CAWTHRON

REPORT NO. 3970

NGĀ AWA MONITORING PROGRAMME: TE HOIERE CATCHMENT REPORTING 2021–22

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ROLAND EVELEENS, LAURA KELLY

Prepared for Department of Conservation

CAWTHRON INSTITUTE
98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042 | New Zealand
Ph. +64 3 548 2319 | Fax. +64 3 546 9464
www.cawthron.org.nz

REVIEWED BY:
Robin Holmes

APPROVED FOR RELEASE BY:
Joanne Clapcott

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EXECUTIVE SUMMARY

This report provides the Department of Conservation (DOC) with an analysis of the data collected from Te Hoiere / Pelorus River (hereafter Te Hoiere) catchment in the 2020/21 and 2021/22 monitoring seasons. The environmental monitoring data were collected as part of the Ngā Awa river restoration programme being implemented by DOC in partnership with other organisations.

The data comprised indicators and measures of freshwater ecological integrity collected from 11 sites within Te Hoiere catchment between March 2021 and March 2022. All sites were located on public conservation land (PCL). The indicators and measures were classed into three high-level categories:

- aquatic life (including fish, macroinvertebrates, megainvertebrates, aquatic plants and periphyton)
- habitat (including habitat types, discharge, substrate stability and deposited sediment)
- water quality (including nutrients, other water chemistry data and visual clarity / suspended sediment).

Where possible, the data were analysed with respect of guideline values or attribute bands from the New Zealand National Policy Statement for Freshwater Management (NPS-FM) and compared with data from other Ngā Awa catchments and DOC's National Freshwater Monitoring Programme (NFMP). Interpretation of results relative to NPS-FM attribute bands has been included to provide context, although the sampling regime used does not allow attribute bands to be designated for each metric. In addition to various environmental metrics, threat classifications and species distributions, were determined for selected aquatic life data. The relationships between metric scores and covariates from other metrics and the River Environment Classification variables were explored to investigate potential drivers of the observed results. The analytical approach closely follows the process taken by Kelly et al. (2023) for analysing data from the NFMP.

Across the attributes measured at the 11 sites surveyed in 2020/21 and 2021/22, all results indicated good water quality and that the catchment within PCL remains in reference state. Aquatic life scores suggest there is high biodiversity across the sites. Similarly, the habitat and water quality measures were generally indicative of pristine conditions. The areas of Te Hoiere catchment within PCL are relatively unmodified, with landcover dominated by indigenous forest, often all the way to the upstream boundaries of the catchment. There were no clear gradients or categories that could be used to stratify or distinguish sites to examine the impact of covariates or drivers on the indicators and measures. The results presented here provide evidence that areas within PCL in Te Hoiere catchment are generally in excellent condition and can be used to assess efforts being made to restore other areas of the catchment.

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GLOSSARY

Average score per metric (ASPM)	The average score obtained from the MCI, EPT taxa richness and %EPT results for macroinvertebrates
Backpack electric fishing	A fishing method where a backpack machine is used to create an electric current, which temporarily stuns fish and enables their capture for identification and measurement
Ecological integrity	The degree to which the physical, chemical and biological components (including composition, structure and process) of an ecosystem and their relationships are present, functioning and maintained
Fish index of biotic integrity (F-IBI)	A measure of the overall health of a fish community, taking into account factors such as species richness and diversity of taxa with varied habitat preferences and pollution tolerance
Hard-bottomed	Freshwater environments with more than 50% hard substrates, such as rocks or gravel, as opposed to soft substrates like mud or sand
Macroinvertebrate Community Index (MCI)	A biotic index used to determine stream or river health based on the presence (or absence) of different macroinvertebrate taxa
Megainvertebrates	Very large invertebrates, such as crayfish (kōura), mussels (kākahi), shrimp and crabs
Meso-habitat	Habitat types determined by channel and flow characteristics, such as runs, riffles and pools
National Environmental Monitoring Standards (NEMS)	A set of technical standards used to ensure national consistency in environmental monitoring in Aotearoa New Zealand
New Zealand Freshwater Fish Database (NZFFD)	A database containing information on the distribution of freshwater fish species in Aotearoa New Zealand
New Zealand National Policy Statement for Freshwater Management (NPS-FM)	A government policy aimed at ensuring the sustainable management of freshwater resources, approved in 2020 and updated in 2023. See MfE (2023).
New Zealand River Environment Classification (REC) system	A system used to classify freshwater environments in Aotearoa New Zealand, based on physical characteristics and land cover
New Zealand Threat Classification System (NZTCS)	A system that classifies species in Aotearoa New Zealand based on their risk of extinction. NZTCS category is the category into which the species is placed, and NZTCS status is the overall conservation status of a species, taking into account factors such as population size, habitat quality and threats
Percent EPT (%EPT)	The percentage of distinct Ephemeroptera, Plecoptera and Trichoptera taxa present. These groups of insects are commonly used as indicators of water quality and ecological integrity because they are sensitive to pollution.
Periphyton	Micro-organisms, including algae, fungi and bacteria, that are attached to the river substrate

Physicochemical factors	Physical and chemical factors that can affect the health and quality of freshwater environments, such as temperature, dissolved oxygen levels and nutrient levels
Primary production	The production of energy by primary producers, such as periphyton, in an ecosystem
Public conservation land and waters (PCL)	Areas of land (and waters) managed by the Department of Conservation
Quantitative Macroinvertebrate Community Index (QMCI)	A quantitative variant of the MCI based on both the number and relative abundance of different taxa present in a macroinvertebrate sample
Soft-bottomed	Freshwater environments with more than 50% soft substrates, such as mud or sand, as opposed to hard substrates such as cobbles, boulders and bedrock
Taxon-Independent Community Index (TICI)	An environmental DNA-based taxon-free, biotic index of riverine ecological health recently developed by Wilderlab NZ Ltd.

1. INTRODUCTION

1.1. Background

The Ngā Awa river restoration programme is being implemented by the Department of Conservation (DOC) in partnership with other organisations. The aim of the programme is to restore the biodiversity of 14 rivers from mountains to sea, and freshwater monitoring is being carried out to establish a baseline ecological state. This monitoring collects data on plant and animal communities and habitat characteristics at a range of monitoring locations throughout the catchments being restored. The objective of this programme is to provide data to enable a robust status and trend assessment of the ecological integrity of focus catchments to aid in directing and assessing the effectiveness of restoration actions.

As part of this programme, DOC has engaged Cawthron Institute (Cawthron) to analyse the initial data collected in three of the catchments included in the Ngā Awa programme. The analysis of these data will enable DOC to realise the intent of the monitoring programme by providing outputs of the field-collected data and interpretation with reference to additional national-scale datasets and national guidelines. Data manipulation and analysis scripts generated for this report are also provided to facilitate future analyses.

This report is one of a series of three reports, each focusing on a different catchment, and outlines the results of monitoring undertaken in the Te Hoiere / Pelorus River (hereafter Te Hoiere) catchment at 11 sites between March 2021 and March 2022. These metrics have been organised by their overarching theme (aquatic life, habitat and water quality) to facilitate analysis, grouping and discussion.

This report and accompanying R-code for data analysis aim to:

- report on the state of components of ecological integrity in rivers and streams within each catchment
- demonstrate the utility and value of the data collected.

1.2. Catchment and monitoring programme description

Te Hoiere catchment is located in the Marlborough District and is the largest river catchment that flows into the Marlborough Sounds. Native forest cover dominates the upper portions of all significant tributaries, including the Rai River, Te Hoiere and the Wakamarina River, most of which are within the Mount Richmond Forest Park. Forest cover is primarily beech forest with some remnant podocarp forest. Exotic forestry, dry stock farming and dairy farming also occur in the lower catchment. Historically, 14 species of native freshwater fishes have been recorded within the catchment, including two Threatened and seven At Risk species (de Lange et al. 2020), and restoration projects are actively taking place within the catchment through partnerships between iwi, local community, council and other organisations (MDC [date unknown]).

Monitoring of the Ngā Awa catchments was based on the monitoring protocols developed for DOC's National Freshwater Monitoring Programme (NFMP; see Kelly et al. 2023). For Te Hoiere catchment, monitoring was conducted to assess the condition of the areas of the catchment within public conservation land and waters (PCL). The two sites sampled in the 2020/21 monitoring season were also used to assess the monitoring methods to be included in the monitoring protocols for the Ngā Awa programme. Sites were selected by DOC using Halton iterative partitioning to generate an ordered list of randomised sample locations that were spatially balanced across the study area using the New Zealand River Environment Classification (REC) river network and stratified by stream order (Larsen et al. 2008; Snelder et al. 2010).

Environmental indicators and metrics were chosen to enable assessment of the broad categories of aquatic life, habitat and water quality. A range of parameters were measured at each site, encompassing stream metrics for sediment and sedimentation, primary production, waterway biological function, water chemistry and physico-chemical factors, and assessments of habitat availability. Environmental DNA (eDNA) samples were collected using Wilderlab kits, with three replicates collected per site during the 2020/21 monitoring season and six replicates collected per site during the 2021/22 monitoring season.

1.3. Description of ecological indicators measured

1.3.1. Aquatic life

The presence and abundance of different functional groups at different trophic levels is one indicator of ecological integrity (Schallenberg et al. 2011). Key groups for which metrics have been developed are macroinvertebrates and fish. The metrics of waterway biological condition are the Macroinvertebrate Community Index (MCI), Quantitative Macroinvertebrate Community Index (QMCI), macroinvertebrate taxonomic richness and diversity (including %EPT by taxa richness), fish index of biotic integrity (F-IBI), and presence / absence of key taxa, including freshwater crayfish, shrimp and mussels.

There are few metrics associated with aquatic plants in relation to waterway health. Thus, the primary metric associated with macrophytes and bryophytes (hornworts, liverworts and mosses) is diversity and the presence of taxa classified as At Risk or Threatened (de Lange et al. 2020).

Primary production can provide an indication of the trophic state of a waterway. Primary production is typically assessed using periphyton cover and chlorophyll-*a* concentrations. The NPS-FM separates sites into productive and default periphyton classes, reflecting that some sites by virtue of their climate and geological attributes naturally have higher primary production (MfE 2023; appendix 2C). The productive classes are defined as having a dry climate (either warm-dry or cool-dry) and geological categories with higher levels of nutrient enrichment: soft-sedimentary, volcanic-basic and volcanic-acidic. All other REC class combinations are considered to belong to the default category.

The guideline values specified in the NPS-FM are intended for sites that are monitored regularly, and the numeric attribute states for most metrics relate to the percentage of times the site exceeds this state or to long-term means / medians for the site. As sites from the Ngā Awa monitoring programme are unlikely to be monitored with the intended frequency outlined in these guidelines, the values are provided only for context and metrics cannot be classed into an attribute band.

1.3.2. Habitat

The suite of metrics associated with stream habitat provides information on the presence and diversity of habitat components that can support a range of species typical of unmodified habitats. For these analyses, the metrics used consisted of those characterising hydrological diversity (the presence of habitat types such as pools, riffles, runs, rapids and gravel beds), along with specific characteristics (such as bank vegetation and woody debris) that provide habitat for fish and other species such as *Hymenolaimus malacorhynchos* (blue duck / whio).

Discharge can provide an indication of the size of the streams that is separate to stream order and can be considered as a covariate that helps to explain patterns observed in other data. For example, deposited sediment can be associated with flow rates, as can fish species that have differing flow preferences.

Broadly, the substrate metrics assessed include an evaluation of the overall geological stability of each site (Pfankuch 1975), the composition and broad size distribution of the fine sediment (sediment assessment methods 1, 3 and 6; Clapcott et al. 2011) and the presence of non-nutrient contaminants (herbicides and pesticides).

1.3.3. Water quality

The metrics collected in this section are necessary both for identifying and monitoring sites subject to human-derived stressors, and also to provide background information for unmodified sites in relation to the other ecological integrity indicators. To aid interpretation, monitoring results were compared to guideline values from ANZECC (1992) and attribute band values from the NPS-FM. Water quality data were divided into nutrient-related data (dissolved reactive phosphorus, nitrogen and ammonia), other water chemistry data (pH, dissolved oxygen, conductivity and the presence of other ions) and water clarity (black disc, turbidity).

1.4. Overview of sites

Eleven sites were monitored over the 2020/21 and 2021/22 monitoring seasons. DOC monitored two sites in the 2020/21 season as a pilot of the Ngā Awa monitoring protocols, while Cawthron were contracted to monitor a further nine sites in the 2021/22 season (Figure 1). Each site was monitored once. The sites monitored included one site in the Rai River, six sites in Te Hoiere, and three sites in the Wakamarina River, as well as one tributary low down in the catchment. Sites spanned all stream orders from first-order tributaries to the main stem of Te Hoiere (fifth order), including two first-order sites, three second-order sites, two third-order sites, one fourth-order site and three fifth-order sites. See Appendix 1 for a full list of sites and locations.

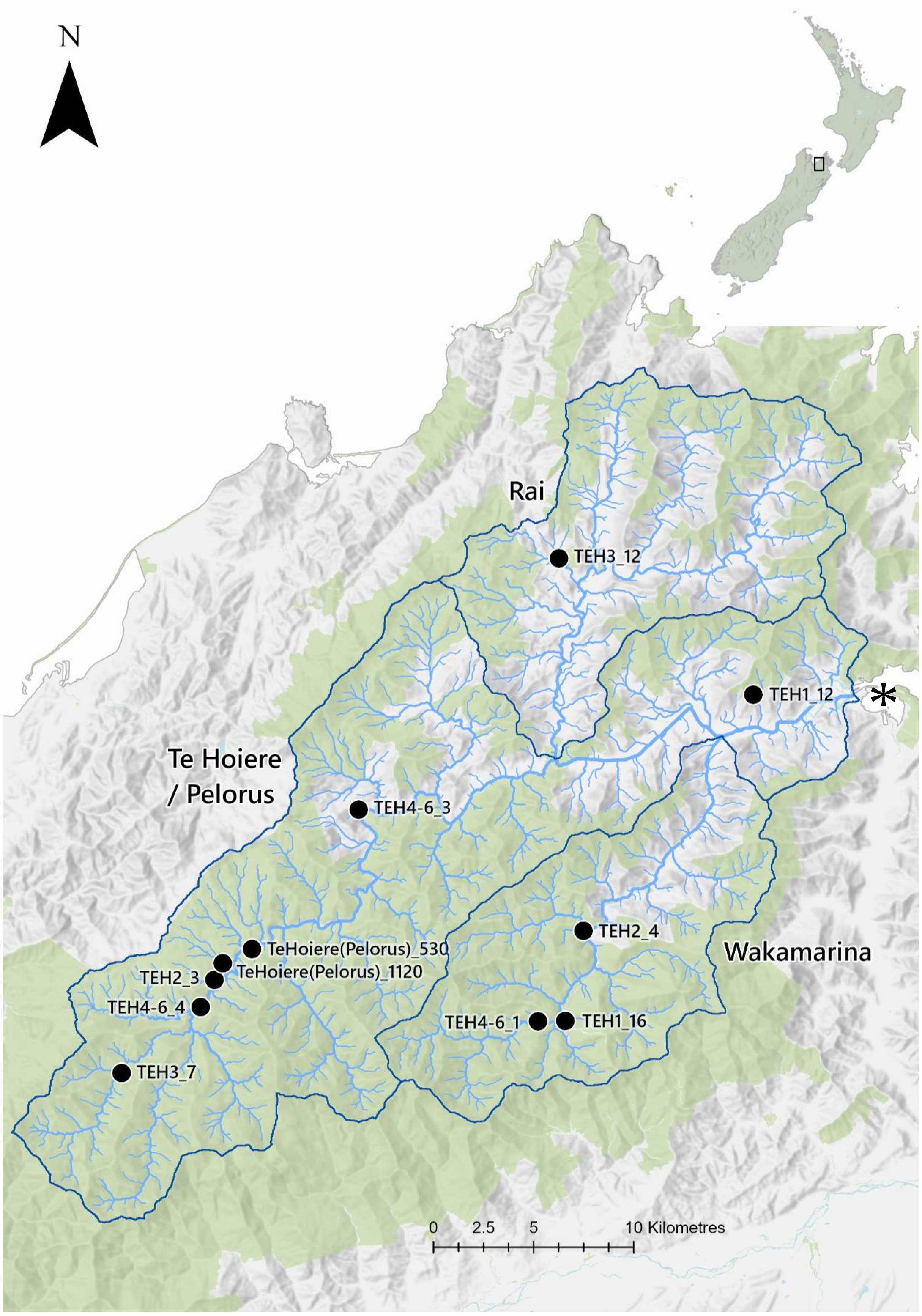


Figure 1. Map of site locations with Te Hoiere / Pelorus River catchment, showing major sub-catchments. The * denotes the river mouth where it flows into Pelorus Sound. Green areas are those within public conservation land. Basemaps generated by Eagle Technologies (2023), sourced from LINZ Data Service (2023) and licensed for reuse under CC BY 4.0.

2. ANALYTICAL APPROACH AND RESULTS

The analytical approach used closely followed the process taken by Kelly et al. (2023) for analysing data from the NFMP, involving three phases of aggregating and curating of the dataset, calculating relevant metrics and values, and analysing and plotting the data. All data analysis steps were undertaken using the R programming language in the RStudio graphical user interface and coding was scripted using R-markdown. A summary of the information flow between stages is illustrated in Figure 2, and the specific package versions used are included in Appendix 2. The full outline of the analytical process followed is presented in Kelly et al. (2023).

ArcPRO was used to create all maps in this report, using the datasets exported from the analytical pipeline outlined above.

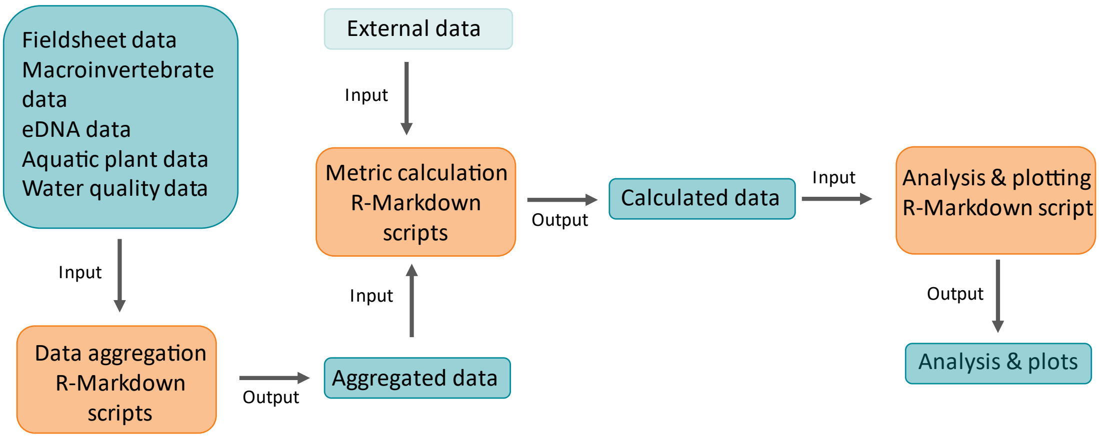


Figure 2. A conceptual overview of the flow of information and relationship between data files and analysis scripts.

3. AQUATIC LIFE

3.1. Fish

3.1.1. Metric calculation

Fish index of biotic integrity (F-IBI)

The F-IBI is one metric used to assess the overall fish communities in Aotearoa New Zealand (Joy and Death 2004). The F-IBI uses six attributes to assess the integrity of fish communities: number of native taxa present, number of native benthic pool-dwelling taxa, number of native benthic riffle-dwelling taxa, number of native pelagic pool-dwelling taxa, number of native intolerant taxa and proportion of native to non-native taxa. Low scores for the F-IBI indicate the absence (or lower diversity) of taxa that belong to these attributes, reflecting loss of biological integrity of the fish communities. This can be interpreted as the consequence of the fish passage barriers downstream, a lack of suitable habitat for some species, or pollution reducing the number of pollution-intolerant taxa. For the purposes of the F-IBI calculations, trout are considered as 'native' species, as they are indicators of good water quality.

Data from the Ministry for the Environment (MfE) F-IBI dataset (MfE 2019), including data from the New Zealand Freshwater Fish Database (NZFFD) on fish records nationally from 1998 to 2018, was downloaded for the construction of quantiles against which to score metrics. As distance inland and elevation are known variables that affect the composition of native fish communities, the reference dataset was used to regress each of the first five metrics against both distance inland and elevation (giving 10 regressions). Quantiles were calculated for each of the 10 regressions at the 33rd and 66th percentiles. Although the methods followed were those outlined in MfE (2019), some quantiles fell to zero for two of the metrics: number of pelagic pool species (both 33rd and 66th percentiles were zero) and number of intolerant species (33rd percentile was zero). This matches the experience of the Bay of Plenty Regional Council (BOPRC 2016), which similarly could not calculate quantiles using national-level data from the NZFFD, and previous experience with data from the NFMP (Kelly et al. 2023). Cross-checking the results of the calculations with the scores output from the MfE data indicated that the outcome was the same using their dataset, indicating the method may need refinement. The result is that the presence of any pelagic pool species results in the maximum score of 5, while for the intolerant species, scores were either 3 or 5.

To ensure consistency in scores and enable future comparison with new data, the dataset used to generate the species richness lines and subsequent quantiles was the same as that used by Statistics New Zealand in the 2018 update to the national picture of F-IBI scores. In addition, the same R script used to calculate F-IBI for the NFMP analyses (Kelly et al. 2023) was used here. The authors are aware that MfE has recently released an online F-IBI calculator through an R Shiny app.[1] However, there is potential that differences in how sites with no fish are treated could introduce artificial variation, thus we used the same method as the NFMP to ensure consistency among datasets.

Threat classes

For each individual fish recorded to species level, the New Zealand Threat Classification System (NZTCS) status and category were assigned. The proportion of individuals belonging to each of the NZTCS threat classes (Dunn et al. 2018) was then determined for the national dataset, and for each site. These data included both fish that were measured and those identified to species level but not measured in the field data.

Environmental DNA (eDNA)

Environmental DNA metabarcoding is the term used for a method of collecting DNA from an environmental sample rather than from the organism itself. This DNA is then amplified and the resulting sequences are attributed to specific organisms based on their similarity to reference sequences. Environmental DNA metabarcoding data consisted of taxon names and read numbers for replicate samples collected per site at the time of sampling. Environmental DNA metabarcoding can be prone to sequencing error, contamination and tag-jumping, which may result in sequences appearing in samples erroneously. Generally, such errors result in sporadic detections of sequences with low read numbers. To reduce the risk of this, all eDNA data were subject to a data-filtering step commonly undertaken when working with eDNA metabarcoding data to reduce the potential for errors in the final data (Pearman et al. 2023). The filtering steps required a taxon to be present in at least two replicate samples and with a minimum of 20 reads in each of those to be recorded as present, or, if a taxon was present in a single sample, it needed at least 100 reads to be considered present. These are very permissive rules in the context of typical bioinformatic data-filtering protocols.

Environmental DNA glossary

Amplicons are short pieces of an organism's genome that have been amplified to a measurable amount by PCR.

Metabarcoding is using PCR to amplify a region of the genome to produce amplicons that will distinguish each taxon in a community.

Multiplexing is when a unique sequence (tag) is added to the PCR and then multiple samples are combined and sequenced together.

PCR is polymerase chain reaction, a method of multiplying a piece of an organism's genome to a measurable amount

Reads / read numbers are the number of times a sequence is detected in a sample.

Sequencing errors are mistakes in the sequence that occur during the laboratory PCR and sequencing steps of eDNA metabarcoding.

Tag-jumping is the process when the unique identifying tag in a multiplexed reaction is incorporated onto a sequence from a different sample.

[1] https://mfenz.shinyapps.io/fish-ibi-calculator/

Following the filtering steps, the presence of the fish taxa for both electric fishing data and eDNA data was filtered to remove genus-level results if a species for that genus was recorded at that site. If no species-level results were recorded for the site, then the genus-level result was retained in the dataset. This was to avoid artificially inflating species richness estimates due to missed fish in the case of electric fishing, or insufficient taxonomic resolution in the case of eDNA data.

Finally, the fish communities found at each site by each method were compared to generate lists of taxa found only with electric fishing and only with eDNA, and taxa found with both methods.

3.1.2. Catchment state

Species present

Six native and two introduced species were caught using electric fishing and identified to species level, including brown trout (*Salmo trutta*), dwarf galaxias (*Galaxias divergens*), kōaro (*Galaxias brevipinnis*), longfin eel (*Anguilla dieffenbachii*), rainbow trout (*Oncorhynchus mykiss*), redfin bully (*Gobiomorphus huttoni*), torrentfish (*Cheimarrichthys* fosteri) and upland bully (*Gobiomorphus breviceps*). Further individuals of *Galaxias* spp. and *Gobiomorphus* spp. were caught but could not be identified to species level. Furthermore, *Anguilla* spp. and *Salmo* spp. were missed during fishing and could not be identified. In general, the number of species detected at each site decreased with elevation and distance from the coast (Figure 3).

In addition, bluegill bully (*Gobiomorphus hubbsi*) and shortfin eel (*Anguilla australis*) were detected using eDNA. A full table of the fish found at each site using both electric fishing and eDNA is presented in Appendix 3.

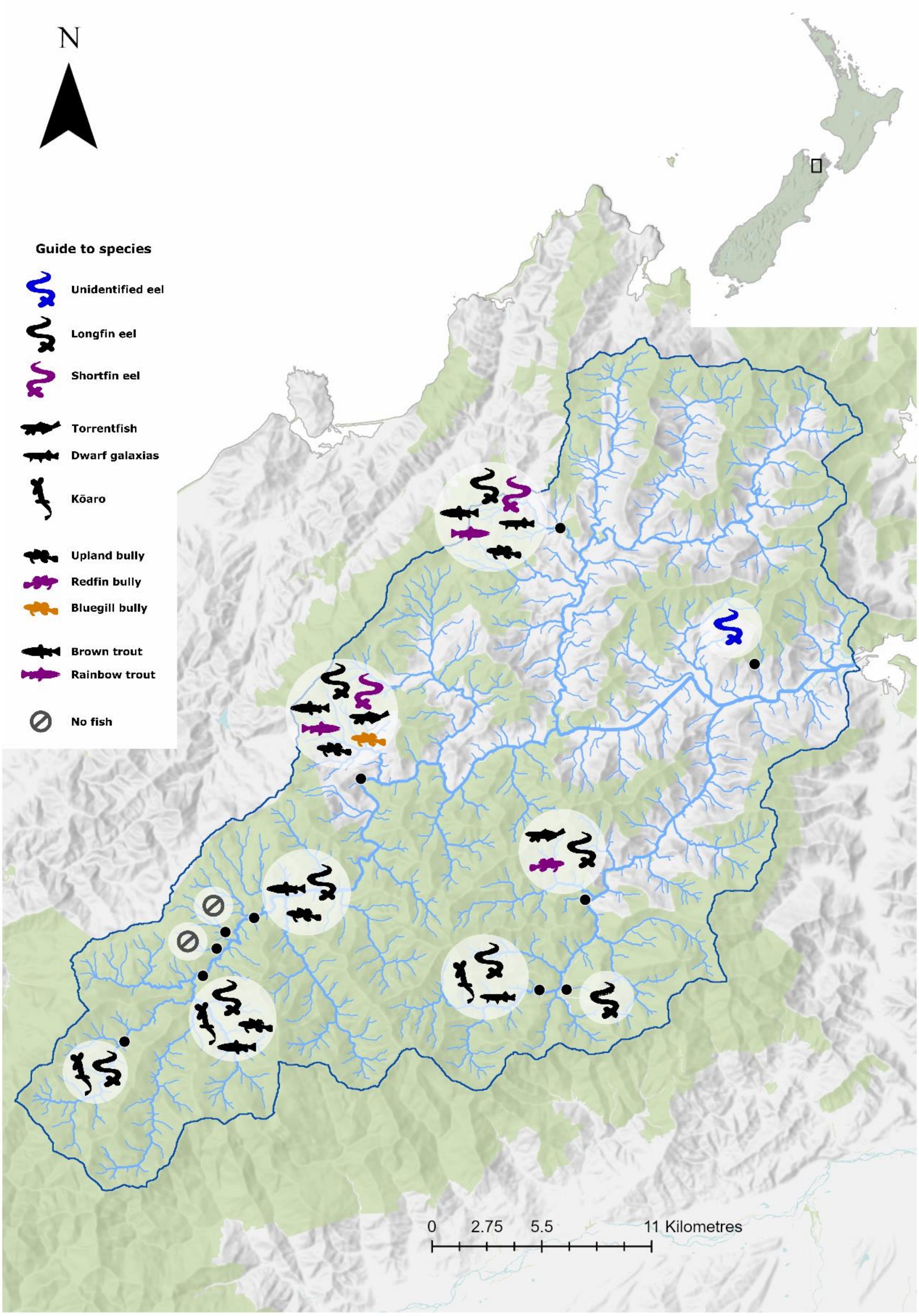


Figure 3. Sites where fish species were found within Te Hoiere / Pelorus River catchment using either electric fishing or eDNA. See Appendix 3 for a full list of species found at each site. Basemaps generated by Eagle Technologies (2023), sourced from LINZ Data Service (2023) and licensed for reuse under CC BY 4.0.

Fish lengths

For fish taxa where more than 15 individuals were caught across all sites, fish length distribution was plotted and compared with the national records from the NZFFD. No lengths outside of the minimum and maximum lengths recorded for each species in the NZFFD were observed. Plots showing the distribution of data compared with the NZFFD are presented in Appendix 4.

Threat classes

Of the fish detected in Te Hoiere catchment, bluegill bully, dwarf galaxias, kōaro, longfin eel and torrentfish are classified as At Risk and Declining. All other fish species found are listed as Not Threatened.

F-IBI

Scores for the F-IBI ranged from a maximum of 46 to a minimum of 20 (out of a possible maximum score of 60), spanning from the NPS-FM A band through to C band (Figure 4). However, there were four sites where no fish were caught and F-IBI could not be calculated for these sites. Only one site fell within C band (TEH2_3), and it is possible that this low score is due to a natural fish passage barrier observed downstream of the site by the field team.

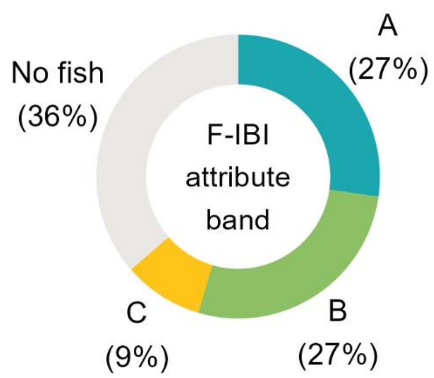


Figure 4. Proportion of sites in each NPS-FM attribute band for the fish index of biotic integrity (F-IBI).

3.2. Macroinvertebrates

3.2.1. Metric calculation

Metrics calculated to assess macroinvertebrate diversity and communities included the Macroinvertebrate Community Index (MCI), Quantitative MCI (QMCI), percentage of Ephemeroptera, Plecoptera and Trichoptera by taxa richness (%EPT), and average score per metric (ASPM). The calculation of MCI, QMCI and ASPM followed the methods set out in the NEMS Macroinvertebrates (National Environmental Monitoring Standards Working Group 2022), with tolerance scores taken solely from Clapcott et al. (2017) to align with the requirements of the NPS-FM 2020 and follow nationally consistent practices. This ensures that MCI, QMCI and ASPM calculations use the same reference values employed nationally and so are comparable to other datasets. As specified by the field sheets, hard-bottomed tolerance scores were used for metric calculations for all sites.

In calculating MCI and QMCI, only one macroinvertebrate taxa could not be assigned a tolerance score. Only one individual of this taxa (an early instar *Notonemouridae* stonefly) was found at one site, so the omission of this taxa is unlikely to affect metric values.

Other metrics calculated were taxa richness, the number of taxa found, the proportion of exotic species and the proportion of taxa within each conservation category / status. The number of taxa included the total number of taxa present at each site, irrespective of the identification level reached. Information on macroinvertebrate conservation category / status was taken from the NZTCS database,[2] primarily based on the Grainger et al. (2018) assessment. The presence of any potential pest macroinvertebrate species was assessed by comparing the taxa found to species designated as pest species by NIWA (2020).

3.2.2. Catchment state

Macroinvertebrate diversity metrics

A total of 86 individual taxa were identified across the 11 sites sampled, and macroinvertebrate diversity metrics could be calculated for all sites. The taxon count for each site ranged from 16 to 33 taxa, while MCI values ranged from 121 to 150, QMCI values ranged from 6.55 to 8.01, ASPM ranged from 0.60 to 0.75, and %EPT ranged from 52.0% to 71.4% (Table 1, Figure 5). The variation in each macroinvertebrate diversity metric differed, and lower diversity at some sites did not result in lower MCI / QMCI scores. While metrics are related, each metric indicates different characteristics of macroinvertebrate communities – e.g. taxa richness indicates the diversity present at a site, while MCI / QMCI score indicates the tolerance of the macroinvertebrate community present.

[2] https://nztcs.org.nz/

Table 1. Macroinvertebrate metrics calculated for all monitoring sites. Average score per metric (ASPM) is the normalised average of Macroinvertebrate Community Index (MCI), the percentage of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa and EPT richness. All sites were hard bottomed.

Site identifier	Monitoring season	MCI score	QMCI score	Number of EPT taxa	Percentage of EPT taxa	ASPM	Number of taxa
TeHoiere(Pelorus)_1120	2020/21	142	7.94	13	52.00	0.71	26
TeHoiere(Pelorus)_530	2020/21	121	7.88	17	56.67	0.61	31
TEH1_12	2021/22	128	6.64	15	53.57	0.64	30
TEH1_16	2021/22	133	6.60	20	71.43	0.66	33
TEH2_3	2021/22	150	7.66	17	68.00	0.75	27
TEH2_4	2021/22	132	6.55	14	66.67	0.66	24
TEH3_12	2021/22	135	7.76	17	65.38	0.68	28
TEH3_7	2021/22	142	7.99	12	63.16	0.71	20
TEH4-6_1	2021/22	133	7.73	11	57.89	0.66	21
TEH4-6_3	2021/22	133	7.76	10	66.67	0.67	16
TEH4-6_4	2021/22	145	8.08	16	69.57	0.73	26

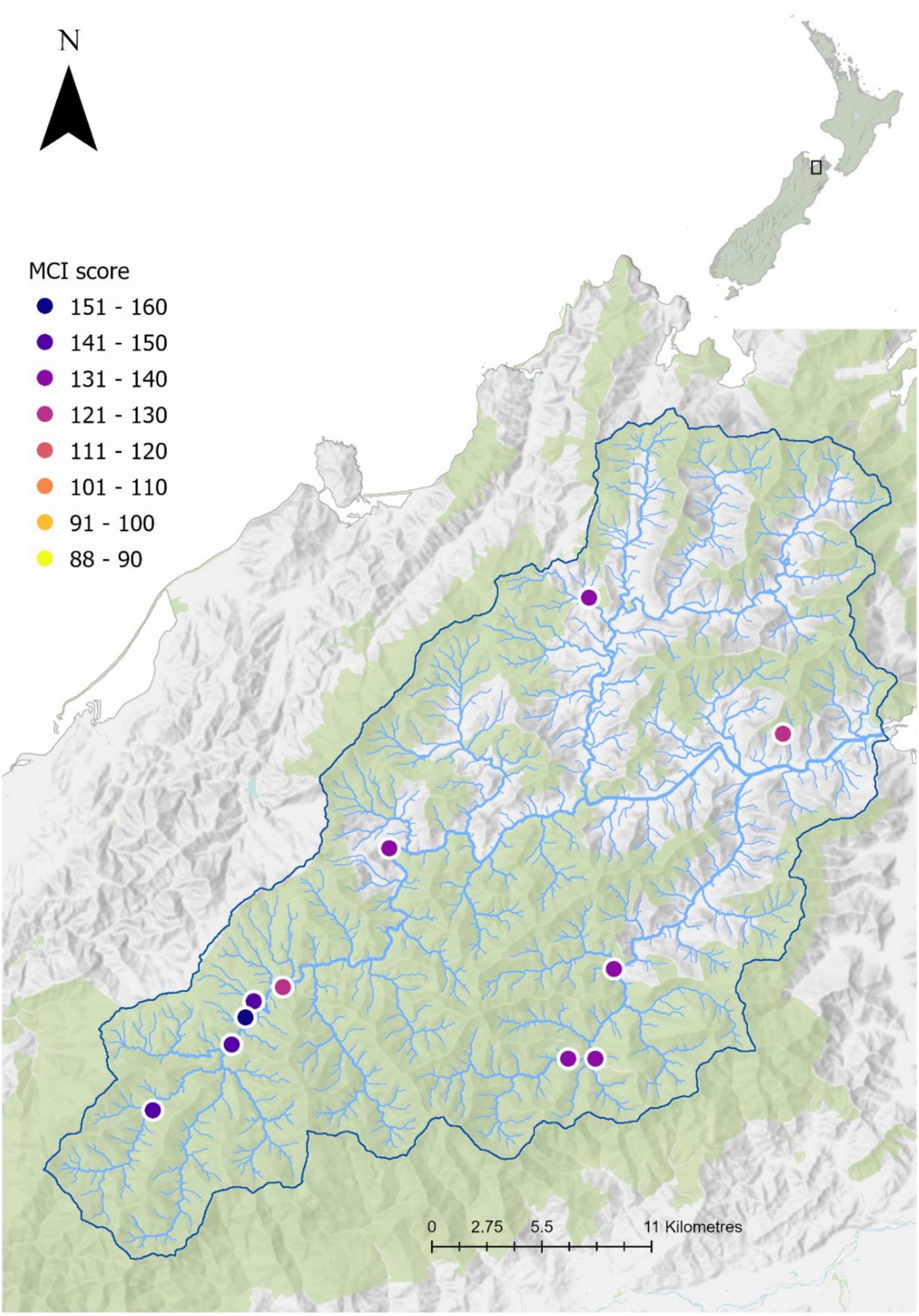


Figure 5. Map of Macroinvertebrate Community Index values across Te Hoiere / Pelorus River catchment. Basemaps generated by Eagle Technologies (2023), sourced from LINZ Data Service (2023) and licensed for reuse under CC BY 4.0.

When interpreted using the NPS-FM attribute bands to relate macroinvertebrate diversity metrics to ecological conditions, nine sites met the MCI threshold of 130 for A band, indicative of pristine or reference conditions. The remaining 2 sites fell into the B band for MCI, suggesting some impact, potentially from low substrate stability or some interstitial fine sediment (see Section 4.3.). Given that the upstream land cover for both sites is completely in native forest and that downstream sites display pristine conditions, it is highly likely that the lower MCI values are natural at these sites and not indicative of organic pollution. For QMCI and ASPM, all sites exceeded the threshold for A band, indicative of pristine or reference conditions (Figure 6).

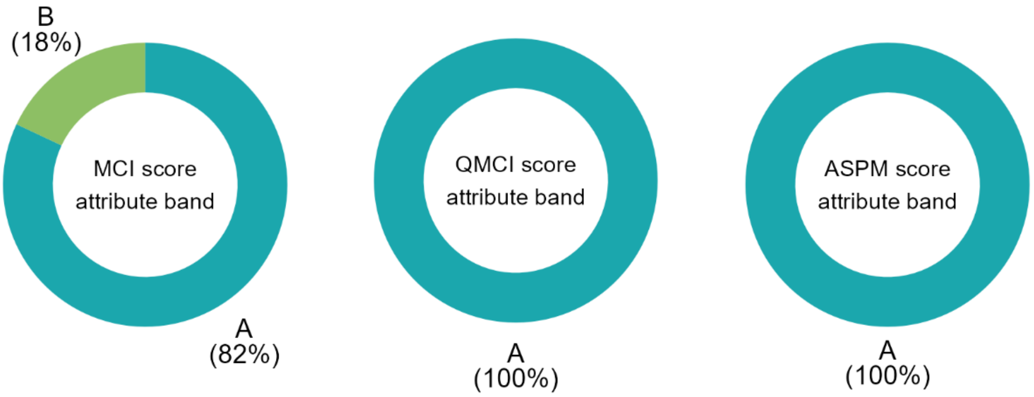


Figure 6. Proportion of sites in each NPS-FM attribute band for Macroinvertebrate Community Index (MCI), Quantitative Macroinvertebrate Community Index (QMCI) and Average score per metric (ASPM).

Threat category and status

Only 34% of taxa found could be assigned to an NZTCS Threat Category and Status. Of the taxa able to be assigned, nearly all were classified as Not Threatened. The only At Risk species found was the stonefly *Stenoperla helsoni*, which has a threat status of Naturally Uncommon and was only recorded at TEH1_16.

Pest species

No macroinvertebrate pest species were found at any sites.

3.3. Megainvertebrates

3.3.1. Metric calculation

The data relating to the detection of megainvertebrates were collated to determine where crabs, kōura, mussels or shrimp were present. These data comprised information from mussel surveys, electric fishing and records of megainvertebrates removed from macroinvertebrate samples.

As with the analyses of the NFMP data (Kelly et al. 2023), we note that information about the presence of megainvertebrates at a site is compiled from information gathered during multiple protocols. Given the potential for inconsistencies in the recording of megainvertebrates in the field data sheets and among field teams, it would be beneficial to apply a specific megainvertebrate protocol if information on megainvertebrate presence or abundance is of interest.

3.3.2. Catchment state

Mussel surveys were conducted at three of the 11 sites surveyed, but no mussels were detected at any sites. It was noted that the rocky nature of the substrate and the mobile nature of the bed at some sites likely made the habitat unsuitable for mussels.

Kōura and the shrimp *Paratya curvirostris* were caught during electric fishing at one site (TEH3_12), with one kōura and four shrimps recorded. In addition, a single kōura was observed at TEH1_12.

3.4. Aquatic plants

Aquatic plants sampled as part of the Ngā Awa monitoring programme included macrophytes and bryophytes (liverworts, hornworts and mosses). Where these plants were present in the periphyton transects, samples were collected to enable taxonomic identification.

3.4.1. Metric calculation

Results for bryophytes are presented as presence–absence data, with accompanying threat classifications from the NZTCS, primarily based on the de Lange et al. (2020) assessment.

There are presently no national standards for macrophytes or bryophytes in Aotearoa New Zealand rivers. Matheson et al. (2012) suggested that, in the absence of guidelines for aquatic plants in rivers, percentage cover of the streambed by surface-growing plants and percentage cross-sectional area volume (CAV) of macrophytes should be less than 50% to avoid adverse ecological effects.

3.4.2. Catchment state

Presence of bryophytes and macrophytes

Bryophytes were only recorded at two sites within Te Hoiere catchment (TEH1_12 and TEH3_7), while no macrophytes were found. Cover was highest at TEH1_12, with 7.7% bryophyte cover observed in periphyton transects, while only 0.1% cover was recorded at TEH3_7. As no macrophytes were present, CAV was not calculated.

Endemicity and threat classification

From specimens collected at the two sites where bryophytes were recorded, three species were identified by Manaaki Whenua Landcare Research. Both *Anthoceros laminiferus* and *Calyptrochaeta flexicollis* were present at TEH1_12, while *Tridontium tasmanicum* was identified at TEH3_7. *Anthoceros laminiferus* is endemic to Aotearoa New Zealand and is listed as Not Threatened, while *C. flexicollis* and *T. tasmanicum* are non-endemic and could not be assigned a threat category due to not being represented in the NZTCS.

3.5. Periphyton

3.5.1. Metric calculation

The periphyton cover was calculated as the average cover of each periphyton type across all the views in the periphyton surveys. Periphyton biomass was assessed at the nine sites sampled in the 2021/22 monitoring season and was supplied in the Hills Laboratory data files as chlorophyll-*a* per square metre sampled, calculated from the analyses of rock scrapings.

3.5.2. Catchment state

Periphyton cover

No sites exceeded 30% cover of long filamentous algae (> 2 cm) or more than 60% cover of thick (> 3 mm) benthic mats (Figure 7), which are the thresholds associated with adverse effects on benthic macroinvertebrate communities (Biggs 2000). Bare substrate comprised a large proportion of the benthos at many sites. No didymo was recorded at any of the sites surveyed.

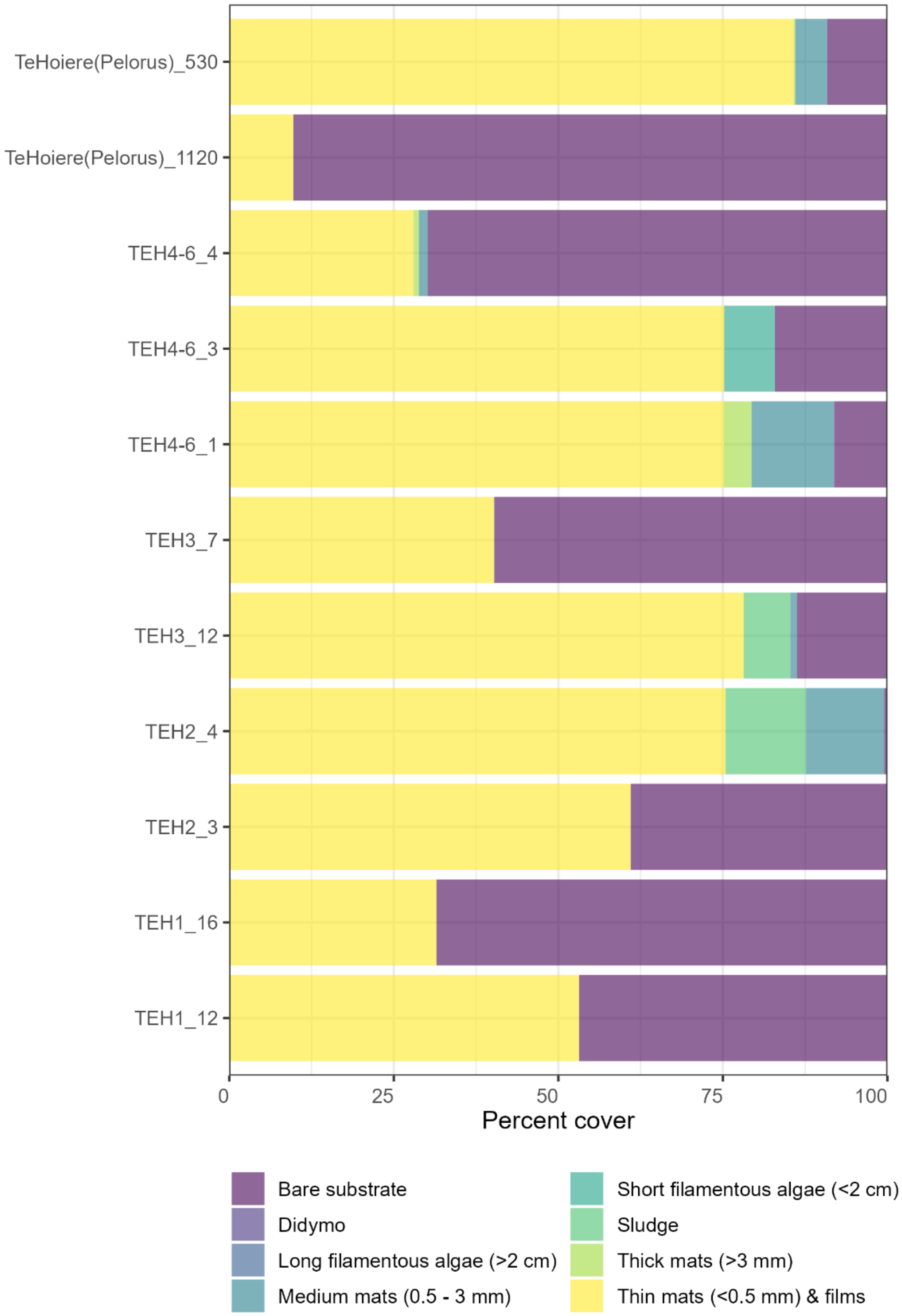


Figure 7. Periphyton cover by type for each site. Mats included green, brown, diatom and cyanobacterial mats.

Periphyton biomass

The periphyton biomass at all sites where samples were collected was very low (with three samples below laboratory detection limits), indicating low periphyton accumulation within the upper catchment. All results were well below the A band threshold in the NPS-FM and the chlorophyll-*a* concentrations that are estimated to adversely affect benthic communities (Biggs 2000; Biggs and Kilroy 2000). Generally, these results indicate that the sampled streams had low primary production or high grazing activity by macroinvertebrates.

3.6. Taxon-Independent Community Index

The Taxon-Independent Community Index (TICI) is an ecosystem health metric developed by Wilderlab NZ Ltd (Wellington, New Zealand). The TICI was developed by relating eDNA metabarcoding data from 40 rivers to MCI scores for those sites.[3] The Wilderlab website notes, 'The TICI is still in development and should be interpreted as an experimental tool at this stage'. The Ngā Awa samples were assessed using the Riverine V1 version of the TICI index.

In Te Hoiere catchment, all but one site yielded a TICI score with the Wilderlab categorisation of 'Pristine' (Table 2), the other site was categorised as 'Good'. The site categorised as 'Good' appears to be an outlier based on the MCI score. The TICI index result provided is solely numeric (with a text qualifier for the state) and based on scores related to the presence of certain amplicon sequence variants (ASV). As the scores associated with each ASV are unknown, the index operates like a black-box, making it impossible for users of the data to investigate why the site has been given an unexpectedly low score that is not explained by any other variables at the site.

[3] https://www.wilderlab.co.nz/tici

Table 2. Median Taxon-Independent Community Index (TICI) values for all monitoring sites. Scores calculated from individual replicates, the number of sequences included and the degree of reliability stated by Wilderlab are included in Appendix 5.

Site identifier	Monitoring season	Median TICI value	TICI rating
TeHoiere(Pelorus)_1120	2020/21	127	Pristine
TeHoiere(Pelorus)_530	2020/21	125	Pristine
TEH1_12	2021/22	126	Pristine
TEH1_16	2021/22	128	Pristine
TEH2_3	2021/22	125	Pristine
TEH2_4	2021/22	126	Pristine
TEH3_12	2021/22	108	Good
TEH3_7	2021/22	130	Pristine
TEH4-6_1	2021/22	128	Pristine
TEH4-6_3	2021/22	123	Pristine
TEH4-6_4	2021/22	127	Pristine

Although there is a strong linear relationship between the TICI and 5-year median MCI score for the sites used in the development of the index, no correlation was observed in the samples from Te Hoiere (Figure 8). The interpretation of the MCI metric is aided by its long history of use (> 30 years) and that it was developed specifically to reflect pressures from organic enrichment on macroinvertebrate communities (Stark 1985; Stark and Maxted 2007). As the TICI has, to the best of our knowledge, been developed by calibrating scores to MCI scores rather than drivers or pressures, it cannot be considered equivalent for the purpose of interpretation. In addition, although the TICI is taxon-independent in its development, the presence of non-aquatic taxa in the indicator dataset means that the index conflates instream responses with potential drivers (e.g. from land use) and the implication of this on interpreting the results requires more investigation. A further consideration is that sampling approaches used for eDNA rely on water samples. The eDNA in these water samples could have originated many kilometres upstream and may not reflect the conditions at the site. In contrast, the macroinvertebrates collected for the MCI are presumed to mostly live at the site.

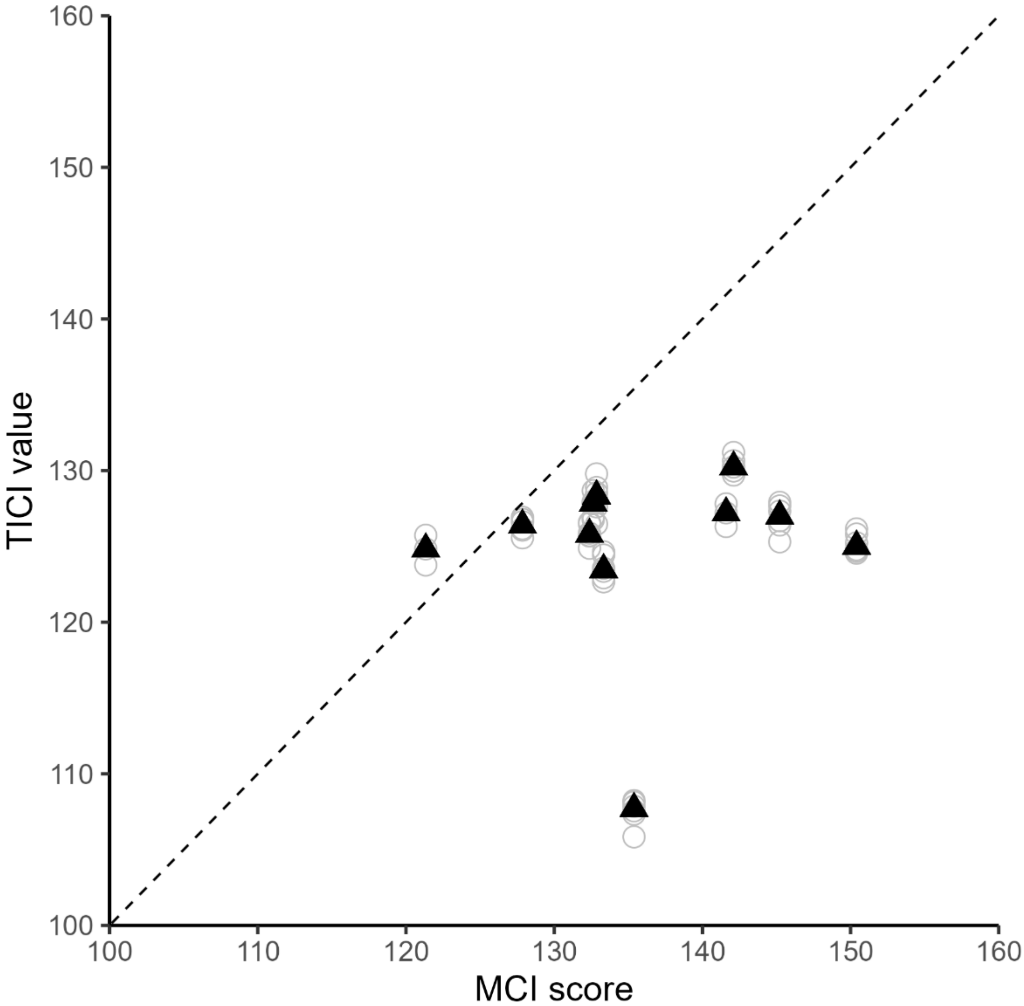


Figure 8. Taxon-Independent Community Index (TICI) scores plotted against Macroinvertebrate Community Index (MCI) scores for each site. Filled triangles are median TICI values for each site, while open circles are individual TICI values from each replicate. The dashed line is a 1-to-1 regression line to provide context when interpreting the plot.

Across all the samples, a reliability score is assigned by Wilderlab (Appendix 5). A threshold of 250 sequences is used by Wilderlab to denote a 'highly reliable' score. This is an extremely low number of sequences in contrast with other eDNA metabarcoding-based indices available in Aotearoa New Zealand (e.g. the Lake Health Index [Pearman et al. 2022] and Benthic Fish Farm Index [Pochon et al. 2020, 2021]), and this raises questions about the robustness of the method. This is likely the result of the degree of multiplexing by Wilderlab to include a broad range of different taxonomic groups in a single sequencing run. To enable a robust assessment of the reliability of the index score and to aid interpretation of the results, both the number of indicator ASVs and the total number of sequences belonging to those ASVs need to be included.

4. HABITAT

4.1. Meso-habitat

Hydrological diversity provides an indication of the variety of flow habitats available at a site (referred to here as meso-habitats). Generally, the greater the meso-habitat heterogeneity (the more habitat types), the more potential for species diversity because differing habitat preferences are catered for. A wide variety of meso-habitat types was available across sites in Te Hoiere catchment, with all but one site having three or more mesohabitat types (Figure 9). Runs and riffles featured as the most common dominant habitat type; however, substantial amounts of cascade, pool and rapid habitats occurred at many sites, reflecting the steep nature of much of the catchment.

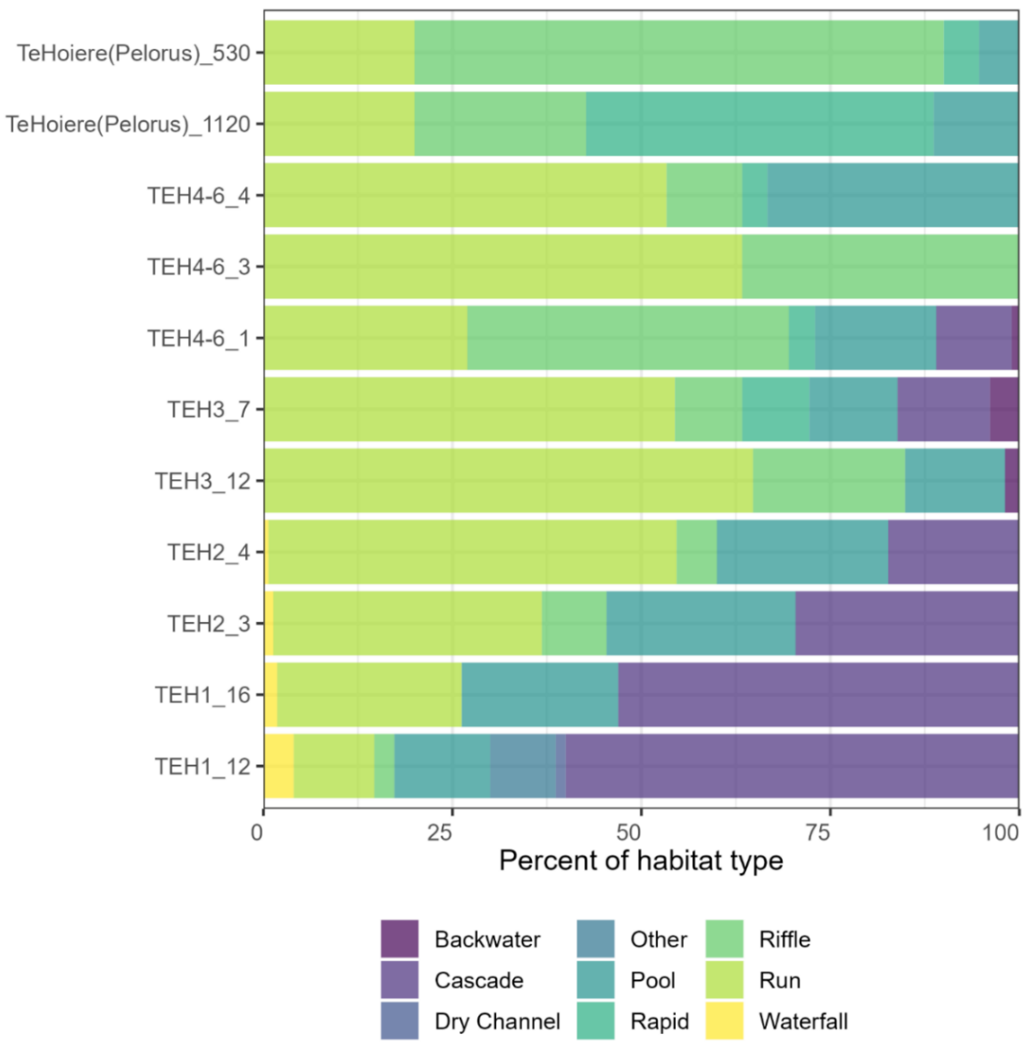


Figure 9. Meso-habitat diversity as a percentage of the 150 m stream reach at each sampling location.

4.2. Discharge

The stream discharge is calculated from the cross-sectional area of the stream and the mean velocity (taken at 0.6 × the water depth). Taken by itself, this is a descriptive measure of the site at the time of sampling and will be highly influenced by preceding rainfall conditions in the catchment.

Most sites had flows of below 1 m^3/s, and the highest flow was 1.54 m^3/s at TEH4-6_3 (Figure 10). No sites were excluded due to being too deep or fast flowing to sample, although multiple sites had deep pools that were unfishable.

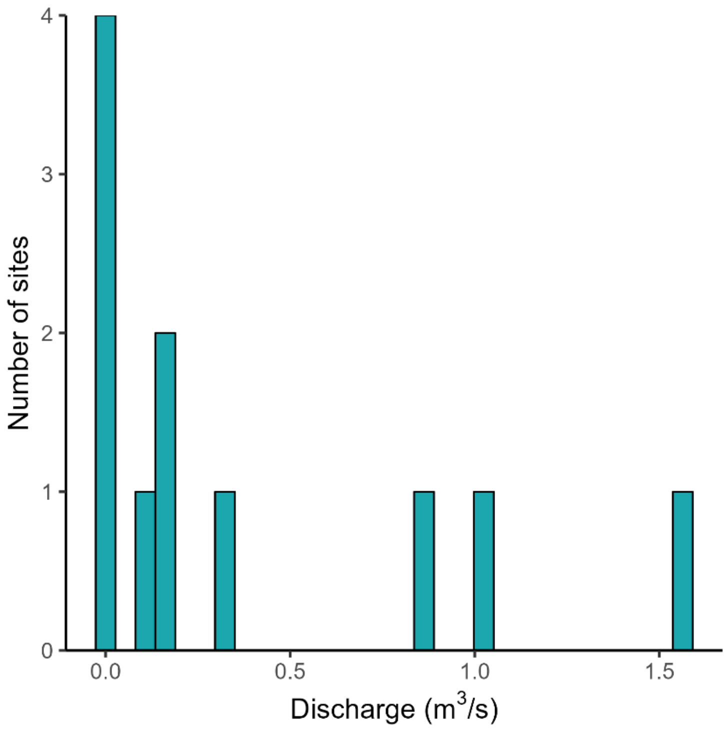


Figure 10. The range of discharge rates in cubic metres per second among sites sampled.

4.3. Substrate stability

The Pfankuch index of substrate stability (Pfankuch 1975) is a measure of the ability of a reach to resist the mobilisation of streambed and stream bank materials under variable flow conditions. In Aotearoa New Zealand and overseas, the stability of a reach has been correlated with periphyton biomass (Death 1991) and the taxonomic richness and density of macroinvertebrates (Rounick and Winterbourn 1982; Collier et al. 1993). In Aotearoa New Zealand, it is also associated with habitat quality for the endemic species *Hymenolaimus malacorhynchos* (blue duck / whio) (Collier et al. 1993). The index comprises a range of factors relating to the upper banks, lower banks and streambed of the site. Collier et al. (1993) provides an excellent introduction to scoring the index in an Aotearoa New Zealand context, with explanatory notes for each scoring category.

Recently, the Pfankuch index has been applied by various regional councils in Aotearoa New Zealand. This has resulted in the Pfankuch score being categorised into broad stream stability bands, representing very high stability (scores < 38), high stability (39–76), moderate stability (77–114) and low stability (> 115) (NRC 2011). It has been suggested that the association between benthic macroinvertebrate communities and the Pfankuch index scores is stronger when considering only the streambed component of the index (Death and Winterbourn 1994).

The Pfankuch index for the sites demonstrated a range of substrate stabilities from moderate to high substrate stability. Most sites (73%) were highly stable, with the remainder moderately stable.

4.4. Deposited sediment and substrate heterogeneity

4.4.1. Fine sediment cover

All sites had low levels of fine sediment cover (maximum = 3.70 %). The deposited sediment cover was correlated with the Pfankuch index. The Pfankuch index includes scoring components associated with deposited sediment within the stream, but this result indicates that the other aspects of the scoring method (upper and lower bank stability) are also associated with the deposited sediment cover (Figure 11).

High levels of fine sediment cover can impact the habitat quality of cobble-bedded rivers for macroinvertebrates and fish. The sediment fills interstitial spaces (the gaps between rocks), reducing habitat availability and refugia for both macroinvertebrates and fish (Clapcott et al. 2011). The low levels of fine sediment cover across all the surveyed sites indicates that deposited fine sediment is highly unlikely to be negatively influencing the ecological communities at those sites.

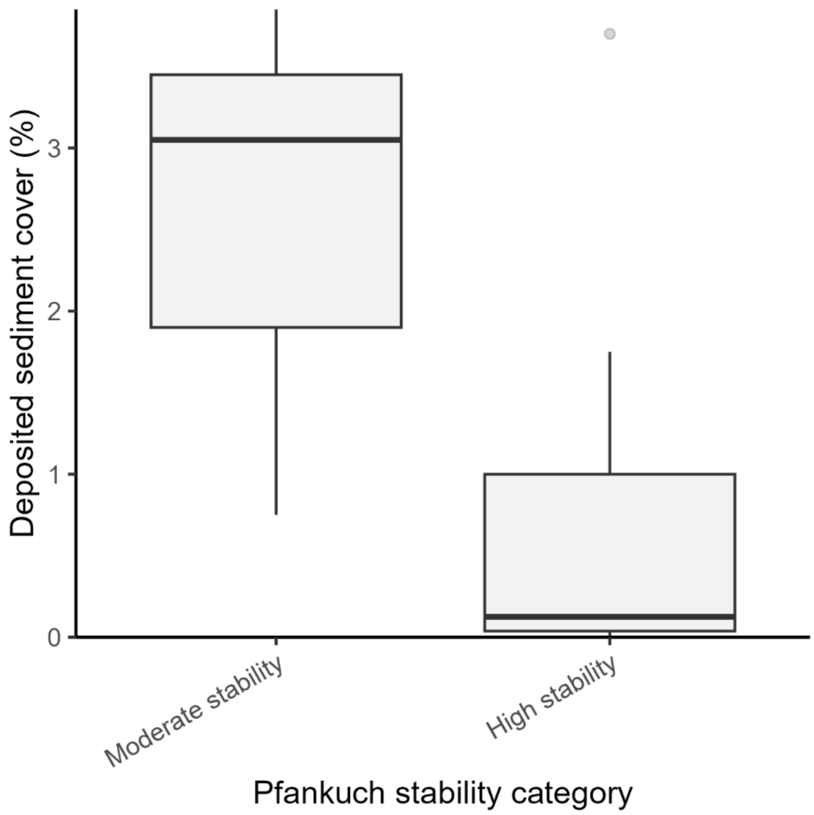


Figure 11. Mean deposited sediment cover across the periphyton transects by the Pfankuch stability category of the sites.

4.4.2. Substrate heterogeneity

The Wolman pebble count (method SAM-3) is a component of the sediment assessment protocols (Clapcott et al. 2011). The purpose of the metric is to quantify the contribution of different size classes of substrate to the overall substrate composition at a site. Like the other sediment assessment metrics, this protocol is intended for use at hard-bottomed sites. In particular, the Wolman pebble count is intended to quantify the percentage of fine sediment relative to guideline values for the preservation of instream values of biodiversity and salmonid spawning habitat. The guideline values for preservation of biodiversity are less than 20% of the substrate as fine sediment or within 10% of a reference condition. For salmonid spawning habitat, the guideline value is less than 20% of substrate composition as fine sediment. There were no sites where fine sediment exceeded 20% of the substrate composition (Figure 12).

Although metrics such as the dominant size class and some indices of substrate diversity can be calculated from the Wolman pebble count data, these are largely habitat descriptors for the sites. There are no anticipated ecological relationships between macroinvertebrate communities based on these metrics, beyond the known relationships between fine sediment and macroinvertebrate and fish communities.

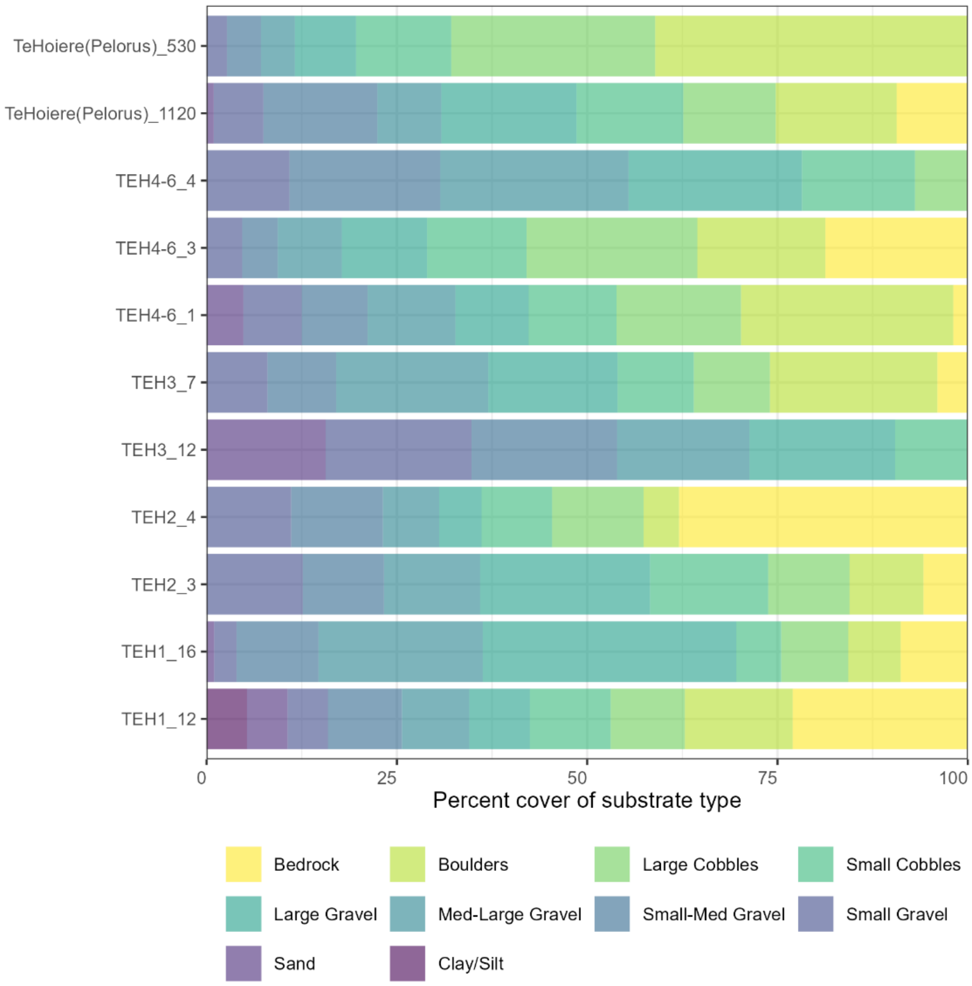


Figure 12. Substrate composition from the Wolman pebble count (SAM-3) assessment. Sand and clay / silt are considered fine sediment using this method.

4.4.3. Pesticides

Sediment samples that could be collected at sites in the 2021/22 monitoring season were tested for a range of pesticide residues by Hills Laboratories (including acid herbicides, multiresidue pesticides and organochlorine pesticides). All samples were below detection limits for all pesticides tested.

5. WATER QUALITY

5.1. Visual clarity

Visual clarity was assessed using black disc measurements. Black disc readings could be taken at nine sites. A maximum observable clarity reading was taken at the remaining two sites (TEH1_16 and TEH2_4), as the habitat available for black disc measurements was not long enough to get a reading because the water was too clear. The mean clarity observed across sites where a black disc reading could be taken was 7.55 m (minimum = 1.60 m, maximum = 14.69 m). There were two sites that were in the D band for visual clarity based on their suspended sediment class in the NPS-FM, and one that was in the C band. The sites that were in the D band had either farming or forestry occurring upstream of the site, suggesting that the reduced clarity was due to land-use influence. The remaining sites had good or excellent visual clarity, indicating low suspended sediment in the water column (Figure 13).

Turbidity (laboratory measurements) was low across all sites where water samples were collected, with a mean of 0.41 FNU. The minimum turbidity value was 0.12 FNU and the maximum was 1.31 FNU at TEH3-12. Laboratory measurements were assessed, as the *in situ* data included both FNU and NTU values, which are not directly comparable. The two sites sampled in the 2020/21 monitoring season did not have laboratory measurements of turbidity, but field measurements of turbidity were low with recorded values of 0.62 FNU and 1.17 FNU for TeHoiere(Pelorus)_1120 and TeHoiere(Pelorus)_530, respectively.

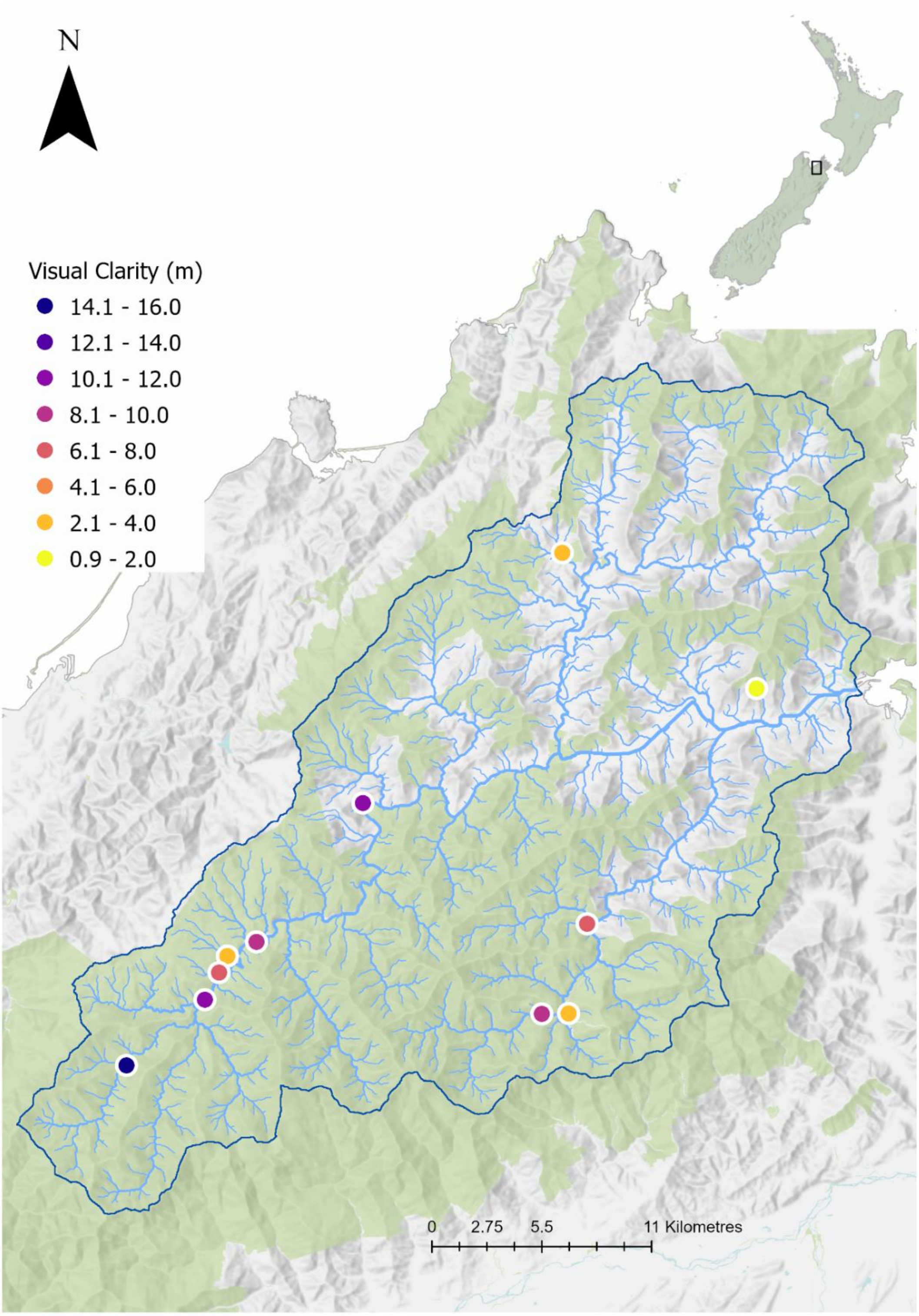


Figure 13. Visual clarity readings across Te Hoiere / Pelorus River catchment presenting both black disc readings (nine sites) and maximum observable clarity for sites where the habitat available prevented a black disc reading from being taken (TEH1_16 and TEH2_4). Basemaps generated by Eagle Technologies (2023), sourced from LINZ Data Service (2023) and licensed for reuse under CC BY 4.0.

5.2. Nutrient concentrations

Water samples were not collected during the 2020/21 monitoring season; results are therefore only reported for the nine sites sampled in the 2021/22 monitoring season.

5.2.1. Dissolved reactive phosphorus

Concentrations of dissolved reactive phosphorus (DRP) ranged from 0.004 g/m^3 to 0.017 g/m^3 (Figure 14, Table 3). When compared to the NPS-FM attribute band for DRP (which assess median concentrations over 5 years of monthly samples), four sites met the threshold for A band, indicating pristine conditions. Another two sites corresponded to B band and the remaining 3 corresponded to C band, suggesting minor and moderate DRP elevation, respectively. The sites with the highest DRP concentrations were all located in the east of the catchment, with two of these within the Wakamarina sub-catchment, suggesting that geology may play a role in influencing DRP concentrations. The site with the highest DRP concentration was TEH1_12. Although TEH1_12 was within PCL, the majority of its upstream catchment was in plantation forestry, which had recently been harvested, and so elevated DRP may have been associated with differences in land use.

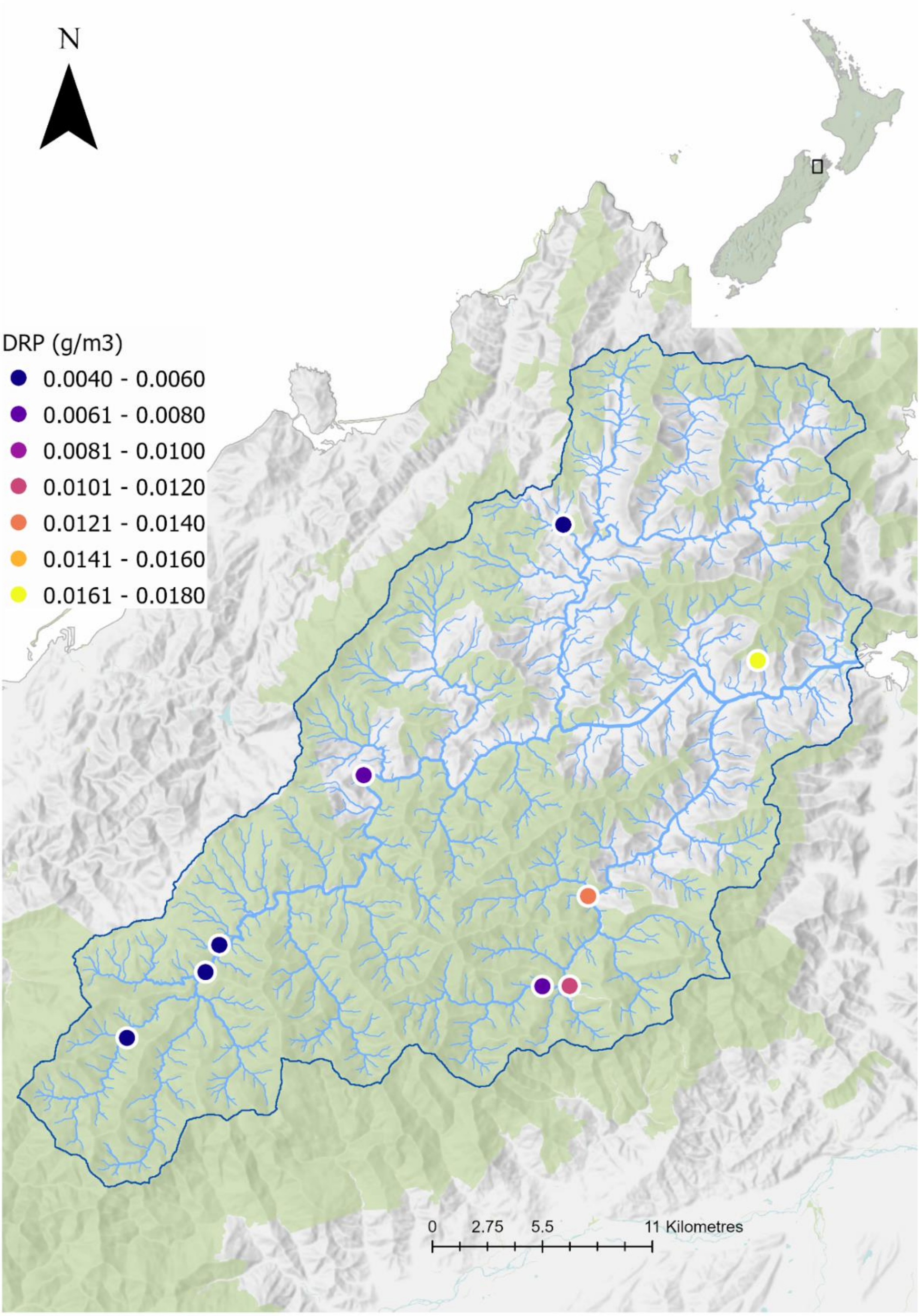


Figure 14. Dissolved reactive phosphorus (DRP) concentrations across Te Hoiere / Pelorus River catchment. Basemaps generated by Eagle Technologies (2023), sourced from LINZ Data Service (2023) and licensed for reuse under CC BY 4.0.

5.2.2. Nitrogen

Concentrations of nitrate-N ranged from 0.005 g/m^3 to 0.146 g/m^3 (mean = 0.045 g/m^3), and concentrations of total ammoniacal nitrogen were below detection limits for all sites (Figure 15, Table 3). The observed concentrations of nitrate-N were well below the threshold for the nitrate (toxicity) A band in the NPS-FM, although bands are assessed using annual medians from monthly samples. Nitrite-N was also below detection limits at all sites, so dissolved inorganic nitrogen consisted entirely of nitrate-N at all sites.

Table 3. Nutrient concentrations recorded for all sites where water samples were collected. Note that neither of the sites sampled in the 2020/21 monitoring season had water samples taken and are therefore not included in the results reported.

Site identifier	Total nitrogen (g/m^3)	Total ammoniacal-N (g/m^3)	Nitrite-N (g/m^3)	Nitrate-N (g/m^3)	Nitrate-nitrite (g/m^3)	Total Kjeldahl nitrogen (g/m^3)	Dissolved reactive phosphorus (g/m^3)	Total phosphorus (g/m^3)
TEH1_12	0.18	< 0.01	< 0.002	0.146	0.146	< 0.10	0.017	0.016
TEH1_16	0.14	< 0.01	< 0.002	0.096	0.096	< 0.10	0.011	0.011
TEH2_3	< 0.11	< 0.01	< 0.002	0.045	0.045	< 0.10	0.005	0.006
TEH2_4	< 0.11	< 0.01	< 0.002	0.052	0.052	< 0.10	0.014	0.015
TEH3_12	< 0.11	< 0.01	< 0.002	0.014	0.014	< 0.10	0.004	0.005
TEH3_7	< 0.11	< 0.01	< 0.002	0.019	0.019	< 0.10	0.005	0.008
TEH4-6_1	< 0.11	< 0.01	< 0.002	0.012	0.013	< 0.10	0.007	0.007
TEH4-6_3	< 0.11	< 0.01	< 0.002	0.005	0.005	< 0.10	0.008	0.009
TEH4-6_4	< 0.11	< 0.01	< 0.002	0.013	0.014	< 0.10	0.005	0.008

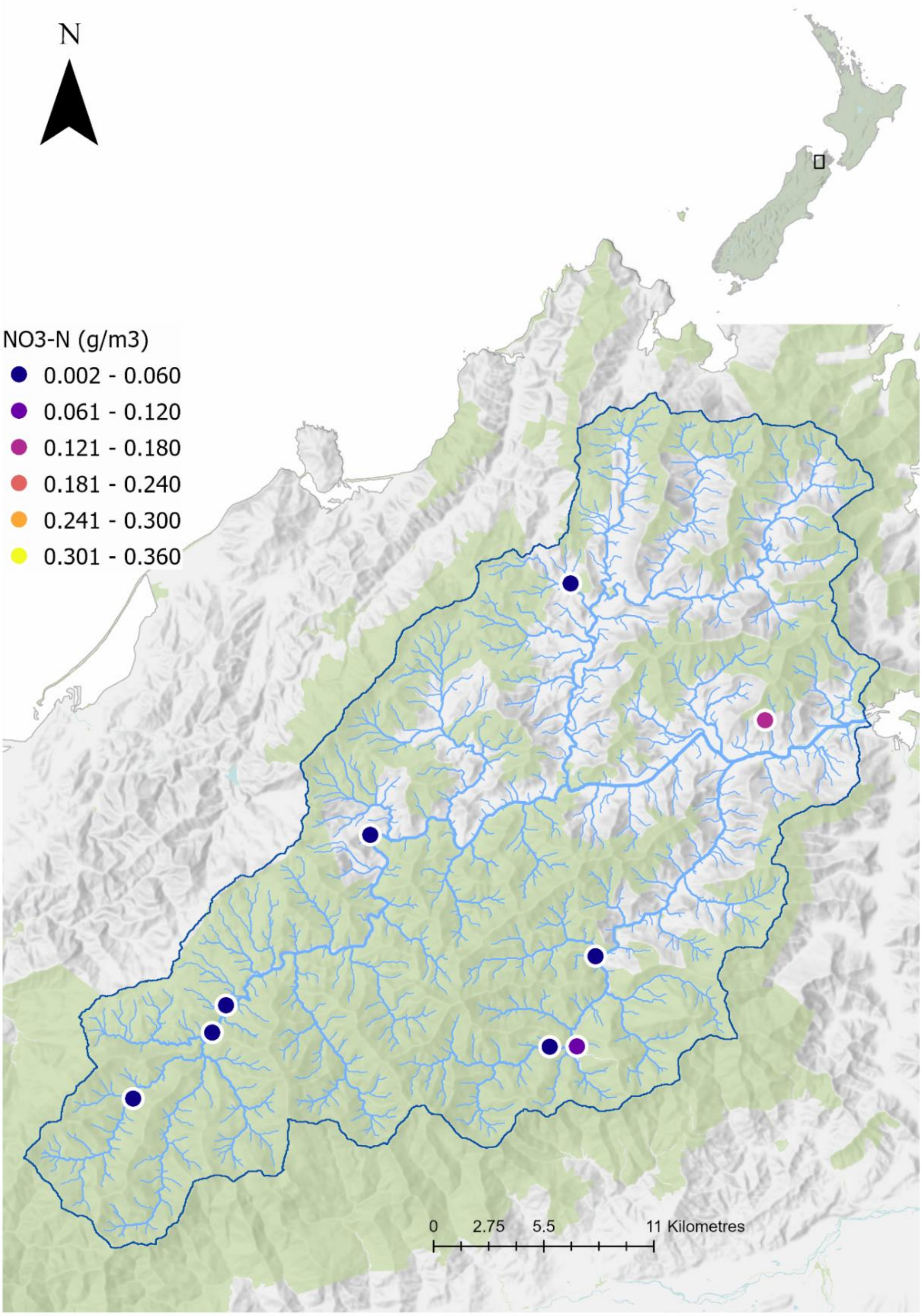


Figure 15. Nitrate concentrations across Te Hoiere / Pelorus River catchment. Basemaps generated by Eagle Technologies (2023), sourced from LINZ Data Service (2023) and licensed for reuse under CC BY 4.0.

5.3. Water chemistry

The pH is a measure of the acidity or alkalinity of the water and is largely influenced by the underlying geology and land cover. Field measurements from 10 sites were circumneutral, with one site slightly acidic (minimum = 6.09, mean= 7.20, maximum = 7.81).

Dissolved oxygen was high (> 8 mg/L) at all sites (minimum = 9.30 mg/L, mean = 10.29 mg/L, maximum = 11.51 mg/L). As these values are from single daytime spot measurements, they cannot be compared with the 7-day mean minimum or 1-day minimum values presented in the NPS-FM, as minimum dissolved oxygen typically occurs at night-time / dawn. However, the values observed significantly exceed the ANZECC minimum limit of 6 mg/L for the protection of the early life stages of aquatic organisms (ANZECC 1992).

A broad range of other water physico-chemical data were collected, including the conductivity and summaries of dissolved ions such as bicarbonate, dissolved metal ions, sodium, chloride, sulphate, and carbon (Appendix 6). The values associated with these results do not have specific guideline values; rather, the data are helpful on a site-by-site level to contextualise other results. Much of the water chemistry is influenced by the underlying geology and can impact primary and secondary production in streams.

6. NATIONAL CONTEXT

To investigate how monitoring results in Te Hoiere catchment compared to other streams and rivers in PCL, 25%, 50% and 75% quantiles were calculated from a combined dataset of recent monitoring conducted on or near PCL. This included data from the NFMP (Kelly et al. 2023), as well as other data collected as part of the Ngā Awa river restoration programme from the Waikanae (Eveleens and Kelly 2023a), Waipoua (Eveleens and Kelly 2023b) and Te Hoiere (reported here) catchments, spanning 109 sites located across the North and South Islands.

Quantiles were calculated for periphyton biomass, MCI, QMCI, ASPM, F-IBI, deposited fine sediment cover, visual clarity, nitrate, ammoniacal nitrogen, total nitrogen, DRP and total phosphorus. For all metrics, quantiles are arranged so that quantile 1 represents the best condition for each water quality or ecosystem health metric. Given that many sites included in the combined dataset displayed good water quality and ecosystem health, the quantiles presented here represent only those instances where metric values fall in relation to other sites in the NFMP and Ngā Awa programmes – i.e. metric values in quantile 4 are likely still indicative of a relatively pristine state. This is because most of the sites that comprise the dataset are from within the conservation estate. For specific detail on the state of metrics for each site, refer to Sections 3, 4 and 5 of the report.

Compared to the combined dataset, sites in Te Hoiere catchment displayed good values for macroinvertebrate indices and visual clarity, but poorer results for nutrient concentrations relative to other sites (Figure 16). In particular, five sites were in the worst 25% of sites for DRP concentrations. For periphyton values in Te Hoiere catchment, some sites were in the best 25% of recorded values and other sites were between 50% and 75% of recorded values. F-IBI and fine sediment values were in the middle of the values recorded in the combined dataset.

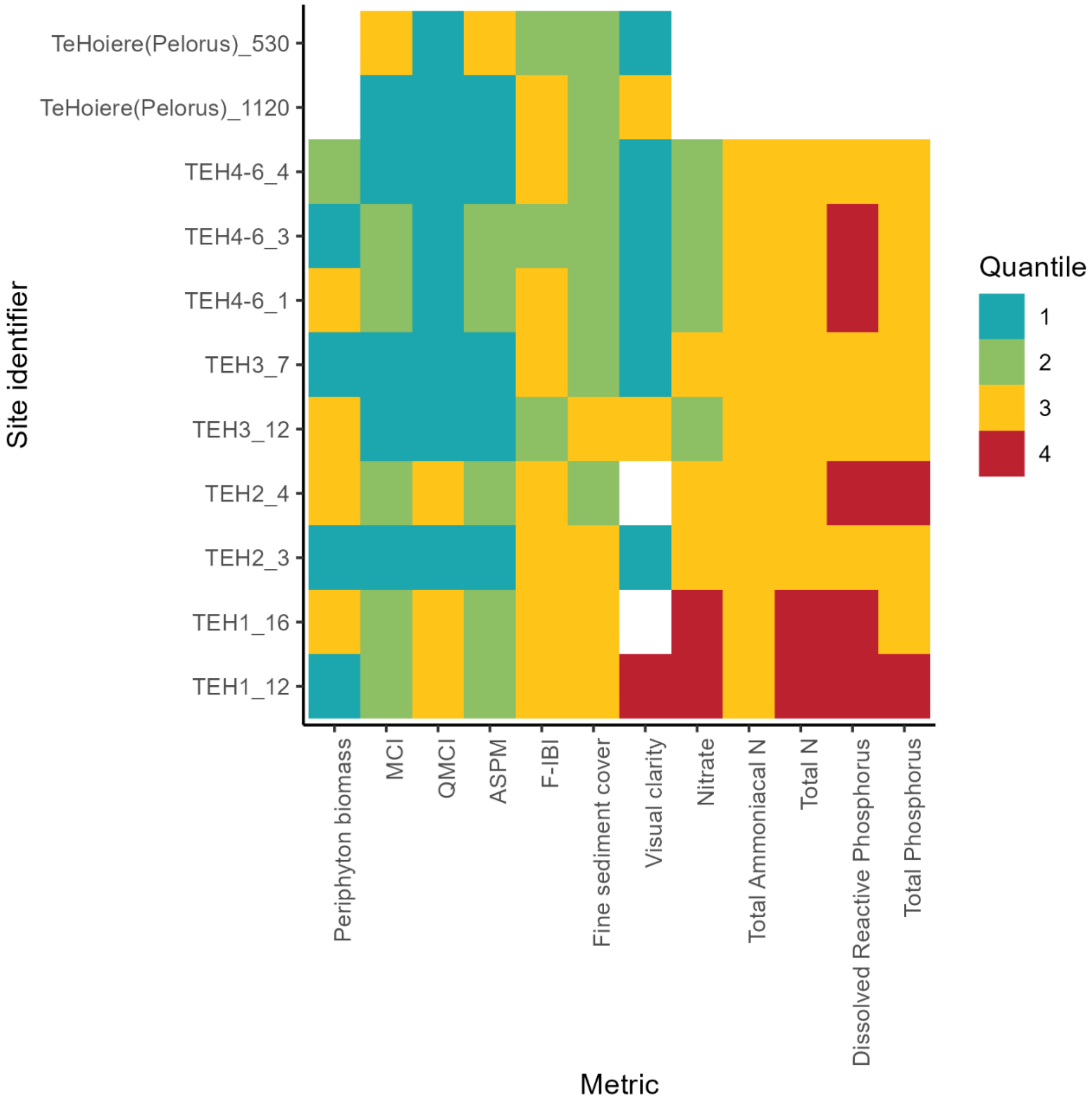


Figure 16. Quantiles for selected ecological health and water quality metrics in Te Hoiere / Pelorus River catchment calculated from a combined national dataset of 109 sites. Quantile 1 represents sites in the best 25% of recorded values for each metric, quantile 2 represents sites between the best 25% and 50% of recorded values, quantile 3 represents sites between 50% and 75% of recorded values, and quantile 4 represents sites in the worst 25% of recorded values. The values at sites in the fourth quantile may still represent excellent water quality overall. Blank squares represent metrics where a complete measurement could not be collected at a site.

7. DISCUSSION

7.1. Overview of findings

Aquatic life scores suggest there is healthy biodiversity across the sites in Te Hoiere catchment. Some sites had lower scores (or no score) for the fish index of biotic integrity (F-IBI) due to a lack of fish, which is likely a result of these sites having relatively high elevation and being a substantial distance inland. One other site with a low F-IBI score had a waterfall and rapids that may be a natural fish passage barrier downstream (TEH2_3). The survey site reaches harboured a significant number of At Risk and Threatened native freshwater fish taxa, with half of the species caught belonging to these threat classes.

Macroinvertebrate communities were generally indicative of pristine or reference conditions, although two sites displayed slightly lower MCI scores. Most of the macroinvertebrates (approximately 65%) could not be assigned to a threat class due to taxonomic resolution issues or lack of information.

Megainvertebrates were only observed at two sites, with both kōura and shrimps caught during electric fishing. Freshwater mussel surveys did not detect any mussels.

Primary production was low at all survey sites, with low periphyton biomass results. Periphyton cover was almost entirely bare substrate or thin mats / films, with low cover of thick mats or long algal filaments at a small number of sites. Bryophytes were present at two sites, with three species identified. No threatened bryophyte species were found.

A diverse array of habitat types were recorded across the survey sites. Most sites had more than three meso-habitats available for a range of organisms. Discharge was biased towards low-flow sites, but this reflects both the survey intent to sample all stream orders present and the size of the waterways present within PCL in Te Hoiere catchment. Substrate stability spanned from moderate to high, with most sites being highly stable.

Deposited fine sediment cover was low. This, accompanied by a diverse range of substrate size classes at most sites, indicates good habitat availability for macroinvertebrates and fish, with low infilling of the interstitial spaces. Pesticide residue was not detected at any of the sites tested.

Water quality parameters were excellent or good at most sites, with the exception of DRP, which was elevated within the Wakamarina sub-catchment, likely reflecting the underlying geology. Visual clarity was good or excellent at most sites, although it could not always be assessed due to the size of the waterway.

When compared with other recent monitoring of streams and rivers in or near PCL, sites displayed good values for macroinvertebrate indices and visual clarity, but poorer values for nutrient concentrations relative to other sites in the Ngā Awa river restoration programme and NFMP.

7.2. Potential future investigations

The data presented here give insight into the current state of Te Hoiere catchment and provide a foundation for guiding restoration efforts and the future assessment of change over time. In terms of potential future investigations, we have grouped our recommendations into risks requiring follow-up, the design of repeated sampling, knowledge gaps, hypotheses-driven questions and the use of other datasets, with further detail provided below.

Risks requiring follow-up

No risks requiring follow-up were identified.

Design of repeated sampling

Repeated sampling will enable assessment of changes over time. The areas of Te Hoiere catchment in PCL effectively remain in reference condition but are likely to be affected by changes in temperature and rainfall patterns arising from climate change. As a result, the wide-ranging dataset collected and presented here offers a baseline to inform future analyses of temporal change if similar monitoring was repeated.

Knowledge gaps

Future monitoring could examine the upstream extent of migratory fish distributions to determine the extent of species habitat within PCL in Te Hoiere catchment, as some migratory fish species present at low elevation sites were not found at higher elevations.

Hypotheses-driven questions

No specific hypotheses-driven questions were identified from the analyses presented here.

Use of other datasets

Combining the data presented here with other monitoring efforts within the lowland and more modified parts of the Te Hoiere catchment could help to identify areas under particular stress and inform decision-making around restoration efforts.

8. APPENDICES

Appendix 1. Site information for each of the sites measured in Te Hoiere / Pelorus River catchment in the 2020/21 and 2021/22 monitoring seasons. The GPS coordinates are for the midpoint of the site. Note that the waterway names have been reproduced here from the field data sheets and are not necessarily the official names for these features.

Site identifier	Waterway name	Monitoring season	Easting (NZTM)	Northing (NZTM)	NZ reach number
TeHoiere(Pelorus)_530	Te Hoiere (Pelorus) River	2020/21	1632951	5418598	11019179
TeHoiere(Pelorus)_1120	Rocks Creek	2020/21	1631498	5417887	11019416
TEH4-6_4	Te Hoiere Mainstem at Roebuck Hut	2021/22	1630379	5415703	11020064
TEH4-6_3	Te Hoiere	2021/22	1638282	5425568	11016573
TEH4-6_1	Wakamarina River	2021/22	1647237	5414994	11020665
TEH3_7	Mates Creek	2021/22	1626442	5412408	11021678
TEH3_12	Brown River	2021/22	1648277	5438124	11012233
TEH2_4	Wakamarina Tributary	2021/22	1649517	5419506	11018893
TEH2_3	Te Hoiere Tributary	2021/22	1631074	5417067	11019811
TEH1_16	Devils Creek Tributary	2021/22	1648594	5415009	11020615
TEH1_12	Kaiumu Stream	2021/22	1658000	5431302	11014338

Appendix 2. R packages and versions used for data curation, analysis and plotting.

Package	Version	Reference
base	4.3.0	R Core Team (2023)
colorblindcheck	1.0.2	Nowosad 2019)
ggnewscale	0.4.9	Campitelli (2023)
ggpubr	0.6.0	Kassambara (2023)
ggVennDiagram	1.2.2	Gao (2022)
grafify	3.2.0	Shenoy (2021)
gridExtra	2.3	Auguie (2017)
gt	0.9.0	Iannone et al. (2023)
knitr	1.43	Xie (2014, 2015, 2023)
maptools	1.1.7	Bivand and Lewin-Koh (2023)
moonBook	0.3.1	Moon (2015)
nzffdr	2.1.0	Lee and Young (2021)
plotrix	3.8.2	Lemon (2006)
quantreg	5.95	Koenker (2023)
rgeos	0.5.9	Bivand and Rundel (2021)
rmarkdown	2.22	Xie et al. (2018, 2020), Allaire et al. (2023)
rprojroot	2.0.3	Müller (2022)
sf	1.0.13	Pebesma (2018), Pebesma and Bivand (2023)
tidyverse	2.0.0	Wickham et al. (2019)
viridisLite	0.4.2	Garnier et al. (2023)
webr	0.1.5	Moon (2020)

Appendix 3. Fish observations at all sites, including all methods used.

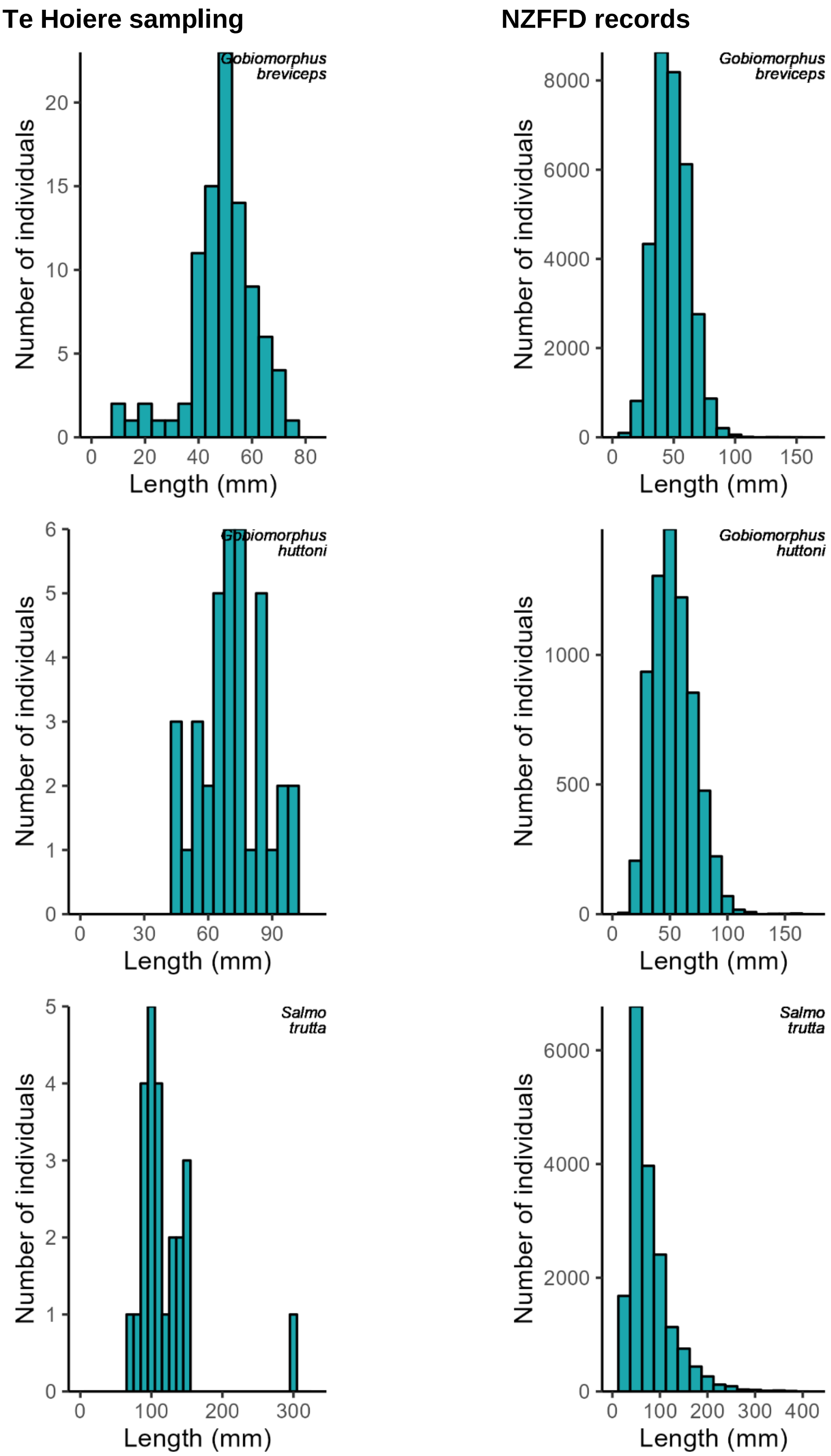
Site identifier	Scientific name	Common name	NZTCS category	NZTCS status	Bio status	Detection method
TeHoiere (Pelorus)_530	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	Electric fishing & eDNA
	Gobiomorphus breviceps	Upland bully	Not Threatened	Not Threatened	Endemic	Electric fishing & eDNA
	Salmo trutta	Brown trout	Introduced and Naturalised	Introduced and Naturalised	Exotic	Electric fishing & eDNA
	Gobiomorphus spp.	Unidentified bully	NA	NA	NA	Electric fishing
	Salmo spp.	NA	NA	NA	NA	Electric fishing
TEH4-6_4	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	eDNA
	Galaxias brevipinnis	Kōaro	At Risk	Declining	Endemic	eDNA
	Gobiomorphus breviceps	Upland bully	Not Threatened	Not Threatened	Endemic	eDNA
	Salmo trutta	Brown trout	Introduced and Naturalised	Introduced and Naturalised	Exotic	eDNA
TEH4-6_3	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	Electric fishing & eDNA
	Gobiomorphus breviceps	Upland bully	Not Threatened	Not Threatened	Endemic	Electric fishing & eDNA
	Salmo trutta	Brown trout	Introduced and Naturalised	Introduced and Naturalised	Exotic	Electric fishing & eDNA
	Cheimarrichthys fosteri	Torrentfish	At Risk	Declining	Endemic	Electric fishing & eDNA
	Oncorhynchus mykiss	Rainbow trout	Introduced and Naturalised	Introduced and Naturalised	Exotic	Electric fishing
	Anguilla australis	Shortfin eel	Not Threatened	Not Threatened	Non-endemic	eDNA
	Gobiomorphus hubbsi	Bluegill bully	At Risk	Declining	Endemic	eDNA
TEH4-6_1	*Galaxias brevipinnis*	Kōaro	At Risk	Declining	Endemic	Electric fishing & eDNA
	Anguilla spp.	Unidentified eel	NA	NA	NA	Electric fishing
	Galaxias spp.	Unidentified galaxid	NA	NA	NA	Electric fishing
	Anguilla dieffenbachii	Longfin eel	At Risk	Declining	Endemic	eDNA
	Galaxias divergens	Dwarf galaxias	At Risk	Declining	Endemic	eDNA

Site identifier	Scientific name	Common name	NZTCS category	NZTCS status	Bio status	Detection method
TEH3_7	*Galaxias spp.*	Unidentified galaxid	NA	NA	NA	Electric fishing
	Anguilla dieffenbachii	Longfin eel	At Risk	Declining	Endemic	eDNA
	Galaxias brevipinnis	Kōaro	At Risk	Declining	Endemic	eDNA
TEH3_12	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	Electric fishing & eDNA
	Galaxias divergens	Dwarf galaxias	At Risk	Declining	Endemic	Electric fishing & eDNA
	Gobiomorphus breviceps	Upland bully	Not Threatened	Not Threatened	Endemic	Electric fishing & eDNA
	Salmo trutta	Brown trout	Introduced and Naturalised	Introduced and Naturalised	Exotic	Electric fishing & eDNA
	Anguilla spp.	Unidentified eel	NA	NA	NA	Electric fishing
	Gobiomorphus spp.	Unidentified bully	NA	NA	NA	Electric fishing
	Oncorhynchus mykiss	Rainbow trout	Introduced and Naturalised	Introduced and Naturalised	Exotic	Electric fishing
	Anguilla australis	Shortfin eel	Not Threatened	Not Threatened	Non-endemic	eDNA
TEH2_4	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	Electric fishing & eDNA
	Gobiomorphus huttoni	Redfin bully	Not Threatened	Not Threatened	Endemic	Electric fishing & eDNA
	Anguilla spp.	Unidentified eel	NA	NA	NA	Electric fishing
	Gobiomorphus spp.	Unidentified bully	NA	NA	NA	Electric fishing
	Cheimarrichthys fosteri	Torrentfish	At Risk	Declining	Endemic	eDNA
TEH2_3	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	eDNA
TEH1_16	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	Electric fishing & eDNA
TEH1_12	*Anguilla spp.*	Unidentified eel	NA	NA	NA	Electric fishing
	Anguilla dieffenbachii	Longfin eel	At Risk	Declining	Endemic	eDNA

Site identifier	Scientific name	Common name	NZTCS category	NZTCS status	Bio status	Detection method
TeHoiere (Pelorus)_530	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	Electric fishing & eDNA
	Gobiomorphus breviceps	Upland bully	Not Threatened	Not Threatened	Endemic	Electric fishing & eDNA
	Salmo trutta	Brown trout	Introduced and Naturalised	Introduced and Naturalised	Exotic	Electric fishing & eDNA
	Gobiomorphus spp.	Unidentified bully	NA	NA	NA	Electric fishing
	Salmo spp.	NA	NA	NA	NA	Electric fishing
TEH4-6_4	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	eDNA
	Galaxias brevipinnis	Kōaro	At Risk	Declining	Endemic	eDNA
	Gobiomorphus breviceps	Upland bully	Not Threatened	Not Threatened	Endemic	eDNA
	Salmo trutta	Brown trout	Introduced and Naturalised	Introduced and Naturalised	Exotic	eDNA
TEH4-6_3	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	Electric fishing & eDNA
	Gobiomorphus breviceps	Upland bully	Not Threatened	Not Threatened	Endemic	Electric fishing & eDNA
	Salmo trutta	Brown trout	Introduced and Naturalised	Introduced and Naturalised	Exotic	Electric fishing & eDNA
	Cheimarrichthys fosteri	Torrentfish	At Risk	Declining	Endemic	Electric fishing & eDNA
	Oncorhynchus mykiss	Rainbow trout	Introduced and Naturalised	Introduced and Naturalised	Exotic	Electric fishing
	Anguilla australis	Shortfin eel	Not Threatened	Not Threatened	Non-endemic	eDNA
	Gobiomorphus hubbsi	Bluegill bully	At Risk	Declining	Endemic	eDNA
TEH4-6_1	*Galaxias brevipinnis*	Kōaro	At Risk	Declining	Endemic	Electric fishing & eDNA
	Anguilla spp.	Unidentified eel	NA	NA	NA	Electric fishing
	Galaxias spp.	Unidentified galaxid	NA	NA	NA	Electric fishing
	Anguilla dieffenbachii	Longfin eel	At Risk	Declining	Endemic	eDNA
	Galaxias divergens	Dwarf galaxias	At Risk	Declining	Endemic	eDNA

Site identifier	Scientific name	Common name	NZTCS category	NZTCS status	Bio status	Detection method
TEH3_7	*Galaxias spp.*	Unidentified galaxid	NA	NA	NA	Electric fishing
	Anguilla dieffenbachii	Longfin eel	At Risk	Declining	Endemic	eDNA
	Galaxias brevipinnis	Kōaro	At Risk	Declining	Endemic	eDNA
TEH3_12	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	Electric fishing & eDNA
	Galaxias divergens	Dwarf galaxias	At Risk	Declining	Endemic	Electric fishing & eDNA
	Gobiomorphus breviceps	Upland bully	Not Threatened	Not Threatened	Endemic	Electric fishing & eDNA
	Salmo trutta	Brown trout	Introduced and Naturalised	Introduced and Naturalised	Exotic	Electric fishing & eDNA
	Anguilla spp.	Unidentified eel	NA	NA	NA	Electric fishing
	Gobiomorphus spp.	Unidentified bully	NA	NA	NA	Electric fishing
	Oncorhynchus mykiss	Rainbow trout	Introduced and Naturalised	Introduced and Naturalised	Exotic	Electric fishing
	Anguilla australis	Shortfin eel	Not Threatened	Not Threatened	Non-endemic	eDNA
TEH2_4	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	Electric fishing & eDNA
	Gobiomorphus huttoni	Redfin bully	Not Threatened	Not Threatened	Endemic	Electric fishing & eDNA
	Anguilla spp.	Unidentified eel	NA	NA	NA	Electric fishing
	Gobiomorphus spp.	Unidentified bully	NA	NA	NA	Electric fishing
	Cheimarrichthys fosteri	Torrentfish	At Risk	Declining	Endemic	eDNA
TEH2_3	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	eDNA
TEH1_16	*Anguilla dieffenbachii*	Longfin eel	At Risk	Declining	Endemic	Electric fishing & eDNA
TEH1_12	*Anguilla spp.*	Unidentified eel	NA	NA	NA	Electric fishing
	Anguilla dieffenbachii	Longfin eel	At Risk	Declining	Endemic	eDNA

Appendix 4. Length distributions of fish taxa where more than 15 individuals were caught across all sites sampled in Te Hoiere / Pelorus River catchment, compared to length records stored in the NZFFD.



Appendix 5. Taxon-Independent Community Index (TICI) results for all replicates collected at all monitoring sites. The reliability of each result is presented as received from Wilderlab.

Site identifier	Monitoring season	TICI value	TICI rating	Number of sequences included	Reliability
TeHoiere(Pelorus)_1120	2020/21	126.31	Pristine	167	Average
	2020/21	127.80	Pristine	182	Average
	2020/21	127.21	Pristine	167	Average
	2020/21	123.77	Pristine	270	High
	2020/21	125.73	Pristine	309	High
	2020/21	124.83	Pristine	300	High
TEH1_12	2021/22	126.78	Pristine	354	Very high
	2021/22	125.56	Pristine	351	Very high
	2021/22	126.92	Pristine	316	High
	2021/22	126.62	Pristine	343	High
	2021/22	126.17	Pristine	335	High
	2021/22	126.07	Pristine	336	High
TEH1_16	2021/22	129.78	Pristine	259	High
	2021/22	128.88	Pristine	272	High
	2021/22	128.52	Pristine	234	Average
	2021/22	126.47	Pristine	216	Average
	2021/22	128.13	Pristine	219	Average
	2021/22	127.61	Pristine	229	Average
TEH2_3	2021/22	124.79	Pristine	331	High
	2021/22	124.55	Pristine	345	High
	2021/22	125.81	Pristine	262	High
	2021/22	125.23	Pristine	321	High
	2021/22	124.68	Pristine	299	High
	2021/22	126.15	Pristine	306	High
TEH2_4	2021/22	126.49	Pristine	359	Very high
	2021/22	125.72	Pristine	444	Very high
	2021/22	125.87	Pristine	404	Very high
	2021/22	124.88	Pristine	417	Very high
	2021/22	125.68	Pristine	390	Very high
	2021/22	126.58	Pristine	426	Very high
TEH3_12	2021/22	107.86	Good	515	Very high
	2021/22	107.34	Good	437	Very high
	2021/22	105.84	Good	460	Very high
	2021/22	108.23	Good	462	Very high
	2021/22	107.56	Good	476	Very high
	2021/22	108.12	Good	535	Very high
TEH3_7	2021/22	129.97	Pristine	301	High
	2021/22	130.64	Pristine	296	High
	2021/22	130.24	Pristine	293	High
	2021/22	131.19	Pristine	264	High
	2021/22	129.70	Pristine	291	High
	2021/22	130.23	Pristine	255	High

Site identifier	Monitoring season	TICI value	TICI rating	Number of sequences included	Reliability
TEH4-6_1	2021/22	127.95	Pristine	405	Very high
	2021/22	127.85	Pristine	445	Very high
	2021/22	126.94	Pristine	448	Very high
	2021/22	127.82	Pristine	424	Very high
	2021/22	126.75	Pristine	452	Very high
	2021/22	128.67	Pristine	420	Very high
TEH4-6_3	2021/22	122.66	Pristine	473	Very high
	2021/22	124.64	Pristine	524	Very high
	2021/22	122.93	Pristine	493	Very high
	2021/22	123.56	Pristine	520	Very high
	2021/22	124.43	Pristine	476	Very high
	2021/22	123.36	Pristine	497	Very high
TEH4-6_4	2021/22	127.32	Pristine	363	Very high
	2021/22	125.30	Pristine	333	High
	2021/22	126.69	Pristine	390	Very high
	2021/22	126.41	Pristine	355	Very high
	2021/22	127.66	Pristine	388	Very high
	2021/22	127.90	Pristine	400	Very high

Appendix 6. Supplementary water chemistry results for each site monitored in the 2021/22 monitoring season. TSS = total suspended solids, DOC = dissolved organic carbon, TOC = total organic carbon.

Site identifier	Anions (mEq/L)	Cations (mEq/L)	Turbidity (FNU)	Conductivity (mS/m)	TSS (g/m^3)	Calcium (g/m^3)	Magnesium (g/m^3)	Potassium (g/m^3)	Sodium (g/m^3)	Chloride (g/m^3)	Sulphate (g/m^3)	DOC (g/m^3)	TOC (g/m^3)
TEH1_12	0.76	0.70	0.78	6.6	3	6.50	1.78	0.44	4.9	3.2	1.0	0.5	0.5
TEH1_16	0.42	0.40	0.22	4.0	3	3.60	0.93	0.45	3.1	1.6	1.3	0.6	1.1
TEH2_3	1.10	1.16	0.27	10.2	3	7.70	7.20	0.35	3.9	3.0	2.3	1.2	1.8
TEH2_4	0.49	0.48	0.22	4.5	3	3.60	1.29	0.56	4.2	2.1	1.3	1.9	2.1
TEH3_12	1.51	1.57	1.31	16.9	3	10.00	3.40	0.65	17.8	28.0	1.4	1.4	3.6
TEH3_7	0.52	0.54	0.12	4.6	3	6.00	1.43	0.28	2.7	0.7	0.9	0.5	1.0
TEH4-6_1	0.55	0.44	0.40	4.1	3	3.90	1.19	0.39	3.2	1.4	1.6	0.5	1.4
TEH4-6_3	0.70	0.64	0.20	6.1	3	5.80	2.10	0.40	3.7	1.7	1.4	0.5	0.5
TEH4-6_4	0.64	0.62	0.14	5.9	3	6.60	1.82	0.36	3.2	1.2	1.5	1.1	0.5

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