# Monitoring Te Mana o Te Wai: Integrating an indigenous cultural health index with conventional biomonitoring tools for improved freshwater management.

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**SHANA JADE TE IAA TARERE EDGECOMBE**

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# Abstract

Globally, there are universal efforts to quantify and address human impacts on ecosystems. In particular, changes in land use and river regulation have led to drastic declines in stream and river ecosystem health. These human impacts are driving the global freshwater biodiversity crisis and degrade ecosystem services provided by aquatic habitats. In Aotearoa New Zealand there is widespread concern about the state of our Nation's freshwater ecosystems. Coupled with a renaissance in Māori culture, there has been a drive to develop indicators that help articulate cultural values, assess ecosystem health from a cultural perspective, and provide greater agency for Māori in environmental monitoring and management. In my thesis, I sought to integrate an established cultural monitoring framework with conventional biomonitoring tools for improved freshwater management. I hypothesized that using a suite of monitoring approaches would help detect the impacts of human land use on stream ecosystem health, and that cultural indicators would be consistent with conventional measures in diagnosing land use impacts. I also hypothesized that there could be discrepancies between cultural monitoring and conventional approaches, as each represent different perspectives and ways of knowing streams and rivers.

To test my hypotheses, I selected ten stream sites across the catchment of the Kuratau River, a major tributary of Lake Taupō. Based on River Environment Classification land cover types, I used a balanced study design with five sites draining indigenous forest, and five sites draining pastoral land. I measured key stream physicochemical properties and collected water samples for determination of nutrient concentration and faecal coliform counts. I also characterised instream and riparian habitat. I collected benthic macroinvertebrate samples and sampled water for environmental DNA (eDNA) to assess different facets of biodiversity. I measured decomposition using the Cotton Strip Assay and quantified periphyton biomass using a portable fluorometer. In combination with these approaches, I also used a Cultural Health Index, an established cultural monitoring framework that assesses three components: customary significance, taonga species/mahinga kai (food gathering), and the Cultural Stream Health Measure (CSHM) to assess identified attributes for stream health.

I found that pastoral land uses lead to a decline in stream ecosystem health when compared to sites draining indigenous forest. Pastoral sites had higher specific conductivity and concentrations of total nitrogen and nitrate. Habitat variables changed, with increased sedimentation and more degraded riparian zones in pastoral streams. Decomposition rates as measured by the cotton strip assay increased in the pasture sites, which was likely a response to increased nutrient availability. There were shifts in macroinvertebrate composition, with key indicator taxa for Indigenous forest sites including pollution-sensitive mayflies and stoneflies. Total taxa, EPT (Ephemeroptera, Plecoptera, Trichoptera), and aquatic insect richness all significantly declined in pastoral sites. Increases in primary production were less pronounced, but did increase alongside abundances of grazing caddisflies and snails in the sites draining pastoral catchments.

The Cultural Health Index indicated that sites in the Kuratau River catchment had customary and mahinga kai values. CSHM responded negatively to pastoral land uses, and the effect size it described was congruent with other responses. The CSHM was strongly correlated with an indicator of riparian habitat condition (the Riparian Condition Index) and had weak negative correlations with sedimentation and stream temperatures. The CSHM was not correlated with macroinvertebrate indices, which may have been because of the relatively few sites sampled, the narrow impact gradient in the Kuratau catchment, and the lack of temporal replication. However, cultural monitoring approaches should be seen to complement conventional environmental monitoring methods for assessing freshwater, and not be expected to duplicate them. The strength of the Cultural Health Index approach comes from establishing Māori agency to assess the environment through a Te Ao Māori lens, and to support and foster inclusion for tangata whenua epistemologies in environmental monitoring and resource management. Future research should consider greater hapū involvement and further explore the mechanisms driving changes in stream health and biodiversity.

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No Waikato me Te Moana o Toi te Huatahi ahau

Ko Whāingaroa toku kainga inaianei

Ko Shana Jade Te Iaa Tarere tōku ingoa

In its most direct description, my pepeha above connects me to my ancestors and describes the whakapapa of the whenua, waters, and community connections that nurture me and my mokopuna (descendants) through my tūpuna (ancestors). As I have introduced myself in my pepeha, I must also begin this thesis by introducing the whakapapa of this research.

Whakapapa can be defined as 'the layering of' people, ideas or things through space and time, and is the central principle in Te Ao Māori (Māori worldview) that orders the universe (Hikuroa 2017). As tangata whenua (people of the land) Māori exist in Te Ao Mārama (world of light) as living representations of the accumulation of our tūpuna, their successes, their failures, their losses, and their lessons. Whakapapa is how we understand, record, discuss, and interpret that accumulation. More detail is provided on the concept of whakapapa and its place in Te Ao Māori below, but for context of this introduction, we can briefly describe whakapapa as the innate connections that exist between people and place, throughout time.

Whakapapa is an important concept in expressing Te Ao Māori as it has a significant influence on the way ideas are understood. The ability to view something from a whakapapa perspective is something that is uniquely Māori and has been a core concept through every phase of the development of this research.

Using my pepeha, I introduce myself following the chronological structure that is tika (correct) in Te Ao Māori, the structure that recognises and acknowledges my whakapapa - the whakapapa of my people – before myself. My journey did not begin with me. I start by introducing my maunga (mountain), as the mountains are the closest to Ranginui (sky) and the first to receive light from Tamanui-te Raa (the Sun). My awa (river) follows next as it is the rivers that flow from the mountains to the sea, then my waka that carried my tūpuna from Hawaiiki to Aotearoa. My Iwi, hapū, marae are acknowledged as the collective that upholds, protects, and supports Māoritanga. I then describe the rohe (regional area) I belong to, and where I currently live in recognition of te mana whenua o Whāingaroa. I would close by stating my koro and kuia, māmā and pāpā, before my individual self in the chronological timeline of who I am. This research, as do I, exists as the manifestation of the accumulation of events that occurred long before these words reached this paper.

## Challenges facing freshwater ecosystems in Aotearoa

Globally, freshwater ecosystems are under increasing pressure from human impacts such as land use, pollution, and climate change (Dodds et al. 2013). In Aotearoa New Zealand, the ongoing decline in the health of wai Māori (water) and tūpuna awa (ancestral rivers) has long been a concern to iwi Māori. The protection of freshwater is a priority for Māori due to the inherent connections and cultural values of te wai puna ariki (water) in Māori culture, and the ecosystem services (e.g., mahinga kai) these habitats provide for the health and well-being of te tangata (people). Taonga species, including native freshwater fish such as galaxiids (shortjaw kōkopu, giant kōkopu, kōaro, and īnanga), lamprey (kanakana), and longfin eels (tuna) are considered by the Ministry for the Environment as either threatened, or at risk of extinction (MfE 2020). The widespread degradation of freshwater is also of major concern for resource managers given the importance of these ecosystems for sustaining biodiversity and human well-being (Erős et al. 2023). There is unequivocal evidence that freshwater systems in Aotearoa New Zealand are under immense pressure from anthropological impacts such as agricultural intensification, urban expansion, hydroelectric development, and climate extremes (Gluckman et al. 2017). To understand the current state of freshwater in Aotearoa New Zealand, we must first examine some of the many changes that have led us here.

Māori arrived in Aotearoa on waka (canoes) from Hawaiiki in East Polynesia between 1250 and 1300 CE (King 2023). In some tribal recollections, the ancestor Kupe is credited as discovering Aotearoa. The Polynesian explorers who settled in Aotearoa adapted to the new lands and developed a distinctive culture that existed in isolation for centuries. It was not until more than three hundred years later in 1642 during the Western Age of Exploration, that Europeans became aware of Aotearoa, and only in 1769 that British explorers set foot on and mapped the country (King 2023). This development instigated change for Māori societies as they became increasingly involved in interactions with European travellers. At first, interactions were based on trade and intermittent visits by whalers and sealers. However, with the goal of increasing the population of European settlers in Aotearoa New Zealand, representatives of the United Kingdom advocated for the formation of a Treaty with Māori. This led to the development of Te Tiriti O Waitangi (Treaty of Waitangi), an agreement formulated to guide Kotahitanga (unity) between the British Crown & Māori, and to protect Tino Rangatiratanga and Mana Motuhake (self-determination) of Māori and their taonga (treasures/natural resources). Te Tiriti O Waitangi was signed by various tribal chiefs and the British Crown in 1840 which led to the formation of the Crown Colony of New Zealand in 1841 (King 2023).

Between 1852 and 1870, the non-Māori population increased from 25,000 to 250,000. At the time of signing Te Tiriti o Waitangi, Māori comprised around 98% of the total population in Aotearoa New Zealand. By 1900, this number had reduced drastically to where Māori accounted for only 5% of the total population (Pool 2015). Increasing tensions between the colonial government and Māori tribes led to a series of conflicts that resulted in the forced confiscation of large amounts of Māori land, coupled with assisted immigration in the late 19th century, led to radical changes in Aotearoa New Zealand as the land was colonised and transformed by European settlers.

Prior to colonisation, Māori existed and lived by their own guiding principles that developed through their interconnected relationship between people and place. The description Māori give for themselves – tangata whenua, translating in English as 'people of the land,' showcases the deep connection Māori have with their ancestral lands. In Te Ao Māori (the Māori worldview), whenua (land) is not considered an ownable commodity or a resource to individually benefit from. The whenua is where we descend from, it is the essence that supports all life in Te Ao Mārama (the world of light) and is a taonga (treasure) gifted from ngā Atua (deities). It is this view that describes the intrinsic connection and responsibility Māori have to protect the whenua and ensure it continues to nurture mokopuna (future generations). Māori view their place in the taiao (environment) as a reciprocal relationship of care and recognise that the health and wellbeing of the whenua is inseparable from the health and wellbeing of the people.

> Te Hauora o te whenua, Te Hauora o te tangata
>
> *The health of the land is equal to the health of the people.*

In pre-European Māori society, tikanga (customary rules and practices), kawa (protocols) and whakapapa (genealogy) underpinned social organisation, and these values still influence the lives, beliefs, and actions of modern Māori. Tikanga (tika translating to correct) encompasses why and how actions are engaged or avoided and provides instructions to help guide Māori society. Tikanga is adaptable but acts in alignment with kawa – protocols that remain constant. Whakapapa is what binds Māori society together and what connects Māori to their environment, to ngā atua, their tūpuna (ancestors) and their mokopuna (descendants). In Te Ao Māori, iwi and hapū carry an intergenerational responsibility to protect whakapapa and whanaungatanga (connections) to ensure the protection of the mana (prestige) of their people (Newton 2019).

Iwi are the amalgamation of the descendants of crew members on the waka that carried their ancestors from Hawaiikī to Aotearoa. Hapū are often described as the sub-tribes of an Iwi, are linked through kinship, connected to each other through a common ancestor, and in pre-European times, lived as a collective unit in pā (villages) serving economic, social, and political functions. Whānau are the groups of extended family members that form the hapū. Ariki and Rangatira (chiefs) are the social and political leaders of Māori societies and exercise authority over whenua boundaries and taonga on behalf of the iwi, hapū, and whānau. These leaders are responsible for ensuring the needs of the people are met. All needs were cared for collectively, and all decisions were made as a collective unit through group discussions known as hui (Newton 2019).

With the changes imposed on Māori through colonisation, the dispossession from land, the development of British colonies and the modern New Zealand society, traditional practices and connections to ancestral whenua have in many places been undermined and severed. However, Māori resistance and the ongoing pursuit for tino rangatiratanga (self-governance) led to the Māori renaissance in the late 20th century resulting in greater recognition of Māori culture and values in contemporary New Zealand society. The ongoing advocacy for Te Reo Māori (the Māori language), Kaupapa Māori (ideas and values), and Mātauranga Māori (Māori knowledge), coupled with increased awareness of the principles outlined through Te Tiriti o Waitangi, developed a greater space for Māori aspirations in the management of their taonga (natural resources). Article two of the English interpretation of Te Tiriti o Waitangi states Māori have “exclusive and undisturbed possession of their properties”, whereas Te Tiriti o Waitangi as signed by the British Crown and ngā Rangatira o ngā hapū o Aotearoa, guarantees Māori ‘te tino rangatiratanga o rātou taonga katoa’ - Māori authority and control over their lands and all other treasured things (Waitangi Tribunal 2011). Baker (2019) describes Te Tiriti o Waitangi as the basis for the recognition of rights and roles of both Māori and the Crown in relation to water. Following the establishment of the Waitangi Tribunal in 1975, and its increased jurisdiction enabled by law in 1985 (King 2023), there has been increased recognition of the role Māori have in environmental management and decision-making in Aotearoa New Zealand.

## Mātauranga Māori and Cultural Values Significant to Māori

Mātauranga Māori has become an increasingly popular kupu (word) often translated in English as Māori 'knowledge.' However, from a Te Ao Māori perspective, the term 'knowledge' alone is inadequate to encompass the kupu 'mātauranga.' From a scholarly perspective, Mātauranga Māori is a continuum of distinct knowledge that encompasses Te Ao Māori values, culture, and cultural practices (tikanga), and informs on perspectives that establish Māori identity, responsibilities, and rights to manage, use and care for natural resources (Clapcott et al. 2018).

In Te Ao Māori, Mātauranga is an ever-evolving system of understanding that encompasses more than knowledge, it is the uniquely Māori way in which we observe, experience, engage and understand what does, has, and holds the potential to, exist in the world – both the seen and unseen. To understand the depth of the term 'Mātauranga,' it is important to have a basic understanding of the whakapapa of the Māori creation story. A story which uses personification and whakapapa to link together significant events of time that occurred over eons.

In the beginning there was an infinite empty void of nothingness – Te Kore. In the endless nothingness lay the seed of potential. It is this seed that contained the mauri (energy of life) that would eventually grow through the many phases of Te Kore, through Te Pō (the darkness) into Te Ao (the light):

> Mai te kore, ki te pō, ki te ao mārama
>
> *From the void, to the night, to the bright light of day*

Papatūānuku (earth mother) and Ranginui (sky father) laid together in darkness for all time emersed as one. Papatūānuku and Ranginui have many children, each of which are regarded as Atua (guardians) connected to some form of the natural world. As the children of Papa and Rangi, ngā atua, multiplied and became restless, the atua Tāne invoked the thought of potential and successfully separated Papa and Rangi to create Te Ao Mārama (the world of light). Tāne is recognised by many names (Tāne Mahuta, Tāne-nui-a-rangi, Tāne-te-wananga, Tāne-te wai-ora) to reflect his many great achievements. He is the atua responsible for natural diversity of te taiao (the environment), for protecting the forests and its children, including tangata whenua (people), manu (birds), pekapeka (bats), ngā rakau (trees/plants) and aitanga pepeke (insects). He is also credited for the retrieval of ngā kete mātauranga (the baskets of knowledge), the establishment of the first whare wānanga ki te ao mārama (place of understanding the world of light) and the gift of Mātauranga to humankind.

Mohiotanga encompasses the pursuit of knowledge and the act of sharing knowledge and was highly valued by tūpuna Māori. As a people without a 'written' language, Māori use various oral methods to embed and share knowledge. Whakapapa (genealogy), pepeha (tribal connections), pūrākau (stories), kupu whakarite (sayings), whakataukī (proverbs), karakia (guiding chants), and waiata (songs) are some of the traditional oral forms used by tūpuna Māori to convey, recite, retain, and pass on ancestral knowledge.

Pūrākau such as the creation story above, are one of the many ways knowledge was preserved and shared through generations. Pūrākau provides insight into the thoughts, actions, ideas, and understandings of our tūpuna, and provide a way to connect the knowledge of our tūpuna to the experience of mokopuna Māori. Mokopuna who navigate life looking forwards to the past, while walking backwards into the future. Or as stated in the following whakataukī in Rameka (2016):

> Kia whakatōmuri te haere whakamua
>
> *I walk backwards into the future with my eyes fixed on my past*

Whakataukī, often defined in English as "sayings" or "proverbs," are another way the thoughts and ideas of tūpuna Māori were passed on. Whaanga et al. (2018) delves further into the use of whakataukī to convey traditional ecological knowledge through relating stories of key ecological species, such as kāeo/kākahi, tuna and kōura, to instructions used to guide thought and action. Whakataukī, through the multilayering of linguistic knowledge, displays the interconnected relationship between people and place, and specifically for Māori, describes the deep connection with the environment that went beyond physical resources to reach into patterns of human behaviour and societal development (Whaanga et al. 2018).

These traditional oral methods were used by Māori to retain and share knowledge of place, history, beliefs, and traditions through generations (Rameka 2016). As described by Tipa (2009), the significance of the environment and land to Māori people goes beyond the natural resources the environment provides, it is central to identity. Māori are interwoven with the environment and their tūpuna through both whakapapa and cultural practices that are interconnected with social, biophysical, spiritual, and cultural qualities of place.

Baker (2018) describes Ngā kete o te Wānanga (three baskets of knowledge) as a framework for conceptualizing traditional Māori knowledge. The three kete described, Te Kete Tua-uri, Te Kete Aronui and Te Kete Tua-ātea, includes aspects such as the metaphysical (beyond what is observable), physical (material world), and future (potential) possible realities to create a mātauranga Māori decision-making framework. Informed by the understanding and writings of Marsden (2003), Ngā kete o te Wānanga aims to support iwi in their role as kaitiaki.

Mātauranga Māori (philosophy), in alignment with kawa (obligations), and tikanga (practices) guides Māori in the ongoing decisions required to fulfil the primary values and principals of the iwi and hapū. Table 1 outlines some of the key values within Te Ao Māori (the Māori worldview) that inform on these actions. It is expected that the many different iwi, hapū and whanau across Aotearoa New Zealand would have their own fundamental values and priorities that guide their practices, and that the list below is not viewed as extensive but describes a broad range of shared values. Iwi Māori have many aspirations in regard to how ngā taonga (natural resources) such as wai (water), whenua (land), ngā opapa (minerals), te hā o ranginui (air) and ngā otaota me ngā aitanga kararehe (flora and fauna), should be managed and cared for.

*Table 1* Key Māori values that hold significance in Te Ao Māori and help guide tikanga.

| VALUE | DESCRIPTION |
|---|---|
| **MANA WHAKAHAERE** | Autonomy over enhancing mana and exercising rights. |
| **TE AO TŪROA** | Natural order of time and space – traditional concept of sustainability. |
| **MANA MOTUHAKE** | The inherent birthright to mana through self-determination. |
| **TAONGA TOKU IHO** | Protection of ancestral taonga. |
| **WHANAUNGATANGA** | Connections. Physical and metaphysical. |
| **MANAAKITANGA** | Giving and sharing care, the act of enhancing mana. |
| **KOTAHITANGA** | Unity, as opposed to uniformity. Collective action towards shared goals. |
| **RANGATIRATANGA** | Self-governance of Māori by Māori. |
| **MOHIOTANGA** | The pursuit of knowledge. |
| **MĀRAMATANGA** | Enlightenment through learning and applying. |
| **KAITIAKITANGA** | The responsibility to both our tūpuna and mokopuna to protect te taiao (environment). |
| **ATUATANGA** | Knowing and respecting the realms of Ngā Atua. |
| **MAURI** | Inherited life force – energy state, health and vitality. |
| **MANA** | Spiritual strength, capability, authority. |

Iwi environmental management plans have been developed across Aotearoa New Zealand to affirm environmental goals and values regarding the management of whenua and wai. Over the past few decades Iwi and hapū have authored hundreds of management plans (MfE 2024) to express their concerns and aspirations regarding the management of natural resources in their rohe (region). Although each individual plan serves various functions, identifying commonly shared or overarching values between Iwi/hapū management plans facilitates collective understanding and usability of concepts, and also provides a link to connecting Māori values and scientific attributes.

## Development of Cultural Monitoring Frameworks

Cultural monitoring assessments have been developed to support Māori in achieving kaitiakitanga - the inherited responsibility of tangata whenua to nurture and protect the mauri within Te Ao (the natural world), te whenua (the land), te ngahere (forest), and wai (water) for mokopuna Māori (descendants). The continued decline of freshwater ecosystems in Aotearoa New Zealand throughout the past few decades has highlighted the need for the development of cultural monitoring frameworks to assess the effectiveness of resource management from a Te Ao Māori perspective.

These efforts have sought to develop: a) monitoring methods that are indicative of Māori values around wai, b) tools to measure progression towards goals and aspirations of Iwi Māori, and c) support Māori to reconnect with ancestral whenua. To enable this, Māori cultural health assessments have been developed and adapted to create alternative approaches to assessing stream health (Tipa and Tierney 2003, 2006).

Western science as a discipline is naturally Eurocentric in origin, but what is often overlooked is that it is also intrinsically Eurocentric in its philosophical understanding and interpretation. Naturally then, the intentions, methods and analysis are implemented from the same perspective. What we know, how we know, and how we understand is highly influenced by the environment in which we grow.

Monitoring approaches using scientific methods typically identify, measure and report on individual aspects of "stream health". This conventional approach to compartmentalise natural functions often contrasts with cultural health assessments, which consider a more holistic approach to stream health and recognise that the combined is greater than the sum of the individual components (Suren and Lee 2014). Cultural assessments are steeped in intergenerational experience informed through cultural methodologies and perspectives. Although it is often argued that cultural approaches are more subjective than Western science assessments, it is important to emphasise the differing epistemologies and often intentions between approaches and reiterate mātauranga Māori monitoring tools have benefits beyond those determined or understood by Western science or philosophy.

Cultural monitoring considers the intergenerational experience of different iwi and hapū with regards to a particular waterway, thus placing it in a broader biocultural context (Lyver et al. 2019) whilst simultaneously providing space for the human experience and metaphysical elements of natural resources and functions, which are generally excluded by more objective measures. Just as conventional Western science measures are informed by Western epistemologies, Māori cultural measures are informed by mātauranga Māori. The value of the environment from a Māori perspective extends beyond the ecological and intrinsic, and into the societal values of psyche, people, and communities, including the existential values of identity formation and relationship to nature (Baker 2018). Cultural Health indices encompass a suite of indicators to assess environmental state or change from a Te Ao Māori perspective and can be used in the same way as scientific indicators to better understand environmental health and set benchmarks (Baker 2018). Mātauranga Māori is not dependent on its value to Western science, but rather its value to Māori (Broughton, 2014). When conventional and cultural approaches to freshwater management are combined, the result is broader, more in-depth stream assessments that can lead to improved decision making.

> Nā tō rourou, Nā taku rourou, ka ora ai to Iwi.
>
> *With your food basket, and my food basket, the people will thrive.*

## The Cultural Health Index

The Cultural Health Index (CHI) was created by Tipa and Teirney (2003, 2006) to monitor stream health using values significant to Māori. The CHI was developed from the Taieri Indicator Project, a case study that arose from the Environmental Performance Indicator (EPI) programme established by the Ministry for the Environment in 1996. The EPI programme aimed to develop and use indicators to measure and report on the environment (Jollands and Harmsworth 2007) and allow assessment of the effectiveness of key environmental legislation and policy (Tipa and Tierney 2006). The first cultural health assessment occurred on the Taieri and Kakanui Rivers in 1997 by Otakou and Moeraki Runanga and was later refined and used to assess the Hakatere (Ashburton) and Tukituki Rivers by Arowhenua and Ngāti Kahungunu, respectively (Tipa and Teirney 2006). Since then, CHI assessments have been developed and used by a reported 12 of 16 regions across Aotearoa New Zealand to assess a range of rivers and streams (Rainforth and Harmsworth 2019). Cultural health assessments are also being developed and used for the assessment of wetlands (Harmsworth 2002, Robb 2014), Lakes (Hughey et.al 2013), and marine environments (Hepburn et al. 2013).

Harmsworth et al. (2011) reports the results of CHI monitoring carried out in the Motueka and Riwaka catchments by members of the six iwi (Ngāti Rārua, Ngāti Tama, Te Āti Awa, Ngāti Koata, Ngāti Apa, and Ngāti Kuia) that hold mana whenua status over these awa. Farquhar (2012) compared relationships between CHI assessments and assessments of stream habitat quality at two sites in the Whanganui River catchment. More recently, Suren and Lee (2014) reports results from CHI stream monitoring in the Bay of Plenty, rohe of Tuhourangi and Ngāti Whakaue who whakapapa to Te Arawa waka.

The first iteration of the CHI as conceived by Tipa and Tierney (2003, 2006) comprises of three components:

1. The site status component assesses the significance of the site to tangata whenua by assigning it to one of four classes that depend on the site's traditional significance, and whether tangata whenua would return to the site in the future.
2. A mahinga kai (taonga kai species) component - recognises that mauri is tangibly represented by the physical characteristics of freshwater including its wellbeing, cultural usage, and productive capacity.
3. The cultural stream health measure (CSHM), based on assessing individual environmental attributes as indicators of stream health. This is regarded as an objective and accurate reflection of tangata whenua evaluations of overall stream health (Tipa and Tierney 2006). The number of individual CSHM indicators used varies throughout different studies using the basic cultural

monitoring framework of the CHI, since the CSHM is adaptable to reflect local conditions and cultural values.

The application of the CHI has generally gravitated towards the CSHM, with different individual indicators being used depending on the location and cultural values of iwi/hapū using it (Tipa and Tierney 2006, Suren and Lee 2014). A version of the CSHM using five indicators was highly correlated with several Western scientific measures of stream health including the Macroinvertebrate Community Index (MCI), and the community-based Stream Health Monitoring and Assessment Kit (SHMAK) assessments that gave both habitat and invertebrate scores (Tipa and Tierney 2003). Harmsworth et al. (2011) compared results from the CHI and Western scientific approaches at 25 sites in the Motueka and Riwaka catchments. Both approaches suggested a decrease in stream health in response to increased pressures of upstream land-use. The results from the two approaches were correlated, suggesting that cultural indicators could be used in a similar manner as scientific indicators. However, with the natural requirement of the CHI to reflect the cultural values and aspirations of the mana whenua of the location, there remains a need for further research of cultural monitoring frameworks for different regions of Aotearoa New Zealand.

Other cultural monitoring approaches have been developed in Aotearoa New Zealand. Below additional cultural monitoring frameworks are briefly described.

### The Mauri Compass

The Mauri Compass was developed by Te Runanga o Turanganui a Kiwa and the Gisborne District Council and is being used in a Resource Management Act (RMA) context for wastewater and stormwater management in the Tairawhiti region (Benson et al. 2020). It was also used by Te Aitanga a Mahaki to compare the mauri of the Waipaoa River Catchment in 2008 and 2018.

The Mauri Compass combines mātauranga Māori with Western science indicators to create a visual compass focused on three kete: Tangata Whenua, Tāne and Tangaroa. It is a digital tool that covers twelve aspects within the three kete to help answer questions about ecosystem health important to iwi and hapū (Rainforth and Harmsworth 2019). The results are presented as a visual compass to assist whanau, hapū iwi and resource managers to assess the impact of factors on the mauri of their land and waters.

### Wai Ora Wai Māori

Wai Ora Wai Māori is a kaupapa-based assessment tool described by (Awatere et al. 2017). It was designed to enable water quality to be measured through determining the state of attributes that fall within three main domains:

1. Taha Kikokiko – the biophysical aspect represents mahinga kai and taonga species. i.e. are species like kaaeo (kākahi), tuna and īnanga safe to consume, and is the whakapapa of those species healthy.
2. Taha Whanau – the social aspect signifies well-being of the community through the availability to support both mana whenua, and manuhiri, and if mana whenua are able to exercise kaitiakitanga and follow tikanga.
3. Taha Wairua – the metaphysical encompasses the Mauri of the ecosystem and the condition of the wai taniwha/tipua/kaitiaki.

Assessments for each attribute are given on a score-based system similar to the CHI, where Taha Kikokiko and Taha Whanau are determined as Ae = 1, Kao = 0, and are scaled as Aue = Low (0), Pōhara = poor (1), Āhua pai = okay (2), Pai = good (3) and Pai rawa = excellent (4). Taha Wairua is scored as Mauri noho = dormant (1), Mauri oho = improving (2), Mauri piki = expanding (3) and Mauri ora = flourishing (4).

The scoring system used the same scale to be consistent with the attribute bands (A, B, C, D) outlined in the National Objectives Framework of the National Policy Statement for Freshwater Management (NPS-FM 2020). This means it can be used to set limits in Freshwater Management Units (FMU) and help support the implementation of the Te Mana o Te Wai principle in the NPS-FM (2020). The Wai Ora Wai Māori framework is available as a paper-based version and as a digital app with a supporting database (Rainforth and Harmsworth 2019). This functionality enables iwi, hapū, whanau to participate and be involved in the planning and decision making regarding how freshwater is managed in Aotearoa New Zealand.

Harmsworth and Rainforth (2019) summarise a total of thirteen kaupapa Māori monitoring tools used for assessing environments, and describe in depth the journey of developing environmental indicators that are informed through Māori epistemologies and act to encompass the metaphysical, cultural, social, and ecological aspects of natural resources.

## Legislation Guiding Freshwater Management

### Resource Management Act 1991

The Resource Management Act 1991 (RMA) is the fundamental legislation guiding how natural resources, such as air, soil, coastal, and freshwaters are managed in Aotearoa New Zealand. The RMA 1991 outlines the key purpose and principles of the legislation for the use and management of the environment. The main purpose of the RMA is outlined in Part 2 Section 5:

> “to promote sustainable management of natural and physical resources (excluding minerals) to meet the foreseeable needs of future generations, to safeguard the life supporting capacity of air, water, soil and ecosystems; and to promote avoiding, remedying, or mitigating any adverse effects of activities on the environment”

Part 2 Section 8 of the RMA 1991 states that all persons exercising functions and powers under the act must take into account the principles of Te Tiriti o Waitangi. As outlined by the Ministry for the Environment (MfE 2022), future legislation will provide greater recognition of Te Ao Māori, including Mātauranga Māori, and states that all persons exercising powers or functions under these acts will be required to give effect to the principles of Te Tiriti o Waitangi. Section 6 outlines the relationship between Māori and their ancestral lands as a matter of national importance, specified as:

> "In achieving the purpose of this Act, all persons exercising functions and powers under the RMA, in relation to managing the use, development and protection of natural resources, shall recognise and provide for: (e) The relationship of Māori and their culture and traditions with their ancestral lands, water, sites, waahi tapu and other taonga".

The RMA is the key piece of legislation for regulation of freshwater in Aotearoa New Zealand, its overarching goal is to promote the sustainable management of natural and physical resources (Baker 2019). Local and regional councils are responsible for implementing the RMA in the management of natural resources, and must take iwi and hapū management plans into consideration in the formulation of district and regional plans and policy statements.

### National Policy Statement for Freshwater Management 2020

The National Policy Statement for Freshwater Management 2020 (NPS-FM) is the guiding document for managing freshwaters in Aotearoa New Zealand. The NPS-FM sets out the objectives and policies for freshwater management under the RMA. One intent of the NPS-FM is to provide local authorities (councils hereafter) with updated direction on how they should manage freshwater under the RMA, and thus meet their statutory obligations. The NPS-FM has created the National Objectives Framework (NOF) to help councils set environmental outcomes for identified values and include them as objectives in regional planning. The NOF requires councils to identify attributes for freshwater values and determine baseline states appropriate for those attributes, thus enabling target attribute states (TAS) to support desired environmental outcomes, limit setting, and action intervention plans where required to achieve the TAS. An important aspect of the NPS-FM is that tangata whenua and local communities must be consulted and engaged with at each step of the NOF process.

A key component of the NPS-FM are the identified attributes for ecosystem and human health that need to be monitored throughout each region to meet the council's obligations under the RMA. The freshwaters attributes identified by the NPS-FM include twenty-one water quality, habitat, and biological indicators. Councils must identify baseline and target attribute states (TAS), and if the baseline state is below the National Bottom Line (NBL) for that attribute as set in the NPS-FM, then the target state must be at or above the bottom line. Another aspect of the NPS-FM is the concept of freshwater management units (FMU), which represent smaller spatial scales than those previously monitored at allowing for variation from place to place. The NPS-FM requires councils to now assess the state of waterways representative of individual FMUs, as opposed to their region. This requirement is likely to greatly increase the size of council monitoring programs. Recent changes now require councils to establish methods for monitoring progress towards achieving TAS and environmental outcomes which must include measures of mātauranga Māori and the health of indigenous flora and fauna in their monitoring plans.

### Te Mana o Te Wai

Te Mana o Te Wai (the mana of water) was included as a fundamental concept in the NPS-FM to recognise the importance of water to sustaining life, and protecting the health of freshwater enhances the integrity of the wider ecosystem. The updated NPS-FM (2020) has elevated Te Mana o Te Wai as the foremost fundamental concept that will determine how Aotearoa New Zealand’s freshwaters are to be managed. Te Mana o Te Wai imposes a hierarchy of obligations prioritising the health and well-being of waterbodies and freshwater ecosystems first, then followed by societal needs such as the provision of drinking water for human health and well-being. The third priority recognises the ability of people and communities to provide for their social, economic, and cultural well-being. In the hierarchy of obligations specific to the Waikato and Waipā catchments - Te Ture Whaimana o te Awa o Waikato (The Vision and Strategy for the Waikato River) developed from the Waikato-Tainui Raupatu treaty settlement, is intended to prevail over any inconsistencies with the NPS-FM.

Key concepts in Te Mana o Te Wai include mana whakahaere, kaitiakitanga, and manaakitanga (Table 1). Mana whakahaere refers to the of actioning of responsibilities as tangata whenua to make decisions that maintain, protect, and sustain the health and well-being of (and their relationship with) freshwater (WRC  2022). Kaitiakitanga recognises the intrinsic obligation to manage taonga in a way that preserves, restores, and protects natural resources to ensure they can sustain future generations. This value encompasses the ideology of the health and wellbeing of the Iwi being directly connected to the health and wellbeing of the environment. Manaakitanga encompasses reciprocity and recognises that mana is upheld by acknowledging and uplifting the mana of others (Baker 2019). Each concept in essential to protect and enhance te mana o te wai (the life sustaining vitality of the water). These definitions however must be considered as guidelines as principle such as Kaitiakitanga and Manaakitanga must be determined by the hapū and Iwi as the depth of these concepts are found in the practices and mātauranga of mana whenua (MfE, 2023). A core tenet of Te Mana o te Wai is the essential role hapū and Iwi hold in determining what this concept means for them. Councils are expected under the NPS-FM to action the five key requirements of Te Mana o Te Wai when developing regional plans, which includes applying the hierarchy of obligations and implementing the National Objectives Framework.

## State of Environment, Freshwater Ecosystem Health & Biomonitoring

As required under the RMA, State of the Environment (SOE) monitoring occurs across Aotearoa New Zealand to record and track the current and historical state of freshwaters. Statutory obligations under the RMA and NPS-FM compel regional councils to assess the ecological state of waterways and monitor trends over time. Under Section 35 of the RMA, regional councils have:

> “a duty to monitor the state of the whole or any part of the environment to the extent that is appropriate to enable the local authority to gather information, monitor and keep records of any necessary information required to effectively carry out their functions under the act.”

SOE monitoring is generally carried out by regional councils who are responsible for recording and reporting on the health of freshwater ecosystems so to reduce pollution, protect human health, and conserve native biodiversity. Under section 33 local authorities can also elect to transfer any one or more of its functions, powers, or duties under the RMA to another public authority.

Ngā hapū o Ngāti Tūwharetoa released their first Environmental Iwi Management Plan in 2003 outlining their aspirations to "be involved in every way possible in the decision-making process that impacts on taonga, and to actively protect taonga for present and future generations". In 2020, Ngāti Tūwharetoa and Waikato Regional Council utilised section 33 of the RMA to become the first council iwi collaboration to successfully transfer SOE monitoring responsibilities in the Lake Taupō catchment.

The term 'ecosystem health' is commonly used in environmental science and management to describe the state of a system relative to a desired management target or reference condition (O'Brien et al. 2016). Other definitions emphasize the integration of ecological, economic, and cultural processes and measures of sustainability and system resilience. Encompassing all these attributes, (Costanza and Mageau 1999) define a healthy ecosystem as one that is sustainable in that it can maintain its structure (organisation) and function (vigour) over time in the face of external stress (resilience). Despite the term 'ecosystem health' being used widely since the 1980s, achieving a state or condition that reflects a healthy ecosystem is an ongoing priority for governments, councils, scientists, and stakeholders in Aotearoa New Zealand and globally.

The health of freshwater ecosystems are determined using a range of scientific measures. Freshwater measures in Aotearoa New Zealand have historically been developed in response to the arising need to understand the physical state and health of freshwater to manage anthropogenic impacts. These measurements have typically focused on water quality, either through direct measurements of physical attributes or biological indicators that integrate responses over time. Water quality assessments are used to measure the physical chemical construction of freshwater through monitoring variables such as dissolved oxygen, electrical conductivity of water, nutrients (phosphorus and nitrogen), turbidity, visual clarity, and water temperature at the time of sampling. These variables provide an understanding of the physical condition of the water and its suitability for supporting human and freshwater communities. Dissolved oxygen is required for respiration of aquatic life and can be depleted through the decomposition of organic matter. Increases in organic matter in streams and rivers through point source pollution or excessive plant growth reduces the availability of dissolved oxygen. Several attributes in the NPS-FM are direct measures of water quality, including nitrate-nitrogen, ammoniacal nitrogen, dissolved reactive phosphorus, and suspended sediment.

Biological monitoring (biomonitoring) methods are used by scientists and researchers to determine freshwater ecosystem health and quality in Aotearoa New Zealand and globally. With limited monitoring budgets and a need for meaningful ecological data, biomonitoring in Aotearoa New Zealand has evolved over time, but for streams and rivers has strongly focused on structural indicators such as benthic macroinvertebrate and freshwater fish communities. These conventional biomonitoring methods generally focus on the biological structure of freshwater ecosystems, such as understanding the ecological condition and responses of organisms inhabiting the freshwater ecosystem. Macroinvertebrates are particularly important for biomonitoring in Aotearoa New Zealand, and national standards have been developed to minimise variation with collecting and processing invertebrate samples (NEMS 2022). Three macroinvertebrate attributes in the NPS-FM are required to assess ecosystem health in Aotearoa New Zealand: the Macroinvertebrate Community Index (MCI), its quantitative variant (QMCI), and the Average Score Per Metric (ASPM).

The MCI and the quantitative variant QMCI (which includes relative abundance of macroinvertebrates in its calculation) have been the most commonly used measures of ecological stream health in Aotearoa New Zealand (Stark 1985). Originally developed from hard-bottomed streams on the Taranaki ring plain (Stark 1985) and extended using soft-bottomed streams from the Auckland region (Stark and Maxted 2007a), the MCI indices established taxon-specific tolerance values which indicate sensitivity to environmental stressors such as changes in temperature, organic pollution and nutrient enrichment (Stark 1985). In the MCI, the overall score is determined using the average tolerance values of all taxa at a site multiplied by twenty. The tolerance values were allocated to each taxon based on their relative percentage occurrence at sites that differed in water quality status (Stark and

Maxted 2007b). The MCI indices can be used to determine changes in ecosystem state – originally intended to be nutrient enrichment and organic pollution, but more broadly reflecting changes in other factors including increases in temperature, light, sediment, and changes in habitat conditions.

Since the initial development of the MCI in 1985, other bioindicators have been developed such as the Average Score Per Metric (ASPM) index (Collier 2008). The ASPM index is calculated using the normalized MCI, %EPT abundance, and EPT richness indices. EPT is the abbreviation for macroinvertebrate orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). EPT represents the orders of benthic invertebrates that are generally more sensitive to river and stream degradation, and as such, generally show a decline when freshwater ecosystem health is degraded. The current macroinvertebrate indices used in Aotearoa New Zealand have been shown to be effective at detecting stream degradation (Stark 1985, Collier et al. 1998, Collier 2008). As a consequence, they are effective indicators of stream ecosystem health, and with ongoing monitoring of macroinvertebrate communities, can also be used to indicate changes in water quality over time.

More recently, there has been a greater recognition of ecosystem processes and moves to incorporate these in biomonitoring. Consequently, functional indicators have been developed for freshwater biomonitoring that provide a greater understanding of ecosystem processes such as stream metabolism, organic matter decomposition, and primary production. Functional indicators support structural measures through providing a more holistic understanding of ecosystem health (Tiegs et al. 2013). They enable managers to assess the activity of freshwater organisms including microbes (bacteria, fungi) and how environmental factors affected by natural and human pressures impact emergent properties at the ecosystem level (Young et al. 2008). In this research I used the cotton strip assay (CSA) as a functional indicator of decomposition, which has been shown to be sensitive to human impacts in streams at a global scale (Tiegs et al. 2024). The CSA has been identified as a next-generation biomonitoring tool because it is a simple, inexpensive, and highly standardised approach (and therefore could also be used by citizen science networks) to measure a fundamental ecosystem process that is comparable at any scale (Jackson et al. 2016).

Another next-generation biomonitoring tool that has emerged over the past decade is environmental DNA, or eDNA as it is more commonly known (David et al. 2021). An eDNA metabarcoding approach relies on coupling DNA barcoding with high-throughput sequencing platforms (NGS) for multi-species identification. eDNA can be filtered from water, and thus is rapidly becoming an integral biomonitoring tool for better understanding freshwater biodiversity (Pawlowski et al. 2021). The approach relies on amplifying sequences from filtered intracellular and extracellular DNA present in the water column and matching them with sequence libraries. Assessing ecosystems using metabarcoded eDNA promises to advance our assessments of ecosystem health beyond binary outcomes (such as impacted/unimpacted) and move towards more diagnostic frameworks able to identify sources of impairment. eDNA also provides a relatively easy approach to determining the presence of other organisms (e.g., fish) that have important ecological and cultural values (e.g. mahinga kai species). Recently there has been an increase in research using eDNA for assessing species distribution, including its use in detecting non-indigenous species to support existing biosecurity systems. In Von Ammon et al. (2023), eDNA was used in three Aotearoa New Zealand harbours, Waitematā, Whangārei and Pēwhairani (Bay of Islands) to revel biogeographical patterns of non-indigenous species.

In this research I used the Cultural Health Index assessment framework (Tipa and Tierney 2003; 2006) alongside a cultural assessment developed by Ngā Kaihautū o te Waikato to assess cultural health of Kuratau River. Currently, there is no provision in the NPS-FM for cultural health monitoring, however there is guidance for local authorities such as regional councils to work collaboratively with local Iwi and hapū and to enable mātauranga informed monitoring initiatives. The greater subjectivity of cultural health indicators and the challenges with standardising cultural monitoring at a national scale is often discussed as an ongoing challenge with interpreting and implementing cultural assessments. There is a need for alternative monitoring measures that are attune with the values of local Māori and appropriate for the freshwater ecosystems they would like to monitor. Demonstrating that cultural health monitoring measures are complementary to conventional Western indicators in assessing stream health and are not intended to match or replicate conventional assessments, gives further agency to iwi and hapū concerned with monitoring the health of the environment. This would have various positive effects on both te taiao and hapū through the ability to practise kaitiakitanga and mana whakahaere. It could also improve freshwater management at a regional scale by explicitly reflecting the values of Māori in biological assessments, broadening the scope of assessments and increasing understanding of the complex interactions between people and place.

## Study Objectives and Hypotheses

One aim of this research was to combine cultural health monitoring measures with more conventional Western science-based measures to assess changes in stream ecosystem health. Identifying how structural and functional indicators could be connected with cultural indicators for monitoring freshwater would provide a template for future environmental assessments and help further demonstrate the knowledge that cultural indicators can supply. I wanted to compare the performance of the various monitoring approaches selected in assessing stream ecosystem health in the Kuratau River catchment, a tributary of Lake Taupō.

The Kuratau catchment has a range of diverse land uses including Native and Exotic plantation (*Pinus radiata*) forests, pastoral agriculture, and contains a large hydroelectrical scheme (Lake Kuratau) that affects the longitudinal connectivity of the river network. These human activities have been shown to have impacts on ecosystem health in other studies (Allan 2004). Therefore, I made the following hypotheses:

1. Streams impacted by upstream agricultural land uses would have lower values (i.e., more degraded) for indicators of ecosystem health than streams with catchments dominated by native forest (Quinn et al. 1997).

2. Cultural health indicators would be consistent with conventional bioindicators in diagnosing land use impacts. For example, low scores for cultural indicators would be matched with low scores for other indicators such as the MCI (Tipa and Teirney 2003).
3. Cultural health indicators would not be strongly correlated with conventional bioindicators because each approach reflects two different knowledge systems and perspectives (Harmsworth et al. 2011).

# Chapter 2 – Study Area

This research occurred in the rohe of Ngāti Tūwharetoa, ngā hapū o Ngāti Parekawa, Ngāti Manunui, Puukawa, Puketapu, and Ngāti Hinemihi, in the Kuratau River catchment - a tributary of Lake Taupō (Figure 1). The headwaters of Kuratau River are located in Pureora Forest Park and flows eastwards through Waituhi Kuratau Reserve. The river consists of two main branches, Mangaongoki Stream and Kuratau River, supported by many significant tributaries in the fluvial network. The two branches join just prior to Lake Kuratau, upstream of the river's final descent to Lake Taupō. The dominant soil types within the Kuratau River catchment are orthic podzols (27%), orthic pumice soils (26%), and orthic allophanic soils (12%) (Taupō DC 2011). In total, the Kuratau River catchment covers 198 km$^2$ (Taupō DC 2015). As of 2011, land cover within the catchment consisted of around 30% pasture, 4% exotic forest, and around 38% native shrub or forest (Taupō DC 2011). This mix of land cover provided an opportunity to monitor changes in the river at a local scale as it traversed through different dominant land use and compare these changes with upstream land uses to also investigate the changes at larger spatial scales (Figure 2, Table 2).

A major anthropogenic feature in the Kuratau River catchment is the Kuratau power station. This hydroelectric scheme is owned by King Country Energy and operated by Manawa Energy. The dam was commissioned in 1962 and has an annual output of 28 GWh. The hydro lake has a boat ramp and offers opportunities for recreation including trout fishing.

Initially, fifteen sites along the reach of Kuratau River were selected for sampling. This included two sites currently monitored for State of Environment (SOE) monitoring, a site below the hydro lake, and four sites each per dominant land use type which identified as pasture, pine forestry and native shrub or bush. However, due to issues with site access or a lack of wadable habitat, ten sites were selected for this research (Figure 2, Table 2).

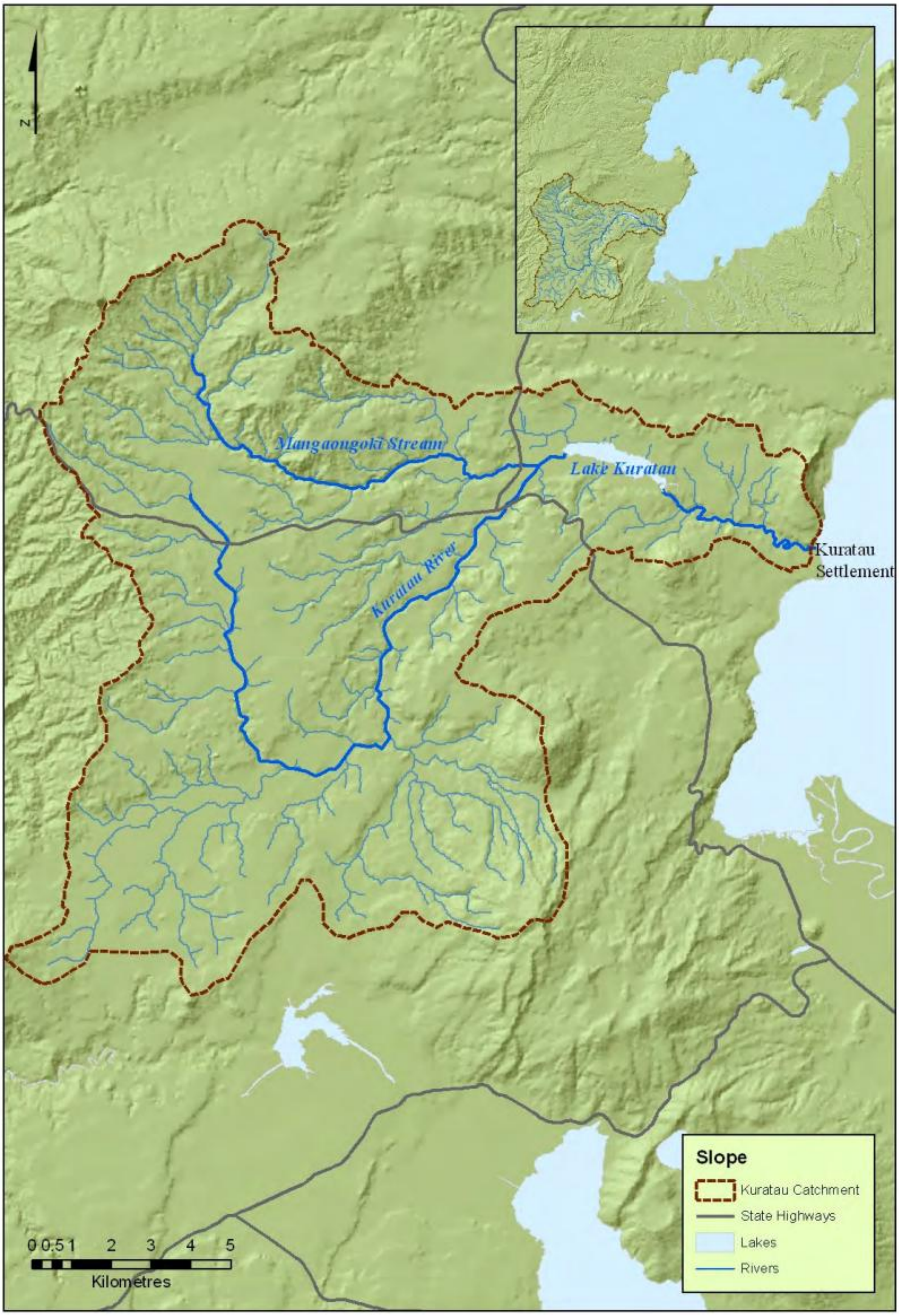

*Figure 1* Kuratau River catchment and significant tributaries. Image sourced from Taupō District Council.

Upstream land uses at each site were determined from the hierarchical River Environment Classification (REC). The REC is a valuable tool for riverine habitat classification in New Zealand (Snelder and Biggs 2002) and describes a range of factors influencing water quality (e.g., land cover, climate, topography, and geology). It is widely used for understanding water quality patterns in New Zealand (Larned et al. 2005) but is not without limitations (Snelder et al. 2004). The REC indicated that the dominant land cover for five sites was indigenous forest, whereas the other five sites were dominated by pastoral land uses (Table 2).

Kuratau River catchment was selected for this research due to the diverse land cover, the river's location relative to Taupō moana (Lake Taupō) and place within the rohe of Ngāti Tūwharetoa. Kuratau River is part of the 1992 agreement between the Crown and the Tūwharetoa Māori Trust Board, meaning that the title to a major part of the riverbed has now transferred from the Crown back to Ngāti Tūwharetoa through the Taupō-Nui-a-Tia Management Board.

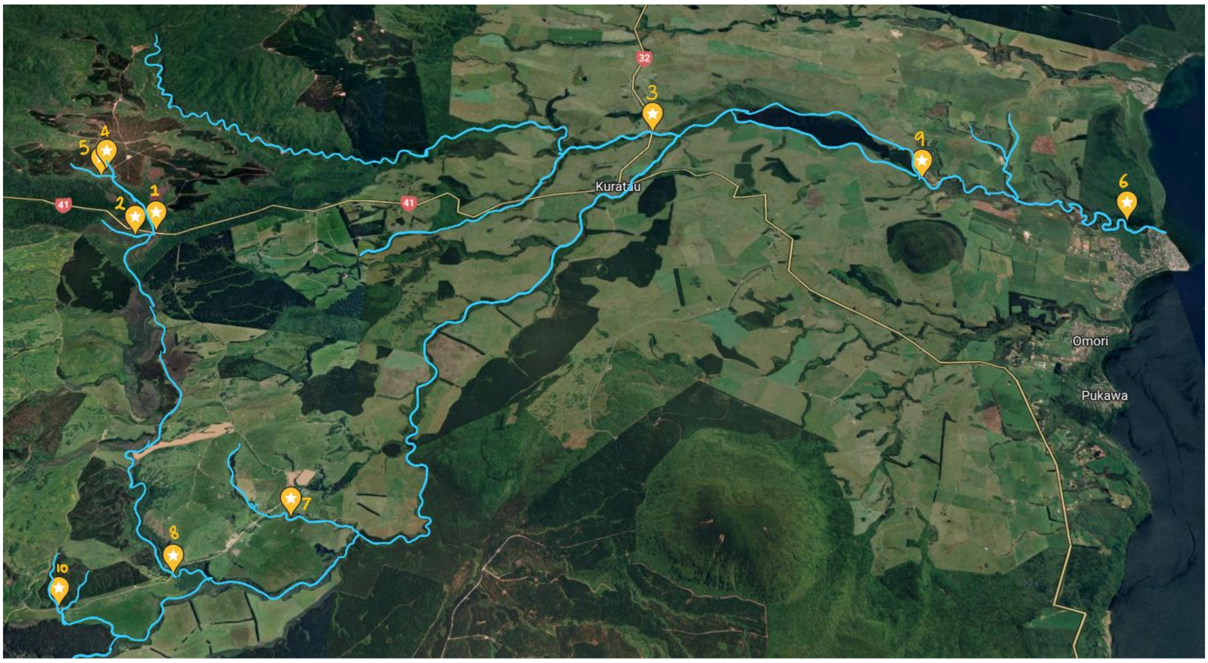

*Figure 2* Aerial photo of the Kuratau River catchment showing study sites (Table 3) and the mixed land-uses of the catchment. The main stream channels are indicated by the blue line, study sites with the orange markers.

*Table 2* Site characteristics of the 10 reaches sampled in the Kuratau River catchment for this research. REC, River Environment Classification (Snelder and Biggs 2002).

| Site # | Stream/River | Soil Type | Locally Dominant Land Use | REC Upstream Land Cover |
|---|---|---|---|---|
| 1 | Kuratau River | Acid Fibric Organic Soils | Native (Podocarp-Hardwood Forest & Scrub) | Indigenous Forest |
| 2 | Tributary Waituhi-Kuratau | Acid fibric organic Soils | Native (Podocarp-Hardwood Forest & Scrub) | Indigenous Forest |
| 3 | Mangaongoki Stream | Podzolic Orthic Pumice soils | Pasture (Low & High Intensity Pasture) | Indigenous Forest |
| 4 | Te Roto Stream | Humose Orthic Podzols | Pine (Exotic Forest & Native Scrub) | Indigenous Forest |
| 5 | Kuratau River | Humose Orthic Podzols | Native (Mixed Native Scrub) | Indigenous Forest |
| 6 | Kuratau River | Podzolic Orthic Pumice Soils | Mixed (Pasture, Mixed Native Scrub, & Peri-Urban) | Pasture |
| 7 | Tributary of Kuratau River | Typic Orthic Pumice Soils | Pasture (High Intensity) | Pasture |
| 8 | Kuratau River | Typic Orthic Pumice Soils | Pasture (Low Intensity & Native Scrub) | Pasture |
| 9 | Kuratau River | Podzolic Orthic Pumice Soils | Mixed (Low & High Intensity Pasture & Mixed Native Scrub) | Pasture |
| 10 | Tributary of Kuratau River | Podzolic Orthic Pumice Soils | Pine (Exotic Forest, Pasture, & Mixed Native Scrub) | Pasture |

The Kuratau River has been monitored monthly as part of Waikato Regional Council's State of Environment (SOE) water quality monitoring programme which began in 1991. The upper reach is monitored where the river crosses under SH41, and the lower reach is monitored close to the river mouth in the settlement of Omori-Kuratau beside Lake Taupō. As previous research has shown increases in nutrients such as nitrogen and phosphorous negatively impact lake water quality, increases in nutrient loads entering Lake Taupō via inflowing streams and rivers is closely monitored. Ten-year trend data for Kuratau river measured between 2002 and 2011 showed total nitrogen (TN) concentrations had increased at a rate of change of 2.8% per year (Vant 2013).

Table 3 details the water quality monitoring data collected from the upper and lower monitoring sites on the Kuratau River in 2021, and 5-year median values for fourteen variables collected monthly between 2017-2021.

*Table 3*. State of Environment sampling data on 14 water quality variables from monthly sampling of upper Kuratau river near Moerangi, and lower Kuratau river at Te Rae St, Omori in 2021. 5-year median values for each site from 2017-2021 included (Salu 2023). No black disc measurements are collected from Te Rae St site.

| Water quality variable | Site | Mean | Median | Min | Max | 5-year median |
|---|---|---|---|---|---|---|
| Black Disc (m) | Upper | 3.4 | 3.8 | 1.7 | 4.9 | 2.8 |
| | Lower | - | - | - | - | - |
| *Escherichia coli* (CFU/100 mL) | Upper | 51 | 48 | 9 | 120 | 19 |
| | Lower | 101 | 100 | 22 | 250 | 70 |
| Conductivity (ms/m) | Upper | 4.2 | 4.2 | 3.4 | 5.1 | 4.2 |
| | Lower | 7.6 | 6.9 | 5.4 | 11.9 | 6.8 |
| Dissolved oxygen (%) | Upper | 93 | 93 | 88 | 96 | 94 |
| | Lower | 97 | 100 | 73 | 104 | 99 |
| Dissolved oxygen (g m$^{-3}$) | Upper | 9.6 | 9.8 | 8.5 | 10.8 | 9.9 |
| | Lower | 9.7 | 9.9 | 7.1 | 11.0 | 9.9 |
| Dissolved Reactive Phosphorus (g m$^{-3}$) | Upper | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| | Lower | 0.006 | 0.002 | 0.002 | 0.002 | 0.004 |
| Total Phosphorus (g m$^{-3}$) | Upper | 0.007 | 0.006 | 0.002 | 0.011 | 0.005 |
| | Lower | 0.016 | 0.015 | 0.011 | 0.032 | 0.013 |
| Ammoniacal Nitrogen (g m$^{-3}$) | Upper | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 |
| | Lower | 0.007 | 0.005 | 0.005 | 0.015 | 0.005 |
| Nitrate/Nitrite (g m$^{-3}$) | Upper | 0.08 | 0.08 | 0.07 | 0.12 | 0.16 |
| | Lower | 0.62 | 0.60 | 0.31 | 1.12 | 0.63 |
| Total Kjeldahl nitrogen (g m$^{-3}$) | Upper | 0.06 | 0.06 | 0.03 | 0.14 | 0.08 |
| | Lower | 0.11 | 0.10 | 0.07 | 0.15 | 0.13 |
| Total Nitrogen (g m$^{-3}$) | Upper | 0.14 | 0.14 | 0.09 | 0.21 | 0.26 |
| | Lower | 0.73 | 0.67 | 0.44 | 1.22 | 0.79 |
| Turbidity (NTU) | Upper | 2.0 | 1.8 | 1.1 | 3.4 | 1.7 |
| | Lower | 1.2 | 1.0 | 0.6 | 3.5 | 1.3 |
| pH | Upper | 6.9 | 7.0 | 6.5 | 7.2 | 7.1 |
| | Lower | 7.3 | 7.3 | 6.7 | 7.7 | 7.4 |
| Temperature (˚C) | Upper | 10.5 | 10.8 | 7.3 | 14.1 | 9.9 |
| | Lower | 14.0 | 13.8 | 8.4 | 21.0 | 12.8 |

Results of 5-year average values for the Kuratau River in 2021 showed that dissolved oxygen (mean = 9.6 $gm^{-3}$, median = 9.7 $gm^{-3}$), DRP (0.002 $gm^{-3}$, 0.006 $gm^{-3}$), ammonia (0.005 $gm^{-3}$, 0.007 $gm^{-3}$) and nitrate-nitrite (0.08 $gm^{-3}$, 0.62 $gm^{-3}$) all returned values within the NPS-FM 2020 attribute Band A for each variable.

Waikato Regional Council's 30-year water quality trends in the Waikato region report detailed trend slopes (% per year) and slope direction probabilities (%) for monthly records of flow-adjusted water quality variables from 1991 – 2020 (Vant 2021). This report determined there was an important deterioration in total nitrogen (TN) in most parts of the Waikato region over the past 30 years, including Kuratau River. At the upper Kuratau river site there was an important deterioration in total nitrogen with the rate of change observed being 2.5% per year, which is well above the regional median trend slope for TN of 1.4% per year. There was also an important deteriorating change detected (2.6 % per year) for Nitrate-N. All other monitored values did not show an important trend in improvement or deterioration. The lower Kuratau river site located at Te Rae St, Omori measured slightly below the regional median trend slope for TN and Nitrate-N. An important improvement was determined for Total Phosphorus 1.3% per year and Dissolved Reactive Phosphorus (DRP) 1.8% per year. No other monitored values on the lower Kuratau River returned significant trends in improvements of deteriorations (Vant 2021).

REC landcover for Sites 1-5 was classified as dominantly indigenous forest. Site 1 (Fig.3A) and site 2 (Fig.3B) are located in the upper catchment near SH41. Site 3 (Fig. 3C) is the only site on the left branch of Kuratau River (Mangaongoki Stream) and was located just prior to the confluence of the two branches. The headwaters of Mangaongoki stream are located within the forests of Hauhungaroa Ranges. Site 4 (Fig.3D) and Site 5 (Fig.3E) are the headwaters of the right branch of Kuratau River. The dominant land-use type classified by REC for sites 6-10 is pasture. Three of these sites were located on Moerangi Station (Fig. 4A, 4B), including site 8 (Fig. 4C), the main stem of the right branch of Kuratau River. Sites 6 (Fig 4D) and 9 (Fig 4E) are located below Lake Kuratau, and at the lowest reach of the river, at the outlet to Lake Taupō.

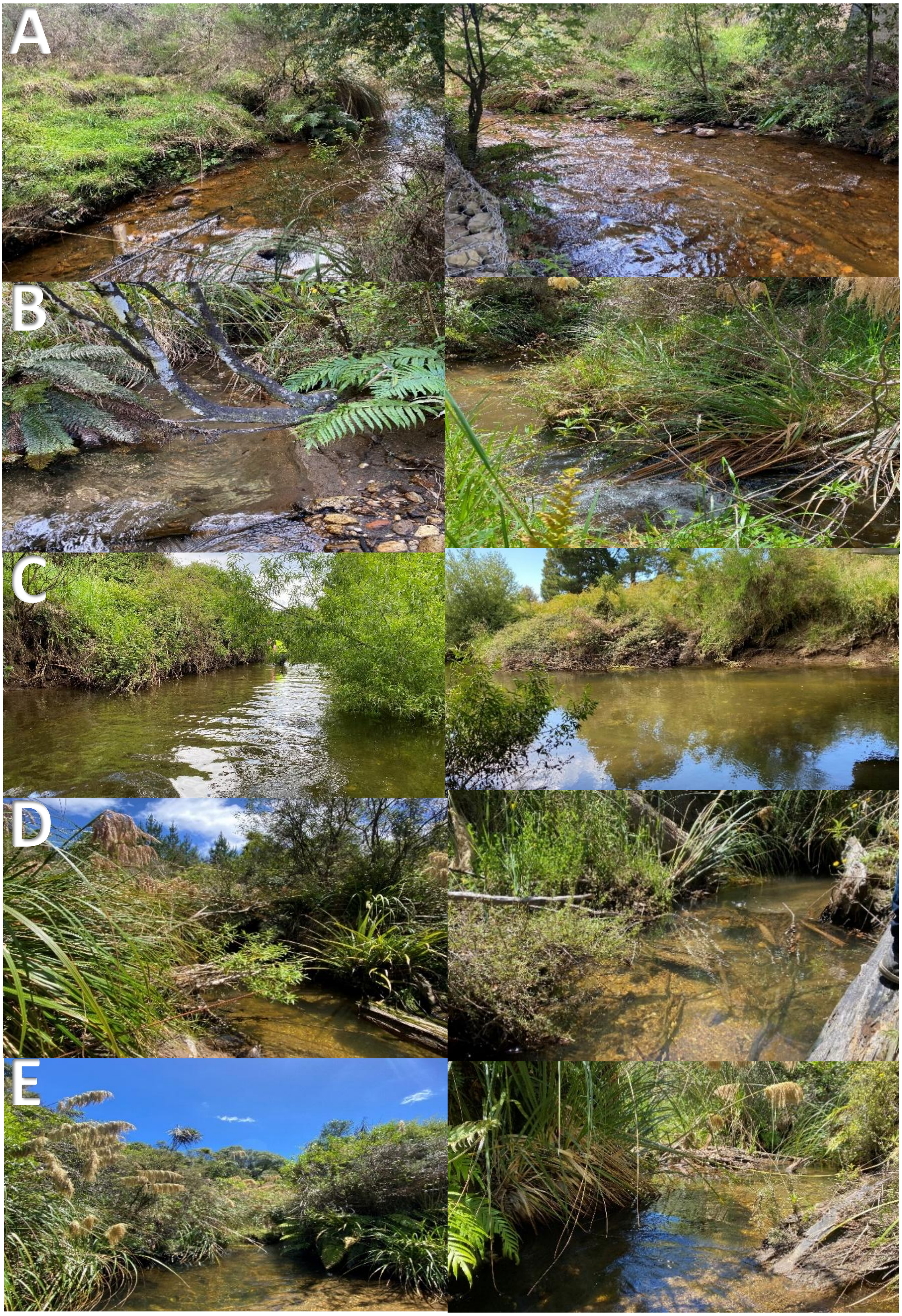

*Figure 3* Sites 1-5 upstream (left), downstream (right). Kuratau River (A), Tributary (B), Mangaongoki Stream (C), Te Roto Stream (D), Kuratau Headwater (E).

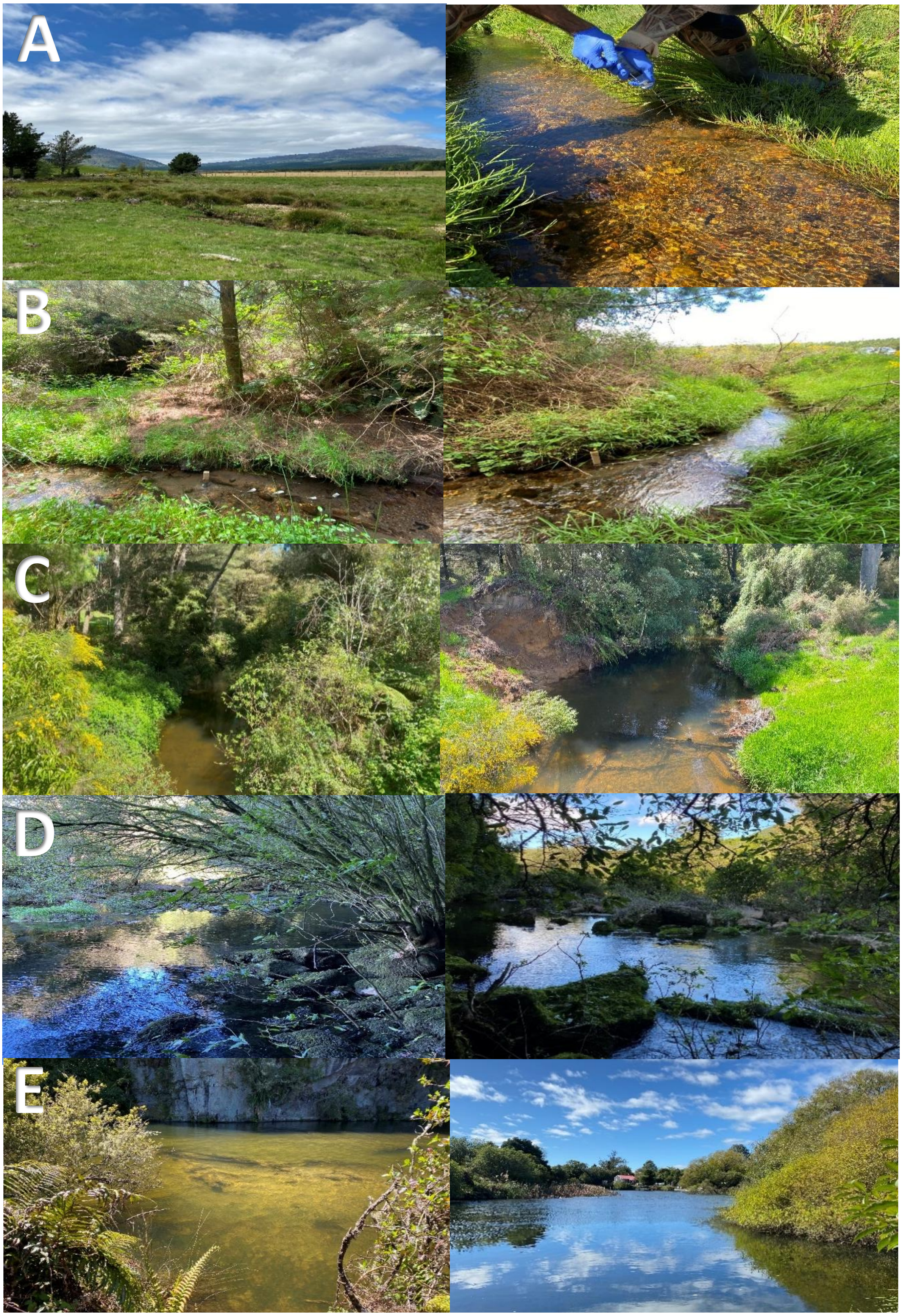

*Figure 4* Sites 6-10 Upstream (left), downstream (right). Moerangi Tributary Pasture (A), Moerangi Tributary Pine (B), Kuratau River – Moerangi (C), Kuratau River – Below Lake Kuratau (D), Kuratau River mouth (E).

# Chapter 3 - Methods

## Environmental Indicators

### Physicochemical

At each site, water temperature (°C), dissolved oxygen concentration (mg/l and percentage saturation), and conductivity (ambient and specific conductivity, measured as µS/cm) values were recorded using a YSI Pro2030 Dissolved Oxygen and Conductivity Meter (YSI Inc., Yellow Springs, OH, USA). The YSI Pro2030 was calibrated at each site prior to sampling. pH was measured using an EC-PCTestr35 handheld probe (Eutech Instruments Pte Ltd, Paisley, UK). These indicators were recorded twice from each site at base flow conditions between 10am and 2pm in the day during summer. For data analyses I used the mean values for each site.

### Water Quality

Water samples were collected for laboratory analyses at each site following the protocols outlined in the National Environmental Monitoring Standards (NEMS) for surface water monitoring. Water samples were collected just below the surface at the channel thalweg using a sampling pole (Mighty Gripper Pole, Whangarei, NZ). A 1 L bottle was used to collect a sample for suspended solids (as an indicator of turbidity) and additional bottles were used to collect a 500 ml sample for microbial analysis, a 500 ml sample for Total Nitrogen (TN) and Dissolved Reactive Phosphorus (DRP), and a 100 ml sample containing sulphuric acid as a preservative for Total Ammoniacal-N, Nitrate-N and Nitrite-N, Total Kjeldahl Nitrogen (TKN), and Total Phosphorus (TP). Water samples were collected once from each site at base flow conditions. All samples were sent to Hill Laboratories (Hamilton, NZ) for analysis.

*Nutrients*

Nutrient concentrations were measured to target key attributes in the NPS-FM that are required for State of the Environment (SOE) monitoring for water quality. These attributes included Total Nitrogen (all forms of nitrogen measured), Total Oxidised Nitrogen (Nitrate-N + Nitrite-N; soluble forms available for plant growth), Total Kjeldahl Nitrogen (the sum of ammoniacal nitrogen and organic nitrogenous compounds), Ammoniacal Nitrogen (ammonia and ammonium), Dissolved Reactive Phosphorus (soluble forms that supports eutrophication), and Total Phosphorus (dissolved, particulate, inorganic and organic phosphorus).

### *Faecal coliforms*

The faecal indicator *Escherichia coli* is a naturally occurring bacteria that lives within the intestines of mammals and birds and is used as a faecal bacteria indicator. The presence of *E. coli* in waterways, measured in colony forming units (CFU) per 100 mL, is used to indicate faecal contamination and the potential presence of other harmful contaminants and pathogens.

### *Water clarity*

Water clarity was measured visually using a 5-m long telescopic pole with a black disc attached at the end and a viewing chamber. The diameter size of the black disc varied depending on the resulting clarity measurements and varied between 60 mm and 200 mm. As clarity was always greater than 0.5 mm, a 20 mm disc was not needed. As outlined in the NEMS for surface water, black disc measurements resulting less than 1.5 m were measured using a 60 mm disc, and measurements greater than 1.5 m were measured using a 200 mm diameter disc. Black disc measurements were taken by looking through a viewing chamber with an angled mirror to allow for viewing vertically under the water, then by slowly moving the black disc away and recording the distance between the viewer and the disc. Two measurements were recorded, the first being the distance the disc disappeared, and the distance it reappears.

## Habitat Assessment

### *Rapid Habitat Assessment*

Instream and riparian habitat at each site were quantified using rapid habitat assessment approaches. These approaches used the P2c, and P2d Stream Habitat Assessment Protocols (SHAP) described in Harding et al. (2009). The P2c protocol involves visual assessment of the percentage of riffle, run, and pool habitat present in the stream reach, with various parameters of stream bed substrate composition, organic matter and fish habitat measured for each of the three habitat types. The P2d protocol involves the scoring of thirteen riparian attributes 1-5 on each bank, and summing the average score for each attribute to derive a Riparian Condition Index, where higher scores indicate more intact higher quality riparian habitat.

### *Fine Sediment*

Benthic substrate composition and deposited fine sediment (DFS) were determined using the two main Sediment Assessment Methods (SAM) described in Clapcott et al. (2011). Fine sediment (< 2mm) is widely recognised as an important pollutant of aquatic habitats that is often associated with human impacts on streams and rivers (Hughes 2016). Deposited fine sediment is a major stressor in stony-bottomed stream and river due to its ability to smother benthic habitat, degrade food resources, cause physical harm through abrasion and gill-clogging, and contribute to increased turbidity (reducing light attenuation), thus negatively impacting stream health (Burdon et al. 2013).

Benthic substrate composition was assessed using the SAM3 protocol (Clapcott et al. 2011). This involved one hundred individual substrate samples selected randomly (i.e., using the Wolman walk) at each site throughout the study reach. Each substrate sample was recorded and categorized based on its size. In order from largest to smallest, these were the substrate size categories recorded: bedrock, boulder (>264 mm), cobble (64–264 mm), gravel (8–64 mm), fine gravel (2–8 mm), sand (0.6–2 mm), and silt (<0.6 mm).

The SAM2 method relies on visual observations of DFS on the streambed. It involves five randomly selected transects across the stream channel within the study reach (Clapcott et al. 2011). The streambed was observed using a bathyscope (underwater viewer) at four randomly selected points along each transect. The visible percentage of DFS cover observed in four quadrants in the bathyscope was estimated and recorded. This process was then repeated for the next four transects, resulting in a total of twenty independent observations taken (Clapcott et al. 2011).

## Structural Indicators

### Macroinvertebrates

Macroinvertebrates are defined as any water-dwelling invertebrate retained by a 0.5 mm mesh (Hauer and Resh 2007). Macroinvertebrates generally occupy benthic habitats in rivers and streams. Benthic macroinvertebrate samples were collected following the guidelines outlined in the National Environmental Monitoring Standards (NEMS 2022). Sites were sampled between 28 October 2022 and 07 April 2023.

Invertebrate samples were collected from each site using a triangular-frame kick net with a 500 µm mesh. The sampling targeted the most commonly available wadeable mesohabitats (e.g., riffles, runs) within the site reach, and the reach length was approximately 20 times the average channel width. One single composite sample comprised of 4–8 unit efforts (subsamples) collected from mesohabitats (fine gravel, rocks, wood, roots). The kick net was placed downstream of the sampled area to catch invertebrates as they drifted with the flow to escape disturbance. Once a suitable area of streambed was sampled (0.6-0.9 $m^2$), the sample was submerged in 70% ethanol and transported to the laboratory for processing and identification of macroinvertebrate taxa.

In the laboratory, macroinvertebrate processing followed the NEMS 200+ fixed count and scanned for missed taxa protocol (NEMS 2022). Samples were rinsed through a clear 0.5 mm sieve and transferred in equal amounts to four white plastic sorting trays. Water was added to each tray to help separate invertebrates from remaining detritus, sticks, leaf litter etc. Invertebrates and were removed using forceps and placed into petri dishes for identification. Each tray was processed until a minimum of two hundred individual macroinvertebrates were removed. Each individual was then examined under a stereo microscope and identified to the lowest practicable level (generally Genus, but Order and/or Family in some instances) using standard guides (Winterbourn et al. 2006). All individuals were grouped and counted to their identified taxon to enable the calculation of macroinvertebrate indices.

I wanted to test differences across site types using macroinvertebrate indices of stream health. The indices I used were the Macroinvertebrate Community Index (MCI), its quantitative equivalent (QMCI), the Average Score Per Metric (ASPM) and its constituent parts (EPT richness, %EPT abundance), and taxa richness. The MCI is a metric that uses taxa tolerance scores to determine an overall score of stream health based on taxa presence. The MCI score is calculated using the following formula (Eq.1):

$$\mathrm{MCI} = \frac{\sum_{i=1}^{i=S} a_i}{S} \times 20 \tag{1}$$

where $S$ = the total number of taxa in the sample, and $a_i$ = the tolerance value for the $i$th taxon. MCI scores range from 0 (where no scoring taxa are present) to 200. The Quantitative MCI (QMCI) is calculated from count (abundance) data using the following formula (Eq.2):

$$\mathrm{QMCI} = \sum_{i=1}^{i=S} \frac{(n_i \times a_i)}{N} \tag{2}$$

Where S = the total number of taxa in a sample, $n_i$ = the abundance for the $i$th scoring taxon, $a_i$ = the tolerance value for the $i$th taxon and $N$ = the total abundance of the scoring taxa for the entire sample.

I also calculated the ASPM index and its constituent parts which includes the MCI. The ASPM also uses the richness and relative abundance of Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa. These taxa are generally sensitive to environmental degradation and belong to the orders of aquatic insect more commonly known as mayflies, stoneflies, and caddisflies, respectively. EPT (% EPT abundance) is calculated from the total number of individuals belonging to the EPT orders divided by the total number of macroinvertebrates present within a sample (and multiplied by 100). EPT richness is simply the number of EPT taxa present in a sample. High percentages and richness of EPT taxa indicates good stream health, but can be influenced by naturally occurring processes. For example, some soft-bottomed streams have naturally low abundances and richness of EPT taxa, because most EPT taxa generally prefer stony and rocky stream habitat (rheophilic). The ASPM is a multi-metric index developed by (Collier 2008) and is calculated as the average scores for %EPT-abundance (normalized to 100), EPT-richness (normalized to 29), and the MCI (normalized to 200) following the protocols stated in the NPS-FM. The ASPM is calculated by taking the mean of the three metrics after being normalised. I also calculated the ASPM index using value from a local reference site (Site 5), to normalise it according to the conditions in the Kuratau River catchment (and also account for any errors in taxonomic identification of EPT).

## Environmental DNA

Environmental DNA (eDNA) was sampled using the methods for Wilderlab (Wellington, NZ) as described in Wilkinson et al. (2024). Briefly here, eDNA sampling involved the six-replicate sampling method recommended for streams. At each site, a Wilderlab eDNA six-replicate kit was used. Each kit contained six encapsulated 30 mm diameter, 1.2 µm cellulose acetate syringe filters with luer-lock inlet and outlet fittings, two 60 mL luer-lock syringes, and 350 µl DNA/RNA Shield preservation buffer (Zymo Research, Irvine, CA, USA) pre-loaded in six 3 mL luer lock syringes, and two pairs of sterile nitrile gloves.

Two approaches were used to collect eDNA samples. If the river was accessible and wadeable, the sample was collected directly from the river. While standing in the river, water was taken using the 60 mL syringe. A second approach was used at sites where the river was unwadeable (or difficult to access). Some sites had seasonally variable flow levels with high base flows at the time of sampling, thus requiring an alternative approach to sampling eDNA. This approach used 1000 mL sterile High-Density Polyethylene (HDPE) bottles (Stowers, Auckland, NZ) to collect water from the river using a sampling pole (Mighty Gripper Pole, Whangarei, NZ). The sample water was then poured into a sterile 1 L glass measuring jug, and the Wilderlab 60 mL syringe then used to filter water from the jug.

In both approaches, 50 mL water was measured using the large syringe. The filter was then connected to the end of the syringe, and the water was pushed through the filter. This was repeated up to twenty times per filter – to a max of 1000 mL, or until the filter was clogged. Exact measurements of water filtered were recorded. Excess water was then pushed out of the filter and the preservative added using the 3 mL luer lock syringe provided. The same filtration steps were repeated for six filters at each site.

Filters were then sent to WilderLab for DNA extraction, polymerase chain reaction (PCR) amplification, sequencing, and bioinformatic processing following the methods described in Wilkinson et al. (2024). This approach used DNA metabarcoding, which involves the simultaneous taxonomic identification of Operational Taxonomic Units (OTUs) or Amplicon Specific Variances (ASVs) in eDNA samples with millions of sequences, generated by PCR amplification using high throughput sequencing (HTS) techniques (Wilkinson et al. 2024).

## Functional Indicators

### Decomposition

Cellulose decomposition potential (CDP) at the ten study sites in the Kuratau River catchment was determined using the cotton strip assay (Tiegs et al. 2013; 2019). Cotton strips were prepared from artist's canvas fabric (Fredrix, Style #548) following the methods described by Tiegs et al. (2013). Briefly, strips were cut to a standard size (80 × 25 mm) and stored in a desiccator prior to deployment in the field.

At each study site, four replicate cotton strips were fixed with cable-binders to a metal chain attached to a wooden stake hammered into the stream substrate. Two Blocks, each with four strips, were spaced apart in riffle-type habitat by approximately seven times the bankfull width. Strips were incubated in streams for 27-45 days (median 35 days) beginning in late October 2022, a duration predicted to yield approximately 50% tensile-strength loss in New Zealand conditions (Tiegs et al. 2013). Temperature was recorded hourly in each stream for the duration of the experiment with a HOBO MX2202 water temperature/light level logger (Onset Computer Corp., Bourne, MA, USA).

After incubation, cotton strips were removed and subsequently submerged in a 50 ml centrifuge tube filled with 90% ethanol for 30 seconds and cleaned gently to remove adhering sediment and biofilm. The strips were then placed individually into labelled plastic bags for transport to the laboratory where they were frozen at -20 °C prior to processing in laboratory. The frozen strips were thawed and transferred to aluminium pans, dried at 60 °C for 48 hours, and then stored in desiccators until tensile-strength determination.

The tensile strength (N) of each strip was measured on a tensiometer (Mark-10, Model MG100, Copiague, NY, USA) mounted to a motorized test stand, and pulled at a rate of 2 cm/min. The initial tensile strength of the strips was determined using a set of control strips that were briefly wetted in stream water, sterilised with ethanol, and then processed with treatment strips. Tensile loss was calculated as the breakdown coefficient *k* per day of incubation (Eq.3) following Burdon et al. (2020a):

$$k_D = \frac{-ln\left(\frac{TS_t}{TS_0}\right)}{t} \qquad (3)$$

where $TS_t$ is the maximum tensile strength recorded for each of the strips incubated in the field, $TS_0$ is the mean tensile strength of the control strips that were not incubated in the field, and $t$ is the incubation period (days). I summed the average daily water temperatures over each incubation period to calculate temperature-days (i.e., the temperature-days accumulated from Day 1 to the retrieval day) for $t$ (Benfield et al. 2017); an approach that accounts for temperature effects.

### Primary Production

Periphyton biomass is used as an indicator of ecosystem health, as increased nutrients, temperatures, and light can increase periphyton growth, which may lead to smothering of the stream bed and excessive community respiration during the night. In river and streams that consist of mainly fine sediments, periphyton growth is restricted due to the instability of the substrate, which can be mobilised and therefore cannot support high biomass accrual.

Algal biomass (chl-a mg/m$^2$) was assessed using a portable fluorometer (Benthotorch, BBE Moldaenke, Schwentinental, Schleswig-Holstein, Germany) which quantifies the fluorescence of chlorophyll-a and converts this information to chlorophyll biomass (Kahlert and McKie 2014). The intensity of the chlorophyll fluorescence is used to calculate the different algae as chlorophyll-a, namely green algae, blue-green algae (cyanobacteria) and diatoms. At each site, the Benthotorch was pressed against suitable rocky substrate surfaces until a reading was returned. This was repeated twenty-five times along the sample reach of the river. To adequately characterise flow conditions, on five replicate measurements across the wetted channel were made on five transects withing the sampling reach (25 readings in total). Each measurement was recorded on a field sheet for later analysis.

## Cultural Health Assessment

### Cultural Health Index

The Cultural Health Index (CHI) was created by Gail Tipa and Laurel Tierney (Tipa and Tierney 2003, 2006) as a tool designed to evaluate the health of streams and rivers in a way the encompasses the values and beliefs of iwi, hapū, and whānau. The overall CHI score consists of the scores of all three components – Site Status, Mahinga Kai Value, and the Cultural Stream Health Measure.

## Site Status

Site Status first determines if the site is considered to be of traditional significance to tangata whenua. For this research, this measure was adapted to include not only known traditional connection, such as traditional food sourcing and waahi tapu, but also includes current significance to mana whenua. This included factors such as known current use of the site to gather kai, to restore wai ora (health), or if the site area is held and/or cared for by tangata whenua. Site Status includes a second value that indicates if there is cause for return to the site. The score was determined as A = site is of cultural significance, B = not culturally significant, and 1 = would return, 0 = would not return.

## Mahinga Kai

The Mahinga Kai measure consists of four parts – (a) mahinga kai species present, (b) comparison of species present to traditional species, (c) access to the site to gather, and (d) if tangata whenua would return to the site in the future to gather kai. The calculation of the Mahinga Kai score was also adapted in this research to account for the lack of local knowledge and challenges with quantifying mahinga kai species. Part (a) was determined using eDNA results for both native and exotic mahinga kai species at each site. The included native species were: kōura, kāeo (kākahi) *Echyridella menziesi*, kōaro *Galaxias brevipinnis*, galaxiids, and the exotic species were: brown trout *Salmo trutta*, rainbow trout *Oncorhynchus mykiss*, and salmonids (salmon/trout species). The eDNA of tuna (eels) was not detected at any of the sites and were therefore not included. Other mahinga kai such as vegetation and birdlife presence was determined using the scores given in the CSHM for “Indigenous Vegetation Margins,” “Native Plant species” “Native Bird Species.” Other attributes included from the CSHM in the Mahinga Kai score included the questions “Would you gather kai,” “Is Access suitable” and “Would you return.” The final Mahinga Kai score was calculated by averaging the six associated attributes from the CSHM, and adding an averaged value assigned to the level (very low, low, mod, high, very high) of eDNA sequence counts picked up for each of the seven species listed above. The assigned value was weighted to factor in native/traditional species and exotic/modern species.

### Cultural Stream Health Measure

The final component of the CHI – the Cultural Stream Health Measure (CSHM) was calculated from the average scores recorded at each site for attributes identified by tangata whenua to represent stream or river health. The CSHM assessment used in this research included a combination of the traditional CSHM which encompass the cultural indicators included in Tipa and Tierney (2003, 2006), and a cultural health assessment developed by Ngā Kaihautū o te awa o Waikato, provided by Tūwharetoa Māori Trust Board (TMTB). The CSHM indicator assessment was carried out in the field at all ten study sites in the Kuratau River catchment. For analysis of the final CSHM score, I averaged the scores for the eight attributes recommended by Tipa and Tierney (2006) derive the "Traditional CSHM". These eight attributes were: "Catchment land use", "Riparian vegetation", "Use of riparian margin", "Riverbed condition/sediment", "Channel modification", "Flow and habitat variety", "Water clarity", and "Water quality". Although similar, these attributes have different descriptors than that used in the Ngāti Tūwharetoa CHI assessment. I used the average of the "Habitat Variability" and "Flow" attributes in the Ngāti Tūwharetoa CHI assessment form for the "Flow and habitat variety" attribute used for the Traditional CSHM.

## Data Analysis

To test my first hypothesis, I analysed differences between the two REC land cover types (Indigenous Forest, Pasture, *n*=5 for each) using a variety of statistical approaches. Univariate differences were analysed using general linear models (GLM). For normally distributed continuous responses I used GLM assuming a Gaussian distribution. For count data (taxa and EPT richness) I used a generalized linear model assuming a Poisson distribution with a log-link function. Where data was nested with multiple measurements per site (decomposition, primary production, fine sediment), I used general linear mixed models (GLMM) with a fixed effect for REC land cover and a random effect term for study site. GLMM were fitted using the *lme4* package in R (Bates et al. 2015). Where data was replicated at the site-level, I also tested differences between individual sites using GLM. Post-hoc comparisons were tested with Tukey's correction for multiplicity using the *lsmeans* package in R (Lenth 2016). Univariate responses were log-transformed where appropriate to improve normality and homoscedasticity. I used permutational multivariate analysis of variance (PERMANOVA) to test differences in benthic macroinvertebrate and eDNA aquatic insect community composition. Community data was Hellinger transformed and converted to a Bray-Curtis similarity matrix. The PERMANOVA model were tested using the *adonis* function in the *vegan* R package (Oksanen et al. 2013). The differences in community composition were visualised with non-metric multidimensional scaling (NMDS) plots. Indicator analysis using *indicspecies* in R (De Cáceres and Legendre 2009) helped highlight taxa characteristic of one land cover type. I also plotted differences among local land-use types (Table 2) to better understand the response of individual sites, but I did not statistically test these due to a lack of replication for exotic forest (*n*=2) and mixed land uses (*n*=2).

To test my second hypothesis, in addition to the GLMs and GLMMs, I also calculated effect sizes for all indicators including the traditional CSHM scores to show congruence in the direction and impact of pastoral land cover relative to native forest cover on stream ecosystem health. I wanted to show that the traditional CSHM provided an equivalent assessment of land use impacts on stream health. I calculated standard mean differences using the *SingleCaseES* R package (Pustejovsky et al. 2023).

To test my third hypothesis, I correlated selected indicators with the traditional CSHM scores to assess potential dissonance in the assessments of stream health. I also plotted selected variables against the traditional CSHM scores to assess the potential relationships. Where there were ecologically significant correlations between the traditional CSHM scores and other indicators, I plotted the data and fitted a linear regression model. A lack of correlations between indicators could be indicative of the complementary nature of approaches as each reflects two different knowledge systems and perspectives, but may also be attributed to low sample size (*n*=10).

All statistical analyses were carried out using R 4.2.2 (R Core Team 2022).

# Chapter 4 - Conventional monitoring

## Environmental Indicators

### Physicochemical

Mean dissolved oxygen (%) values were generally high across all sites (Fig.5a). The highest value at Site 6 below the hydro dam exceeded saturation which was a potential indicator of eutrophication. In contrast, mean water temperatures were lowest in the forested sites, and highest in Site 6 below the hydro dam (Fig.5b). Ambient and specific conductivity generally increased with human land uses, with the highest mean values observed at the two mixed land use sites below the hydro dam (Fig.5c,d). pH was generally circumneutral and unrelated to land use, but the more alkaline values observed at Site 6 were consistent with indications of eutrophication (Fig.5e). The highest water clarity values were observed at the two sites below the hydro dam, whereas water clarity values were generally lower in pastoral and exotic forest land uses (Fig.5f).

I also compared physicochemical indicators across the two REC landcover types (indigenous forest, pasture). There was no significant differences in dissolved oxygen (concentrations and %; Fig.6a,b). Water temperatures were generally warmer in pastoral sites (Fig.6c), but this difference was not statistically significant ($F_{1,8}$=3.80, *P*=0.087). Both ambient and specific conductivity were significantly higher in pastoral sites (Fig.6d,e). Ambient conductivity increased from 31 µS/cm in indigenous forest streams to 56 µS/cm in pastoral sites ($F_{1,8}$=15.5, *P*<0.01). Similarly, specific conductivity increased from 43 µS/cm in indigenous forest streams to 73 µS/cm in pastoral sites ($F_{1,8}$=11.4, *P*<0.01). There was no difference in pH or water clarity between the two landcover types (Fig.6f,g).

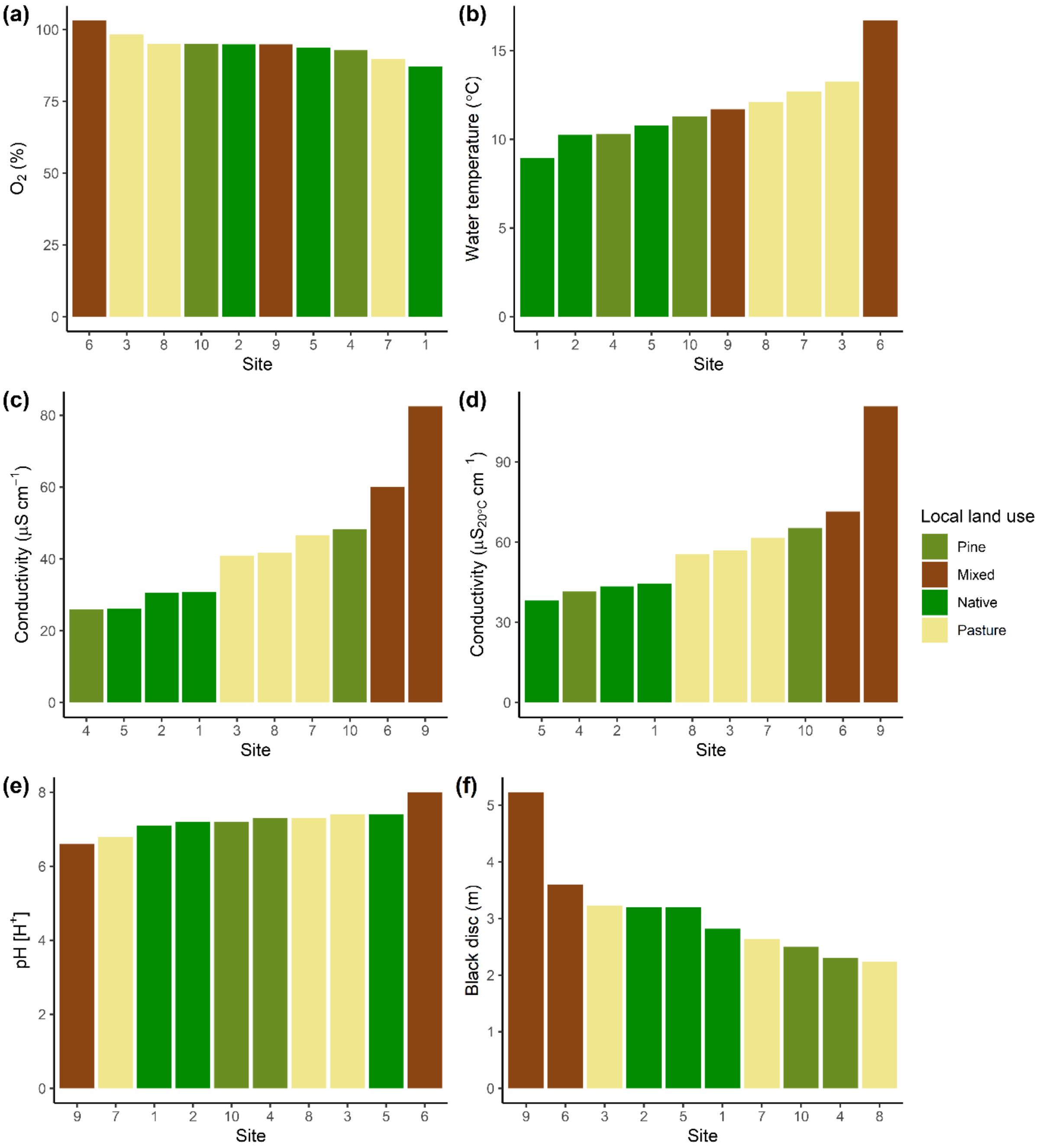

*Figure 5* Ranked bar plots of ten sites located across the Kuratau River catchment for (a) dissolved oxygen (%), (b) water temperature, (c) ambient and (d) specific conductivities, (e) pH, and (f) water clarity. Colours indicate the local land-use type.

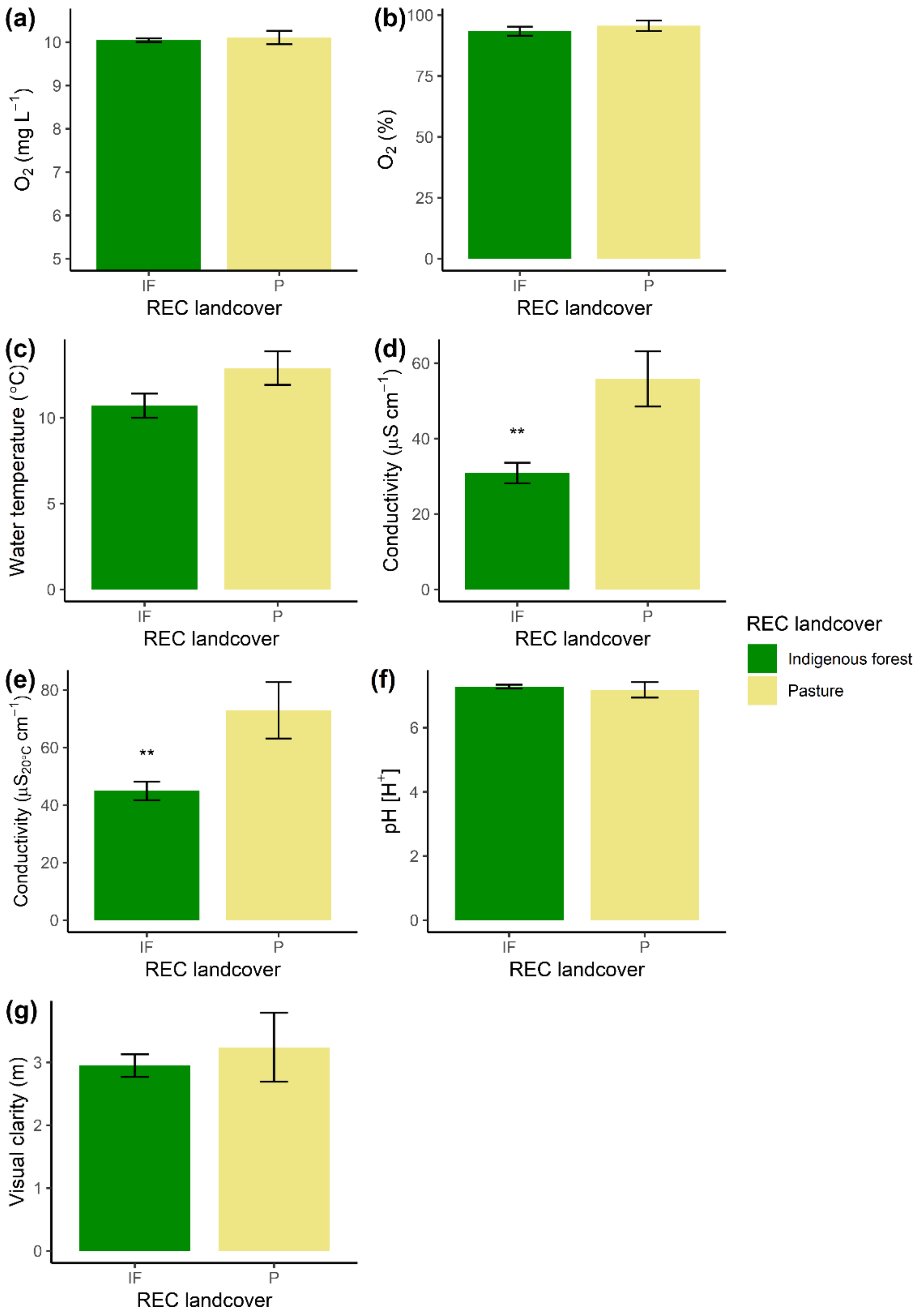

*Figure 6* Bar plots (± SE) for (a) dissolved oxygen (mg/L), (b) dissolved oxygen (%), (c) water temperature, (d) ambient and (e) specific conductivities, (f) pH, and (g) water clarity. The ten sites located across the Kuratau River catchment were grouped by River Environment Classification landcover types (*n*=5). ***P*<0.01

## Water quality

Nutrient concentrations were highly variable across sites (Fig.7). Total nitrogen and nitrate-N concentrations were generally higher in sites affected by human land uses (Fig.7a,b). Seven sites had nitrate-N concentrations in the NPS-FM Band A, whereas three sites were in Band B. Total phosphorus and dissolved reactive phosphorus concentrations were generally low (Fig.7c,d). Site 6 below the hydro dam had extremely high concentrations of DRP, which might be a consequence of a high groundwater contribution at base flow and naturally high phosphorus due to volcanic geologies. Counts of *E. coli* were mostly low, although elevated in pastoral sites (Fig.7e). However, the site with the highest *E. coli* counts was surrounded by exotic forest. The counts at this site were high enough to put it in the NPS-FM D Band, and the source may have been feral deer with extensive evidence of their presence (e.g., droppings).

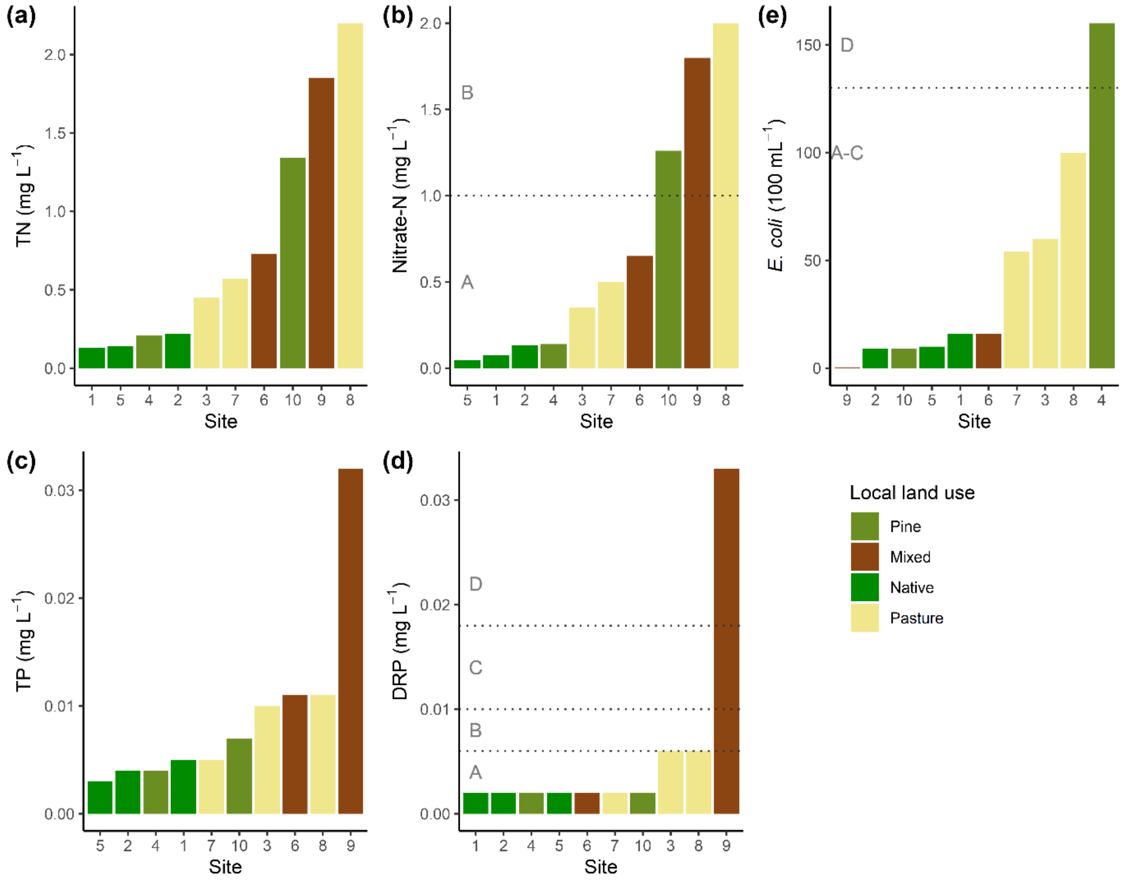

*Figure 7* Ranked bar plots (low to high) of ten sites located across the Kuratau River catchment for concentrations (mg/L) of (a) Total Nitrogen, (b) Nitrate, (c) Total Phosphorus, (d) Dissolved Reactive Phosphorus, and counts (per 100 mL) of the faecal coliform bacteria *Escherichia coli*. Colours indicate the local land-use type. Dotted lines indicate attribute bands for biocriteria (A-D) in the National Policy Statement for Freshwater Management (NPS-FM).

Comparing the water quality attributes across REC landcover types showed that total nitrogen concentrations were significantly higher in pastoral sites ($F_{1,8}$=25.8, $P<0.001$; Fig.8a). A similar pattern of higher nitrate-N concentrations in pastoral sites was also observed ($F_{1,8}$=26.0, $P<0.001$), with the concentrations within the NPS-FM B Band (Fig.8b). Total phosphorus concentrations were higher in pastoral sites, but this difference was not significant at α=0.05 ($F_{1,8}$=4.67, $P$=0.063; Fig.8c). There was no significant differences in DRP concentrations or *E. coli* counts between landcover types (Fig.8d,e). The mean DRP concentrations in the pastoral streams were in the NPS-FM B Band.

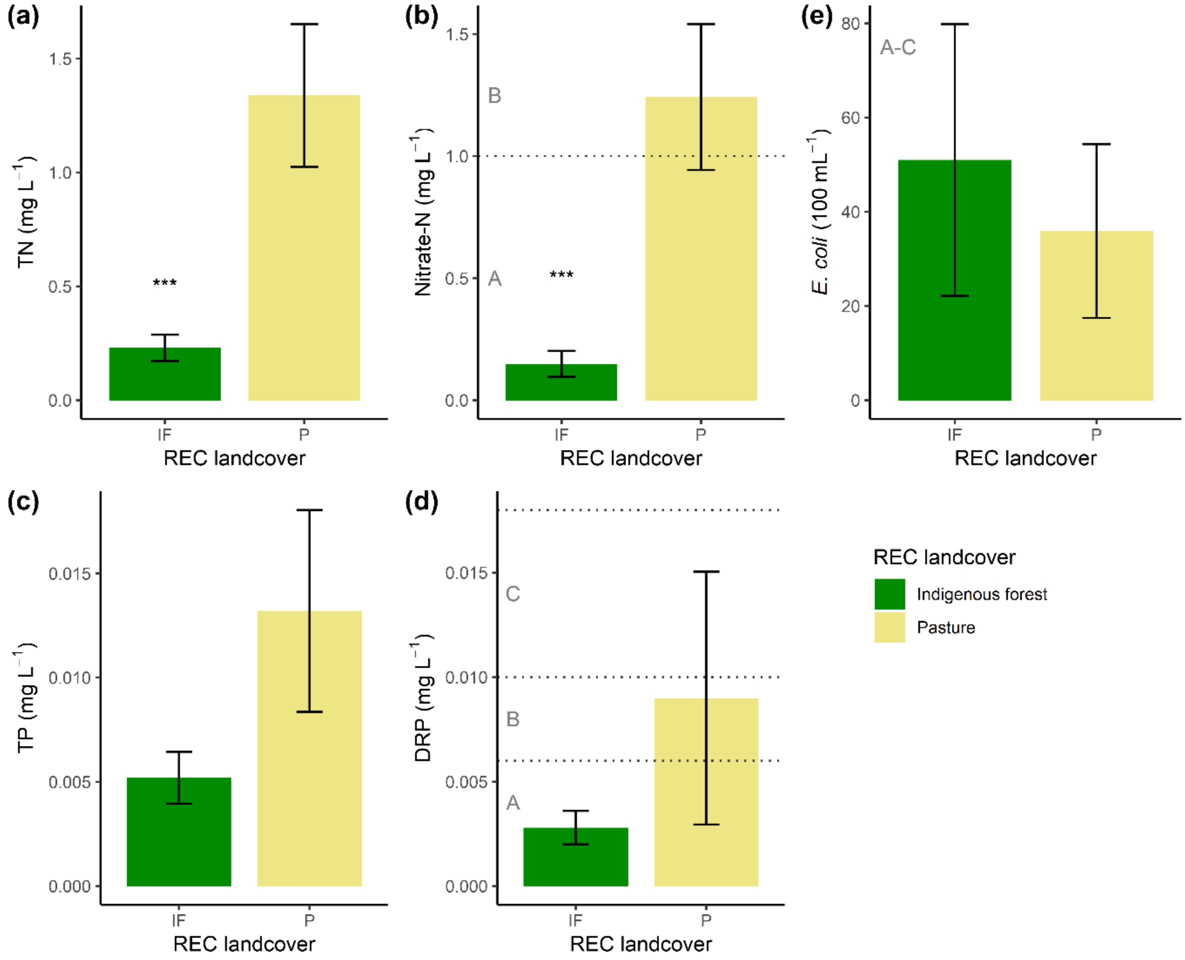

*Figure 8* Bar plots (± SE) for concentrations (mg/L) of (a) Total Nitrogen, (b) Nitrate, (c) Total Phosphorus, (d) Dissolved Reactive Phosphorus, and (e) counts (per 100 mL) of the faecal coliform bacteria *Escherichia coli*. The ten sites located across the Kuratau River catchment were grouped by River Environment Classification landcover types (n=5). Dotted lines indicate attribute bands for biocriteria (A-C) in the NPS-FM, solid lines national bottom lines (D Band). ***$P<0.001$

## Habitat

Deposited fine sediment levels were high, which reflected the underlying volcanic geology with deep soil layers of fine pumice and ash tephra (Fig.9a). Mean sediment levels (% cover) were highest in the most downstream site near the outlet to Lake Taupō (Site 6). The lowest sediment levels were in Site 9, directly below the hydro dam which was indicative of armouring and loss of a natural sediment regime (Fig.9a). Based on the NPS-FM, most of the sites (7) were in Band D for the deposited sediment attribute, with one in Band C, and two in Band A. Deposited fine sediment cover was higher in REC pastoral sites when compared to the indigenous forest sites (Fig.9b), but this difference was not significantly different.

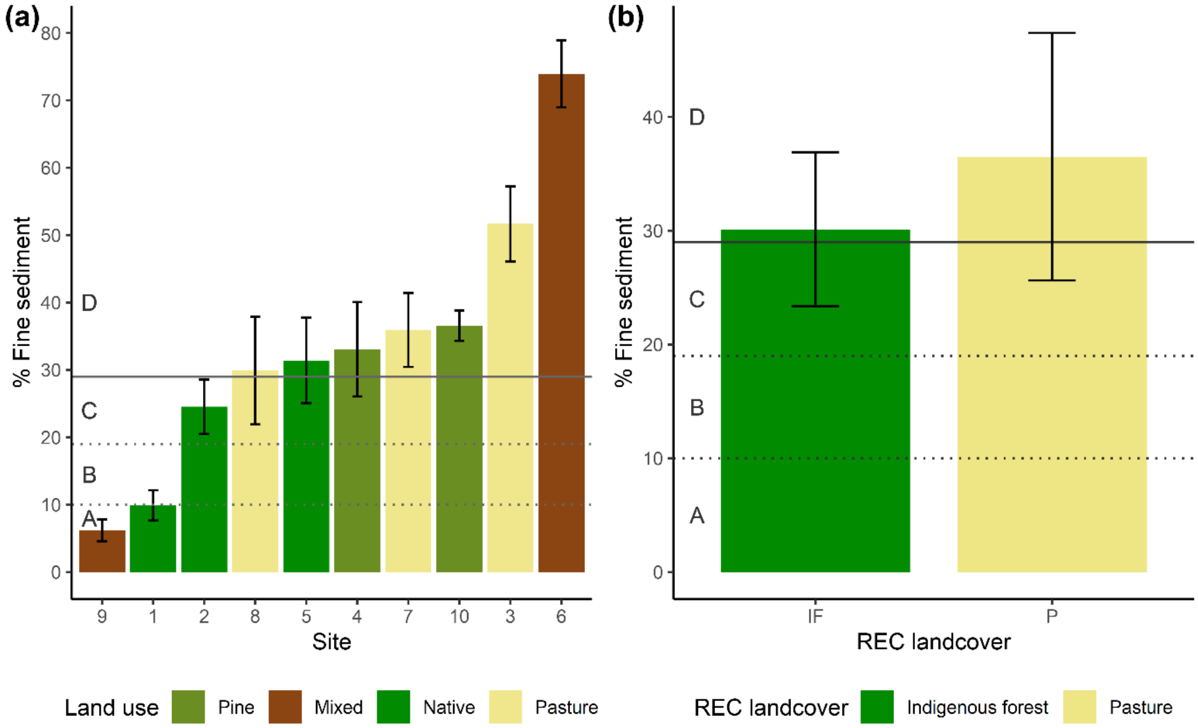

*Figure 9* Deposited fine sediment cover (%) at ten sites located across the Kuratau River catchment. (a) Ranked bar plots (± SE) going from low sediment cover to high sediment cover. Colours indicate the local land-use type. (b) Bar plots (± SE) for sites grouped by River Environment Classification landcover types (*n*=5). Dotted lines indicate attribute bands for biocriteria (A-C) in the NPS-FM, solid lines national bottom lines (D Band).

I used the Riparian Condition Index (RCI) to assess the quality of riparian habitat across study sites. The highest RCI scores were observed in the native forest reference sites (Fig.10a). In general, riparian condition declined with human land uses, and the lowest RCI score was recorded at Site 7, a pastoral site with little to no riparian management. Mean RCI scores were higher in the indigenous forest landcover sites when compared to the pastoral sites (Fig.10b), but this difference was not statistically significant ($F_{1,8}$=0.435, $P$=0.528).

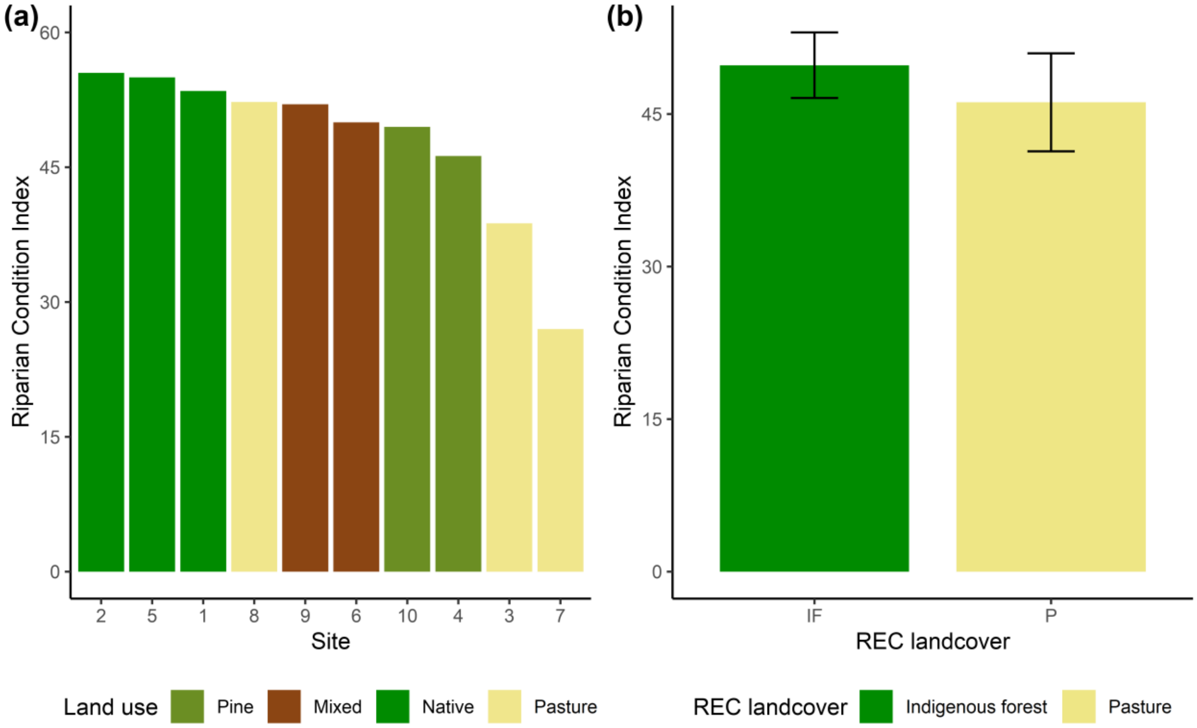

*Figure 10* Deposited fine sediment cover (%) at ten sites located across the Kuratau River catchment. (a) Ranked bar plots (± SE) going from low sediment cover to high sediment cover. Colours indicate the local land-use type. (b) Bar plots (± SE) for sites grouped by River Environment Classification landcover types (*n*=5). Dotted lines indicate attribute bands for biocriteria (A-C) in the NPS-FM, solid lines national bottom lines (D Band).

# Structural Indicators

## Macroinvertebrates

Out of the nearly 2550 individual invertebrates enumerated across the ten sites, 52 taxa were identified. The most common taxon was the mayfly *Zephlebia*, followed closely by the mayfly *Coloburiscus*. There was no significant difference in community composition between the two REC landcover types at $\alpha=0.05$ ($F_{1,8}=1.87$, $P=0.07$, $R^2=18.9\%$). However, I was able to identify two indicator taxa for the Indigenous forest sites (Fig.11a). These were the stoneflies *Megaleptoperla* ($P<0.01$) and *Zelandobius* ($P<0.05$). Other common taxa more likely to be associated with the forested sites were the mayflies *Austroclima* and *Coloburiscus* and the cranefly *Aphrophila* (Fig.11a). Common taxa more likely to be associated with pastoral sites included chironomid midges, oligochaete worms, the snail *Potamopyrgus*, and the grazing caddisfly *Pycnocentrodes* (Fig.11a). The two mixed land use sites below the hydro dam were the most different in invertebrate composition when compared to the headwater native forest sites (Fig.11b).

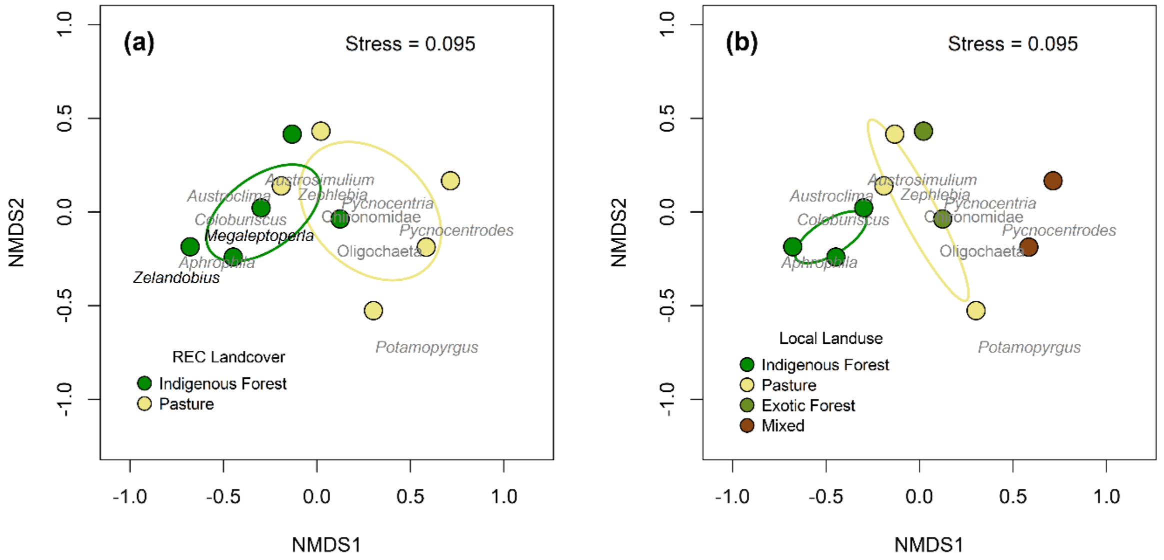

*Figure 11* Non-metric Multidimensional Scaling (NMDS) plots of benthic macroinvertebrates in ten sites located across the Kuratau River catchment. Sites are grouped by (a) REC landcover types, and (b) local land-use types. Indicator taxa for indigenous forest sites are shown in black, common taxa making up 76% of relative abundance are shown in grey.

The MCI scores ranged from 102-141, putting all sites within the NPS-FM bands A–C (Table 4, Fig.12a). Five sites where in the A Band (Pristine), two sites in Band B (Mild Pollution), and the remaining three in Band C (Moderate Pollution). The highest MCI score was observed in a native forested headwater stream of the Kuratau River (Fig.12a). The lowest MCI score was observed in a pastoral headwater stream, however the two mixed land-use sites below the hydro dam were also characterized by low MCI scores (Fig.12a).

*Table 4* Table of macroinvertebrate community indices at ten sites in the Kuratau River catchment. REC, River Environment Classification; IF, Indigenous Forest; P, Pasture; MCI, Macroinvertebrate Community Index and its quantitative equivalent (QMCI); ASPM, Average Score Per Metric index calculated according to the National Policy Statement for Freshwater Management; EPT, Ephemeroptera, Plecoptera, Trichoptera.

| Site | REC land cover | Local land use | Taxa Richness | Diversity | MCI | QMCI | ASPM | EPT-Richness | EPT% |
|---|---|---|---|---|---|---|---|---|---|
| 1 | IF | Native | 30 | 0.90 | 124 | 6.8 | 0.55 | 14 | 54.4 |
| 2 | IF | Native | 26 | 0.86 | 141 | 7.1 | 0.60 | 15 | 59.2 |
| 3 | IF | Pasture | 24 | 0.83 | 130 | 6.9 | 0.70 | 17 | 87.3 |
| 4 | IF | Forestry | 20 | 0.86 | 111 | 4.7 | 0.43 | 10 | 39.8 |
| 5 | IF | Native | 26 | 0.72 | 131 | 7.2 | 0.66 | 16 | 77.4 |
| 6 | P | Mixed | 13 | 0.78 | 103 | 4.3 | 0.49 | 9 | 64.4 |
| 7 | P | Pasture | 13 | 0.71 | 102 | 4.4 | 0.37 | 7 | 36.4 |
| 8 | P | Pasture | 19 | 0.86 | 131 | 6.8 | 0.62 | 14 | 73.0 |
| 9 | P | Mixed | 15 | 0.86 | 108 | 4.9 | 0.47 | 8 | 60.1 |
| 10 | P | Forestry | 16 | 0.81 | 134 | 7.0 | 0.63 | 11 | 84.1 |

The QMCI results ranged from 4.3–7.2 (Table 4). Six sites were >6.5, thus placing them in the A Band (Fig.12b). There were no sites in the B Band, two sites in C Band, and two sites in the D Band (Severe Pollution), which was below the national bottom line. The highest QMCI score was observed in a native forested headwater stream of the Kuratau River. The lowest QMCI score was recorded at Site 6, which was a mixed land-use site just downstream of the hydro dam (Fig.12b).

I calculated the ASPM metric based on the approach recommended in the NPS-FM, in addition to an approach relying on a local reference site (Site 5) following Collier (2008). For the NPS-FM version of the ASPM, I found that it ranged from 0.37–0.70 (Table 4). Five sites were in Band A, four in Band B, and the remaining site in Band C (Fig.12c). The highest scoring site was a pastoral site with headwaters dominated by native forest, whereas the lowest scoring site a pastoral headwater stream. Using a local reference site to calculate the ASPM index increased the range to 0.62–0.90 (Table 4) and suggested that seven sites were in Band A, with the remaining three sites in Band B (Fig.12d). This approach did change the ranking of some sites, but the highest and lowest scoring sites remained the same as the NPS-FM version of the ASPM (Fig.12c,d).

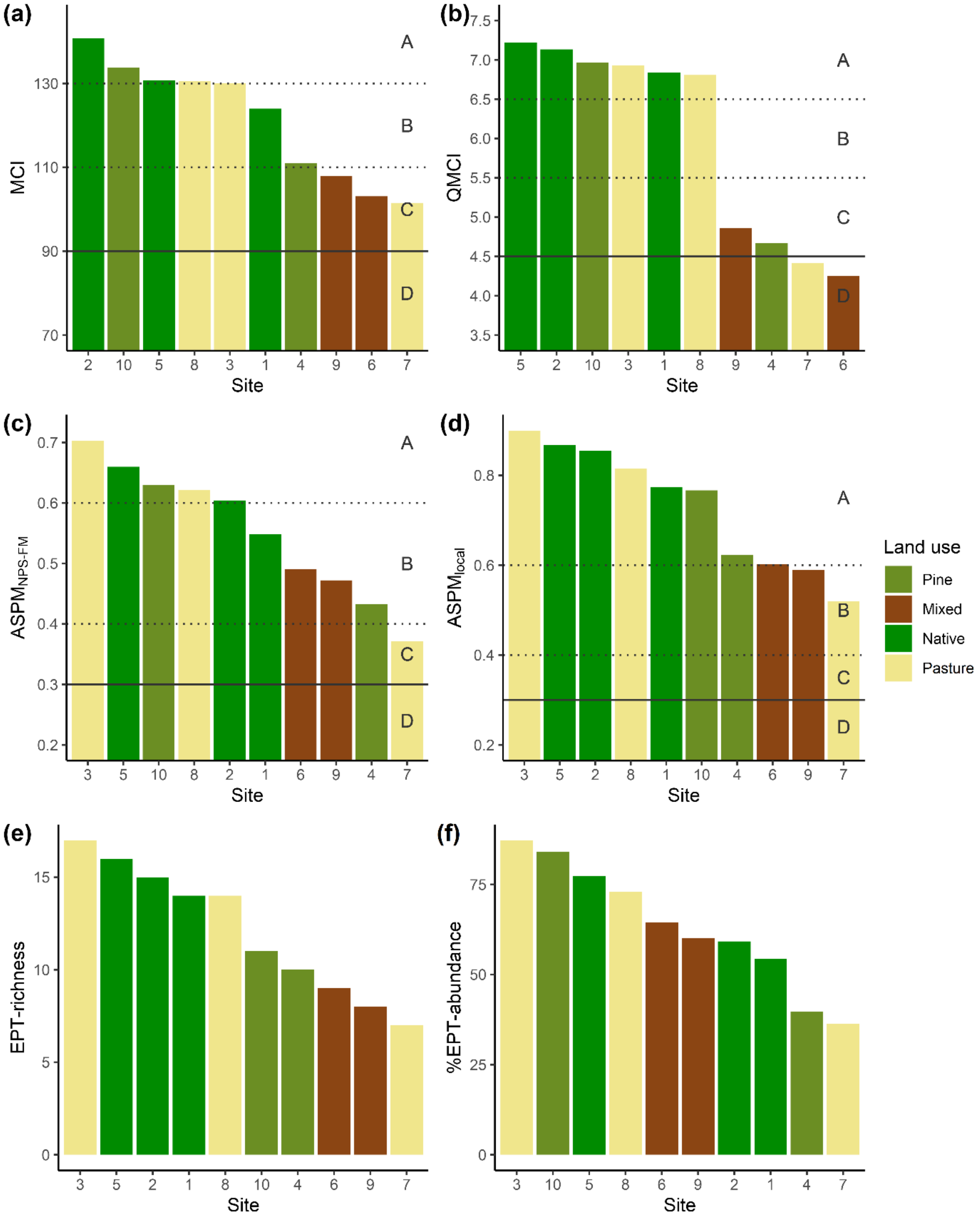

*Figure 12* Ranked bar plots (good to poor) of ten sites located across the Kuratau River catchment for the (a) Macroinvertebrate Community Index (MCI), (b) its quantitative equivalent (QMCI), Average Score Per Metric (ASPM) index calculated according to the National Policy Statement for Freshwater Management (NPS-FM), (d) ASPM calculated using a local reference site (Site 5), (e) Ephemeroptera, Plecoptera, Trichoptera (EPT) richness, and (f) %EPT abundance. Colours indicate the local land-use type. Dotted lines indicate attribute bands for biocriteria (A-C) in the NPS-FM, solid lines national bottom lines (D Band).

I tested the difference in macroinvertebrate biotic indices between stream sites in two land cover types (indigenous forest and pastoral). Although there were no statistically significant differences between land cover types for the three metrics used in the NPS-FM, these indicators of ecosystem health were generally lower in the pastoral sites (Fig.13a-c). The mean values for the MCI and ASPM both occupied the B Band, but the QMCI showed the indigenous forest sites had a mean value in the A Band, with the pastoral sites in the C Band. Taxa richness was significantly lower in the pastoral sites ($F_{1,8}$=26.8, $P$<0.001; Fig.13d), dropping from a mean of 25 in the indigenous forest sites to a mean of 15 in the pastoral sites. EPT richness was also significantly lower in the pastoral site ($F_{1,8}$=6.81, $P$<0.001), although the mean difference was less than 5 EPT taxa between the land cover types (Fig.13e). There was no different in the relative abundance of EPT taxa (Fig.13f).

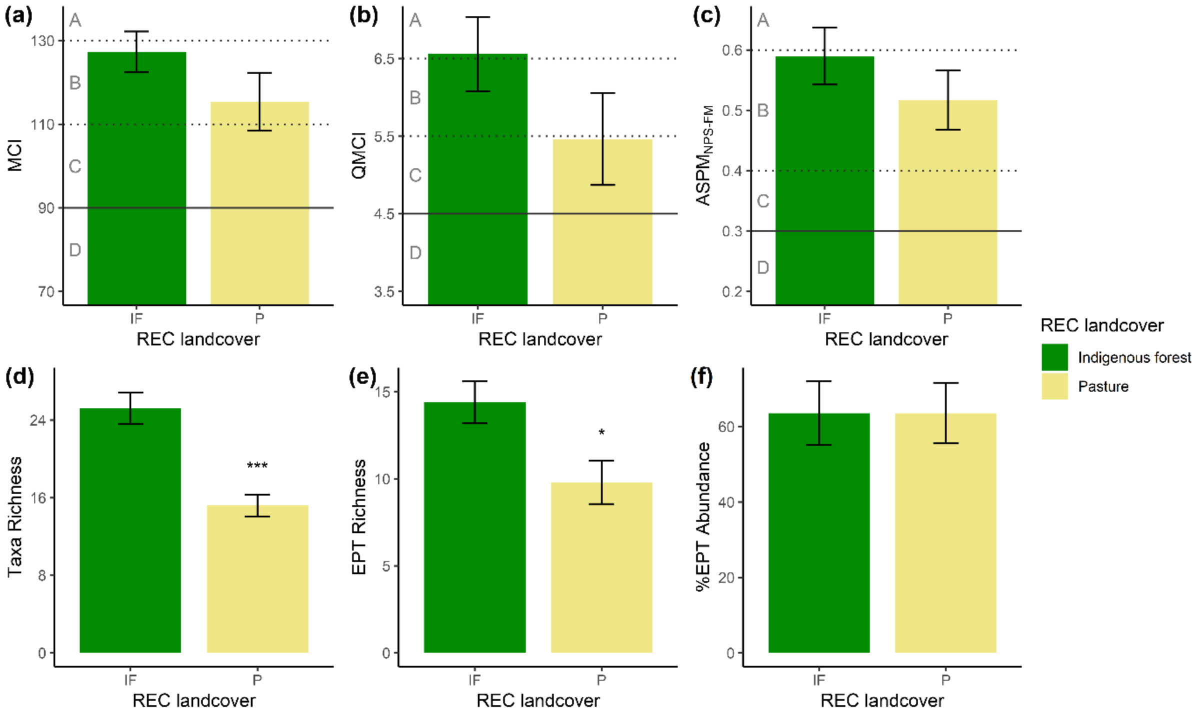

*Figure 13* Bar plots (± SE) of the (a) Macroinvertebrate Community Index (MCI), (b) its quantitative equivalent (QMCI), Average Score Per Metric (ASPM) index calculated according to the National Policy Statement for Freshwater Management (NPS-FM), (d) taxa richness, (e), Ephemeroptera, Plecoptera, Trichoptera (EPT) richness, and (f) %EPT abundance. Ten sites located across the Kuratau River catchment were grouped by REC landcover types (n=5). Dotted lines indicate attribute bands for biocriteria (A-C) in the NPS-FM, solid lines national bottom lines (D Band). *$P$<0.05, ***$P$<0.001

For the comparison of the ASPM index between the two land cover types, I used two versions (i.e., the ASPM based on the NPS-FM approach and based on a local reference site). In both instances, there was no significant difference between land cover types (Fig.14), although the ASPM values based on the local reference site (Site 5) were higher, with the mean values occupying A Band (Fig.14b).

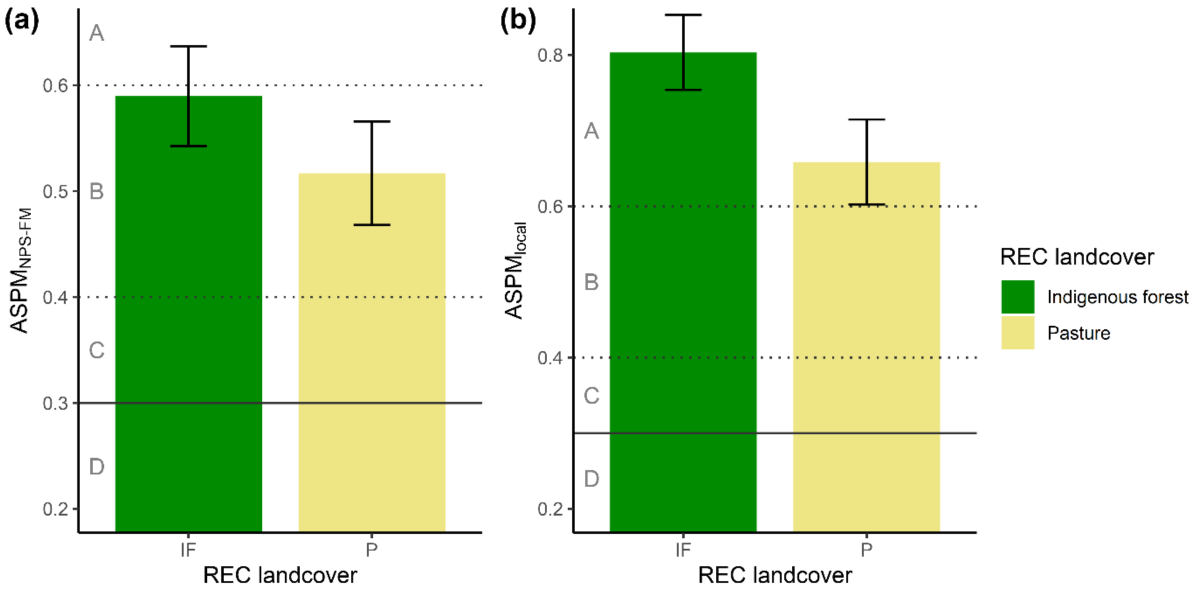

*Figure 14* Bar plots (± SE) of the macroinvertebrate (a) Average Score Per Metric (ASPM) index calculated according to the National Policy Statement for Freshwater Management (NPS-FM), and (b) ASPM calculated using a local reference site (Site 5). The ten sites located across the Kuratau River catchment were grouped by REC landcover types ($n$=5). Dotted lines indicate attribute bands for biocriteria (A-C) in the NPS-FM, solid lines national bottom lines (D Band).

## Environmental DNA

I used the species recorded in the eDNA samples to explore biodiversity patterns across the two REC landcover types. There was no significant difference in eDNA community composition of aquatic insects across the landcover types ($F_{1,8}$=1.91, $P$=0.127, $R^2$=19.3%), but the indicator analysis showed that the mayfly *Ameletopsis perscitus* was characteristic of forested streams ($P$<0.05; Fig.15a). Common aquatic insects associated with Indigenous forest sites included the mayfly *Ichthybotus hudsoni* and the free-living caddisfly *Hydrobiosis gollanis*. The two mixed land use sites below the hydro dam had considerably different aquatic insect eDNA composition when compared to the other sites (Fig.15b). Common aquatic insects associated with these downstream mixed land-use sites included the free-living caddisfly *Aoteapsyche colonica* and the chironomid midge *Tanytarsus* sp.

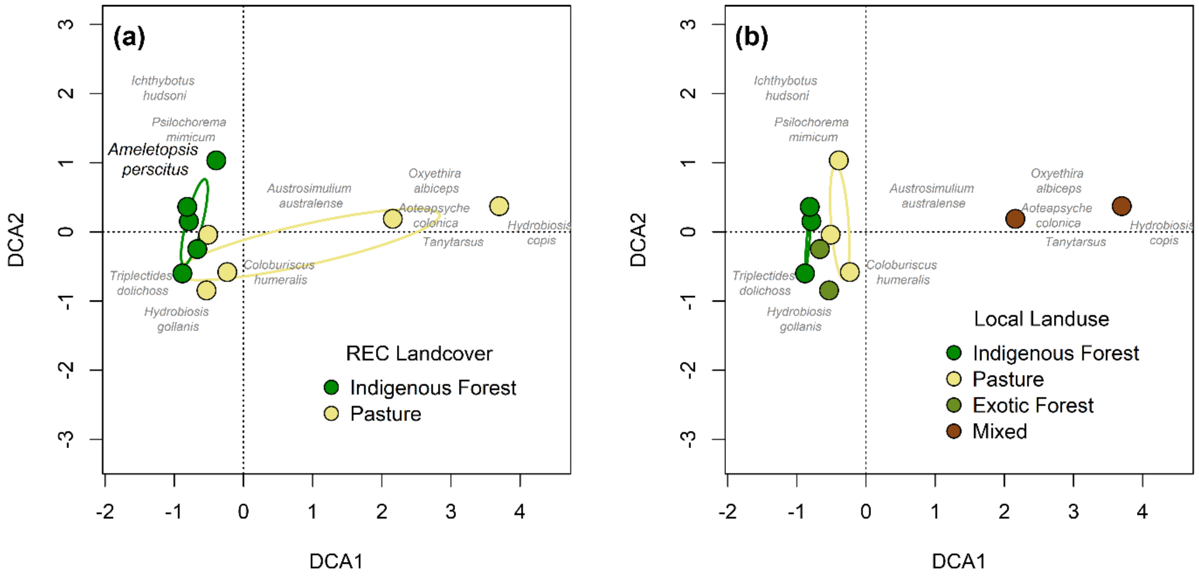

*Figure 15* Detrended Correspondence Analysis (DCA) of aquatic insects detected by environmental DNA (eDNA) in ten sites located across the Kuratau River catchment. Sites are grouped by (a) REC landcover types, and (b) local land-use types. Indicator taxa for indigenous forest sites are shown in black, common taxa making up 86% of total occurrences are shown in grey.

Consistent with the benthic macroinvertebrate data, aquatic insect species richness using eDNA was significantly lower in the pastoral sites when compared to the Indigenous forest sites ($F_{1,8}$=8.33, $P<0.05$; Fig.16a). In contrast, species richness for fish, birds, and mammals all increased in pastoral sites although these differences were not statistically significant (Fig.16b-d).

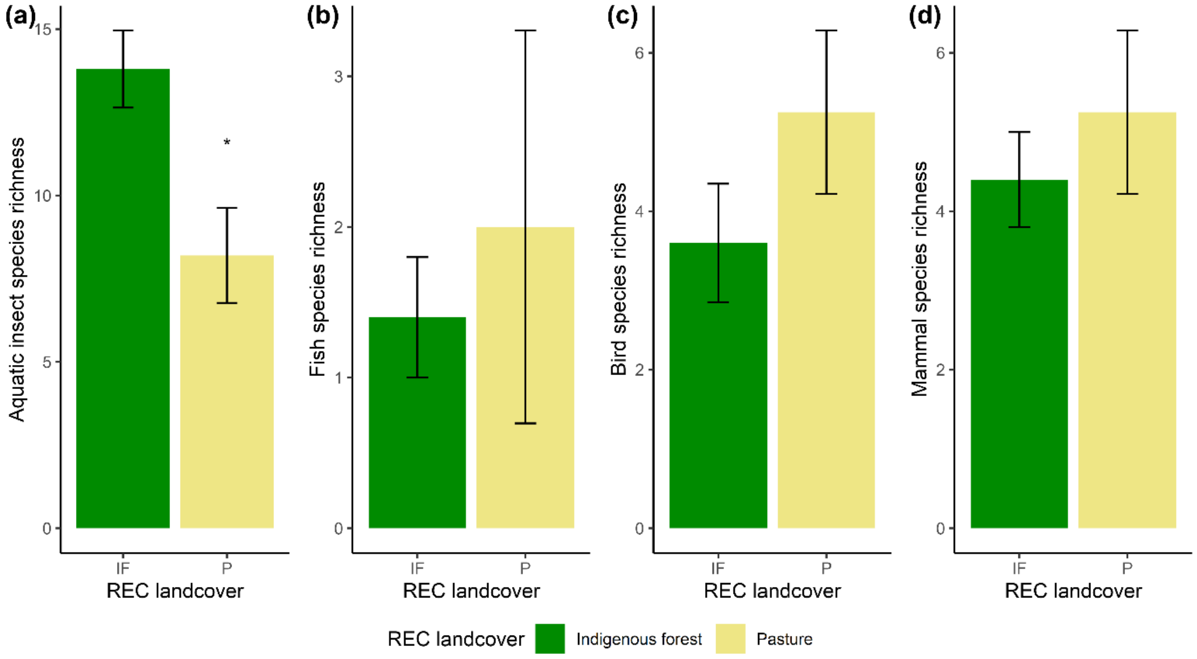

*Figure 16* Bar plots (± SE) of (a) aquatic insect, (b) fish, (c) bird, and (d) mammal species detected by environmental DNA (eDNA). Ten sites located across the Kuratau River catchment were grouped by REC landcover types (*n*=5). **P*<0.05

## Functional Indicators

### Decomposition

Cotton strip tensile strength loss ranged from 52% to 86%, with a median of 62%. Cotton strip tensile strength loss rates were generally lower in forested sites and higher in the pastoral and mixed land use sites (Fig.17a). This overall pattern did not differ when decomposition rates were temperature-corrected (Fig.17b). In both instances, the fastest decomposition rates were observed at Site 9 below the Lake Kuratau outlet.

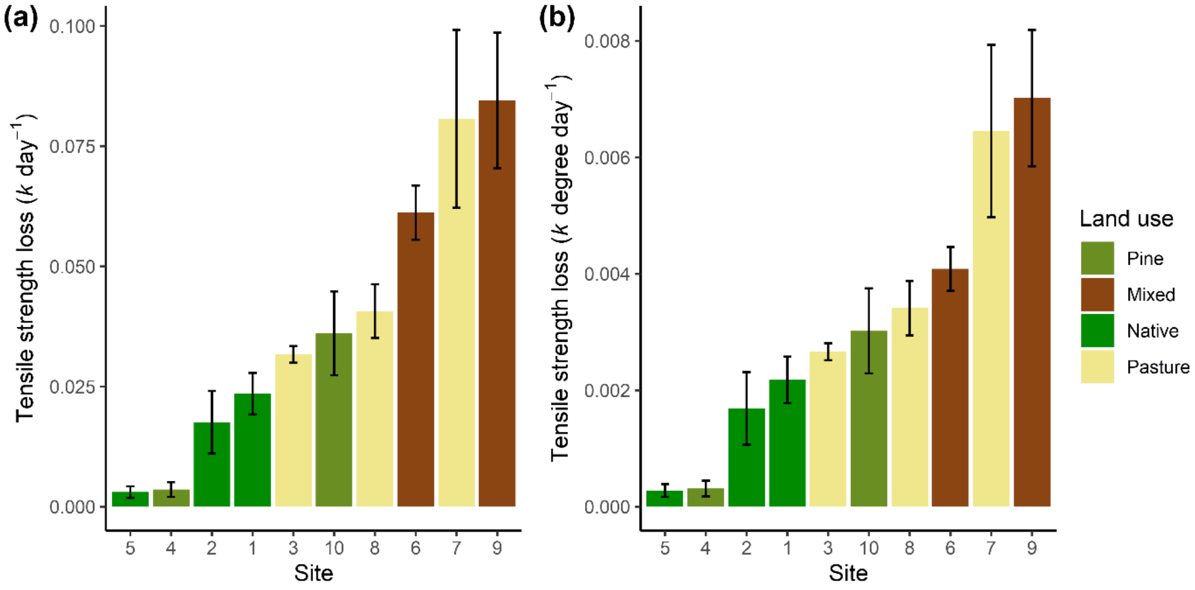

*Figure 17* Ranked (slow to fast) bar plots (± SE) for decomposition rates of cotton strips deployed to ten stream sites located across the Kuratau River catchment. (a) *k* rates per day for tensile strength loss, (b) temperature-corrected *k* rates for tensile strength loss. Colours indicate the local land-use type.

Using the REC landcover attributes, cotton strip tensile strength loss rates were greater in pasture stream sites when compared to the forested sites ($F_{1,8}$=15.4, $P$<0.01, Fig.18a). Correcting for temperatures (cumulative degree days) did not result in a qualitative change in the large difference in decomposition rates between the two land cover types ($F_{1,8}$=12.3, $P$<0.01, Fig.18b).

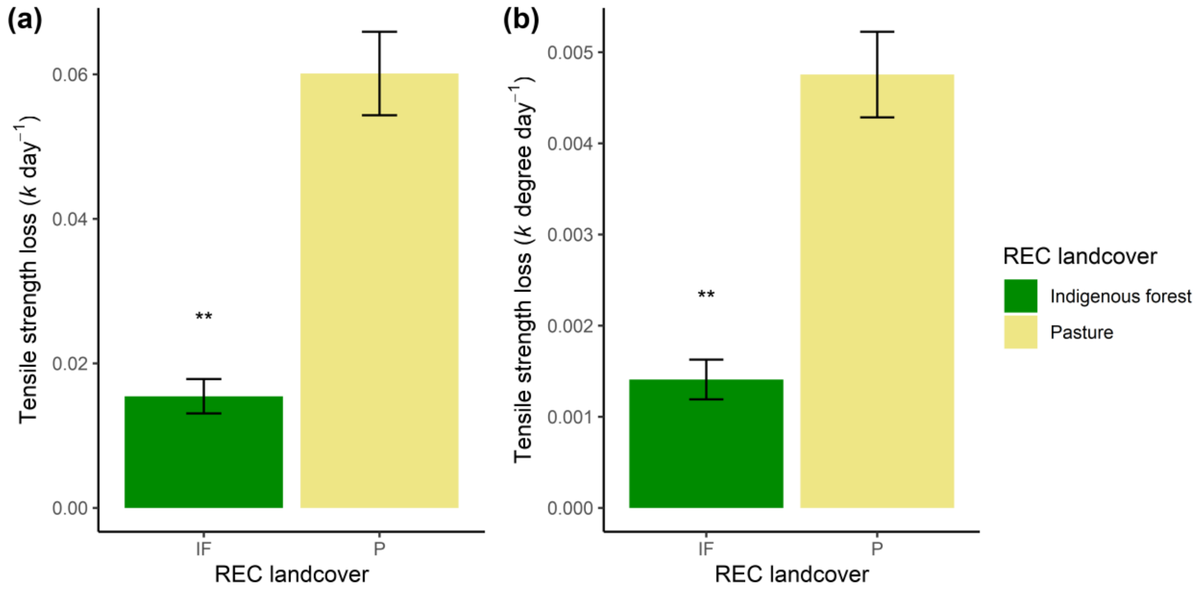

*Figure 18* Bar plots (± SE) of instream cotton-strip decomposition rates for different landcover types in the Kuratau River catchment. (a) *k* rates per day for tensile strength loss, (b) temperature-corrected *k* rates for tensile strength loss. The ten sites located across the Kuratau River catchment were grouped by REC landcover types ($n$=5). **$P$<0.01

## Primary Production

Benthic algae (periphyton) was measured as a surrogate for primary production, and showed variation across sites. Periphyton ranged from 9 to 113 Chl-*a* mg per $m^2$ , but were generally low, occupying the 'A' attribute band (Fig.19a). Periphyton was more variable than decomposition rates across land uses, with similar patterns observed for diatoms (Fig.19b) and cyanobacteria (Fig.19c). In all instances, the highest chlorophyll concentrations were observed at Site 9 below the Lake Kuratau outlet, indicating a role for flow stability and DRP concentrations. In contrast, green algae was more sporadically distributed, but higher concentrations were observed at two native forest sites (Fig.19d).

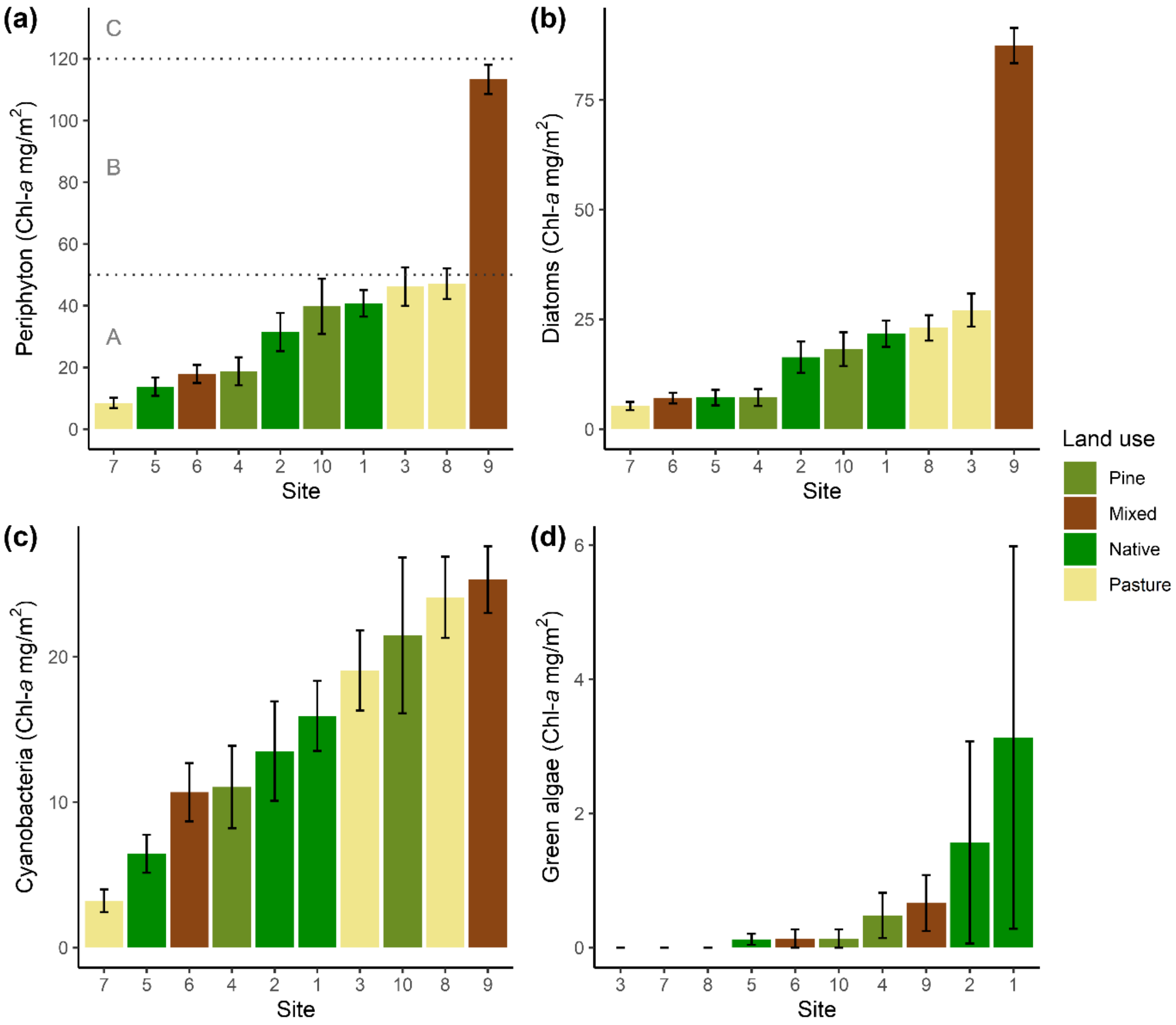

*Figure 19* Ranked (low to high biomass) bar plots (± SE) for periphyton in ten stream sites located across the Kuratau River catchment. (a) total benthic periphyton biomass, (b) benthic diatom biomass, (c) benthic cyanobacteria biomass, and (d) benthic green algae biomass. Colours indicate the local land-use type. Dotted lines indicate attribute bands for biocriteria (A-C) in the NPS-FM.

Overall, stream periphyton biomass was greater in the REC landcover pasture stream sites when compared to the forested sites, but the difference was not statistically significant ($F_{1,8}$=0.08, $P$=0.786, Fig.20a). Between landcover types, diatom and cyanobacteria biomass was greater in the pastoral streams. However, there was no significant difference in diatom biomass ($F_{1,8}$=0.34, $P$=0.576, Fig.20b) or cyanobacteria biomass ($F_{1,8}$=0.07, $P$=0.802, Fig.20c). Green algae biomass was more variable across sites, but showed a trend of being more abundant in forest streams compared to pastoral sites. This difference was not statistically significant ($F_{1,8}$=0.74, $P$=0.415, Fig.20d).

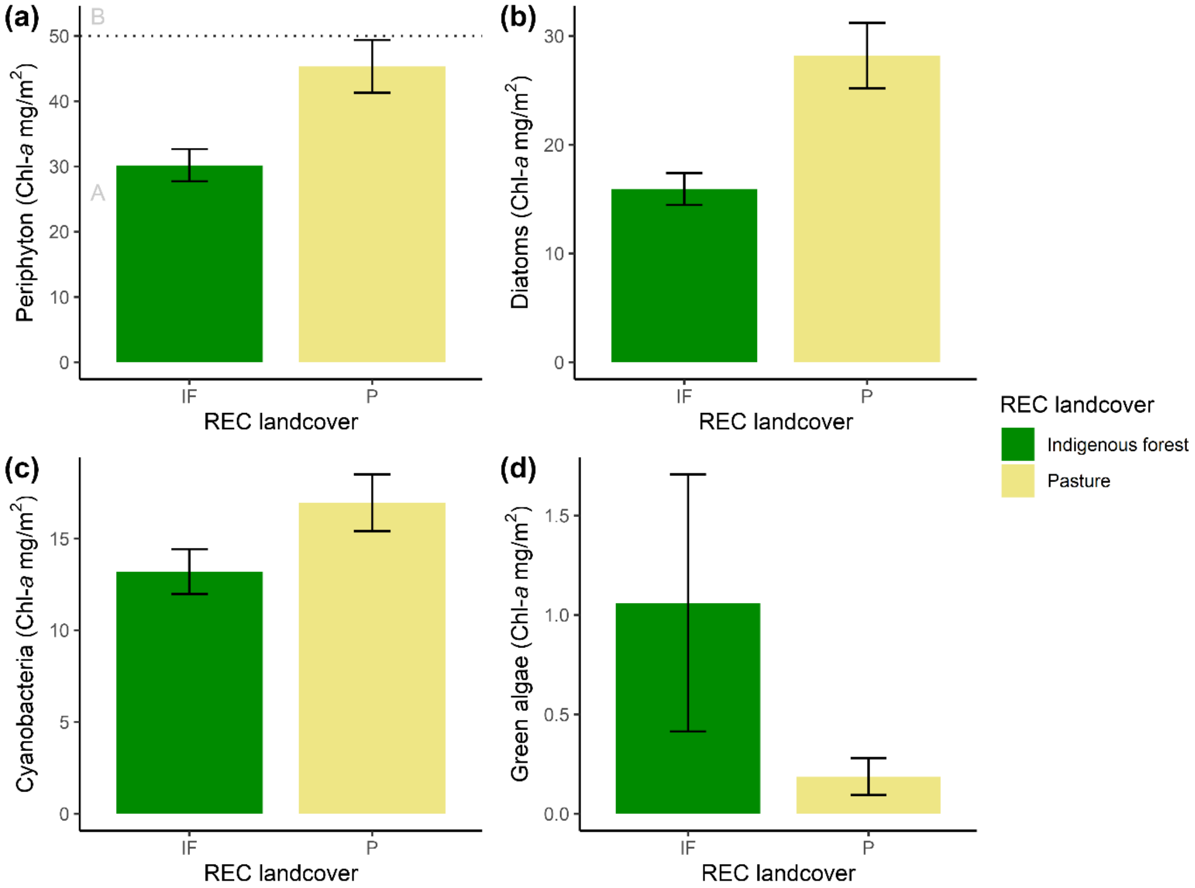

*Figure 20* Bar plots (± SE) of periphyton for different landcover types in the Kuratau River catchment. (a) total benthic periphyton biomass, (b) benthic diatom biomass, (c) benthic cyanobacteria biomass, and (d) benthic green algae biomass. The ten sites located across the Kuratau River catchment were grouped by REC landcover types. The dotted line indicates the attribute bands for biocriteria (A-B) in the NPS-FM.

# Chapter 5 - Cultural Health Monitoring

## Cultural Health Index

In Table 5, I document the results for the Cultural Health Index (CHI) for the ten sites across the Kuratau River catchment. This version of the CHI uses the cultural assessment provided by Ngāti Tūwharetoa to determine attributes for the Cultural Stream Health Measure (CSHM). I also provide explanations on how I applied the environmental DNA (eDNA) data to determine Mahinga Kai status.

The lowest scoring site for the CSHM (2.33) and Mahinga Kai (2.3) was recorded at Site 3 on the Mangaongoki Stream. The site status assessment determined the site was not of cultural significance and assessors would likely not return. Site 3 scored poorly in bank margin (<30m), native vegetation and bird presence, but had good access and habitat availability for mahinga kai. eDNA results picked up low-moderate counts of kōaro, and kōura. Rainbow trout had the highest amount of sequence counts for the determined mahinga kai species. For the attributes in the CSHM, site 3 scored highly in riverbank condition, channel, water quality, water clarity, and access, but lowest in surrounding land use, indigenous vegetation, and birdlife, as well as in the more intrinsic attributes such as sound and mauri.

The next lowest scoring CHI site was Site 7. This site was considered significant to tangata whenua as it is located within Moerangi Station and flows through an ecologically significant wetland restoration area, however due to the current condition of the surrounding area, it was determined to be a site not to return to. The mahinga kai score (2.9) at this site was low. Although the site has good access and “moderate” levels of kōura present indicated by eDNA, the site had low scores for vegetation and birdlife. The overall CSHM score (2.7) was also low, but the site scored high for riverbed and channel quality, flow conditions, water clarity, and access.

Site 6 was the next lowest scoring site and is located near where the Kuratau River discharges to Lake Taupō. It has been monitored as a State of the Environment site by the regional council for over a decade. The CHI score assessed at Site 6 showed the site status determined it was not a site of cultural significance to hapū, however its location in proximity to Taupō roto, and its natural value makes it a site to return to.

*Table 5* Cultural Health Index scores for ten sites across the Kuratau River. Site Status A=Significant, B= Not significant, 1 = would return, 2 = would not return. Mahinga Kai scores were determined using sequence read counts from environmental DNA (eDNA) sampling. CSHM, Cultural Stream Health Measure score determined using the cultural assessment provided by Ngāti Tūwharetoa.

| **Site Number** | **Local Land Use Type** | **Site Status** | **Mahinga Kai** (Fish taxa present in eDNA) | **CSHM Score** |
|---|---|---|---|---|
| *1* | Native | **B-0** | Kōura (Mod)<br>*Brown Trout (Very High)*<br>**Score = 3.6** | **3.38** |
| *2* | Native | **A-0** | Kōura (High)<br>*Brown Trout (Very High)*<br>**Score =4.5** | **3.70** |
| *3* | Pasture | **B-0** | Kōura (Mod)<br>Kōaro (Low)<br>*Brown Trout (Mod)*<br>*Rainbow Trout (High)*<br>**Score =2.3** | **2.33** |
| *4* | Forestry | **B-0** | Kōura (Low)<br>*Brown Trout (Very High)*<br>**Score =3.5** | **3.26** |
| *5* | Native | **A-1** | Kōura (Low)<br>*Brown Trout (Very High)*<br>**Score =4.5** | **3.50** |
| *6* | Mixed | **B-1** | Kōura (High)<br>Kākahi (Low)<br>Kōaro (Low)<br>Galaxiids (Very Low)<br>*Brown Trout (Very Low)*<br>*Rainbow Trout (Very Low)*<br>**Score =3.9** | **2.98** |
| *7* | Pasture | **A-0** | Kōura (Mod)<br>**Score =2.9** | **2.70** |
| *8* | Pasture | **A-1** | Kōura (High)<br>*Brown Trout (Very High)*<br>**Score =4.7** | **3.46** |
| *9* | Mixed | **A-1** | Kōura (Mod)<br>Kōaro (Low)<br>Galaxiids (Low)<br>*Rainbow Trout (Very Low)*<br>*Salmon/Trout (Low)*<br>**Score =4.3** | **3.39** |
| *10* | Forestry | **A-0** | Kōura (Very Low)<br>**Score =3.0** | **3.09** |

The mahinga kai score for Site 6 was above average (3.8) as the site had three indigenous species present as detected by eDNA. These species were kākahi/kāeo (which was absent at all other sites), kōaro, and kōura. The CSHM score (3.0) however was relatively low as the attributes were reduced with the adverse impacts of surrounding land uses (urban, pasture) and an overall feeling of a decline in water health.

Sites 1 and 4 returned similar CHI results, both recorded B-0 site status values, indicating sites were not culturally significant and due to current human impacts at these sites, would not be returned to. The mahinga kai scores were relatively low (Site 1 = 3.6, Site 4=3.5). This was because the eDNA results showed moderate to very low levels of kōura at each site, and very high levels of brown trout present. Access and habitat for mahinga kai was relatively poor. The CSHM scores were also relatively low (Site 1 = 3.4, Site 4 = 3.3).

The CHI score for Site 10 showed the site was of cultural significance as it has historically been a place where mana whenua would harvest watercress (*Brassicaceae* family), an important food source to many Māori. However, due to previous erosion events the site has changed in morphology and is in a current state of renewal. As such it was deemed to not have cause for return. The mahinga kai score (3.0) was moderately low, eDNA sequence read counts showed an absence of native and exotic freshwater fish at this site and very low counts for kōura. The CSHM score (3.1) was also moderately low attributed to catchment land use and reduced native vegetation, however this site did score highly in attributes for water quality, riverbed, flow and overall health and mauri.

Sites 5, 8 and 9 all returned A-1 site status values. This states that the sites were of cultural significance and would give cause to return to. All of these sites had well established indigenous vegetation on and within <30m of the riverbanks, had good access to the river, supported birdlife, and had various stream habitats to support aquatic life. The mahinga kai scores for these sites were all above average (Site 5 = 4.5, Site 8 = 4.7, Site 9 = 4.3). However, the CSHM scores for these sites were relatively lower (Site 5

= 3.5, Site 8 = 3.5, Site 9 = 3.4) due to the presence of manufactured structures at the sites and the overall feeling of loss of mauri as a result of catchment land use influences.

The highest scoring site for the CHI was Site 2. Site status showed that the site is of cultural significance to tangata whenua due to its location within established ancient indigenous forest, and its current use to access the forest. However, past human influences have impacted the mauri of the site and as such returned a site status score of A-0 (Table 6). The mahinga kai value (4.5) was above average due to the surrounding indigenous vegetation, the riparian reach (>30m), biodiversity present, stream habitats and accessibility. eDNA results showed high levels of kōura present, and very high numbers of brown trout. The CSHM score (3.7), although still moderately low, likely due to the mentioned negative historic human influences, was the highest recorded for all sites.

*Table 6* Cultural Health Index scores for ten sites across the Kuratau River catchment based on the cultural assessment provided by Ngāti Tūwharetoa. Mahinga Kai scores were determined using sequence read counts from environmental DNA (eDNA) sampling. CSHM, Cultural Stream Health Measure. *Traditional CSHM based on eight indicators described by Tipa and Tierney (2006). REC Landcover IF = Indigenous Forest, P= Pasture.

| Site Number | REC Landcover | Site Status | Mahinga Kai | CSHM | CSHM* |
|---|---|---|---|---|---|
| 1 | IF | B-0 | 3.5 | 3.38 | 3.88 |
| 2 | IF | A-0 | 4.5 | 3.70 | 4.38 |
| 3 | IF | B-0 | 2.3 | 2.33 | 2.91 |
| 4 | IF | B-0 | 3.5 | 3.26 | 3.78 |
| 5 | IF | A-1 | 4.5 | 3.50 | 3.94 |
| 6 | P | B-1 | 3.9 | 2.98 | 3.22 |
| 7 | P | A-0 | 2.9 | 2.70 | 2.88 |
| 8 | P | A-1 | 4.7 | 3.46 | 4.06 |
| 9 | P | A-1 | 4.3 | 3.39 | 3.88 |
| 10 | P | A-0 | 3.0 | 3.09 | 3.25 |

## Cultural Stream Health Measure

The Cultural Stream Health Measure (CSHM) was calculated using the Ngāti Tūwharetoa assessment form in addition to the traditional CSHM which consisted of eight indicators described by Tipa and Teirney (2006). For the following analyses, I have used the traditional CSHM to better enable comparison with other studies (Harmsworth et al. 2011). The traditional CSHM showed that a native forest site (Site 2) had the highest score, and pastoral sites (Site 7, and 3 respectively) had the lowest scores (Fig.21a). In general, sites affected by human activities (notably surrounding land use) scored lower. The site on the Mangaongoki Stream (Site 3) had the second lowest traditional CSHM score.

I also tested the ability of the traditional CSHM to determine the difference between the two REC landcover types. The traditional CSHM scores were higher in Indigenous forest sites when compared the pastoral sites (Fig.21b), but this difference was not statistically significant ($F_{1,8}$=0.882, $P$=0.375).

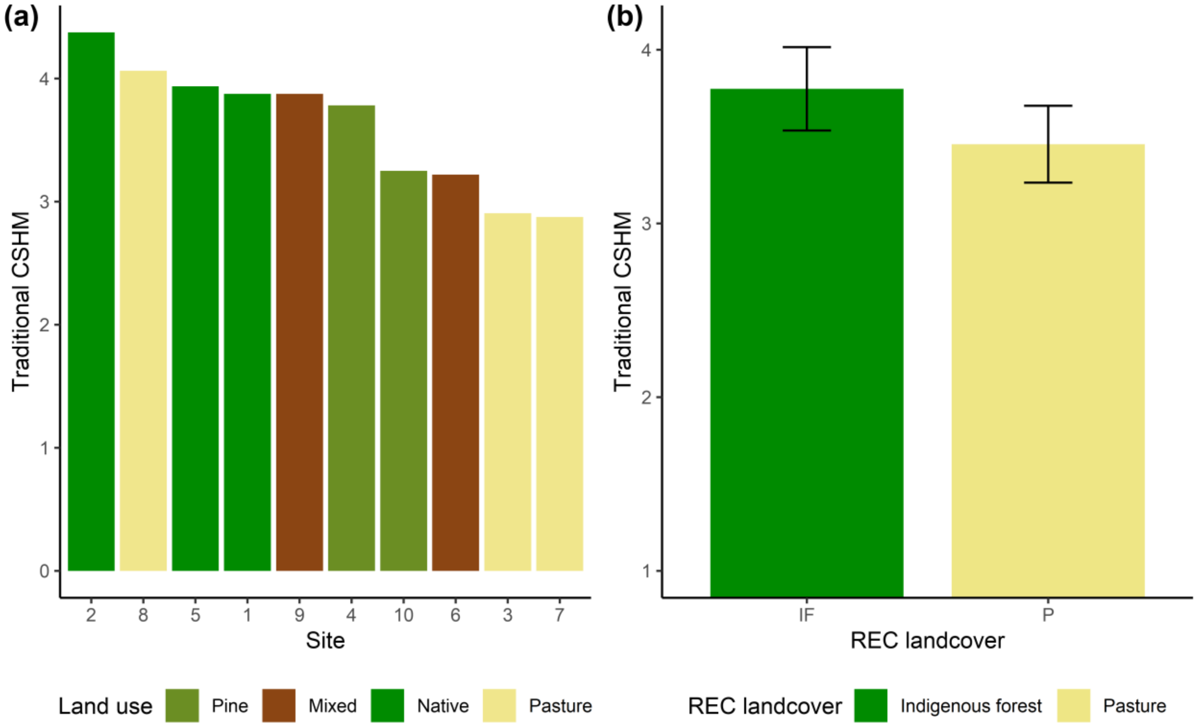

*Figure 21* Cultural Stream Health Measure (CSHM) scores at ten sites located across the Kuratau River catchment. (a) Ranked bar plots of CSHM scores going from high to low cultural health. Colours indicate the local land-use type. (b) Bar plots of CSHM scores (mean ± SE) for sites grouped by River Environment Classification (REC) landcover types (n=5). The traditional CSHM was based on eight indicators described by Tipa and Tierney (2006).

To better understand how the eight indicators used for the traditional CSHM were correlated and might influence the overall site score, I used Principal Components Analysis (PCA). Most of variance amongst sites was explained by Axis 1 (PC1; 53%). The PCA showed that native forest sites generally had negative Axis 1 site scores, with human affected sites tending to be positive (Fig.22a).

Fig.22b shows that the individual indicators tended to be negatively correlated with Axis 1 (PC1), indicating how sites with negative scores tended to have higher CSHM scores.

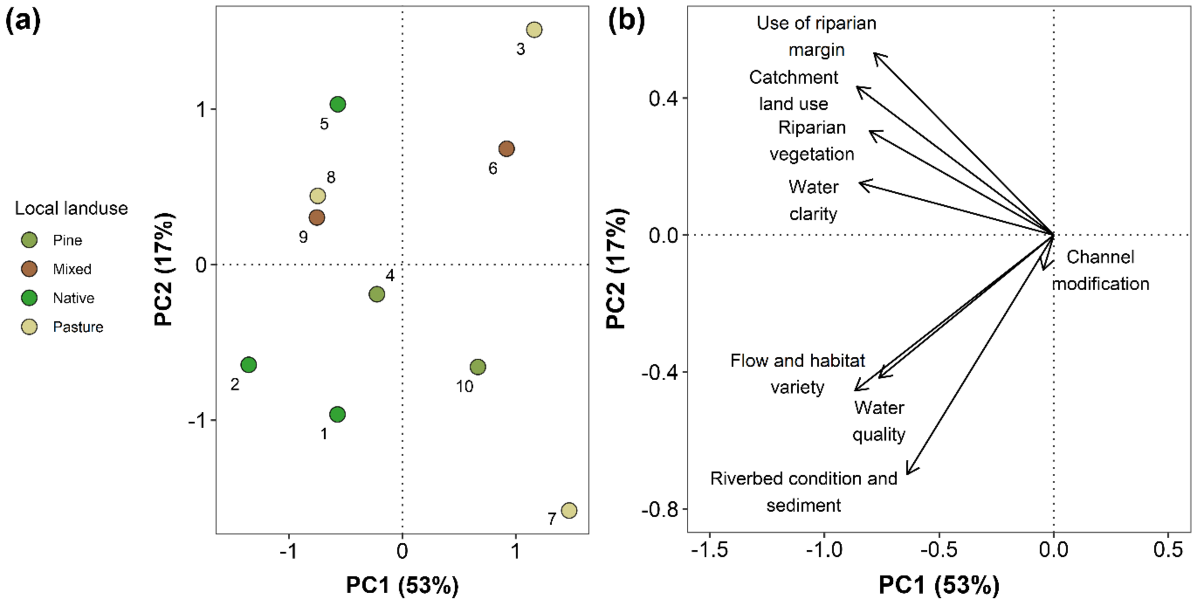

*Figure 22* Principal Components Analysis (PCA) of the eight indicators used in the traditional CSHM at ten sites located across the Kuratau River catchment. (a) Site scores for the PCA, where colours indicate the local land-use type, and the numbers indicate the site. (b) Vectors associated with the eight indicators used for the PCA. The traditional CSHM was described by Tipa and Tierney (2006).

I also considered the same PCA using the REC landcover sites. This showed that the Indigenous forest sites tended to have negative site scores (Fig.23a) that were associated with higher scores for the eight indicators used in the traditional CSHM (Fig.22b). However, there was no multivariate difference between the site scores for the two landcover types ($F_{1,8}$=0.606, $P$=0.612, $R^2$=7.4%). Likewise, the difference between the Axis 1 site scores was not significantly different ($F_{1,8}$=1.03, $P$=0.339; Fig.23b).

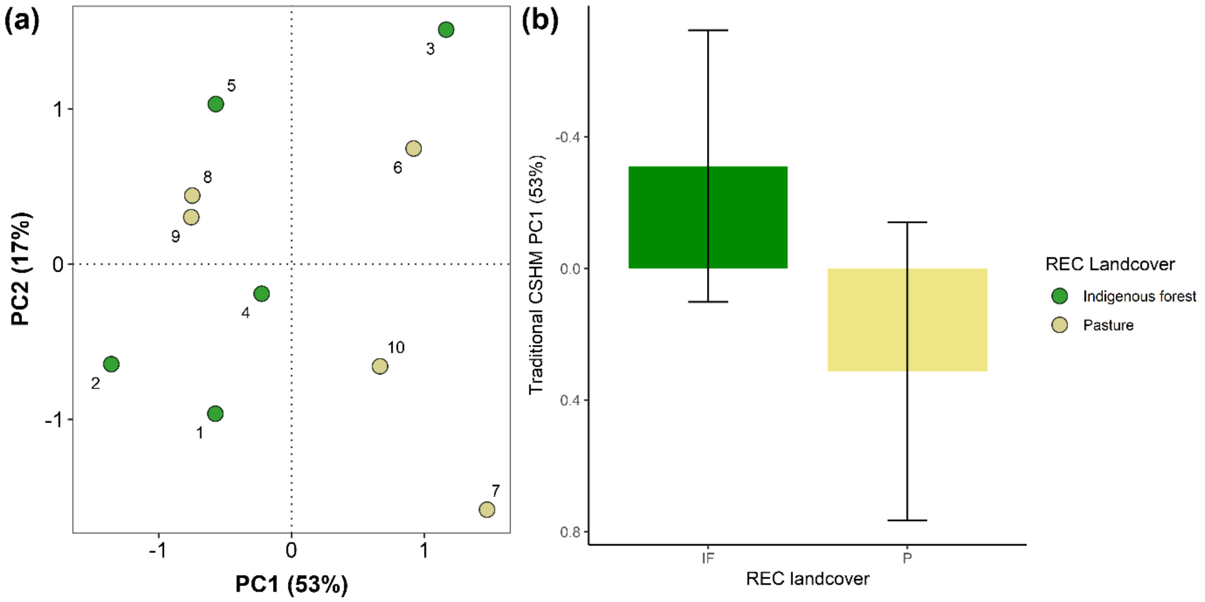

*Figure 23* Principal Components Analysis (PCA) of the eight indicators used in the traditional CSHM at ten sites located across the Kuratau River catchment. (a) Site scores for the PCA, where colours indicate the River Environment Classification (REC) landcover type, and the numbers indicate the site. (b) Bar plots (mean ± SE) for PC1 site scores grouped by REC landcover types (*n*=5). The traditional CSHM was described by Tipa and Tierney (2006).

## Effect sizes: CSHM compared to other indicators

One of my key hypotheses (H2) was that cultural health indicators would be congruent with conventional bioindicators in diagnosing land use impacts. To assess this objectively I compared the effect sizes for the traditional CSHM with the other indicators measured. The effect I was interested in was the difference between indigenous forest and pastoral landcover sites (according to River Environment Classification). I found that the effect size of the CSHM was weak to moderate (-0.475 ± 0.505) in detecting differences between the two landcover types (Fig.24). This effect size compared well with riparian condition (-0.405 ± 0.653) and the median effect size (-0.553 ± 0.649) for indicators where a negative response was deemed to be harmful for ecosystem health (Fig.24).

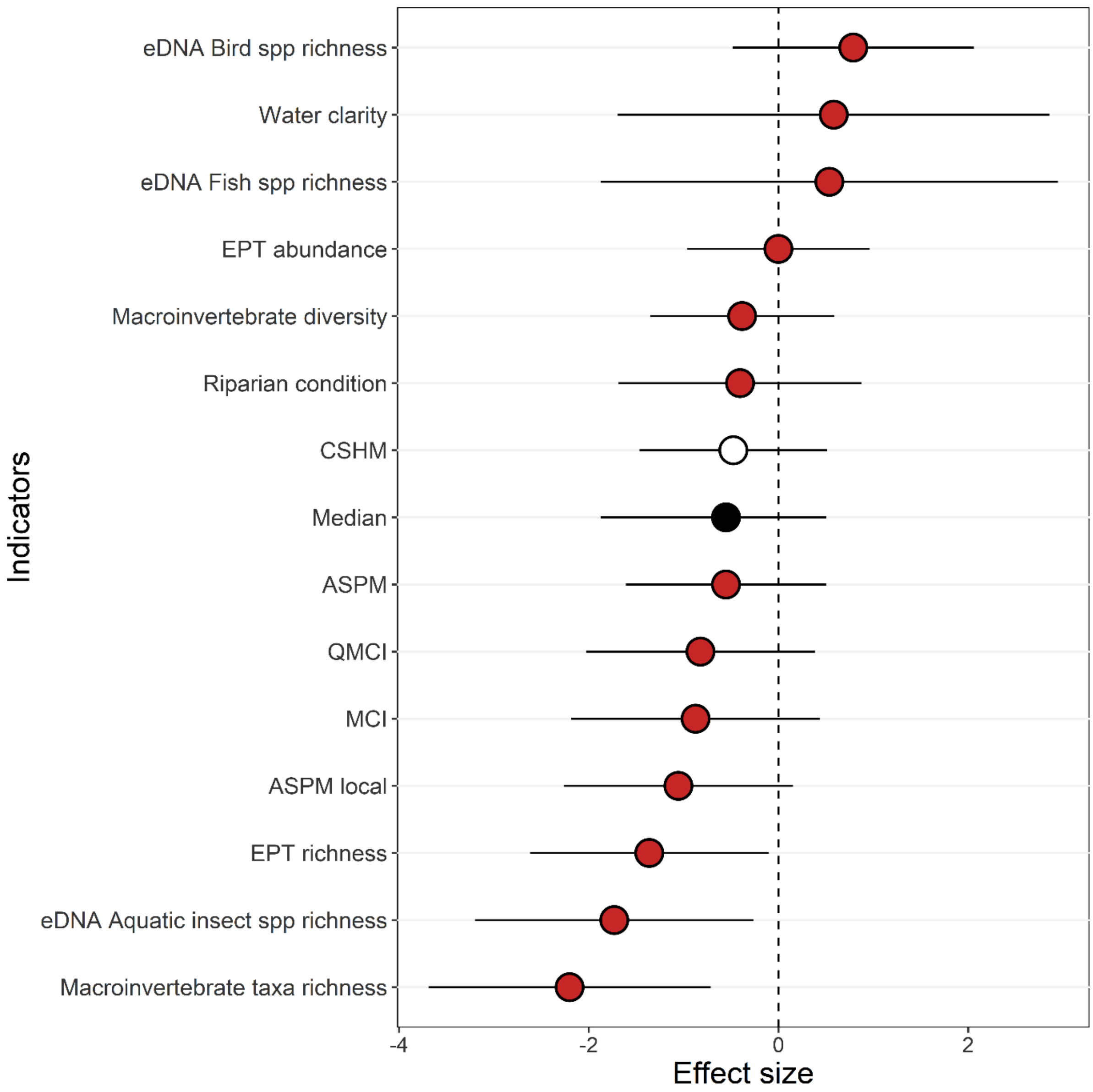

*Figure 24* Standardised mean differences (± 95% confidence interval) for selected stream indicators assessing the effect of pastoral landcover relative to indigenous forest landcover in the Kuratau River catchment. Stream indicators were selected where a negative response was deemed to be harmful for ecosystem health. that Landcover for sites (n=5) was determined using the River Environmental Classification (REC) database. White dot, CSHM, Cultural Stream Health Measure based on the eight indicators described by Tipa and Tierney (2006). Black dot, median value for all indicators (red dots) other than the CSHM.

The absolute value for the CSHM effect size was weaker than the median effect size (1.11 ± 1.31) for indicators where a positive response was deemed to be harmful for ecosystem health (Fig.25). These indicators generally reflected environmental conditions such as water quality, as opposed to the biodiversity values described in Fig.24.

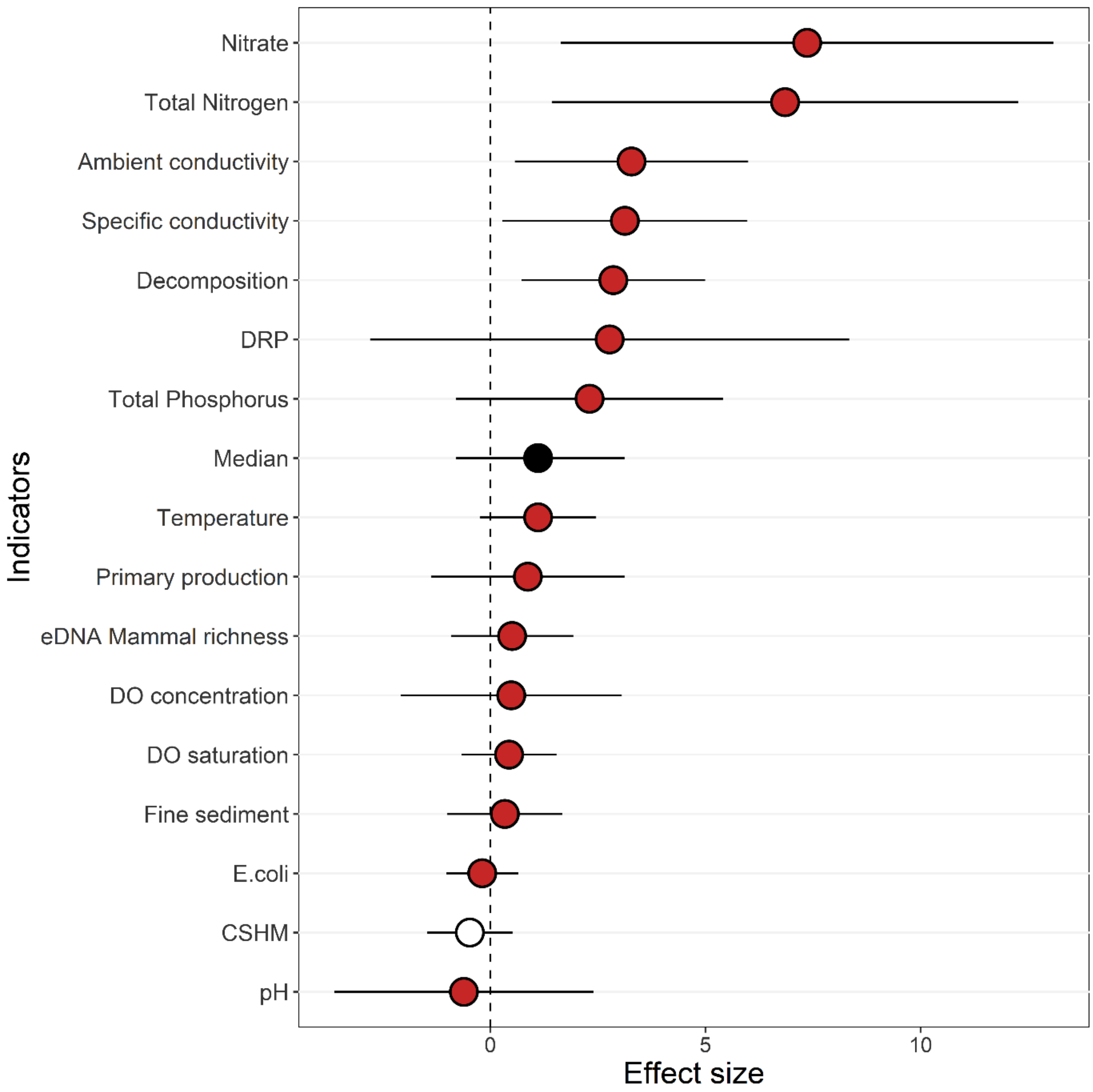

*Figure 25* Standardised mean differences (± 95% confidence interval) for selected stream indicators assessing the effect of pastoral landcover relative to indigenous forest landcover in the Kuratau River catchment. Stream indicators were selected where a positive response was deemed to be harmful for ecosystem health (except for the CSHM). Positive changes in decomposition, dissolved oxygen and pH were expected to be due to increased microbial activity and photosynthesis, thus potential indicators of eutrophication. Landcover for sites (*n*=5) was determined using the River Environmental Classification (REC) database. White dot, CSHM, Cultural Stream Health Measure based on the eight indicators described by Tipa and Tierney (2006) where a negative change indicates a decrease in ecosystem health. Black dot, median value for all indicators (red dots) other than the CSHM.

## Correlations of the CSHM with other indicators

My final hypothesis (H3) was that cultural health indicators would diverge with conventional bioindicators as they reflect different knowledge systems. To test this hypothesis, I first used a correlation matrix to assess the collinearity between the CSHM and selected indicators (Fig.26). This highlighted that the CSHM was correlated with relatively few indicators.

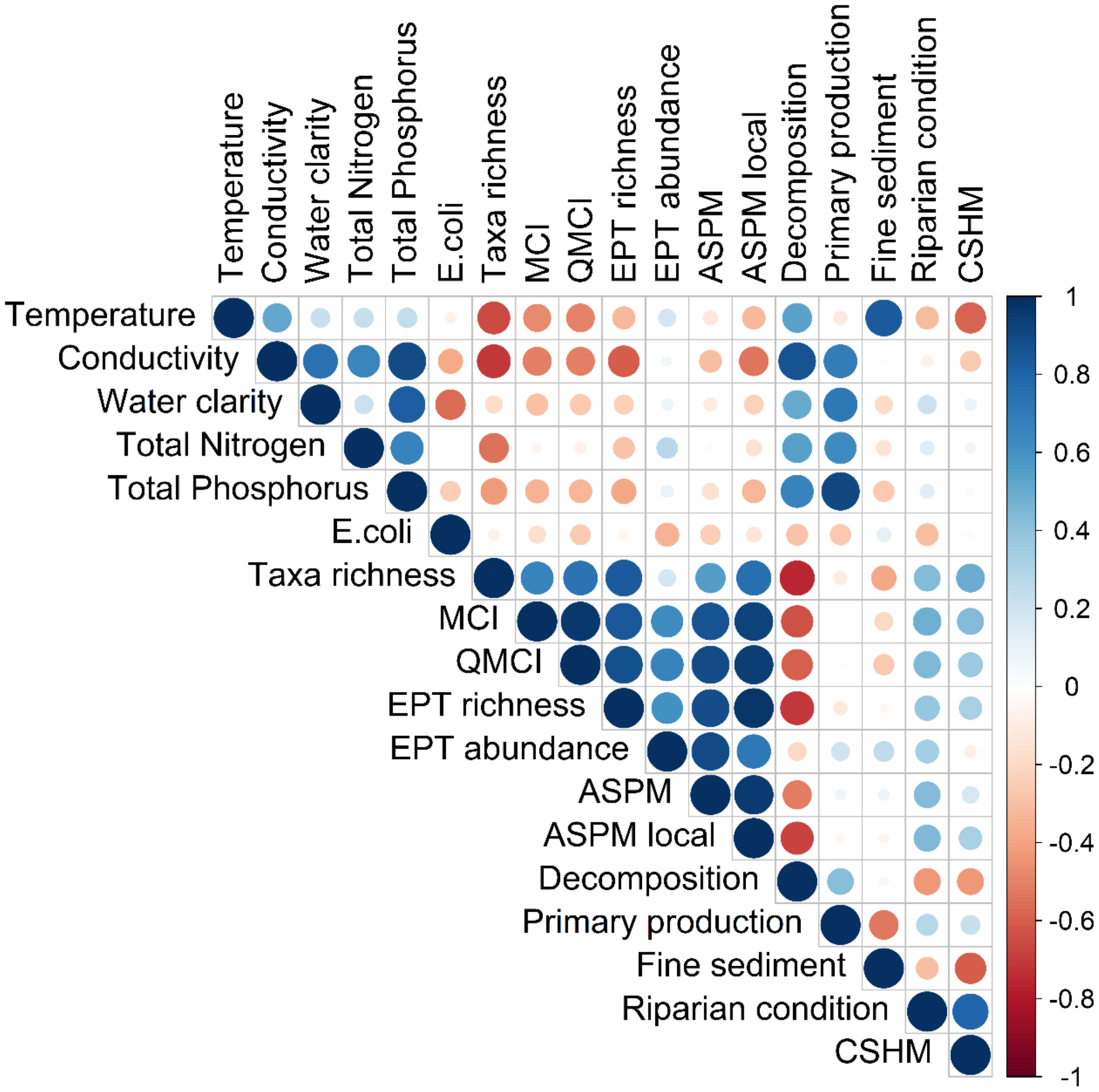

*Figure 26* Correlation matrix of selected indicators measured at 10 sites across the Kuratau River catchment. The size of the dot indicates the strength of correlation, and the heat gradient indicates both the strength and the direction of the correlation.

There were some indicators that were correlated with the traditional CSHM. Riparian condition was positively correlated with a highly significant relationship ($t_8$=4.20, $P$<0.01; Fig.27a). Water temperature was negatively correlated with the CSHM, but this relationship was not significant at α=0.05 ($t_8$=-2.15, $P$<0.064, $R$=-0.61). Likewise, deposited fine sediment was negatively correlated with the CSHM but the relationship was not statistically significant ($t_8$=-1.88, $P$=0.096; Fig.27b). Taxa richness was negatively correlated with the CSHM, but this relationship was not significant ($t_8$=-1.73, $P$=0.123, $R$=-0.52).

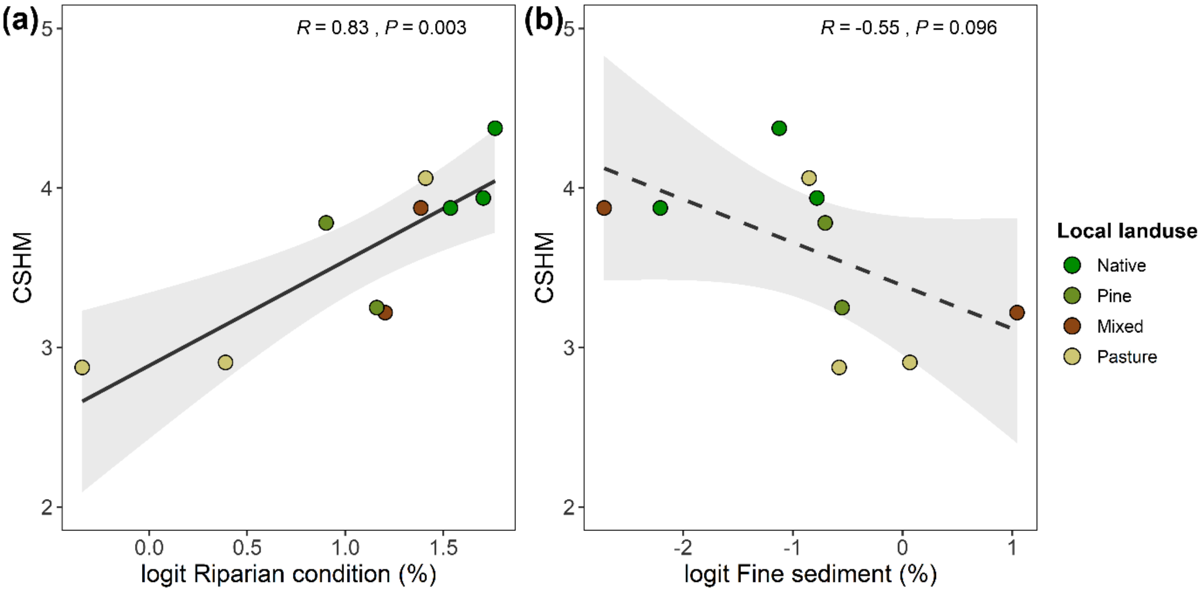

*Figure 27* Correlations of the traditional Cultural Stream Health Measure (CSHM) with (a) Riparian condition, and (b) deposited fine sediment (% cover) measured at 10 sites across the Kuratau River catchment. The Riparian condition scores were converted to a proportion of their theoretical maximum and logit-transformed to help improve their normality. The solid line indicates a significant correlation, the dashed line indicates a non-significant correlation, and grey ribbons indicate the 95% confidence interval.

# Chapter 6 – Discussion

In my research I sought to integrate cultural monitoring with Western scientific monitoring approaches to assess freshwater health. Conventional science-based approaches use ecological and biological assessments to determine environmental indicators to represent the health of waterbodies. These indicators include measuring factors such as water quality and deposited fine sediment, along with bioindicators using benthic macroinvertebrates and environmental DNA. I was able to show the impacts of land use on stream ecosystem health in the Kuratau River catchment, strengthening previous research that has linked land use pressure to ecological degradation (Allan 2004). The declines in macroinvertebrate richness and bioindicators showed how streams impacted by upstream agricultural land uses had poorer ecosystem health than streams with catchments dominated by native forest. This is in alignment with my first hypothesis (H1).

I also used a Cultural Health Index (CHI) to assess the ecological integrity of the Kuratau River catchment. I objectively tested the congruence of the traditional CSHM in detecting effects of upstream land use using a balanced design. The impact of upstream pastoral land cover on the CSHM relative to Indigenous forest land cover had a similar effect size when compared to other indicators. This helped support my second hypothesis that cultural health indicators would be consistent with conventional bioindicators in diagnosing land use impacts (H2). Although there were some correlations between the CSHM and other indicators, overall, the relationship between cultural and ecological indicators were generally weak to non-existent.

This result supported my third hypothesis that cultural health indicators would not be strongly correlated with conventional bioindicators because each approach reflects two different knowledge systems and perspectives (H3). In the following discussion, I examine the results more in-depth and attempt to explain the key patterns and processes leading to differences in ecological and cultural indicators across sites in the Kuratau River catchment.

## Water quality

Nutrient concentrations showed large increases between indigenous forest and pastoral stream sites. This finding is consistent with results previously described in New Zealand (Quinn et al. 1997) and internationally (Allan 2004). In particular, nitrogen concentrations greatly increased, which was likely due to fertilizer additions for grass growth and stocking of grazing ungulates on pastoral lands. Such changes are of concern in the Lake Taupō catchment, since there is “cap-and-trade” management scheme for diffuse emissions of nitrogen in the Lake Taupō catchment, and overall, there has been a goal of reducing the nitrogen load by 20% (OECD 2015). Some caution needs to be applied to my water quality results, since the nutrient concentrations only represent a snapshot in time and may not be indicative of long-term conditions. However, the State of the Environment (SOE) monitoring by the Waikato Regional Council (WRC) has shown that nitrate concentrations have increased over time at Site 6 (Vant 2018), the most downstream site sampled in my survey. This long-term trend indicates that land use change and intensification has contributed to increased nutrient concentrations entering Lake Taupō from the Kuratau catchment. These impacts may reflect temporal ‘legacy effects’ (Allan 2004), with a lag between nitrate entering groundwater and then finally emerging in surface waters.

I also observed variation in phosphorus concentrations across the sites in the Kuratau catchment, with very high concentrations at Site 6 below the hydro-dam. The DRP concentration (0.033 mg/L) I recorded at this site was indicative of an ecosystem state that exceeds the national bottom line (>0.018 mg/L) for the DRP attribute in the NPS-FM (noting that the NBL is based on median values from five years). The residual flows below the hydro-dam appear to be groundwater-fed and not discharge from the tail race, which enters the river further downstream. Thus, it seems likely that the high concentrations of DRP observed have natural origins. Surface waters in the central North Island can have naturally high DRP concentrations due to the underlying volcanic geology (Burdon and Özkundakci 2023). In the neighbouring Bay of Plenty region, sites near their headwaters with spring sources are more likely to be affected by phosphorus enrichment of underlying groundwater through porous volcanic geology (Scholes 2021). This naturally occurring process can depend on the geological origins of the contributing groundwater sources and the contact time with relevant geological formations (Morgenstern et al. 2015). This suggests that the groundwater entering the Kuratau River at Site 6 has a long residence time, although the elevated levels of nitrate at the same site indicate that residence times are congruent with the timeline for agricultural intensification in the catchment.

The nutrient concentrations across the ten sites were positively associated with measures of ecosystem functioning (decomposition, primary production). Elevated nutrient concentrations can drive greater biomass accrual in periphyton (Biggs 2000), although similar stream types in the Bay of Plenty are thought to have less strong nutrient-chlorophyll relationships due to the frequent flood disturbance of the more unstable benthic pumice substrates (Kilroy et al. 2020). Similarly, previous research has indicated that the cotton strip assay (CSA) is sensitive to elevated nutrient concentrations (Tiegs et al. 2024), further suggesting that this functional indicator is able to link nutrient stressors to altered stream ecosystem functioning. Although elevated nitrogen and phosphorus concentrations are important to increased rates of cotton degradation, studies using the CSA have tended to show phosphorus as the more influential nutrient (Burdon et al. 2020a, Pingram et al. 2020). This means the relative fast rates observed across all sites (2.1% tensile strength loss per day) is likely driven by the high background concentrations of phosphorus due to the underlying volcanic geology in the catchment. The study by (Tiegs et al. 2013) included sites in the South Island of Aotearoa, New Zealand, and reported consistently lower decomposition rates using the CSA in indigenous forest streams (median = 0.087% TSL degree-day$^{-1}$, $n$=7) than those sampled in the Kuratau River catchment (median = 0.169% TSL degree-day$^{-1}$, $n$=5). The results in Tiegs et al. (2013) suggest that lower background levels of DRP in the South Island sites may have contributed to slower breakdown rates than that observed in my study.

## Habitat quality

Levels of fine inorganic sediment were elevated across most sites and included native forest sites. Seven of the sites sampled had deposited fine sediment that were indicative of ecosystem states in the D attribute band for the NPS-FM (i.e., >29% leading to a “High impact of deposited fine sediment on instream biota”). However, the deep layers of volcanic ash and pumice that cover large portions of the central North Island leads to naturally high levels of fine sediment in streams and rivers (Burdon and Özkundakci 2023). The geology of the wider region (including the Kuratau River catchment) is characterised by mantles of tephra including volcanic ashes and pumice gravels underlaid by welded igneous rocks (Collier and Bowman 2003, Collier and Smith 2003). Streams in this region are typically spring-fed with benthic substrates dominated by mobile beds of pumice sand and gravels (Collier and Halliday 2000). However, the soils include weakly structured yellow-brown pumice which are prone to severe sheet erosion, meaning that pastoral land-uses can upset the delicate balance with the naturally high background levels of deposited fine sediment in streams. Evidence of these impacts were observed at Site 6 (the most downstream site) where the low gradients likely exacerbated the accumulation of deposited sediment due to upstream inputs that have been increased through human land uses (Allan 2004).

Another important factor affecting the distribution of fine sediment in the Kuratau River catchment is the hydro-dam. The lowest sediment levels were observed at Site 9 below the dam, which indicated that this reach was sediment-starved, and there was evidence of ‘armouring’ (coarsening) of the riverbed. Water and sediment inputs are fundamental drivers of river ecosystems, but river management has tended to prioritize flow regimes at the expense of the sediment regime (Wohl et al. 2015). High-flow releases below dams into sediment-starved reaches lacking sediment inputs can cause riverbed coarsening and the loss of habitat (Jacobson and Galat 2008, Wohl et al. 2015). Conversely, reduced flows below dams combined with abundant sediment supply can cause sedimentation of the riverbed, leading to the loss of benthic and fish habitat (Wohl et al. 2015). The

Kuratau River appears to conform to both these impacts, with a sediment-starved reach directly downstream of the dam (Site 9) followed by the lower reaches of the river characterised by high levels of deposited fine sediment (Site 6). These impacts on the natural sediment regime in the Kuratau River have broader implications for its ecology, and the high levels of fine sediment at Site 6 help explain the lower macroinvertebrate indices recorded in this reach. For example, lowest score for the QMCI (4.3) was recorded at Site 6. Deposited fine sediment is well-recognised for having negative impact on sensitive stream macroinvertebrates, which include the loss of benthic habitat, degraded food sources, and direct stress effects (Burdon et al. 2013).

I quantified riparian habitat using the P2d form in (Harding et al. 2009). This approach has been used to score a qualitative index of riparian integrity that has been associated with macroinvertebrate responses in New Zealand (Burdon et al. 2013) and Europe (Burdon et al. 2020b). In my study, there were only weak positive correlations between riparian condition and macroinvertebrates, and some sites with poor instream habitat qualities (Sites 6, 9) had relatively intact riparian buffers characterised by extensive stands of native woody vegetation. The sites that had low riparian condition were two sites characterised by pastoral land uses at the local scale. One of these sites (Site 3) still had its headwaters in indigenous forest, which may have decoupled the relationship between local riparian habitat and macroinvertebrates. However, the site with the lowest riparian condition score (Site 7) was a stream tributary that had its entire catchment dominated by pastoral land cover. This site also had the lowest MCI and ASPM scores, indicating that degraded riparian habitat contributed in part to declines in stream ecosystem health. Poor riparian habitat was generally influenced by the lack of woody vegetation, which can lead to less shading and warmer temperature, greater bankside erosion and sediment inputs, and lower litter inputs and instream habitat (Allan 2004).

## Biodiversity

In general, agricultural land uses have negative effects on stream species richness (Petsch et al. 2021). I used benthic macroinvertebrates as key indicators of stream ecosystem health. In both the NEMS kicknets and eDNA samples, I found evidence for negative impacts of pastoral land cover on aquatic macroinvertebrate taxa richness. This indicated that invertebrate biodiversity was substantially reduced in the sites affected by upstream pastoral land uses. Other studies have shown reduced taxonomic richness in pastoral streams. Across Aotearoa New Zealand, Quinn and Hickey (1990) observed a 21% decrease in macroinvertebrate taxonomic richness in streams draining highly modified catchments compared to catchments with low development. In South Island streams, Harding and Winterbourn (1995) found lower taxonomic richness in pastoral streams when compared to streams with catchments dominated by native vegetation. However, other studies have shown more equivocal results with alpha diversity responses such as taxa richness. Quinn et al. (1997) did not find any differences in taxa richness between pastoral and forested streams in the Waikato. Likewise, Clapcott et al. (2012) found that benthic macroinvertebrate richness was a relatively weak indicator of land-use effects. Taxonomic richness results can be equivocal due to mass effects (source-sink dynamics) from unaffected upstream tributaries that weaken the invertebrate-environment relationship (Heino 2013), but I did not see evidence of this influence in the Kuratau River catchment.

Another aspect of biodiversity change that needs to be considered is high taxonomic turnover leading to an increase in beta-diversity despite maintaining similar levels of richness. Quinn et al. (1997) showed that macroinvertebrate communities in pastoral streams had different composition to the communities in the forested streams. The pastoral streams were dominated by tolerant taxa like chironomid midges, oligochaete worms and the snail *Potamopygus*. This contrasted with higher abundances of the mayflies *Deleatidium*, *Acanthophlebia*, and *Ameletopsis* and the stonefly *Zelandobius* in the forested sites. In my study, I found that the pastoral sites were more associated with tolerant taxa like chironomid midges, oligochaete worms and the snail *Potamopygus.* In contrast, I found that two stoneflies (*Zelandobius* and *Megaleptoperla*) and the mayfly *Ameletopsis* were indicator taxa for the indigenous forest land cover sites. This likely reflected differences in stream temperatures between land cover types, since stoneflies and mayflies are typically less abundant in streams that experience warmer summer temperatures (Quinn and Hickey 1990). Overall, my results conform with Petsch et al. (2021) who showed that beta-diversity responses of stream biodiversity are often strong in response to agricultural land uses.

In my study, the bioindicators used in the macroinvertebrate attribute of the NPS-FM (MCI, QMCI, ASPM) showed negative responses to pastoral land cover when compared to the indigenous forest sites. The strongest response came from the ASPM metric calculated using a local reference site and the MCI, although the QMCI and ASPM (NPS-FM) both had negative effects. The negative effect on the MCI was not surprising, since it is based on the occupancy of sensitive and tolerant taxa. Thus, the significant negative response of EPT taxa richness indicated that these generally sensitive taxa had lower occupancy in pastoral land cover sites, contributing to the negative response of the MCI. Likewise, the ASPM responses were consistent with expectations since both the MCI and EPT richness are constituent metrics. However, the third constituent metric of the ASPM, %EPT abundance, showed no difference between REC land cover sites and had relatively high values (median=62%). There was virtually no influence of deposited fine sediment on the invertebrate metrics, which was surprising because other studies have shown strong negative sediment-invertebrate relationships, especially for %EPT abundance (Burdon et al. 2013). At least four sites had macroinvertebrate metric scores that were indicative of the A Band under the NPS-FM but were in the D band for deposited fine sediment. These sites may have had patch-dynamics due to the steeper channel gradients and greater stream power reflective of the hill country dominating the catchment. Such dynamism might mean fine sediment was prone to flux, leading to high spatio-temporal heterogeneity that can help preserve suitable benthic habitat for stream invertebrates (Townsend and Hildrew 1994). Submerged large wood in the forested sites could provide an important stable refuge (Collier and Halliday 2000) and structure stream geomorphology (Quinn et al. 1997). Furthermore, the relatively low intensity land-uses in much of the Kuratau River catchment may mean that there are stable habitat dynamics at larger spatial scales, thus preserving populations of sensitive stream invertebrates and leading to strong source-sink dynamics in the metacommunities (Heino 2013). In summary, the streams draining pastoral lands in the Kuratau River catchment had reduced biodiversity with the replacement of sensitive taxa (e.g., mayflies, stoneflies) with more tolerant taxa when compared to the less developed indigenous forest catchments.

## Cultural Health

I used the Cultural Health Index (CHI) to assess the ecological integrity of the Kuratau River catchment from a Te Ao Māori perspective. To test my second hypothesis, I used the traditional Cultural Stream Health Measure (CSHM) described by (Tipa and Teirney 2006) to detect effects of upstream landuse on stream ecosystem health and compared the size of this effect with the other indicators used. My results showed that CSHM was able to approximate the median effect size for indicators where a negative response had an adverse effect on ecosystem health. These indicators mostly reflected biodiversity values associated with stream macroinvertebrates. The indicator that had the most similar effect size to the traditional CSHM was riparian condition. This was not surprising, because both indicators are subjective, qualitative indices based on a Likert scale that are at least partly assessed visually. They both have overlapping attributes as part of their scoring system, such as surrounding land use, riparian vegetation, and riparian margins. These qualities meant that the CSHM was strongly correlated with riparian condition, which refuted my third hypothesis that cultural health indicators would diverge from conventional indicators. Harmsworth et al. (2011) similarly found that in the Riwaka and Motueka River catchments, the CSHM was strongly correlated with the proportion of native vegetation upstream. Townsend et al. (2004) also found that the CSHM in the Taieri and Kakaunui River catchments was more strongly associated with riparian habitat at the stream segment scale than other indicators. Those authors were also able to associate the CSHM with instream habitat scores, which I saw further indication of with the weak correlation between deposited fine sediment and the CSHM in the Kuratau River catchment.

However, consistent with my third hypothesis, I found that the CSHM was not strongly correlated with macroinvertebrate indices. This contrasted with previous studies, which have found significant correlations between the CSHM and the MCI metrics (Townsend et al. 2004, Harmsworth et al. 2011). Part of this discrepancy could be due to the limited number of sites I sampled, meaning that there was insufficient power to detect a relationship. Another aspect that influenced the ability of the CSHM to approximate the instream biodiversity trends was the impact gradient in the Kuratau River catchment. The MCI scores ranged from 102 to 141 (median=127), meaning that there were not the highly impacted sites that would help describe a linear relationship between the two indicators. Thirdly, my results are a snapshot in time, and repeated sampling might improve the estimates of the CSHM and the other metrics, thus enabling a stronger relationship to emerge between it and the instream indicators. However, putting these aspects to the side, there is a philosophical argument underpinned by my third hypothesis suggesting that the two approaches are complementary and represent different ways of knowing stream ecosystems (Hikuroa et al. 2021). One of the strengths of the cultural monitoring approach is that it provides Māori with greater agency in environmental assessment and management by giving a voice to Te Ao Māori.

## Conclusions

My results were consistent with previous studies that have shown negative impacts of agricultural land uses on stream ecosystem health. Although the impacts of land use are relatively moderate in the Kuratau River catchment, the increases in nutrient concentrations were of concern given the sensitive receiving environment of Lake Taupō. My results also showed negative impacts on stream macroinvertebrate biodiversity which indicates that riparian restoration could help reduce negative impacts of sediment runoff and elevated summer temperatures. Results also suggest that the Kuratau hydro dam has impacts on the natural sediment regime, leading to stream coarsening near the foot of the dam and increased sedimentation further downstream. These impacts, coupled with altered flow regimes and reduced connectivity highlight the ecological costs of impoundments in river networks. These impacts need to be balanced with the benefits of the dam, which may help prevent non-native fish (e.g., brown bullhead catfish) from penetrating further into the catchment, and the ecosystem services provided by Lake Kuratau which include power generation and recreational activities (boating, fishing).

A key goal of my thesis was to incorporate culturing monitoring with more conventional biomonitoring tools to assess stream/river health. Within the framework of the Cultural Health Index, I was able to describe freshwater health in a way that identifies the customary connection of hapū and iwi Māori to freshwater and determine the mahinga kai values of the sites, alongside the physical and ecological condition of the wai. I was also able to highlight the ability of the Cultural Stream Health Measure (CSHM) to discern the impacts of pastoral land uses on stream ecosystem health. The strength of this impact was equivalent with the median effect size for indicators of negative change, and the cultural monitoring metric was closely aligned with a similar metric for assessing riparian habitat. Although there were not strong correlations of the CSHM with instream indicators, this could have been due to the limited number of sites samples, the relatively narrow impact gradient, and the lack of temporal replication to improve estimated values. However, I expected that indicators might not correlate due to cultural monitoring frameworks being grounded in a separate knowledge system. Any absence of correlation does not invalidate either approach, and they should be viewed as complementary with separate values and advantages. A key advantage of cultural monitoring approaches is through giving Māori greater agency in environmental monitoring. Incorporating mātauranga informed initiatives and cultural monitoring approaches recognises the plurality of knowledge systems. Increasing tangata whenua involvement in both the decision-making process and the application of freshwater management leads to the expansion of both knowledge systems, which will ultimately lead to improved outcomes in freshwater management.

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# Appendix I - eDNA biodiversity

eDNA biodiversity wheels detailing the range of terrestrial and aquatic organisms detected at each site in the Kuratau catchment.

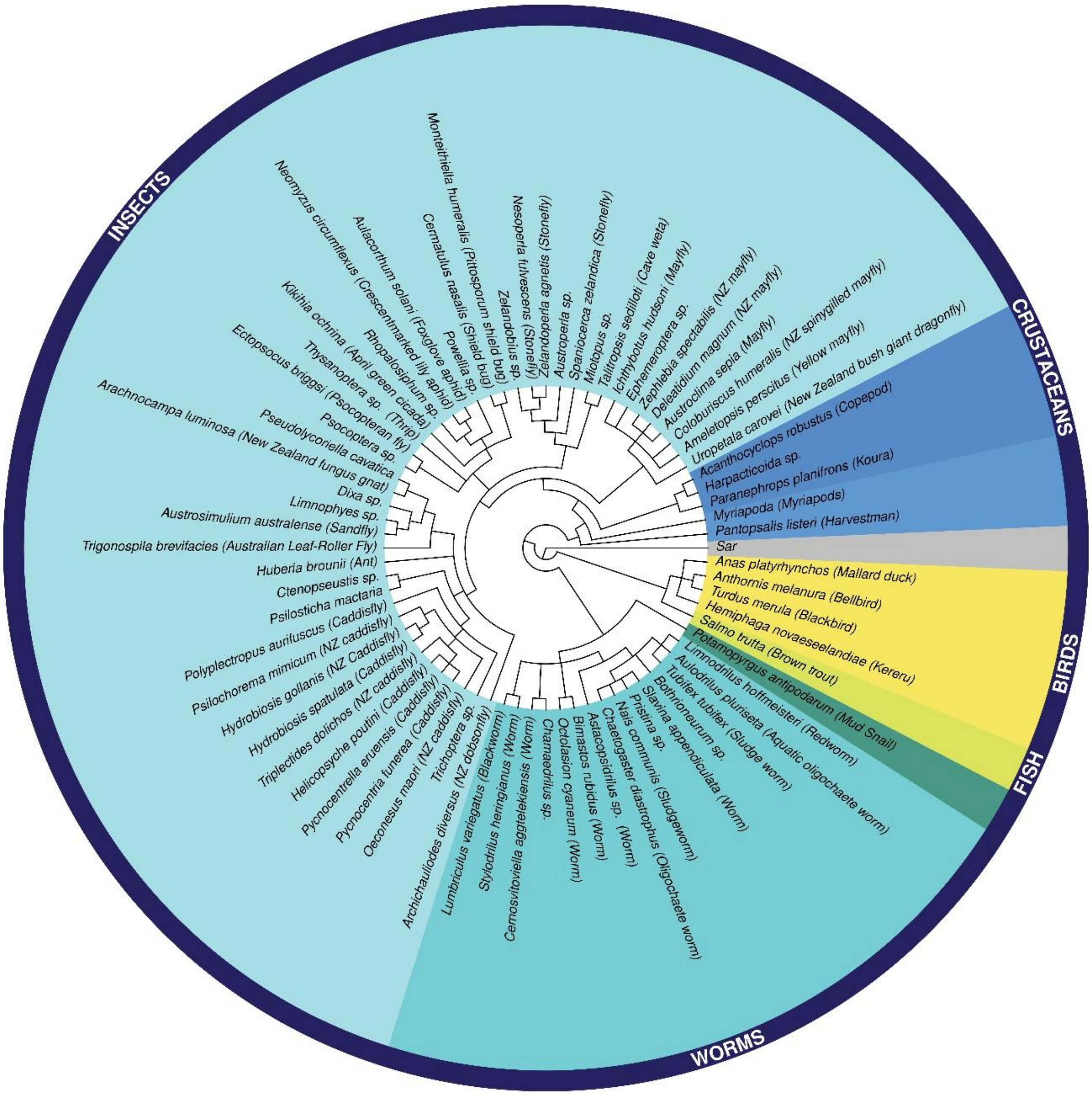

*Figure 28 Site 1 - Kuratau River (Upper SOE monitoring site)*

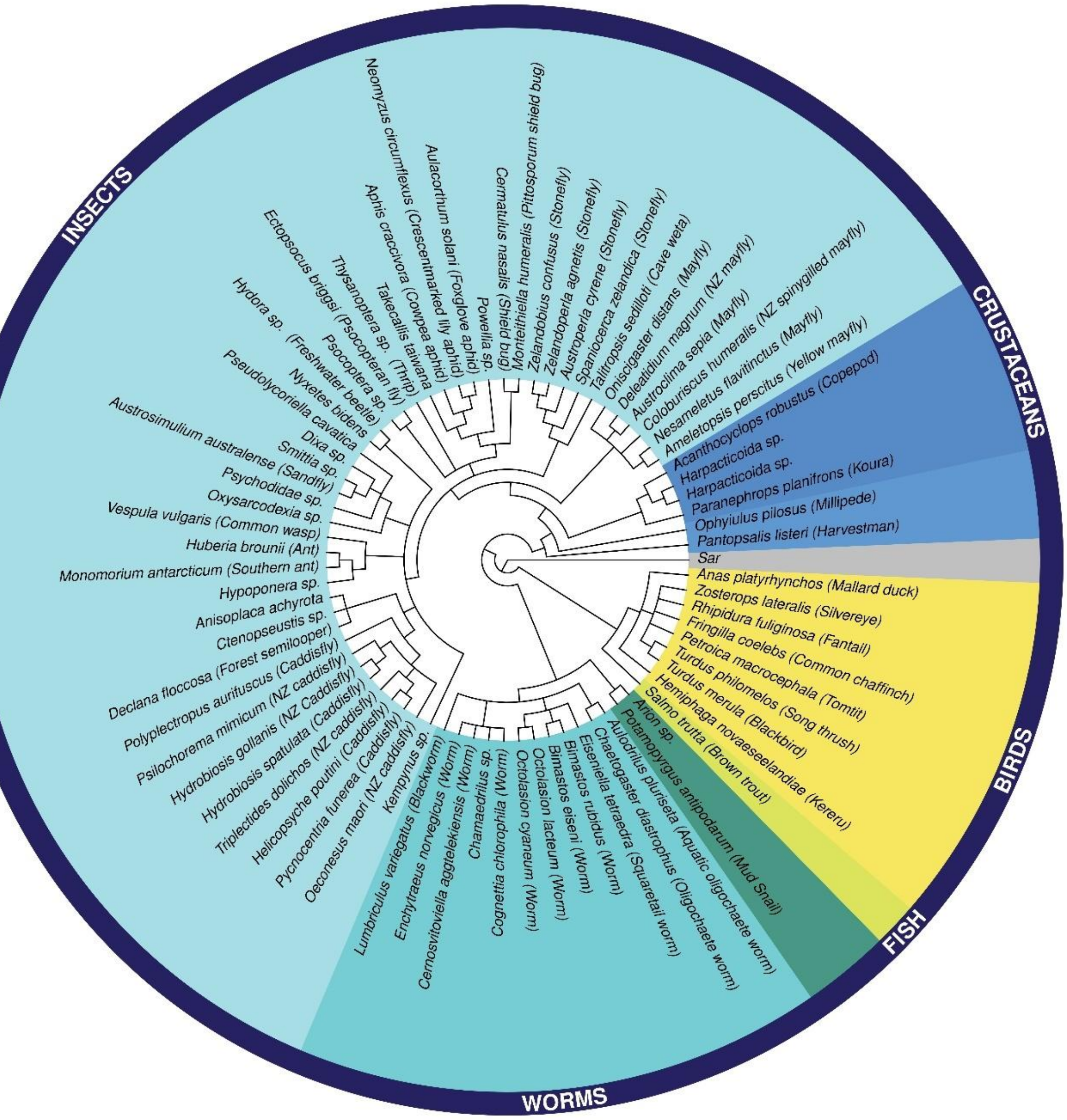

*Figure 28 Site 2 - Tributary Waituhi-Kuratau*

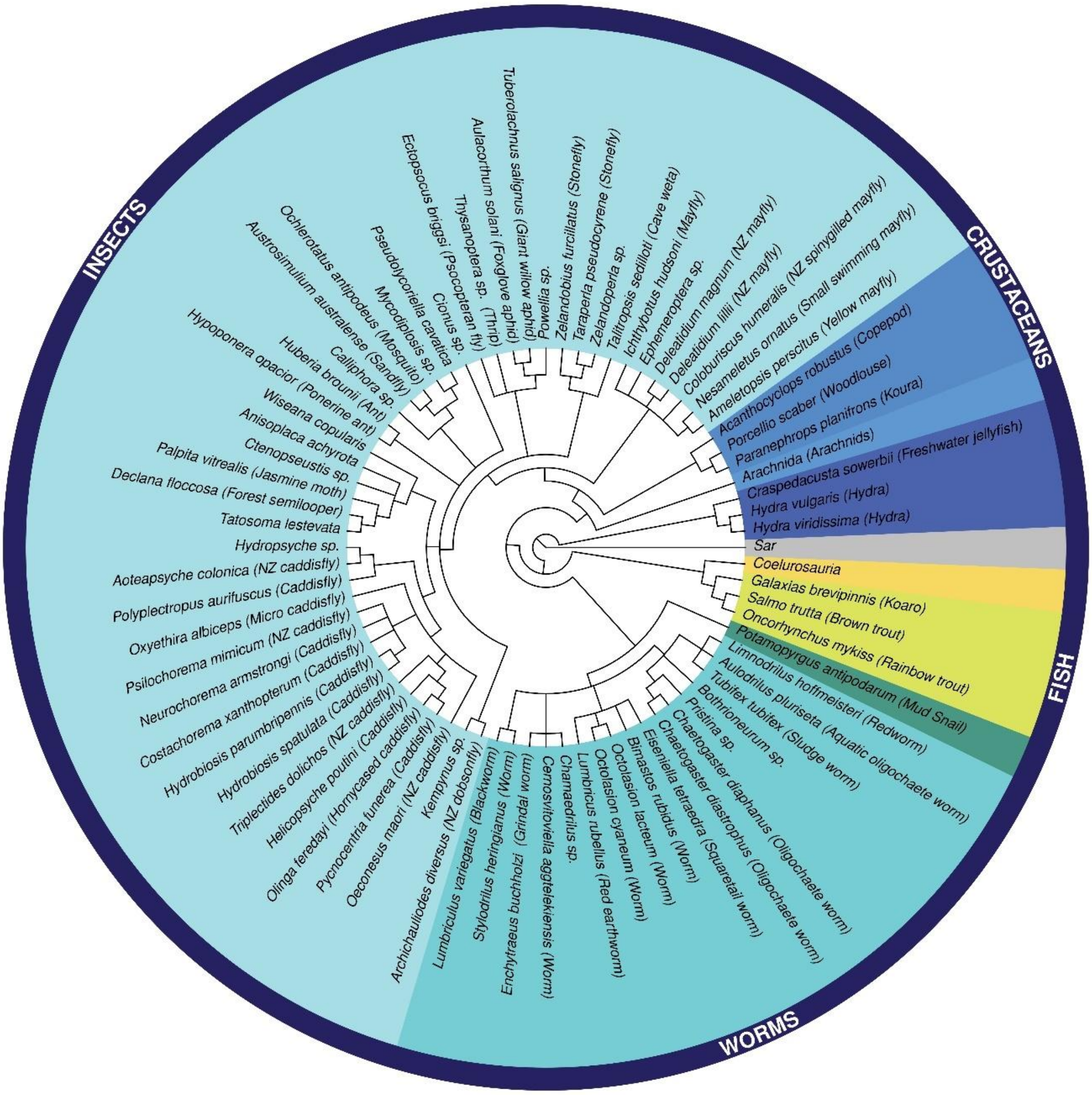

*Figure 29 Site 3 - Mangaongoki Stream*

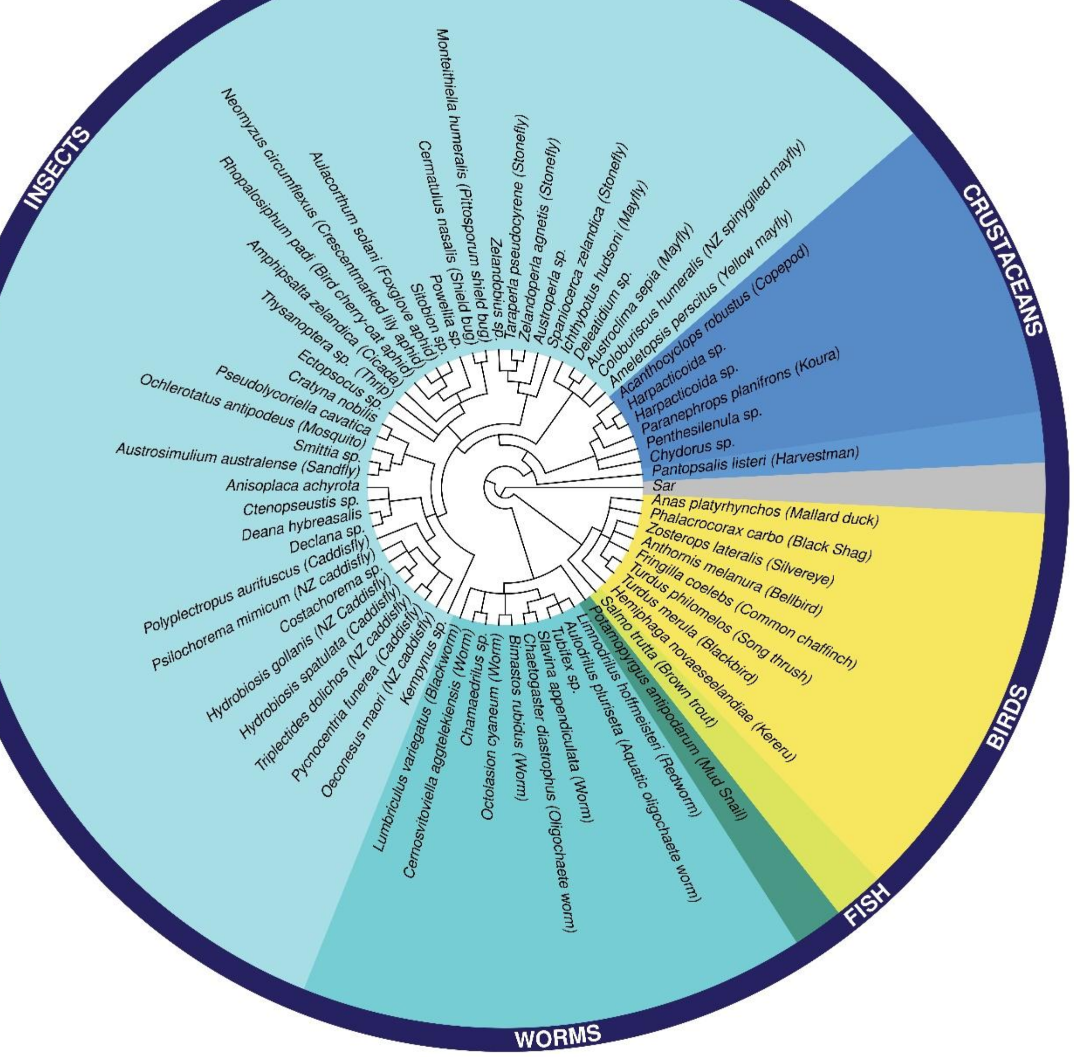

*Figure 30 Site 4 - Te Roto Stream*

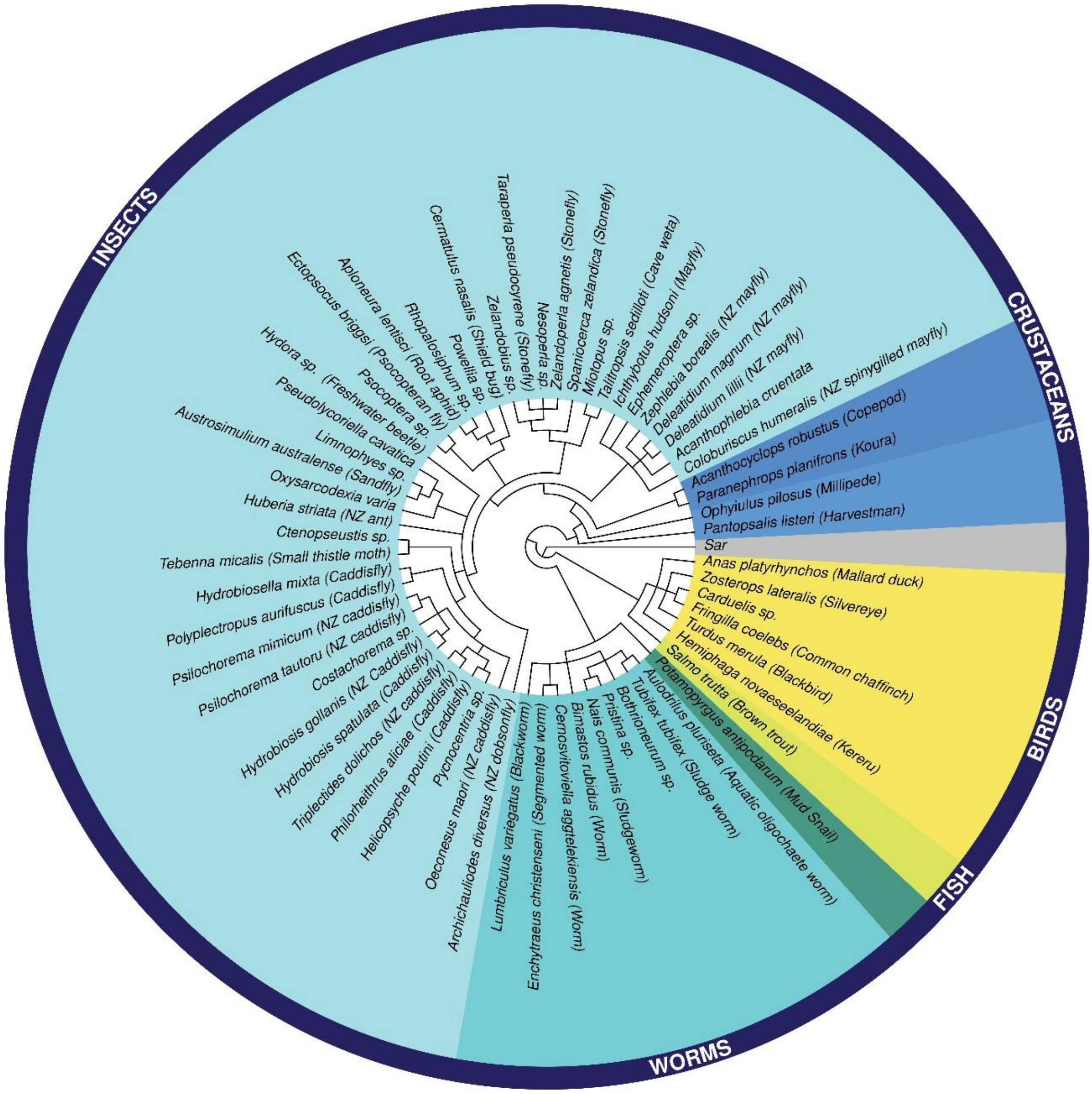

*Figure 31 Site 5 - Kuratau River Headwater*

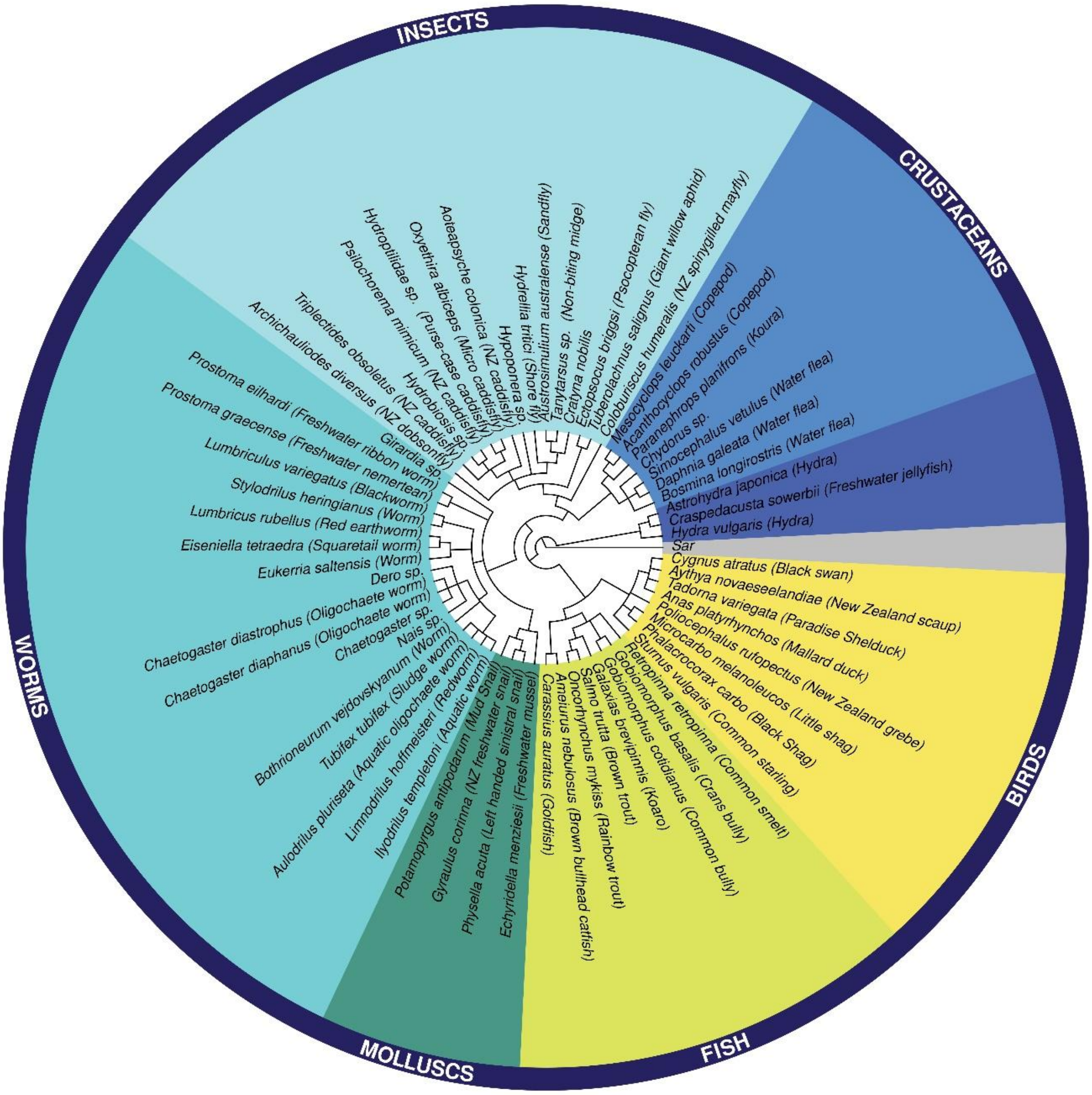

*Figure 32 Site 6 - Kuratau River Mouth (Lower SOE monitoring site)*

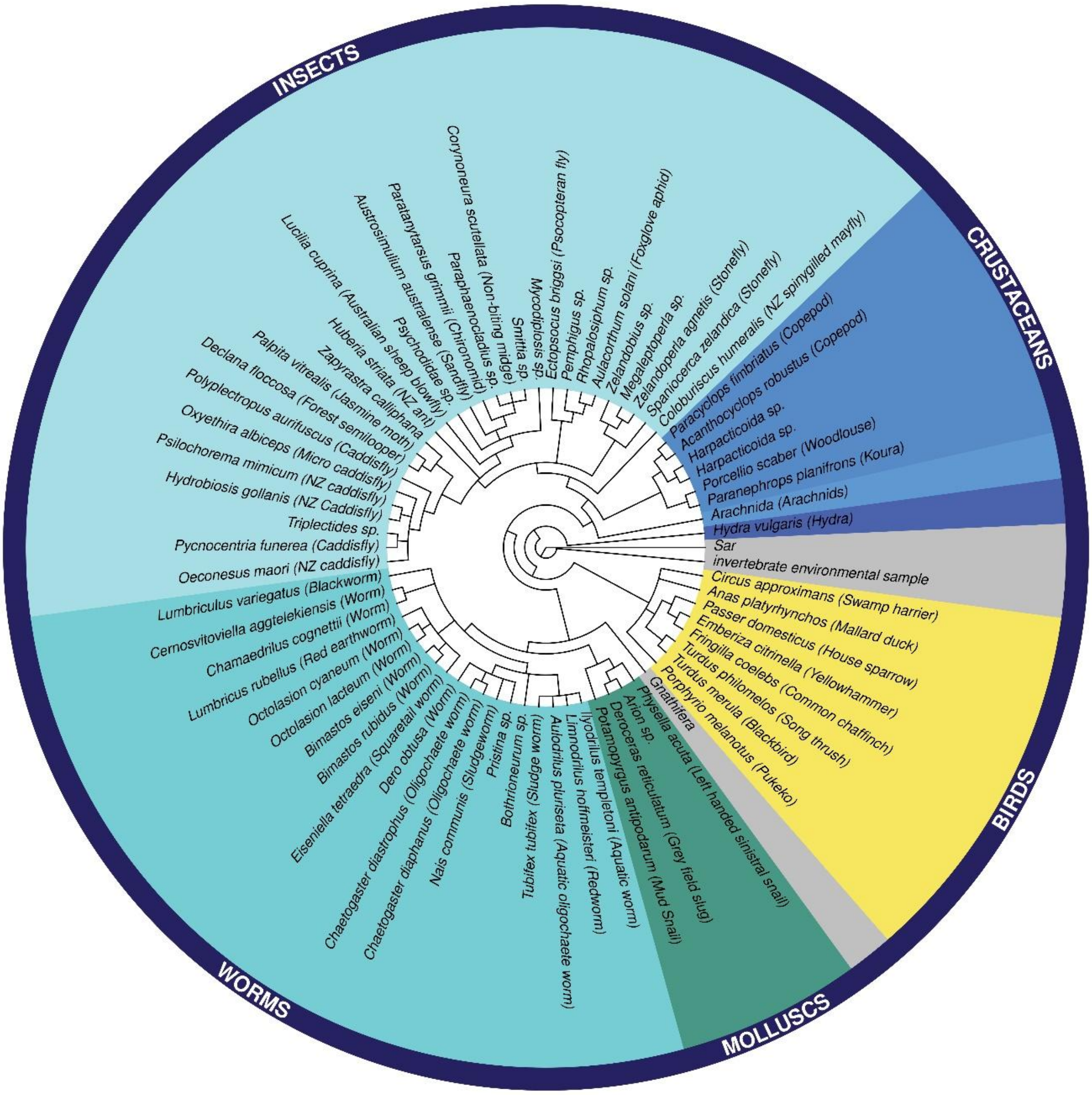

Figure 33 Site 7 - Moerangi Tributary Pasture

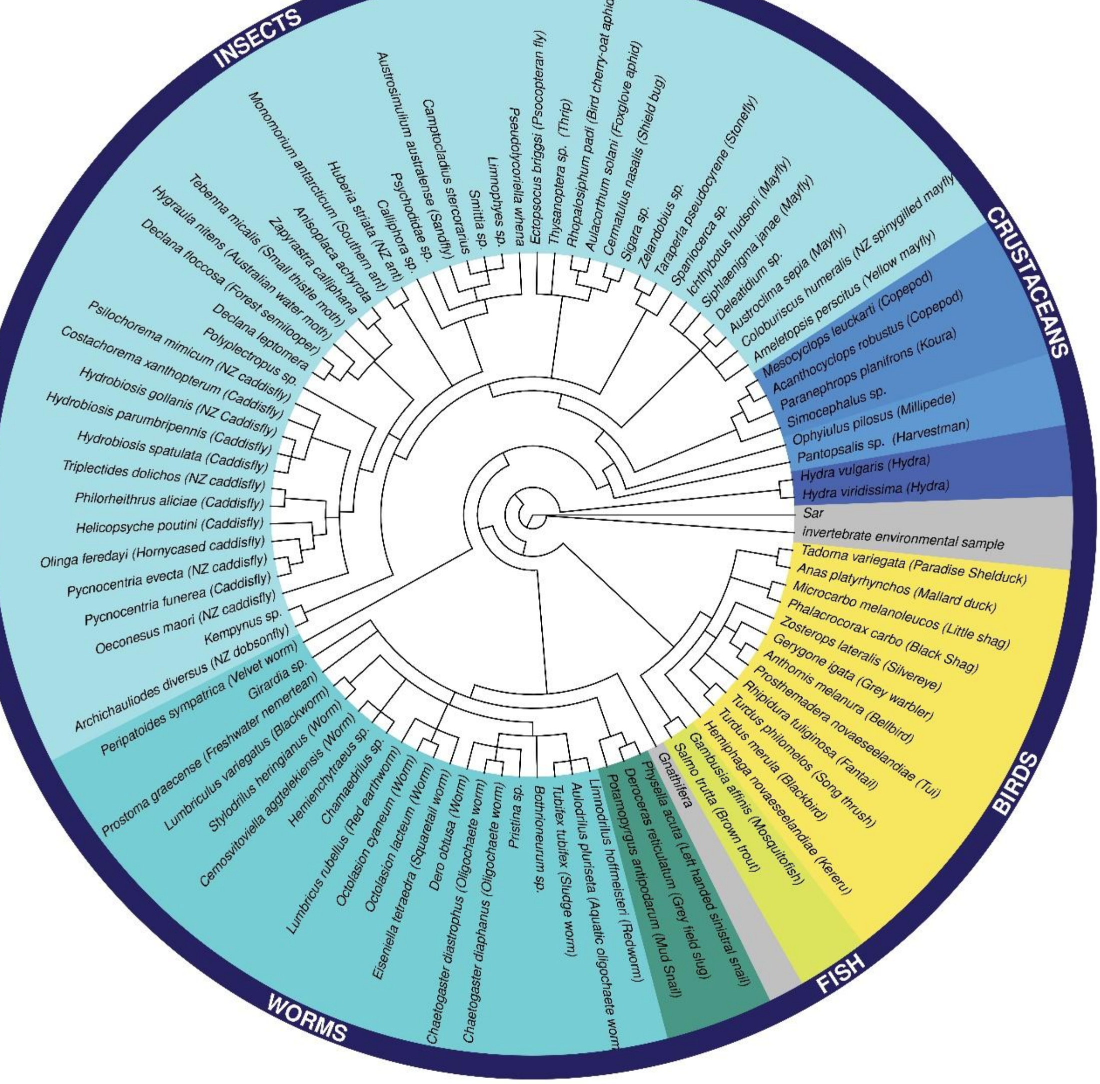

*Figure 34 Site 8 - Kuratau River Moerangi*

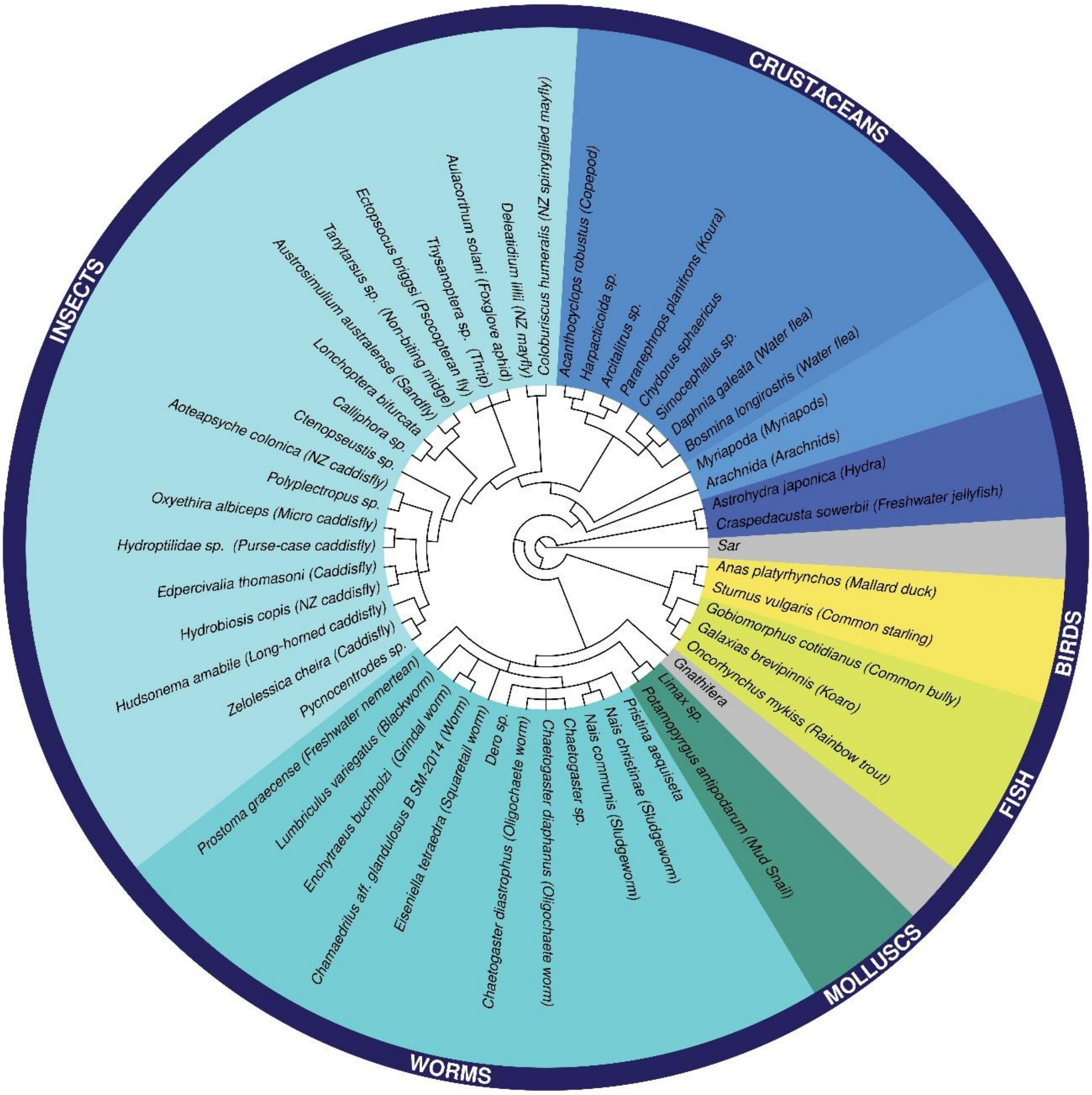

*Figure 35 Site 9 - Kuratau River (Below Hydro Lake)*

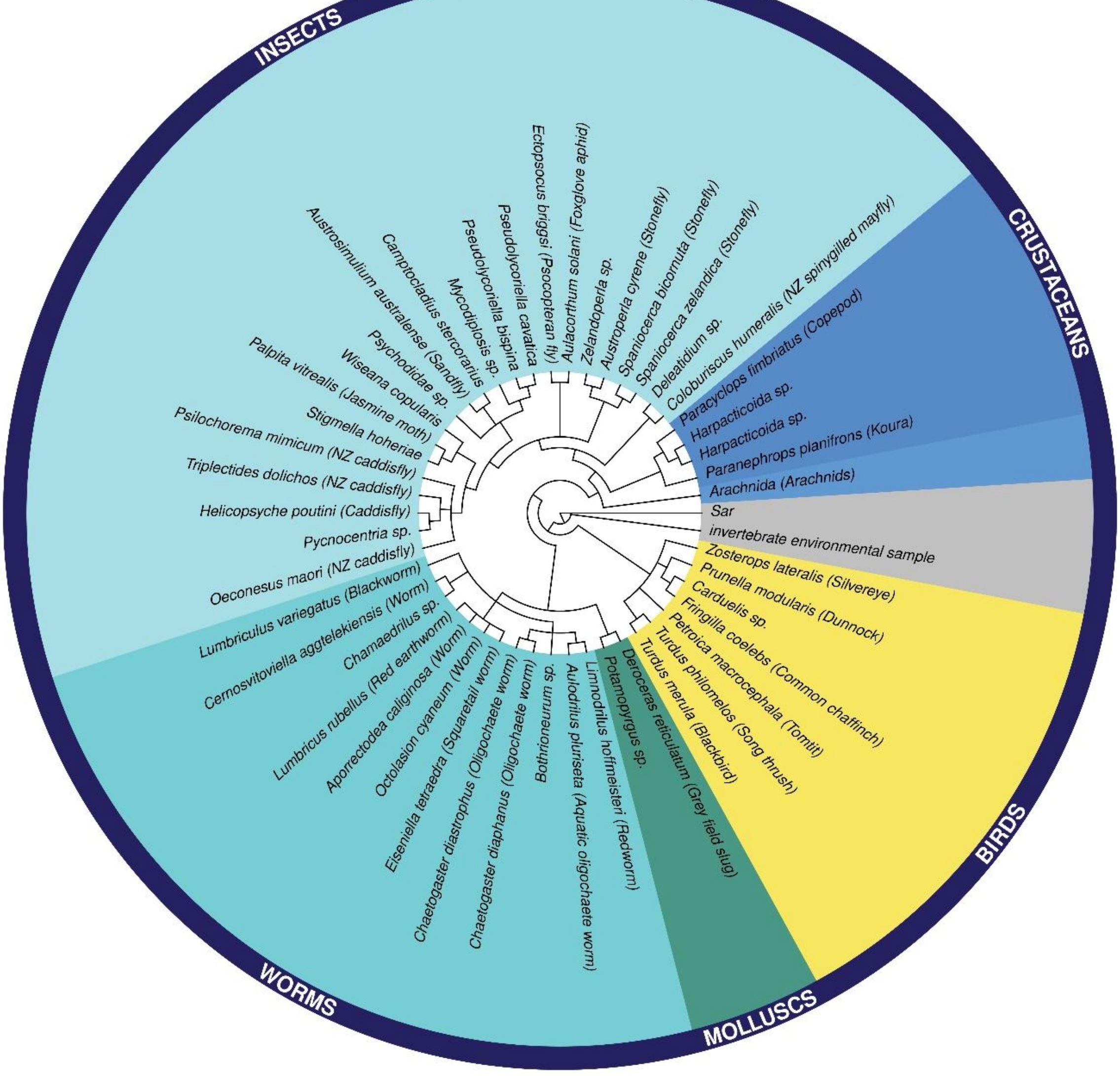

*Figure 36 Site 10 - Moerangi Tributary Pine*