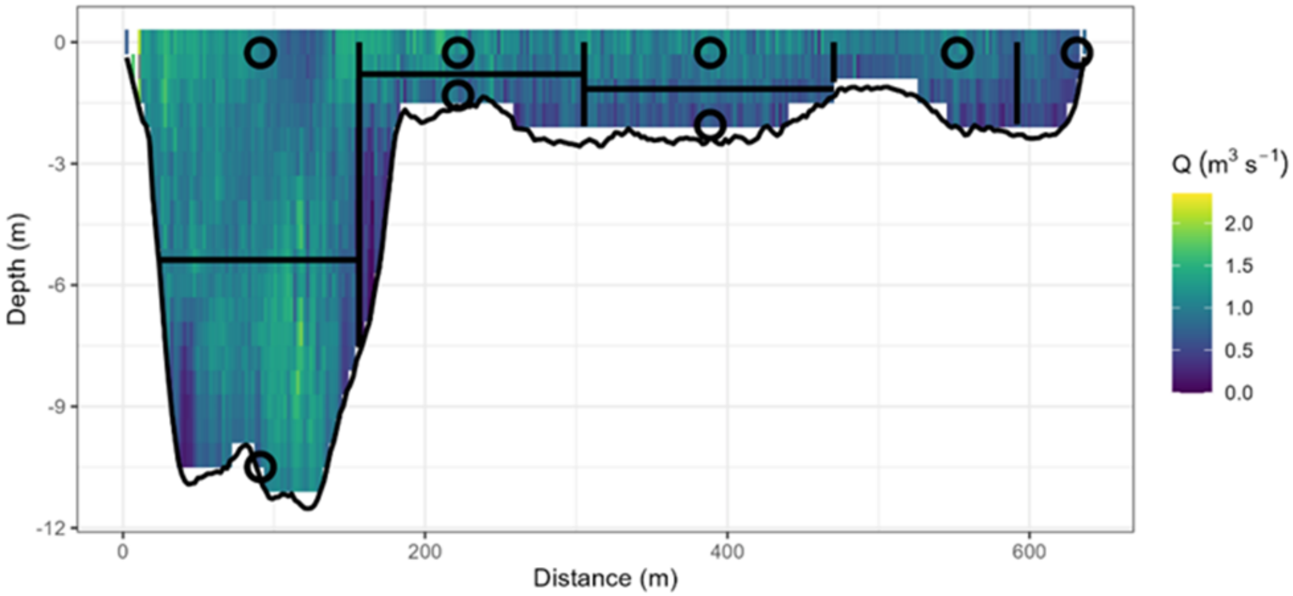

Figure 14: The acoustic doppler current profiles of site A and the positioning of nets set within the site.

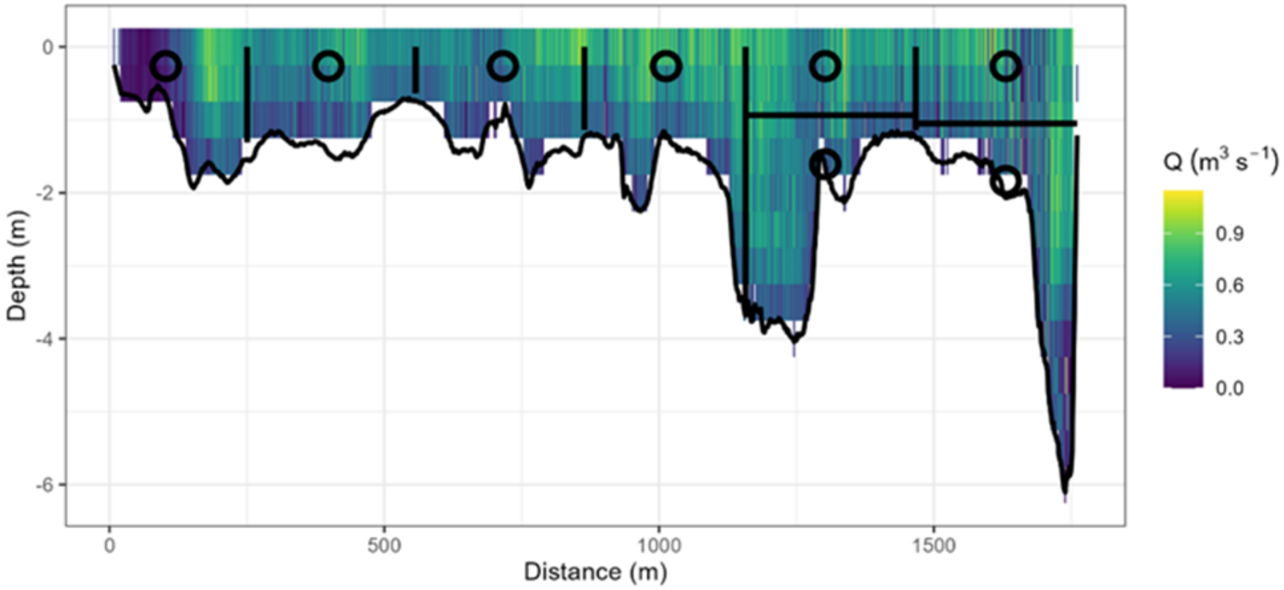

Figure 15: The acoustic doppler current profile of site B and the positioning of the nets within the site.

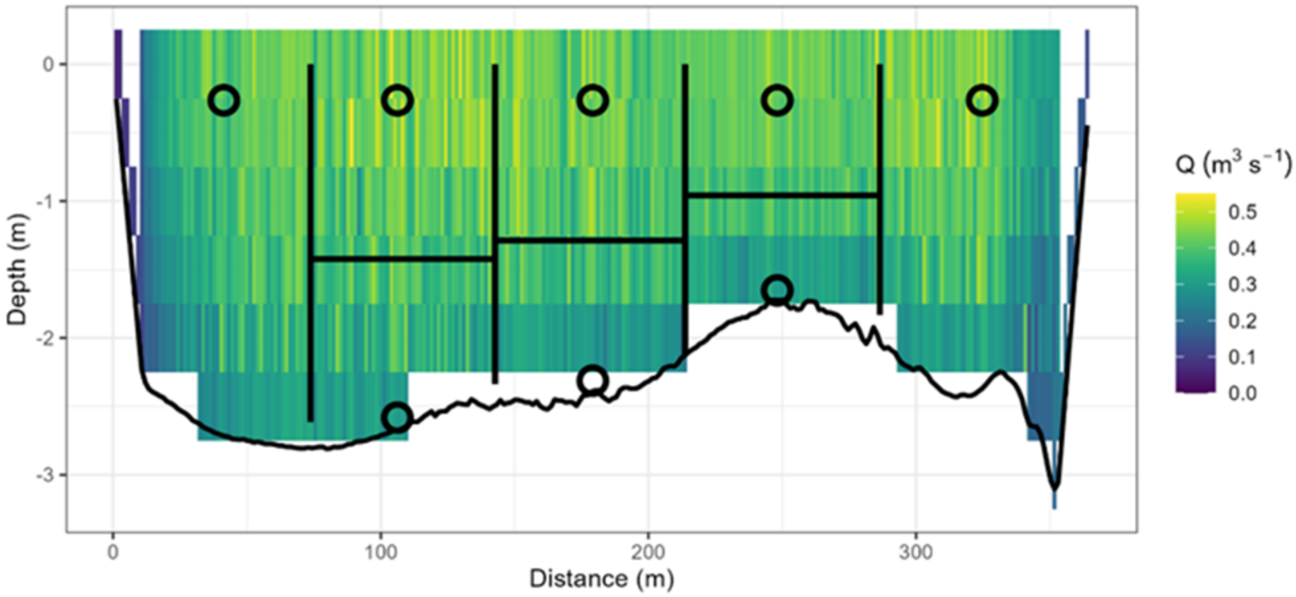

Figure 16: The acoustic doppler current profile of site C and the positioning of nets set at the site.

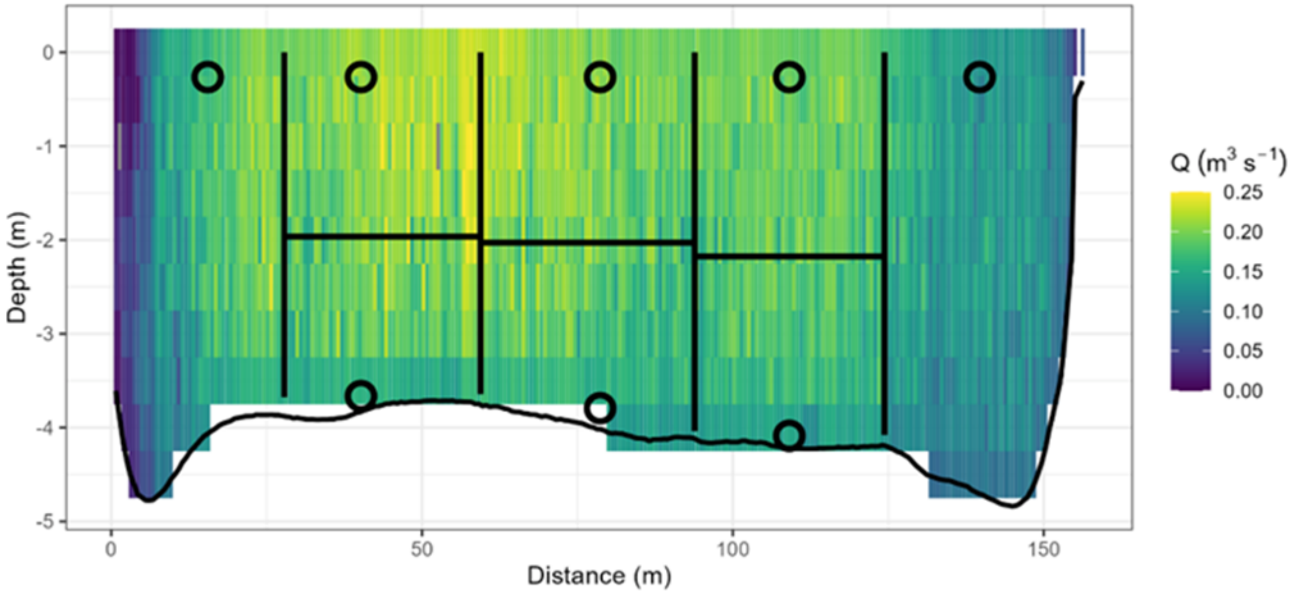

Figure 17: The acoustic doppler current profile at site D and the positioning of the nets set at the site.

Sampling Protocol

Two teams were utilised in the sampling. Team one sampled sites A and C, and team two sampled sites B and D. To avoid the tidal lag and the sampling of the same larval stock, the two lower sites were sampled first. The two teams sampled simultaneously, and sampling was synchronised via phone call prior to starting at each site. Sampling at site A and B began at 6:15 pm following dusk, as Poorohe larvae undergo diel migration and enter the upper water column at this time (Ward et al., 2005). After sampling and processing was completed at sites A and B, respectively, each team drove to their next site because it was safer than boating between sites due to the distance between sites, the river islands, and inability to sight hazards in the dark.

Prior to sampling a transect was mapped using GPS. During each sampling event, buoys with lights were deployed on either side of the transect to aid the boat captain in navigating the transect. A boat hook was used to retrieve each net, and the mouth of the net was lifted into the boat first to avoid losing any larval out the net mouth.

Site A, B, and D were not sampled on every sampling occasion due to river conditions that created health and safety concerns or concerns about losing equipment. Additionally, site A was sampled with six nets on two occasions and seven on one occasion. Site D also had issues with sampling, on one occasion two samples were not retrieved, another occasion only one net was set at the site because the nets were not holding with the flow conditions and on one occasion a cod-end broke *in-situ.*

Field Sample Processing

To wash all materials into the cod-end, the nets were scooped through the river water without the open mouth going under the water using a washing machine motion. Squeeze bottles filled with water from the river were used to rinse stubborn material into the cod-ends. This was done to avoid compromising the samples by introducing or releasing larvae from the nets. For the same reason, cod-ends were detached from the nets over an open 1.5 L hexagonal sample pottle. The cod-ends were rinsed through the mesh window into the pottle using the squeeze bottles. Samples with excess water were drained through a sieve that screwed onto the top of the pottles. Samples were preserved with a solution of 5% formalin and 0.01% Rose Bengal. Gloves were worn when handling the formalin solution and a drip tray was used to prevent spills. Samples were then stored in NIWA (National Institute of Water & Atmospheric) Hamilton’s Dangerous Goods stores.

Additional measurements

Water Quality Measurements

Water quality exo-sondes were deployed at sites B and C (Fig 18). The sondes were calibrated prior to deployment and recorded salinity levels, temperature, and dissolved oxygen concentrations. The sondes were housed in PVC piping and secured against existing structures in the river using BandIt straps and steel cable ties. The sondes were deployed on 4 April 2024 and were retrieved on 4 July 2024. The sondes were calibrated to record data at 15-minute increments.

Figure 18: Position of the two sonde sites at sites B and C in Te Puuaha o Waikato (Google Earth n.d.).

Acoustic doppler current profiles

Cross-section profiles of water depth and velocity were taken at each site using a boat mounted Acoustic doppler current profiler (ADCP). The ADCP readings were taken along the sampling transects and this took place during the day on a similar tidal level because of safety concerns related conducting the sampling transects simultaneously to sampling.

Laboratory protocols

Sample preparation

To safely process the samples, the samples were first degassed. While handling the unprepared samples, including sealed containers, gloves were worn. The samples were moved from the Dangerous Goods stores to a fume hood. A funnel with a 250µm sieve was positioned into a waste formalin container and the sample was poured through the sieve. Samples were rinsed with tap water on the 250µm sieve for between 10- and 25-minutes until the water ran clear. Using a wide funnel, the sample was returned to the original 1.5 L container and filled with water. The sample was left in the fume hood to degas for 24 hours. The water was then drained off the de-gassed sample and replaced prior to sorting.

Sorting and identification protocol

Prepared samples were sorted under a Lecia binocular microscope. To ensure safety while handling the de-gassed samples, extraction pipes situated around the microscope were running while the samples were being sorted. All larval fish were removed individually from the sample using tweezers and preserved in 70% isopropyl alcohol. Once the larval fish were removed from the samples, the excess material was returned to their original 1.5L containers and left in a fume-hood to degas for three days. These were then drained, and the organic materials were disposed of. Larvae were identified and counted using McCarter (1994) and reference material from Baker and Bartels (2011).

Statistical Methods

Larval density calculations

Larval density was calculated using the volume of water passed through the net during the sampling period. The volume calculation used the difference in flowmeter readings from when the nets were deployed and retrieved. However, the filtering efficiency and accuracy of the flowmeters specifically in the bottom nets were influenced by the distance from the bottom the nets were set at. Therefore, when flowmeter readings were determined to be inaccurate (e.g. the flowmeter values had not moved or moved very marginally compared to other nets), judgements regarding accuracy were made based on readings from other nets at comparable sites and nets.

The river flow from the ADCP transect was apportioned into sections where the nets were positioned. A 10m margin on each ADCP transect was not measured due to the accessibility of the margins. The positions of the nets were calculated by measuring the distances between the GPS co-ordinates of the nets and the halfway points between the net positions.

At site A, the net positions were not calculated because the ACPD transect was not taken along the sampling transect because there were two different sets of co-ordinates recorded during the site profile surveying prior to sampling events and the wrong transect got used for the ADCP transect. Therefore, the proportion of the total transect that each net was located at was used in assigning distances from the true left bank for each net based on the total distance of the ADCP transect.

In the larval density calculations, we standardised the river flow to $100m^3s^{-1}$ because the combination of the river flow and outgoing tide created different flows across all four sites. Through standardising the river flow, the larval density of all sites were able to be compared.

The data was non-parametric and Kruskal-Wallis tests were run on the relationship between larval density and sites and the relationship between larval density and sampling events. Additionally, a Mann-Whitney U non-parametric test was run to compare larval densities in top and bottom nets.

Water quality measurements

Time series graphs for the temperature, salinity and dissolved oxygen concentrations were plotted for both water quality sondes. The water quality sondes were calibrated prior to deployment and were deployed on 4 April 2024 at low tide. The sondes were retrieved on 4 July at low tide and processed following retrieval. The water quality sonde at site C malfunctioned and only recorded from 4 April 2024 to 26 April 2024. Temperature was measured in degrees Celsius, salinity was measured in Practical Salinity Units (PSU), and dissolved oxygen was measured in mg/L.

Since there was a period either side of the deployment where the sonde was recording but not in-situ, data recorded before 12pm the day of deployment and 12am the day of retrieval was removed prior to analysis.

Results

Water quality

Overall, the water temperature gradually decreased from approximately 20˚C to 10˚C between 4 April and 4 July 2024 (Fig 19). There were small daily fluctuations; however, these fluctuations do not have an overall influence on the water temperature trend (Fig 19). The maximum temperature reached at site B was 19.9˚C in April and minimum temperature was 7.2˚C in July (Table 2). Similarly, the temperature profile at site C experienced small daily fluctuations but is overall decreasing (Fig 19). The maximum temperature at both sites were comparable; however, the minimum temperature at site C only dropped as low as 16.4C in late April (Table 2 & Table 3).

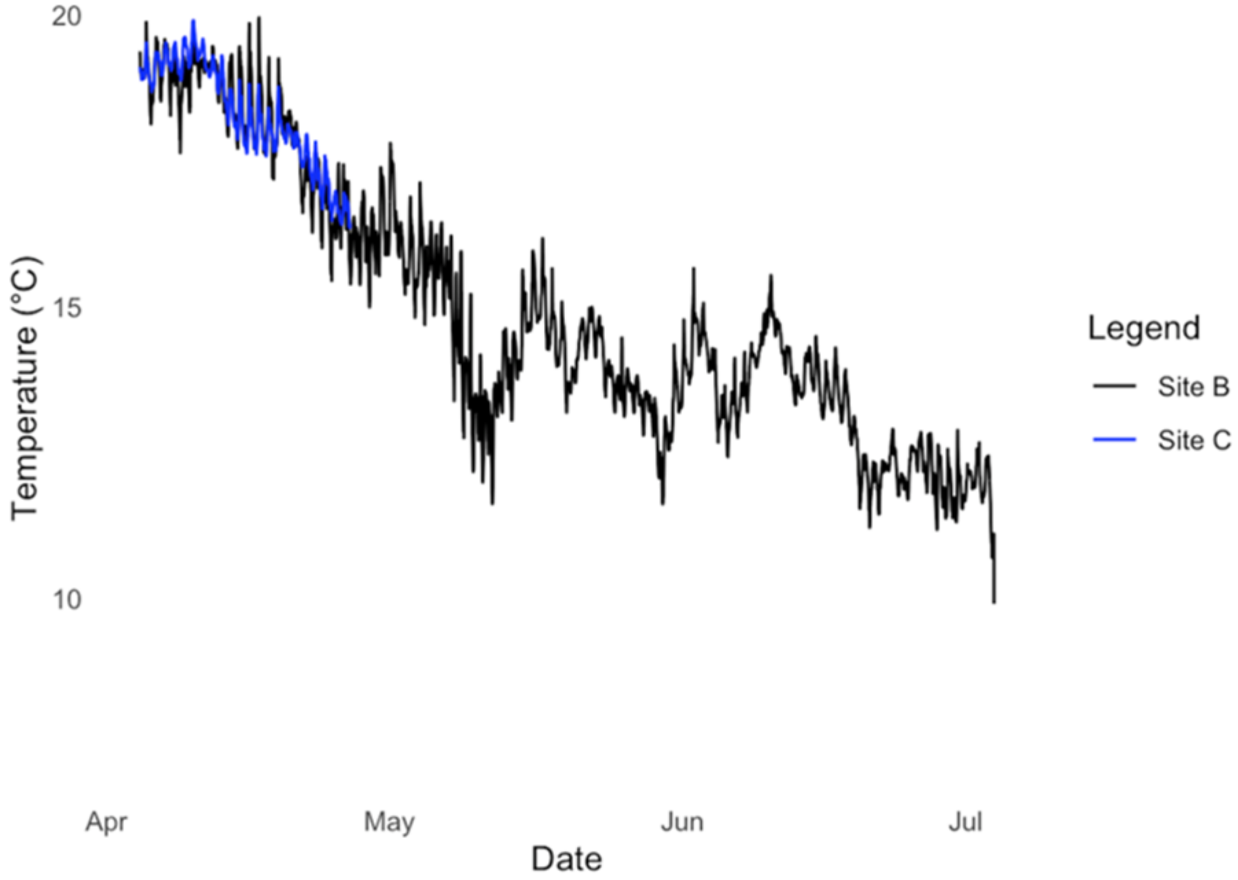

Figure 19: The temperature profile measured in degrees Celsius (˚C). Site B (black) temperature profile measured from 4 April 2024 and 4 July 2024. The temperature profile of site C (blue) temperature profile measured from 4 April 2024 to 26 April 2024.

The dissolved oxygen concentrations at site B experienced significant daily fluctuations, with peaks and troughs appearing regularly (Fig 20). Between April and mid-May there was a steady decrease in dissolved oxygen concentrations; however, the concentration began to increase over June (Fig 20). Similarly, the dissolved oxygen concentration at site C experienced small daily fluctuations; however, the dissolved oxygen concentration was higher at site C compared to site B (Fig 20). During the operational period of the site C sonde, the dissolved oxygen concentrations had a large peak following the sonde deployment (Fig 20). The maximum dissolved oxygen concentration reached was 11.62mg/L and the minimum concentration observed was 7.46mg/L (Table 3). Site B had a similar profile of dissolved oxygen concentrations, where the maximum concentration was 11.25mg/L and the minimum concentration was 5.43mg/L (Table 2).

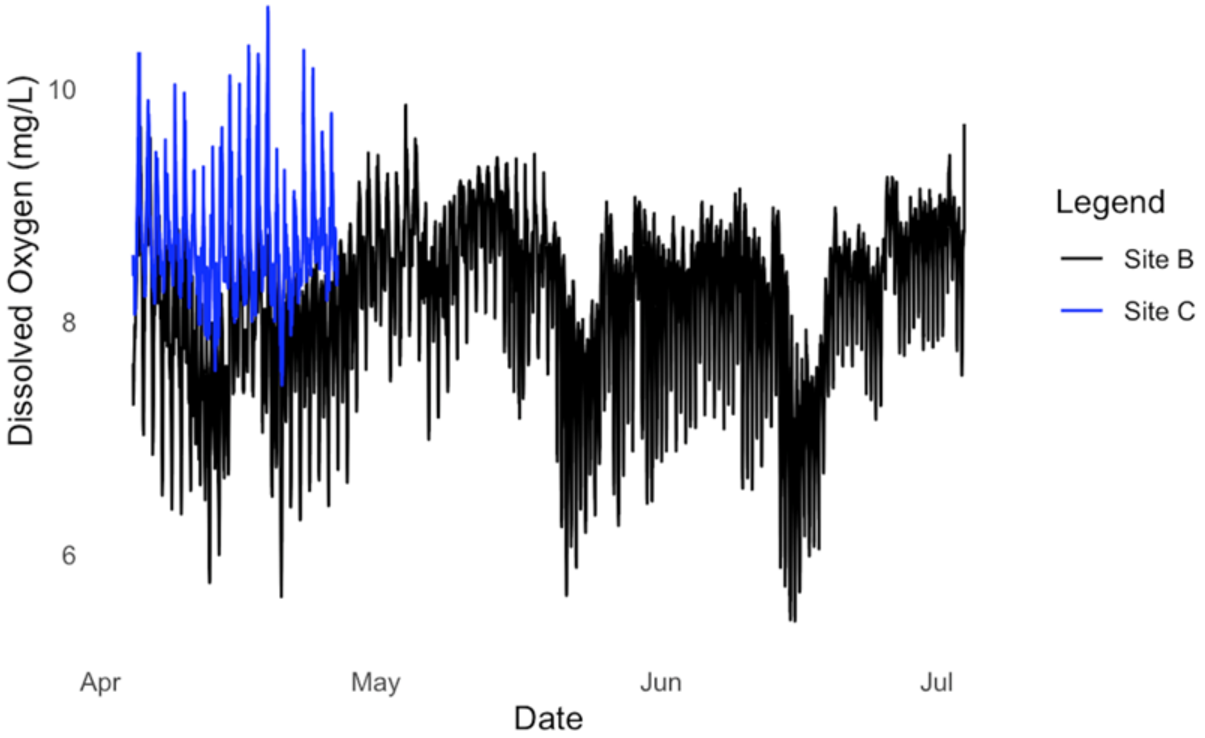

Figure 20: Dissolved oxygen concentration profile measured in mg/L. Site B (black) dissolved oxygen concentration measured between 4 May 2024 and 4 July 2024. Site C (blue) dissolved oxygen profile measured between 4 April 2024 and 26 April 2024

Site B had periodically elevated salinity levels that were influenced by high tides. Peaks in salinity levels indicated high tides. The salinity concentration of site B ranged between 0.00PSU and 25.87PSU between April and July (Table 2). Through early April, there are high daily oscillations of salinity levels at site B (Fig 21). The high salinity levels at site B were more sporadic through May, June, and early July (Fig 21). The salinity profile of site C was stable which is expected because saltwater does not exceed the river islands (Fig 21). The minimum salinity was 0.000PSU, and the maximum salinity was 0.079PSU (Table 2).

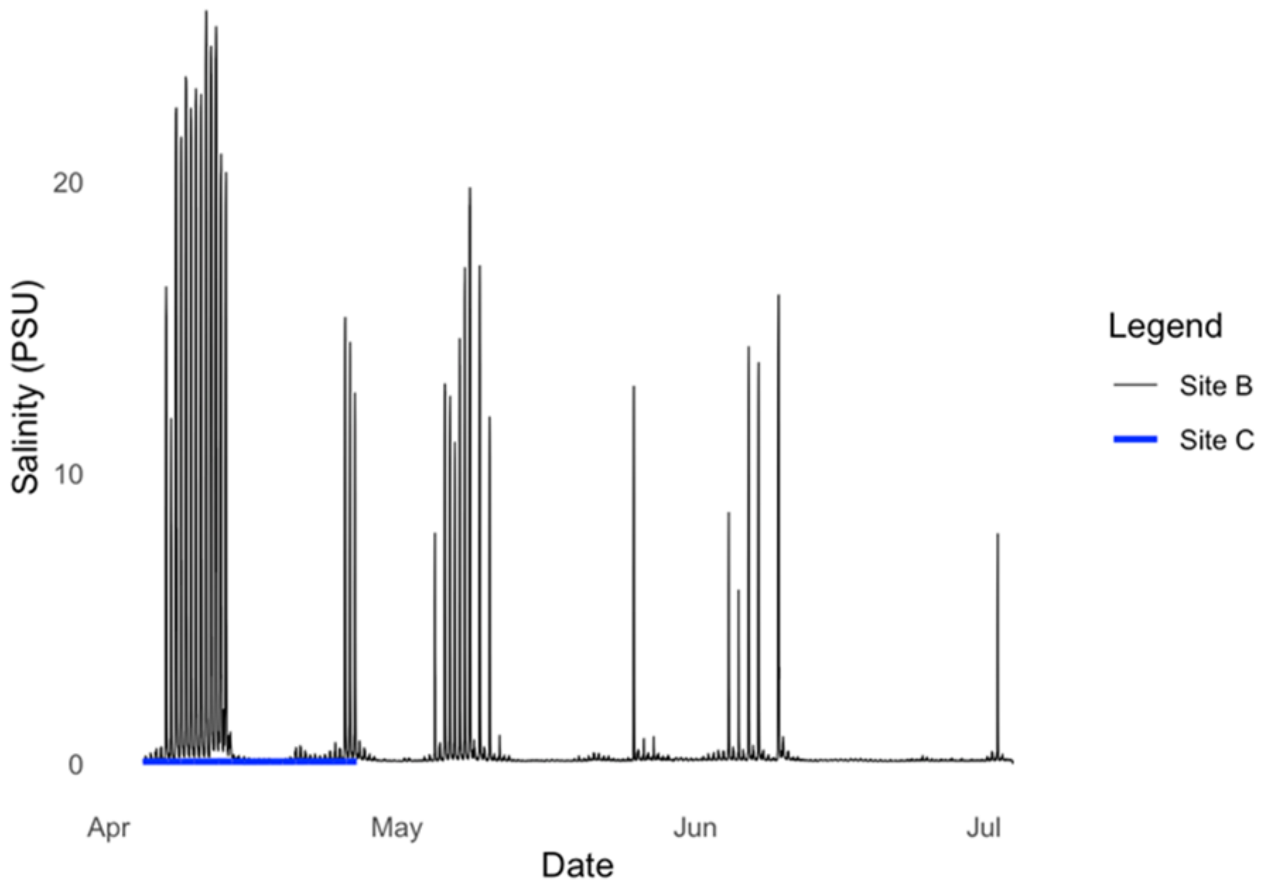

Figure 21: The salinity profile measured in PSU. Site B (black) salinity profile was measured between 4 April 2024 and 4 July 2024. Site C (Blue) measured between 4 April 2024 and 26 April 2024.

Table 2: Summary of water quality profiles (Temperature (°C), Salinity (PSU), Dissolved Oxygen (mg/L). Measurements taken from Site B between 4 April 2024 and 4 July 2024.

	Temperature (°C)	Salinity (PSU)	Dissolved Oxygen (mg/L)
Min	7.24	0.003	7.75
1st Quartile	13.26	0.11	8.31
Median	14.91	0.84	8.16
3rd Quartile	16.52	0.21	8.68
Max	19.95	15.87	11.25

Table 3: Summary of water quality measurements (Temperature (˚C), Salinity (PSU), Dissolved Oxygen (mg/L). Measurements taken from site C between 4 April 2024 and 26 April 2024.

	Temperature (°C)	Salinity (PSU)	Dissolved Oxygen (mg/L)
Min	16.35	0.000	7.46
1st Quartile	17.71	0.075	8.4
Median	18.25	0.076	8.60
Mean	18.30	0.076	8.73
3rd Quartile	19.12	0.077	8.97
Max	19.20	0.079	11.62

Larval density

The larval densities across all four sites overlapped. Site B appeared to have a larger interquartile range and higher median in comparison to the other three sites (Fig 22). Site D has the smallest interquartile range (Fig 22). Outliers were present at sites A, C and D with high caches represented (Fig 22). However, there was no statistically significant difference in larval densities among sites (*p*-value = 0.41) (Table 4).

Across the sampling events there is some variation in larval density across the four sites (Fig 16). The sampling event on the 15 May 2024 has the most variation in larval density with a large interquartile range at sites B and D on this date (Fig 23). There were some outliers at site A in the sampling event on the 1 May 2024 and site D on the 30 May 2024 (Fig 23). Despite the variation across the sampling events, there was no significant difference in larval densities across the four sampling occasions (*p*-value =0.71) (Table 4).

Table 4: Kruskal-Wallis non-parametric tests for (a) the relationship between larval density and site sampled (b) the relationship between larval density across the four sampling events

	Kruskal-Wallis Chi-Squared	Degrees of Freedom	p-value
Larval density ~ site	2.89	3	0.41
Larval density ~ sampling event	2.17	4	0.71

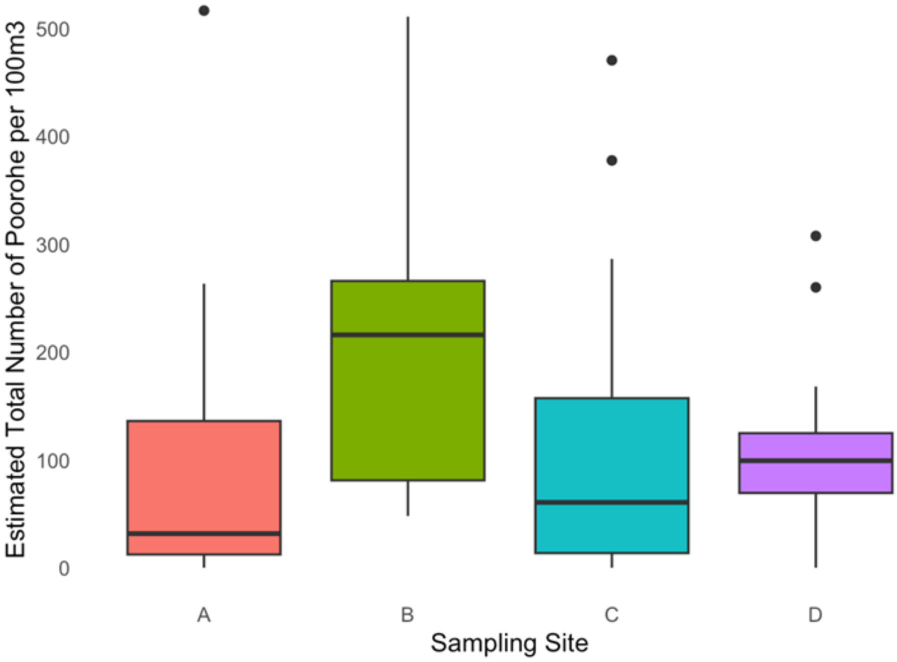

Figure 22: Estimated total number of larval Poorohe per 100m^3 at each site.

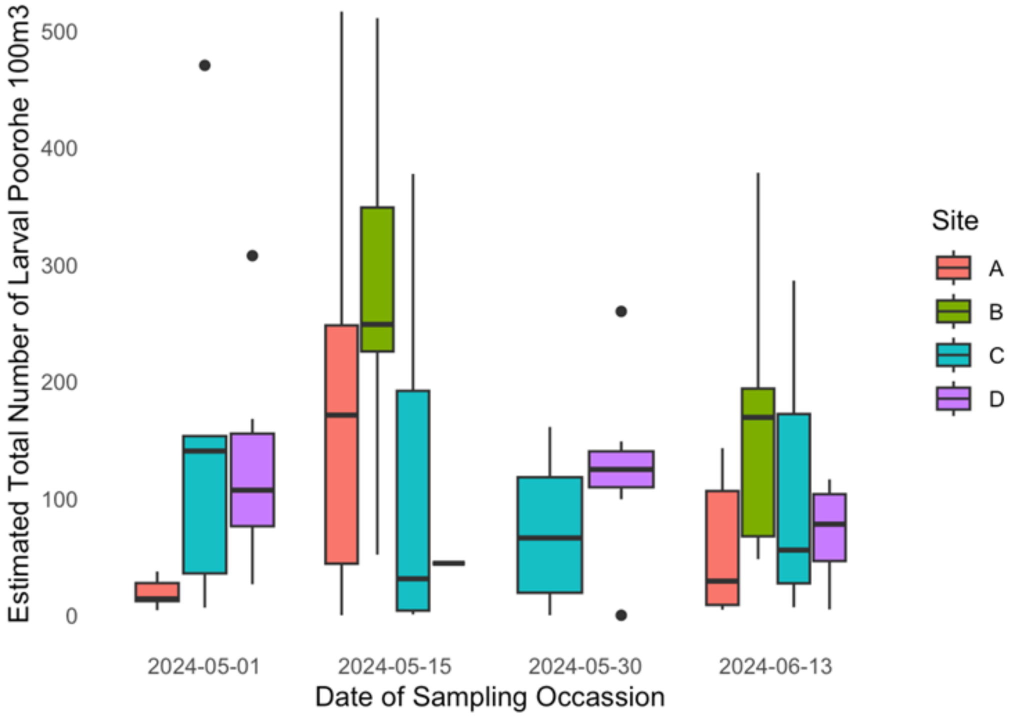

Figure 23: Estimated total number of larval Poorohe per 100m^3 of water across all four sampling events and sites.

There is very little variation in larval density between top and bottom nets (Fig 24). On the 15 May 2024, the interquartile range of the top nets is a larger compared to the bottom nets on the same sampling occasion. Additionally, the interquartile range of the top nets on the 15 May 2024 is larger compared to other sampling events (Fig 24). The median value is particularly low in the top nets on the 1 May 2024 sampling event. There are outliers on the 1 May 2024 and the 15 May 2024 sampling event (Fig 24). The *p*-value is 0.69 which indicates there is no significant difference between top and bottom nets.

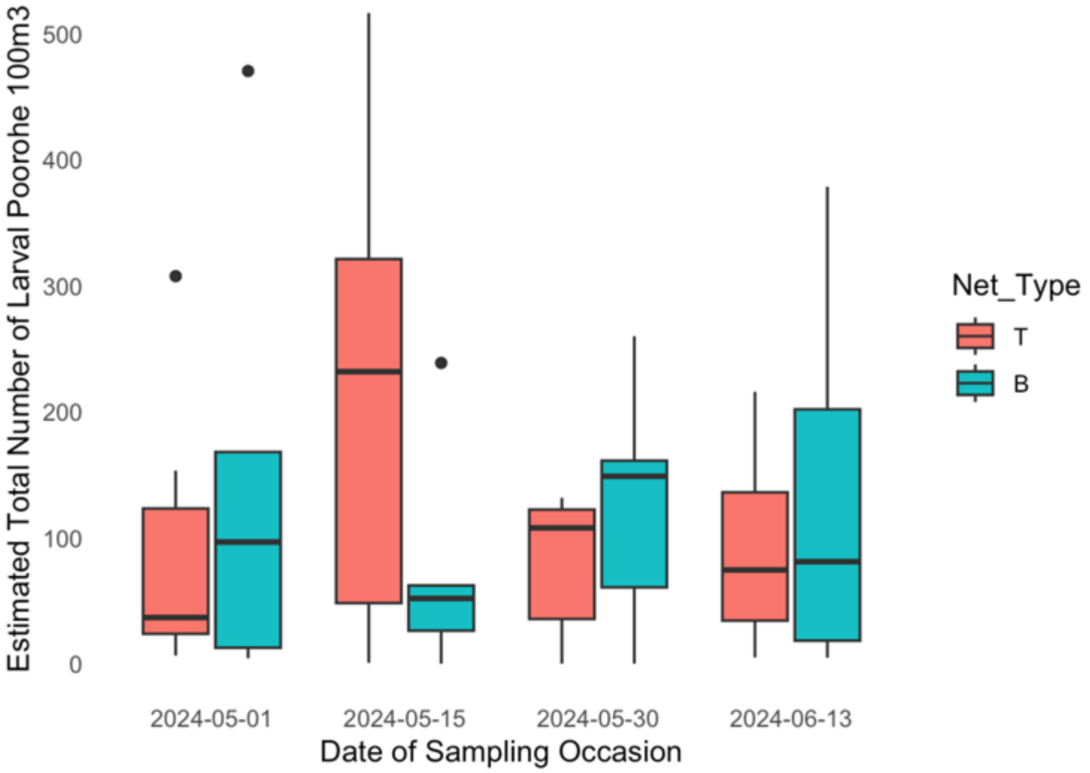

Figure 24: Estimated total larval Poorohe per 100m^3 of water in top and bottom nets.

Discussion

Meredith et al. (1989) and Baker & Bartels (2011) expected larval densities would increase below Tuakau bridge but not in the estuarine sites; however, I found larval density to remain relatively consistent across the four sites and there were no significant differences in density among the four sites. There is a large distance between sites B and C because of the complex river island system and sand bars, which was thought to house important spawning habitat. A large increase in larval densities between the two sites would be expected if spawning had occurred in the river delta. Meredith et al. (1989) and Baker & Bartels (2011) experienced a fourfold increase between their Huntly and Tuakau sites. The larval density would increase if spawning was occurring in this section of the river because larvae are drifting down river from other locations would add to the larvae hatched in that section of the river. However, there was no significant differences among the four sites that would indicate the presence of such habitat, which suggests large amounts of spawning are not occurring in the island delta (Fig 18).

There was some variation in the larval densities at site B across the two sampling events, where the 15 May 2024 sampling event had higher larval density compared to the 13 June 2024 sampling event. However, this variation was not significant and it is unlikely that this variability is caused by the temporal variability in saltwater concentrations (Fig 15, Table 2). The site was only sampled on two occasions because of dangerous weather conditions, further sampling of this site would likely determine if these differences between sampling events is the result of the temporal variability of the saltwater concentration. The Waikato River is classified as a tidal river mouth because river flow is dominant (Podrumac, 2020). This means the position of the salt wedge is largely dependent on the river flow and magnitude of the tide (James, 2024). In New Zealand, the salinity concentration of the ocean is approximately 35 PSU (Vincent et al., 1991) and the maximum saltwater concentration reached at site B was 15.1 PSU, which shows that site B is temporarily brackish. The position of the saltwater wedge at site B during the Poorohe spawning season is likely to change from year-to-year, which could influence larval density at this site. The river flow in the lower river is largely controlled by the operation of the hydroelectricity dams, the amount of rainfall and inputs from tributaries. Water level plays an important role in the functioning of the hydroelectricity stations along the river. Therefore, during periods of low rainfall, the water released at Karapiro Dam would be the minimum consented amount (NIWA, 2010). Similarly, during periods of high rainfall, increased water volumes are released to maintain hydro lake levels (NIWA, 2010). Since river volume plays an important role in saltwater intrusion, high river flows will aid in depressing the inland intrusion of saltwater under high rainfall conditions (Mohammed & Scholz, 2018). It is possible that spawning occurs in conditions within elevated salinity concentrations. Diet studies in three saltwater lakes on

Reekohu (Chatham Island) indicated Poorohe persist across salinity gradients (Fortune-Kelly et al., 2023). The Chatham Island study examined the diet in Poorohe across several lakes with different salinity concentrations. Three saltwater influenced lakes were sampled and Lake Pateriki had the highest saltwater concentration. Sampling in their study primarily took place in spring; however, sampling in Lake Pateriki also occurred in autumn, which coincides with spawning. Lake Pateriki had lower Poorohe densities compared to the other two saltwater influenced lakes, Lake Te Wapu and Lake Waikauia (Fortune-Kelly et al., 2023). However, their study was not focused on the spawning of Poorohe and the effect of saltwater intrusion on spawning remains unclear.

The river temperature was below 20°C degrees prior to beginning sampling and continued to drop over the duration of sampling (Fig 13). At 21°C, Poorohe spawning is expected to be delayed; however, in April the river temperature was below 20°C and would need to have increased by approximately 6°C through early May to cause delayed spawning (Mora & Boubee, 1993). Over the Poorohe spawning season, the river temperature remains within the optimal temperature range (14.1°C - 17.4°C) for egg development (Mora & Boubee, 1993). While the water temperatures did not reach a point of concern; however, continued increases in water temperature will have adverse effects on abundance of Poorohe (Fig 13, Table 2). The management of rivers have resulted in them being particularly vulnerable to temperature increases, further catchment management through riparian planting is necessary to prevent water temperatures exceeding these temperature thresholds (Johnson et al., 2024).

Site D was the only site that had previously been sampled by Meredith et al. (1989) and Baker & Bartels, (2011). Baker & Bartels (2011) had slightly higher range in larval density in comparison to the larval Poorohe densities of this study (Fig 16). Baker & Bartels (2011)'s upper limit was approximately 170 larvae per 100m^3 and their lower limit was approximately 80 larvae per 100m^3. Meredith et al. (1989) measured an estimated 5553 million larvae through site D. The scale used by Meredith et al., (1989) differed from the scale used by Baker & Bartel (2011); however, comparative analysis has been done between the two past studies and suggests no significant decline in larval density between 1989 and 2011. This difference may be because larval abundances have declined with temperature increases between 2011 and 2024. Furthermore, Baker et al., (2024) suggests Poorohe reared in the river and other warm streams experience lower fecundity related to decreasing length of fish. However, this difference could also be the result of yearly variation in larval abundance, because recruitment and spawning success will control annual productivity (Baker & Bartels, 2011). A temporal decline in Poorohe larval abundance at site D cannot be confirmed without further statistical analysis.

There were no significant differences between top and bottom nets (Fig 18). It was expected top nets would capture more Poorohe larvae compared to the bottom nets because larval Poorohe exhibit a vertical diel migration. Meredith et al., (1989) and Baker & Bartels (2011) suggest a vertical diel migration, but caught more larvae in bottom nets. This may be a result of differences in flow between the upper net position and lower net positions. Sites A and B had unique net configurations because the river profile was shallow on one side with a deep channel whereas sites C and D had a relatively uniform profile (Fig 14-17). Therefore, comparing the vertical distribution of larval caught is hard because sites A and B had less bottom nets. Over the sampling events, the weather during sampling was clear and fine apart from the sampling event on 1 May 2024, which had periods of heavy rain which may influence the vertical distribution of larvae. The lunar phases during two sampling events were three quarter moons. On one sampling event the lunar phase was a first quarter moon, and one sampling event had a waxing crescent lunar phase. The Maramataka of these lunar phases suggest that the conditions for fishing were not optimal (Hanara & Jackson, 2019). These lunar phases should not influence the vertical migrations of Poorohe.

The sampling regime did not encapsulate the full extent of the spawning period because the sampling events were heavily restricted by the required position of the tide for sampling to go ahead. For example, the correct tide position only coincided with dusk every 14 days, which limited sampling occasions across the eight-week spawning season. In addition, adverse weather conditions posed further logistical constraints on sampling, given survey days were unable to be rescheduled. Prior larval fish surveys indicate peak spawning occurs over a period of one to two months (Meredith et al. 1987, 1989; Empson et al. 1992; Baker & Bartels 2011). The spawning period fell within the sampling window because Baker et al., (2024)'s fish health surveys reported spent fish being caught through the sampling period. The prior larval density surveys completed by Meredith et al. (1989) and Baker & Bartels (2011) sampled sites on consecutive nights, which likely better represented the fluctuations in larval densities, which was not possible at these sites because of the tidal position requirements to sample these sites.

Limitations, considerations, and assumptions

There were many challenges associated with the sampling for larval density in Te Puuaha. This type of sampling was carried out for the first time in three of the sites and different challenges arose across the sites. Therefore, within this research multiple assumptions and considerations were necessary due to the limitations of sampling.

The first limitation to the results was the number of samples collected across each sampling event (Table 6). On three occasions, there were sites that were not sampled and there were occasions where not all eight samples were collected because weather and flow conditions prevented sampling.

Initially it was planned that site A and site C would be sampled simultaneously. The team sampling site A would transit in the boat up to site B following the processing of site A samples while the team at site C would trailer the boat and drive to site D. Under this sampling regime, larval drift would be accounted for because of the large distance between site B and site C. Site B was the shallowest and widest of the four sites therefore, on the outgoing tide, sand bars along the sampling transect became exposed. This created conditions too dangerous for the team to sample at site B on the 01/05/2025 (Table 6). To account for these challenges and ensure site B would be sampleable, the teams sampled sites A and B simultaneously. The team sampling site B would also launch from a boat ramp closer to site B, which lower the distance of in-river transiting. Following the sampling of these two sites, both teams would trailer the boats and drive to their next site.

Sites A and B were not sampled on the 30 May 2024 because of the 42 knot South Westerly wind. This created conditions at both sites, which were too dangerous to sample; however, both sites C and D were sampled.

The channel on the true right side of site A was not successfully sampled on any occasion. This channel was characterized as a deep and high flow channel, which created high drag conditions when the nets were in position. This resulted in nets that were lost, inattempt to remedy this challenge, additional floats were added to the nets set in the channel. Furthermore, on the 15 May 2024 sampling occasion, we attempted to elevate the drag created by the double nets through reconfiguring the nets (Fig 25). The double net in channel on the true left became a singular net and net number four became a double net (Fig 8 &25). This configuration was changed back to the previous iteration because the bottom net at position four sat in the riverbed and the 23L marine floats were utilised.

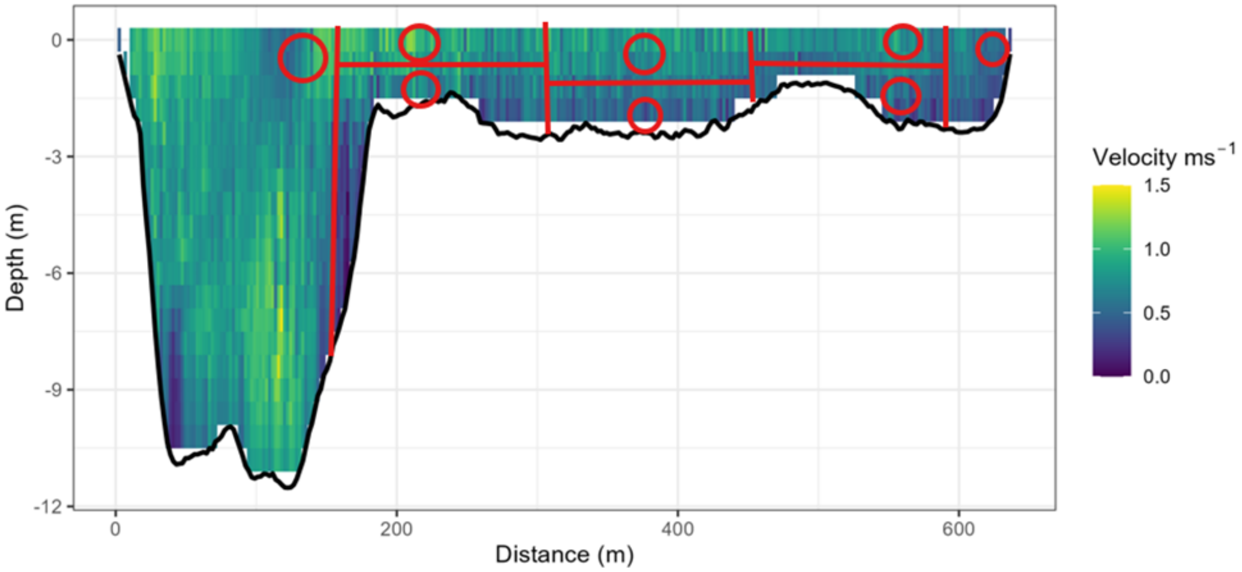

Figure 25: Approximate positions of the re-configured nets and approximate segments of flow per net from the sampling event on 15 May 2024

Site D also had challenges with sampling. During the 1 May 2024 sampling event, a double net was not retrieved. Additionally, the sampling event on the 15 May 2024, only one sample was collected. Setting the remaining nets was attempted; however, the high river flow meant the nets were not holding properly and it was decided to not risk the possibility of not being able to retrieve the nets. Following this sampling event, bigger buoys were purchased and inflated an extra 10% to accommodate for high flows. The bottom net sample at site D on the 30 May 2024 sampling event was also not collected because the cod-end broke in-situ which prevented sampling the entire site.

Table 5: The sites that were sampled and the number of successful samples from each site.

	SITE A	SITE B	SITE C	SITE D
1 MAY 2024	6	0	8	6
15 MAY 2024	7	8	8	1
30 MAY 2024	0	0	7	7
13 JUNE 2024	6	8	8	8

Another limitation was the ability to carry out ADCP transects with sampling events. Preferably the ADCP transects would be carried out every night with sampling; however, the tide and changing flow meant that the conditions were not the same between sampling and taking the ADCP transect. Additionally, the amount of time to take ADCP transect during sampling would have taken too long as the other upriver sites still needed to be sampled. Additionally, the boats used for sampling would not be sufficient to have the sampling equipment, ADCP equipment and personnel on board. Therefore, on an alternate date, and during the day, the ADCP transect was taken. The transects were carried out on river flows that were assumed to be comparable to river flow during larval sampling events. Across the sampling occasions, the average height of the high tide at 3pm was approximately 2.5m. High tide at 3pm meant that by 6:15pm the tide would be outgoing. Additionally, the 3pm high tide accounts also accounted for the tidal lag of approximately three hours at sites C and D.

Luckily, the tidal height when the ADCP transects were taken were of a similar magnitude. This allowed the assumption that river flow would be similar across the four sampling events.

The river flow used in larval density calculations was standardised to 100m3/s in order to account for different flows at sites A and B due to the presence of tidal water. While the water level at all four sites is influenced by the tide, the flow was most inflated at sites A and B. The ADCP transect revealed the combination of tidal influence and river flow resulted in the flow of 1770 m^3/s at site A and at site B a flow of 1462m^3/s, compared to around 400m^3/s at sites C and D. Therefore, standardising the flow allows for comparison across all four sites.

Future research

Further developing frameworks and tools that aid whaanau in better understanding the future challenges the river and its inhabitants will face is important because it helps whaanau in leading and developing climate strategies.

Poorohe are one of New Zealand's more sensitive freshwater fishes (Ward et al., 2005). Limited availability of literature around Poorohe has meant that a CCVA has not been developed (Egan et al., 2020). The key objective of this research was to aid the future development of a CCVA for Poorohe. This research has provided some useful and important information that enables a better understanding of Poorohe in relation to climate change. Therefore, to develop a CCVA, more research on Poorohe both in general and relating to factors of climate change is required. It is particularly important to develop a CCVA for this species because they are much more sensitive to environmental changes compared to other native species (Ward et al., 2005). A CCVA for Poorohe could further be used in the development of additional thresholds and frameworks.

There was a substantial amount of time between the two prior larval distribution studies and the sites of these studies. With an exception of the Tuakau bridge site, the sites of these studies have not been repeated in approximately a decade. Therefore, repeating the larval distribution would aid in understanding the effects of temperature on Poorohe. Longitudinal larval distribution studies from Baker & Bartels (2011) and Meredith and Empson (1986) only extended to Tuakau Bridge and this project was the first attempt at sampling below Tuakau. Additionally, developing long-term data sets from the lower river could aid in detection of climate change factors. Overall, it would be beneficial to continue including these sites in future longitudinal larval distribution studies. It would provide more comprehensive information regarding the location of Poorohe spawning habitat and estimations of larval Poorohe which could indicate declining numbers. Such information would aid in future planning efforts to protect these habitats.

The amphidromous life cycle of Poorohe means it can tolerate saltwater at various stages of their life cycle (McDowall, 2011). The effect of saltwater intrusion on Poorohe spawning is unclear. Further research regarding the ability of Poorohe to spawn in various concentrations of saltwater would be valuable in determining the impacts of saltwater intrusion on the abundance of Poorohe.

Understanding the potential effects that other climate change factors may exert on Poorohe populations would be invaluable as there is a variety of complex issues at could arise. One concern is declining habitat availability because Poorohe have specific spawning habitat preferences (Ward et al., 2005). Over time the amount of sand coming down the river has declined because of the hydro-dams (Healy & Wo, 2002). Additionally, sand abstraction has taken place throughout the lower river (Fenton, 1989). This has further resulted in less sand that makes up the mobile sand bars within the river coming down the river. Further changes to the bedload and increased sedimentation may impact important spawning habitat through altering the existing habitat smothering the sand (Ward et al., 2005). Since Poorohe have specific spawning habitat requirements, changes to this habitat would likely decrease spawning or impact the viability of spawning. Better understanding possible changes to the morphology of the riverbed and mobile sandbars is important as it may provide important insights to degradation and changes to spawning habitat.

An unanticipated discovery of sampling was the presence of golden clam (*Corbicula fluminea*). Golden clam was first detected in the Waikato River in 2023 at Bob's Landing, Karapiro (Somerville et al., 2024). In other freshwater ecosystems, golden clam is known as an 'ecosystem engineer', by outcompeting bivalve species and altering substrate availability (Somerville et al., 2024). Therefore, *C. fluminea* is likely to have severe negative impacts on the spawning habitat of Poorohe. Golden clams were present in samples from sites B, C, and D. Some clams from these samples were measured, and the size class information of these specimens will be utilised in other research within NIWA's freshwater ecology team. Further research regarding the ability of Poorohe to subsist within habitats impacted by golden clam is important because Poorohe have highly specific spawning habitat which may be further impacted by environmental changes like sedimentation.

Conclusion

In conclusion, larval density did not significantly change between sampling sites which suggests Poorohe spawning habitat may not increase in the lower Waikato River below Tuakau Bridge. However, it is also important to recognise that the nature of the sites severely restricted the ability to sample.

Increased water temperature associated with climate change are expected to negatively impact on Poorohe spawning through multiple avenues. Temperature increases can delay spawning and compromise in-egg development which may further reduce the abundance of Poorohe in the Waikato River. Baker et al., (2024) have already indicated high temperature during the maturation period results in reduced size and fecundity in Poorohe.

It is difficult to determine the influence of saltwater intrusion on Poorohe spawning because high river flow can depress the influences of the tide. Especially since spawning occurs throughout autumn and early winter, when river flow conditions are typically increased.

General Summary

To conclude, Poorohe are a valued kai species for whaanau in Te Puuaha and they are particularly vulnerable to environmental changes (Ward et al., 2005: Mahuta & van Schravendijk-Goodman, 2024). Whaanau are concerned by changes they've noticed in the Poorohe caught in annual harvests. The experiences of fisher whaanau who harvest Poorohe in Te Puuaha have been impacted and changed by various facets of colonization. Settlement and other mechanisms have aided in mitigating some of the changes felt through colonization. However, these experiences are likely to continue to change with climate change and the maatauranga that underpins these experiences is also threatened.

Under current conditions, temperature increases, and saltwater intrusion do not have a significant effect on Poorohe spawning. However, in the future these two variables may have considerable consequences for Poorohe. Prior larval distribution studies from Meredith et al., (1989) and Baker & Bartels, (2011) in the Waikato River had indicated Poorohe spawning habitat increases down river. There was no significant spawning habitat indicated by larval density throughout the lower river delta. Further research is necessary to better understand the effects of these variables on climate change and other variables that will affect Poorohe populations.

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