Waikato Regional Council Technical Report 2022/32

# Current ecological state of wadeable streams in the Waikato region 2018-2020

www.waikatoregion.govt.nz
ISSN 2230-4363 (Online)

Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato

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March 2023

Document #: 24138887

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## Disclaimer

# Acknowledgements

We gratefully acknowledge the input and advice of Tony Olsen (USEPA) when setting up the probability monitoring network for wadeable streams the Waikato region. Many people assisted with the collection of field data throughout the monitoring programme, including Kevin Collier, Alicia Williams, Nathan Singleton, Brooke Swanson, Cassidy Chaytor, Flavian Ember, Abbie Chaytor, Sharnaye Hall, Nina Hennig, Brandon Ruehle, Rebecca Booth, Emily Fensham, Matt Scott, Connor Muir, Anna Coman, Sam Lancaster-Robertson, Dayna Zidich-Murrell, Tammy Valler, Nicky Kerr, Matthew Barson, Jacoro Lati, Aroha Salu, Kayla Manson, Taylor Scott, Baylee Kelepamu, Callum Bourke, Manon Cellier, Katie Noakes, Sophie Fisher, Stephen Scothern, Johlene Kelly, Jen Iles, Emma Coleman, Hannah Jones, Melany Ginders, Toni Snell, Michael Lake, Dean Miller, Kris Taipeti and Holly Molesworth. Figures were visualised using the R packages ggplot2 (H. Wickham. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York, 2016) and ggpubr (Alboukadel Kassambara, ggpubr: 'ggplot2' Based Publication Ready Plots. 2018). Macroinvertebrate samples were processed by EOS Ecology, New Zealand. We thank Dr Evan Harrison and Dr Roger Hodson for their constructive and thoughtful peer review comments.

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# Abstract

This report presents the results from the Waikato Regional Council's (WRC's) Regional Ecological Monitoring of wadeable Streams (REMS) programme, focusing on the state of indices as they appear in the National Policy Statement for Freshwater Management (NPS-FM, 2020). WRC's REMS probabilistic network incorporates a random design of up to 180 sites on developed land sampled on a 3 yearly rotation which allows statistically robust estimates of stream condition to be generated at both regional and Freshwater Management Unit (FMU) scales. Core ecological components of aquatic invertebrates, fish, instream habitat, shade, periphyton, and aquatic plants are presented. A 'change analysis' to explore the temporal change in region-wide condition was also applied (up to 2020). Regionally, for invertebrate indices, average (median) condition for wadeable streams on developed land was estimated to fall within the NPS C band for the Macroinvertebrate Community Index (MCI) and Average Score Per Metric (ASPM), and D Band for Quantitative MCI (QMCI) (below national bottom line). The estimated extent of stream length falling below the national bottom line for MCI, QMCI, and ASPM ranged from 40 – 60% (up to around 8,500 km). The largest proportions of stream length below the national bottom line for individual FMU's were expected to be in the Lower Waikato and Waihou-Piako. Regionally, for fish communities, based on the National Policy Statement Index of Biological Integrity (NPSIBI) banding for fish, the median condition was B band. For the regionally developed Waikato Quantile IBI (QIBI) for fish <25% of stream length is estimated to be in D band (equivalent to around 3,500 km), while for the NPSIBI <5% was estimated to be D band, reflecting differences in band thresholds between the two methods rather than site specific scores. In terms of important stressors to aquatic ecological communities, fine sediment deposition in the form of sand, silt, and clay particles, was identified, with c. 60% of wadeable stream length estimated to have more than 40% streambed cover. Importantly, negative effects on aquatic communities are well-documented to occur when surficial coverage of the stream bed by fine sediments exceeds a threshold of 20%, illustrating the widespread scale and ecological significance of this stressor across the region. With respect to aquatic plants, macrophyte growth was expected to be problematic across >25% of stream length, where they exceeded 40% cover of the bed of a reach, while periphyton was unlikely to be a major issue across most of the wadeable stream network. While only a relatively small percentage of the sampled stream network had total habitat scores indicative of poor condition, the majority can be considered marginal overall, indicating that aspects of habitat (including fine sediments and riparian condition) are likely to be playing a role in shaping ecological indices at individual sites. Taking steps to reduce deposited fine sediment, and to improve instream habitat conditions will be critical to improving the ecological health of the region's wadeable streams. Looking to the future, riparian improvements that lead to greater canopy shade may be an effective tool for regulating solar radiation, instream temperatures and dissolved oxygen, acting as a buffer to warming water temperatures resulting from climate change. For fish communities and river function, relatively rapid gains in biodiversity and physical improvement are likely to occur through improving riverscape connectivity via the removal or remediation of anthropogenic barriers to downstream substrate and bi-directional fish migration.

# Executive summary

***Purpose***
This report presents the results from the Waikato Regional Council's Regional Ecological Monitoring of streams (REMS) programme (2018 – 2020), focusing on the state of a selection of core policy relevant indices as they appear in the National Policy Statement for Freshwater Management (NPS-FM; Ministry for the Environment, 2020). In addition to the core ecological components of aquatic invertebrates and fish, the report also provides updated information on other measured stream attributes such as instream habitat, shade, periphyton and macrophytes. More specifically, the principal aims of this report are to provide an update on previous reports for the Waikato region 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 macroinvertebrate, fish, habitat, deposited fine sediment, macrophyte and periphyton indices for the years 2018-2020,
(ii) employing a **change analysis to explore the temporal patterns in region-wide condition estimates** (up to 2020), for macroinvertebrate, fish, habitat, deposited fine sediment, macrophyte and periphyton indices,
(iii) **discussing drivers** of ecological conditions, and
(iv) developing **recommendations to utilise routine ecological monitoring further**, for more detailed assessment of policy effectiveness and development, and for informing and assessing the outcomes of catchment restoration actions.

***Design***
The majority of results presented are generated from a network of surveyed **wadeable** sites designed to provide a population level survey of streams on developed land. This design allows statistically robust estimates of target stream condition to be generated at both regional and Freshwater Management Unit (FMU) scales and has been in effect since 2009. These analyses are supported by a second network of historical sites which have been retained to provide additional long term data sets through time, a subset of which are chosen to reflect least impaired conditions (i.e., native forest). All sites in the programme are sampled from December to April using standardised protocols conducted at a 100m (REMS) and 150m (Fish) reach lengths across the wadeable network.

Attributes developed specifically for reporting on ecosystem health in streams and utilised in this report are predominantly interpreted using quality bandings sourced from the NPS-FM (2020). NPS-FM (2020) indices reported here include the National Fish Index of Biotic Integrity (NPSIBI), and the Macroinvertebrate Community Index (MCI), its Quantitative derivative (QMCI), and the Average Score Per Metric (ASPM). In addition, we utilise a Waikato Region specific Fish Index of Biotic Integrity (Waikato QIBI), and report on deposited fine sediment, reach scale habitat, and instream plant growth.

***Results***
At a regional scale, median condition for wadeable streams on developed land was estimated to fall within the C band of NPS Tables 13-15 for MCI, ASPM, and D Band for QMCI (below national bottom line). Concerningly, at a regional level the estimated extent of stream length falling below the national bottom line (D Band) for MCI, QMCI, and ASPM ranged from 40 – 60% (up to around 8,500 km). The proportion of stream length in a given attribute state is not, evenly distributed throughout the region (i.e., between FMUs), with the largest proportions of stream length below the national bottom line expected to be in the Lower Waikato and Waihou-Piako FMU's. While for fish communities, based on the national NPSIBI banding for fish, the median condition was B band. For the Waikato QIBI <25% of stream length is estimated to be in D band (equivalent to c. 3,500 km) while the NPSIBI was estimated to be <5%, reflecting the differences in band thresholds between the two methods rather than site specific scores. There are also

notable differences between the state of fish and invertebrate indices generally, with median values for invertebrates exhibiting consistently lower quality banding scores (over the reported time-period) than for fish. In part these differences reflect differing responses of invertebrates and fish to some existing regional stressors. Over the four rotations of sites completed throughout this programme (spanning a 12-year monitoring period), the ecological indicators used for evaluating state and trend in fish and invertebrates have displayed minimal temporal change at the regional level.

A stressor that is likely to negatively affect both invertebrate and fish indices across the region is deposited fine sediment. Fine deposited sediment, in the form of sand, silt, and clay particles, was reported to have a median percent cover of >60%, and c. 60% of wadeable stream length was estimated to have more than 40% cover, illustrating the scale and significance of this stressor. Even at the FMU scale, median reach scale cover by sand, silt, and clay particles was estimated to be >40% for all FMU's, except for the Coromandel peninsula. Ecologically, negative responses have been reported previously for both invertebrate and fish indices where fine deposited sediments exceeded 20% surficial bed coverage in the Waikato region (Pingram et al. 2019), a threshold that is consistent with findings in other studies (e.g., Burdon et al. 2013; Mathers et al. 2022). Clearly fine sediment deposition is a broad regional issue affecting more than an estimated 60% of the regional wadable river network extent. Addressing fine deposited sediment requires improved spatial identification of primary sources, in association with further development of targeted land-use policies or incentives. Regardless, based on the data from this programme and previous studies, setting an upper threshold of 20% deposition for protecting ecological communities appears to be a meaningful policy target.

With respect to other reported habitat measures, including qualitative and rapid habitat assessments, the majority of the region's wadeable streams on developed land are estimated to have conditions reflective of a degree of impairment. Total scores from these assessments however, while providing an overall picture at a regional scale, may be driven by different factors at different survey reaches. Estimates of plant cover appear to indicate that periphyton growths are unlikely to be a major issue across the wadeable stream network at large, although some extreme values are present. Conversely, macrophyte growth is expected to be problematic across >25% of streams, where they exceed 40% cover of the bed at a reach scale. Plant growth in streams can be driven by interactions between several variables including shade/light (which is a function of stream width, aspect, and riparian cover), nutrients, gradient, disturbance, river flows, and dominant substrate.

***Conclusions***

Poor invertebrate indices tend to correlate with broader suboptimal water quality conditions (e.g., deposited and suspended sediment, and nutrient enrichment) in rivers and streams across the region (Pingram et al. 2019; Pingram et al. 2020). With respect to fish, although median values for the regional Waikato QIBI also fell within the C band, and lower scores were associated with higher amounts of fine deposited sediment, fish communities appear to be more tolerant to suboptimal water quality (generally) than invertebrates. In contrast to invertebrates, impaired riverscape connectivity (e.g., perched culverts, weirs, dams) was likely to be a more important factor constraining regional fish diversity across the network (given the obligatory migratory requirements to and from the ocean for many species). For example, the only FMU with a median A band rating for both the regional and national fish IBIs was the Coromandel where close proximity to the coast, generally good connectivity, and proximity to native forest catchments for predominantly native fish communities still exist. In contrast, the mid Waikato River unit exhibits a relatively clear breakpoint for migratory fish whereby their upstream penetration is limited by a series of eight consecutive hydro-electric dams, the most downstream being at Lake Karāpiro (c. 150 km from the coast). This FMU contained the highest proportion of 'fishless' sites in the region, however, manual releases of shortfin and longfin elvers (and accidental and intentional releases of introduced species) to the hydro lakes (and tributaries) from the base of Karāpiro dam also influence native and introduced fish species diversity in some of these upper Waikato units.

***Future directions***

It is important to recognise that the ability to infer the effect of different regional stressors on aquatic organisms in this current report is limited by the metrics required to be reported on and the banding criteria that have been developed for national use. For fish it was apparent that there were considerable differences between bands developed for regional compared to NPSIBI categories, even though the calculated scores between the two indices were similar. More specifically, NPSIBI bandings present a less impaired representation of fish communities than those represented by Waikato QIBI bandings. The national indicator does not readily differentiate between sites that may be naturally fishless, but in good condition, or fishless due to very poor conditions. Both the national NPSIBI and Waikato QIBI metrics lack sensitivity to detect subtle change. That is, species need to have disappeared (or not be present) for the change to affect the index. Clearly, indicators that include an abundance component (e.g., enabling temporal shifts in communities to be identified before they disappear) are required for management to be effective. A separate programme of work to identify priority migration barriers to fish is currently underway to better evaluate the impact of these on native fish communities across the Waikato region. Substantial scope exists to improve current indices to more effectively ‘triage’ aquatic systems rather than simply reporting on their degradation through time. Potential advancements which can be gleaned from both new and existing data include development of indicators which are more sensitive to change, thereby allowing both degradation and improvement to be recognised earlier.

Taking steps to reduce deposited fine sediment, and to improve instream habitat conditions will be critical to improving the ecological health of the region’s wadeable streams. Looking to the future, riparian improvements that lead to greater canopy shade may be an effective tool for regulating solar radiation, instream temperatures and dissolved oxygen, acting as a buffer to warming water temperatures resulting from climate change. For fish communities and river function, relatively rapid gains in biodiversity and physical improvement are likely to occur through improving riverscape connectivity via the removal or remediation of anthropogenic barriers to downstream substrate and bi-directional fish migration.

# 1 Introduction

## 1.1 Ecological monitoring of streams

Monitoring of ecological responses to human pressures in lotic environments is essential for directing sustainable environmental management. Understanding the responses and relationships between multiple biotic groups (e.g., macrophyte, macroinvertebrate and fish communities in streams) and environmental stressors (e.g., nutrients, sediment, riparian disturbance) is challenging (Leps et al. 2015) but necessary if achievable national and regional policy targets are to be developed (Matthaei et al. 2010), and progress towards evaluated. Key to determining the relative significance of stressors over broad scales in target ecosystems is access to unbiased estimates of resource condition and extent across dominant stressor gradients.

The Waikato Regional Council (WRC) has been conducting annual surveys of aquatic invertebrates 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). The history and objectives of this monitoring programme were reviewed by Collier (2005) and results up to 2014 are reported in Collier & Hamer (2012), and Pingram et al. (2016). The REMS network was modified in 2005 to incorporate (i) a network of native forest reference sites on streams in unmodified (native vegetation) catchments (see Collier et al. 2007), and (ii) a range of sites around the region reflecting different levels of upstream catchment development (see Collier 2005). A land cover assessment (reported in Collier & Hamer 2010) was replaced in 2009 by a revised survey design involving the sampling of 180 randomly selected sites using a probability-based site selection process to provide an unbiased estimate of wadeable stream condition on developed land across the region. The first set of results derived from this design was presented in Collier & Hamer (2012) with subsequent reporting by Pingram et al. (2016), and more detailed exploration by Pingram et al. (2019) for data collected between 2013 and 2015.

A core component of the REMS programme involves the standardised collection of stream invertebrates. The composition of invertebrate communities provides an integrated measure of a stream's ecological health which is influenced by local and upstream activities that affect water quality and the physical stream environment. Invertebrate community composition can be condensed into metrics and indices that can then be used as indicators to report changes over time (trends) or patterns across the region (state). Similar approaches are used among other regional councils in New Zealand, and management agencies internationally, to document stream ecological condition. As invertebrate community composition reflects a range of interacting factors, it can provide a holistic and cumulative understanding of ecosystem condition and augments other measures such as water quality (e.g., chemistry, microbes). Aspects of habitat and instream plant cover are assessed concurrently with macroinvertebrate collections (for details see Collier & Kelly 2005; Collier et al. 2014). Invertebrate indices and interpretation of ecological condition bands are described in the National Policy statement for Freshwater (NPS-FM 2020; see Tables 1 – 3). Specifically, these are the Macroinvertebrate Community Index (MCI), its quantitative derivative (QMCI), and the average score per metric (ASPM, an average value of three standardised metrics).

An additional ecological component for assessing river health in regional council monitoring programmes is freshwater fish. This is recognised in the NPS – FM (2020) with the inclusion of the national Fish Index of Biotic Integrity (NPSIBI; Joy & Death 2003, 2004) and in this current report we also report on a Waikato region specific fish Quantile Index of Biotic Integrity (Waikato QIBI; Joy 2007). Notwithstanding their important recreational (e.g., trout, whitebait), customary, and commercial value (e.g., eels, mullet), freshwater fish are a vital component of freshwater biodiversity. In New Zealand, numerous freshwater fish species and one crustacean, the shrimp

*Paratya curvirostris*, move bi-directionally throughout river networks with around one third of them requiring access to and from the marine environment to complete their lifecycles. This life-history, known as diadromy is reliant on unimpeded access throughout river networks. As a result, reach scale fish community diversity can be impaired by instream barriers such as perched culverts and weirs (Jellyman & Harding 2012). For many nationally distributed species like the endemic longfin eel (*Anguilla dieffenbachii*) and torrentfish (*Cheimarrichthys fosteri*) diadromy is obligatory to complete their lifestyle. Thus, incorporation of fish community indices into traditional reach scale river health assessments can provide important information to evaluate the integrity of riverscape connectivity and river condition.

With approximately one third of New Zealand's native freshwater fish species using the ocean as part of their lifecycle, many of the same species can be found throughout both the North and South Islands, particularly in catchments close to the coast. In effect, juveniles born in one region may disperse at sea and could potentially recruit to other regions. To confidently establish the state of these stocks and to enable appropriate regional assessment and management, a consistent and coordinated approach to assessing their populations at the national scale is necessary. Consistent collection of such data at both regional and national scales is becoming increasingly important considering that currently more than two thirds of New Zealand's native fish taxa are listed as 'declining' or worse (Dunn et al. 2018). In addition to insights on riverscape connectivity and broader national spatial scale recruitment effects, many fish in New Zealand are long-lived so the presence or absence of fish at a particular place can provide information on both current and historic conditions at a site that could potentially span many decades (e.g., longfin eels may exceed 80 years of age and exhibit limited movement).

Although standardised protocols for sampling aquatic macroinvertebrates have been around since the early 2000s (i.e., Stark et al. 2001; Stark & Maxted, 2007), it wasn't until a decade later that standardised protocols were developed for fish, partly explaining their historical absence from regional council monitoring. Between 2008 and 2009, 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). Since then and coinciding with WRC's switch to the previously mentioned probabilistic network design in 2009, freshwater fish surveys were added to WRC's REMS programme to complement other aquatic biological data. A preliminary assessment of the fish data collected within the first three years was undertaken by David et al. (2016) with the fish programme now in its 12$^{th}$ consecutive year.

The current report presents the fourth complete set of results for the three-year 'rotating panel' of randomly selected sites (2018-2020) used to assess ecological condition or state (developed land only) for both invertebrates and fish. Updated information on other stream attributes such as instream habitat, shade, and aquatic plants are also provided. The principal aims of this report are to provide 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 macroinvertebrate, fish, habitat, deposited fine sediment, macrophyte and periphyton indices for the years 2018-2020,
(ii) employing a **change analysis to explore the temporal patterns in region-wide condition estimates** (up to 2020), for macroinvertebrate, fish, habitat, deposited fine sediment, macrophyte and periphyton indices,
(iii) **discussing drivers** of ecological conditions, and
(iv) developing **recommendations to utilise routine ecological monitoring further**, for more detailed assessment of policy effectiveness and development, and for informing and assessing the outcomes of catchment restoration actions.

# 2 Methods

## 2.1 Network design and Statistical analyses

***Probabilistic network***

The randomised probabilistic survey design was first implemented by Waikato Regional Council in 2009, with detailed descriptions and results for specific rotations reported for invertebrates in Collier & Hamer (2012) and Pingram et al. (2016), and for fish in David et al. (2016). The survey design involves randomly selecting wadeable sites on developed land with known probability of inclusion using the survey design software package spsurvey (https://cran.r-project.org/web/packages/spsurvey/index.html). The target population for site selection was non-reference (i.e., on developed land), non-tidal, perennial, wadeable streams. Equal numbers of $1^{st}$, $2^{nd}$, $3^{rd}$ and $\geq 4^{th}$ order streams were selected (i.e., balanced unequal probability design) using the River Environment Classification (REC, version1; Snelder & Biggs, 2002) river network layer as the sample frame. This survey design ensures an even spread of sites across stream sizes so that sampling sites are not skewed towards small streams which comprise most of the stream network length regionally. However, it should be noted that the REC network layer does not identify all small perennial headwater streams, and therefore the target network length will be underestimated 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 which can be quantified as either a length (km) of stream length, or as a proportion of overall stream length.

In the first round of sampling, between 2009-2011, potential sites were screened and defined as non-target if they were non-wadeable, non-perennial, drains in artificial catchments, entirely in native forest ('reference condition'), or represented non-target habitats (e.g., lakes, wetlands) or REC inaccuracies (see Table A 1 for estimated network lengths). Candidate sites were initially screened using aerial photos to determine whether they could form part of the target population. Further details of candidate site selection and screening are provided in Collier & Olsen (2013). Up to 60 target sites are sampled each year on a rotating 3-yearly basis. This provides up to 180 samples from 180 different sites over a given 3-year period, and then these same sites are sampled again over the subsequent 3-year period. As sites occasionally need to be replaced, at the 2018-2020 rotation a total of 621 sites have been screened. Of these 266 were evaluated as target sites, a proportion of which were not sampled mainly because of access difficulties, leading to 174 sites being sampled (Figure 1). Minor variations to the sites making up the survey network have been implemented between 3-year rotations for both the invertebrate and fish sampling programmes. 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 selection. Estimated target and non-target network lengths can vary slightly between completed rotations depending on the nature 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 (i.e., Collier & Hamer, 2012; Pingram et al. 2016; Pingram et al. 2019). Based on this approach it is possible to estimate the relative proportion and length of wadeable streams on developed land represented as part of the wider stream network at large.

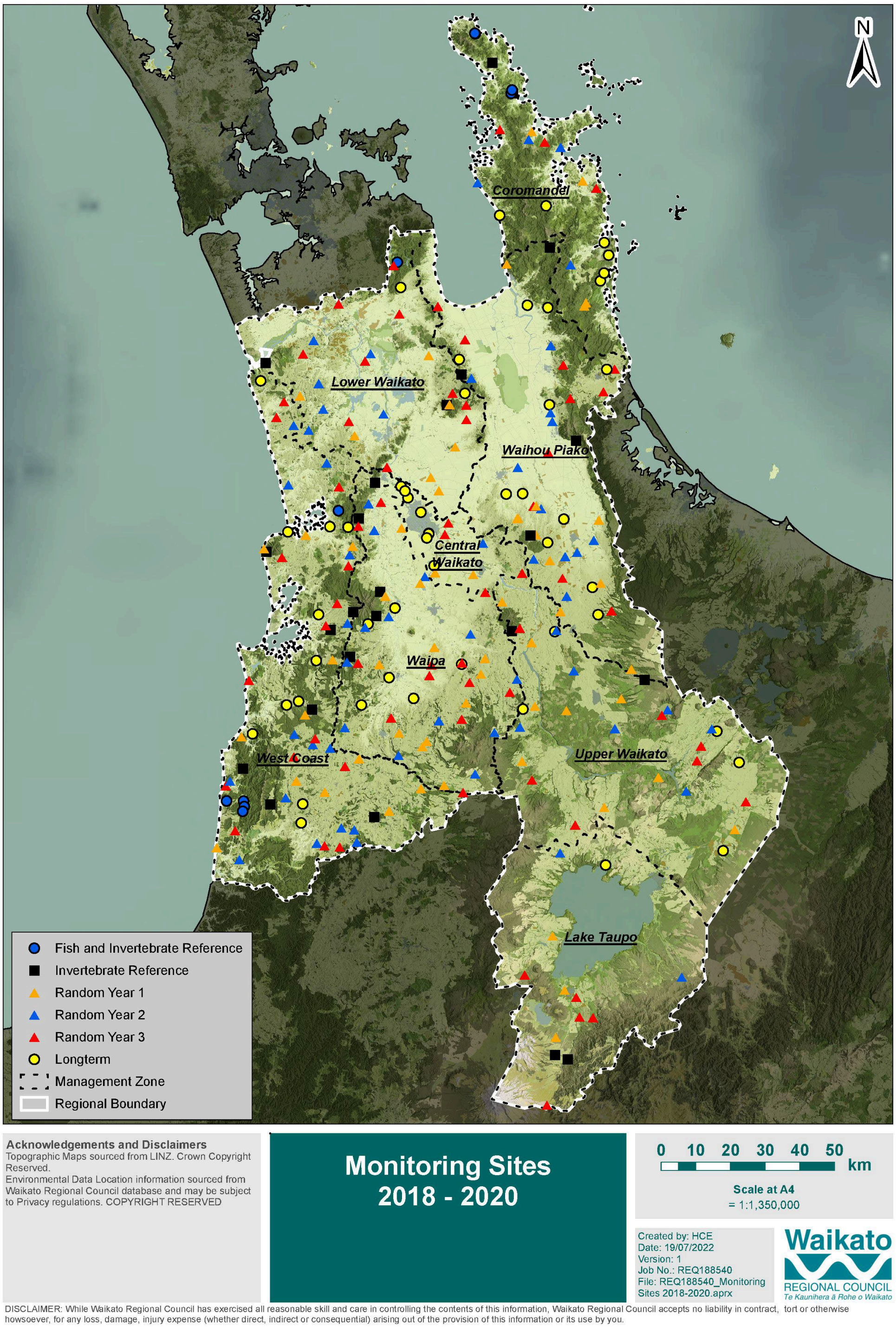


**Figure 1: Map showing approximate locations of monitored sites across region. Sites shown are those sampled 2018-2020. Management zones are present Integrated Catchment Management Zones.**

### *Spsurvey statistical analyses and estimates*

The R software (R Core Team 2019), package 'spsurvey' (version 4.1.0; Kincaid et al. 2019) was used to estimate the percentage and total length of wadeable streams on 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. Because the network design involved unequal probability of selection to achieve balanced numbers of 1st, 2nd, 3rd and ≥4th order sites from the sample frame, it was necessary to adjust the data for the known probability of site selection, rather than being a simple random sample. This adjustment enables calculation of an unbiased and appropriately weighted estimate of stream length in a given condition band, 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). Proposed draft freshwater management units (akin to the present catchment management zones) were used as subpopulations in the spsurvey analyses. Target stream length (and proportion of network) is not evenly distributed between FMU's (nor is non-target reference condition or non-wadeable stream length), and as a result the number of sites in a given FMU is reflective of the proportion of target stream length. 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 were produced at both the regional and FMU scale, and for the region through time. Regional patterns through time were visualised using boxplots and comparisons between the 2009-2011 and 2018-2020 rotations were undertaken for categorical and continuous variables using the change.analysis function in spsurvey, which provides an estimate of population change. Only values where upper and lower 95% confidence intervals were both positive, or both negative, were considered significant.

### *Target and non-target stream length*

Based on the most recent rotation, target streams are expected to represent around 38% of the REC (1) network length (or c. 14,500 km; Figure 2), forested sites with >80% upstream catchment in native vegetation are expected to account for another c. 17% (c. 6500 km), and non-wadeable (for sampling purposes) rivers another c. 8%. Target stream length differs by FMU with the largest length being in the West Coast FMU (c. 3200 km), and the shortest in the Coromandel FMU (c. 925km); this is determined by a range of factors including the relative proportions of non-wadeable and reference condition (native forest) reaches in each FMU. For the 2018-2020 rotation, surrounding land-use at sampled sites was predominantly pastoral (c. 69% of sites), with the remainder made up of native forest or shrubs (13%), exotic forestry (9%), retired pasture (6%), horticulture and urban (each <3%; Table A 1).

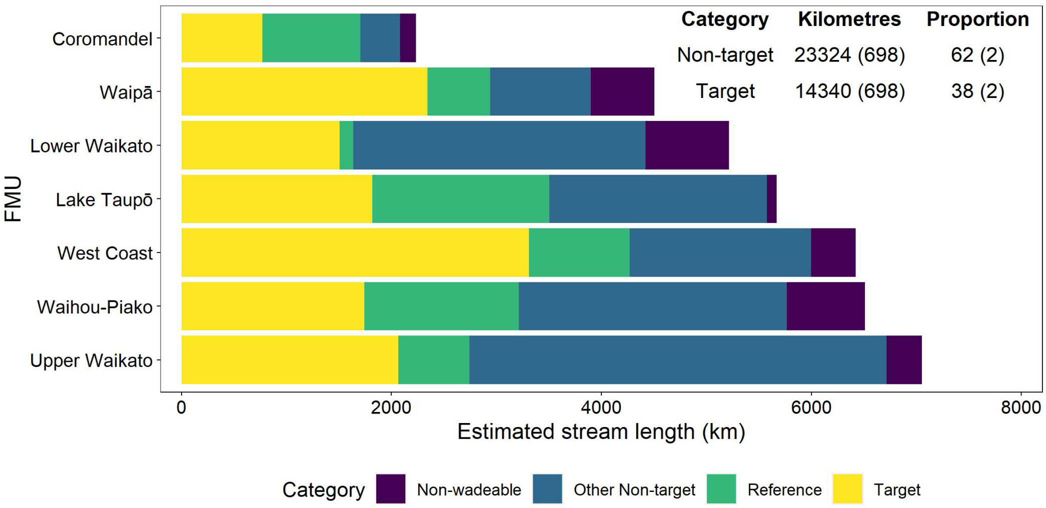


**Figure 2: Estimated classifications of Target (perennial, wadeable streams on developed land) and Non-target stream lengths by FMU. Non-target is represented in this figure by non-wadeable reaches, reference condition (>80% native vegetation), and other (which includes REC reaches that were assessed as dry, intermittent, tidal, lake or wetland, inaccurate, or artificial). Inset table are overall regional estimates (± 1 SE; see Table A 1 for more details).**

### *Native forest reference condition network*

The reference network is comprised of 35 sites (Figure 1), predominantly located in catchments with >80% unmodified native vegetation cover (see Collier et al. 2007), which are sampled annually. These sites are used to provide an undisturbed baseline 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 et al. 2005, 2007). Sites are spread across geographic zones within the region and across four dominant stream types identified by Level 3 of the REC. Twenty-five of these sites are utilised for macroinvertebrate comparisons, and eleven for fish (with one semi-reference site). Fish reference sites are further selected to be free of non-natural downstream barriers to migratory species (David et al. 2016). Each reference site was sampled up to three times during the 3-year study period. Reference site selection was based on achieving a spread of sites across geographic zones (Collier et al. 2007, Collier & Hamer, 2012).

## 2.2 Sampling period

Sampling was undertaken during the austral summers from 2018–2020 (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 invertebrate crews visiting and where possible, as close to the previous rotation sample date (within that month). 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 proximal to that flow site recorder. This precautionary approach is to alleviate bed moving flow events potentially altering the structure and function of local communities (in the short term) from that exhibited during typical base-flow conditions. Data for fish species elsewhere in New Zealand rivers suggests that different fish may respond differentially to flood events with some species apparently affected and others less so or not at all (e.g., Hayes et al. 2010; McEwan & Joy 2013).

## 2.3 Invertebrate sampling protocols

***Collection***

Macroinvertebrates were sampled over a 100 m reach using the standard protocols for New Zealand wadeable streams as described by Stark et al. (2001). Briefly, in streams dominated by hard substrates (i.e., those with >50% benthic substrates made up of gravels, cobbles, boulders, or bedrock) up to five samples from riffles were taken using an aluminium D-net with a 0.5 mm mesh, so that c. 0.5–1.0 $m^2$ of riffle habitat was sampled and pooled into a composite sample. In streams where stony substrates were not dominant substrates (i.e., those with >50% benthic substrates made up of sand, silt, or clay), sampling involved brushing wood, and jabbing the net in and along submerged macrophytes and bankside vegetation at up to 10 locations in run habitats, so that an area of c. 3 $m^2$ was sampled and pooled into a composite sample. The composite macroinvertebrate sample for each site was preserved in a final concentration of 70% isopropanol and later sorted using a 200-fixed count followed by scan for rare taxa (Protocol P2 of Stark et al. 2001) by EOS Ecology Ltd with periodic quality assurance of invertebrate identification undertaken by NIWA.

***Indices***

Three main indices are calculated from sorted and identified macroinvertebrate samples: the Macroinvertebrate Community Index (MCI), the Quantitative MCI (QMCI), and the Average Score Per Metric (ASPM) which is an aggregation of EPT* richness, %EPT* abundance and MCI standardised to nationally set minimums and maximums (NPS-FM 2020); this is different to ASPM results in previous reports (e.g., Collier & Hamer 2012, Pingram et al. 2016) where values from regional reference (native forest) sites were used for the standardisation in a particular year, as originally developed by Collier (2008). The acronym EPT refers to the sensitive groups Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). Metrics derived from EPT exclude Hydroptilidae (denoted by "*") because the commonest members of this family can proliferate in degraded conditions characterised by growths of filamentous algae (Maxted et al. 2003). 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 consistency through time, Dolomedes spider were omitted from calculations as this is the approach traditionally employed in Waikato Regional Council reporting. For taxa with no score listed, the score at the next taxonomic level up was used, where these were available, otherwise taxa were excluded from MCI and QMCI calculations. Soft-bottomed or hard-bottomed MCI and QMCI values were calculated based on the sampling protocol used at individual sites. Where both a hard-bottomed and soft-bottomed sample were collected the hard-bottomed was used based on the assumption that the site was likely to be naturally hard-bottomed. Scores were then assigned to the numeric attribute states listed in Tables 14 and 15 of the NPS-FM (2020; see Table 1), these bands differ slightly from those presented in earlier reports which used the degradation classes of Stark & Maxted (2007).

**Table 1: Interpretation of Macroinvertebrate indices (reproduced from NPS-FM 2020). [1] quality class applies to values derived using hard or soft-bottomed scores as appropriate.**

| 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 – 130 | 5.5 – 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 – 110 | 4.5 – 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. | | | 0.4-0.6 |
| **C** | Macroinvertebrate communities have moderate-to-severe loss of ecological integrity. | | | 0.3-0.4 |
| **D** | Macroinvertebrate communities have severe loss of ecological integrity. | | | < 0.3 |

## 2.4 Fish sampling protocols

***Collection***

Fish surveys were carried out at 149 of the developed land sites using the wadeable stream survey methods of Joy et al. (2013). Briefly, survey reaches were 150 m in length (David et al. 2010) and centred on the same 100 m reach used for macroinvertebrate collection, with the inclusion of an additional 25 m up- and down-stream. In suitable streams all habitats were electro-fished using a NIWA Kainga EFM300 backpack electric fishing machine in an unbiased fashion. 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 provide comparable information for the 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.

***Indices***

First pioneered in the United States of America, the Fish Index of Biological Integrity (Fish IBI; Karr 1981, 1987, Karr et al. 1986), was subsequently modified and adopted for use in New Zealand (Joy & Death 2003, 2004). A Waikato region specific fish IBI was later developed (Joy 2006), and then refined further using a quantile regression approach (Joy 2007). The quantile index takes into account fish diversity for distance inland and elevation, two variables known to be strong drivers explaining fish community composition in New Zealand. In addition to taxonomic richness, the index also incorporates three metrics related to habitat guilds used by different specialist fish species (riffle, benthic pool, pelagic pool), one metric related to tolerance to different environmental variables and one metric related to the proportion of native to exotic species present (excluding trout). A Fish IBI was incorporated as an attribute in the National Policy Statement for Freshwater Management (NPS-FM) in 2020. The NPS-FM requires regional councils to survey fish communities to calculate IBI scores and, at a minimum, develop action plans to achieve target states determined in consultation with communities. As variation in fish community composition in New Zealand has been demonstrated to be more affected by landscape scale factors rather than instream variables and the mode of action for nutrient and sediment stressors on fish populations may differ to that for macroinvertebrates (Lange et al. 2014a,b), they provide a complimentary lens to macroinvertebrates for identifying environmental impacts.

The national fish IBI (NPSIBI hereon) uses data calculated from sites surveyed and logged in the NZ Freshwater Fish Database between 2010-2017 to develop relationships for comparison against. Records that used electric fishing over at least 150 m were used, as recommended in Joy et al. (2013) and where sites were in the database multiple times, a random occasion was selected. The bands used for fish IBI (which included trout as an 'honorary native') correspond to: A-band (top 25% nationally), B-band (top 50%), C-band (top 75% nationally), and D-band (the worst 25%) (Table 2). WRC have an extensive fish monitoring programme which has enabled the development and reporting of a regionally specific fish quantile IBI (Waikato QIBI hereon; Joy 2007) based on local data (see Table 2 for bands). Both are presented in this report to allow regionally specific issues to be targeted and allow national comparison. It is worth noting that despite similar calculation approaches the banding approaches differ markedly (note: at the time of writing MfE is in the process of reviewing how scores at individual sites are derived, and these may require review in future reporting). Although both the NPSIBI and the Waikato QIBI are presented here we consider outputs from the Waikato QIBI to be a more accurate representation of fish community health across the Waikato region.

**Table 2: Interpretation of Fish indices (reproduced from the NPS-FM (2020), and Joy (2007)).**

| Band | Description | NPSIBI | Waikato QIBI |
|---|---|---|---|
| **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 | |
| **A** | Comparable to the best situations without human disturbance; all regionally expected species for the stream position are present. | | 47 - 60 |
| **B** | Species richness and habitat or migratory access reduced. Shows some signs of stress. | | 36 - 46 |
| **C** | Species richness is reduced. Habitat and or access is impaired. | | 27 - 35 |
| **D** | Site is impacted or migratory access almost non-existent. | | 6 - 26 |
| **E** | No Fish | | < 6 |

## 2.5 Physical habitat and water quality assessment

***Assessments***

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 (also reported here). To compliment this, since 2015 a nationally consistent Rapid Habitat Assessment (RHA) is also undertaken (see Clapcott 2015 for details) and yield similar overall results (Figures A 1 & A 2). Both assessments can then be summed to produce a 'total score' out of 160 and 100 respectively.

At each site both the invertebrate and fish monitoring teams recorded point in time measures for stream temperature, dissolved oxygen and conductivity using a portable handheld meter (Hach HQ40d). Shade was measured using a densiometer (Forestry Suppliers, U.S.A) in the middle of the stream every 30 m and 20 m in fish and macroinvertebrate surveys respectively. Measures were taken by holding the unit in the palm of the hand at hip height and counting the total number of filled squares (out of a total of 96) reflected by the overhead canopy onto the gridded convex mirror. 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 a mean calculated from the average of the four readings at each subreach (4 readings x 5 subreaches = 20 values). For simplicity, results presented here are those for the 100 m reach collected during the macroinvertebrate sampling.

Percent bed cover by substrate size classes was estimated by undertaking a modified Wolman assessment of streambed particles, whereby 100 particles are sampled across five evenly spaced transects (20 per transect), using the intermediate axis dimension (width) to place the substrate into size divisions. At each transect the relative proportion of different periphyton and macrophyte groups was also recorded following the methods outlined in Collier et al (2014) for macrophytes and the RAM2 from Biggs & Kilroy (2000) for periphyton.

***Indices***

Qualitative Habitat Assessment (QHA) scores are derived by adding qualitative assessments of 8 measures of riparian, bank, and channel condition on a scale of 1 (lowest condition) to 20 (highest condition; see Collier & Kelly 2005). Derivation of periphyton and macrophyte indices follow the methods described in Collier et al. (2006, 2014). The indices reported here are a Periphyton Proliferation Index modified to include medium mats and short filaments as a more inclusive measure of periphyton cover (PPI^), a periphyton weighted composite cover (after Matheson et al. 2012) also modified to include short filaments and medium mats, as a more inclusive overall indicator of periphyton growth (WCC^). Macrophyte cover is reported using the Macrophyte Total Cover (MTC; % planar surface covered), Macrophyte Channel Clogginess (MCC; areal cover weighted by plant height class), as developed by Collier et al. (2014). As fine sediment deposition is a significant driver of ecological communities in some streams it is summarised here as two indices: i) percent silt cover (<0.06 mm; %Silt) to allow for some sites in the Waikato region having naturally sand or clay-based substrates, and ii) the percent cover by all particles <2mm in size (i.e., Sand, Silt, and Clay, %SSC hereon), to provide some consistency with the NPS-FM. Values from these assessments were then placed into ecosystem health 'bands' to allow extent estimate to be derived, details 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). | Collier & Kelly, (2005) |
| **Rapid Habitat Assessment (RHA)** | >85 | 55-85 | 25-54 | <25 | Based on groupings provided in assessment | Clapcott, (2015) |
| **Periphyton Proliferation Index (PPI^)** | <10 | 10-20 | 20-40 | >40 | Recreational cover limits in Waikato Regional Plan used as guide | Collier et al. (2014), Section 3.2, Waikato Regional Plan |
| **Periphyton Weighted Composite Cover (WCC^)** | <20 | 20-39 | 40-55 | >55 | Proposed provisional guidelines | Matheson et al. (2012) |
| **Macrophyte Total Cover (MTC)** | <10 | 10-20 | 20-40 | >40 | Adapted from recreational cover limits for periphyton | Collier et al. (2014), Section 3.2, Waikato Regional Plan |
| **Macrophyte Channel Clogginess (MCC)** | <10 | 10-20 | 20-40 | >40 | Adapted from recreational cover limits for periphyton | Collier et al. (2014), Section 3.2, Waikato Regional Plan |
| **Streambed cover by silt (%Silt)** | <10 | 10-20 | 20-40 | >40 | Derived from literature thresholds, but restricted to silt cover estimates | Burdon et al. (2013) |
| **Streambed cover by Sand, Silt and Clay (%SSC)** | <10 | 10-20 | 20-40 | >40 | Derived from literature thresholds for deposited fine sediment | Burdon et al. (2013) |

# 3 Results

## 3.1 Biological condition indices

### 3.1.1 Regional – STATE

The regional median condition for wadeable streams on developed land was estimated to fall within the C band of NPS-FM Tables 13-15 for MCI, ASPM (Figure 3, grey boxes – centre panels), and the Waikato QIBI (Figure 4), while QMCI fell into the D band (Figure 3). Across the Waikato, the proportion of wadeable stream length on developed land in a given NPS attribute state for each of the macroinvertebrate indices evaluated was similar. Regionally, D band (below national bottom line) condition is estimated to represent the ecological condition of the largest proportion of target streams (Figure 3 for data collected 2018-2020, and Table A 2 for all rotations). Estimates for D band extent ranged from c. 40% for MCI (equivalent to >5,500 km, Table A 2) to c. 60% for QMCI (equivalent to >8,500 km, Table A 2), with the remainder spread across A-C bands. For fish communities the median condition was B band based on the national NPSIBI. For the Waikato QIBI, <25% of stream length is estimated to be in D band (Figure 2, equivalent to c. 3,500 km, Table A 2), while the NPSBI was estimated to be <5% (Figure 4 for data collected 2018-2020, and Table A 2 for all rotations).

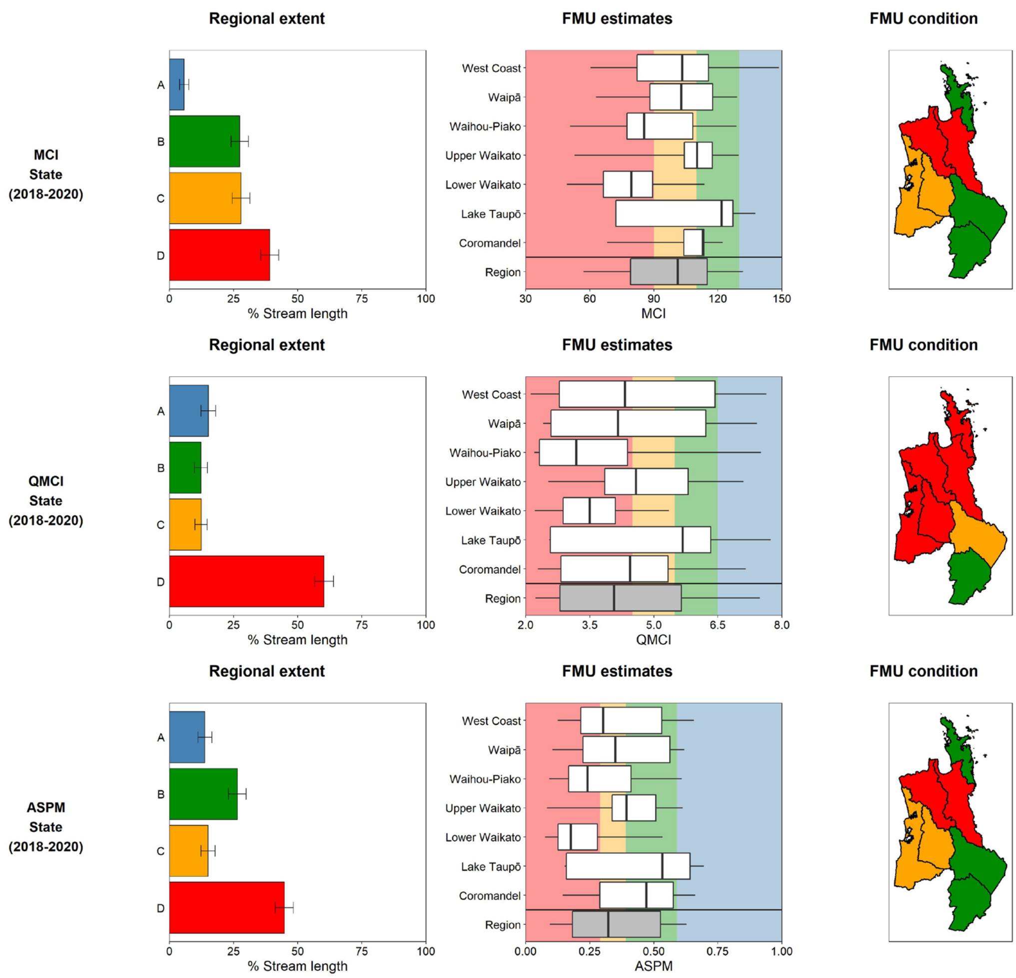


**Figure 3: Regional extent (estimated proportion of wadeable stream length) in a given NPS-FM (2020). Macroinvertebrate attribute state, left. Estimated distribution of macroinvertebrate indices values, centre; and proposed FMU's graded by estimated median macroinvertebrate attribute value, right.**

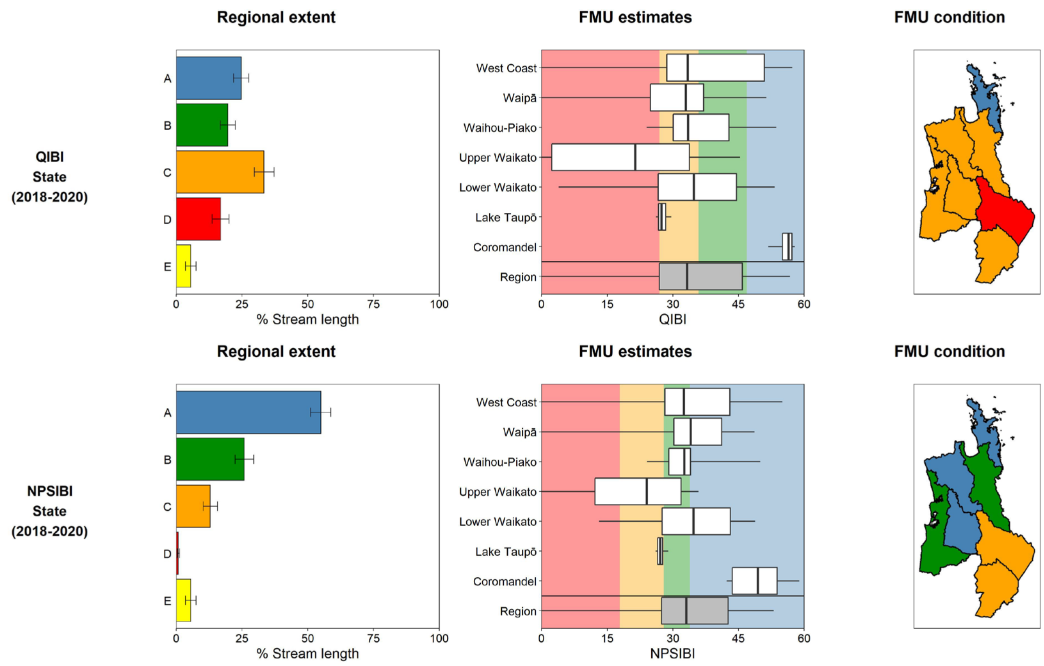


**Figure 4: Regional extent (estimated proportion of wadeable stream length) in a given fish attribute state (Waikato QIBI and NPSIBI), left. Estimated distribution of Fish indices values, centre; and proposed FMUs graded by estimated Median Fish attribute value, right. NB: 'E band' represents sites with no fish recorded.**

### 3.1.2 Freshwater Management Units (FMU's) - STATE

Median MCI scores ranged from 79.5 in the Lower Waikato (including central Waikato) to 121.7 in the Lake Taupō FMU (Figure 3). Three FMU's had median values equivalent to B Band (Coromandel, Lake Taupō, Upper Waikato), two in C Band (Waipā, West Coast), and two in the D band (Lower Waikato (including central Waikato), Waihou-Piako). Median QMCI scores ranged from 3.2 in the Waihou-Piako FMU to 5.7 in the Lake Taupō FMU. Two FMU's had median QMCI above D Band, these were Upper Waikato (C band) and Lake Taupō (B Band). In terms of relative extent of attribute state categories, the two predominantly lowland FMU's (Lower Waikato and Waihou-Piako) had the highest proportion of D band stream length (up to nearly 75%), although the Waipā, Coromandel, and West Coast FMU's were >50% D band state for QMCI.

With respect to fish communities, median Waikato QIBI scores ranged from around 20 (D band, Figure 4) in the Upper Waikato FMU (C band for NPSIBI, Figure 4) to 56 (A band) in the Coromandel which largely reflects the influence of riverscape connectivity on the Waikato QIBI score between these units. The five remaining FMU's had median values equivalent to C band for the Waikato QIBI (Figure 4).

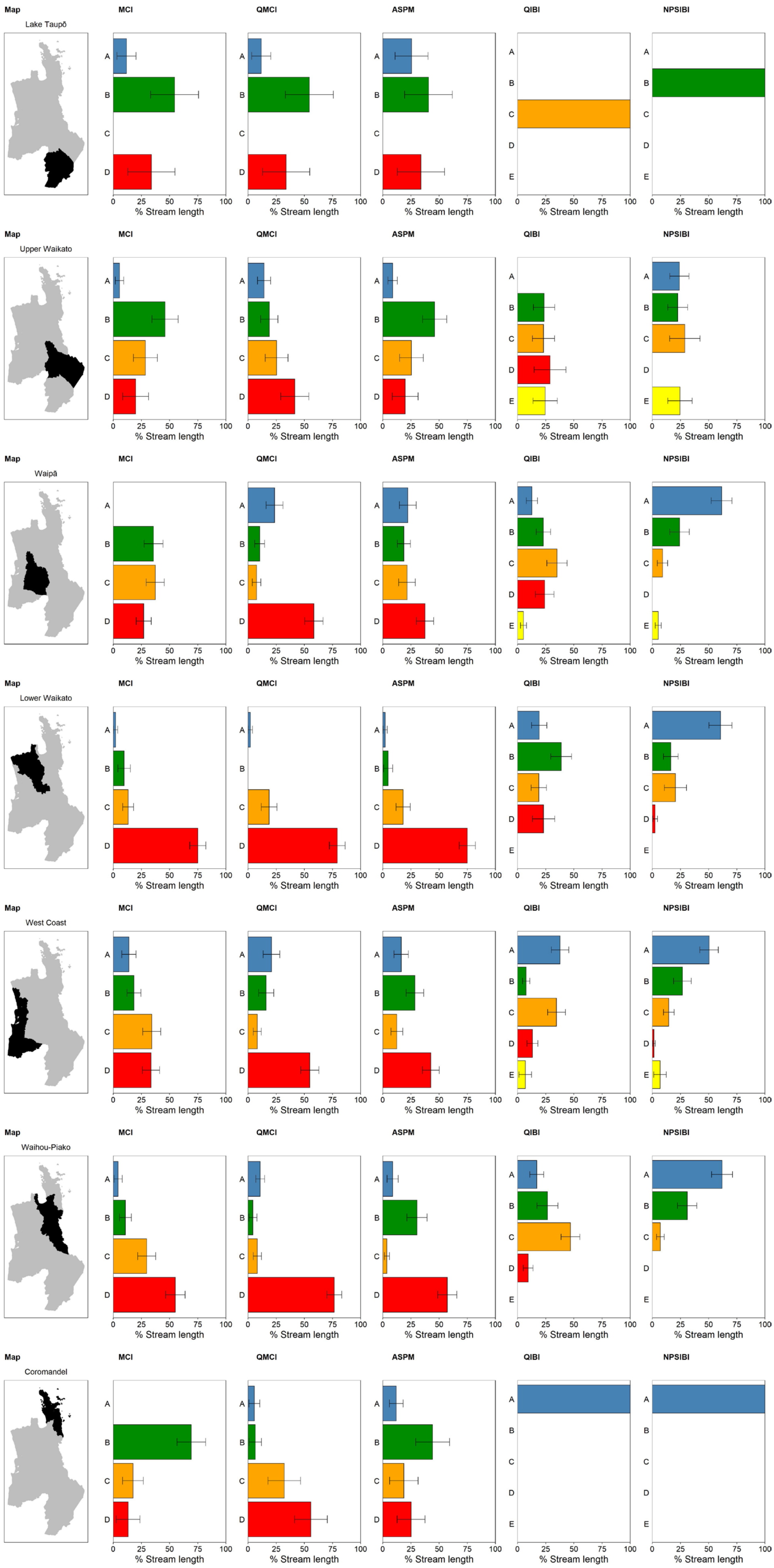


**Figure 5: Extent estimates of biological condition in streams on developed land (estimated proportion of wadeable stream length) for each proposed FMU.**

When considering expected fish diversity by FMU, the upper Waikato and Taupō units score poorly, or have naturally fishless sites, using the Waikato QIBI (Figures 3 and 5). This largely reflects the influence of multiple hydro dams on native fish diversity coupled with distance from the coast and the presence of introduced non migratory fish species. Despite access to the coast and few known barriers, around 60% of stream length in the Waihou-Piako FMU was estimated to score a C band or less using the Waikato QIBI banding (Figure 5). The FMU 'outlier' for highest Waikato QIBI scores and extent was the Coromandel unit where 100% of sites scored in the A band (Figure 5). Sites in the Coromandel FMU have close proximity to the coast, good riverscape connectivity, intact native forest headwaters, diverse range of habitat types and a general absence of introduced species. The unit with perhaps the greatest variability in Waikato QIBI scores and extent was in the West Coast FMU (Figure 4). While there are numerous stressors on developed land in this area, where land-use is mainly sheep, beef and forestry, there are also known anthropogenic barriers on larger rivers in this unit (e.g., Mokauiti). However, there are also numerous remote areas with relatively low impact for fish from land development. These sites, in association with low incidence of introduced species and close proximity to the coast, tend to reflect some of the higher Waikato QIBI (A band) scores in this management unit.

### 3.1.3 Regional - TIME

No statistically significant changes in estimated extent estimates of a given attribute state were observed when comparing between 2009-2011 and 2018-2020 rotations for any of the five main indices (Figure 6). Estimated mean values were relatively unchanged through time when compared to the first survey (2009-2011), although occasional minor differences were observed (Figure 6). Average fish community state could generally be considered 'moderate' using both regional and national narratives with the pattern relatively consistent across every three-year rotation completed since 2012 (Figure 6).**Error! Reference source not found.**

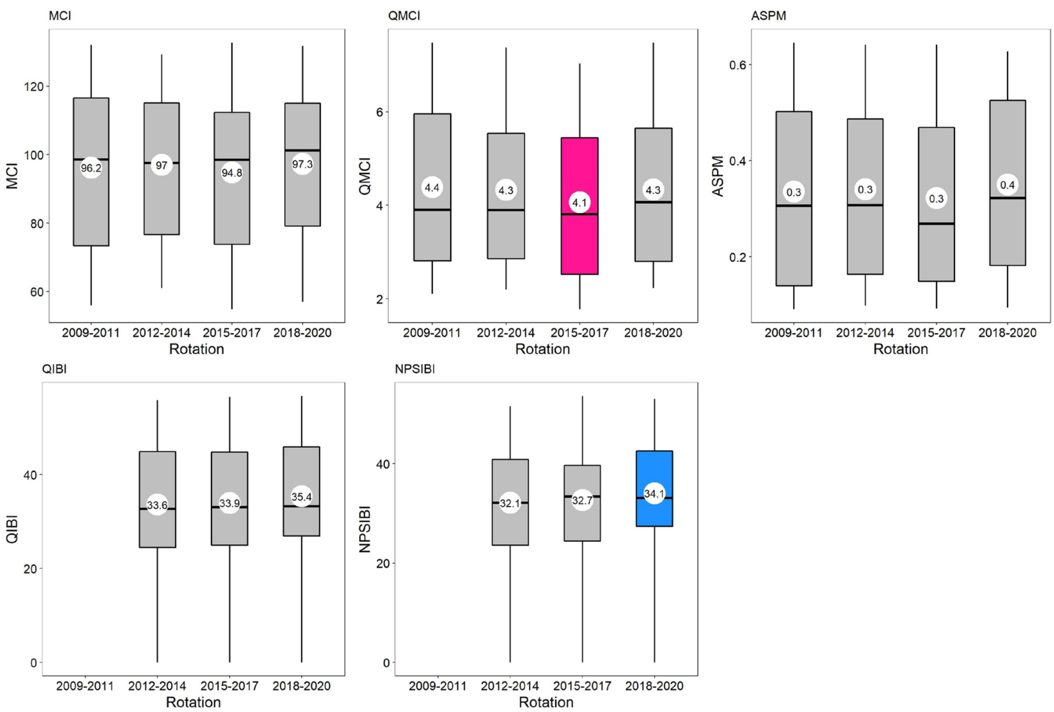


**Figure 6: Boxplots of estimated percentile (5th, 25th, 50th, 75th, 95th) and mean (white dots) values for selected macroinvertebrate and fish indices, through time for each rotation from 2009 to 2020. NB: for the 2009-2011 rotation the fish survey design was under development. Grey boxes indicate no statistically significant change, blue boxes a positive statistically significant change (improving condition), and pink boxes a statistically significant negative change (degrading condition), in mean values between the first rotation in 2009-2011 and any subsequent rotation.**

## 3.2 Habitat Quality

### 3.2.1 Regional

Both habitat assessments produced similar results. Overall median regional scores for both methods placed the majority of habitat quality into a 'C' or marginal state (see Table 3), represented by around 45-50% of the proportion of available stream length respectively for these two attributes (Figure 7). For both attributes, higher median values were recorded from FMU's in the eastern parts of the region compared to those FMU's to the west (Figure 7).

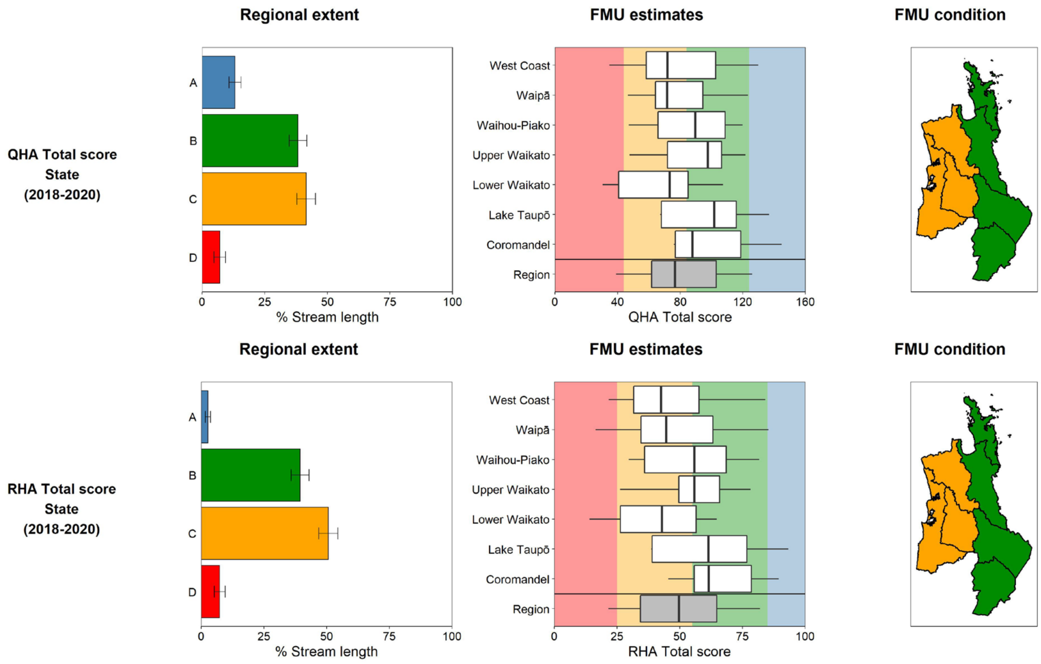


**Figure 7: Regional extent (estimated proportion of wadeable stream length) in the Waikato region in a given category of reach scale habitat quality, represented by total QHA (excluding Q9 – periphyton) and RHA scores, left. Estimated distribution of measured values, centre; and proposed FMU's graded by estimated median value, right.**

Excessive summer algal growth did not appear to be a great issue for the region only effecting up to 10% (PPI^) of the region's stream length, although there were some high values at selected sites (across most FMU's). Aquatic plants likewise were not a great issue for wadeable streams with the majority being good with only up to 30% of wadeable streams being considered poor for this attribute (Figure 8). This potentially reflects that low macrophyte cover tends to be evident in hard-bottomed streams, with higher cover observed at a larger proportion of soft-bottomed stream sites.

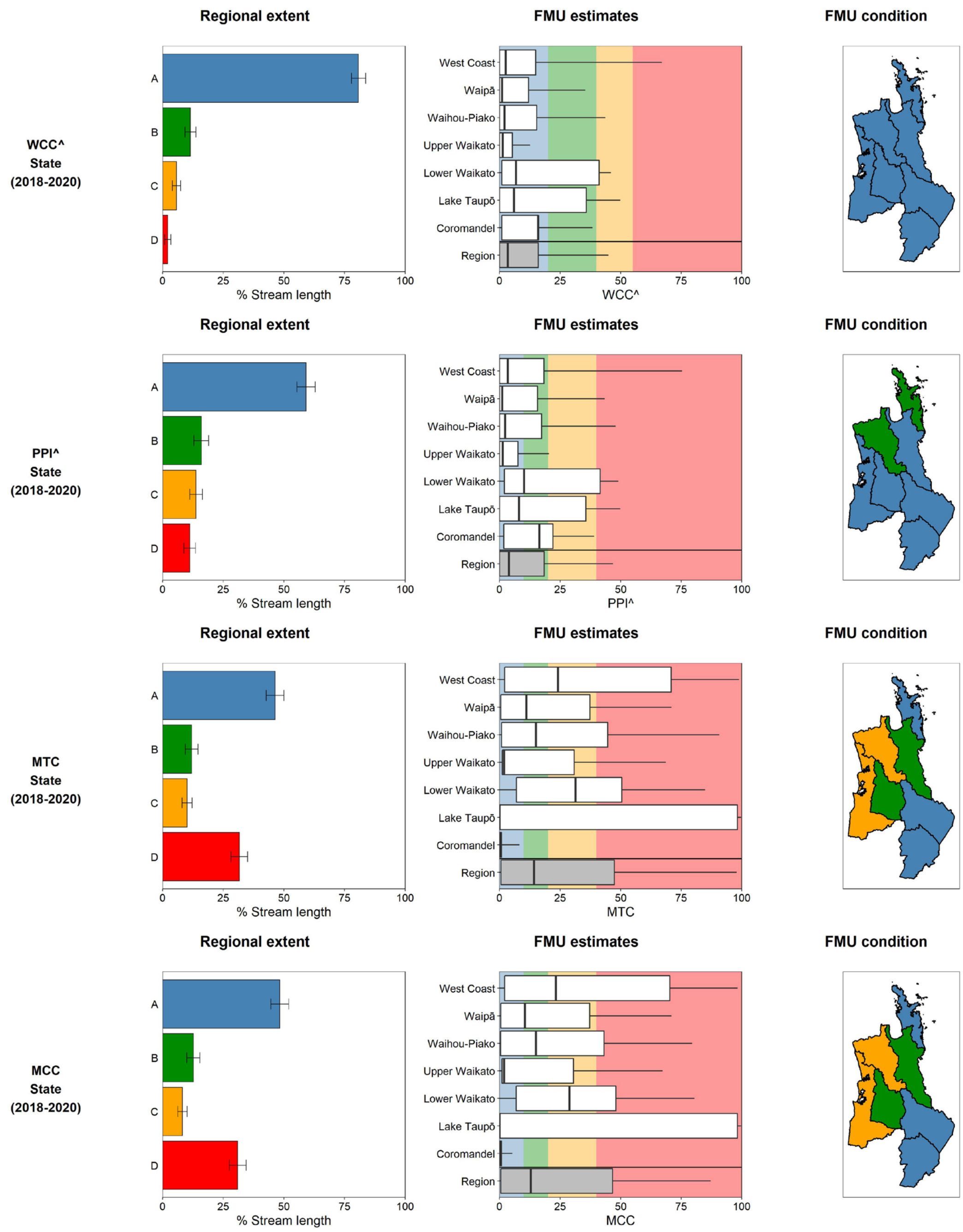


**Figure 8: Regional extent (estimated proportion of wadeable stream length) in the Waikato region in a given category of reach scale plant cover (Periphyton – WCC^ and PPI^; Macrophytes – MTC and MCC), left. Estimated distribution of measured values, centre; and proposed FMU's graded by estimated median value, right.**

While the sediment reporting method differs from that outlined in the NPS-FM it is still clear that 60% of the region's stream length is considered to have fine deposited sediment cover at levels beyond literature thresholds at which ecological communities are severely impacted (Figure 9; Table 3). If the analysis is limited to silt deposition, then >25% is similarly affected (Figure 9), and as with biological indicators the extent of the issue is not uniformly distributed between FMUs.

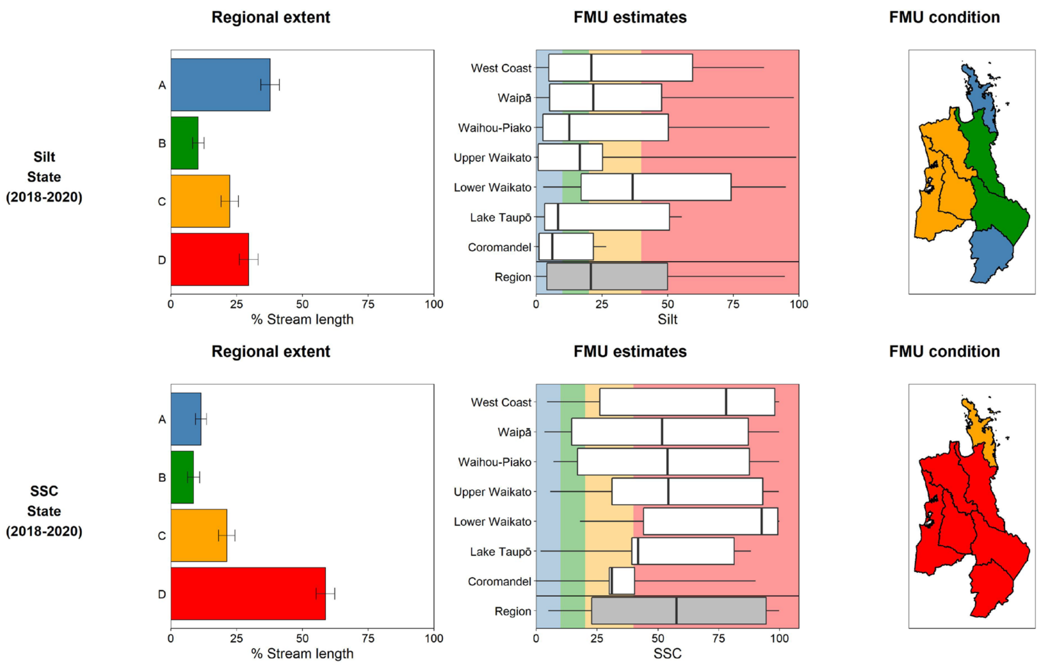


**Figure 9: Regional extent (estimated proportion of wadeable stream length) in the Waikato region in a given category of reach scale percent deposited fine sediment cover, represented by %Silt (i.e., particles <0.06 mm), and percent Sand, Silt and Clay (%SSC, i.e., all size classes <2mm), left. Estimated distribution of measured values, centre; and proposed FMU's graded by estimated median value, right**

As with biological attributes, there was little temporal change in qualitative habitat scores between 2009-2011 and 2018-2020. Although small but statistically significant improvements in mean values of some riparian and instream habitat sub-metrics were observed (Figure 10).

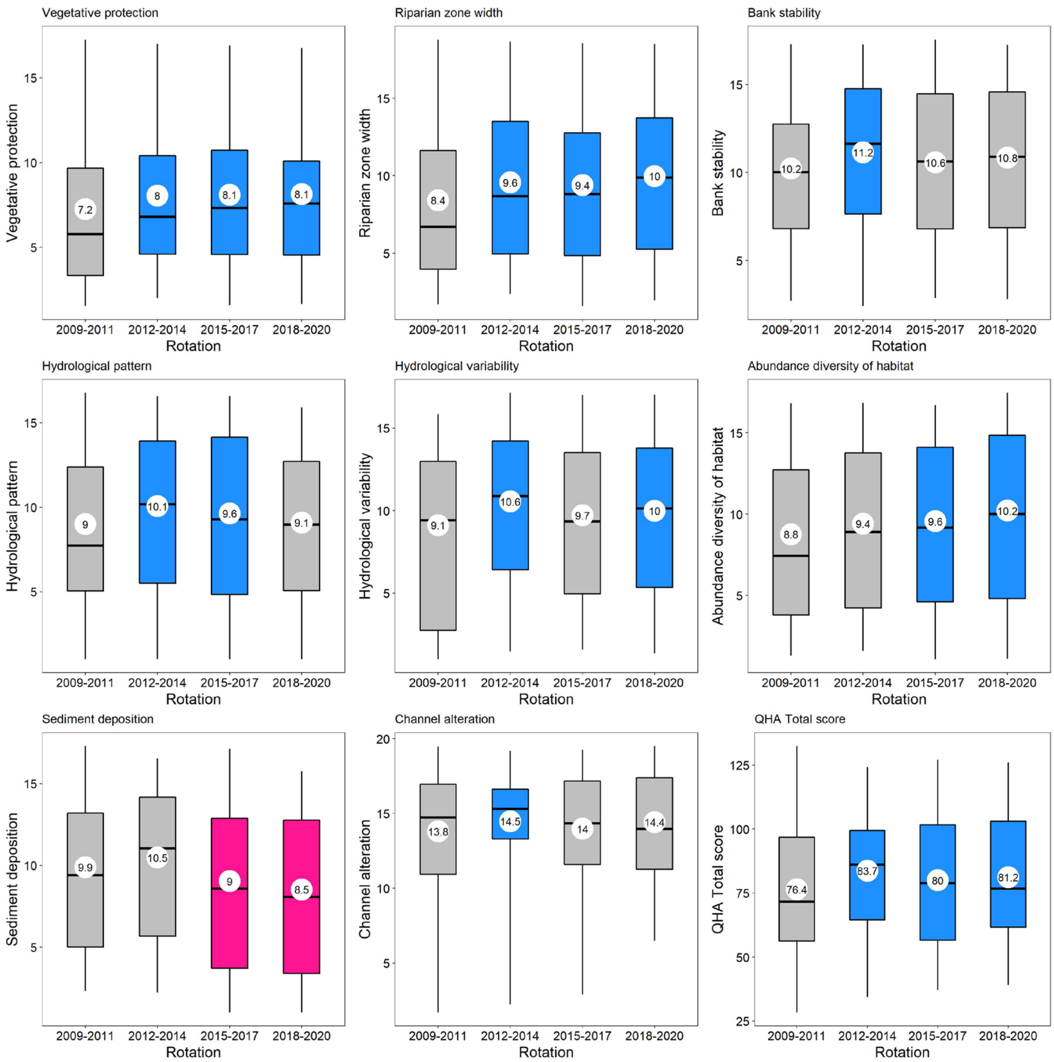


**Figure 10: Boxplots of estimated percentile (5th, 25th, 50th, 75th, 95th) and mean (white dots) values for qualitative habitat assessment variables and total scores (excluding Q9 – periphyton), through time for each rotation from 2009 to 2020. Grey boxes indicate no statistically significant change, blue boxes a positive statistically significant change (improving condition), and pink boxes a statistically significant negative change (degrading condition) in mean values between the first rotation in 2009-and any subsequent rotation. X-axis values are assessment scores out of 20 for individual variable and out of 160 for total scores.**

Plant cover at a reach scale, represented by both periphyton and macrophytes, was stable through time (Figure 11), as were the two deposited fine sediment indices presented in Figure 12, with no statistically significant change observed between 2009-2011 and 2018-2020 surveys.

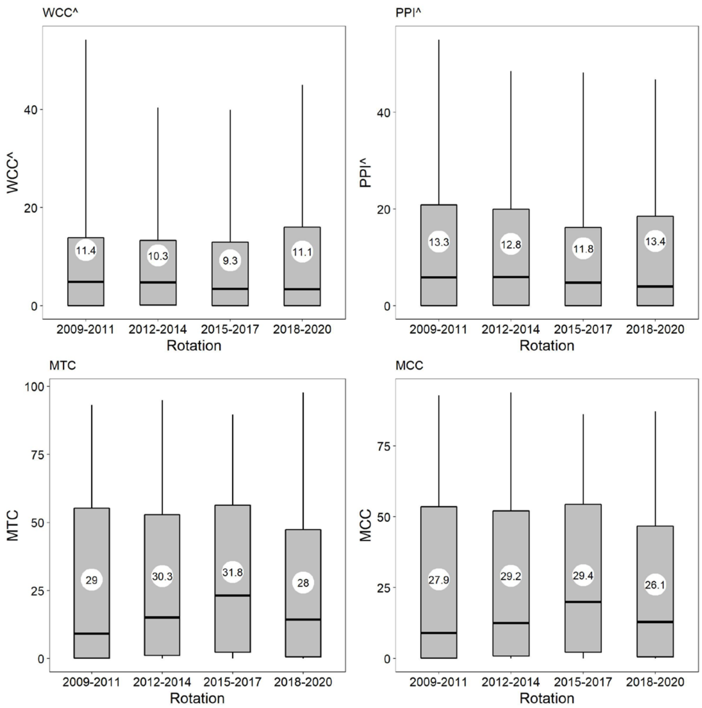


**Figure 11: Boxplots of estimated percentile (5th, 25th, 50th, 75th, 95th) and mean (white dots) values for measured plant cover. Represented by filaments and medium to thick mats (periphyton WCC^ and PPI^), and macrophytes (MTC and MCC). Grey boxes indicate no statistically significant change, blue boxes a positive statistically significant change, and pink boxes a statistically significant negative change in mean values between the first rotation in 2009-2011 and any subsequent rotation.**

As noted above, regional estimates mean and median fine deposited sediment cover at a reach scale are above values expected to have marked impacts on macroinvertebrate community composition, and subsequently indices of ecosystem health (e.g., MCI). There has been no significant temporal change in sediment cover in the last 10 years (Figure 12).

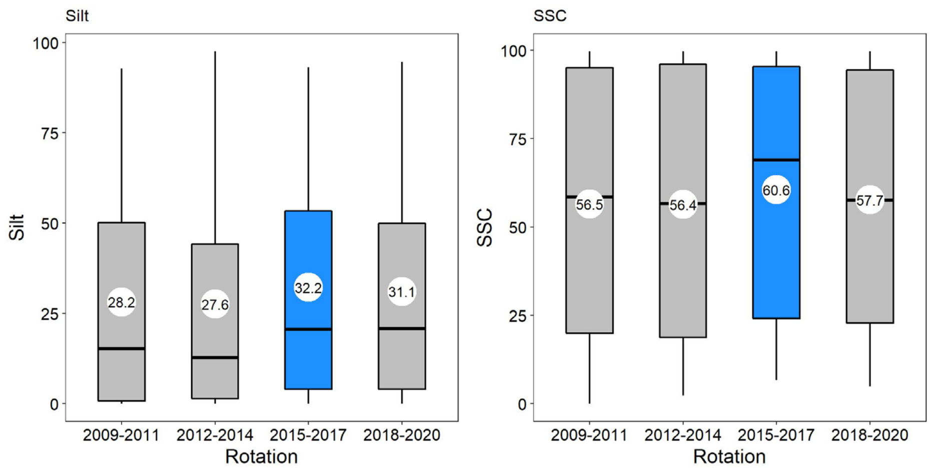


**Figure 12: Boxplots of estimated percentile (5th, 25th, 50th, 75th, 95th) and mean (white dots) values for measured percent fine deposited sediment cover. Represented by % Silt (i.e., particles <0.06 mm; left hand panel), and % Sand, Silt and Clay (%SSC, i.e., all size classes <2mm; right hand panel). Grey boxes indicate no statistically significant change, blue boxes a positive statistically significant change (degrading condition), and pink boxes a statistically significant negative change (improving condition), in mean values between the first rotation in 2009-2011 and any subsequent rotation. Note reversed colour interpretation from previous plots.**

## 3.3 Comparison with native forest sites

A comparison of ecological indices between wadeable native forest (reference condition) and developed land sites across 2018-2020 shows that in any given year a deviation from reference condition for streams in developed land is evident (Figures 13), highlighting published correlations between decreasing upstream native landcover and decreasing ecological condition.

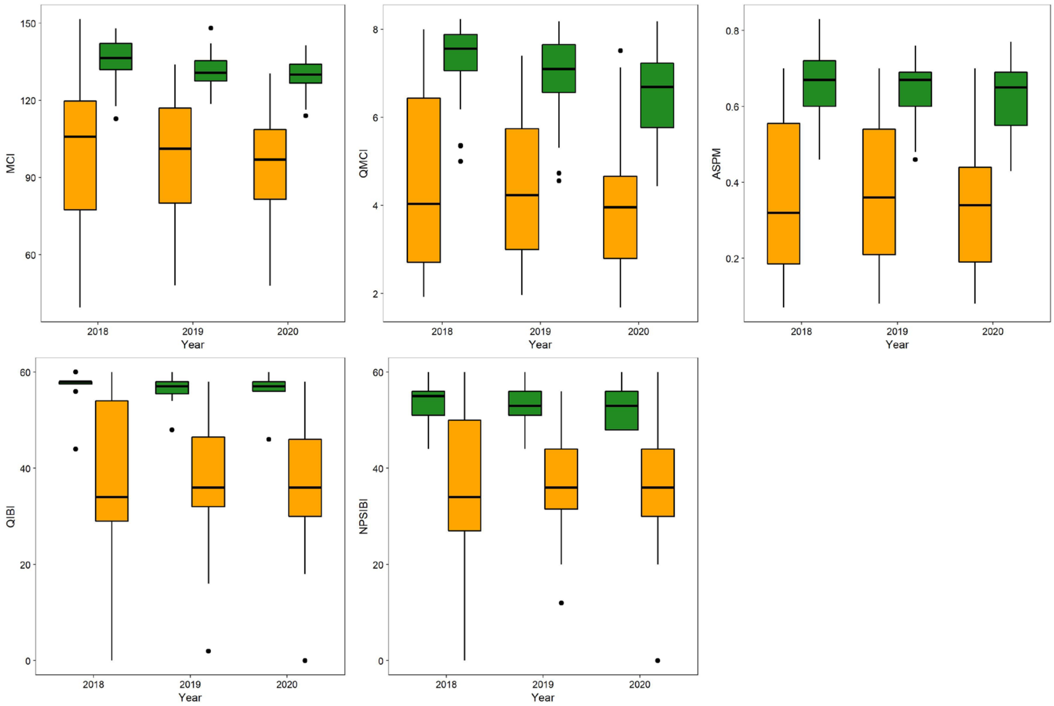


**Figure 13: Boxplots (5th, 25th, 50th, 75th, 95th percentiles, with outliers as dots) of measurement values recorded at probabilistic (orange) and native forest reference sites each year (green) for macroinvertebrate indices[1] MCI, QMCI, ASPM, and fish indices[2] – NPSIBI and Waikato QIBI. [1]based on macroinvertebrate reference sites, and [2]based on fish reference sites only.**

Median values from habitat assessments of native forest reference sites were around 30-40% higher than those from developed land sites in any given year (Figure 14).

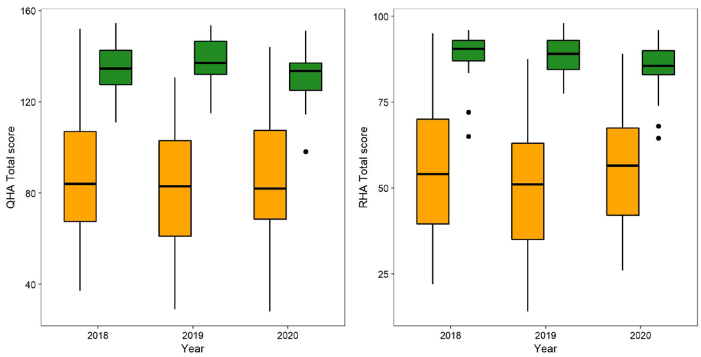


**Figure 14: Boxplots (5th, 25th, 50th, 75th, 95th percentiles, with outliers as dots) of measurement values recorded at probabilistic (orange) and native forest reference sites each year (green) for total scores derived from habitat assessments – QHA and RHA. [1]based on macroinvertebrate reference sites only.**

Although periphyton statistics were more similar, higher values were more frequently observed in developed land sites, as were macrophytes which were generally absent from native forest reference sites (Figure 15), likely due to the high shading by overhead cover at these sites.

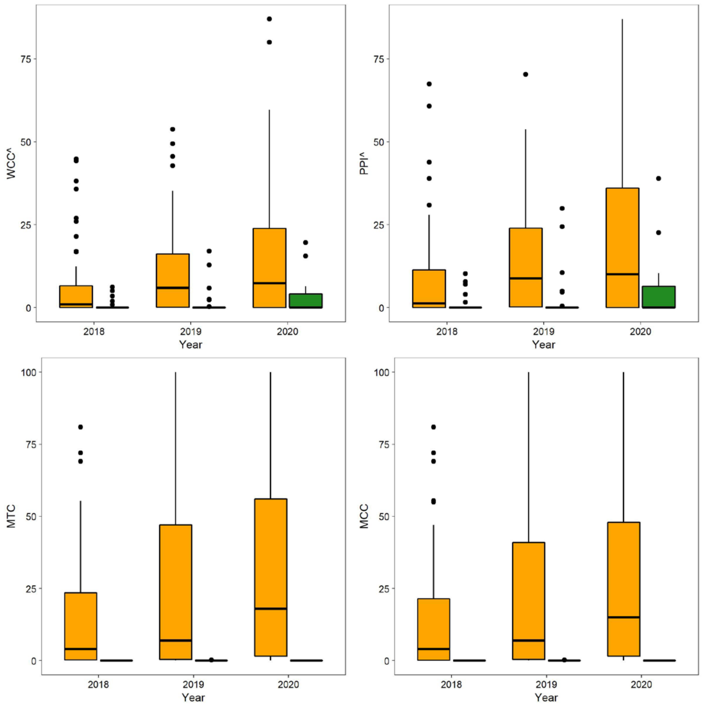


**Figure 15: Boxplots (5th, 25th, 50th, 75th, 95th percentiles, with outliers as dots) of measurement values recorded at probabilistic (orange) and native forest reference sites each year (green) for macrophyte and periphyton cover indices[1]. [1]based on macroinvertebrate native forest reference sites only.**

The distribution of fine deposited sediment measurements clearly shows the impact of upstream land-use on this driver of ecosystem health, with values from native forest reference sites representing a relatively small proportion of the measured range of developed land sites (Figure 16).

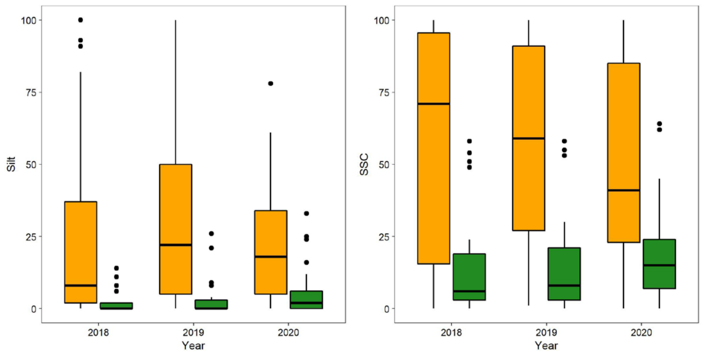


**Figure 16: Boxplots (5th, 25th, 50th, 75th, 95th percentiles, with outliers as dots) of measurement values recorded at probabilistic (orange) and native forest reference sites each year (green) for reach scale percent deposited fine sediment cover, represented by % Silt (i.e., particles <0.06 mm), and % Sand, Silt and Clay (%SSC, i.e., all size classes <2mm) [1]. [1]based on macroinvertebrate native forest reference sites only.**

# 4 Discussion

## 4.1 Ecological condition

At a regional scale, the probability survey design for perennial, non-tidal, wadeable streams on developed land in the Waikato region indicates that the condition of macroinvertebrate communities are of concern. Based on 2018 to 2020 sampling, around half (40-60%) of stream length on developed can be considered to have ‘poor’ ecological condition (based on MCI, QMCI and ASPM), this is synonymous to being in D band (or being below national trigger value) in the NPS-FM 2020. The remainder of stream length was largely estimated to fall into B and C bands. This suggests that ‘Action Plans’, policies, and interventions will likely need to be applied at wide spatial scales rather than localised sites (ideally at a catchment or FMU scale), highlighting the strength of broad-scale network designs for estimating overall condition at larger spatial scales. Fish communities, while under pressure in many locations due to a myriad of local, upstream, and downstream factors, have a lower estimated extent of poor condition than macroinvertebrate communities (although see below). Measurements of instream plant growth indicate that macrophyte cover is of concern at around 30% of the target network, and it is likely this is associated with low gradient and unshaded streams (Ellawala Kankanamge et al. 2019), with unshaded stream reaches estimated to account for around 50% of the stream network on developed land (Table A 2). Estimates of overall reach habitat conditions (excluding periphyton) indicate that a large proportion of the target stream network conditions are likely to marginal to poor, depending on the combination of answers, with lowest scores often being for the quality of riparian vegetation and fine deposited sediment components. Overall, the extent estimates of ecological condition are similar to those from estimates produced from the same monitoring network in previous rotations (2009-2011, 2012-2014, 2015-2017).

Reversing reach scale degradation is likely to require environmental improvements to occur at entire catchment or sub-regional scales in many cases (e.g., for habitat quality, riparian condition, sediment retention, total nutrients) before local improvements in ecological indices respond (esp. macroinvertebrates see Death & Collier, 2010; Stoll et al. 2016). Actions will also need to be sufficient and appropriate to drive biophysical responses in the stressors of most concern (e.g., Holmes et al. 2016; Pingram et al. 2019; Greenwood et al. 2021). However, policy and reporting targets will need to be flexible enough to accommodate lag times between the commencement of interventions and ecological responses in many cases (e.g., Sundermann et al. 2011; Leps et al. 2016), and more detailed indicators will need to be derived from ecological data if early signs of improvement (or further degradation) are to be detected (e.g., Graham & Quinn, 2020).

## 4.2 Land-use

When reporting on the state of aquatic ecosystems at a regional scale, it is important to understand the spatial and temporal context of land-use (and other potential stressors) that may be influencing observed results. Estimates of adjacent land use for the network range from around 70% for pasture to around 0.5% for urban uses. This makes intuitive sense when allowing for the network being designed with developed land as a target criterion (cf. ‘managed’) and overall regional land cover. Land Air Water Aotearoa (LAWA) (https://www.lawa.org.nz/explore-data/land-cover/; accessed 1 July 2022) estimates that, based on the New Zealand Land Cover Database, of the developed land area in the Waikato Region, more than two-thirds is used for primary production. The greatest area comprises exotic grassland (53% area), followed by exotic forestry (13%) and cropping and horticulture (1%), with urban land use presently occupying around 1% of land area. Spatial land-use is not static however, with large-scale conversions between different uses occurring over potentially short time frames. For instance, approximately 41,527 hectares (net) of pine forest was converted pasture between 2001-2018 (Hill & Borman, 2022). While concurrently, the urban and industrial footprints also increasing over the same period (Jones & Borman 2022), with much of the development focussed on the 'corridor' between Hamilton and Auckland, where conversion of predominantly pastoral to urban land has occurred (Jones & Borman 2022). In addition, more volatile but warmer and drier climatic conditions experienced within the Waikato region, particularly in the last decade (Koh & Jenkins 2022) have resulted in record-breaking groundwater recharge deficits in some river catchments (particularly those with predominantly spring flow sources), that will take many above-average wet years to replenish (Koh & Jenkins 2022). Coupled with a generally increasing demand for water, and associated increase in domestic and commercial consented ground and surface water takes, the cumulative effects of these activities, in association with climate, have resulted in diverse spatial and temporal effects on aquatic ecosystems across the region during the decade of investigation. Such dynamic temporal and spatial changes to land-use at this scale, generates substantial added complexity when attempting to identify key stressors impacting the health of aquatic wadeable ecosystem components. Despite these complexities, some general regional inferences for biological communities were apparent across the wadeable REMS network.

## 4.3 Fine deposited sediments

Fine sediment particles (sands, silts and clays) are well recognised as a key driver of aquatic fauna, particularly fish and invertebrates (Richardson & Jowett 2002, Rowe et al. 2002, Burdon et al. 2013). Excess fine deposited sediments can smother local stream bed surfaces reducing stream bed complexity for both invertebrates and fish resulting in negative effects for both feeding and reproduction. The relative impact and deposition of fine sediments at a reach scale is to some degree influenced by local stream gradient and power (with greater deposition and impacts more likely in lower gradient settings). Concerningly, fine deposited sediment (<2 mm) cover was estimated to be beyond ecological thresholds across a large proportion of the wadeable river network (around 60% is estimated to have a cover of >40% regionally). Ecologically, negative responses are well known to occur for both invertebrates and fish when fine sediments exceeded 20% surficial bed coverage (Burdon et al. 2013; Mathers et al. 2022), and this is estimated to occur at around 80% of the wadeable stream network on developed land. Even allowing for some sites having natural sand and clay substrates, silt (<0.05mm) cover exceeding 20% of the bed is expected to occur at more than 50% of the same stream network. Previous analyses using the same network of sites demonstrated that QMCI was twice as likely to be less than 4.0 and Waikato QIBI 'poor' if deposited silt cover is greater than approximately 20% (Pingram et al. 2019). Another factor for determining the response to catchment interventions is the accrual of deposited sediments through time, with larger/deeper deposits potentially taking many years, or requiring large flow events, to be transported further downstream. Although fine deposited sediment depth isn't measured by the REMS programme it could be an important local determinant in understanding potential ecological responses to environmental improvements at catchment or stream reach scales.

Excess fine sediment as a stressor of concern is not limited to the wadeable stream network, with other water quality and land-use programmes also independently reporting sub optimal results for this variable at the regional scale. Results from the water quality network (Ryan & Jenkins 2022) reported suspended sediment as generally poor (D band) across the region (except for the upper Waikato and Taupō areas). Although these water quality sites are generally at the lower parts of larger catchments the results indicate that fine particles are regularly being mobilised, while in suspension fine particles also impact on the base of the food web by reducing the feeding abilities of aquatic invertebrates and fish (e.g., Broekhuizen et al. 2001). Synonymous with silt deposition, sediment runoff is up to 5 times higher from pastoral land than that with forest cover (Ritchie 2012). Broadly speaking there appears to be an East/West divide in deposited fine sediment and qualitative habitat assessments (Figures 7 & 9) where softer more erodible sedimentary rock in western parts of the region may be playing a role in the differences observed between FMU's. Despite targeted work to control this stressor on some land-use types, there is likely to be a lag time before ecological responses to these actions are measurable across the network (Harding et al 1998). Furthermore, at the site level, fine sediment can arise from many sources including locally (e.g., from the erosion of streambanks lacking cohesion), from areas upstream (e.g., from either recent or historical forestry harvest), or from local overland flow through preferential flow paths (e.g., critical source zones; Ritchie 2012).

To respond to the challenge posed by fine deposited sediment in streams of the Waikato region, meaningful policies and FMU targets, and improved effectiveness evaluations for both for sediment deposition and ecological responses (including specific taxa), are required. Advances in sediment source tracking capabilities coupled with real time sediment samplers, new technology and loggers are likely to be required to generate sufficient data to understand the problem sufficiently for any given FMU (Westerhoff et al. 2022). Additionally, catchment based geomorphic assessments like those undertaken recently for the Waipā catchment (Wheeler et al. 2022) are likely to provide highly useful information for identifying where management actions are likely to be effective. Use of high-resolution LiDAR, and regional satellite imagery can also assist in identifying key input sources at larger landscape scales, and to target those areas accordingly, either through improved farm planting plans, forestry harvesting practices or river rehabilitation initiatives (e.g., reinstating or incentivising laterally unconfined floodplain function to encourage off channel sediment deposition). Based on the data generated from the current ecological programme and previous studies (e.g., Pingram et al. 2019), reducing fine silt deposition appears to be a meaningful policy objective for improving degraded aquatic ecological communities in many wadeable streams regionally. The 20% threshold applied in this report is supported by experimental studies (e.g., Burdon et al. 2013), and as a departure from native forest reference conditions (e.g., Pingram et al. 2019), however local catchment characteristics may also play a role in determining which size fractions are of particular concern (e.g., silt vs. sand, silt, and clay).

## 4.4 Parallels with water quality

Separately to the wadeable REMS monitoring programme, recent analysis of WRC's regional surface water monitoring programme from 1991-2020 has reported a trend of increasing concentrations of nitrogen in surface waters across 64% of regional monthly water quality monitoring sites and more deteriorating rather than improving trends for *E. coli* and turbidity (Vant 2021). Increases in nitrogen, and the deterioration of this water quality parameter across the wider Waikato region, was linked to the proportion of upstream catchment in pasture (Vant 2021). It is notable that poor banding scores for suspended sediment were also often associated with high *E. coli* concentrations at many sites (Ryan & Jenkins 2022). Perhaps unsurprisingly then and given the known sensitivity of invertebrates to nutrient enrichment and sediment, the mean and median condition for wadeable streams on developed land was estimated to fall within the C band for the Macroinvertebrate Community Index (MCI) and the Average Score per Metric (ASPM) under the NPS banding criteria, while the quantitative version of the MCI, the QMCI, fell into the D band. Thus, a combination of factors generally associated with streams flowing through developed landscapes such as reduced shading, increased fine sediment deposition, nutrient enrichment (which promotes algal growth), higher water temperatures, and reduced habitat quality are likely to be collectively responsible for the median estimated poor-fair (D-C) state of invertebrate communities across much (c. 70% or c. 10,000 kms) of the region's wadeable river network (outside of native forest). Regardless of the indices used, a significant portion of the region's waterway length falls below the national bottom line for NPS-FM attributes MCI, QMCI and ASPM. As a result, the NPS-FM (2020) directs that action plans are required to be developed and implemented to address this degradation. While nutrient concentrations can be high in some streams, suitable substrate may be a limiting factor in nuisance algal growths at a regional scale, however macrophytes can be problematic at some.

## 4.5 Connectivity

With respect to fish, although median values for the Waikato QIBI also fell within the C band, and lower scores were often associated with higher amounts of fine deposited sediment (Figures

A 1 & A 2), most fish (excluding salmonids) can tolerate sub-optimal water quality (including temperature and dissolved oxygen) longer than invertebrates (Quinn et al. 1994, Richardson et al. 1994, Landman et al. 2005, Olsen et al. 2012, Franklin 2013). Although native fish may be more tolerant to reduced water quality, they are sensitive to impaired riverscape connectivity (e.g., perched culverts, weirs, dams), due to a high proportion of the native fauna requiring access to the marine environment to complete their respective life cycles. Consequently, reduced connectivity is likely to be a key factor constraining regional fish diversity across the wadeable network. For example, the only regional FMU with a median A band rating for both the Waikato QIBI and national NPSIBI was the Coromandel where proximity to the coast and generally good connectivity for predominantly native fish communities still exist. In contrast, the Upper Waikato unit exhibits a relatively clear breakpoint for migratory fish whereby their upstream penetration was limited historically by numerous waterfalls and since 1930 by the creation of eight hydro-electric dams, the most downstream being Karāpiro (c. 150 km from the coast). This FMU also reported the highest proportion of 'fishless' sites in the region, some of which are likely to be 'naturally' fishless (i.e., have always been inaccessible).

Notwithstanding the importance of riverscape connectivity for maintaining regional native fish biodiversity, the Waikato region also supports two non-migratory eleotrid fish species, Crans and Upland bully (*Gobiomorphus basalis, G. breviceps* respectively), the former of which is relatively widespread across many inland wadeable streams. These species tend to occur in geologically older parts of the riverscape where natural barriers (i.e., waterfalls, uplifted escarpments) and historic volcanic activity (Shelly et al. 2020) have subsequently excluded virtually all other fish species except occasionally eels or introduced species. While these watercourses may not generate high fish IBI scores, a low IBI score alone does not necessarily reflect a lack of biotic integrity or a deviation from natural condition for some of these naturally inaccessible sites, and perhaps illustrates another challenge to the interpretation and use of fish IBI indices. A separate programme of work to identify priority migratory barriers to fish is currently underway to better evaluate the impact of this variable on native fish communities across the Waikato region and to set connectivity targets.

As alluded to earlier it is not unusual to find high native fish diversity in moderately enriched rivers, providing that those sites are not compromised with respect to connectivity, structural habitat or abundant introduced fish species. To some degree however, sites with high nutrient enrichment are often associated with warmer, lower gradient watercourses, with low or highly fluctuating dissolved oxygen and low structural cover. Such sites are typically found in wadeable floodplain sites across the Lower Waikato and Waihou-Piako units and where more tolerant and adaptable non migratory invasive fish species also tend to proliferate (Pingram et al. 2021). Periodically however, these sites may be subject to broad-scale summer events in warmer months where the physiological tolerances of even the most tolerant fish species are exceeded, with fish deaths occurring (Pingram et al. 2021). Causes of death are invariably related to extended hypoxic conditions created by high temperatures, anoxia, and microbial activity under drought conditions, or the sudden delivery of excess nutrients and carbon following tropical cyclone downpours which fuel extreme oxygen consumption by bacteria within floodplain watercourses (Pingram et al. 2021). The impact however can occur over larger areas than would typically be expected, due to the inability of waterways to expand and contract because of infrastructure. As a crucial receiving environment within lowland riverscapes, the state of floodplain function, condition, and connectivity is at least in part representative of broader catchment conditions and management. Therefore, these areas provide a useful area to evaluate broader catchment policy and management effectiveness, and require further assessment of connectivity across a range of high and low flow conditions.

## 4.6 Comparison with native forest reference sites

As documented above, and based on established indices of the ecological condition, wadeable streams on developed land in the Waikato region are generally poor to moderate for fish and invertebrates. Extent estimates, and average condition have displayed minimal temporal change at a regional scale (improvements or declines over time) since the beginning of the probabilistic random network programme in 2009. The general lack of ecological change in observed indices can be interpreted in various ways. A useful starting point to understanding current state is to compare the state of sites on developed land with sites exhibiting minimal anthropogenic impairment. In addition to the probabilistic wadeable network, WRC has also been monitoring a selection of least impaired wadeable native forest reference sites on an annual (rather than rotational) basis throughout the same period). Although native forest reference sites were selected using a different methodology (see Collier et al. 2007), they provide a representation of stream types that currently exist in a least impaired condition. As demonstrated in Figures 13 – 16 above, large differences in median ecological condition between the probabilistic and reference networks exist for many ecological attributes (including indices derived from fish, invertebrate, and plant surveys). Additional temporal data for least impaired sites (with some sites having >20 years data) will be analysed separately. One interpretation of these data is that, in a generalised sense, much of the ecological degradation observed across the probabilistic wadeable network may have largely taken place prior to the creation of the monitoring network (i.e., prior to 2009, during earlier phases of intensification). Alternatively, given that environmental improvements can take time to affect biological indices at a reach scale, and when combined with the relative catchment position of many sites, improvements at a regional scale may take several years or decades (Harding et al. 1998) to become apparent. It is also possible that for some degraded sites, the ecological capacity to recover may be limited or constrained by existing upstream conditions, or other variables requiring further investigation; therefore, determining limitations to site recovery is required to assist directing additional investment at sites above agreed minimum standards, and potentially targeting sites with greater or quicker recovery potential. Bearing in mind all of the proposed FMUs had a percentage of D band sites, action plans are required to be developed for most large catchments. Questions also remain as to whether current policies will result in measurable improvements in ecological communities on developed land over time using existing indices, and whether these existing indices are indeed sensitive enough to detect any changes (positive or otherwise) that may occur.

## 4.7 Indices

Although the NPS-FM (2020) requires reporting of specific indices for ecological health, as alluded to above, the current indices are likely to lack the sensitivity required to address declines before they have already occurred thus limiting their relevance for effective management. Since different organisms and groups respond differently to different stressors, we propose that a variety of indicators should be used and combined to provide a more complete picture of state and to target relevant stressors more effectively. Rather than aggregated presence absence type metrics, we consider indices that include an abundance component (e.g., QMCI) may be better at identifying change. For example, abundances of particular taxa can change differently across stressor gradients in response to favourable or unfavourable conditions, this level of information can be explored at both taxa and community levels to provide an indication of critical thresholds for biological communities (e.g., Baker & King; King et al. 2011). Further, more detailed assessment of taxonomic level information and relative abundances can be used to develop more sensitive indicators of response to both restoration (e.g., Action Plan implementation) and degradation. Though not presented in here, abundance data is collected in the fish monitoring programmes with fish crews also measuring fish length enabling any changes in fish recruitment to also be identified. Potentially a new multi-metric ecosystem index could be developed that includes measures of water quality, periphyton, macrophytes, macroinvertebrates and fish, ideally incorporating both structural and functional aspects of the communities present. Similar frameworks have been successfully trialled in other regions, such as the Hawkes Bay (Clapcott et al. 2020)

## 4.8 Future work

The purpose of the random probabilistic 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, including at an FMU scale. The primary purpose of the network has been to assess state and change over time, and for broadly identifying key stressors relevant at a regional scale (e.g., fine deposited sediment). At an FMU scale this information could be used to develop a framework or process for identifying where management efforts would be best targeted for improving ecological condition at different spatial scales or classifications. One approach for identifying the most beneficial places to apply targeted management is to undertake a prioritisation exercise using existing knowledge and data. For instance, the SNA rivers draft list (Collier et al. 2010), could be used or updated to identify those FMU's which may have low median ecological scores (e.g., for MCI, Waikato QIBI) but where high ranking streams (within the top 20%) may still exist within the broader FMU. In this case specific management could be aimed at connecting these higher value biodiversity sites by targeting site or catchment specific improvements to improve overall condition within the selected FMU (as better condition sites may provide habitat for adult fish or source populations for recolonising invertebrates).

However, for management to be effective, understanding the origins of particular stressor(s) 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. A further consideration is to ensure that a broader and more sensitive range of biological indicators are developed for improved effectiveness monitoring. Utilising, for instance, important species-specific responses that may be occurring at local or regional scales. For example, the numerical abundance of different size classes of redfin bullies or longfin eels may be responsive to the abundance of structural habitat at a site (e.g., amount of wood or stream bed substrate composition), with other mobile species such as īnanga less so. Conversely, īnanga may better reflect connectivity issues at a site than redfin bullies or eels which both have climbing capabilities. Capacity to assess these associations exist within the data we collect and are likely to be more sensitive to management than presence-absence type indices. Being able to identify important species-specific responses to specific variables is likely to be valuable for directing prescriptive targeted management and for evaluating management effectiveness. Additionally new monitoring techniques such as eDNA (while only presence/absence currently) could also be applied for a more holistic understanding of ecological response and to substantially increase the range of aquatic organisms that may have differential spatial and temporal responses to different ecosystem stressors. Certainly, one aspect of the broader regional network that requires closer evaluation is identification of present-day anthropogenic barriers to river connectivity and fish passage. There are likely to be large numbers of unconsented, formerly consented and originally permitted structures that no longer meet that criterion hampering riverscape connectivity throughout the region. At this stage the impact of this important variable on riverscape diversity (for fish) and sediment transport is an unknown quantum. However, new technology such as LiDAR, remote sensing, and high-resolution aerials, in association with rapid detection techniques such as eDNA monitoring mentioned above, are likely to enhance the identification of problematic barriers.

Expanding on this report and to advance the utilisation of the ecological monitoring network the following projects are either underway or proposed:

- Analysis and reporting of state and trend for ecological variables at long term (annually sampled) sites, sampled for around 15 years;
- Development of a RIVPACS model to predict community composition at a reach scale that reflects a least impaired condition, to inform target setting and action plan development;
- Development of a riverscape Connectivity indicator, with a focus on fish passage;

- Improved and more sensitive indicators for detecting change at a taxa level (improve and degradation), including:
    - Application of statistical methodologies to derive thresholds at which the relative composition of macroinvertebrates and fish changes in response to given stressors (e.g., following the TITAN approach of Baker & King, 2010);
    - Exploration of long-term community data and community composition patterns across differing land uses, in comparison to communities at native forest reference sites;
- Utilising the above to develop a framework for identifying “bottlenecks” and limitations for restoring a site/catchment, e.g., for identifying key interventions, knowledge gaps presented in Greenwood et al. (2021) for developing action plans;
- Identify minimum level of change or performance standard required at wide spatial temporal scales to either remedy D band ecological condition, arrest degradation, or maintain current acceptable condition. This will need to address both local and diffuse/upstream drivers of stressors;
- Review the current network and sampling frequencies for possible improvements, efficiencies and to balance the increasing number of expectations;
- Utilise native forest reference condition sites to develop regionally relevant and specific benchmarks for habitat drivers of ecological condition;
- Continue ongoing investigations and broad-scale assessments of the ecological health of large rivers systems (including non-wadeable rivers), in collaboration with other regional councils and practitioners.

## 4.9 Conclusions

Excess fine deposited sediment in wadeable streams continues to be a critical stressor in need of reduction across the region, consequently maintaining and improving instream ecology at any given site will require reductions in fine deposited sediment. Identifying primary sources of fine deposited sediment within an FMU is likely to require more targeted investigation for identifying where and when resources are best directed. Temporal derivation of major sediment contributions also require investigation (e.g., magnitude of rainfall events, frequency and duration of bankfull flows). The high proportion of stream length in the Waikato region considered below the national bottom line based on macroinvertebrate indices is a concern. Although much effort has been invested in improving water quality, to see ecological gains additional considerations are likely required, such as response time lag, insufficient buffer widths, land use intensification, land clearance or climatic affects overriding the impact of these efforts.

In the long term, riparian improvements that lead to greater canopy shade may be an effective tool for regulating solar radiation, instream temperatures and dissolved oxygen, acting as a buffer to warming water temperatures resulting from climate change. For fish communities and river function, relatively rapid gains in biodiversity and physical improvement are likely to occur through improving riverscape connectivity via the removal or remediation of anthropogenic barriers to downstream substrate and bi-directional fish migration. Presence-absence indices for fish currently used describe the health of fish communities are, however, insensitive to detecting subtle change (e.g., changing relative abundance or ageing populations) until it has occurred. Incorporation of quantitative information into fish related indices, including species abundances and size class specific responses to specific stressors, would likely improve the sensitivity of fish indices for detecting change.

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# 6 Appendices

## 6.1 Tables

**Table A 1: Regional Target and non-Target classification of REC network based on 2018-2020 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 | 2886 (336) | 20 (2) |
| Modified | 194 (113) | 1 (1) |
| Not sampled | 1198 (244) | 8 (2) |
| Target and sampled | 9131 (498) | 64 (3) |
| Total | 14340 (512) | 100 (0) |
| **Non-target** | | |
| Coastal | 203 (74) | 1 (0) |
| Drain | 248 (115) | 1 (0) |
| Non-perennial watercourse | 7295 (630) | 31 (2) |
| Inaccessible | 27 (23) | <1 (0) |
| Lake or Pond | 1196 (253) | 5 (1) |
| Modified | 130 (108) | 1 (0) |
| Non-wadeable | 3151 (257) | 14 (1) |
| Out of Region 2013 | 64 (57) | <1 (0) |
| REC Inaccurate | 1657 (331) | 7 (1) |
| Reference (native forest) | 6450 (525) | 28 (2) |
| Unnatural drain | 1194 (267) | 5 (1) |
| Wetland | 1709 (372) | 7 (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 2009-2020.**

| Estimated proportion (%) length of target river network. Parentheses are estimated SE, followed lower and upper 95th confidence interval | | | | |
|---|---|---|---|---|
| | 2009-2011 | 2012-2014 | 2015-2017 | 2018-2020 |
| **MCI** | | | | |
| **A** | 8.4 (1.9, 4.7-12.1) | 4.8 (1.5, 2.0-7.7) | 7.9 (2.0, 3.9-11.9) | 5.7 (1.8, 2.1-9.2) |
| **B** | 26.4 (3.3, 19.8-32.9) | 27.7 (3.3, 21.2-34.1) | 22.5 (2.9, 16.8-28.2) | 27.4 (3.4, 20.7-34.1) |
| **C** | 27.2 (3.5, 20.4-34.1) | 26.3 (3.3, 19.8-32.8) | 27.6 (3.4, 21.0-34.2) | 27.9 (3.5, 21.1-34.6) |
| **D** | 38.1 (3.4, 31.4-44.7) | 41.2 (3.6, 34.2-48.2) | 42.0 (3.5, 35.2-48.8) | 39.1 (3.5, 32.2-45.9) |
| **QMCI** | | | | |
| **A** | 17.1 (2.6, 12.0-22.2) | 17.1 (2.9, 11.5-22.7) | 12.9 (2.6, 7.9-17.9) | 15.1 (2.8, 9.6-20.7) |
| **B** | 14.8 (2.6, 9.8-19.8) | 9.6 (2.1, 5.5-13.7) | 11.6 (2.5, 6.6-16.6) | 12.3 (2.6, 7.2-17.3) |
| **C** | 8.5 (1.9, 4.7-12.3) | 13.4 (2.3, 8.9-18.0) | 13.0 (2.3, 8.4-17.5) | 12.3 (2.4, 7.6-17.0) |
| **D** | 59.6 (3.5, 52.8-66.4) | 59.9 (3.4, 53.1-66.6) | 62.5 (3.5, 55.6-69.5) | 60.3 (3.7, 53.1-67.5) |
| **ASPM** | | | | |
| **A** | 12.8 (2.4, 8.1-17.5) | 14.1 (2.6, 9.0-19.2) | 9.6 (2.3, 5.1-14.0) | 13.8 (2.7, 8.5-19.0) |
| **B** | 25.8 (3.0, 19.9-31.8) | 22.6 (2.8, 17.1-28.0) | 26.3 (3.0, 20.4-32.3) | 26.4 (3.4, 19.7-33.2) |
| **C** | 14.4 (2.7, 9.1-19.7) | 16.2 (2.9, 10.6-21.9) | 9.7 (2.0, 5.9-13.6) | 15.0 (2.8, 9.6-20.4) |
| **D** | 47.0 (3.5, 40.1-53.8) | 47.1 (3.5, 40.2-54.0) | 54.4 (3.5, 47.5-61.3) | 44.8 (3.6, 37.8-51.7) |
| **PPI^** | | | | |
| **A** | 60.1 (3.7, 52.8-67.4) | 61.3 (3.6, 54.2-68.4) | 63.2 (3.6, 56.1-70.2) | 59.1 (3.8, 51.8-66.5) |
| **B** | 14.2 (2.8, 8.7-19.7) | 14.8 (2.9, 9.2-20.5) | 17.5 (3.0, 11.6-23.5) | 15.9 (3.0, 10.1-21.8) |
| **C** | 15.5 (2.7, 10.2-20.8) | 14.2 (2.4, 9.4-19.0) | 11.4 (2.1, 7.2-15.5) | 13.8 (2.6, 8.7-18.9) |
| **D** | 10.2 (2.1, 6.1-14.3) | 9.7 (2.2, 5.4-14.0) | 8.0 (2.0, 4.1-11.8) | 11.2 (2.4, 6.5-15.8) |
| **MTC** | | | | |
| **A** | 51.0 (3.6, 43.9-58.1) | 46.2 (3.5, 39.3-53.1) | 39.9 (3.6, 32.8-46.9) | 46.4 (3.6, 39.2-53.5) |
| **B** | 6.7 (1.8, 3.2-10.1) | 6.2 (1.8, 2.7-9.7) | 7.4 (2.0, 3.4-11.3) | 11.9 (2.7, 6.7-17.1) |
| **C** | 10.0 (2.2, 5.6-14.4) | 12.6 (2.4, 7.8-17.4) | 17.5 (3.0, 11.7-23.4) | 10.1 (2.1, 6.0-14.1) |
| **D** | 32.3 (3.6, 25.3-39.3) | 35.0 (3.8, 27.7-42.4) | 35.2 (3.8, 27.7-42.7) | 31.6 (3.5, 24.8-38.4) |
| **MCC** | | | | |
| **A** | 51.6 (3.6, 44.5-58.8) | 46.2 (3.5, 39.3-53.1) | 40.2 (3.6, 33.1-47.3) | 48.3 (3.7, 41.0-55.6) |
| **B** | 7.0 (1.8, 3.5-10.4) | 7.4 (1.9, 3.8-11.1) | 9.9 (2.2, 5.5-14.3) | 12.6 (2.7, 7.4-17.9) |
| **C** | 12.8 (2.5, 7.8-17.8) | 12.8 (2.5, 8.0-17.6) | 17.5 (3.0, 11.7-23.4) | 8.1 (1.9, 4.4-11.9) |
| **D** | 28.6 (3.5, 21.7-35.6) | 33.5 (3.7, 26.2-40.8) | 32.4 (3.8, 25.0-39.8) | 31.0 (3.5, 24.1-37.8) |
| **%Silt** | | | | |
| **A** | 47.6 (3.6, 40.7-54.6) | 46.5 (3.6, 39.5-53.5) | 36.6 (3.5, 29.7-43.6) | 37.7 (3.5, 30.8-44.5) |
| **B** | 9.7 (2.2, 5.3-14.0) | 12.5 (2.2, 8.1-16.8) | 11.3 (2.3, 6.9-15.8) | 10.4 (2.2, 6.1-14.7) |
| **C** | 15.1 (2.8, 9.6-20.6) | 13.4 (2.5, 8.4-18.4) | 17.5 (2.8, 12.0-23.0) | 22.4 (3.3, 16.0-28.8) |
| **D** | 27.6 (3.4, 20.9-34.3) | 27.6 (3.5, 20.7-34.6) | 34.5 (3.7, 27.4-41.7) | 29.6 (3.6, 22.5-36.6) |
| **%SSC** | | | | |
| **A** | 15.9 (2.6, 10.8-21.0) | 14.5 (2.6, 9.4-19.6) | 10.4 (2.4, 5.7-15.1) | 11.4 (2.1, 7.2-15.5) |
| **B** | 9.1 (1.9, 5.4-12.7) | 13.3 (2.3, 8.7-17.9) | 11.9 (2.4, 7.3-16.5) | 8.6 (2.3, 4.1-13.1) |
| **C** | 14.8 (2.6, 9.6-20.0) | 13.0 (2.3, 8.4-17.5) | 16.2 (2.5, 11.3-21.2) | 21.3 (3.1, 15.1-27.4) |
| **D** | 60.2 (3.4, 53.6-66.8) | 59.3 (3.4, 52.6-65.9) | 61.5 (3.3, 55.0-68.0) | 58.8 (3.6, 51.8-65.8) |
| **NPSIBI** | | | | |
| **A** | - | 50.5 (4.1, 42.5-58.5) | 55.3 (4.0, 47.5-63.0) | 54.9 (3.8, 47.4-62.5) |
| **B** | - | 18.0 (3.1, 12.0-24.1) | 16.9 (2.8, 11.4-22.4) | 25.9 (3.6, 18.9-32.8) |
| **C** | - | 20.5 (3.6, 13.4-27.7) | 18.8 (3.5, 11.8-25.7) | 12.9 (2.7, 7.6-18.3) |

| Estimated proportion (%) length of target river network<br>Parentheses are estimated SE, followed lower and upper 95th confidence interval | | | | |
|---|---|---|---|---|
| | **2009-2011** | **2012-2014** | **2015-2017** | **2018-2020** |
| **D** | - | 3.0 (1.5, 0.0-5.9) | 1.1 (0.5, 0.0-2.2) | 0.7 (0.4, 0.0-1.6) |
| **E** | - | 8.0 (2.5, 3.1-12.9) | 8.0 (2.4, 3.2-12.7) | 5.5 (2.0, 1.6-9.4) |
| **QIBI** | | | | |
| **A** | - | 23.3 (3.3, 16.8-29.8) | 20.7 (2.8, 15.2-26.1) | 24.7 (2.9, 19.1-30.3) |
| **B** | - | 19.0 (3.0, 13.1-24.9) | 20.3 (2.7, 15.0-25.6) | 19.6 (2.9, 14.0-25.2) |
| **C** | - | 27.8 (3.5, 20.9-34.8) | 30.9 (3.4, 24.3-37.6) | 33.4 (3.7, 26.1-40.7) |
| **D** | - | 21.9 (3.7, 14.6-29.2) | 20.1 (3.7, 12.8-27.4) | 16.8 (3.2, 10.5-23.1) |
| **E** | - | 8.0 (2.5, 3.1-12.9) | 8.0 (2.4, 3.2-12.7) | 5.5 (2.0, 1.6-9.4) |
| **QHA Total score** | | | | |
| **A** | 10.3 (2.2, 6.1-14.6) | 14.4 (2.6, 9.3-19.5) | 14.5 (2.6, 9.4-19.7) | 13.1 (2.4, 8.4-17.9) |
| **B** | 39.4 (3.7, 32.2-46.6) | 52.1 (3.8, 44.6-59.6) | 42.1 (3.6, 34.9-49.2) | 38.3 (3.5, 31.3-45.2) |
| **C** | 39.8 (3.8, 32.5-47.2) | 28.1 (3.5, 21.2-35.0) | 38.2 (3.6, 31.1-45.3) | 41.5 (3.8, 34.2-48.9) |
| **D** | 10.4 (2.6, 5.3-15.6) | 5.4 (1.9, 1.7-9.1) | 5.2 (1.8, 1.7-8.8) | 7.0 (2.2, 2.6-11.4) |
| **WCC^** | | | | |
| **A** | 80.6 (2.9, 74.9-86.3) | 83.1 (2.8, 77.7-88.6) | 85.3 (2.5, 80.5-90.1) | 80.8 (2.9, 75.1-86.5) |
| **B** | 11.5 (2.3, 6.9-16.0) | 11.1 (2.4, 6.3-15.8) | 8.6 (1.9, 4.8-12.3) | 11.5 (2.3, 7.0-16.0) |
| **C** | 2.7 (0.9, 0.8-4.5) | 4.3 (1.4, 1.6-7.0) | 5.8 (1.8, 2.3-9.3) | 5.7 (1.7, 2.3-9.1) |
| **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 (1.2, 0.0-4.5) |
| **RHA Total score** | | | | |
| **A** | - | - | 5.2 (2.2, 0.8-9.5) | 2.6 (1.0, 0.7-4.6) |
| **B** | - | - | 43.0 (4.6, 34.0-52.0) | 39.4 (3.6, 32.4-46.4) |
| **C** | - | - | 44.6 (4.3, 36.1-53.0) | 50.6 (3.8, 43.2-58.1) |
| **D** | - | - | 7.3 (3.1, 1.3-13.3) | 7.3 (2.2, 3.1-11.6) |

**Table A 3: Length (km) estimates of wadeable, perennial streams (Target) in a given condition banding for ecologically relevant indices, for completed rotations 2009-2020.**

| | Estimated km length of target river network<br>Parentheses are estimated SE, followed lower and upper 95th confidence interval | | | |
|---|---|---|---|---|
| | **2009-2011** | **2012-2014** | **2015-2017** | **2018-2020** |
| | | **MCI** | | |
| **A** | 1307 (295, 730-1885) | 751 (227, 307-1196) | 1229 (318, 607-1852) | 810 (260, 301-1319) |
| **B** | 4121 (520, 3101-5141) | 4290 (512, 3286-5294) | 3489 (453, 2600-4377) | 3914 (488, 2957-4871) |
| **C** | 4255 (546, 3184-5326) | 4081 (515, 3071-5091) | 4277 (521, 3256-5298) | 3981 (495, 3011-4950) |
| **D** | 5952 (532, 4909-6995) | 6382 (554, 5295-7468) | 6509 (540, 5451-7567) | 5582 (501, 4600-6564) |
| | | **QMCI** | | |
| **A** | 2674 (410, 1870-3477) | 2649 (442, 1783-3516) | 1999 (397, 1221-2778) | 2159 (404, 1367-2951) |
| **B** | 2314 (403, 1525-3103) | 1492 (326, 852-2131) | 1800 (393, 1030-2570) | 1750 (365, 1034-2466) |
| **C** | 1328 (300, 740-1916) | 2082 (361, 1374-2790) | 2009 (360, 1304-2714) | 1761 (342, 1091-2431) |
| **D** | 9320 (544, 8253-10387) | 9281 (533, 8235-10326) | 9695 (549, 8619-10772) | 8617 (523, 7593-9642) |
| | | **ASPM** | | |
| **A** | 2001 (376, 1264-2738) | 2189 (402, 1400-2978) | 1484 (354, 789-2178) | 1968 (384, 1215-2721) |
| **B** | 4042 (475, 3110-4973) | 3496 (430, 2653-4340) | 4080 (469, 3160-5001) | 3776 (492, 2813-4740) |
| **C** | 2251 (422, 1424-3078) | 2515 (446, 1642-3389) | 1506 (304, 911-2101) | 2146 (395, 1372-2921) |
| **D** | 7342 (550, 6264-8419) | 7303 (549, 6226-8379) | 8434 (545, 7366-9501) | 6396 (508, 5400-7393) |
| | | **PPI^** | | |
| **A** | 9396 (584, 8251-10540) | 9502 (564, 8397-10606) | 9794 (558, 8700-10888) | 8449 (538, 7395-9504) |
| **B** | 2217 (437, 1361-3074) | 2300 (448, 1422-3178) | 2717 (472, 1792-3642) | 2275 (428, 1436-3114) |
| **C** | 2420 (424, 1589-3251) | 2199 (380, 1455-2944) | 1760 (328, 1118-2403) | 1969 (372, 1239-2698) |
| **D** | 1602 (327, 961-2243) | 1503 (344, 830-2176) | 1233 (305, 634-1832) | 1594 (340, 927-2261) |
| | | **MTC** | | |
| **A** | 7976 (567, 6864-9088) | 7164 (549, 6089-8239) | 6183 (559, 5087-7279) | 6626 (520, 5606-7645) |
| **B** | 1044 (276, 502-1586) | 965 (276, 423-1507) | 1142 (311, 533-1751) | 1701 (380, 955-2447) |
| **C** | 1564 (350, 879-2250) | 1948 (380, 1203-2692) | 2720 (466, 1807-3633) | 1440 (296, 861-2020) |
| **D** | 5051 (560, 3953-6149) | 5427 (581, 4288-6567) | 5459 (595, 4293-6625) | 4520 (495, 3549-5490) |
| | | **MCC** | | |
| **A** | 8071 (570, 6953-9189) | 7164 (549, 6089-8239) | 6228 (560, 5130-7326) | 6899 (532, 5857-7941) |
| **B** | 1087 (277, 544-1630) | 1153 (289, 588-1719) | 1536 (348, 854-2218) | 1805 (382, 1056-2553) |
| **C** | 2000 (397, 1223-2778) | 1987 (380, 1242-2732) | 2720 (461, 1817-3623) | 1161 (274, 624-1698) |
| **D** | 4477 (553, 3392-5561) | 5200 (578, 4068-6332) | 5020 (585, 3873-6166) | 4422 (497, 3449-5396) |
| | | **%Silt** | | |
| **A** | 7447 (556, 6357-8537) | 7211 (554, 6125-8298) | 5679 (549, 4603-6756) | 5381 (502, 4398-6365) |
| **B** | 1511 (344, 836-2185) | 1930 (345, 1254-2606) | 1758 (350, 1072-2443) | 1486 (315, 868-2103) |
| **C** | 2359 (439, 1498-3220) | 2076 (394, 1305-2848) | 2711 (433, 1863-3559) | 3194 (467, 2279-4109) |
| **D** | 4318 (534, 3272-5365) | 4285 (547, 3213-5358) | 5356 (567, 4244-6467) | 4226 (513, 3221-5231) |
| | | **%SSC** | | |
| **A** | 2487 (409, 1685-3288) | 2243 (403, 1452-3033) | 1610 (371, 884-2337) | 1625 (303, 1032-2218) |
| **B** | 1417 (290, 848-1986) | 2062 (362, 1353-2770) | 1843 (364, 1129-2557) | 1227 (329, 582-1873) |
| **C** | 2316 (413, 1506-3126) | 2009 (360, 1304-2714) | 2516 (390, 1750-3281) | 3038 (447, 2162-3915) |
| **D** | 9416 (525, 8387-10445) | 9191 (527, 8157-10224) | 9535 (513, 8529-10542) | 8396 (511, 7395-9397) |
| | | **NPSIBI** | | |
| **A** | - | 7823 (633, 6581-9064) | 8566 (613, 7365-9767) | 7850 (549, 6773-8927) |
| **B** | - | 2798 (479, 1860-3737) | 2622 (433, 1773-3471) | 3696 (508, 2701-4691) |
| **C** | - | 3185 (564, 2079-4291) | 2907 (550, 1829-3985) | 1849 (392, 1080-2618) |

| Estimated km length of target river network<br>Parentheses are estimated SE, followed lower and upper 95th confidence interval | | | | |
|---|---|---|---|---|
| | **2009-2011** | **2012-2014** | **2015-2017** | **2018-2020** |
| **D** | - | 458 (230, 6-910) | 172 (85, 5-339) | 104 (62, 0-226) |
| **E** | - | 1240 (384, 487-1993) | 1236 (377, 497-1976) | 787 (287, 226-1349) |
| | | **QIBI** | | |
| **A** | - | 3606 (514, 2599-4613) | 3202 (433, 2354-4050) | 3528 (409, 2727-4329) |
| **B** | - | 2950 (466, 2036-3864) | 3150 (422, 2324-3976) | 2801 (409, 2000-3602) |
| **C** | - | 4316 (549, 3240-5392) | 4797 (528, 3763-5831) | 4769 (534, 3723-5816) |
| **D** | - | 3392 (580, 2256-4528) | 3118 (576, 1989-4247) | 2401 (459, 1501-3302) |
| **E** | - | 1240 (384, 487-1993) | 1236 (377, 497-1976) | 787 (287, 226-1349) |
| | | **QHA Total score** | | |
| **A** | 1618 (339, 953-2282) | 2229 (403, 1440-3019) | 2254 (409, 1452-3057) | 1878 (349, 1194-2562) |
| **B** | 6159 (573, 5037-7281) | 8079 (593, 6917-9242) | 6521 (564, 5415-7627) | 5469 (505, 4478-6459) |
| **C** | 6225 (587, 5074-7377) | 4357 (548, 3283-5431) | 5917 (562, 4815-7019) | 5935 (538, 4881-6989) |
| **D** | 1633 (409, 831-2434) | 838 (290, 270-1406) | 812 (280, 264-1360) | 1005 (321, 376-1634) |
| | | **WCC^** | | |
| **A** | 12604 (453, 11716-13492) | 12890 (434, 12040-13740) | 13230 (381, 12484-13976) | 11541 (415, 10727-12355) |
| **B** | 1790 (360, 1085-2495) | 1717 (375, 982-2452) | 1326 (297, 745-1907) | 1638 (328, 995-2281) |
| **C** | 418 (148, 128-708) | 664 (216, 242-1087) | 903 (276, 362-1444) | 813 (248, 328-1299) |
| **D** | 823 (281, 274-1373) | 232 (105, 26-439) | 45 (42, 0-127) | 294 (178, 0-643) |
| | | **RHA Total score** | | |
| **A** | - | - | 799 (348, 117-1480) | 377 (144, 95-659) |
| **B** | - | - | 6665 (710, 5274-8056) | 5631 (513, 4626-6636) |
| **C** | - | - | 6908 (670, 5595-8222) | 7231 (544, 6166-8297) |
| **D** | - | - | 1132 (477, 198-2066) | 1048 (309, 442-1653) |

**Table A 4: Proportional (%) estimates of wadeable, perennial streams (Target) in a given condition banding for additional metrics referred to in report.**

| | Regional | Coromandel | Lake Taupō | Lower Waikato | Upper Waikato | Waihou-Piako | Waipā | West Coast |
|---|---|---|---|---|---|---|---|---|
| **Estimated % condition of target river network. Parentheses are estimated SE, followed lower and upper 95th confidence interval** | | | | | | | | |
| Turbidity | | | | | | | | |
| Clear | 79.5 (2.8, 73.9-85.1) | 81.3 (11.7, 58.3-100.0) | 94.2 (5.6, 83.2-100.0) | 70.1 (8.0, 54.3-85.8) | 100.0 (0.0, 100.0-100.0) | 83.6 (7.8, 68.3-98.9) | 73.7 (5.6, 62.8-84.6) | 75.6 (6.9, 61.9-89.2) |
| Highly turbid | 3.3 (1.2, 1.0-5.6) | | | 16.1 (7.0, 2.4-29.8) | | | 1.5 (1.3, 0.0-4.1) | 2.4 (1.5, 0.0-5.3) |
| Slightly turbid | 13.7 (2.4, 9.0-18.4) | 5.6 (5.3, 0.0-15.9) | 5.8 (5.6, 0.0-16.8) | 9.2 (4.9, 0.0-18.7) | | 16.4 (7.8, 1.1-31.7) | 21.8 (4.8, 12.3-31.3) | 16.4 (5.9, 4.9-27.9) |
| Stained | 3.5 (1.2, 1.0-5.9) | 13.2 (10.6, 0.0-33.9) | | 4.7 (2.5, 0.0-9.6) | | | 3.1 (2.4, 0.0-7.8) | 5.6 (3.5, 0.0-12.5) |
| Canopy cover | | | | | | | | |
| Open | 52.9 (3.7, 45.6-60.2) | 11.9 (8.0, 0.0-27.7) | 33.9 (20.9, 0.0-74.9) | 68.4 (7.8, 53.1-83.8) | 40.7 (10.0, 21.2-60.2) | 45.0 (9.0, 27.4-62.6) | 54.7 (8.6, 37.9-71.5) | 65.1 (7.7, 49.9-80.3) |
| Partly shaded | 31.8 (3.4, 25.1-38.5) | 69.3 (14.3, 41.4-97.2) | 5.8 (5.6, 0.0-16.7) | 22.4 (6.9, 8.9-35.9) | 51.0 (11.0, 29.4-72.6) | 37.6 (8.9, 20.2-55.0) | 30.3 (7.6, 15.4-45.1) | 24.0 (6.5, 11.3-36.7) |
| Significantly shaded | 15.3 (2.8, 9.8-20.8) | 18.7 (12.5, 0.0-43.2) | 60.3 (20.1, 20.9-99.6) | 9.2 (4.9, 0.0-18.7) | 8.3 (4.4, 0.0-17.0) | 17.4 (6.3, 5.0-29.8) | 15.0 (6.5, 2.3-27.8) | 10.9 (5.4, 0.3-21.5) |
| Dominant riparian vegetation | | | | | | | | |
| Crops/Hort | 2.7 (1.3, 0.2-5.3) | | | 8.9 (4.8, 0.0-18.3) | | | 6.2 (4.7, 0.0-15.4) | |
| Forestry | 9.3 (2.2, 5.0-13.5) | 6.4 (5.5, 0.0-17.1) | 53.6 (18.8, 16.6-90.5) | | 28.6 (10.6, 7.8-49.4) | 15.2 (7.8, 0.0-30.5) | 3.1 (2.5, 0.0-8.0) | |
| Native forest | 5.1 (1.6, 2.0-8.2) | 11.9 (6.3, 0.0-24.3) | | 2.3 (2.0, 0.0-6.2) | | 6.4 (4.3, 0.0-14.8) | 7.7 (5.4, 0.0-18.3) | 5.1 (2.3, 0.6-9.6) |
| Native shrub | 7.4 (2.1, 3.3-11.6) | 11.1 (7.1, 0.0-25.0) | 5.8 (5.6, 0.0-16.8) | 11.6 (5.3, 1.3-22.0) | | 10.5 (5.0, 0.8-20.2) | | 12.6 (6.6, 0.0-25.6) |
| Pasture | 69.4 (3.4, 62.7-76.1) | 38.3 (11.9, 15.0-61.6) | 34.7 (19.1, 0.0-72.1) | 77.2 (7.3, 62.9-91.5) | 65.9 (11.2, 44.0-87.7) | 61.3 (8.3, 45.1-77.6) | 80.1 (7.2, 65.9-94.2) | 75.4 (7.7, 60.4-90.5) |

| | Estimated % condition of target river network<br>Parentheses are estimated SE, followed lower and upper 95th confidence interval | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Regional** | **Coromandel** | **Lake Taupō** | **Lower Waikato** | **Upper Waikato** | **Waihou-Piako** | **Waipā** | **West Coast** |
| Retired grass | 5.8 (1.8, 2.2-9.3) | 26.7 (15.2, 0.0-56.5) | 5.8 (5.6, 0.0-16.7) | | 5.5 (3.8, 0.0-12.9) | 6.4 (4.4, 0.0-15.1) | 3.1 (2.6, 0.0-8.1) | 6.9 (4.5, 0.0-15.7) |
| Urban | 0.3 (0.3, 0.0-0.8) | 5.6 (5.3, 0.0-15.9) | | | | | | |
| Fencing | | | | | | | | |
| Complete both sides | 29.2 (3.1, 23.1-35.3) | 17.5 (9.2, 0.0-35.5) | 40.6 (17.6, 6.1-75.1) | 41.2 (8.7, 24.1-58.3) | 40.1 (12.1, 16.4-63.7) | 43.9 (8.2, 27.8-59.9) | 27.5 (6.4, 14.9-40.0) | 9.8 (4.5, 1.0-18.7) |
| None or ineffective | 52.7 (3.7, 45.3-60.0) | 69.3 (12.8, 44.3-94.4) | 59.4 (17.6, 24.9-93.9) | 40.7 (9.6, 21.9-59.5) | 54.4 (11.7, 31.4-77.4) | 51.8 (8.7, 34.7-68.9) | 40.7 (7.4, 26.2-55.1) | 65.6 (8.1, 49.8-81.4) |
| One side or partial | 18.1 (3.1, 12.1-24.2) | 13.2 (10.6, 0.0-33.9) | | 18.1 (7.2, 4.0-32.3) | 5.5 (3.4, 0.0-12.2) | 4.3 (3.5, 0.0-11.2) | 31.8 (7.8, 16.5-47.2) | 24.6 (7.7, 9.5-39.6) |
| Inorganic substrate compaction | | | | | | | | |
| Assorted sizes, tightly packed | 8.8 (2.0, 4.9-12.6) | 11.9 (6.1, 0.0-23.9) | 19.7 (13.8, 0.0-46.8) | 4.8 (4.1, 0.0-12.8) | 9.7 (6.0, 0.0-21.5) | 10.4 (4.6, 1.5-19.3) | 5.6 (2.9, 0.0-11.4) | 9.6 (5.0, 0.0-19.5) |
| Moderately packed | 26.4 (3.2, 20.1-32.8) | 76.1 (10.5, 55.5-96.7) | 5.8 (5.6, 0.0-16.8) | 15.0 (5.2, 4.8-25.1) | 17.4 (6.9, 3.9-31.0) | 35.6 (7.7, 20.5-50.7) | 25.0 (6.7, 11.8-38.2) | 26.0 (7.9, 10.6-41.5) |
| Mostly a loose assortment | 16.5 (2.9, 10.9-22.2) | 6.4 (6.0, 0.0-18.1) | 34.7 (19.1, 0.0-72.1) | 9.5 (4.5, 0.6-18.3) | 21.9 (8.8, 4.5-39.2) | 3.9 (2.3, 0.0-8.5) | 31.9 (8.2, 15.9-47.9) | 10.8 (4.6, 1.7-19.9) |
| No packing | 48.3 (3.6, 41.3-55.2) | 5.6 (5.3, 0.0-15.9) | 39.7 (20.2, 0.2-79.3) | 70.8 (7.2, 56.7-84.9) | 51.0 (11.9, 27.6-74.3) | 50.1 (7.3, 35.8-64.3) | 37.5 (6.8, 24.2-50.8) | 53.5 (8.1, 37.7-69.4) |
| Embeddedness | | | | | | | | |
| <5% covered by fine sediment | 1.5 (0.6, 0.3-2.7) | 5.6 (4.9, 0.0-15.1) | 5.8 (5.8, 0.0-17.2) | | | | 2.6 (1.7, 0.0-5.9) | 1.4 (1.2, 0.0-3.6) |
| >75% covered by fine sediment | 45.1 (3.5, 38.2-52.0) | 11.1 (7.2, 0.0-25.1) | 5.8 (5.6, 0.0-16.8) | 73.1 (7.2, 59.0-87.2) | 45.4 (12.4, 21.1-69.7) | 45.7 (7.7, 30.7-60.7) | 34.1 (7.0, 20.5-47.8) | 53.5 (7.5, 38.8-68.3) |

**Estimated % condition of target river network**

**Parentheses are estimated SE, followed lower and upper 95th confidence interval**

| | **Regional** | **Coromandel** | **Lake Taupō** | **Lower Waikato** | **Upper Waikato** | **Waihou-Piako** | **Waipā** | **West Coast** |
|---|---|---|---|---|---|---|---|---|
| 25-49% covered by fine sediment | 19.0 (2.9, 13.3-24.6) | 65.0 (12.4, 40.6-89.4) | 13.9 (12.7, 0.0-38.7) | 8.9 (4.8, 0.0-18.3) | 11.5 (5.5, 0.7-22.3) | 19.1 (6.1, 7.1-31.1) | 19.6 (6.7, 6.6-32.7) | 18.6 (6.2, 6.5-30.8) |
| 5-24% covered by fine sediment | 18.3 (2.8, 12.8-23.8) | 12.8 (6.5, 0.0-25.5) | 5.8 (5.6, 0.0-16.8) | 18.0 (6.1, 6.0-30.1) | 16.1 (7.0, 2.4-29.8) | 18.1 (6.2, 6.0-30.3) | 20.9 (6.3, 8.5-33.3) | 20.8 (7.1, 6.8-34.8) |
| 50-74% covered by fine sediment | 16.1 (3.0, 10.2-22.0) | 5.6 (5.3, 0.0-15.9) | 68.6 (15.8, 37.6-99.6) | | 27.0 (8.9, 9.5-44.5) | 17.1 (7.6, 2.2-31.9) | 22.8 (8.0, 7.2-38.4) | 5.6 (3.5, 0.0-12.6) |
| Sample type | | | | | | | | |
| Hard | 48.4 (3.6, 41.4-55.4) | 81.3 (11.7, 58.3-100.0) | 66.1 (20.9, 25.1-100.0) | 24.4 (6.5, 11.6-37.2) | 46.3 (11.7, 23.4-69.2) | 46.0 (7.2, 31.9-60.1) | 63.0 (7.0, 49.2-76.8) | 40.8 (7.7, 25.7-55.9) |
| Soft | 51.6 (3.6, 44.6-58.6) | 18.7 (11.7, 0.0-41.7) | 33.9 (20.9, 0.0-74.9) | 75.6 (6.5, 62.8-88.4) | 53.7 (11.7, 30.8-76.6) | 54.0 (7.2, 39.9-68.1) | 37.0 (7.0, 23.2-50.8) | 59.2 (7.7, 44.1-74.3) |

**Table A 5: Length (km) estimates of wadeable, perennial streams (Target) in a given condition banding for additional metrics referred to in report.**

| | Estimated km length of target river network<br>Parentheses are estimated SE, followed lower and upper 95th confidence interval | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Regional** | **Coromandel** | **Lake Taupō** | **Lower Waikato** | **Upper Waikato** | **Waihou-Piako** | **Waipā** | **West Coast** |
| | | | | Turbidity | | | | |
| Clear | 11357 (406, 10561-12153) | 751 (108, 539-924) | 1669 (99, 1474-1772) | 1223 (140, 948-1498) | 2217 (0, 2217-2217) | 1543 (144, 1261-1825) | 1961 (148, 1671-2251) | 2429 (223, 1991-2867) |
| Highly turbid | 470 (169, 140-801) | | | 281 (122, 42-520) | | | 39 (35, 0-108) | 76 (48, 0-170) |
| Slightly turbid | 1960 (342, 1290-2630) | 51 (49, 0-147) | 104 (99, 0-298) | 160 (85, 0-327) | | 303 (144, 21-584) | 580 (129, 327-833) | 528 (189, 158-898) |
| Stained | 499 (178, 150-849) | 122 (98, 0-313) | | 81 (44, 0-167) | | | 81 (65, 0-208) | 181 (113, 0-402) |
| | | | | Canopy cover | | | | |
| Open | 7559 (532, 6517-8601) | 110 (74, 0-256) | 600 (370, 0-1327) | 1194 (136, 927-1462) | 902 (221, 469-1335) | 831 (166, 506-1156) | 1455 (228, 1009-1902) | 2093 (249, 1605-2581) |
| Partly shaded | 4542 (491, 3580-5506) | 641 (132, 382-899) | 104 (98, 0-297) | 391 (120, 156-626) | 1131 (245, 651-1610) | 693 (164, 372-1015) | 806 (202, 410-1202) | 771 (209, 362-1181) |
| Significantly shaded | 2186 (399, 1404-2967) | 173 (115, 0-399) | 1068 (356, 371-1766) | 160 (85, 0-326) | 184 (99, 0-378) | 321 (116, 92-549) | 400 (173, 61-739) | 350 (174, 9-691) |
| | | | | Dominant riparian vegetation | | | | |
| Crops/Hort | 389 (187, 23-755) | | | 155 (84, 0-320) | | | 164 (125, 0-410) | |
| Forestry | 1328 (310, 720-1936) | 59 (51, 0-158) | 950 (334, 295-1604) | | 634 (235, 173-1094) | 281 (143, 0-562) | 81 (68, 0-214) | |
| Native forest | 723 (227, 279-1167) | 110 (58, 0-225) | | 41 (35, 0-109) | | 119 (79, 0-273) | 204 (144, 0-486) | 164 (74, 18-310) |
| Native shrub | 1063 (300, 476-1651) | 103 (66, 0-231) | 104 (99, 0-298) | 203 (92, 23-383) | | 194 (91, 15-373) | | 404 (213, 0-823) |

| Estimated km length of target river network<br>Parentheses are estimated SE, followed lower and upper 95th confidence interval | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Regional** | **Coromandel** | **Lake Taupō** | **Lower Waikato** | **Upper Waikato** | **Waihou-Piako** | **Waipā** | **West Coast** |
| Pasture | 9915 (489, 8956-10874) | 354 (110, 139-569) | 616 (338, 0-1278) | 1346 (127, 1097-1596) | 1461 (247, 976-1945) | 1132 (153, 833-1431) | 2131 (192, 1755-2507) | 2425 (247, 1940-2909) |
| Retired grass | 826 (259, 318-1334) | 247 (140, 0-522) | 104 (98, 0-297) | | 123 (83, 0-286) | 119 (81, 0-278) | 81 (69, 0-216) | 221 (144, 0-503) |
| Urban | 42 (38, 0-116) | 51 (49, 0-147) | | | | | | |
| Fencing | | | | | | | | |
| Complete both sides | 4172 (443, 3304-5040) | 162 (85, 0-328) | 719 (312, 108-1331) | 718 (152, 420-1017) | 888 (267, 364-1412) | 809 (151, 514-1105) | 731 (171, 397-1066) | 315 (145, 31-600) |
| None or ineffective | 7522 (533, 6478-8567) | 641 (118, 409-872) | 1053 (312, 441-1665) | 710 (167, 382-1038) | 1206 (260, 696-1715) | 956 (161, 641-1271) | 1082 (196, 698-1466) | 2108 (260, 1600-2618) |
| One side or partial | 2592 (438, 1733-3452) | 122 (98, 0-313) | | 317 (126, 69-564) | 123 (75, 0-270) | 80 (65, 0-208) | 848 (208, 440-1256) | 791 (247, 307-1274) |
| Inorganic substrate compaction | | | | | | | | |
| Assorted sizes, tightly packed | 1252 (281, 701-1804) | 110 (56, 0-220) | 349 (245, 0-830) | 84 (71, 0-224) | 216 (133, 0-477) | 192 (84, 27-356) | 150 (78, 0-303) | 309 (162, 0-627) |
| Moderately packed | 3778 (462, 2873-4683) | 704 (97, 513-894) | 104 (99, 0-297) | 261 (90, 84-438) | 387 (153, 86-687) | 657 (142, 379-935) | 665 (179, 314-1016) | 836 (254, 340-1333) |
| Mostly a loose assortment | 2362 (414, 1551-3173) | 59 (55, 0-168) | 616 (338, 0-1278) | 165 (79, 11-320) | 485 (196, 101-869) | 73 (43, 0-157) | 850 (217, 424-1275) | 348 (149, 56-640) |
| No packing | 6894 (508, 5900-7889) | 51 (49, 0-147) | 704 (358, 3-1405) | 1235 (126, 989-1481) | 1130 (264, 612-1648) | 924 (134, 661-1187) | 997 (180, 644-1351) | 1721 (259, 1213-2229) |
| Embeddedness | | | | | | | | |
| <5% covered by fine sediment | 218 (87, 48-389) | 51 (45, 0-140) | 104 (102, 0-304) | | | | 68 (46, 0-158) | 44 (38, 0-117) |

| | Estimated km length of target river network<br>Parentheses are estimated SE, followed lower and upper 95th confidence interval | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Regional** | **Coromandel** | **Lake Taupō** | **Lower Waikato** | **Upper Waikato** | **Waihou-Piako** | **Waipā** | **West Coast** |
| >75% covered by fine sediment | 6444 (502, 5459-7429) | 103 (66, 0-232) | 104 (99, 0-298) | 1276 (125, 1030-1521) | 1007 (275, 467-1546) | 844 (141, 567-1121) | 908 (185, 546-1271) | 1721 (242, 1247-2195) |
| 25-49% covered by fine sediment | 2711 (412, 1903-3518) | 601 (115, 376-826) | 246 (225, 0-686) | 155 (84, 0-318) | 255 (122, 15-495) | 352 (113, 130-574) | 523 (177, 176-870) | 599 (199, 209-989) |
| 5-24% covered by fine sediment | 2613 (399, 1831-3396) | 118 (60, 0-236) | 104 (99, 0-297) | 315 (107, 105-525) | 357 (155, 54-660) | 334 (114, 110-558) | 555 (168, 225-885) | 670 (230, 220-1119) |
| 50-74% covered by fine sediment | 2300 (431, 1456-3145) | 51 (49, 0-147) | 1216 (280, 666-1766) | | 598 (198, 210-987) | 315 (140, 41-589) | 607 (212, 192-1021) | 181 (114, 0-404) |
| Sample type | | | | | | | | |
| Hard | 6915 (510, 5916-7914) | 751 (108, 539-924) | 1172 (370, 446-1772) | 426 (114, 203-649) | 1026 (259, 519-1533) | 849 (133, 588-1110) | 1677 (187, 1309-2044) | 1312 (248, 826-1798) |
| Soft | 7372 (510, 6373-8371) | 173 (108, 0-385) | 600 (370, 0-1327) | 1319 (114, 1096-1542) | 1191 (259, 684-1698) | 997 (133, 736-1258) | 985 (187, 617-1352) | 1902 (248, 1416-2388) |

## 6.2 Figures

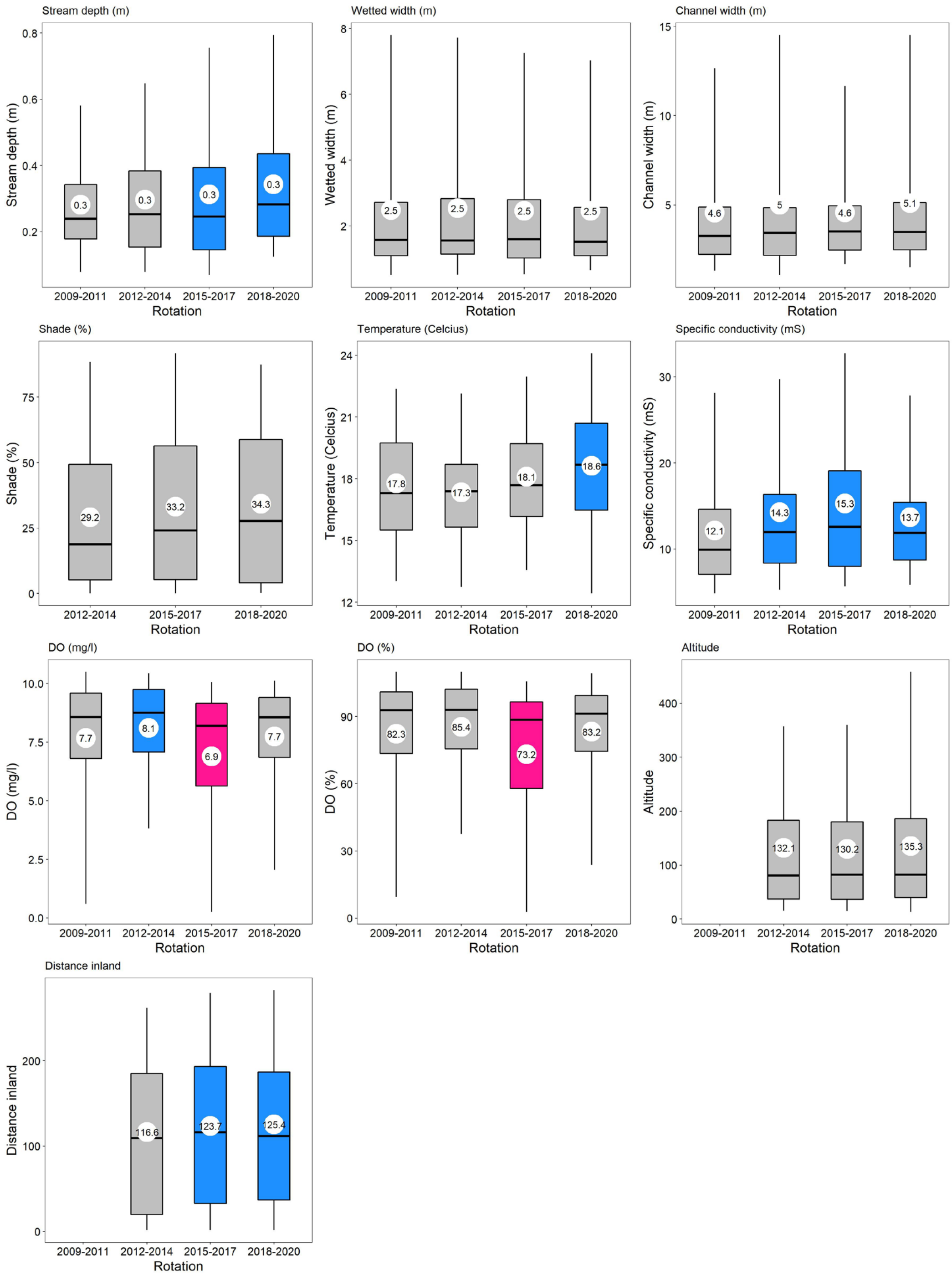


**Figure A 1: Boxplots of estimated percentile (5th, 25th, 50th, 75th, 95th) and mean (white dots) values for additional continuous variables measured at sites on developed land (excluding Q9 – periphyton), through time for each rotation from 2009 to 2020. Grey boxes indicate no statistically significant change, blue boxes a positive statistically significant change, and pink boxes a statistically significant negative change in mean values between the first rotation in 2009-2011 and any subsequent rotation.**

## Random and Reference Sites 2018-2020

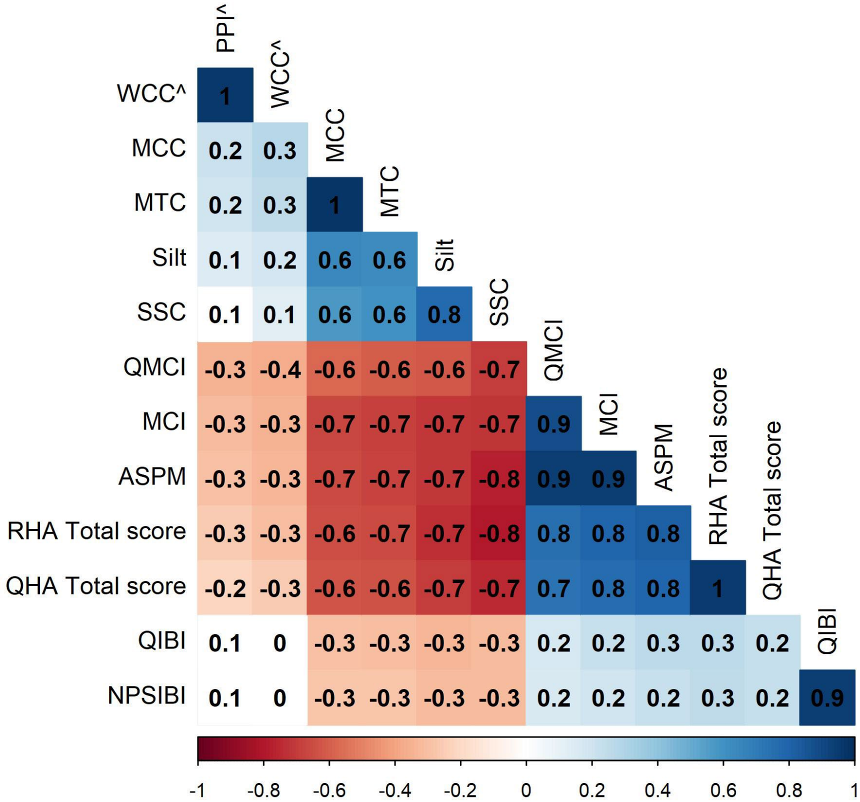


**Figure A 2: Matrix of Pearson correlation coefficients between main variables discussed in report.**

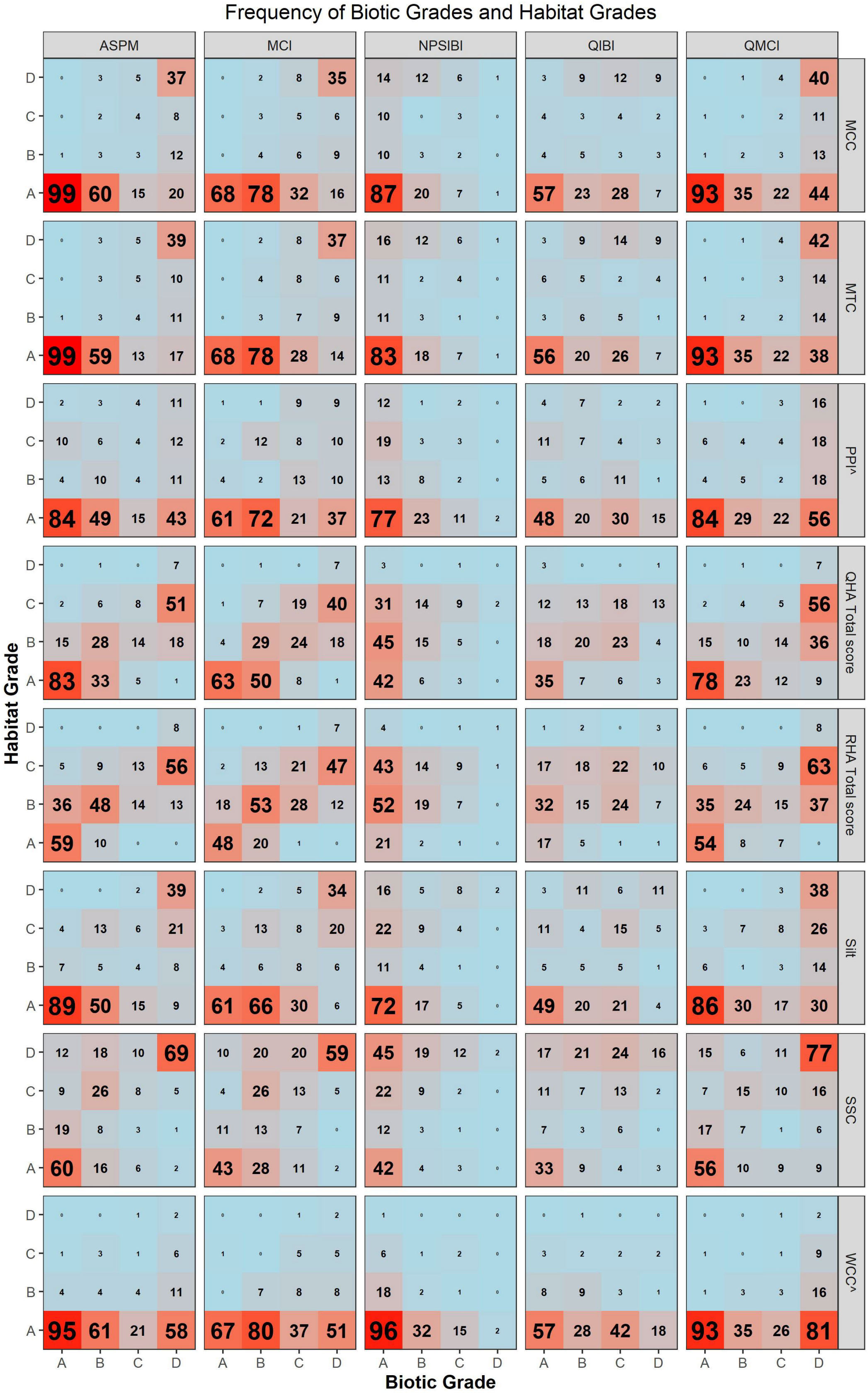


**Figure A 3: Frequency contingency table of cooccurring gradings for main variables discussed in report. Data used includes developed land (random probabilistic) and native forest (reference sites).**