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The ecological state of wadeable streams in the Waikato region 2021-2023

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Abstract

This report presents updated results from the Waikato Regional Council's (WRC's) Regional Ecological Monitoring of wadeable Streams (REMS) programme for 2021-2023. The REMS programme involves annual surveys in summer of aquatic invertebrate macroinvertebrates, fish and instream habitat to document the state and trend of the ecological condition (state) of streams. Standardised surveys of stream macroinvertebrates, fish, and habitat (including instream plant cover, deposited fine sediment, and shade) are undertaken on wadeable streams. The composition of macroinvertebrate and fish communities, and habitat measures, can be condensed into indices to provide integrated measures of a stream's ecological health which can then be compared across sites regionally. As with previous reports average condition for wadeable streams on developed land remains within the National Policy Statement for Freshwater Management (2020; NPS-FM) C band for the Macroinvertebrate Community Index (MCI) and Average Score Per Metric (ASPM), and D Band for Quantitative MCI (QMCI). At a regional level the estimated extent of stream length falling below the national bottom line for at least one of MCI, QMCI, and ASPM ranged from 40 – 60% (c.6,000 – 8,000 km). For fish communities, based on the NPS-FM (2020) Index of Biological Integrity (NPSIBI) banding, the average condition was B band, with around 10% of stream length on developed land estimated to be in D band (c.1,500 km). Fine sediment deposition in the form of 'sands, silts and clays', a key driver of ecological health in small streams, remains concerning with >50% of wadeable stream length estimated to have more than 40% streambed cover. A high proportion of streams are estimated to have <50% shading of the bed. Shade provides important functions for the stream and prevents excessive growths of aquatic plants and algae. Aquatic macrophyte growth was demonstrated to be problematic across >25% of streams, where it exceeded 40% of the bed, while periphyton was unlikely to be a major issue across most of the wadeable stream network. Riparian planting (especially of small streams) should see positive outcomes for both reducing fine deposited sediment and improving stream shading. For fish biodiversity, relatively rapid gains are likely to occur through improving riverscape connectivity via the removal or remediation of anthropogenic barriers to bi-directional fish migration, with barrier assessments being undertaken actively in other WRC monitoring programmes.

Executive summary

This report presents updated results from the Waikato Regional Council's (WRC's) Regional Ecological Monitoring of wadeable Streams (REMS) programme for 2021-2023. Annual standardised surveys of aquatic macroinvertebrates, fish, and stream habitat have been undertaken to document the ecological condition (state) of streams in the current format since 2009. The REMS probabilistic network incorporates a random design of c. 180 sites on developed land, complimented by a network of reference streams in native forest. A key benefit of the random network design is that inferences can be made with a quantified level of accuracy to unmonitored parts of the stream network. These estimates can then also be quantified as either a length (km) of stream, or as a proportion (%) of overall stream length. The composition of macroinvertebrate and fish communities can be condensed into indices to provide integrated measures of a stream's ecological health which is influenced by local habitat factors, flow, and the upstream catchment, including activities that affect water quality. These indices can then be compared across sites regionally. This report serves as a comprehensive resource for understanding the current condition of freshwater ecosystems in the Waikato region. To do this, the report:

i. provides an unbiased broad-scale estimate of the ecological condition of perennial, non-tidal, wadeable streams on developed land in the Waikato region, incorporating freshwater ecological metrics and physical habitat aspects for the years 2021 – 2023;
ii. discuss relationships between habitat and biological indices of ecosystem health;
iii. discuss the differences between developed land sites and reference condition sites in native forest;

As with previous reports average condition for wadeable streams on developed land remains within the National Policy Statement for Freshwater Management (2020) (NPS) C band for the Macroinvertebrate Community Index (MCI) and Average Score Per Metric (ASPM), and D Band for Quantitative MCI (QMCI). At a regional level the estimated extent of stream length falling below the national bottom line for at least one of MCI, QMCI, and ASPM ranged from 40 – 60% (c.6,000-8,000 km). For fish communities, based on the national NPS Index of Biological Integrity (NPSIBI) banding for fish, the average condition was B band, with around 10% of stream length on developed land estimated to be in D band (c.1,500 km). Fine sediment deposition in the form of 'sands, silts and clays', a key driver of ecological health in small streams, remains concerning with >50% of wadeable stream length estimated to have more than 40% streambed cover. Aquatic plant growth was demonstrated to be problematic across

>25% of streams, where they exceeded 40% of the bed of a reach while periphyton was unlikely to be a major issue across most of the wadeable stream network. Deposited fine sediment, riparian shade and habitat assessments show significant correlations with biological indices.

Freshwater ecosystems in the Waikato region face numerous challenges, including pollution from agricultural and urban sources, habitat modification, and the impacts of climate change. Excess deposited fine sediment is a widespread and impactful stressor on wadeable stream ecology in developed land. The adverse effects of sediment on wadeable aquatic ecosystems, particularly on developed land, are well established. Ongoing effort is required across the region to address and reduce the adverse ecological effects of deposited fine sediment in streams. Increasing stream shading, through improved riparian vegetation along the region's streams, would be beneficial given the high proportion of streams estimated to have < 50% shading. Riparian planting (especially small streams) should see positive outcomes for both reducing fine deposited sediment and improving stream shading. For fish biodiversity, relatively rapid gains are likely to occur through improving riverscape connectivity via the removal or remediation of anthropogenic barriers to bi-directional fish migration, with barrier assessments being undertaken actively in other WRC monitoring programmes.

1 Introduction

1.1 1.1 Ecological monitoring of streams

The Waikato region has a diverse network of freshwater ecosystems that are vital to both ecological health and human well-being. This report presents an in-depth analysis into the current state of freshwater ecology in the region's wadeable streams, focusing on key indicators measured through comprehensive monitoring efforts. Freshwater ecosystems in the Waikato region face numerous pressures, including pollution from agricultural and urban sources, habitat modification, and the impacts of climate change. These factors increase the importance of ongoing monitoring to assess ecosystem health, identify stressors, and guide effective management and conservation strategies (Leps et al., 2016). Although sometimes challenging, ecological monitoring is essential for better understanding the responses and relationships between organisms (e.g., macrophyte, macroinvertebrate and fish communities in streams) and environmental pressures (e.g., nutrients, sediment, riparian disturbance). Understanding these relationships assists sustainable environmental management, development of targets, and identification of potential rehabilitation measures in streams (Matthaei et al. 2010). The key to achieving this at broad (i.e. regional) scales in target ecosystems is access to unbiased estimates of condition and extent across dominant stressor gradients.

To contribute to meeting its Resource Management Act (1991) requirements the Waikato Regional Council (WRC) has been conducting annual surveys of aquatic macroinvertebrates and stream habitat to document the state and trend of the ecological condition of streams and rivers in the region since 1994 (Regional Ecological Monitoring of Streams – REMS; Collier & Hamer, 2010), with freshwater fish monitoring commencing in 2009 (David et al., 2016). The early history and objectives of this monitoring programme were reviewed by Collier (2005), whereupon a land-use based design (Collier & Hamer 2010) was subsequently complimented by native forest streams in unmodified catchments (Collier et al., 2007). This was then utilised alongside a probability based random site selection design, implemented to reduce potential biases in site selection across developed land, in 2009 (Collier & Hamer, 2012). Consequently, the overall network comprises sites representing different levels of upstream catchment development and local land uses across the region. A key benefit of the random network design is that inferences can be made with a quantified level of accuracy to unmonitored parts of the stream network. These estimates can then also be quantified as either a length (km) of stream, or as a proportion (%) of overall stream length.

1.2 1.2 Purpose of this report

This report describes the ecological condition (state) of the regions' wadeable streams, on developed land. To do this, the report provides an update on previous reports by:

i. providing an unbiased broad-scale estimate of the ecological condition of perennial, non-tidal, wadeable streams on developed land in the Waikato region, incorporating freshwater ecological metrics and physical habitat aspects for the years 2021 – 2023;
ii. discussing relationships between habitat and biological indices of ecosystem, health;
iii. discussing the differences between developed land sites and reference condition sites in native forest.

2 Methods

2.1 2.1 Network design and site selection

2.1.1 2.1.1 Probabilistic network

The randomised probabilistic survey design was first implemented by Waikato Regional Council in 2009, with detailed descriptions and results for three-yearly rotations reported for macroinvertebrates in Collier & Hamer (2012) and Pingram et al. (2016), and for fish in David et al. (2016). The survey design involved randomly selecting sites, with known probability of inclusion based on the spatial layer used, using the survey design software package spsurvey (https://cran.r-project.org/web/packages/spsurvey/index.html). To ensure sampling sites are not skewed towards small streams, which comprise most of the stream network length regionally, a balanced unequal probability design was used. This selected equal numbers of 1st, 2nd, 3rd and ≥4th order streams using the River Environment Classification (REC, version1; Snelder & Biggs (2002)) river network layer as the sample frame (Collier & Olsen 2013). However, it should be noted that the REC network layer does not identify all small perennial headwater streams and identifies others that are dry. Therefore, the target network length will be inaccurate by an unknown quantity. A key benefit of this type of monitoring network design is that inferences can be made from a limited number of sites to the rest of the region's waterways with a quantified level of precision, making it highly cost-effective in terms of providing unbiased estimates of regional stream resource quality. These estimates can be quantified as either a length of stream or as a proportion of overall stream length.

To select a network of 180 sites in the first round of sampling, between 2009-2011, potential sites were screened and classed as either:

1) Target, where they were a
    a) non-tidal, and
    b) perennial and,
    c) wadeable stream, and
    d) with an upstream catchment landcover of <80 % native vegetation (i.e. in a developed land catchment),
2) Non-Target, where the site was:
    a) non-wadeable (for sampling purposes), or
    b) non-perennial, or
    c) a drain in an artificial catchment, or
    d) tidal,
    e) located in native forest with an upstream catchment landcover of >80% native vegetation, or
    f) not a stream (e.g. where the REC was inaccurate or passing through another type of waterbody (e.g., lakes, wetlands).

Candidate sites were initially screened using aerial photos followed by a site visit to confirm they were part of the target population. A proportion of valid target sites were also screened out as possible sampling sites due to access issues (e.g. distance from a road or track, unsafe access). As at the 2023 rotation a total of 621 sites has been screened, with 266 evaluated as target sites, with 86 being inaccessible. While the initial sample panel includes equal numbers of sites in each stream order group, following screening for target sites based on the conditions above 35% of sites were on 1st order streams, 33% on 2nd order streams, 21% on 3rd order streams and 11% on 4th and 5th order streams combined (WRC, unpublished data). Up to 60 target sites are sampled each year on a rotating 3-yearly basis, providing samples from the 180 sites over a given 3-year period. These same sites are then sampled again over the subsequent 3-year period. During the 2021-2023 rotation 178 sites were sampled for macroinvertebrates and habitat (two sites were temporarily inaccessible), 148 of these are also surveyed for fish communities (Figure

1; the smaller number of fish sites is due to additional access constraints for effective fish sampling, e.g. dense overhanging or instream vegetation). Minor variations to the sites making up the survey network have been implemented between 3-year rotations for both the macroinvertebrate and fish sampling programmes as sites occasionally need to be replaced due to unforeseen reasons (e.g. change in access, long-term drought). As a result, sites are regularly reviewed with regard to access and survey collection constraints, and where necessary, the next suitable replacement site is selected from the original over-sample list. Estimated target and non-target network lengths can vary slightly between rotations depending on the nature (stream order) of potential replacement sites. However, the estimated proportions and lengths of the main categories of interest (e.g., target, non-target, reference condition, or non-wadeable river) are consistent with those reported previously. Based on this approach it is possible to estimate the relative proportion and length of wadeable streams in developed land catchments as part of the wider Waikato region stream network.

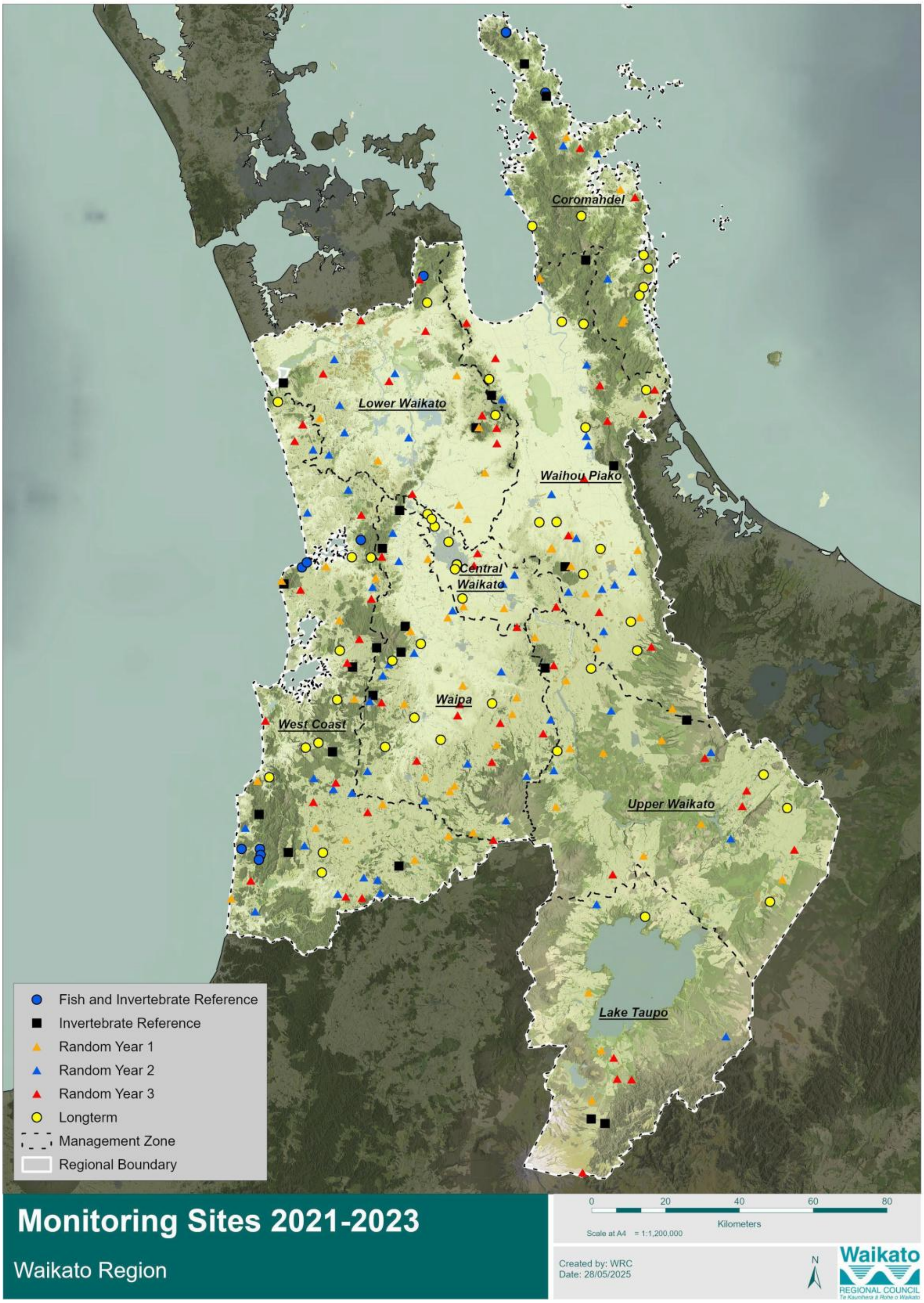

Figure 1: Map showing locations of monitored sites across the region in 2021-2023. Management zones present are Integrated Catchment Management Zones that approximate FMU's. NB: Longterm sites are shown here for information only, results for these sites can be viewed at https://www.lawa.org.nz/explore-data/waikato-region/river-quality.

2.1.2 Native forest reference condition network

The reference network consists of 35 sites (Figure 1), located in native forest with an upstream catchment of >80% unmodified native vegetation cover (Collier, et al., 2007) and are sampled annually. These sites are used to provide an undisturbed benchmark or reference against which to measure the magnitude of change at other sites and to help account for regional influences of climatic variation between years (see Collier & Kelly, 2005; Collier, et al., 2007). Reference site selection was based on achieving a spread of sites across geographic zones (Collier et al., 2007, Collier & Hamer, 2012). Originally 25 sites were selected to represent macroinvertebrate communities, and 10 separate sites were added later to account for fish communities. While all 35 sites are sampled for macroinvertebrates and habitat, only 10 are sampled for fish reference communities due to the additional criteria of being free of non-natural downstream barriers to migratory species (David, et al., 2016). Each reference site was sampled annually during the 3-year study period.

2.2 Sampling period and flood stand-down

Sampling was undertaken during the austral summers from 2021–2023 (December–April) and included the simultaneous collection of reach scale environmental stressor data and biological response information. Since 2012, each probabilistic site is visited twice in a summer; once to undertake fish surveys and once to collect macroinvertebrates and other environmental measurements, to ensure electric fishing did not impact on the macroinvertebrates sampled and vice versa. In most cases the same site was sampled within two weeks of either fish or macroinvertebrate crews visiting and where possible, as close to the previous rotation sample date (within the same month) as possible. Occasionally, adverse weather and bed-moving flood stand-down protocols were enacted forcing some sites to be sampled later. With respect to bed moving events, a regional network of telemetered flow monitoring sites is used with each site having an established bed moving flow trigger value developed using the methods of Clausen & Plew (2004). If this value is triggered, a minimum stand-down period of two weeks is enacted for any sites in the catchment or near to that flow site recorder. This precautionary approach is to ensure samples are representative of the site and alleviate the potential for bed moving flow events to alter the structure and function of local macroinvertebrate communities (in the short term) from that exhibited during typical base-flow conditions. Although fish may respond differently to flood events the stand-down is observed for these surveys as well (species can be affected to differing degrees, depending on the size of the flood and catchment characteristics (e.g., Hayes et al., 2010; McEwan & Joy, 2013).

2.3 Macroinvertebrate sampling protocols and metrics

2.3.1 Collection and processing

A core component of the REMS programme involves the standardised collection of stream macroinvertebrates. The composition of macroinvertebrate communities provides an integrated measure of a stream's ecological health which is influenced by local habitat factors, flow, and the upstream catchment, including activities that affect water quality. Macroinvertebrate community composition can be condensed into metrics and indices that can then be used as indicators to report patterns across the region (state) or changes over time (trends). Furthermore, macroinvertebrate community composition reflects a range of interacting factors, it can therefore provide a holistic and cumulative understanding of ecosystem condition.

Standardised protocols for sampling aquatic macroinvertebrates have been around since the early 2000s (i.e., Stark et al., 2001; Maxted et al., 2003). Macroinvertebrates were sampled over a 100 m reach using the standard protocols for New Zealand wadeable streams as described by Stark et al., (2001) and Maxted et al., (2003). The methods vary with predominant bed substrate type. In streams dominated by hard substrates (i.e., those with >50% benthic substrates made up of gravels, cobbles, boulders, or bedrock), and referred to as 'hard-bottomed', up to five kick-net samples from riffles were taken using an D-net with a 0.5 mm mesh, so that c. 1.0 m2 of riffle habitat was sampled and pooled into a composite pottle (Stark et al., 2001). In streams dominated by sand and silt substrates (i.e., those with >50% benthic substrates made up of sand, silt, or clay), and referred to as 'soft-bottomed', sampling involved brushing wood, and jabbing the net in and along submerged macrophytes and bankside vegetation at up to 7 locations in run habitats, so that an area of c. 3 m2 was sampled and pooled into a composite pottle (Maxted et al., 2003). At sites with mixed substate characteristics (40–60% hard or soft substates), both sample types were collected and sorted separately. The composite macroinvertebrate sample for each site was preserved in a final concentration of 70% isopropanol (IPA), and later sorted using a 200+ fixed count followed by scan for rare taxa (Protocol P2 of Stark et al., 2001). EOS Ecology Ltd completed the identification to the taxonomic levels laid out in Clapcott et al., (2017), with periodic quality assurance of macroinvertebrate identification undertaken by ESNZ.

2.3.2 Macroinvertebrate metrics

Three main indices are calculated from macroinvertebrate data: the Macroinvertebrate Community Index (MCI), the Quantitative MCI (QMCI), and the Average Score Per Metric (ASPM). The ASPM is an aggregation of Ephemeroptera, Plecoptera, Trichoptera (EPT)[1] taxa richness, EPT percent abundance and MCI standardised to nationally set minimums and maximums (NPS-FM 2020). This calculation differs to ASPM results in previous reports (e.g., Collier & Hamer, 2012 and Pingram et al., 2016) where values from regional reference sites were used for the standardisation in each particular year, as originally developed by Collier (2008). All three indices are used here to inform assessments of state and temporal change. Tolerance scores used for MCI calculations were those listed in Table A1.1 of Clapcott et al. (2017), which is slightly revised version of Table 1 from Stark & Maxted (2007). For taxa with no score listed, the score at the next taxonomic level up was used where available, otherwise taxa were excluded from MCI and QMCI calculations. Soft-bottomed or hard-bottomed MCI and QMCI tolerance scores were used to calculate indices based on the sampling protocol used at individual sites. Where both a hard-bottomed and soft-bottomed sample were collected the hard-bottomed data was used based on the assumption that the site was likely to be naturally hard-bottomed. Index scores were used to assign sites to the numeric attribute states listed in Tables 14 and 15 of the NPS-FM (2020; see Table 1).

[1] The acronym EPT refers to the sensitive groups Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). Metrics derived from EPT exclude Hydroptilidae because the commonest members of this family can proliferate in degraded conditions characterised by growths of filamentous algae (Maxted et al., 2003).

Table 1: Interpretation of Macroinvertebrate indices (reproduced from NPS-FM 2020). Values derived using hard or soft-bottomed tolerance scores based on sample method used at a particular site.

Band	Description	MCI[1]	QMCI[1]	ASPM[1]
A	Macroinvertebrate community, indicative of pristine conditions with almost no organic pollution or nutrient enrichment.	≥ 130	≥ 6.5	
B	Macroinvertebrate community indicative of mild organic pollution or nutrient enrichment. Largely composed of taxa sensitive to organic pollution/nutrient enrichment.	≥110 and <130	≥5.5 and <6.5	
C	Macroinvertebrate community indicative of moderate organic pollution or nutrient enrichment. There is a mix of taxa sensitive and insensitive to organic pollution/nutrient enrichment	≥90 and <110	≥4.5 and <5.5	
D	Macroinvertebrate community indicative of severe organic pollution or nutrient enrichment. Communities are largely composed of taxa insensitive to inorganic pollution/nutrient enrichment.	< 90	< 4.5	
A	Macroinvertebrate communities have high ecological integrity, similar to that expected in reference conditions.			≥0.6
B	Macroinvertebrate communities have mild-to-moderate loss of ecological integrity.			<0.6 and ≥0.4
C	Macroinvertebrate communities have moderate-to-severe loss of ecological integrity.			<0.4 and ≥0.3
D	Macroinvertebrate communities have severe loss of ecological integrity.			< 0.3

2.4 Fish sampling protocols and metrics

2.4.1 Collection

Freshwater fish are an integral part of freshwater ecosystems and are important for assessing overall river health in this monitoring programme. Notwithstanding their important recreational (e.g., trout, whitebait), customary (e.g. eels, lamprey), and commercial value (e.g., eels, mullet), freshwater fish are a vital component, of freshwater biodiversity. This is recognised in the NPS-FM (2020) with the inclusion of the national Fish Index of Biotic Integrity (NPS IBI; Joy & Death, 2003, 2004; Ministry for the Environment, 2020). Reach scale fish community diversity in New Zealand can be affected by factors that have a lesser effect on macroinvertebrate communities, notably instream barriers such as culverts, weirs and dams (Jellyman & Harding, 2012). For many nationally distributed species like the endemic longfin eel (*Anguilla dieffenbachii*) and torrentfish (*Cheimarrichthys fosteri*), diadromy and passage is obligatory to complete their lifecycle. Fish community composition in New Zealand has been demonstrated to be more affected by landscape scale factors (e.g. connectivity between waterbodies) than, instream variables (e.g. water quality), with differing responses to stressors than macroinvertebrates (Lange et al., 2014a; Lange et al., 2014b). Therefore, fish provide a complimentary assessment to macroinvertebrates for identifying environmental impacts.

Standardised protocols for monitoring reach scale fish communities in wadeable streams were developed and tested regionally (David & Hamer, 2010) and then nationally (David et al., 2010; Joy et al., 2013). Survey reaches were 150 m in length and centered on the same 100 m reach used for macroinvertebrate collection, with the inclusion of an additional 25 m up- and down-stream. All habitats were electro-fished using a NIWA Kainga EFM300 backpack electric fishing machine in an unbiased fashion, any area unable to be fished was recorded. The netting protocols of Joy et al. (2013) were used when the protocol matrix showed netting to be the most appropriate option (i.e., average depth >0.6 m). Both techniques generally provide robust and comparable information for presence-absence based indices, and a detailed comparison of the two techniques can be found in Joy et al. (2013). Captured fish were identified, counted, and measured (for length) on site before being released. Any sites that could not be accessed for these fishing techniques, were not included in subsequent fish related statistical analyses.

2.4.2 Fish indices

The Fish Index of Biological Integrity (Fish IBI; Karr, 1981; Karr, 1987; Karr, et al., 1986), has been modified and adopted for use in New Zealand (Joy & Death, 2004; Ministry for the Environment, 2020; Ministry for the Environment, 2023). In addition to taxonomic richness, the index also incorporates metrics related to habitat guilds used by different specialist fish species (riffle, benthic pool, pelagic pool), a metric related to tolerances to different environmental variables, and the proportion of native to exotic species richness present. The Fish IBI was incorporated as an attribute in the National Policy Statement for Freshwater Management (NPS-FM) in 2020. Although not reported here, due to being superseded by the nationally consistent NPS-FM IBI metric, a Waikato region specific fish IBI has also been previously developed (Joy, 2006; Joy, 2007). This report uses the nationally consistent IBI scores calculated using the publicly available calculator tool, as developed by MfE (Ministry for the Environment, 2023). The calculator tool was used to calculate the IBI scores for each site, and these are referred to throughout as the NPS IBI.

Table 2: Interpretation of Fish indices (reproduced from the NPS-FM (2020), bands from the NPS-FM (2020) from Ministry for the Environment (2023)). *Sites where no fish were recorded and that have also been previously modelled to be fishless.

Band	Description	NPSIBI
A	High integrity of fish community. Habitat and migratory access have minimal degradation.	≥ 34
B	Moderate integrity of fish community. Habitat and/or migratory access are reduced and show some signs of stress.	< 34 and ≥ 28
C	Low integrity of fish community. Habitat and/or migratory access is considerably impairing and stressing the community.	< 28 and ≥ 18
D	Severe loss of fish community integrity. There is substantial loss of habitat and/or migratory access, causing a high level of stress on the community.	< 18
E	'Naturally' No Fish*	0

2.5 Physical habitat assessments

2.5.1 Habitat assessment

Aspects of habitat and instream plant cover are assessed concurrently with macroinvertebrate collections. A qualitative habitat assessment (QHA) was conducted at each site using the approach of Collier & Kelly (2005), whereby nine measures of riparian, bank and channel condition are assessed on a scale of 1 (lowest condition) to 20 (highest condition). Here, we report and utilise eight of these, as Q9 – 'periphyton' is better represented by quantitative measures from transects as outlined below. To compliment this, since 2015, a nationally consistent Rapid Habitat Assessment (RHA) was also undertaken (see Clapcott, 2015 for details) and yields similar overall results (see Section 3). Both assessments can be summed to produce a 'total score' out of 160 and 100, respectively. The dominant riparian land use, degree of reach shade, and to what extent it is fenced, at each site were also recorded.

At each site, in situ, point in time measures for stream temperature, dissolved oxygen and conductivity were recorded using a portable handheld meter (Hach HQ40d).

Every 20 m along the 100 m reach, transects were used to assess stream habitat variables including: width, depth, shade, substrate composition, periphyton and macrophyte composition. Shade was measured using a densiometer (Forestry Suppliers, U.S.A) in the middle of the stream where four readings were taken at each locality; one facing each of upstream, downstream, true left and true right. Shade for the entire site was represented as an average of the four readings at each sub-reach transect (4 readings x 5 sub-reaches = 20 values). Substrate size class composition was estimated by undertaking a modified Wolman assessment of streambed particles, whereby 100 particles are sampled across the five evenly spaced transects (20 per transect). The intermediate axis dimension (width) is used to place the substrate into size divisions of the modified Wentworth scale as per Harding, et al., (2009) using a gravelometer. At each transect the relative proportion of different periphyton growth forms and macrophyte groups was also recorded following the methods outlined in Collier et al. (2014).

2.5.2 Habitat metrics

QHA scores are derived by summing the 8 measures of riparian, bank, and channel condition on a scale of 1 (lowest condition) to 20 (highest condition; see Collier & Kelly, 2005). Likewise, the RHA score is the sum of the 10 questions.

Derivation of periphyton and macrophyte metrics follow the methods described in Matheson et al., (2012) and Collier et al., (2014) respectively. The metrics reported here are a Periphyton weighted composite cover, modified to include medium mats and short filaments as a more inclusive measure of periphyton cover (WCC^) (modified from Matheson et al., (2012)). For aquatic plants, Macrophyte Channel Clogginess (MCC) is recorded, where areal cover is weighted by plant growth form, as developed by Collier et al. (2014). The metric indicator bands are based on information provided by Matheson et al., (2012).

Fine sediment cover was derived from the substrate size class data. The percent cover from all particle types <2 mm in size is combined to a percentage cover of fine sediment called %SSC (i.e., % Sand, Silt, and Clay cover). Details of habitat assessment thresholds and banding used to interpret results are provided in Table 3.

Table 3: Habitat indicators, banding categories used in this report, description of interpretation, and associated source.

Indicator	A	B	C	D	Description	Reference(s)
Qualitative Habitat Assessment (QHA)	>125	85-125	45-84	<45	Based on bands provided in assessment (i.e., Optimal – Poor). Total score excluding periphyton.	Collier & Kelly, (2005)
Rapid Habitat Assessment (RHA)	>85	55-85	25-54	<25	Based on groupings provided in assessment	Clapcott, (2015)
Periphyton weighted composite cover (WCC^)	<20	20-39	40-55	>55	Based on periphyton colour/thickness classes (Collier et al., 2014). ^Expanded to include medium mats.	Bands modified from Matheson et al., (2012)
Shade (%)	>80	50-80	20-50	<20	Based on descriptions of unshaded and heavily shaded.	Harding et al., (2009)
Macrophyte Channel Clogginess (MCC)	<15	15-35	35-50	>50	Based on weighted cross-sectional habit of macrophyte classes (Collier, et al., 2014).	Bands modified from Matheson et al., (2012)
Streambed cover by Sand, Silt and Clay (%SSC)	<10	10-20	20-40	>40	Derived from literature thresholds for deposited fine sediment	Bands modified from Burdon et al., (2013)

2.6 Statistical analyses

2.6.1 Probabilistic sites

The R software package ‘spsurvey’ (version 4.1.0; Kincaid et al., 2019) was used to estimate the percentage and length of wadeable streams across developed land for (i) categorical variables (e.g., target or non-target, condition bands – A, B, C, D); and (ii) percentile and mean values for continuous measurements (e.g, metric values). The network design involves unequal probability of selection to achieve balanced numbers of 1st, 2nd, 3rd and ≥4th order sites from the sample frame. Therefore, it was necessary to adjust the data for the known probability of site selection. This adjustment enables calculation of an unbiased and appropriately weighted estimate of stream length in a given condition band or group, and summary statistics for individual indices across the target population of streams. Standard error (SE) estimates were based on the local neighbourhood method described by Stevens & Olsen (2003). Broad-scale sub-regional/catchment management zones (akin to the freshwater management unit approach of the NPS-FM (2020) were treated as subpopulations in the spsurvey analyses. Target stream length (and proportion of the overall regional network) is not evenly distributed between FMU’s, and as a result the number of sites varies (as they were selected to be spatially balanced at a region-wide scale rather than FMU scale). For the current report the Central and Lower Waikato, FMU’s have been combined due to the small size of the Central FMU, and the hydro power dam at Karāpiro being a logical distinction between the upper and lower Waikato River catchment(s) due to its role as a barrier to fish migration.

Estimates of biological condition metrics, habitat assessments, and riparian fencing, were produced at both the regional and FMU scale and for the region through time using the R package spsurvey (Kincaid et al., 2019). Figures were created using the R packages ggplot2 (Wickham. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York, 2016) and ggpubr (Alboukadel Kassambara. ggpubr: 'ggplot2' Based Publication Ready Plots. 2018). Tables of results were created using the R package gt (Richard Iannone and Joe Cheng and Barret

Schloerke and Ellis Hughes and Alexandra Lauer and JooYoung Seo and Ken Brevoort and Olivier Roy. gt: Easily Create Presentation-Ready Display Tables. 2024). Change in extent estimates and mean parameter values was estimated using the change analysis function in the spsurvey package. The spsurvey change estimation compares differences between two points in time. The variance of this difference incorporates the variability at point in time and the correlation between sites that were sampled in each time period (Dumelle et al., 2023). Only estimated differences where the upper 95% confidence intervals were both positive, or lower 95% confidence intervals were both negative, were considered significant (after Van Sickle & Paulsen, 2008).

2.6.2 Comparisons between reference and developed land sites

Comparisons were made using boxplots. For reference condition sites, sampled more than once across 2021 – 2023 summers, the median value was used. Simple Wilcoxon tests were undertaken to compare the two groups using functions in the R package ggpubr.

2.6.3 Correlations between ecological metrics

Previous studies have linked habitat factors such as increased deposited fine sediment and periphyton cover with lower ecological indicator scores (Biggs 2000; Biggs & Kilroy 2000; Clapcott et al., 2011; Burdon et al., 2013). An assessment was undertaken of the potential relationships between biological indicators of ecosystem health, as measured by the MCI, QMCI, ASPM and NPSIBI, with habitat metrics, including deposited fine sediment. Relationships were tested using Kendall rank correlations using the R package corrplot (Taiyun Wei and Viliam Simko. 'corrplot': Visualization of a Correlation Matrix. 2024). Non-parametric Kendall rank correlation was used due to the non-normal and integer nature of some indices. For reference condition sites, sampled more than once across 2021 – 2023 summers, the median value was used in correlations.

3 Results

3.1 Regional ecological condition

3.1.1 Target and non-target stream length

Based on the most recent completed rotation (2021, 2022, 2023), target streams are expected to represent 38% of the REC (1) network length or c. 14,340 km (Figure 2). Forested sites with >80% upstream catchment in native vegetation are expected to account for another 17% (c. 6,450 km), and non-wadeable rivers another c. 8% (3,120 km). Target stream length differs by FMU with the greatest length being in the West Coast FMU (c. 3,200 km), and the shortest in the Coromandel FMU (c. 770 km). This variation in length is determined by a range of factors including the different total length of waterways present, and the relative proportions of non-wadeable and reference condition (native forest) reaches in each FMU (Figure 2). For the 2021-2023 rotation, surrounding land-use at sampled sites was predominantly pastoral (c. 72% of sites), with the remainder made up of native forest or shrubs (15%), exotic forestry (7%), retired pasture (3%), horticulture and urban (each <3%; Figure 2; Table A 1).

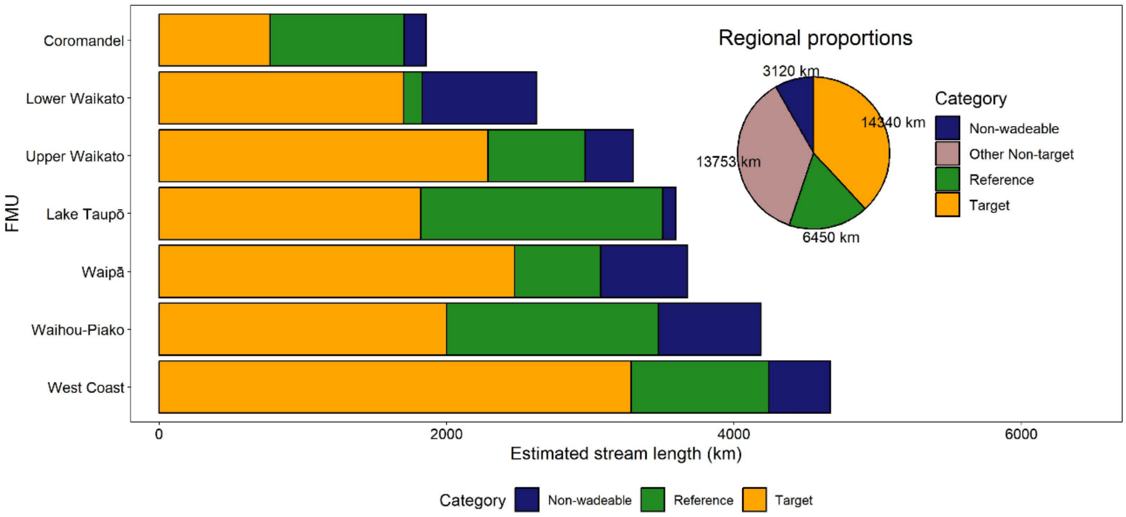

Figure 2: Category estimates of Target and Non-target stream lengths by FMU. Inset pie graph shows overall regional estimates (+/- 1 SE; see Table A 1 for more details).

3.1.2 Regional state on developed land

The metrics presented below in Figure 3 illustrate the regional extent (% of stream length) for each metric result by the condition band for that attribute (e.g. as sourced from the NPS-FM). Overall, regional extent estimates show that approximately half of the waterway length in developed land catchments is in band D and below the national bottom line when assessed against macroinvertebrate indicators of ecological health (Figure 3). Forty percent (equivalent to 5,760 km) of the regions' stream length on developed land is estimated to have an MCI score in band D (Table A 3), 28% and 26% of the regions' streams are in bands B and C, respectively, and 6% in band A. For QMCI, 56% of stream length is in band D (equivalent to 8,000 km), 16% in band C, 11% of stream length is in band B and 16% in band A. For ASPM 48% of the regions stream length was in band D (equivalent to 6,900 km) and 52% combined into bands A to C (Figure 3; Table A 2). The NPSIBI metric showed only 7% of stream length was below the national bottom line and the majority of stream length (82%) was in bands A to C (Figure 3). For the NPS-FM attributes assessed here, the median regional condition for wadeable streams on developed land fell within band C for MCI, ASPM, and the NPSIBI (Table A 2), while QMCI fell into band D (Table A 2). A further <1% of waterway length on developed land had no fish present (band E) where none were expected to be present, the majority of these were inland sites above natural barriers (Figure 3; Table A 2).

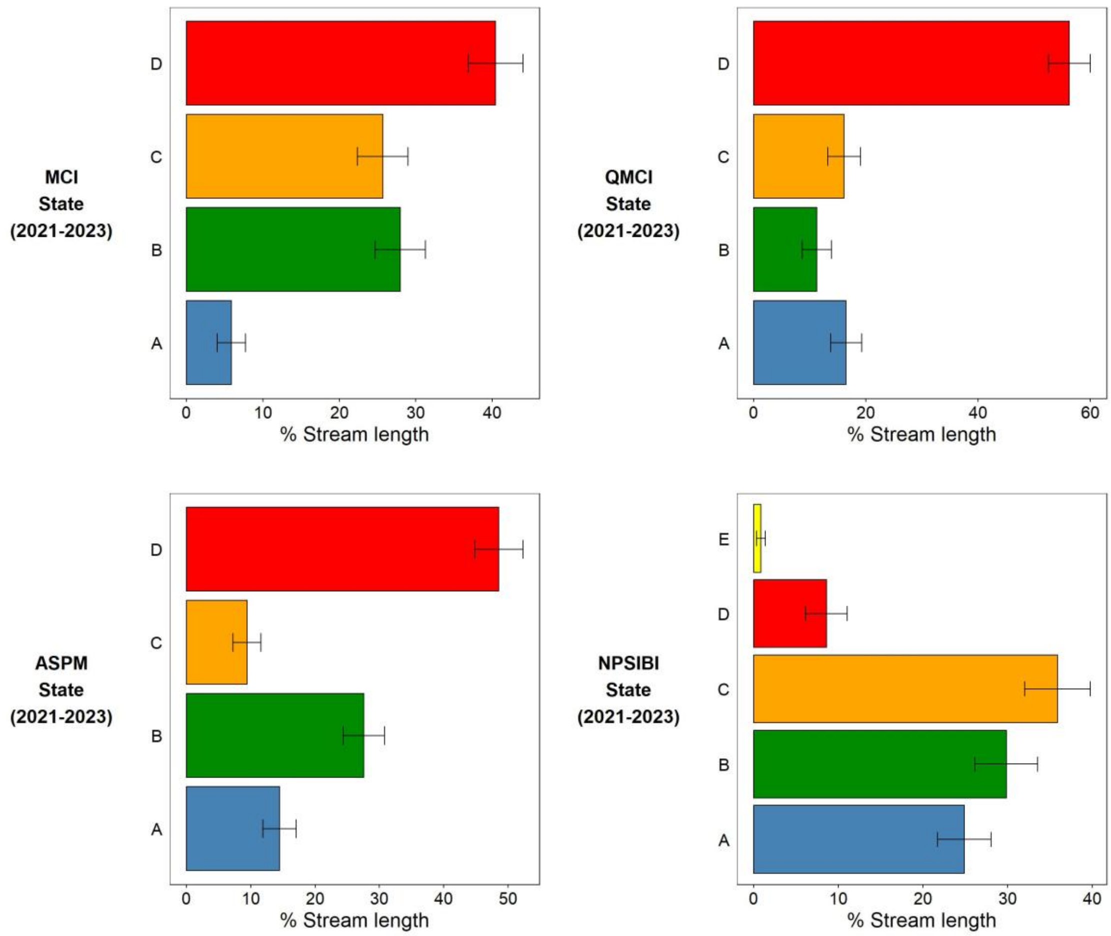

Figure 3: Regional extent estimates (proportion of wadeable stream length on developed land) of biological attribute state (NPS-FM 2020) for MCI, QMCI, ASPM and NPSIBI 2021-2023. NB: 'E band' represents sites with no fish recorded and where this was expected based on previously modelled fish distributions.

3.1.3 Sub-regional state

Figure 4 presents extent estimates at a sub-regional FMU scale, with the distribution of measured values shown using boxplots for each FMU, and spatially on a map colour coded to the estimated mean value for a particular index. Estimated mean MCI scores ranged from 77 in the Lower Waikato FMU to 107 in the Coromandel FMU (Table A 6). The Coromandel FMU had an estimated mean value equivalent to band B, with the other FMU's, excluding the Lower Waikato (Band D), were in band C (Waipā, West Coast and Upper Waikato). All FMUs had estimated distributions spanning a range of condition bands for MCI, with approximately >50% of stream length in three FMUs expected to be below the national bottom line for this metric, as represented by extent estimates and median values (illustrated in Figure 4, Table A 6). QMCI scores generally spanned a greater range of ecological condition in each FMU (Figure 4). As with regional estimates, ecological condition was occasionally assessed as being poorer than MCI when using QMCI, and three FMU's had estimated mean QMCI values in band D. This was also reflected by extent estimates and median values, with four FMUs having >50% of stream length estimated to be in D band for QMCI (Figure 4, Table A 6). For ASPM, which incorporates the number and proportion of sensitive EPT macroinvertebrates and the MCI into a single index, scores present a similar picture to the other two macroinvertebrate metrics, although mean condition was higher in both the West Coast and Coromandel FMUs. For MCI the lowland Lower Waikato FMU had the highest proportion of D band stream length (for macroinvertebrate metrics). For QMCI and ASPM all FMUs, had at least 25% of stream length estimated to be in D band (Figure 4 - left).

With respect to fish communities, mean NPSIBI scores ranged from 10 in the Lake Taupō FMU to 42 in the Coromandel. These scores largely reflect the influence of riverscape connectivity on the NPSIBI scores in these two FMU's for migratory species, with Taupō being the furthest from the sea (and upstream of multiple large dams) compared to Coromandel which has shorter, often forested headwaters draining rapidly to the coast). The five remaining FMU's had mean values across Bands B and C for the NPSIBI attribute (Figure 4 - right).

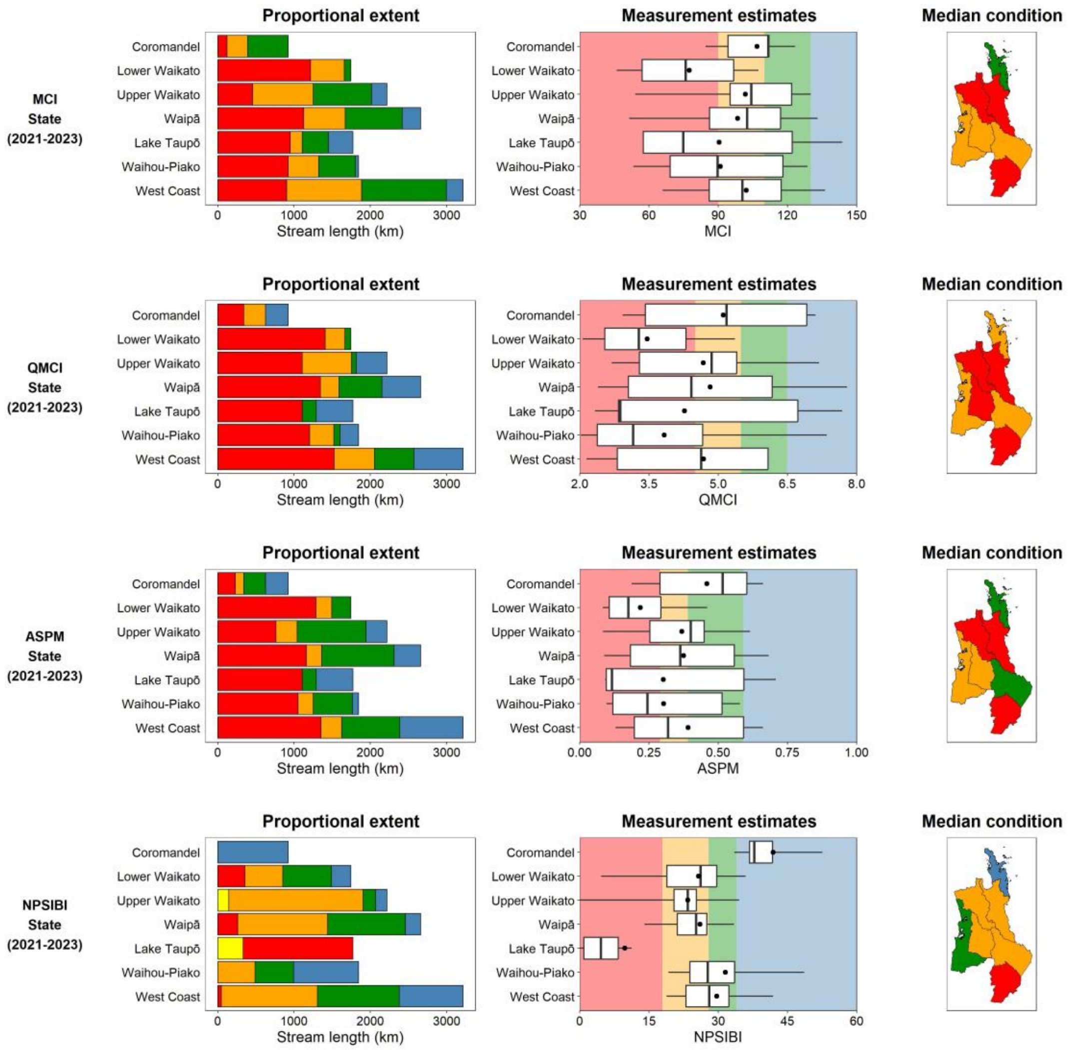

Figure 4: FMU attribute state for biological parameters (MCI, QMCI, ASPM and NPSIBI). Left - Sub-regional extent estimates (wadeable stream length on developed land), Centre - Sub-regional distributions of metric values shown in boxplots of upper and lower quartile and median, with mean values indicated by points. Right - sub-regions graded by median attribute value, noting that Means and Medians may give different overall gradings. Colours: band A – Blue, band B – Green, band C – Orange, band D – Red, for NPSIBI the proportion of sites with no fish recorded and where this was considered to be natural is indicated in yellow. See Tables A 4 and A 5 for values and confidence intervals.

3.1.4 Habitat quality – state

The estimated mean QHA score for the streams across the region on developed land was 81, falling within the Waikato derived attribute band C, which can be described as 'marginal' for ecological health. The majority of streams on developed land are estimated to be within bands B and C (Figure 5; c. 80%) based on total QHA scores. Similarly, most of the region is expected to have RHA falling into condition bands B and C (40% and 50% respectively). Around 10% of wadeable stream length on developed land across the region fell into band D for both indices, which is considered to be indicative of ecologically poor or significantly impacted habitat conditions (Figure 5).

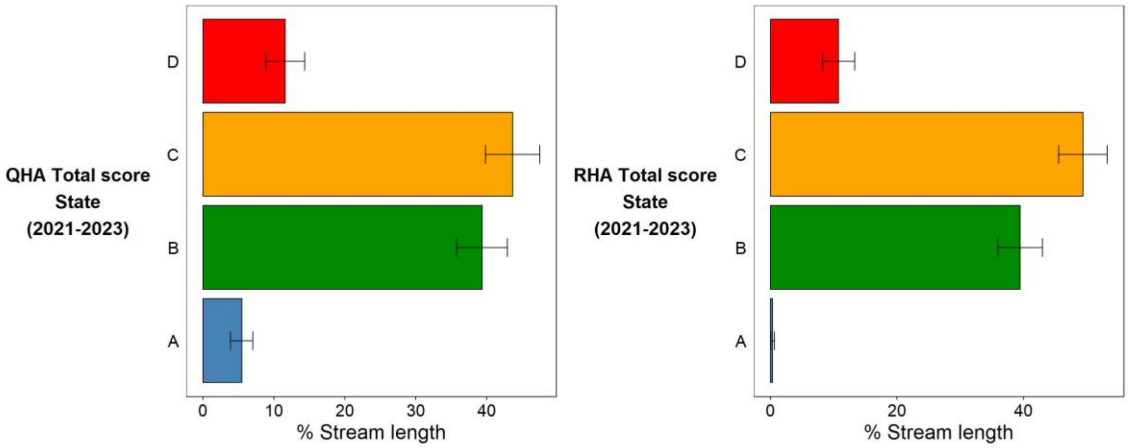

Figure 5: Regional extent estimates (proportion of wadeable stream length on developed land) of Habitat Quality state based on the Quality Habitat Assessment method (QHA), left; based on the Rapid Habitat Assessment (RHA), right.

Average habitat condition at an FMU scale was generally assessed to be in band C (marginal); the exception being the Coromandel which could be classed as B band (or sub-optimal) on average, for both QHA and RHA scores (Figure 6).

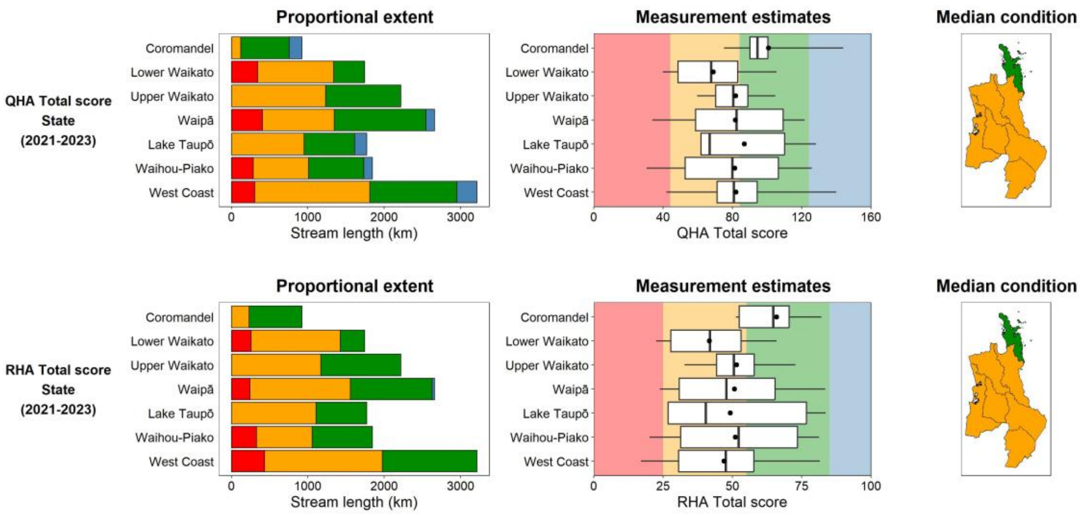

Figure 6: Habitat Quality state based on total Qualitative Habitat Assessment scores (WRC) and total Rapid Habitat Assessment scores (RHA), Left - Sub-regional extent estimates (wadeable stream length on developed land), Centre - Sub-regional distributions of metric values shown in boxplots of upper and lower quartile and median, with mean values indicated by points. Right - sub-regions graded by median attribute value, noting that Means and Medians may give different overall gradings. Colours: band A – Blue, band B – Green, band C – Orange, band D – Red. See Tables A 4 and A 5 for values and confidence intervals.

The aquatic plant metric (MCC) indicated 60% of wadeable streams (stream length) at a regional level to be in band A and B, with approximately 26% of wadeable streams being considered in band D (or where clogging of channels could be of concern) for this attribute (Figure 7).

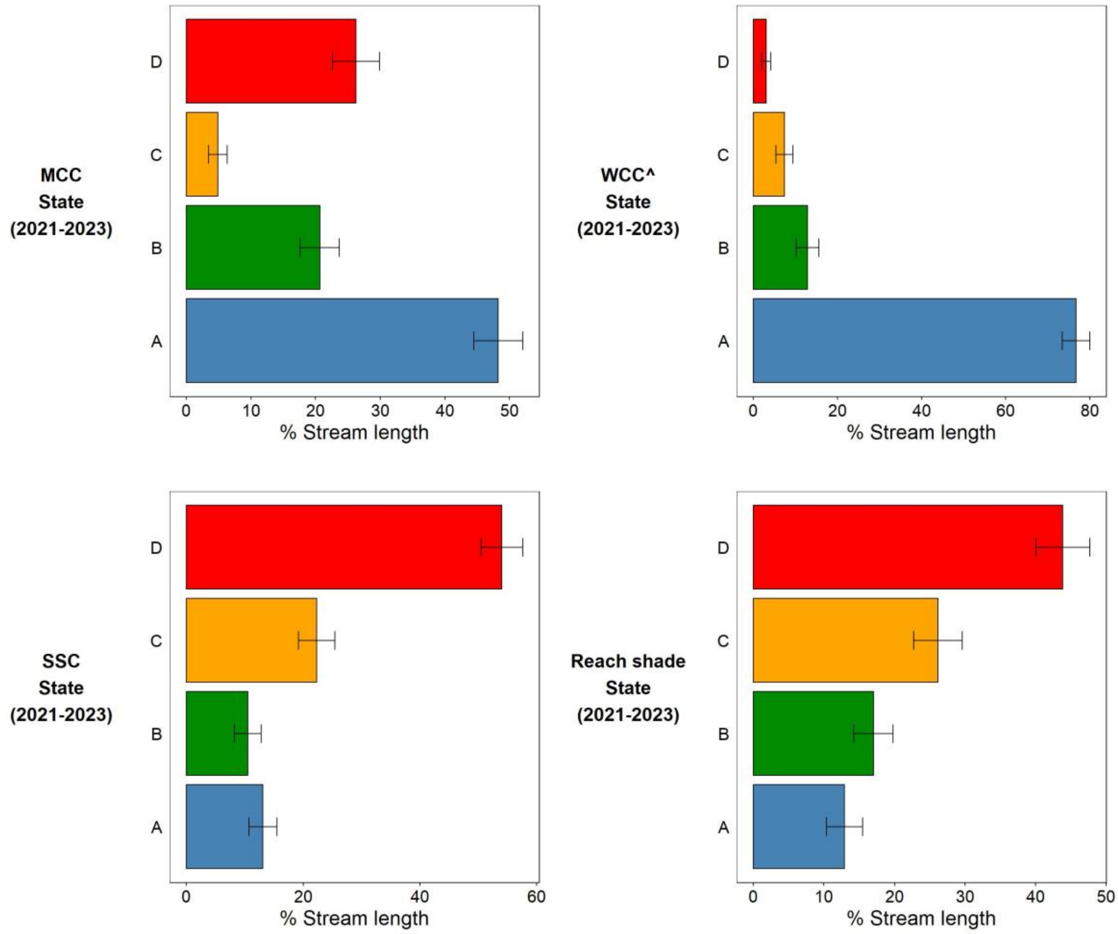

Figure 7: Regional extent estimates (proportion of wadeable stream length on developed land) of Macrophyte cover (MCC), Periphyton cover (WCC), Deposited fine sediment (SSC - % sand/silt/clay), and reach shade.

Summer algal growth did not appear to be a substantive issue for the region with 77% of the regions stream length on developed land having little to no algae present and only 3% of the region's stream length having excessive summer algal growth (WCC^; Figure 7). The estimated mean regional state for the periphyton indicator used here was band A. There were some high values at around 3% of individual sites across the region highlighting excessive periphyton growth can be an issue when conditions allow. For deposited fine sediment cover (represented by the total of sand, silt and clay particles-SSC) 24% of the regions stream length on developed land can be considered to have levels of low concern (bands A or B), with 54% of the regions stream length on developed land above levels considered to have negative effects on ecosystem health (band D; Figure 7). For context, the probabilistic network is made up of roughly 50/50 Hard and Soft bottomed sampling sites. Only a small, c. 13% of the wadeable streams on developed land have more than 80% of the bed shaded (band A), with the majority of streams (c. 70%), being <50% shaded (bands C & D; with more than half of those being <20% shaded, band D; Figure 7).

Generally speaking, at an individual FMU level, excessive periphyton growth on hard substrates appears to be a localised issue where it occurs. At the FMU (Sub-region) scale, FMUs with a greater proportion of stream estimated to have substrates dominated by deposited fine sediment, and with low gradient, generally tend to have the greatest estimated extent of potential macrophyte (MCC) issues (Figure 8). Mean values for macrophyte channel clogginess were generally less 35, although a notable proportion of streams in the Taupō, Waihou-Piako and West Coast FMUs were estimated to be dominated by aquatic plant growth (Figure 8). There are small areas of sub-region stream length with excessive algal growth in most subregions except the Coromandel and upper Waikato (Figure 8). Deposited fine sediment (SSC) cover is above 40% for large proportions of each FMU, except Coromandel, and mean values were greater than or equal to 20% for all FMUs (Figure 8; Table A6). The Coromandel generally has high levels of stream shading while the Taupō sub-region has a low proportion of stream shading (Figure 8). Shade estimates as a proportion of the stream network (Figure 8) are consistent with the regional pattern observed in Figure 7 for the other sub-regions.

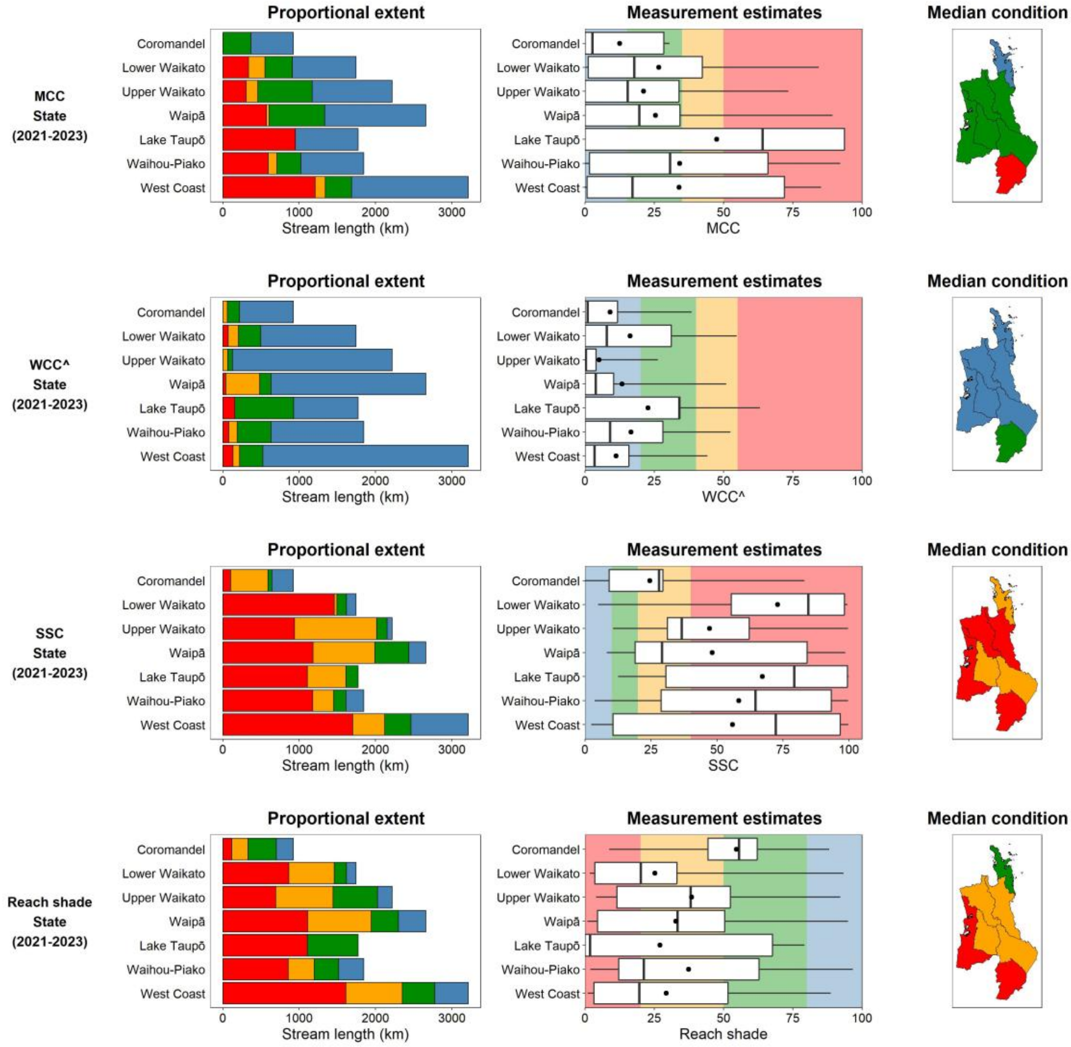

Figure 8: Macrophyte cover (MCC), Periphyton cover (WCC), Deposited fine sediment (SSC - % sand/silt/clay), Reach shade (%) state indices. Left - Sub-regional extent estimates (wadeable stream length on developed land), Centre - Sub-regional distributions of metric values shown in boxplots of upper and lower quartile and median, with mean values indicated by points. Right - sub-regions graded by median attribute value, noting that Means and Medians may give different overall gradings. Colours: band A – Blue, band B – Green, band C – Orange, band D – Red. See Tables A 4 and A 5 for values and confidence intervals.

3.1.5 Regional state through time

Regional extent estimates for ecological metrics are generally consistent through time, including for the four main biological indices MCI, QMCI, ASPM and NPSIBI (Table A2). When comparing the first rotation in 2009-2011 with subsequent rotations, including 2021-2023, the spsurvey change analysis found no significant patterns of shifting band prevalence (Tables A2 & A3). Estimated regional mean values for the measured biological indicators were also relatively unchanged through time (Table A 7). Small but statistically significant improvements in mean values of the QHA habitat metric (Table A 7), do appear to have occurred since 2009-2011. Plant cover at a reach scale, represented by both periphyton and macrophytes, was stable through time (Table A 7), with no statistically significant change observed between 2009-2011 and 2021-2023 surveys. There has been no significant temporal change in sediment cover in the last 10 years (Table A 7).

3.1.6 Riparian fencing and vegetation

The dominant riparian land use along target streams is estimated to be made up of approximately 75% pastoral land uses, 9% native shrub, 7% exotic forestry, 6% native forest, 3% horticulture and cropping and <1% urban parkland across the target stream network (Table 4). In terms of overall site shade, 60% of stream length is considered to have an "open" canopy, 29% to be "partly shaded" and 11% to be "significantly shaded" based on site observations (Table 4).

Table 4: Proportion (%) of wadeable stream length in developed land catchments estimated to fall into each of A) Canopy cover category, and B) dominant riparian land use categories. (Parentheses are estimated SE, followed by lower and upper 95th confidence interval).

A)	**Canopy cover**	**Open**	**Partly shaded**	**Significantly shaded**			
		60 (4, 53-67)	29 (3, 22-35)	11 (3, 6-16)			
B)	**Dominant riparian land use**	**Crops /Horticulture**	**Forestry**	**Native forest**	**Native shrub**	**Other (Urban & Parks)**	**Pasture**
		3 (1, 0-5)	7 (2, 3 -11)	6 (1.6, 2-9)	9 (2, 5-14)	0.3 (0.3, 0.0-1)	75 (3, 69-82)

Complete riparian fencing (on both stream banks) has been assessed to cover 33% of the regions stream length on developed land, with a further 17% protecting one stream bank (Table 5A). At 33% for complete fencing or 50% for complete or partial fencing (Table 5), the proportion of stream length fenced across the Waikato region in this study is slightly lower than that described by Norris et al. (2025) in their pastoral landuse fencing assessment, which estimated c. 57% of pastoral streams are effectively fenced. However, the two studies differ in their site selection approach, with the ecological network being targeted to wadeable small streams across all land uses on developed land, and the riparian monitoring of Norris et al. (2020 & 2025) targeted more towards pastoral land uses, regardless of stream size. Norris et al. (2020) found that significantly more dairy land (87%) was fenced than drystock land (48%). The estimates presented here include land uses that may not typically include, or require, nearby stream fencing, such as exotic forestry plantations (Table 5B). Fencing estimates also vary at a sub-regional scale (Table 5A), and this is potentially due to the different proportions of adjacent land uses and stream orders (size) across the region. A greater proportion of larger waterways is expected to have effective fencing (Table 5C). Overtime the proportion of streams with effective fencing on both banks has increased (Table 5D), with the largest proportional increases estimated to have taken place on streams ≥ 2nd Order. The estimated percentage of target streams with effective fencing on both banks has increased from 21% (2009-2011) to 39% (2021-2023) – Table 5D. Certain combinations of grouping/category/fencing in Table 5 have large spread of confidence intervals, and this is due to a low a number sites being present in a given combination, as such sub-regional estimates with large confidence intervals should be treated as indicative.

Table 5: Proportion (%) of wadeable stream length on developed land with complete fencing, partial or no fencing across A) the Waikato region and various FMU's, B) dominant riparian land uses, C) Stream orders, and D) rotations (Parentheses are estimated SE, followed by lower and upper 95th confidence intervals).

Grouping	Category	Complete both sides	One side or partial	None or ineffective
A) Region and Sub-Regional FMUs	**Regional**	33 (3, 27-39)	17 (2, 11-22)	50 (3, 43-57)
	Coromandel	6 (6, 0-18)	38 (12, 12-62)	56 (12, 31-81)
	Lake Taupō	52 (23, 6-98)	10 (10, 0-30)	37 (20, 0-77)
	Lower Waikato	48 (9, 30-66)	26 (9, 8-44)	25 (7, 10-40)
	Upper Waikato	49 (12, 23-73)	3 (2, 0-8)	48 (12, 23-73)
	Waihou - Piako	52 (8, 34-68)	6 (4, 0-14)	42 (9, 23-60)
	Waipā	31 (6, 17-44)	26 (7, 12-39)	43 (6, 30-56)
	West Coast	11 (3, 3-18)	12 (5, 1-23)	77 (6, 63-89)
B) Dominant Riparian Land use	**Crops/Horticulture**	12 (16, 0-44)	29 (33, 0-94)	59 (37, 0-100)
	Forestry	0 (0, 0-0)	15 (11, 0-36)	85 (11, 64-100)
	Native forest	20 (12, 0-42)	27 (17, 0-60)	54 (15, 24-84)
	Native shrub	71 (11, 50-91)	19 (9, 1-36)	11 (7, 0-24)
	Pasture	39 (4, 31-47)	16 (3, 10-22)	45 (4, 37-53)
C) Stream Order	**1st**	21 (7, 7-35)	21 (7, 8-34)	58 (9, 42-75)
	2nd	38 (6, 26-50)	18 (5, 8-27)	44 (6, 32-57)
	3rd	40 (4, 32-48)	11 (3, 6-17)	49 (5, 40-58)
	4th+	44 (8, 29-59)	13 (5, 2-23)	44 (8, 29-59)
D) Rotation	**2009-2011**	20 (3, 14-25)	25 (3, 18-31)	56 (4, 49-63)
	2012-2014	21 (3, 16-27)	23 (3, 17-29)	56 (4, 49-63)
	2015-2017	28 (3, 21-34)	27 (4, 20-34)	46 (4, 38-53)
	2018-2020	29 (3, 23-35)	18 (3, 12-25)	53 (4, 45-60)
	2021-2023	33 (3, 27-39)	17 (3, 11-23)	50 (4, 43-57)

3.2 Developed land and reference condition comparison

A comparison of ecological indices between reference condition sites (i.e., located in native shrub and forest and with upstream catchments >80% native shrub and forest) and developed land sites from the probabilistic network sampled across 2021-2023 shows evident differences (Figure 9). Reference condition streams in native forest sites are typically of higher ecological health than randomly selected sites on developed land. Average differences across the 3 years for ecosystem health metrics are 35 points for MCI, 2.68 points for QMCI, 0.298 for ASPM and 11.4 for NPSIBI scores (Figure 9; Table A 8); Wilcoxon statistical comparisons also indicate that median values between the two groups are statistically different for all ecological metrics explored here ($p<0.01$; Figures 9-11). This result aligns with published correlations between decreasing upstream native landcover and decreasing ecological condition (e.g. Death & Collier, 2010). In the Waikato region, sites on developed land typically have reduced ecological health due to anthropogenic activities and are, on average, poorer than unimpacted native forest reference sites.

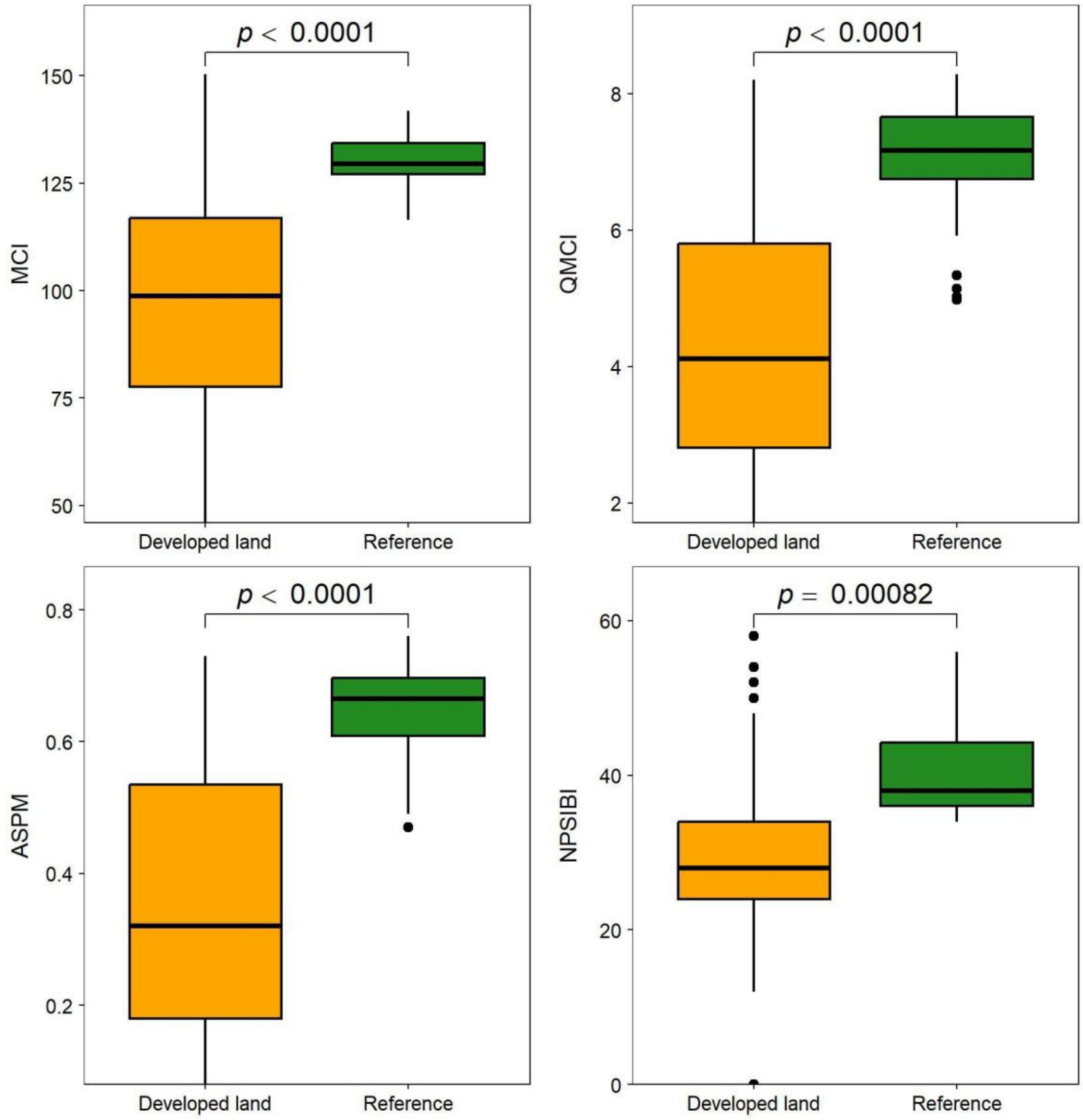

Figure 9: Comparison of freshwater ecological health metrics (MCI, QMCI, ASPM and NPSIBI) between native forest reference (green) and developed land target sites (orange). Fish sites (NPSIBI) are a subset of macroinvertebrate sites. P-values indicate Wilcoxon test significance values for comparing median values at developed land sites compared to reference condition sites. Boxplots present percentile values (5th, 25th, 50th, 75th, 95th), with outliers indicated by points.

Median values from habitat assessments (QHA and RHA) of native forest reference sites were around 35% higher than those from developed land sites in any given year (Figure 10; Table A 8). This demonstrates that habitat characteristics such as riparian vegetation, erosion, hydrology, channelisation, sediment deposition and instream habitat have been collectively reduced in quality from an ecological perspective by land development.

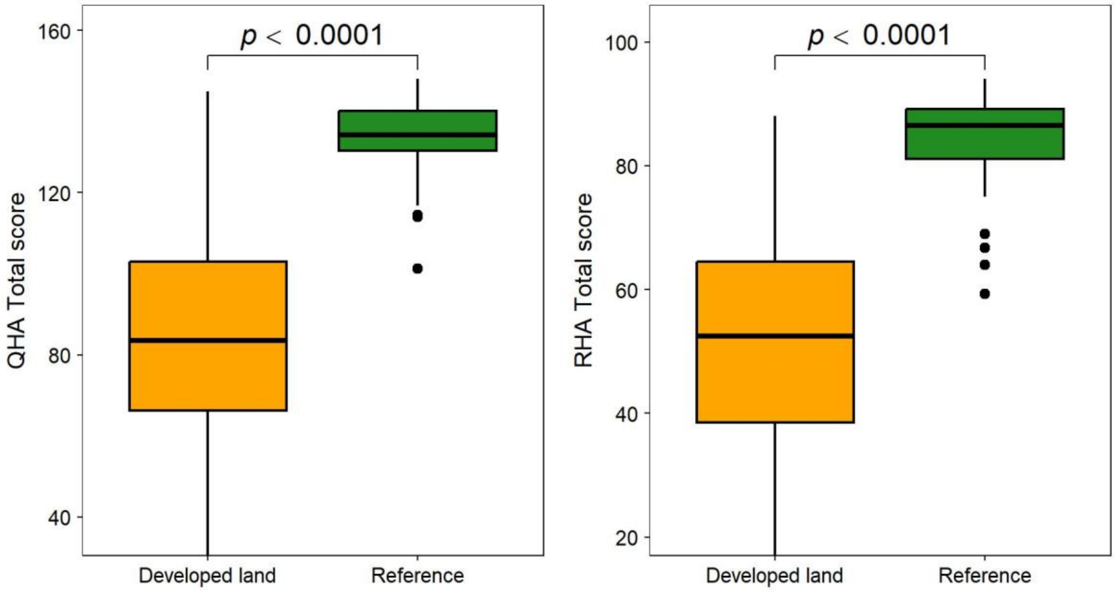

Figure 10: Comparison of total habitat metrics, Qualitative (QHA) and Rapid (RHA) habitat assessments between native forest reference (green) and developed land random selected sites (orange). P-values indicate Wilcoxon test significance values for comparing median values at developed land sites compared to reference condition sites. Boxplots present percentile values (5th, 25th, 50th, 75th, 95th), with outliers indicated by points.

As with the macroinvertebrate and fish metrics above, instream habitat metrics Macrophyte Channel Clogginess (MCC), Weighted Periphyton Cover (WCC^), fine sediment cover (% sand/silt/clay) and reach shade, are significantly better in reference sites on average when compared to developed land sites overall (Figure 11; Table A 8). Stream shade, a key regulator of plant growth (periphyton and macrophytes) and other ecological processes, was significantly greater on average in native forested streams. This is reflected by periphyton (WCC^) and macrophyte (MCC) indices being close to zero in most reference site surveys (Figure 11). The absence of macrophytes is also partly a function of the dominant substrate type being found at these sites (with reference site substrate generally comprising of stable hard substrates, and macrophytes typically being found in streams dominated by finer substrates and with lower gradients). Average deposited fine sediment (SSC) was significantly lower at native reference sites (dominated by hard substrates such as boulders, cobbles and gravels) when compared to developed land sites which often have higher cover by sand, silt, and clay particle sizes (Figure 11).

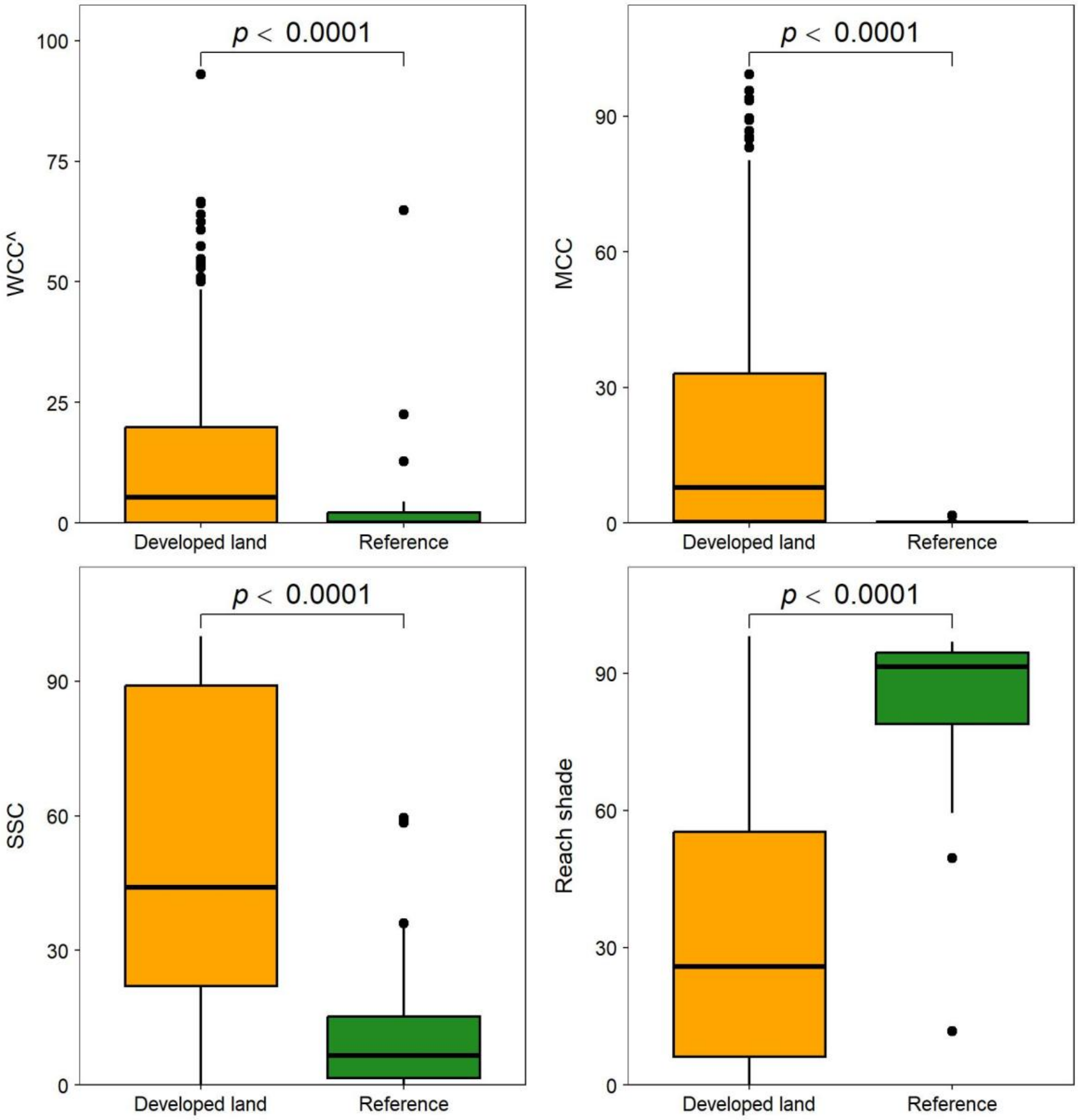

Figure 11: Comparison of instream ecological habitat metrics, Periphyton cover (WCC^), Macrophyte channel clogginess (MCC), Sand, silt, clay cover (SSC), and reach shade, between native forest reference (green) and developed land random selected sites (orange). P-values indicate Wilcoxon test significance values for comparing mean values at developed land sites compared to reference condition sites. Boxplots present percentile values (5th, 25th, 50th, 75th, 95th), with outliers indicated by points.

3.3 Relationships between ecological indicators

Relationships between ecological indicators have been previously reviewed within a New Zealand context, with habitat variables, such as deposited fine sediment observed to have negative impacts on macroinvertebrate community metrics, and weaker relationships with fish metrics (Clapcott, et al., 2011). Figure 12, below, explores indicative relationships between the metrics explored in this report using data collected at both randomly selected developed sites and native forest reference sites. A non-parametric Kendall rank correlation was used due to the non-normal nature of the data. Moderate negative correlations were found between habitat variables - deposited fine sediment (SSC), macrophyte cover (MCC), and macroinvertebrate metrics (MCI, QMCI, ASPM), which also had weaker correlations with periphyton (WCC; Figure 12). SSC and MCC were positively correlated with each other, and also negatively correlated with reach shade, and the qualitative habitat metrics (RHA and QHA). Positive associations were also observed between macroinvertebrate metrics and reach shade and both the qualitative habitat metrics (RHA and QHA). Fish IBI (NPSIBI) and Periphyton cover (WCC^) indices were both generally weakly correlated with other indices.

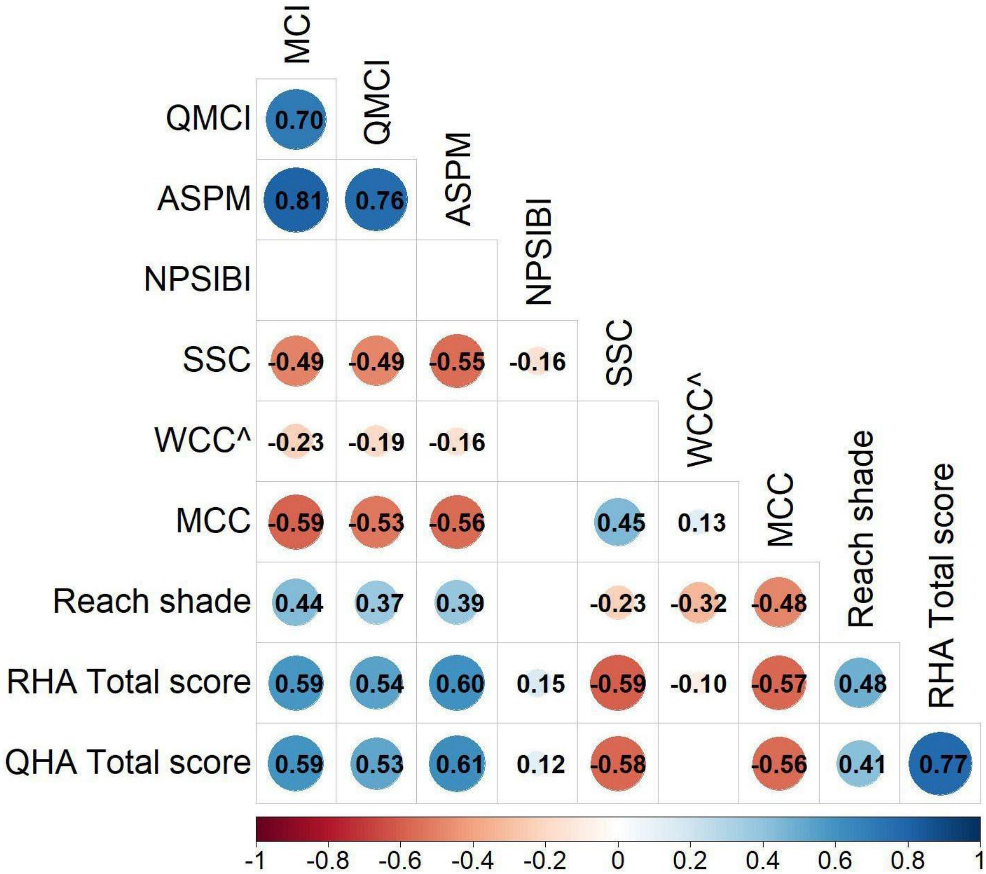

Figure 12: Kendall correlation coefficient comparison matrix between ecological metrics. All correlation coefficients presented that are >= 0.15 (+ or - relative to direction of relationship) have p-values of <0.01, otherwise p-values of <0.05, blank squares represent non-significant correlation coefficients.

4 Discussion

4.1 Biological state

The results of the 2021-2023 probability-based survey of wadeable streams on developed land in the Waikato region indicates that regionally approximately half of the waterway length flowing through developed land is expected to be below the national bottom line for macroinvertebrate indicators of ecological health in the NPS-FM (2020; MCI 40%, QMCI 56%, and ASPM 48%). A smaller proportion (6 – 17%) of the regions waterway length on developed land was found to be in band A for the macroinvertebrate metrics. Fish communities are expected to be above the national bottom line in most cases, although up to c.30-40% are estimated to have fish communities of a low ecological integrity low integrity (band C).

When each 3-yearly rotation of developed land sites across the region was compared over the last 15 years (Tables A 2 and A 7), little temporal variation was observed in macroinvertebrate, fish, or habitat metrics in terms of average values and also extent estimates. Some sites will almost certainly change between condition bands, however when all the data is collated across the region there has been no consistent directional change (across all sites). Some variation in condition bands at a site level is to be expected due to inter-annual differences in summer environmental conditions at individual sites, and the fixed nature of band classifications. Although a significant proportion of measured indices are indicative of ecological degradation, the condition of macroinvertebrate and fish communities overall, as well as of their habitats, has been relatively stable over the last 15 years at the regional scale. It is worth noting that there may be lag times between the commencement of interventions and measurable ecological responses in many cases (e.g., Sundermann et al. 2011; Leps et al. 2016), which may mean improvements will be seen into the future. On average, FMU's dominated by lowland catchments (Lower Waikato and Waihou - Piako) and the Lake Taupō FMU generally had the lowest macroinvertebrate metric values. Agricultural and horticultural activities preferentially occur on flatter land, and therefore lowland waterways are more commonly in poorer a state due to greater pressure from multiple, often interacting, and difficult to disentangle, stressors originating both locally and from the surrounding catchment (Matthaei et al., 2010). These can include:

- low dissolved oxygen (Wilding et al., 2012), and high water temperatures (Cox & Rutherford, 2000);
- lack of shade (Collier, 1995) and minimal riparian zone protection (Death & Collier, 2010);
- fine sediment deposition (Quinn & Hickey, 1990);
- increased nutrients (McDowell et al., 2009);
- alterations to hydrology and influence of geology (Castro & Thorne 2019);
- land use change (Quinn & Hickey, 1990), including wetland drainage (BOPRC, 2018);
- emerging contaminants (Bernot et al., 2019).

With regard to fish, differences in NPSIBI scores across the region are partly reflective of geography and river connectivity. The Upper Waikato and Lake Taupō FMU's typically have lower fish diversity in streams due to the greater distance inland, altitude and presence of barriers (such as dams on the Waikato River). The FMU with the highest NPSIBI scores was the Coromandel where the majority of sites scored in band A. Sites in the Coromandel FMU, in comparatively close proximity to the coast, have generally good riverscape connectivity and intact native forest headwaters (Pingram, et al., 2023). Native fish are generally more tolerant to reduced water quality (including water temperature and dissolved oxygen) than sensitive aquatic macroinvertebrates, they are however, sensitive to impaired riverscape connectivity (e.g., perched culverts, weirs, dams), due to many native fish requiring access to the marine environment to complete their life cycles (Franklin, et al., 2024). These factors can override any local scale differences in stream reach habitat that would otherwise influence fish community integrity.

Poor water quality can still impact on fish communities, particularly as sites with high nutrient enrichment are often associated with warmer, hydrologically modified, lower gradient watercourses, with low or highly fluctuating dissolved oxygen and low structural habitat cover. Such sites are typically found in non-wadeable floodplain sites across the Lower Waikato and Waihou – Piako -FMUs and where more tolerant and adaptable non-migratory invasive fish species also tend to proliferate (Pingram et al., 2021; 2023). Periodically however, these sites may be subject to broad-scale summer events where the physiological tolerances of even the most tolerant fish species are exceeded (Pingram et al. 2021; 2023). Extended hypoxic conditions can occur in low gradient waterways, particularly in low summer flow conditions and streams with low shade due, high temperatures, and vigorous microbial activity; in addition, the sudden delivery of additional nutrients and carbon following tropical cyclone downpours can fuel extreme oxygen consumption by bacteria within floodplain watercourses (see Abell & Doucet, 2024). As these lowland waterways are an important part of the wider riverscape, especially for mobile fish species, low dissolved oxygen conditions in these environments are of management concern.

In many cases improving reach scale ecosystem health is likely to require environmental improvements to occur at the entire catchment or sub-catchment scales (e.g., for habitat quality, riparian condition, sediment retention, nutrients; see Death & Collier, 2010; Stoll et al., 2016). Actions will also need to be sufficient and appropriate to lead to measurable improvements in stressors to levels that can initiate ecological change (e.g., deposited fine sediment, nutrients and riparian condition (Pingram, et al., 2019)). As noted in previous reports policy and reporting targets need to be flexible enough to accommodate lag times between the implementation of interventions and subsequent ecological responses, without delaying or putting off commencing rehabilitation initiatives (e.g. Pingram et al., 2023). With regard to fish, potentially focusing on specific species, life stages, or size classes, of interest to stakeholders may provide more meaningful measures for engaging with communities.

4.2 Habitat state

The condition of physical habitat, particularly measures of deposited fine sediment and shade, of the regions' wadeable streams in developed land is likely to be playing a key role in shaping ecosystem health. For some metrics, such as periphyton (WCC^) and macrophyte cover (MCC), issues do not appear to be as widespread for wadeable streams across the region, although they are of concern in some in some areas. Holistic physical habitat metrics, such as the Qualitative Habitat Assessment (QHA) and Rapid Habitat Assessment (RHA), were generally indicative of moderate condition. These metrics aggregate scores of both instream and riparian stream reach characteristics, with fine deposited sediment and riparian vegetation being important considerations. Sedimentation and low stream shading appear to be a widespread issue that influences ecosystem health, including effects on macroinvertebrate metrics, across the Waikato region. Deposited fine sediment levels beyond ecological thresholds at which macroinvertebrate and fish communities are severely impacted (e.g. Richardson & Jowett, 2002, Rowe et al., 2002, Burdon et al., 2013; Clapcott et al., 2011; Pingram, et al., 2019), are widespread, with mean values in some FMUs being above these values. Deposited fine sediments fill interstitial spaces reducing habitat for sensitive macroinvertebrates (Clapcott et al., 2011 and references therein). Increased deposited fine sediment also creates habitat for tolerant species such as oligochaetes, and also interacts with other habitat parameters such as providing suitable substrate for macrophyte growth. Macroinvertebrate community composition begins to change significantly when the stream bed is 18-20% covered by fine sediment (Burdon et al., 2013; Mathers et al., 2022). The relative impact and deposition of fine sediment can be influenced by stream gradient and power, with greater deposition and impact more likely in lower gradient reaches where fine sediments tend to settle and build up (Pingram et al., 2023).

Management and restoration actions, such as those outlined by Drewry et al., (2024), should relate to the specific type and extent of erosive process and sediment source for a particular location. Streambank erosion, ground surface erosion, mass movement erosion, earthflow erosion, gully erosion and wind erosion are outlined as erosion processes present in the Waikato (Drewry et al., 2024). For instance, McKergow et al. (2010) suggested that half the fine sediment load in the Raglan catchment is sourced from streambank erosion and Norris et al. (2025) demonstrate that 9% of the region's riverbanks were actively eroding, while Ritchie (2012) found that generally more sediment is lost from pastoral land than plantation forestry land. Drewry et al. (2024) suggested tree planting, structural control, bank regrading, vegetation layering, bank reseeding, fencing and subsurface drainage as the most effective approaches to combat this type of erosion. It is worth noting that certain interventions can have positive impacts on multiple stressors. For example, riparian planting of tall species can stabilise banks, improve stream shading, reduce instream plant growth, and contribute to improving habitat complexity (e.g. root mats, submerged wood). Shading of streams can significantly reduce macrophyte cover of the bed, particularly for non-native macrophyte species (Collins et al. 2019), while native macrophytes are favoured at higher shade levels thereby improving biodiversity values of modified or managed watercourses (Kankanamge et al., 2019). Reduced problematic plant cover in streams, especially of introduced species, can also improve water conveyance functions without the need for annual drain excavation (where macrophyte growth is the issue of concern), reducing sediment and nutrient mobilisation to downstream waterbodies. The various FMU sub-catchments within the region showed generally moderate to low levels of aquatic plant and algal cover. Algal growth and cover are controlled by a number of factors including regular flushing flows, low nutrients, light, temperature and macroinvertebrate grazers. However, in the Waikato it is particularly limited by the availability of hard stable substrates across the region's waterways (Matheson & Wells, 2017). Conversely, an overall higher proportion of macrophyte cover is present in open, slower flowing, soft sediment streams particularly in the Lake Taupō, Waihou - Piako and West Coast FMU's, where channel clogginess by excessive macrophyte growth can be considered an issue for around a quarter of the region's wadeable streams on developed land (Figure 7).

Approximately 30% of the regions stream length on developed land receive acceptable amounts of shading (>50% of the bed), however a significant proportion of streams (c. 45%) have less than a fifth of the stream bed with overhead shade (Figure 7). Norris et al., (2025) reported that riparian fencing has improved over time in the Waikato, but vegetation cover and buffer width remain limited in many areas. Stream-bank erosion persists as an issue, especially where stock access is still present. Additionally, many riparian zones are dominated by grass or low shrubs, offering minimal canopy cover (Norris, et al., 2025). Norris et al., (2025) notes that shade-related benefits (e.g. temperature regulation and algal suppression) may not yet be fully realised due the growth rate of planted trees. The delayed shading effect demonstrates a temporal lag between restoration actions and ecological benefits (Norris, et al., 2025). Trees and other plants can take several years to grow sufficiently broad and high enough to provide a canopy that can shade a stream, especially in wider streams (Stansfield & Zwan 2014; Doering et al., 2019). This has been reported to take as long as 24 years (Parkyn et al., 2003) and 15 years (Stansfield & Zwan, 2014), by some researchers. As time goes on, the impact of riparian restoration activities will become increasingly apparent via increases in shading, which has been linked to lower mean and maximum water temperatures in Waikato streams (Stansfield & Zwan 2014; Booth, 2022). Controls on maximum water temperature in summer through increased shading has been identified as a potential predictor of MCI scores in Waikato streams (Booth, 2022), as has improved riparian zone condition in other regions also (e.g., Taranaki (Graham et al., 2018)).

4.3 Comparison with reference condition and Relationships between indicators

As demonstrated in Figure 9, large differences in average ecological condition exist between the developed land and reference condition sites for the biological attributes explored here (fish and macroinvertebrate communities), a difference also reflected in habitat indices (Figures 10 & 11). Correlations between habitat and biological indices suggest that decreasing habitat quality (such as deposited fine sediment cover, reduced shade, overall habitat assessments) is associated with decreased macroinvertebrate and fish indices and increased macrophyte growth (Figure 12). Increasing deposited fine sediment levels and reduced shade are also associated with increases in macrophyte and periphyton cover. Sedimentation and macrophyte growth are often both associated with lower gradient, slower flowing water ways. Historical land clearance for development (often agriculture) is known to be associated with elevated levels of nutrients, reduced riparian condition and increased fine sediment levels (Paulsen et al., 2008). Collectively, stressor impacts associated with vegetation removal are well documented to drive decreases in ecological integrity (Death & Collier, 2010; Clapcott et al., 2012).

4.4 Summary and Recommendations

The purpose of the randomised network used in this current report was to provide a broad-scale unbiased estimate of ecological condition across wadeable streams flowing through developed land within the Waikato region. The utility of the network is to assess state and change over time, and to broadly identify key stressors relevant at a regional scale (e.g., deposited fine sediment). This is also complemented by the reference condition network of sites in least modified catchments. At the FMU scale this information can be used to develop a framework or process for identifying where management efforts would be best targeted for improving ecological condition. However, for management actions to be effective, understanding the origins of particular stressors and the temporal and spatial scale of their relevance within an FMU is critical, and more detailed analysis will be required to underpin meaningful policy targets or action plans.

Excess deposited fine sediment is a widespread and impactful stressor on wadeable stream ecology in developed land, and the adverse effects of fine sediment on wadeable aquatic ecosystems, are well established. Although much effort has been invested in improving water quality, additional considerations are likely required to see ecological gains, improve habitat conditions and reduce deposited fine sediment. These include response improving our understanding of time lags, buffer widths, critical source areas, land use intensification, streambank modifications, land clearance, and climate change (Pingram et al., 2023; Drewry et al., 2024). Addressing the drivers of deposited fine sediment issues is expected to have a positive effect on macroinvertebrate community metrics, as demonstrated using data from this network previously (see Pingram et al., 2019). Innovative and widespread actions such as providing space for rivers, regrading banks, widening planted buffer widths and reconnecting streams to floodplains may be required to successfully restore instream habitats. Riparian improvements may require taller plant species to be used to achieve canopy shading and aid in the regulation of solar radiation, stream bank erosion, instream temperatures and dissolved oxygen. Effective shading of the regions streams would alleviate a stress factor incident upon the high proportion of streams estimated to have < 50% shading. For fish biodiversity, relatively rapid gains are likely to occur through improving riverscape connectivity via the removal or remediation of anthropogenic barriers to bi-directional fish migration (Pingram et al., 2023).

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6 Appendices

Table A 1: Regional Target and non-Target classification of REC network based on 2021-2023 rotation. Parentheses indicate ±1 SE.

Estimated target and non-target river network lengths		
	Length in Kms	**Proportion of group length**
Target		
Not flowing	933 (266)	7 (2)
Inaccessible	2767 (335)	19 (2)
Modified	194 (113)	1 (1)
Not sampled	1171 (243)	8 (2)
Target and sampled	9276 (494)	65 (3)
Total	14340 (512)	100 (0)
Non-Target		
Coastal	203 (74)	1 (0)
Non-perennial watercourse	6879 (610)	29 (2)
Inaccessible	27 (23)	0 (0)
Lake or Pond	1287 (253)	6 (1)
Non-wadeable	3120 (259)	13 (1)
Out of Region 2013	64 (57)	0 (0)
REC Inaccurate	1632 (343)	7 (1)
Reference (native forest)	6450 (525)	28 (2)
Unnatural drain	1629 (311)	7 (1)
Wetland	2032 (393)	9 (2)
Total	23324 (673)	100 (0)

Table A 2: Proportion (%) estimates of wadeable, perennial streams (Target) in a given condition banding for ecologically relevant indices, for completed rotations 2009-2023. Parentheses are estimated SE, followed by lower and upper 95th confidence interval.

	2009-2011	2012-2014	2015-2017	2018-2020	2021-2023
			MCI		
A	8.4 (1.9, 4.7-12.1)	4.8 (1.5, 2.0-7.7)	7.8 (2.0, 3.9-11.8)	5.7 (1.8, 2.1-9.2)	5.9 (1.8, 2.2-9.5)
B	26.4 (3.3, 19.8-32.9)	27.7 (3.3, 21.2-34.1)	22.2 (2.9, 16.5-27.9)	27.3 (3.4, 20.6-34.0)	28.0 (3.3, 21.6-34.4)
C	27.2 (3.5, 20.4-34.1)	26.3 (3.3, 19.8-32.8)	27.2 (3.3, 20.7-33.7)	27.8 (3.5, 21.0-34.5)	25.7 (3.3, 19.1-32.2)
D	38.1 (3.4, 31.4-44.7)	41.2 (3.6, 34.2-48.2)	42.8 (3.5, 35.8-49.7)	39.3 (3.5, 32.4-46.1)	40.5 (3.6, 33.5-47.4)
			QMCI		
A	17.1 (2.6, 12.0-22.2)	17.1 (2.9, 11.5-22.7)	12.7 (2.5, 7.8-17.7)	15.1 (2.8, 9.5-20.6)	16.5 (2.8, 11.0-21.9)
B	14.8 (2.6, 9.8-19.8)	9.6 (2.1, 5.5-13.7)	11.5 (2.5, 6.5-16.4)	12.2 (2.6, 7.2-17.2)	11.2 (2.6, 6.1-16.3)
C	8.5 (1.9, 4.7-12.3)	13.4 (2.3, 8.9-18.0)	13.4 (2.4, 8.8-18.0)	12.3 (2.4, 7.6-17.0)	16.1 (2.9, 10.3-21.9)
D	59.6 (3.5, 52.8-66.4)	59.9 (3.4, 53.1-66.6)	62.4 (3.6, 55.4-69.4)	60.4 (3.7, 53.3-67.6)	56.2 (3.7, 49.0-63.5)
			ASPM		
A	12.8 (2.4, 8.1-17.5)	14.1 (2.6, 9.0-19.2)	9.4 (2.3, 5.0-13.9)	13.7 (2.7, 8.5-19.0)	14.4 (2.6, 9.4-19.5)
B	25.8 (3.0, 19.9-31.8)	22.6 (2.8, 17.1-28.0)	26.0 (3.0, 20.1-31.9)	26.3 (3.4, 19.6-33.1)	27.6 (3.2, 21.3-33.9)
C	14.4 (2.7, 9.1-19.7)	16.2 (2.9, 10.6-21.9)	9.6 (1.9, 5.8-13.4)	15.0 (2.8, 9.6-20.4)	9.4 (2.2, 5.2-13.7)
D	47.0 (3.5, 40.1-53.8)	47.1 (3.5, 40.2-54.0)	55.0 (3.5, 48.1-61.9)	45.0 (3.6, 38.0-51.9)	48.6 (3.7, 41.3-55.9)
			NPSIBI		
A	-	31.0 (5.7, 19.7-42.2)	21.2 (2.8, 15.8-26.6)	24.8 (3.0, 18.9-30.7)	24.9 (3.2, 18.7-31.1)
B	-	25.2 (5.7, 14.0-36.4)	31.0 (3.4, 24.2-37.7)	28.3 (3.6, 21.2-35.3)	29.8 (3.7, 22.6-37.1)
C	-	23.7 (5.2, 13.5-33.8)	33.1 (3.6, 26.0-40.1)	34.3 (3.6, 27.3-41.3)	35.9 (3.9, 28.3-43.5)
D	-	2.1 (1.3, 0.0-4.7)	6.2 (1.7, 2.8-9.6)	10.1 (2.5, 5.2-15.0)	8.6 (2.5, 3.7-13.4)
E	-	18.1 (5.8, 6.7-29.4)	8.6 (2.5, 3.7-13.5)	2.5 (1.5, 0.0-5.5)	0.8 (0.5, 0.0-1.9)
			MCC		

	2009-2011	2012-2014	2015-2017	2018-2020	2021-2023
A	55.8 (3.7, 48.5-63.0)	51.1 (3.7, 43.8-58.4)	45.7 (3.7, 38.4-52.9)	54.0 (3.7, 46.8-61.3)	48.2 (3.8, 40.8-55.7)
B	12.5 (2.5, 7.6-17.4)	11.0 (2.4, 6.4-15.6)	18.4 (2.9, 12.8-24.1)	12.2 (2.5, 7.2-17.1)	20.6 (3.1, 14.7-26.6)
C	5.8 (1.8, 2.2-9.3)	10.5 (2.3, 6.1-15.0)	9.6 (2.3, 5.2-14.1)	10.6 (2.3, 6.1-15.2)	4.9 (1.4, 2.1-7.6)
D	25.9 (3.5, 19.1-32.7)	27.4 (3.6, 20.3-34.4)	26.3 (3.6, 19.1-33.4)	23.2 (3.4, 16.5-29.8)	26.3 (3.6, 19.1-33.4)
			WCC^		
A	80.6 (2.9, 74.9-86.3)	83.1 (2.8, 77.7-88.6)	85.8 (2.4, 81.0-90.5)	80.7 (2.9, 75.0-86.5)	76.7 (3.2, 70.3-83.1)
B	11.5 (2.3, 6.9-16.0)	11.4 (2.4, 6.6-16.1)	9.8 (2.2, 5.5-14.1)	11.5 (2.3, 6.9-16.1)	12.9 (2.7, 7.5-18.2)
C	2.7 (0.9, 0.8-4.5)	4.0 (1.4, 1.3-6.7)	4.1 (1.4, 1.4-6.9)	5.7 (1.7, 2.3-9.1)	7.4 (2.0, 3.4-11.3)
D	5.3 (1.8, 1.8-8.8)	1.5 (0.7, 0.2-2.8)	0.3 (0.3, 0.0-0.8)	2.1 (1.3, 0.0-4.5)	3.1 (1.1, 0.9-5.2)
			SSC		
A	15.9 (2.6, 10.8-21.0)	14.5 (2.6, 9.4-19.6)	10.3 (2.4, 5.6-14.9)	10.7 (2.1, 6.7-14.8)	13.1 (2.4, 8.4-17.8)
B	9.1 (1.9, 5.4-12.7)	13.3 (2.3, 8.7-17.9)	11.5 (2.3, 6.9-16.0)	8.6 (2.3, 4.1-13.2)	10.5 (2.3, 6.1-15.0)
C	14.8 (2.6, 9.6-20.0)	13.0 (2.3, 8.4-17.5)	16.1 (2.5, 11.2-21.0)	21.3 (3.2, 15.2-27.5)	22.3 (3.1, 16.2-28.5)
D	60.2 (3.4, 53.6-66.8)	59.3 (3.4, 52.6-65.9)	62.2 (3.3, 55.7-68.7)	59.3 (3.6, 52.3-66.3)	54.0 (3.6, 47.1-61.0)
			QHA Total score		
A	6.4 (1.8, 2.9-9.8)	5.0 (1.6, 1.8-8.2)	6.7 (1.9, 3.0-10.4)	5.6 (1.6, 2.5-8.7)	5.4 (1.6, 2.4-8.5)
B	30.7 (3.2, 24.6-36.9)	49.5 (3.7, 42.3-56.7)	36.7 (3.6, 29.6-43.7)	35.9 (3.3, 29.4-42.5)	39.3 (3.6, 32.4-46.3)
C	46.8 (3.9, 39.2-54.3)	38.7 (3.6, 31.6-45.8)	42.9 (3.8, 35.4-50.3)	49.7 (3.7, 42.5-57.0)	43.6 (3.8, 36.1-51.1)
D	16.1 (3.2, 9.9-22.3)	6.7 (2.1, 2.6-10.9)	13.8 (2.9, 8.1-19.5)	8.7 (2.3, 4.2-13.2)	11.6 (2.8, 6.2-17.0)
			Reach shade (%)		
A	-	8.7 (2.8, 3.2-14.2)	11.1 (2.4, 6.3-15.9)	11.0 (2.5, 6.2-15.8)	12.9 (2.6, 7.9-18.0)
B	-	16.6 (3.4, 9.9-23.3)	17.1 (2.8, 11.6-22.6)	22.8 (3.3, 16.3-29.2)	17.0 (2.8, 11.6-22.5)
C	-	23.0 (3.7, 15.7-30.3)	25.5 (3.1, 19.4-31.6)	23.9 (3.2, 17.8-30.1)	26.2 (3.4, 19.5-32.9)
D	-	51.7 (4.5, 42.8-60.5)	46.4 (3.9, 38.6-54.1)	42.3 (3.7, 35.1-49.5)	43.9 (3.8, 36.4-51.3)

	2009-2011	2012-2014	2015-2017	2018-2020	2021-2023
			RHA Total score		
A	-	-	5.1 (2.2, 0.7-9.4)	2.6 (1.0, 0.7-4.6)	0.3 (0.3, 0.0-0.9)
B	-	-	41.8 (4.6, 32.7-50.9)	39.3 (3.6, 32.3-46.3)	39.5 (3.5, 32.6-46.4)
C	-	-	43.8 (4.2, 35.5-52.1)	50.8 (3.8, 43.3-58.2)	49.4 (3.8, 41.9-57.0)
D	-	-	9.3 (3.4, 2.6-16.0)	7.3 (2.2, 3.1-11.5)	10.8 (2.5, 5.8-15.8)

Table A 3: Length (km) estimates of wadeable, perennial streams (Target) in a given condition banding for ecologically relevant indices, for completed rotations 2009-2023. Parentheses are estimated SE, followed lower and upper 95th confidence interval.

	2009-2011	2012-2014	2015-2017	2018-2020	2021-2023
			MCI		
A	1307 (295, 730-1885)	751 (227, 307-1196)	1213 (313, 599-1826)	808 (259, 301-1315)	838 (263, 321-1354)
B	4121 (520, 3101-5141)	4290 (512, 3286-5294)	3442 (451, 2559-4325)	3901 (488, 2945-4857)	4000 (470, 3079-4921)
C	4255 (546, 3184-5326)	4081 (515, 3071-5091)	4219 (515, 3210-5229)	3967 (493, 3000-4934)	3668 (476, 2735-4602)
D	5952 (532, 4909-6995)	6382 (554, 5295-7468)	6630 (547, 5558-7702)	5612 (501, 4630-6593)	5781 (509, 4784-6778)
			QMCI		
A	2674 (410, 1870-3477)	2649 (442, 1783-3516)	1972 (392, 1204-2741)	2151 (403, 1362-2941)	2351 (396, 1575-3128)
B	2314 (403, 1525-3103)	1492 (326, 852-2131)	1776 (389, 1013-2539)	1744 (366, 1027-2462)	1602 (373, 872-2332)
C	1328 (300, 740-1916)	2082 (361, 1374-2790)	2080 (365, 1366-2795)	1755 (341, 1087-2422)	2300 (420, 1476-3124)
D	9320 (544, 8253-10387)	9281 (533, 8235-10326)	9675 (554, 8589-10761)	8636 (523, 7612-9661)	8033 (530, 6994-9073)
			ASPM		
A	2001 (376, 1264-2738)	2189 (402, 1400-2978)	1464 (349, 779-2148)	1961 (383, 1210-2712)	2064 (370, 1338-2790)
B	4042 (475, 3110-4973)	3496 (430, 2653-4340)	4026 (467, 3111-4940)	3763 (491, 2802-4725)	3939 (459, 3040-4838)
C	2251 (422, 1424-3078)	2515 (446, 1642-3389)	1486 (300, 898-2074)	2139 (394, 1367-2911)	1344 (309, 738-1951)
D	7342 (550, 6264-8419)	7303 (549, 6226-8379)	8529 (549, 7453-9604)	6423 (508, 5428-7419)	6940 (533, 5895-7985)
			NPSIBI		
A	-	4800 (887, 3061-6539)	3286 (429, 2445-4126)	3540 (429, 2699-4381)	3553 (451, 2669-4438)
B	-	3908 (883, 2177-5639)	4801 (535, 3753-5849)	4038 (516, 3026-5050)	4264 (531, 3223-5304)
C	-	3668 (801, 2099-5237)	5127 (558, 4033-6221)	4901 (511, 3900-5902)	5123 (554, 4037-6209)
D	-	325 (206, 0-730)	958 (270, 429-1488)	1449 (357, 750-2149)	1226 (353, 533-1918)
E	-	2802 (896, 1046-4558)	1332 (390, 567-2096)	359 (218, 0-787)	121 (74, 0-266)
			MCC		

	2009-2011	2012-2014	2015-2017	2018-2020	2021-2023
A	8722 (578, 7589-9856)	7924 (577, 6794-9055)	7080 (575, 5953-8207)	7717 (528, 6683-8751)	6893 (540, 5835-7952)
B	1958 (393, 1187-2728)	1702 (366, 985-2420)	2858 (446, 1985-3732)	1741 (360, 1036-2447)	2948 (436, 2094-3803)
C	899 (280, 351-1448)	1635 (352, 946-2324)	1491 (352, 801-2182)	1520 (332, 868-2171)	695 (202, 298-1092)
D	4056 (542, 2994-5118)	4242 (556, 3152-5332)	4074 (565, 2966-5182)	3309 (484, 2361-4257)	3750 (521, 2730-4771)
			WCC^		
A	12604 (453, 11716-13492)	12890 (434, 12040-13740)	13299 (375, 12563-14035)	11531 (419, 10709-12353)	10958 (464, 10048-11867)
B	1790 (360, 1085-2495)	1761 (378, 1021-2501)	1521 (337, 860-2181)	1644 (333, 992-2296)	1841 (389, 1078-2604)
C	418 (148, 128-708)	620 (212, 205-1036)	640 (216, 217-1062)	816 (249, 329-1304)	1050 (290, 482-1619)
D	823 (281, 274-1373)	232 (105, 26-439)	45 (41, 0-126)	296 (179, 0-646)	438 (155, 134-742)
			SSC		
A	2487 (409, 1685-3288)	2243 (403, 1452-3033)	1593 (367, 874-2312)	1530 (295, 951-2110)	1875 (344, 1201-2549)
B	1417 (290, 848-1986)	2062 (362, 1353-2770)	1779 (361, 1070-2487)	1232 (331, 584-1880)	1502 (324, 866-2137)
C	2316 (413, 1506-3126)	2009 (360, 1304-2714)	2489 (388, 1729-3249)	3049 (450, 2167-3931)	3190 (448, 2312-4068)
D	9416 (525, 8387-10445)	9191 (527, 8157-10224)	9643 (511, 8641-10645)	8475 (510, 7476-9474)	7721 (509, 6723-8718)
			QHA Total score		
A	998 (275, 458-1537)	777 (253, 282-1272)	1036 (290, 468-1605)	805 (225, 364-1246)	779 (226, 336-1221)
B	4808 (493, 3841-5775)	7677 (569, 6563-8791)	5684 (558, 4591-6776)	5133 (477, 4198-6068)	5621 (509, 4623-6619)
C	7314 (603, 6131-8496)	6007 (562, 4906-7108)	6644 (588, 5493-7796)	7104 (528, 6070-8138)	6233 (546, 5162-7304)
D	2516 (495, 1547-3485)	1042 (328, 400-1685)	2139 (453, 1251-3027)	1245 (329, 599-1890)	1654 (395, 881-2428)
			Reach shade (%)		
A	-	1347 (433, 498-2196)	1719 (377, 980-2458)	1575 (352, 885-2264)	1846 (367, 1127-2565)
B	-	2578 (531, 1538-3619)	2645 (434, 1795-3496)	3250 (470, 2330-4171)	2432 (399, 1650-3214)
C	-	3570 (577, 2439-4700)	3952 (485, 3001-4903)	3420 (450, 2537-4302)	3739 (489, 2781-4697)
D	-	8008 (698, 6640-9377)	7187 (612, 5988-8386)	6042 (527, 5009-7075)	6269 (543, 5205-7334)

	2009-2011	2012-2014	2015-2017	2018-2020	2021-2023
			RHA Total score		
A	-	-	785 (342, 115-1456)	376 (143, 95-657)	43 (41, 0-123)
B	-	-	6485 (720, 5074-7896)	5612 (512, 4609-6615)	5642 (503, 4657-6627)
C	-	-	6795 (657, 5507-8082)	7255 (543, 6191-8320)	7061 (549, 5985-8138)
D	-	-	1438 (530, 399-2478)	1044 (308, 440-1648)	1540 (363, 828-2252)

Table A 4: Proportion (%) estimates of wadeable, perennial streams (Target) in a given condition banding for ecologically relevant indices, for the 2021-2023 rotation for each FMU. Parentheses are estimated SE, followed lower and upper 95th confidence interval.

	Coromandel	Lake Taupō	Lower Waikato	Upper Waikato	Waihou-Piako	Waipā	West Coast
				MCI			
A	0	18.0 (13, 0.0-44)	0	9.1 (5.0, 0.0-19.0)	2.1 (2.0, 0.0-6.1)	9 (4, 0.0-18)	6 (4, 0.0-15)
B	57 (14, 29-85)	19 (11, 0.0-42.1)	4 (4.0, 0.0-12)	34 (10, 14-54)	26 (8, 9-42)	28.0 (6, 14-41.0)	34 (7, 19-49)
C	29 (11, 6-52)	9.0 (8, 0.0-25)	25 (7, 11-39)	35 (11, 13-57)	21 (7.1, 7-35)	20 (6, 8.1-32)	30 (7, 15-45)
D	13 (10, 0.0-33)	53 (22, 9-97)	69 (8.0, 54.1-85)	20 (11, 0.0-43)	50 (7, 35-65)	42 (8, 26-58)	28.1 (6, 14-41)
				QMCI			
A	32 (13, 5-59.1)	27.0 (16, 0.0-59)	0	18.1 (6, 4-31)	13.1 (4, 3-22)	19.1 (5, 7-30)	20.1 (6, 6-33)
B	0	10 (9, 0.0-29)	4 (2, 0.0-10.0)	2 (2, 0.0-8.1)	4 (3, 0.0-11)	21 (7, 6-36.0)	16.1 (6.1, 4.1-28.0)
C	30 (12, 6-54)	0	14 (6, 1-27)	29.1 (10, 9.0-49)	17.1 (7, 1-32)	9.1 (4, 0-17)	16 (6, 3-29)
D	37.1 (14, 9.1-65.1)	62 (19, 24-100.0)	80 (7.1, 66-94)	49 (10, 29-70)	65 (8, 47-82)	50 (8, 34.1-67)	47 (8.1, 31-63)
				ASPM			
A	32 (13, 5-59.1)	27.0 (16, 0.0-59)	0	12 (5, 1-23)	4 (2, 0.0-10.0)	13.1 (5.1, 3.1-23.1)	25 (6, 12-38)
B	30 (12, 6-54)	10 (9, 0.0-29)	14 (5, 2-25)	40 (10, 20.1-61.1)	27 (8, 11-44)	35 (8.0, 20-51)	23 (5, 12.1-35)
C	11 (8.0, 0.0-27)	0	11 (6.0, 0-23)	12 (5, 1-23)	10 (5, 0-21)	7 (3, 0.0-14)	8 (5.0, 0.0-18)
D	25.1 (12, 1.0-49)	62 (19, 24-100.0)	73 (7, 58-89)	34 (13.0, 9.1-59)	57 (7, 41-72)	43 (8, 27-60.0)	42 (8, 26-58.1)
				NPSIBI			
A	100.0 (0.0, 100.0-100.0)	0	14.5 (5.2, 4.2-24.8)	6.6 (5.6, 0.0-17.6)	46.0 (10.7, 25.0-67.0)	7.6 (3.1, 1.4-13.7)	26.0 (7.1, 12.1-39.9)
B	0	0	36.5 (8.2, 20.4-52.6)	7.6 (6.7, 0.0-20.7)	27.3 (9.0, 9.7-45.0)	38.3 (8.4, 21.8-54.8)	33.4 (8.6, 16.5-50.3)
C	0	0	28.6 (8.7, 11.5-45.6)	79.3 (9.4, 60.9-97.6)	26.7 (7.4, 12.2-41.1)	44.2 (9.6, 25.5-63.0)	39.1 (7.5, 24.3-53.8)
D	0	81.1 (15.8, 50.1-100.0)	20.4 (9.3, 2.1-38.7)	0	0	9.9 (6.2, 0.0-22.0)	1.6 (1.3, 0.0-4.2)
E	0	18.9 (15.8, 0.0-49.9)	0	6.6 (6.0, 0.0-18.4)	0	0	0
				MCC			

	Coromandel	Lake Taupō	Lower Waikato	Upper Waikato	Waihou-Piako	Waipā	West Coast
A	60.1 (16, 28-91)	46 (22, 2-90)	47 (9, 28-66)	47 (10, 26-68)	44 (8, 28-61.1)	49 (8, 32-66)	47 (7, 32-62)
B	39 (16, 8.1-71)	0	20 (6, 7.1-34)	32 (10, 12.0-52)	16 (6, 4-29)	27 (7, 12-42.1)	10 (5.0, 0-20)
C	0	0	12 (6, 0.0-24)	6 (5, 0.0-18.1)	6 (3, 0.0-12)	1 (1.1, 0.0-3)	4.1 (2, 0.0-9)
D	0	53 (22, 9-97)	19 (8, 3-35)	13 (11.1, 0.0-35)	32 (7, 17.1-47)	21 (7, 6-36)	37 (8, 21-53)
				WCC^			
A	76.1 (11.1, 54-97)	47 (22, 4-91)	71 (8, 54-88)	94 (3, 86-100.0)	65 (7, 50-81)	76 (7.1, 62-90)	83 (5, 72.0-95)
B	17 (9, 0.0-36)	43 (25, 0.0-92)	16 (8, 0-33)	2 (2, 0.0-8)	24.0 (8.0, 8-39)	5 (2, 0-10)	9 (5.1, 0.0-19)
C	6 (6.0, 0.0-18.1)	0	7 (4, 0.0-16)	2 (2, 0.0-8.1)	5 (3.1, 0.0-12.0)	16 (6, 3-30.1)	2 (1, 0.0-6.1)
D	0	9.0 (8, 0.0-25)	4 (2, 0.0-9)	0	4 (3, 0.0-11)	1 (1, 0.0-4.1)	4.1 (2, 0.0-9)
				SSC			
A	30 (11.1, 8-52.0)	0	7.1 (4, 0.0-15)	2 (2, 0.0-8.1)	12 (6, 0.0-26)	8 (3, 1-15)	23 (6, 10-35)
B	5 (5, 0.0-16.0)	9.0 (8, 0.0-26)	7.1 (4, 0.0-16.1)	6 (3, 0.0-13)	8 (4, 0.0-17)	16 (5, 5-28.0)	10 (5, 0-20)
C	53.1 (14, 24-81)	28 (15.0, 0.0-57)	2.1 (1, 0.0-5)	48 (12, 24.0-73.0)	14 (5, 3-25)	30 (7, 14-45)	13.0 (4, 3-22)
D	11.1 (7, 0.0-25)	62 (19, 24-100.0)	83 (5, 72-94)	42 (12.1, 18-66)	63 (7, 49-78)	44 (7, 29-59)	52 (8.0, 37-68)
				QHA Total score			
A	18.3 (5.9, 6.8-29.8)	9.0 (8.8, 0.0-26.2)	0	0	6.1 (3.4, 0.0-12.8)	4.3 (2.9, 0.0-10.1)	8.2 (4.8, 0.0-17.6)
B	68.5 (11.7, 45.6-91.4)	37.4 (19.2, 0.0-75.0)	23.3 (7.3, 8.9-37.7)	44.3 (9.6, 25.6-63.0)	39.1 (8.9, 21.6-56.6)	45.0 (8.6, 28.3-61.8)	35.5 (7.7, 20.4-50.6)
C	13.2 (10.6, 0.0-33.9)	53.6 (22.5, 9.5-97.6)	56.8 (10.1, 37.0-76.6)	55.7 (9.6, 37.0-74.4)	39.2 (8.7, 22.1-56.3)	35.2 (8.2, 19.1-51.3)	46.8 (8.2, 30.7-62.8)
D	0	0	19.9 (9.8, 0.6-39.2)	0	15.5 (7.8, 0.2-30.8)	15.4 (6.5, 2.8-28.1)	9.6 (4.5, 0.8-18.4)
				RHA Total score			
A	0	0	0	0	0	1 (1, 0.0-3)	0
B	74 (12, 50.0-99)	37 (19, 0.0-75)	18 (6, 5-31.0)	47 (10, 27.0-67)	42 (8, 26.0-59)	40.1 (8, 24.0-56)	38 (7, 24-52)
C	25.1 (12, 0-50.0)	62 (19, 24-100.0)	66 (9, 48-84)	52 (10, 32-73.0)	39 (8, 23-55)	49 (8, 32-65)	48.0 (8, 32.0-63)
D	0	0	14 (7, 0.0-30)	0	17 (7, 2-33)	9 (5.1, 0.0-19)	13 (5.1, 3-23)

	Coromandel	Lake Taupō	Lower Waikato	Upper Waikato	Waihou-Piako	Waipā	West Coast
				Reach shade (%)			
A	24 (12, 0.0-49)	0	7.1 (4, 0.0-16.1)	8 (4, 0-17.1)	17 (6, 4-30)	13 (6.1, 1-25)	13 (5, 2-24)
B	39 (16, 8.1-71)	37 (19, 0.0-75)	9.1 (4.1, 1.1-17)	26 (9, 7-45.0)	17 (7, 2-32.0)	13 (5, 3-23)	13 (5, 3.1-23)
C	23.1 (10, 2-43)	0	34.1 (9, 15-52)	33 (13, 8.0-59)	18 (5, 6-29)	31 (7, 16-46)	23.0 (6, 10-35)
D	12 (8, 0.0-29)	62 (19, 24-100.0)	49 (9, 31-68)	31 (9, 12-49)	46 (8.1, 30-62)	41 (8, 24-58)	50.1 (8, 33-66)

Table A 5: Length (km) estimates of wadeable, perennial streams (Target) in a given condition banding for ecologically relevant indices, for the 2021-2023 rotation for each FMU. Parentheses are estimated SE, followed lower and upper 95th confidence interval.

	Coromandel	Lake Taupō	Lower Waikato	Upper Waikato	Waihou-Piako	Waipā	West Coast
				MCI			
A	0	320 (237, 0-783)	0	201 (112, 0-420)	40 (37, 0-112)	246 (131, 0-502)	219 (139, 0-492)
B	530 (132, 272-788)	343 (205, 0-746)	86 (71, 0-224)	763 (228, 317-1209)	484 (156, 178-791)	744 (177, 397-1091)	1110 (240, 640-1581)
C	272 (108, 60-484)	160 (153, 0-460)	443 (126, 195-691)	796 (249, 307-1284)	396 (131, 140-652)	542 (167, 215-870)	982 (248, 496-1467)
D	122 (98, 0-313)	950 (398, 169-1731)	1216 (139, 944-1488)	458 (263, 0-973)	926 (141, 649-1203)	1129 (220, 698-1561)	904 (216, 479-1328)
				QMCI			
A	298 (127, 50-546)	479 (294, 0-1055)	0	402 (150, 108-696)	242 (87, 71-414)	508 (157, 200-816)	646 (217, 220-1071)
B	0	183 (173, 0-521)	78 (49, 0-174)	64 (59, 0-180)	82 (66, 0-211)	565 (201, 171-958)	516 (196, 132-901)
C	284 (113, 63-505)	0	257 (117, 28-486)	644 (227, 199-1090)	316 (144, 33-599)	241 (112, 21-461)	527 (209, 116-937)
D	343 (132, 84-602)	1110 (341, 440-1772)	1410 (124, 1168-1653)	1107 (231, 655-1559)	1205 (164, 885-1526)	1348 (225, 907-1789)	1525 (261, 1014-2036)
				ASPM			
A	298 (127, 50-546)	479 (294, 0-1055)	0	274 (126, 28-520)	79 (54, 0-184)	348 (136, 82-615)	827 (211, 413-1240)
B	284 (113, 63-505)	183 (173, 0-521)	249 (103, 47-451)	900 (232, 445-1354)	514 (155, 211-817)	953 (212, 537-1369)	762 (191, 389-1136)
C	110 (74, 0-255)	0	207 (104, 3-412)	279 (128, 28-530)	198 (99, 5-391)	197 (102, 0-396)	270 (160, 0-584)
D	232 (114, 9-455)	1110 (341, 440-1772)	1289 (138, 1018-1559)	764 (287, 201-1327)	1055 (145, 771-1338)	1164 (222, 729-1598)	1355 (262, 841-1869)
				NPSIBI			
A	924 (0, 924-924)	0	253 (92, 74-433)	146 (124, 0-390)	850 (198, 462-1237)	202 (83, 38-365)	836 (228, 389-1283)
B	0	0	637 (144, 356-919)	168 (148, 0-459)	504 (166, 178-830)	1019 (224, 580-1458)	1072 (277, 529-1615)
C	0	0	498 (152, 201-796)	1758 (207, 1351-2164)	492 (136, 226-758)	1177 (254, 679-1676)	1256 (242, 780-1731)
D	0	1438 (281, 887-1772)	356 (163, 37-675)	0	0	263 (164, 0-584)	50 (43, 0-135)
E	0	335 (281, 0-885)	0	146 (134, 0-408)	0	0	0
				MCC			

	Coromandel	Lake Taupō	Lower Waikato	Upper Waikato	Waihou-Piako	Waipā	West Coast
A	556 (150, 262-850)	822 (398, 42-1603)	833 (167, 504-1161)	1046 (237, 582-1511)	825 (154, 523-1128)	1326 (229, 876-1775)	1527 (251, 1035-2019)
B	369 (150, 74-663)	0	361 (120, 125-596)	713 (229, 265-1161)	311 (116, 83-539)	729 (200, 338-1120)	346 (161, 30-662)
C	0	0	213 (109, 0-425)	151 (128, 0-402)	114 (60, 0-231)	34 (30, 0-94)	133 (84, 0-297)
D	0	950 (398, 169-1731)	339 (144, 58-621)	306 (246, 0-789)	595 (143, 316-875)	572 (203, 174-971)	1209 (264, 691-1727)
				WCC^			
A	704 (102, 503-904)	846 (393, 76-1616)	1247 (151, 950-1543)	2089 (87, 1919-2217)	1213 (147, 926-1501)	2031 (188, 1662-2400)	2687 (190, 2315-3059)
B	162 (89, 0-336)	767 (448, 0-1645)	294 (148, 5-583)	64 (60, 0-181)	442 (148, 152-733)	147 (69, 12-282)	308 (162, 0-627)
C	59 (55, 0-168)	0	130 (80, 0-287)	64 (59, 0-180)	108 (57, 0-221)	444 (182, 87-801)	87 (57, 0-197)
D	0	160 (153, 0-460)	74 (45, 0-163)	0	82 (68, 0-215)	39 (36, 0-110)	133 (85, 0-299)
				SSC			
A	280 (103, 78-481)	0	125 (77, 0-275)	64 (59, 0-180)	234 (128, 0-485)	223 (97, 33-414)	748 (203, 350-1146)
B	51 (49, 0-148)	160 (155, 0-464)	125 (79, 0-280)	137 (85, 0-305)	161 (85, 0-328)	447 (152, 149-745)	346 (167, 19-673)
C	490 (134, 228-753)	503 (265, 0-1022)	37 (32, 0-99)	1075 (277, 532-1618)	272 (105, 65-478)	808 (211, 395-1220)	419 (157, 111-728)
D	103 (67, 0-235)	1110 (341, 440-1772)	1458 (101, 1261-1656)	941 (269, 415-1468)	1179 (136, 911-1446)	1183 (207, 778-1588)	1701 (257, 1198-2204)
				QHA Total score			
A	169 (54, 63-276)	160 (155, 0-464)	0	0	114 (63, 0-237)	115 (78, 0-269)	262 (156, 0-567)
B	633 (108, 421-845)	663 (340, 0-1328)	407 (128, 156-658)	982 (212, 567-1398)	722 (165, 399-1045)	1198 (228, 752-1645)	1140 (247, 655-1625)
C	122 (98, 0-313)	950 (398, 169-1731)	992 (176, 646-1337)	1235 (212, 819-1650)	724 (161, 408-1040)	938 (218, 509-1366)	1504 (263, 988-2020
D	0	0	347 (172, 10-683)	0	287 (144, 4-569)	410 (172, 73-747)	308 (145, 25-592)
				RHA Total score			
A	0	0	0	0	0	34 (32, 0-96)	0
B	692 (117, 462-922)	663 (341, 0-1332)	321 (112, 101-541)	1046 (229, 598-1495)	788 (157, 480-1096)	1068 (220, 638-1499)	1238 (234, 779-1696)
C	232 (117, 2-463)	1110 (341, 440-1772)	1165 (162, 848-1482)	1171 (229, 722-1619)	729 (154, 428-1030)	1313 (223, 877-1750)	1542 (262, 1028-2055)

	Coromandel	Lake Taupō	Lower Waikato	Upper Waikato	Waihou-Piako	Waipā	West Coast
D	0	0	259 (138, 0-530)	0	329 (146, 42-616)	246 (136, 0-512)	435 (165, 111-760)
				Reach shade (%)			
A	225 (120, 0-459)	0	125 (80, 0-281)	192 (96, 4-379)	327 (121, 90-563)	361 (162, 44-678)	435 (175, 92-779)
B	369 (150, 74-663)	663 (341, 0-1332)	159 (72, 19-299)	581 (213, 163-998)	321 (138, 51-591)	356 (138, 86-627)	427 (168, 99-755)
C	213 (97, 24-402)	0	594 (166, 268-920)	750 (292, 178-1321)	338 (109, 125-551)	832 (202, 435-1229)	741 (207, 336-1145)
D	118 (78, 0-270)	1110 (341, 440-1772)	867 (165, 544-1190)	695 (210, 284-1107)	860 (150, 567-1153)	1112 (230, 660-1563)	1611 (270, 1083-2140)

Table A 6: Estimated summary distribution statistics of ecological condition metrics for Target streams regionally 2021-2023.

	5Pct	10Pct	25Pct	50Pct	75Pct	90Pct	95Pct	Mean	SD
QMCI									
Waikato	2.15	2.36	2.88	3.96	5.78	7.05	7.35	4.40	1.73
Coromandel	2.93	3.23	3.42	5.18	6.92	6.94	7.11	5.10	1.49
Lake Taupō	2.33	2.40	2.84	2.88	6.72	7.06	7.68	4.27	2.03
Lower Waikato	2.06	2.10	2.54	3.28	4.30	5.00	5.36	3.46	1.11
Upper Waikato	2.69	2.71	3.29	4.85	5.40	7.09	7.18	4.68	1.53
Waihou Piako	2.03	2.17	2.38	3.15	4.66	6.48	7.35	3.83	1.62
Waipā	2.40	2.95	3.05	4.42	6.17	7.30	7.79	4.82	1.76
West Coast	2.15	2.37	2.81	4.63	6.07	7.00	8.10	4.68	1.82
ASPM									
Waikato	0.09	0.11	0.17	0.30	0.54	0.60	0.65	0.35	0.19
Coromandel	0.19	0.20	0.29	0.52	0.60	0.61	0.66	0.46	0.16
Lake Taupō	0.09	0.09	0.10	0.12	0.59	0.65	0.71	0.30	0.25
Lower Waikato	0.08	0.09	0.11	0.18	0.29	0.44	0.46	0.22	0.12
Upper Waikato	0.08	0.09	0.25	0.40	0.45	0.60	0.61	0.37	0.17
Waihou Piako	0.10	0.11	0.12	0.24	0.51	0.56	0.58	0.30	0.18
Waipā	0.09	0.11	0.18	0.36	0.56	0.60	0.68	0.37	0.20
West Coast	0.13	0.15	0.20	0.32	0.59	0.64	0.66	0.39	0.19
MCI									
Waikato	54.00	59.50	77.40	96.30	117.00	124.00	130.00	95.60	24.30
Coromandel	84.50	84.80	94.30	112.00	112.00	122.00	123.00	107.00	12.10
Lake Taupō	57.50	57.50	57.60	74.90	122.00	136.00	144.00	90.30	34.40
Lower Waikato	46.00	46.10	57.00	75.90	96.60	104.00	107.00	77.40	20.70
Upper Waikato	54.00	54.40	95.10	104.00	122.00	124.00	130.00	102.00	23.00
Waihou Piako	53.20	61.10	69.10	89.70	118.00	127.00	129.00	90.80	25.10
Waipā	51.50	64.20	86.20	102.00	117.00	126.00	133.00	98.40	24.00
West Coast	65.90	77.20	86.10	100.00	117.00	128.00	136.00	102.00	20.30
Reach shade (%)									
Waikato	0.86	1.46	5.75	22.90	53.50	85.50	89.70	33.10	30.10
Coromandel	8.68	15.50	44.40	55.60	62.10	87.70	88.10	54.60	24.40
Lake Taupō	0.00	0.00	0.00	1.85	67.60	74.60	79.20	27.00	34.30
Lower Waikato	1.65	1.73	3.50	20.10	33.20	76.50	93.30	25.20	26.60
Upper Waikato	3.90	9.43	11.50	38.10	52.40	71.80	92.10	38.40	25.00
Waihou Piako	1.92	2.29	12.20	21.20	62.80	91.20	96.60	37.40	32.60
Waipā	0.81	0.88	4.51	33.40	50.40	83.80	94.90	32.70	29.70
West Coast	0.96	1.13	3.24	19.60	51.50	85.60	88.60	29.20	30.00
RHA Total score									
Waikato	22.50	24.00	32.00	48.60	62.40	75.90	81.60	49.30	18.20
Coromandel	51.30	51.50	52.50	64.70	70.40	81.70	82.10	65.90	9.70
Lake Taupō	26.60	26.60	26.80	40.30	76.70	81.00	83.60	49.30	22.90

	5Pct	10Pct	25Pct	50Pct	75Pct	90Pct	95Pct	Mean	SD
Lower Waikato	22.50	23.00	27.70	41.90	53.10	55.60	65.90	41.70	13.60
Upper Waikato	32.70	35.60	44.20	50.50	57.80	66.40	72.70	51.50	11.60
Waihou Piako	20.10	21.20	31.40	52.20	73.40	77.10	81.20	51.10	20.80
Waipā	23.80	26.00	30.80	47.80	65.40	81.60	83.50	50.70	19.30
West Coast	17.00	23.70	30.50	47.60	57.70	75.40	81.60	47.00	18.00
QHA Total score									
Waikato	39.10	41.90	60.60	80.40	98.70	115.00	124.00	81.10	26.70
Coromandel	75.20	75.40	90.10	94.30	100.00	143.00	144.00	101.00	20.10
Lake Taupō	61.60	61.60	61.80	66.80	110.00	122.00	128.00	86.80	26.40
Lower Waikato	39.80	40.00	48.60	67.60	83.10	102.00	105.00	68.90	21.50
Upper Waikato	59.70	59.90	70.30	80.50	89.00	103.00	105.00	81.80	14.40
Waihou Piako	30.50	31.00	52.70	79.90	106.00	122.00	126.00	81.30	32.10
Waipā	33.70	37.40	58.80	82.30	109.00	119.00	122.00	81.60	28.80
West Coast	41.90	43.70	71.20	80.80	94.20	115.00	140.00	82.00	25.40
SSC									
Waikato	3.07	6.87	22.50	49.20	93.50	99.20	99.60	54.60	35.80
Coromandel	0.00	1.80	9.17	28.10	29.50	47.20	83.10	24.50	19.10
Lake Taupō	12.60	29.10	30.70	79.20	99.40	99.80	99.90	67.20	33.40
Lower Waikato	4.99	10.60	55.40	84.60	98.20	99.00	99.50	73.00	31.60
Upper Waikato	10.60	23.30	31.20	36.60	62.20	99.30	99.60	47.10	26.00
Waihou Piako	3.56	4.56	28.80	64.50	93.30	99.30	99.70	58.30	34.70
Waipā	8.26	10.50	18.90	29.20	84.10	98.10	98.60	48.20	32.80
West Coast	2.30	2.70	10.60	72.30	96.70	99.50	99.80	55.90	40.80
WCC^									
Waikato	0.00	0.00	0.00	3.87	19.00	40.70	50.90	12.90	17.90
Coromandel	0.00	0.00	0.00	0.89	11.80	29.20	38.50	9.01	12.50
Lake Taupō	0.00	0.00	0.00	34.00	34.20	34.40	63.10	22.70	19.70
Lower Waikato	0.00	0.00	0.00	7.83	31.10	42.00	54.70	16.20	20.40
Upper Waikato	0.00	0.00	0.00	0.32	4.00	14.30	26.30	4.98	9.14
Waihou Piako	0.00	0.00	0.00	9.07	28.10	45.30	52.50	16.60	18.80
Waipā	0.00	0.00	0.00	3.86	10.30	50.10	50.90	13.30	19.30
West Coast	0.00	0.00	0.00	3.40	15.80	35.00	44.20	11.20	16.10
MCC									
Waikato	0.00	0.00	0.40	16.80	57.90	83.50	89.40	28.80	32.10
Coromandel	0.00	0.00	0.00	2.67	28.40	30.40	30.50	12.50	13.90
Lake Taupō	0.00	0.00	0.00	64.00	93.60	93.70	93.80	47.50	44.70
Lower Waikato	0.15	0.86	1.18	17.80	42.30	83.40	84.40	26.60	28.80
Upper Waikato	0.00	0.00	0.00	15.40	33.90	73.30	73.40	21.10	24.90
Waihou Piako	0.00	0.00	1.58	30.60	66.00	90.00	92.10	34.10	34.60
Waipā	0.00	0.00	0.00	19.50	34.30	71.40	89.30	25.40	29.40
West Coast	0.00	0.00	0.70	17.10	72.00	82.80	85.20	33.90	34.90

	5Pct	10Pct	25Pct	50Pct	75Pct	90Pct	95Pct	Mean	SD
					NPSIBI				
Waikato	10.60	18.00	22.40	26.60	32.00	38.50	41.90	28.20	8.96
Coromandel	33.50	36.10	36.80	37.80	41.70	51.60	52.50	41.80	6.04
Lake Taupō	0.00	0.00	0.90	4.60	8.30	10.50	11.30	9.73	4.70
Lower Waikato	4.65	9.30	18.90	26.20	29.70	34.90	36.00	25.70	8.15
Upper Waikato	0.00	18.40	20.40	23.40	25.30	29.10	34.50	23.40	7.35
Waihou Piako	19.20	22.40	23.80	27.70	33.60	41.20	48.60	31.50	8.38
Waipā	14.00	18.00	21.10	25.20	27.50	31.40	33.40	26.00	6.40
West Coast	18.80	19.90	23.00	28.00	32.30	40.00	41.90	29.70	7.72

Table A 7: Summary distribution statistics of ecological condition metrics for Target streams regionally 2009 – 2023.

	5Pct	10Pct	25Pct	50Pct	75Pct	90Pct	95Pct	Mean	SD
QMCI									
2009-2011	2.15	2.30	2.82	3.93	5.97	7.17	7.48	4.39	1.81
2012-2014	2.22	2.34	2.86	3.89	5.54	7.00	7.37	4.33	1.72
2015-2017	1.80	2.21	2.54	3.71	5.25	6.61	7.02	4.06	1.70
2018-2020	2.24	2.43	2.80	4.06	5.64	6.90	7.48	4.33	1.69
2021-2023	2.15	2.36	2.88	3.96	5.78	7.05	7.35	4.40	1.73
ASPM									
2009-2011	0.09	0.11	0.14	0.31	0.50	0.60	0.65	0.34	0.19
2012-2014	0.10	0.12	0.16	0.31	0.49	0.61	0.64	0.34	0.18
2015-2017	0.09	0.10	0.15	0.27	0.47	0.59	0.64	0.32	0.18
2018-2020	0.09	0.12	0.18	0.32	0.52	0.61	0.63	0.35	0.18
2021-2023	0.09	0.11	0.17	0.30	0.54	0.60	0.65	0.35	0.19
MCI									
2009-2011	56.10	62.30	73.40	98.60	117.00	126.00	132.00	96.20	24.60
2012-2014	61.00	67.40	76.60	97.60	115.00	126.00	129.00	97.00	22.50
2015-2017	55.00	58.70	72.90	98.40	112.00	126.00	133.00	94.30	24.60
2018-2020	56.30	63.00	79.10	101.00	115.00	124.00	132.00	97.20	23.40
2021-2023	54.00	59.50	77.40	96.30	117.00	124.00	130.00	95.60	24.30
QHA Total score									
2009-2011	28.40	37.20	56.30	71.60	96.80	115.00	132.00	76.40	29.70
2012-2014	34.40	48.40	64.60	86.10	99.40	119.00	124.00	83.80	26.20
2015-2017	33.70	39.50	56.30	78.20	101.00	118.00	127.00	79.00	30.00
2018-2020	39.20	45.50	61.40	76.70	103.00	118.00	126.00	81.10	26.80
2021-2023	39.10	41.90	60.60	80.40	98.70	115.00	124.00	81.10	26.70
SSC									
2009-2011	0.00	6.68	20.00	58.50	95.10	99.50	99.80	56.50	36.30
2012-2014	2.37	4.95	18.70	56.60	96.10	99.40	99.70	56.40	37.00
2015-2017	6.82	9.89	24.60	69.70	95.70	99.50	99.80	61.30	35.60
2018-2020	5.24	8.79	23.10	58.20	94.70	99.40	99.70	58.30	35.10
2021-2023	3.07	6.87	22.50	49.20	93.50	99.20	99.60	54.60	35.80
WCC^									
2009-2011	0.00	0.00	0.00	4.85	13.90	31.40	54.20	11.40	15.60
2012-2014	0.00	0.00	0.16	4.76	13.30	30.00	40.40	10.30	13.80
2015-2017	0.00	0.00	0.00	3.09	12.90	26.60	39.70	9.02	13.00
2018-2020	0.00	0.00	0.00	3.65	16.00	35.80	45.00	11.10	16.60
2021-2023	0.00	0.00	0.00	3.87	19.00	40.70	50.90	12.90	17.90
MCC									
2009-2011	**0.00**	**0.00**	**0.19**	**8.98**	**53.60**	**84.60**	**92.80**	**27.90**	**33.50**
2012-2014	0.00	0.00	0.83	12.50	52.10	86.80	93.90	29.20	32.50
2015-2017	0.00	0.00	2.40	19.20	53.80	74.10	86.10	29.10	29.80

	5Pct	10Pct	25Pct	50Pct	75Pct	90Pct	95Pct	Mean	SD
2018-2020	0.00	0.00	0.60	12.90	46.70	72.00	87.20	26.20	30.40
2021-2023	0.00	0.00	0.40	16.80	57.90	83.50	89.40	28.80	32.10
					Reach shade (%)				
2012-2014	0.00	0.70	5.22	18.70	49.30	74.00	88.40	29.20	28.20
2015-2017	0.08	0.93	4.42	23.00	56.30	81.70	91.90	32.80	30.20
2018-2020	0.10	1.08	4.04	27.10	58.60	82.00	87.40	34.20	30.70
2021-2023	0.86	1.46	5.75	22.90	53.50	85.50	89.70	33.10	30.10
					NPSIBI				
2012-2014	0.00	0.00	18.50	26.70	35.30	41.40	44.10	25.70	14.40
2015-2017	0.00	5.00	19.00	26.30	30.90	37.80	41.30	25.90	11.30
2018-2020	5.99	13.90	21.50	26.40	31.90	38.30	41.20	27.40	9.49
2021-2023	10.60	18.00	22.40	26.60	32.00	38.50	41.90	28.20	8.96
					RHA Total score				
2015-2017	19.40	25.40	37.70	52.80	71.80	78.00	84.60	53.60	20.20
2018-2020	21.50	26.30	34.20	49.60	64.70	78.60	81.90	50.40	19.40
2021-2023	22.50	24.00	32.00	48.60	62.40	75.90	81.60	49.30	18.20

Table A 8:Summary statistics for ecological metrics across sites in developed land (REMS Random) and native forest sites (REMS Reference), sampled 2021-2023.

	Mean	SD	5th Pct	25th Pct	50th Pct	75th Pct	95th Pct
				MCI			
REMS Random	96.1	23.9	55.8	77.6	98.7	117	130
REMS Reference	131	6.88	119	127	131	135	142
				QMCI			
REMS Random	4.40	1.77	2.13	2.80	4.11	5.80	7.32
REMS Reference	7.08	0.918	5.13	6.69	7.29	7.65	8.16
				ASPM			
REMS Random	0.353	0.190	0.100	0.180	0.320	0.535	0.640
REMS Reference	0.651	0.0729	0.492	0.610	0.670	0.690	0.758
				NPSIBI			
REMS Random	29.3	10.1	12.0	24.0	28.0	34.0	48.4
REMS Reference	40.7	7.71	34.0	36.0	38.0	44.0	55.8
				WCC^			
REMS Random	14.1	18.4	0	0	5.37	19.9	53.5
REMS Reference	3.51	11.1	0	0	0	2.40	15.4
				MCC			
REMS Random	22.1	28.5	0	0.400	7.80	33.1	85.4
REMS Reference	0.0671	0.375	0	0	0	0	0.200
				SSC			
REMS Random	52.3	34.8	4.00	22.0	44.0	89.0	100
REMS Reference	11.7	14.6	0	1.00	7.00	15.0	42.2
				Reach shade (%)			
REMS Random	34.1	30.1	1.01	6.18	25.9	55.3	88.9
REMS Reference	84.5	16.8	56.5	79.3	91.7	94.6	96.8
				QHA Total score			
REMS Random	84.7	25.3	43.2	66.2	83.5	103	127
REMS Reference	134	10.8	114	129	135	141	147
				RHA Total score			
REMS Random	51.9	17.5	24.0	38.5	52.5	64.5	81.2
REMS Reference	83.7	8.49	67.6	81.0	86.0	89.0	93.0