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Ecological health of rivers and streams in the Wellington Region

An assessment of the current state of habitat, periphyton, macroinvertebrate and fish communities

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Executive summary

Greater Wellington Regional Council (GWRC) has several river and stream monitoring programmes to aid its management of aquatic resources in the Wellington Region. Over the last four years, GWRC has been trialling a new monitoring programme that differs from its existing programmes in that it: (i) involves more ecologically focussed indicators; (ii) uses a new monitoring network design based on randomly selected sites with a known probability of occurrence (ie, a “probabilistic network design”); and, (iii) will enable extent estimates of ecological health for mapped rivers and streams on developed land. The purpose of this report is to summarise the data collected to date from this new monitoring approach and, where appropriate, compare data against the numerical and narrative aquatic ecosystem health objectives in GWRC’s Proposed Natural Resources Plan (PNRP).

This new monitoring approach involves undertaking assessments of periphyton and macrophyte cover, macroinvertebrate and fish communities, and aspects of aquatic habitat quality, at 48 sites that were randomly selected and located on permanently flowing streams and rivers on developed land (ie, <100% indigenous forest cover in the upstream catchment). Sampling was undertaken during the summer and autumn months and spread over a four year period (2016-2019).

Based on the analyses undertaken here, the potential impacts/issues associated with periphyton and macrophyte cover on river and stream health in the Wellington Region are estimated to be relatively minor; with most river and stream reaches on developed land estimated to be compliant with objectives in GWRC’s PNRP (78.1 and 70.8% of river length compliant, respectively). In contrast, the majority of river and stream length on developed land is estimated to be non-compliant with the objectives stated in the PNRP for healthy macroinvertebrate and fish communities (75.3 and 64.8% of river length non-compliant, respectively). While it was outside of the scope of this report to examine drivers of the current state, analysis of habitat variables collected indicate the widespread occurrence of degraded river and stream habitat which is likely contributing to the poor condition of macroinvertebrate and fish communities.

The application of a probabilistic network design and the analyses presented here mean that unbiased estimates of the state of aquatic ecological health in rivers and streams in the Wellington Region can be presented for the first time. The conclusions presented apply to mapped, perennial, non-tidal rivers and streams on developed land. Recommendations to improve the robustness of this monitoring programme and potential future analyses/linkages with other GWRC monitoring programmes are also provided.

Contents

1. Introduction

Greater Wellington Regional Council (GWRC) manages water quality and ecosystem health in rivers and streams of the Wellington Region for natural state, public water supply, recreation and amenity, trout habitat, and aquatic ecosystem health. Regular monitoring of physico-chemical and microbiological water quality, together with assessments of ecosystem health, are integral in managing rivers and streams for these purposes. This monitoring is also important for understanding the potential flow-on effects for the health of downstream receiving environments such as lakes and estuaries.

River and stream water quality and ecology in the Wellington Region have been monitored in some form by GWRC since 1987. Since this time, the monitoring network (numbers and locations of sites) and monitoring variables (physico-chemical, bacteriological and biological) have undergone a number of changes to ensure monitoring and reporting has kept up with the evolving science and information needs of GWRC (see Milne & Perrie 2005; Perrie et al. 2012; Mitchell & Heath 2018).

In recent years, there has been more emphasis on collecting relevant and regionally representative data related to the ecological health of rivers and streams (Clapcott et al. 2018; MfE 2019; GWRC 2019). Over the last four years, GWRC has been trialling a new monitoring programme that differs from its existing programmes in that it: (i) involves more ecologically focussed indicators; (ii) uses a new monitoring network design based on randomly selected sites with a known probability of occurrence (ie, a "probabilistic network design"); (iii) will enable extent estimates of ecological health for mapped rivers and streams on developed land. A focus on ecological variables, such as macroinvertebrate and fish communities, allows for more meaningful conclusions on stream and river ecological health to be made (cf. other approaches that rely heavily on measures of water quality (eg, Perrie et al. 2012)). Furthermore, the random selection of sites with a known probability of occurrence provides an unbiased picture of river and stream health, and the analytical approach used allows for statistically robust estimates of the extent of ecological health across the Wellington Region's rivers and streams to be made.

The purpose of this report is to summarise the data from this new monitoring approach over the first four-year sampling period, and, where appropriate, compare data against the numerical and narrative aquatic ecosystem health objectives in GWRC's Proposed Natural Resources Plan[1] (PNRP; GWRC 2019; see Table 1.1). Assessments of data against other relevant ecological thresholds, such as the National Objectives Framework (NOF) outlined in the National Policy Statement for Freshwater Management (NPS-FM; MfE 2014 & 2019), were also undertaken and recommendations for further work, including modifications to the existing monitoring programme, are made. It was outside of the scope of this report to undertake an in-depth examination of the drivers behind the current state of river and stream health presented here.

[1] For the purposes of this report, data has been assessed against the "all rivers" objectives in the PNRP.

Table 1.1: The narrative and numerical river and stream aquatic ecosystem health (all rivers) objectives from Table 3.4 of GWRC's Proposed Natural Resources Plan (PNRP; GWRC 2019) that are assessed in this report

River class[1]		Macrophytes	Periphyton cover[2] (PeriWCC)	Invertebrates Macroinvertebrate Community Index	Fish
1	Steep, hard sedimentary	Indigenous macrophyte communities are resilient and their structure, composition and diversity are balanced	<20	≥ 120	Indigenous fish communities are resilient and their structure composition and diversity are balanced
2	Mid-gradient, coastal and hard sedimentary		<40	≥ 105	
3	Mid-gradient, soft sedimentary		<40	≥ 105	
4	Lowland, large, draining ranges		<40	≥ 110	
5	Lowland, large, draining plains and eastern Wairarapa		<40	≥ 100	
6	Lowland, small		<40	≥ 100	

[1]The river classes in the PNRP are based on a the Freshwater Environments of New Zealand (Leathwick et al. 2008) classification system that has been slightly modified for use in the Wellington Region (see Warr 2010 and Greenfield et al. 2013).

[2]Note that these values are presented as per the guidance provided in Greer (2018) as opposed to those in the PNRP (GWRC 2019) which includes typographical errors.

2. Methodology

2.1 Site monitoring network

Sites on rivers and streams in the Wellington Region were selected using the ‘spsurvey’ design package (Kincaid and Olsen, 2016) in R (R Core Team 2017). This approach involves randomly selecting sites with a known probability of inclusion that meet the target population criteria. Criteria of the target population were that a site needed to be located on a stream or river on developed land (ie, not in “reference condition” and, for this process, “developed land” was defined for a site as having <100% indigenous forest landcover in its upstream catchment[2]), perennial and non-tidal. A balanced unequal probability design was used to ensure, as far as possible, an equal number of sites was included across 1st, 2nd, 3rd and ≥ 4th order streams with the River Environment Classification (REC) river network layer used as the sample frame.

The advantage of using a probability based survey design is that it is a cost-effective way of quantifying the extent and condition of aquatic resources with a known level of precision. This approach has been widely endorsed by the US EPA following the acknowledgement that ‘traditional’ site networks (eg, sites not selected randomly) did not enable adequate quantification of resource condition and extent at regional scales (Olsen & Peck 2008). In New Zealand, the Waikato Regional Council (WRC) has successfully used a probabilistic network design to provide unbiased regional stream length estimates (in perennial, wadeable, non-tidal streams on developed land) of aquatic plant (periphyton and macrophytes), macroinvertebrate and fish community condition (eg, Collier & Hamer 2012; Pingram et al. 2018).

In regards to the REC river network layer used as the sampling frame, it does not identify all small perennial headwater streams (Pingram et al. 2016) and in the Wellington Region it does include some man-made waterways such as water races and some of the larger man-made drainage networks. Hence, small perennial headwater streams may be underrepresented by this sampling design, and some sites may be included on man-made systems (cf. “natural” rivers and streams).

2.1.1 Creating the site network

A total of 116 randomly selected sites were initially screened against the target population criteria using the REC GIS layer, aerial photographs and/or site visits. Of these, 53 sites were considered to be “non-target” (ie, they did not meet the criteria) and 63 sites were considered “target” (Table 2.1). Of the sites considered target, landowner access was not gained for five sites and ten sites were considered inaccessible to sample safely. Non-target sites were predominantly sites that were considered to be in reference condition (ie, not located on developed land) or were considered dry (or likely dry) during the sampling period based on existing knowledge (Table 2.1). This process resulted in the selection of 48 sites that met the target population criteria and could be safely surveyed.

[2] The River Environment Classification (RECv1) GIS layer, as well as a visual inspection of aerial photographs, were used to classify whether a site was located on developed land or not.

Sampling site locations are presented in Figure 2.1 and sampling site characteristics are presented in Appendix 1. Application of the probabilistic network design achieved reasonable geographical representation across the region. In regards to representation across the five GWRC whaitua[3], sites were more likely to be located in the whaitua with larger land areas (and hence greater extent of river and stream length). The majority of sites were located in the Ruamāhanga Whaitua (29 sites; 43.9% of the region by area), followed by the Eastern Wairarapa Whaitua (ten sites; 30.4%), Te Whanganui-a-Tara (seven sites; 14.6%) and Te Awarua-o-Porirua (two sites; 2.5%). No sites were located in the Kāpiti Coast Whaitua which reflects, to some extent, the small proportion this whaitua makes up at a regional scale (8.6%) and the limited stream length on developed compared with indigenous forest (Figure 2.1).

Table 2.1: Estimated target and non-target river and stream proportions (%) and lengths (km) calculated using the R package 'spsurvey'. Values in parentheses are ± one standard error.

	n sites	River extent estimates	
		Proportion (%)	Length (km)
Target			
Access denied	5	8.8 (3.4)	456.8 (180.9)
Inaccessible	10	18.1 (4.3)	946.1 (245.2)
Sampled	48	73.1 (5.0)	3,815.9 (338.3)
Total	63	100	5,218.7 (341.9)
Non-target			
Dry	20	39.8 (5.8)	2,845.1 (442.1)
Lake	2	2.5 (1.4)	180.3 (99.3)
Network inaccuracy	2	5.6 (3.2)	402.5 (236.6)
Reference condition	23	42.2 (5.2)	3,012.7 (416.6)
Tidal	3	2.5 (1.2)	179.8 (81.7)
Wetland	3	7.3 (3.2)	522.9 (230.2)
Total	53	100	7,143.3 (405.6)
Total mapped river/stream length in region			12,362

[3] Whaitua means a designated space or catchment. Greater Wellington Regional Council has five whaitua (see Figure 2.1) where it is working closely with communities to manage land and water resources through whaitua committees.

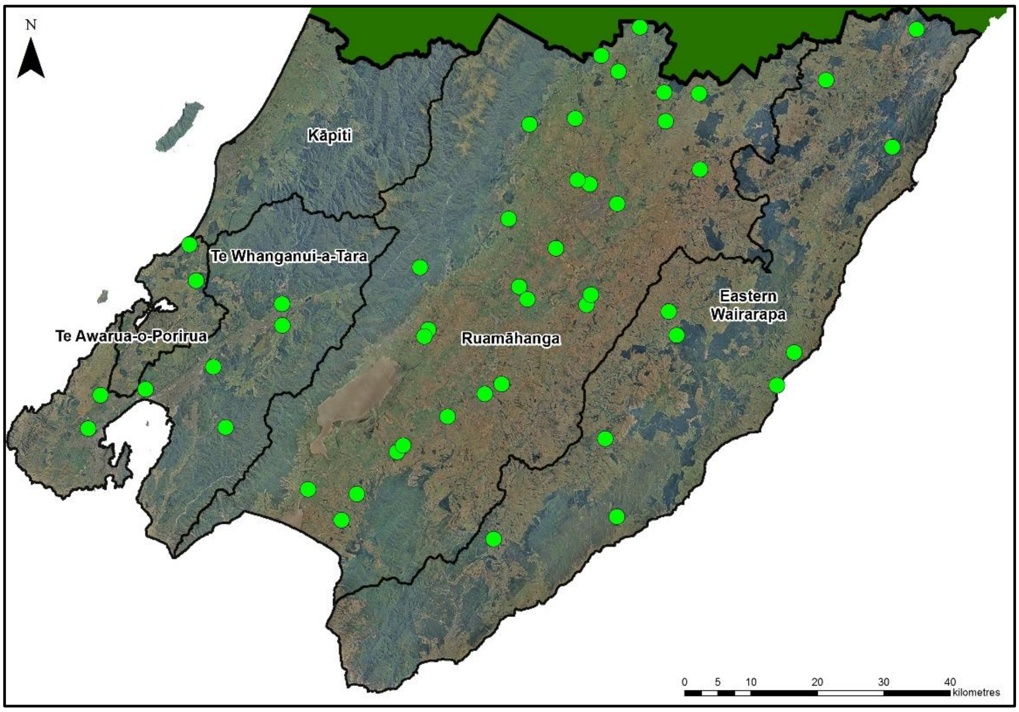

Figure 2.1: Locations of the 48 sites selected randomly using the R package spsurvey and sampled during the 2016-2019 period. Whaitua boundaries are also indicated

The Strahler stream order and REC landcover classifications for the 48 sites surveyed and reported on here are summarised in Table 2.2 (see also Appendix 1). Despite the application of an unequal probabilistic network design, 1st and 2nd order streams can still be considered under-represented in the sampling network (seven and three sites, respectively). This was because many of the sites initially selected in these orders were more likely to be classified through the screening process as either dry or in a reference state (ie, not located on developed land) and hence did not meet the target criteria. Based on the REC classification of dominant upstream catchment landcover[4], sites were predominantly "pastoral" (38 sites). Six sites were classified as "indigenous forest and scrub" and two sites each were classified as "exotic forest" and "urban" (Table 2.2).

Table 2.2: Summary of Strahler stream order and REC upstream catchment landcover classes for the 48 sites surveyed

Strahler stream order	*n* sites	REC landcover	*n* sites
1	7	Pastoral	38
2	3	Indigenous forest & scrub	6
3	19	Exotic forest	2
≥4	19	Urban	2

[4] REC landcover classes are assigned based on the spatially dominant landcover except in the case of pastoral and urban landcover. If pastoral landcover exceeds 25% of the upstream catchment area, the REC landcover class is pastoral. Similarly, if the urban landcover exceeds 15%, the REC landcover class is urban.

2.2 Timing and monitoring frequency

All surveys were undertaken between November to May (inclusive) of each year and surveys only occurred in the first two weeks of May if settled autumn weather remained. Sites were surveyed in no particular order over this period but at least two weeks of stable flows proceeded each sampling occasion. We note that this sampling window (November to May) means that some sites were sampled outside of the timeframes recommended for some biological sampling protocols (eg, Joy et al. 2013: December to April (inclusive)).

Surveys were also limited to one-off assessments carried out between 2016 and 2019; with seven sites sampled in the summer/autumn of 2016, four sites in 2016/17, 19 sites in 2017/18 and 18 sites in 2018/19. Given that surveys were one-off assessments, some care must be taken with the interpretation of the results presented here as for some indicators it is recommended that multiple years of annual data are collected (eg, Greenfield et al. 2015), or, in some cases, multiple years of monthly collected data are utilised for assessments of state (eg, MfE 2019). Furthermore, given that sites were sampled over a four year period, atypical summer/autumn conditions in any one year had the potential to influence the results and this (inter-annual) sampling effort may add additional variability to the estimates of regional parameter statistics and extent.

2.3 Monitoring variables

2.3.1 Habitat

(a) Sampling

Habitat assessments were undertaken following the Rapid Habitat Assessment (RHA) method outlined in Clapcott (2015). The RHA provides an indication of the condition of the physical habitat and its ability to support stream biota. It incorporates the following variables: deposited sediment cover, invertebrate habitat abundance and diversity, fish habitat abundance and diversity, hydraulic heterogeneity, bank erosion and vegetation, and riparian width and shade. Each category is scored between 1 (‘Poor’) and 10 (‘Excellent’). Summation of individual scores provides an overall total habitat quality score for each site (lowest and highest possible RHA scores are 10 and 100, respectively). The RHA methodology was developed with a focus on wadeable hard-bottomed streams (Clapcott 2015) and hence its applicability to other stream/river types (eg, naturally soft-bottomed sites and larger rivers) has not yet been explored.

In addition to the deposited sediment cover estimate in the RHA (which is a “bankside” type assessment of the reach), an assessment of instream fine deposited sediment cover was undertaken largely following protocol SAM2 in Clapcott et al. (2011). Briefly, an underwater viewer was used to record five observations of fine sediment cover across four randomly selected transects in run-type habitat. This differs from Clapcott et al. (2011) which specifies four observations across five transects. This modification was undertaken to align the sediment cover sampling method with the periphyton cover assessment method.

(b) Reporting

While river and stream habitat is recognised as a key component of monitoring ecosystem health (Clapcott et al. 2018), there are no standardised approaches that are regularly used to report on habitat and classify overall habitat condition. Therefore we simply summarised the individual components and overall scores of the RHA. Measurements of instream deposited fine sediment cover were averaged across observations/transects and compared against the proposed deposited fine sediment cover river-specific thresholds in the NPS-FM NOF (MfE 2019; Table 2.3). Although the recommended survey method (SAM2 in Clapcott et al. 2012) was largely followed, the assessment methodology in MfE (2019) stipulates a comparison with a median value generated from monthly monitoring over a two year period, whereas in this assessment only one sampling event following a preceding stable flow period was available for each site.

Table 2.3: NPS-FM NOF (MfE 2019) proposed deposited fine sediment cover attribute bands for the twelve different river/stream sediment classes

River/stream sediment class[1]	1	2	3	4	5	6	7	8	9	10	11	12
Attribute band	**River/Streambed fine sediment cover (%)**											
A	<84	<9	<42	<12	<80	<30	<41	<22	<48	<15	<76	<27
B	<90	<15	<50	<17	<86	<38	<48	<33	<54	<22	<82	<36
C	≤97	≤21	≤60	≤23	≤92	≤46	≤56	≤45	≤61	≤29	≤89	≤45
D	>97	>21	>60	>23	>92	>46	>56	>45	>61	>29	>89	>45

[1]Fine sediment classes for each site were assigned as per MfE (2019) and are presented in Appendix 1.

2.3.2 Periphyton cover

(a) Sampling

Across each of four randomly selected transects located in run-type habitat, five observations of periphyton cover were undertaken using an underwater viewer; with care taken to space observations across the stream width. Proportions of periphyton cover at each observation were assigned into the following categories used by Greenfield (2016): no algae, film, mats, sludge, cyanobacterial mats, green filamentous, other filamentous, bryophytes and macrophytes.

(b) Reporting

Periphyton cover was expressed as weighted composite cover (PeriWCC) following Matheson et al. (2012). To enable calculation of PeriWCC, periphyton cover observations from each transect were averaged for each category, and mat and filamentous categories combined. PeriWCC values from these one-off assessments were then compared against the numeric periphyton cover threshold in the PNRP (Table 2.4) for assessment of compliance, and the provisional quality classes in Matheson et al. (2012) (Table 2.5). In both instances, these thresholds relate to the protection of ecological condition or maintenance of healthy aquatic ecosystems (Matheson et al. 2012; Greenfield 2014; Greer 2018). Both Matheson et al. (2012) and Greer (2018) indicate that assessment against thresholds should be undertaken using annual statistics generated from monthly monitoring as opposed to the one-off assessments used here.

Table 2.4: PNRP river-specific periphyton cover (as PeriWCC) thresholds to maintain healthy aquatic ecosystems

River class		Periphyton cover (as PeriWCC)
		All rivers[1]
1	Steep, hard sedimentary	<20%[2]
2	Mid-gradient, coastal and hard sedimentary	<40%[2]
3	Mid-gradient, soft sedimentary	<40%
4	Lowland, large, draining ranges	<40%
5	Lowland, large, draining plains and eastern Wairarapa	<40%
6	Lowland, small	<40%

[1]All sites were assessed against the "All rivers" threshold in the PNRP.

[2]Note that these values are presented as per the guidance provided in Greer (2018) as opposed to those in the PNRP (GWRC 2019) which include typographical errors.

Table 2.5: Provisional periphyton cover (as PeriWCC) thresholds recommended in Matheson et al. (2012) as indicators of ecological condition

Ecological condition classes	Periphyton cover (as PeriWCC)
Excellent	<20%
Good	20-39%
Fair	40-55%
Poor	>55%

2.3.3 Macrophyte cover

(a) Sampling

Macrophyte cover was assessed following the method in Collier et al. (2014), except that (i) information on the native and exotic components of the macrophyte community and channel clogginess were not recorded at every site and hence are not reported; and (ii) four transects were used as opposed to five. In brief, this method provides a general overview of reach scale rooted macrophyte cover (Collier et al. 2014) and involves estimating the proportion of emergent, surface reaching and submerged rooted macrophyte cover in 1 m strips at four evenly spaced transects along a sampling reach (~150 m). Total macrophyte cover was calculated by summing the total cover from each transect (eg, % emergent + % surface reaching + % subsurface) and dividing by four.

(b) Reporting

The aquatic ecosystem health macrophyte objective of GWRC's PNRP (GWRC 2019) states that:

"*Indigenous macrophyte communities are resilient and their structure and composition and diversity are balanced*".

Greenfield et al. (2015) indicate that assessment of this narrative objective could, in part, include a comparison against the ≤50% macrophyte cover threshold in Matheson et al. (2012). However, Greenfield et al. (2015) notes the limitation of this approach for assessing the macrophyte objective in the PNRP (eg, this threshold is proposed to protect aesthetic and recreational values rather than ecological values), as well as an overall lack of guidance and national monitoring and reporting protocols in New Zealand for dealing with the resilience, structure and composition of macrophyte communities.

In the absence of alternative options, and for the purposes of this report, we have compared the one-off macrophyte cover measurements against the 50% cover threshold proposed in Matheson et al. (2012). Macrophyte cover below or equal to 50% was considered to comply with PNRP objective and above 50% was considered non-compliant. Note that it is typically recommended that macrophyte assessments are based on multiple months of measurements rather than the one-off assessment used here (Greenfield et al. 2015).

2.3.4 Macroinvertebrates

(a) Sampling

Macroinvertebrate samples were collected from riffle habitat at the 35 sites that were classified as having hard-substrate[5] following Protocol C1 of the national macroinvertebrate sampling protocols (Stark et al. 2001). At the thirteen sites classified as having soft-substrate, Protocol C2 of the national protocols was used whereby sampling effort was distributed among stable habitats (eg, overhanging bank vegetation, wood, macrophytes) in proportion to their occurrence in the sampling reach. All samples are processed in accordance with Protocol P2 (Stark et al. 2001).

(b) Reporting

For each site, Macroinvertebrate Community Index (MCI) scores were calculated (following Stark & Maxted 2007[6]) and compared against the river-specific quality class thresholds developed for the Wellington Region (Clapcott & Goodwin 2014) (Table 2.6). Macroinvertebrate Community Index scores were also assessed for compliance against the river-specific PNRP objective (numeric MCI thresholds) that represent whether a macroinvertebrate community is in "good" or better state (Greenfield et al. 2015; GWRC 2019; Table 2.6)

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[5] Classification of hard-substrate sites to employ the C1 protocol of Stark et al. (2001) at was largely based on the presence of riffle-type habitat. For example, the overall reach may have been predominantly dominated by soft-substrate (> 50% cover of deposited fine sediment) but C1 was still used if riffle-type habitat (containing cobbles and gravels) was present and allowed for adequate sampling using this method.

[6] Hard-bottomed MCI scores were calculated for sites sampled using Protocol C1 and soft-bottomed MCI scores were calculated for sites sampled using Protocol C2.

Table 2.6: MCI quality classification based on Clapcott and Goodwin (2014) and PNRP MCI objectives for health aquatic ecosystems in the Wellington Region

River class		MCI quality class				PNRP MCI objective
		Poor	Fair	Good	Excellent	
1	Steep, hard sedimentary	<110	110-120	120-130	≥130	≥ 120
2	Mid-gradient, coastal and hard sedimentary	<80	80-105	105-130	≥130	≥ 105
3	Mid-gradient, soft sedimentary	<80	80-105	105-130	≥130	≥ 105
4	Lowland, large, draining ranges	<90	90-110	110-130	≥130	≥ 110
5	Lowland, large, draining plains and eastern Wairarapa	<80	80-100	100-120	≥120	≥ 100
6	Lowland, small	<80	80-100	100-120	≥120	≥ 100

Quantitative MCI (QMCI) scores and the Average Score Per Metric (ASPM were also calculated following Stark and Maxted (2007) and Collier (2008), respectively. These metrics, along with the MCI, were then also compared against thresholds in the proposed NPS-FM (MfE 2019; Table 2.7). For all macroinvertebrate assessments (PNRP and NPS-FM), it is important to acknowledge that it is recommended that these assessments are undertaken using a summary statistic calculated from samples collected annually across multiple years (eg, five years for NPS-FM), rather than the one-off samples used here.

Table 2.7: NPS-FM NOF (MfE 2019) proposed QMCI, MCI and ASPM states

Attribute state	Numeric attribute state		
	QMCI	MCI	ASPM
A	≥6.5	≥130	≥0.6
B	≥5.5 & <6.5	≥110 & <130	≥0.4 & <0.6
C	≥4.5 & <5.5	≥90 & <110	≥0.3 & <0.4
D	<4.5	<90	<0.3

2.3.5 Fish

(a) Sampling

Assessments of fish communities were undertaken following the netting/trapping or backpack electric fishing protocols in Joy et al. (2013) at 18 and 23 sites, respectively. The remaining seven sites were not suitable for application of the wadeable protocols in Joy et al. (2013) because of their larger size. There are no existing national protocols for assessing fish communities at non-wadeable large river reaches, so GWRC is currently developing methodologies to assess these types of riverine habitat. As part of this development, four of these seven sites, were surveyed using backpack electric fishing of wadeable habitats present (eg, riffles and shallow runs) and at the remaining three sites, a combination of backpack electric fishing of wadeable habitat and netting/trapping of deeper water habitats (eg, pools and deep runs) were used.

All fish caught were identified, measured and released at the site of capture, except in the case of pest species (eg, rudd) which were euthanised.

(b) Reporting

The aquatic ecosystem health objective for fish in GWRC's PNRP (GWRC 2019) states that:

"*Indigenous fish communities are resilient and their structure and composition and diversity are balanced.*"

Greenfield et al. (2015) indicate that the method for assessing a river/site against this narrative objective still needs to be determined. However, they indicate that this should include: "comparison against expected (based on expert opinion and predictive models) community composition, calculation of fish community indices such as Fish Index of Biotic Integrity (Fish-IBI; Joy & Death 2004), abundance of key species and determination of size-frequency classes for key species". However, the only method currently available to assess the condition of the fish communities is the Fish-IBI for which a version has been calibrated for the Wellington Region (Joy 2004).

The Fish-IBI is a presence/absence based multimetric that was developed specifically to assess the condition of New Zealand's fish fauna taking into account the fact that many species exhibit diadromous life histories (ie, often migrate between the ocean and freshwater at some point in their lifecycle). The Fish-IBI compares the species found at a site with those expected to be at a site, while taking into account natural changes that occur with distance inland and elevation (Joy & Death 2004). The Fish-IBI has also been endorsed as a nationally important indicator by MfE (2019), although at the time of writing this report, the necessary documentation and guidance (eg, calculation methods) were not available to enable an assessment of the data collected here against the proposed thresholds in the NPS-FM (MfE 2019). Therefore, only the Fish-IBI developed by Joy (2004) for the Wellington Region was used here.

Fish-IBI scores were generated for each site in a Microsoft Excel spreadsheet macro using a version of the Fish-IBI calibrated for the Wellington Region following Joy (2004). For large river sites that were surveyed using both backpack electric fishing and netting/trapping, data were combined from both methods for each site. Fish-IBI scores can range from 0 (no fish present) to 60, with a score of 60 indicating that all fish that were expected to be present were found. Fish-IBI scores were then assessed against thresholds in Table 2.8 to determine a site's "integrity class". These thresholds differ slightly to those proposed in Joy (2004) in that the number of "classes" was reduced by merging several of the existing classes to enable ease of reporting[7] (see Table 2.8). For the purposes of assessing compliance against the fish narrative objective in the PNRP, the threshold between the "Poor" and "Fair" quality classes was used to determine whether this objective was met or not (Table 2.8).

Table 2.8: Attributes and suggested thresholds for interpretation of IBI scores for the Wellington Region from Joy (2004) as well as the revised integrity classes and thresholds utilised in this report. The threshold used to interpret compliance with the PNRP narrative indigenous fish objective is also presented.

From Joy (2004)			Used in this report	
IBI score	**Integrity class**	**Attributes**	**Revised integrity classes**	**PNRP fish objective**
52–60	Excellent	Comparable to the best situations without human disturbance; all regionally expected species for the stream position are present. Site is above the 97th percentile of Wellington sites.	Excellent	Meets objective "*Indigenous fish communities are resilient and their structure and composition and diversity are balanced.*"
48–51	Very good	Site is above the 90th percentile of all Wellington sites; species richness is slightly less then best for the region.		
38–47	Good	Site is above the 70th percentile of Wellington sites but species richness, habitat or migratory access[1] is reduced; some signs of stress.	Good	
30–37	Fair	Score is just above 50th percentile but species richness is significantly reduced; habitat and or access[1] impaired.	Fair	
18–29	Poor	Site is less than the 50th percentile, thus species richness and or habitat or access[1] are severely impacted.	Poor	Does not meet objective
2–17	Very poor	Site is impacted or migratory access almost non-existent[1].		
0	No native fish	Site is grossly impacted or access for fish is non-existent[1].		

[1]impairment of access for migratory species may be due to man-made barriers or natural barriers.

2.4 Statistical analyses and graphs

Estimates of the proportion (%) of target river and stream length on developed land were calculated for each indicator in terms of (i) the categorical assignment to (ii) different quality classes (eg, Excellent, Good, Fair, Poor), and (iii) compliance classes based on the PNRP (Compliant, Non-compliant). For continuous variables (eg, MCI and IBI scores), both the proportion and length (km) were calculated as cumulative distributions and regional summary statistics (e.g., percentiles, means).

These analyses were done using the spsurvey software package in R. Given that an unequal balanced probability design was used to ensure, as far as possible, selection of an equal number of sites across 1^{st}, 2^{nd}, 3^{rd} and $\geq 4^{th}$ order streams, these calculations required an adjustment of the data for the known probability of site selection (ie, this was not a simple random sample). This allowed an unbiased estimate of regional target stream and river length for indicators to be calculated.

[7] This approach should only be considered interim and further work is required to develop and/or validate a reporting approach for fish communities.

Site classifications used to assign site-specific condition classes for the indicators that required this (eg, PNRP MCI thresholds) are provided for each site in Appendix 1. Raw metric values used in these calculations are also provided in Appendix 1 and summary statistics and cumulative distribution plots, generated by spsurvey in R, are provided in Appendix 2.

To examine the potential of sampling method bias on the calculation of Fish-IBI scores, a Mann-Whitney Rank Sum Test, undertaken in SigmaPlot 13.0, was used to compare the scores calculated by the two main sampling methods (backpack electric fishing and netting/trapping protocols as per Joy et al. (2013)). All additional graphs were created in SigmaPlot 13.0 and in regard to boxplots, the lower and upper boundaries of the box represent the 25th percentile and 75th percentile of the dataset, respectively; the horizontal line within the box represents the median value; the 'whiskers' (error bars) extending above and below the box (interquartile range) represent the 90th and 10th percentile values respectively; and the black dots represent outliers.

3. Results

3.1 Habitat

Rapid Habitat Assessments were undertaken at all 48 sites and total scores ranged from 21 to 97.5 out of a maximum possible score of 100. The estimated median total RHA score calculated by spsurvey for target river and stream length was 46 (Table 3.1). Estimated median values for individual habitat assessment variables are presented in Table 3.1 (further summary statistics are provided in Appendix 2).

Table 3.1: Estimated median total and individual variable scores (calculated in spsurvey) of the Rapid Habitat Assessment (RHA) for target river and stream reaches in the Wellington Region. Interpretation of median scores for individual variables is based on descriptions in Clapcott (2015). Values in parentheses are the 25th and 75th percentiles calculated in spsurvey

Variable[1]	Estimated median score	RHA interpretation of estimated median score
Deposited sediment	2.1 (1 - 6.5)	Between 50 & 60% of bed covered by fine sediment
Invertebrate habitat diversity	5.9 (2.2 - 9.2)	Number of different habitat types available for macroinvertebrates
Invertebrate habitat abundance	1.4 (1 – 6.6)	Between zero & 15% of bed favourable for sensitive macroinvertebrate (EPT taxa) colonisation
Fish cover diversity	6.0 (3.4 – 8.9)	Number of different habitat types available for fish
Fish cover abundance	6.4 (5.4 – 8.1)	Between 40 & 50% of bed provides cover for fish
Hydraulic heterogeneity	2.7 (1.7 – 6.4)	Two to three hydraulic habitat types present
Bank erosion	7.1 (4.9 – 8.6)	Between 5 & 15% active erosion present
Bank vegetation	2.9 (2.1 – 5.1)	Mainly shrubs or sparse tree cover or grasses
Riparian width (potential)	3.5 (1 – 8.3)	3.5 m of riparian buffer width (potentially) available. Not necessarily utilised
Riparian shade	2.7 (1.4 – 4.7)	Between 10 & 15% shading of the bed
Total RHA score[2]	**46.0 (32.6 - 62.9)**	NA

[1] Possible scores for individual variables in the RHA range from 1 to 10.

[2] Possible total RHA scores range from 10 to 100.

The lowest estimated median scores calculated by spsurvey for individual RHA variables were deposited sediment and invertebrate habitat abundance. Invertebrate habitat diversity, fish cover diversity and abundance, and bank erosion, had the highest estimated median scores for river and stream reaches that meet the target population (Table 3.1).

Quantitative assessments of fine sediment cover in runs were available for 40 of the 48 sites assessed. Measured cover ranged from zero percent (three sites) to 100% (eight sites). The estimated median fine sediment cover calculated in spsurvey for target river and stream length was 66%; not too dissimilar to the median cover estimate from the RHA (50 – 60%; see Table 3.1).

Based on an assessment against the proposed NPS-FM (MfE 2019) fine sediment cover thresholds, 41.9% (± 8.2% 1SE) of target river and stream length are estimated to be in the 'A' state, 8.7% (± 3.5%), in the 'B' state, 3.4% (± 2.2%) in the 'C' state and 46.0% (± 8.5%) in the 'D' state (Figure 3.1).

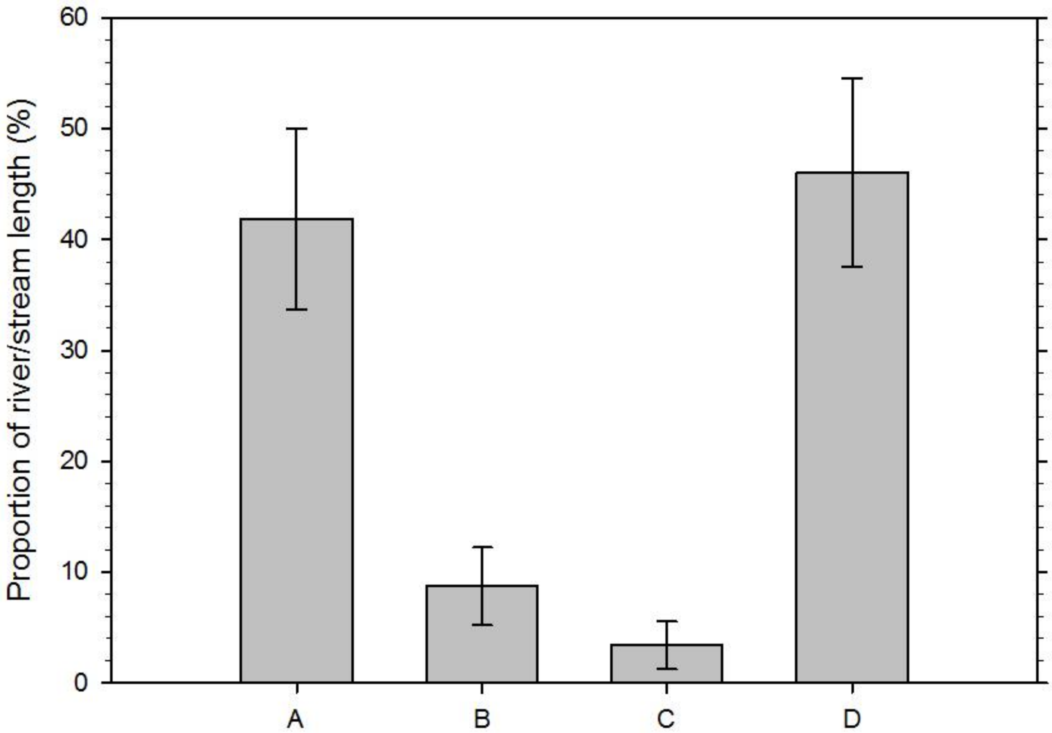

Figure 3.1: Estimates of the percentages (± 1SE) of target river and stream length in the Wellington Region that fall within each of the four deposited fine sediment cover states proposed in the NPS-FM (MfE 2019)

3.2 Periphyton cover

Periphyton cover (reported here as PeriWCC; see Matheson et al. 2012) was recorded from a total of 31 of the 48 sites. Cover was not assessed at a number of sites due to turbidity preventing observations from being made and was also not assessed at sites surveyed during the first year of this monitoring trial. PeriWCC scores ranged from zero percent (eight sites) to 74%. The estimated median PeriWCC score calculated in spsurvey for target river and stream length was 2.5% (further summary statistics are provided in Appendix 2).

Estimates of the proportion of river and stream length in the Wellington Region that fall within each of the four periphyton quality classes in Matheson et al. (2012) are presented in Figure 3.2. The majority of river and stream length based on periphyton quality classes is estimated to be in the "Excellent" class (75% ±7.4% SE) and only 14.4% (±7.4% SE) is estimated to be in the "Poor" class. Application of the river-class-specific thresholds in the PNRP are presented in Figure 3.3. The majority (78.1% ± 7.4 SE) of river and stream length is estimated to comply with the periphyton cover thresholds in the PNRP (Figure 3.3).

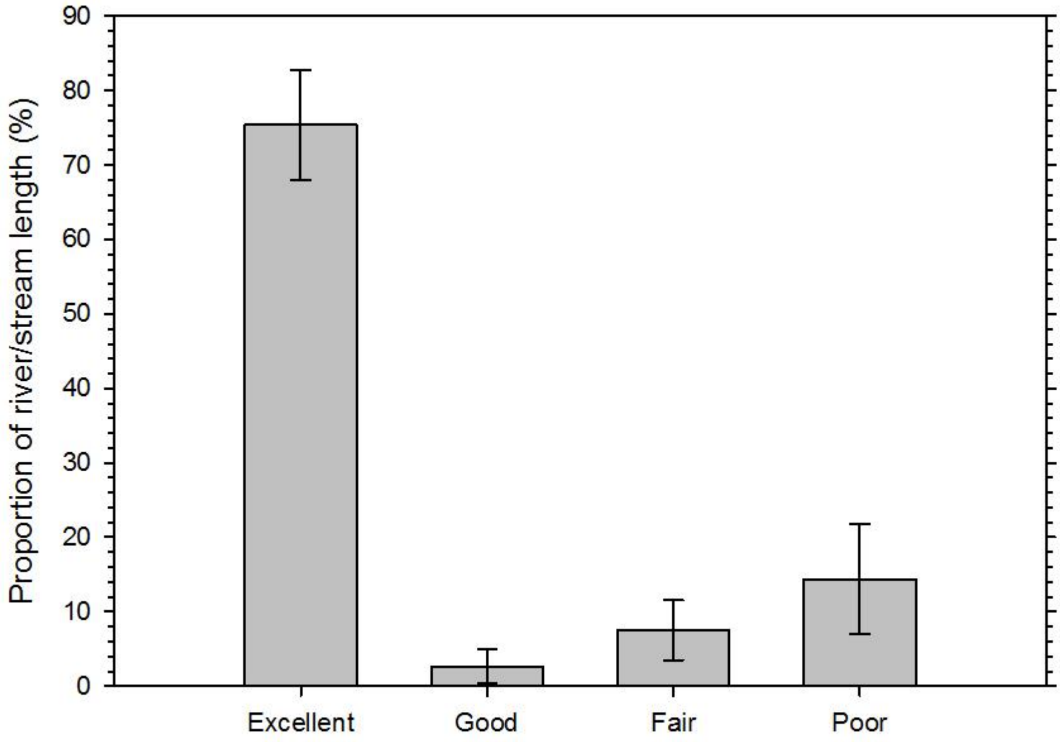

Figure 3.2: Estimates of the percentages (± 1SE) of target river and stream length in the Wellington Region that fall within each of the four periphyton quality classes proposed in Matheson et al. (2012)

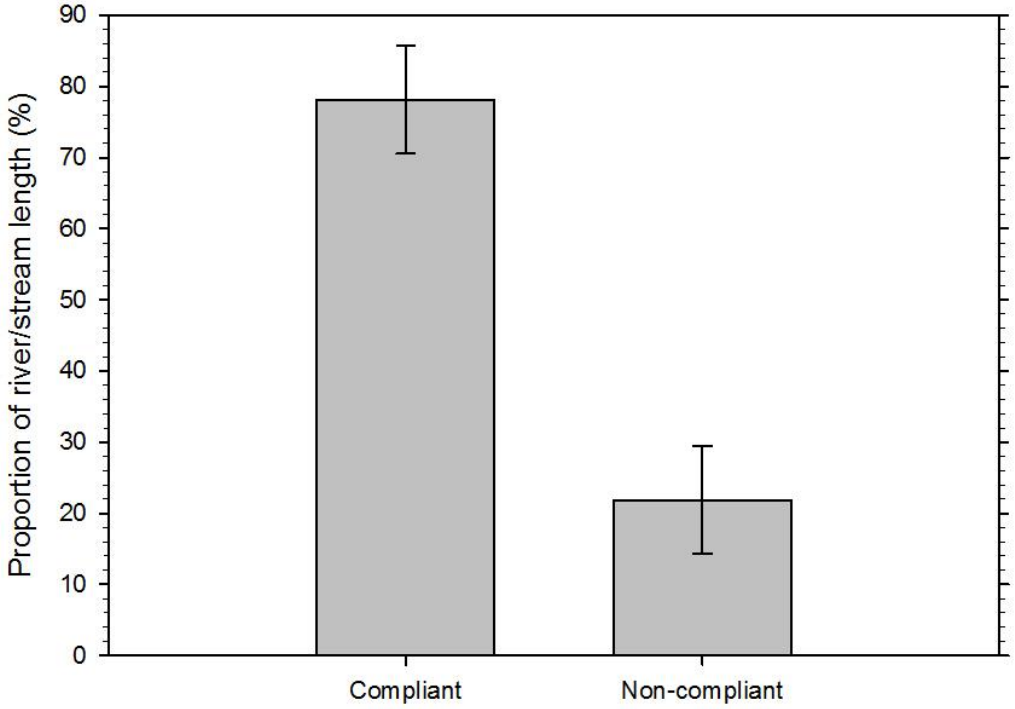

Figure 3.3: Estimates of the percentages (± 1SE) of target river and stream length in the Wellington Region that are compliant and non-compliant with the river-class-specific periphyton cover objectives in the PNRP

3.3 Macrophyte cover

Macrophyte cover was recorded from a total of 35 of the 48 sites. Cover was not assessed at a number of sites due to turbidity preventing observations from being made and was also not assessed at sites surveyed during the first year of this monitoring trial. Of the 35 sites assessed, no macrophyte cover was recorded at 16 sites and measured cover ranged from 0.25 to 98.5%. The estimated median macrophyte cover calculated in spsurvey for target river and stream length was <1% (further summary statistics are provided in Appendix 2).

The proportion of river and stream length that was estimated to exceed the recommended <50% total macrophyte cover threshold in Matheson et al. (2012) was 29.2% (±9.1% SE). For the purposes of this reporting, 70.8% of target regional stream and river length was estimated to be compliant with the macrophyte cover narrative objective in the PNRP (Figure 3.4).

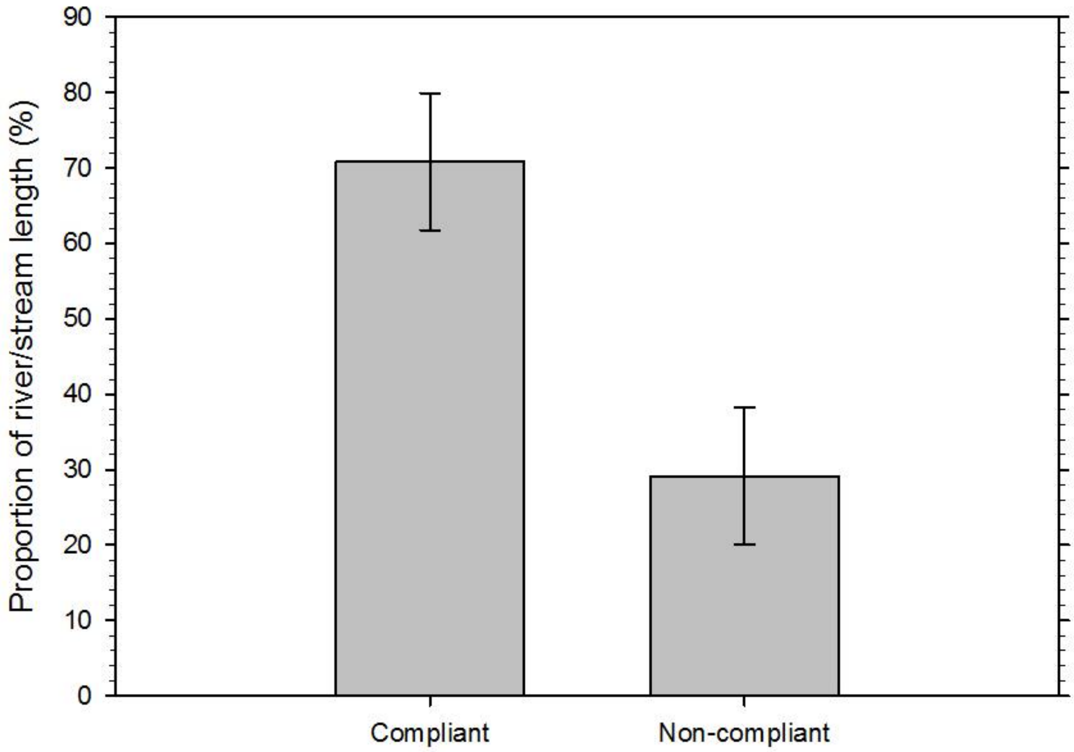

Figure 3.4: Estimates of the percentages (± 1SE) of target river and stream length in the Wellington Region that are compliant or non-compliant with the Matheson et al. (2012) total macrophyte cover threshold (<50% cover). For this reporting, the Matheson et al. (2012) threshold was also used to determine compliance with the PNRP macrophyte narrative objective

3.4 Macroinvertebrates

Macroinvertebrate Community Index (MCI) scores ranged from 51.7 to 141.5. The estimated median MCI score calculated by spsurvey for target river and stream length was 90.7 (further summary statistics are provided in Appendix 2).

Application of the river class-specific MCI thresholds in the PNRP are presented in Figure 3.5. The majority of river and stream length on developed land are estimated to be in the 'Fair' (32.9% ±6.4% 1SE) or 'Poor' (42.4 ±7.2% 1SE) classes, and only 22.2% (±4.3% 1SE) and 2.5% (±1.5% 1SE) are estimated to be in the 'Good' and 'Excellent' classes, respectively. Given that the PNRP MCI objective is set at the 'Good' (or better) threshold, 24.7% (±4.5% 1SE) of rivers and streams on developed land are estimated to comply (Figure 3.6).

Estimates of the proportion of river and stream length in each of the MCI states in the proposed NPS-FM (MfE 2019) provide a similar picture to the application of the PNRP classes (Figures 3.5 & 3.7) with 36.6% (±7.2%) and 48.7% (±6.9%) of target stream and river length being classified as being in 'C' and 'D' states. Application of the additional macroinvertebrate metrics (QMCI and ASPM) and thresholds proposed in the NPS-FM (MfE 2019) are also comparable with both the PNRP and NPS-FM MCI results (see Appendices 2 and 3).

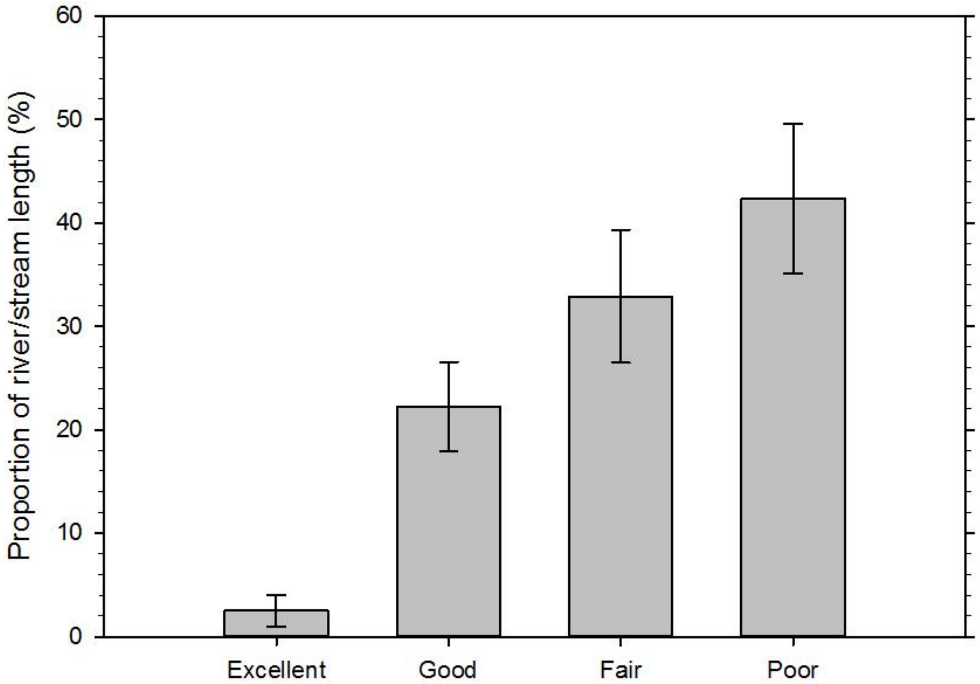

Figure 3.5: Estimates of the percentages (±1 SE) of target river and stream length in the Wellington Region that fall within each of the river-class-specific MCI quality classes in the PNRP

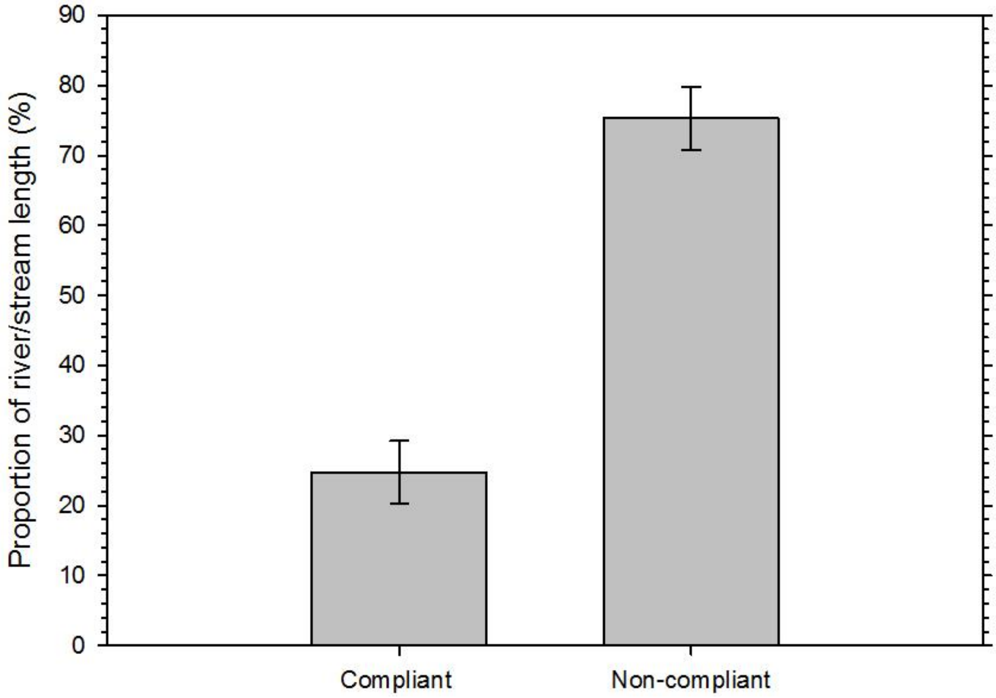

Figure 3.6: Estimates of the percentages (% ±1 SE) of target river and stream length in the Wellington Region that are compliant or non-compliant with PNRP river-class-specific MCI thresholds representing whether a macroinvertebrate community is in a "good" or better state

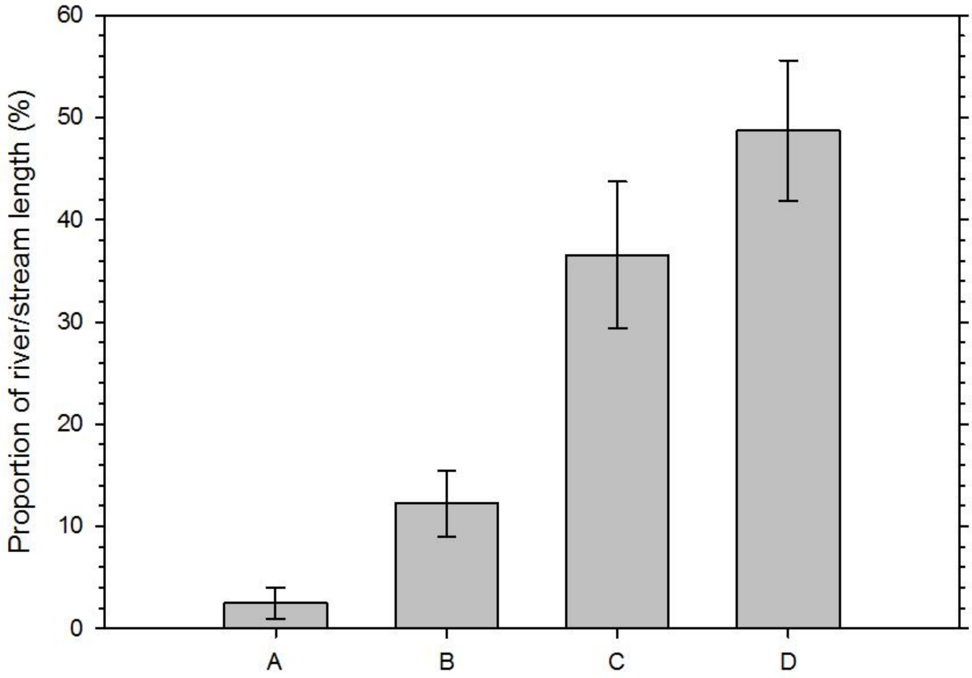

Figure 3.7: Estimates of the percentages (±1 SE) of target river and stream length in the Wellington Region that fall within each of MCI quality states proposed in the NPS-FM (MfE 2019)

3.5 Fish and large Crustacea

A total of 16 indigenous and four introduced fish species were caught across the 48 sites surveyed (Table 3.2). Fish species diversity (indigenous and introduced) ranged from no fish (two sites) through to nine species (one site), with a median of three species per site. The most commonly caught indigenous species were shortfin and longfin eel, followed by Cran's bully and common bully. Infrequently encountered indigenous species were dwarf galaxias and brown mudfish (one site each; Table 3.2). Brown trout and perch were the most commonly caught introduced species. Koura (freshwater crayfish) and shrimp were recorded at 22 and three sites, respectively. The estimated percentage of mapped stream and river length occupied by each species on target river and stream reaches on developed land is provided in Table 3.2.

The number of species caught was similar across sites regardless of whether backpack electric fishing or netting/trapping protocols of Joy et al. (2013) were used, and both methods recorded a median species richness (indigenous plus introduced) of three species per site (Figure 3.8). For the three larger river sites that were fished using a combination of backpack electric fishing and netting/trapping, the combination of catches from these two methods tended to slightly increase the number of species recorded at a site (eg, using both methods will likely result in a more diverse fish community being recorded).

Table 3.2: Fish and large Crustacea caught during surveys undertaken between 2016 and 2019. The number and percentage of sites a species is recorded at is presented as well as the estimated proportion (%) of occurrence (presence) calculated by spsurvey for each species in rivers and streams that meet the target population criteria

Species	Sites recorded at (total *n*=48)	% sites recorded at	Estimated mean percentage of target river and stream length occupied for each species (± 1SE)
Indigenous			
Shortfin eel	37	77.1	79.4 (±5.4)
Longfin eel	32	66.7	53.6 (±7.2)
Cran's bully	18	37.5	35.3 (±6.4)
Common bully	17	35.4	32.8 (±6.9)
Inanga	14	29.2	30.0 (±5.2)
Upland bully	11	22.9	27.7 (±7.1)
Redfin bully	8	16.7	11.6 (±3.3)
Koaro	6	12.5	7.8 (±2.8)
Torrentfish	4	8.3	10.0 (±4.8)
Banded kokopu	2	4.2	2.5 (±1.5)
Giant bully	2	4.2	3.1 (±1.8)
Bluegill bully	2	4.2	2.8 (±1.8)
Common smelt	2	4.2	3.1 (±1.9)
Black flounder	2	4.2	3.1 (±1.9)
Dwarf galaxias	1	2.1	1.3 (±1.1)
Brown mudfish	1	2.1	5.3 (±4.4)
Introduced			
Brown trout	6	12.5	12.8 (±5.0)
Perch	5	10.4	7.2 (±2.8)
Rudd	3	6.3	4.7 (±2.4)
Rainbow trout	2	4.2	6.8 (±4.5)
Large crustacea			
Koura	22	45.8	45.0 (±7.5)
Shrimp	3	6.3	8.1 (±4.6)

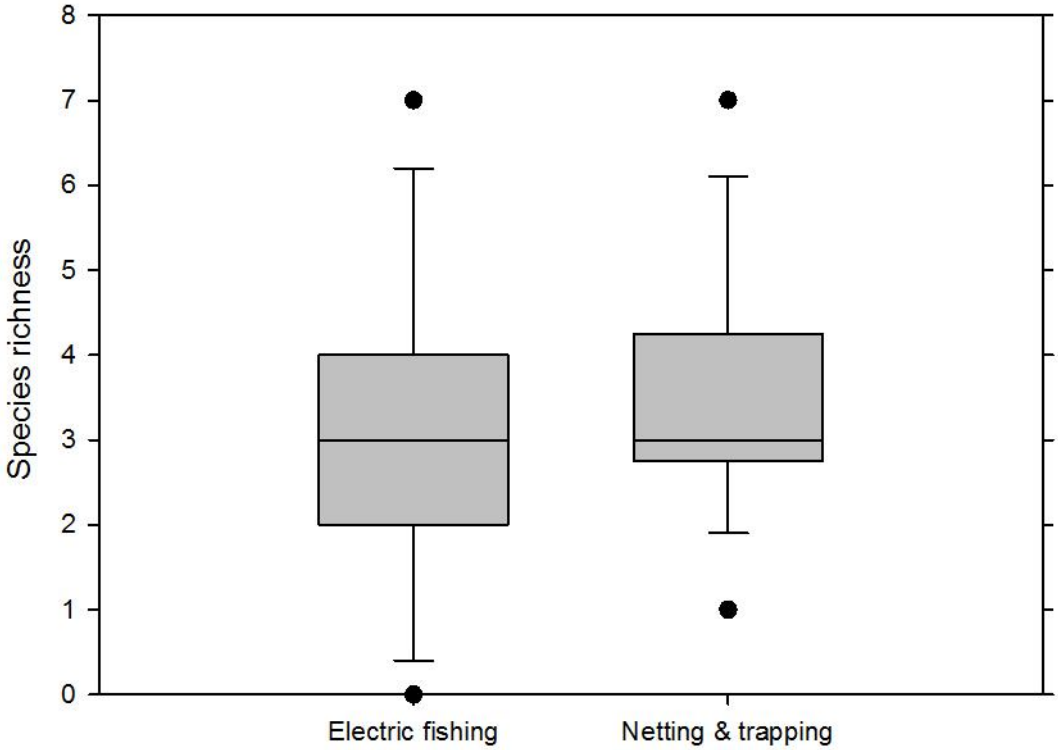

Figure 3.8: Boxplot illustrating the fish species richness (indigenous + introduced) at sites surveyed using the backpack electric fishing (23 sites) and netting and trapping (18 sites) protocols in Joy et al. (2013)

Fish-IBI scores calculated for the Wellington Region ranged from zero (no fish; two sites) to 50 (two sites). The estimated median Fish-IBI score calculated by spsurvey for target rivers and streams on developed land was 24.9 (see Appendix 2 for further summary statistics). There were no obvious differences in the range of Fish-IBI scores calculated for sites that were surveyed using either the backpack electric fishing or the netting and trapping protocols (Figure 3.9; Mann-Whitney Rank Sum Test, P=0.874).

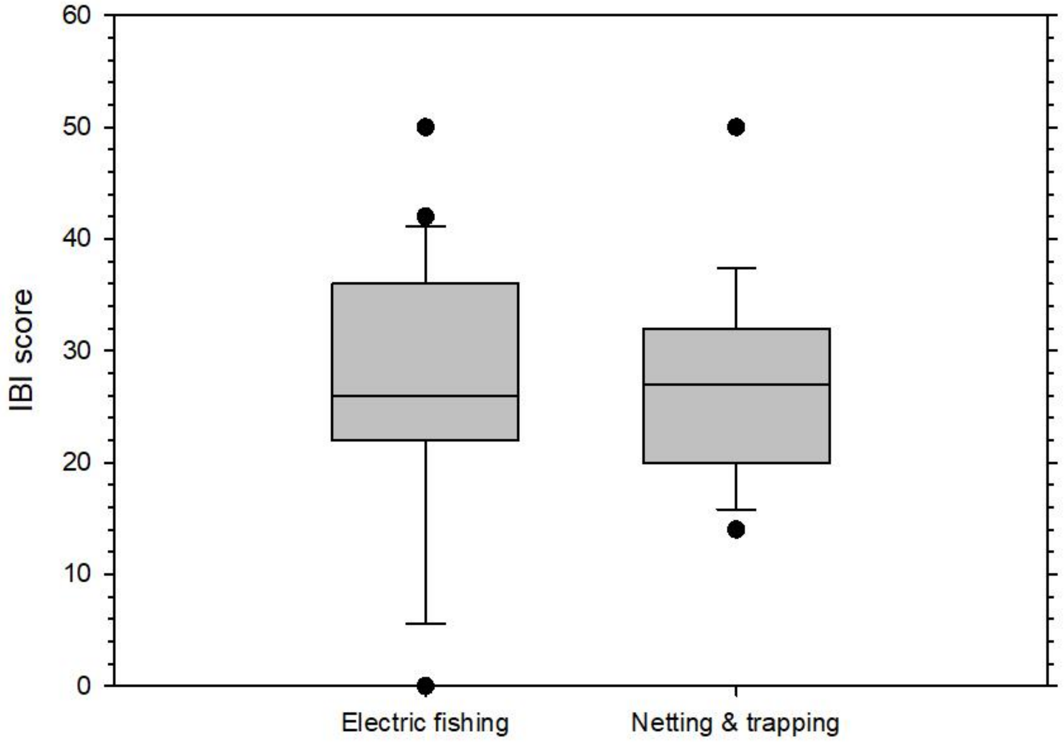

Figure 3.9: Boxplot illustrating Fish-IBI scores calculated for sites surveyed using the backpack electric fishing (23 sites) and netting and trapping (18 sites) protocols in Joy et al. (2013)

The estimated proportion of river and stream length in each of the Fish-IBI condition classes used in for this report is presented in Figure 3.10. Almost two thirds of target river and stream length in the Wellington Region are estimated to be in the 'Poor' class (64.8% ±5.9% 1SE), 25.1% (±5.0%) are estimated as 'Fair' and the remaining 10% are estimated as being in either the 'Good' or 'Excellent' classes. For this reporting, the Fish-IBI 'Poor' category threshold is being used to determine compliance with the PNRP indigenous fish narrative objective in the PNRP; hence, almost two-thirds of target river and stream length on developed land is estimated to not comply with this objective (Figure 3.10).

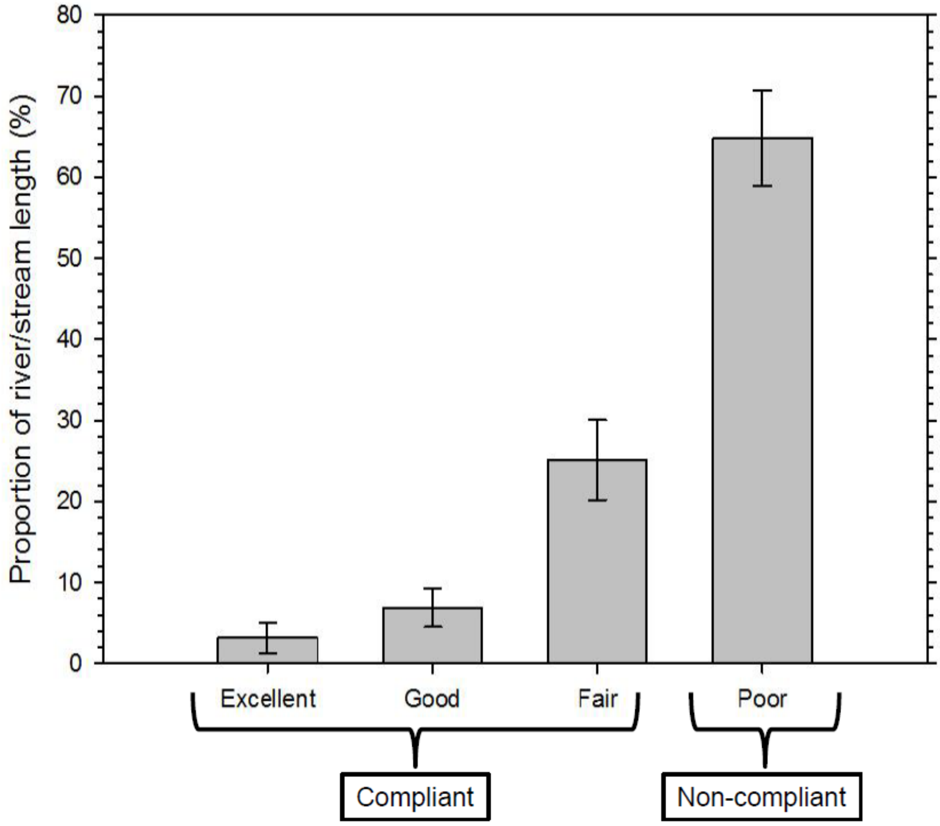

Figure 3.10: Estimate of the percentage (±1 SE) of target river and stream length in the Wellington Region that fall within each of the four IBI classes used in this report. Compliance or non-compliance with the PNRP indigenous fish narrative objective is also indicated

4. Discussion

Application of a probabilistic network design with monitoring focused on a range of ecological indicators has, for the first time, allowed GWRC to present unbiased estimates of the state of ecological health for perennial, non-tidal rivers and streams on developed land across the Wellington Region. Based on the analyses undertaken here, the potential impacts/issues associated with periphyton and macrophyte cover on river and stream health in the Wellington Region are estimated to be relatively minor; with most target river and stream length on developed land estimated to be compliant with objectives in GWRC's PNRP (78.1 and 70.8% of river length compliant, respectively; Figure 4.1). In contrast, the majority of river and stream length on developed land is estimated to not meet the objectives stated in the PNRP for healthy macroinvertebrate and fish communities (75.3 and 64.8% non-compliant, respectively; Figure 4.1).

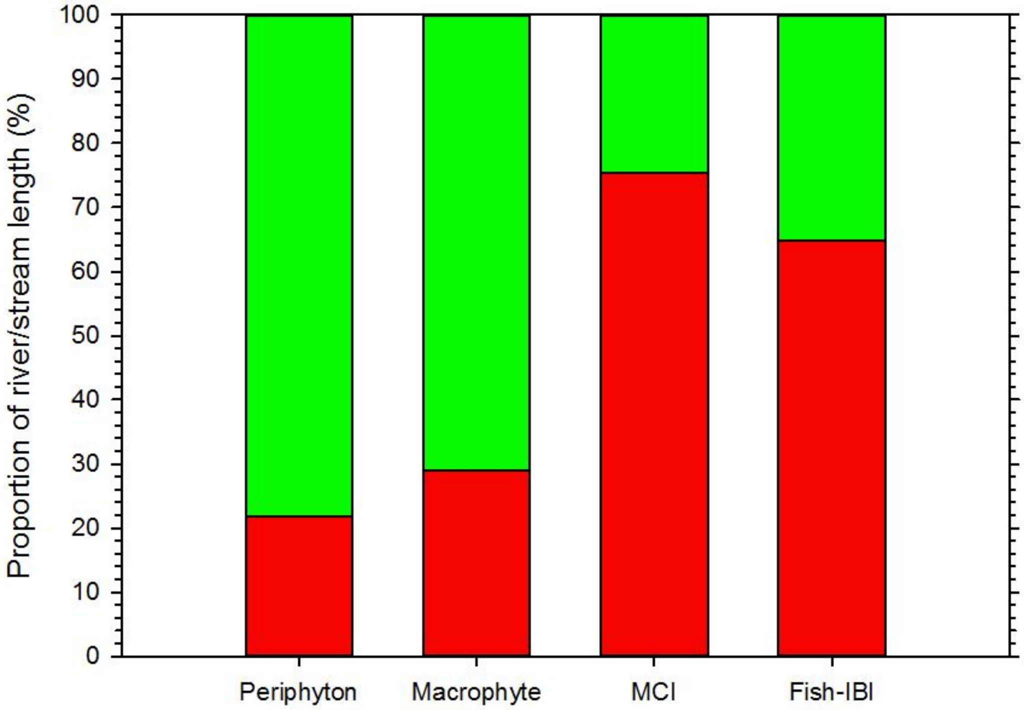

Figure 4.1: Estimates of the percentages of target river and stream length in the Wellington Region that are compliant (green) or non-compliant (red) with PNRP objectives. Assessments are based on one-off surveys undertaken at 48 sites between 2016 and 2019

While the purpose of this report was not to examine drivers of the current state, the analysis of habitat variables collected indicate the widespread occurrence of degraded river and stream habitat. For example, on average, river and stream reaches on developed land are estimated to have poor riparian shade, low abundance of suitable macroinvertebrate habitat and a significant amount of the river/stream bed (> 50%) covered in deposited fine sediment. Using the fine sediment thresholds in the proposed NPS-FM (MfE 2019), nearly half (46%) of river and stream length on developed land is estimated to be in the "D" state (eg, below the bottom line). The extent of poor habitat in river and streams on developed land in the Wellington Region is a likely contributing factor to the poor state of the macroinvertebrate and fish communities.

Issues associated with water quality may also be a driver of the poor state of macroinvertebrate and fish communities on developed land. Water quality sampling was not undertaken as part of this trial given the high variability of water quality measurements related to flow conditions. However, Pingram et al. (2018) demonstrate that one-off water quality measurements collected under base flow conditions (eg, two weeks of stable summer flows), can still be useful for the examination of drivers of ecological condition and consideration should be given to including water quality sampling in the future.

Discrepancies in the state of rivers and streams in the Wellington Region, as observed via different ecological indicators (eg, Figure 4.1), are not surprising given that drivers (both natural and anthropogenic) affect these various indicators in different ways (Clapcott et al. 2018). For example, nutrient enrichment has the potential to create problems with periphyton and macrophyte cover and yet is less likely to impact fish communities (not discounting in-direct impacts on habitat, food webs and toxicity of nitrate and ammonia at high concentrations). Additionally, instream barriers that impede migratory fish can have a significant impact on fish communities and yet are unlikely to impact on macroinvertebrate communities, with the exclusion of migratory shrimps. Hence, the use of several different indicators, as employed here, is required to provide a more accurate assessment of river and stream in the Wellington Region.

The differences in the assessment of state presented by the different indicators in Figure 4.1 may also be because the thresholds/classes for each indicator have typically been developed separately and that the purpose behind the threshold development for each indicator may not always have been comparable. Notwithstanding these issues, where alternative thresholds or assessment methods are available (or proposed), their application tends to present similar outcomes. For example, estimates of the MCI classes in the proposed NPS-FM (MfE 2019) place 85.3% of the region's target river and stream length in the 'C' and 'D' states compared with 75.3% deemed non-compliant, based on PNRP threshold.

The application of some PNRP narrative objectives for macrophytes and fish communities should be considered interim and further work is required to develop and/or validate the approaches (eg, are the metrics appropriate for reporting against the narrative objective, are the thresholds ecologically meaningful). Furthermore, the development of a 'reference' site network to complement the existing (random) site network on developed land would greatly aid the development of these assessment methods and thresholds by allowing a reference state to be established and, from there, the divergence from reference state for the sites selected randomly could be calculated. Quantification of reference state would also help further validate indicators where numerical objectives have already been established in the PNRP.

Some care must also be taken with the findings presented here given that this assessment was based on one-off surveys undertaken across several years. Thus temporal variability at both shorter (monthly) and longer (annual) time scales has not been accounted for. This will more likely influence some indicators more than others. For example, periphyton cover is known to potentially vary over quite short time frames, and while one-off sampling occurred after at least two weeks of stable flows, the periphyton cover recorded, and hence estimates of compliance with PNRP periphyton thresholds presented here, may not accurately reflect the current state. One-off assessments of macroinvertebrate and fish communities are expected to be less variable than periphyton cover, especially when based on presence-absence metrics, although annual assessments over several years are still typically recommended for most assessments of state (eg, Greenfield et al. 2015).

To reduce the potential for inter-annual variability (eg, a drought year) impacting on conclusions drawn by this programme, increasing the number of sites sampled each year would be beneficial and/or sampling representative sites every year to quantify inter-annual variation should be considered. Sampling of all sites every year, while resource demanding, would have the added benefit of allowing for trend assessments to be undertaken. At the rate which sites have been sampled to date, an assessment of trends is unlikely to be feasible in the foreseeable future.

5. Conclusions and recommendations

Based on the analyses undertaken here, the potential impacts/issues associated with periphyton and macrophyte cover on river and stream health in the Wellington Region are estimated to be relatively minor; with most river and stream reaches on developed land estimated to be compliant with objectives in GWRC's PNRP (78.1 and 70.8% of river length compliant, respectively). In contrast, the majority of river and stream length on developed land is estimated to be non-compliant with the objectives stated in the PNRP for healthy macroinvertebrate and fish communities (75.3 and 64.8% of river length non-compliant, respectively). While it was outside of the scope of this report to examine drivers of the current state, analysis of habitat variables collected indicate the widespread occurrence of degraded river and stream habitat which is likely contributing to the poor condition of macroinvertebrate and fish communities. The contrasting compliance with objectives across the indicators presented here is further evidence that multiple indicators are required to accurately report on the current state of rivers and streams in the Wellington Region.

The results presented in this report provide unbiased estimates of the state of aquatic ecological health in rivers and streams in the Wellington Region for the first time; with the conclusions presented applying to mapped, perennial, non-tidal rivers and streams on developed land. However, some care must be taken with these results given that the assessments undertaken were limited to one-off samples, sampling was spread over a four year period, and that some sampling occurred outside recommended sampling windows. Further, for some indicators (eg, macrophytes and fish) substantially more work is required to develop and validate monitoring and reporting approaches.

5.1 Recommendations

Recommendations to improve the robustness of the data collected, the accuracy of the condition estimates derived, and the reporting undertaken by this programme are presented below, as well as recommendations for further analysis of drivers of river and stream ecological health in the Wellington Region.

Sampling and reporting

1. If possible, all sites should be sampled each year. This would remove the potential for inter-annual variability to impact on the assessment of state presented, allow for more robust assessments to be made (eg, following recommendations in Greenfield et al. 2015), and would enable data collected via this programme to be used (eventually) for assessments of trends.

2. If possible, all sites should be sampled during established "sampling windows" or, where this is not possible, the impact (if any) from undertaking sampling outside of these established sampling windows should be investigated.

3. A reference site network should be established to determine, as far as practicable, a 'reference state' for all indicators. This would enable the

divergence from this reference state to be calculated for the sites selected randomly.

4. Further work is required, at both the regional and national scales, to develop and validate reporting approaches for macrophytes and fish communities. The approaches used here should only be considered interim.

5. Consideration should be given to the collection of one-off water quality samples along with other measurements. Despite the limitations of one-off water quality measurements, inclusion of such measurements would, over time, allow for further examination of the drivers of aquatic ecosystem health.

Analysis of drivers

1. While outside of the scope of this report, further analysis of the ecological and habitat data to help determine key drivers of aquatic ecosystem health in rivers and streams in the Wellington Region could be undertaken. Ideally, this work would also include relevant data collected via other GWRC monitoring programmes such as the Rivers Water Quality, and Urban Stream Biodiversity monitoring programmes (eg, Mitchell & Heath 2018 and Harrison 2019).

Acknowledgements

We would like to thank Kevin Collier for introducing us to "probabilistic network design" monitoring approaches, aiding us with the initial set-up of the site network, and providing a technical review of a draft version of this report. We would also like to thank Mark Hamer for discussions on the practical implications of assessing and accessing sites selected randomly and Michael Pingram for his patience in helping us run spsurvey scripts in R and discussions around results and the future development of this programme. Mike Joy's insistence that you cannot report on fish without monitoring fish, as well as Bruno David's improvement of fish monitoring methods in New Zealand, have also been vital in the development of this monitoring programme.

We would like to thank Juliet Milne and Summer Greenfield for their early support in trialling this new (to us) monitoring approach and Megan Oliver, Pam Guest and Rachel Pawson for reviewing a draft version (or sections) of this report. Lastly, we would like to thank the many people who have provided assistance with the fieldwork over the years and the landowners who provided access to the rivers and streams on their properties.

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Appendix 1: Site characteristics and metric summaries

Table A1.1: Site characteristics for the 48 sites surveyed in this report; R = Ruamāhanga; E = Eastern Wairarapa; TW = Te Whanganui-a-Tara; TA = Te Awarua-o-Porirua

Site ID	Whaitua	Stream order	GWRC river class	REC landcover class	CSOFG (REC)	Deposited fine sediment class (NPS-FM 2019)	Altitude (m)	Distance inland (km)	Invert sampling method	Fish sampling method
RAN007	R	3	5	Pasture	WW/L/Al	11	59	84	C2	Net/Trap
RAN008	R	3	3	Pasture	CW/L/SS	12	227	172	C2	Net/Trap
RAN012	E	3	6	Pasture	WD/L/SS	5	2	1	C1	E-Fishing
RAN017	R	1	6	Pasture	WD/L/Al	1	39	45	C2	E-Fishing
RAN020	R	1	6	Pasture	WD/L/Al	1	133	113	C1	E-Fishing
RAN021	R	2	6	Pasture	WD/L/SS	5	15	29	C1	E-Fishing
RAN023	R	4	6	Pasture	WD/L/SS	5	32	59	C1	Net/Trap
RAN024	R	3	6	Pasture	CW/L/SS	12	252	151	C2	Net/Trap
RAN025	TW	5	4	Ind.Forest	CW/H/HS	10	76	28	C1	E-Fish[1]
RAN030	E	5	3	Pasture	CD/L/SS	7	145	94	C2	Net/Trap
RAN031	E	3	2	Ex.Forest	WW/L/HS	6	41	7	C1	E-Fishing
RAN032	R	1	6	Pasture	WD/L/Al	1	2	8	C2	Net/Trap
RAN035	R	2	3	Pasture	CW/L/SS	12	161	94	C1	E-Fishing
RAN036	R	5	4	Pasture	CW/L/SS	12	106	110	C1	EF & NT[2]
RAN037	R	1	6	Pasture	WD/L/Al	1	29	45	C2	Net/Trap
RAN038	TA	1	2	Pasture	CW/L/HS	10	182	13	C1	E-Fishing
RAN041	TW	3	1	Ind.Forest	CW/L/HS	10	141	31	C1	E-Fishing
RAN043	E	4	3	Pasture	CW/L/SS	12	77	60	C1	Net/Trap
RAN050	TW	2	2	Pasture	CW/L/HS	10	131	13	C1	E-Fishing
RAN051	R	3	6	Pasture	CD/L/SS	7	69	94	C1	E-Fishing
RAN052	R	4	6	Pasture	CW/L/SS	12	194	142	C1	Net/Trap
RAN054	TA	3	2	Pasture	CW/L/HS	10	50	7	C1	E-Fishing
RAN055	E	6	5	Pasture	CW/L/SS	12	31	31	C1	E-Fish[1]
RAN063	R	5	4	Pasture	CW/L/HS	10	215	127	C1	E-Fish[1]
RAN068	R	5	4	Pasture	CW/L/HS	10	133	116	C1	E-Fish[1]
RAN070	TW	3	2	Urban	CW/L/HS	10	48	16	C1	E-Fishing
RAN071	R	4	5	Pasture	WD/L/Al	1	47	80	C1	E-Fishing
RAN072	R	5	3	Pasture	CW/L/SS	12	108	147	C2	Net/Trap
RAN074	E	6	5	Pasture	CW/L/SS	12	3	6	C1	EF & NT[2]
RAN076	E	3	6	Pasture	WD/L/SS	5	10	3	C2	Net/Trap
RAN079	E	3	2	Pasture	CW/L/SS	12	109	22	C1	E-Fishing
RAN080	R	4	4	Scrub	CW/H/HS	10	49	12	C1	E-Fishing
RAN083	R	3	6	Pasture	CW/L/Al	3	97	92	C2	Net/Trap
RAN084	R	3	1	Ind.Forest	CW/H/HS	10	293	133	C1	E-Fishing
RAN085	R	7	4	Pasture	CW/L/SS	12	2	27	C1	Net/Trap
RAN086	TW	3	2	Urban	CW/L/HS	10	57	4	C1	E-Fishing
RAN088	R	3	3	Pasture	CW/L/SS	12	224	140	C2	Net/Trap
RAN089	TW	4	4	Pasture	CW/L/HS	10	126	37	C1	EF & NT[2]
RAN090	E	4	3	Pasture	WD/L/SS	5	53	21	C1	E-Fishing
RAN092	R	3	3	Pasture	CD/L/HS	6	34	20	C1	E-Fishing
RAN094	E	3	6	Ex.Forest	CD/L/SS	7	172	93	C1	E-Fishing
RAN096	R	4	6	Pasture	WD/L/SS	5	8	3	C1	Net/Trap
RAN101	R	1	4	Pasture	WD/L/Al	1	23	56	C1	E-Fishing
RAN111	R	1	1	Scrub	CW/H/HS	10	355	159	C1	E-Fishing
RAN113	R	3	6	Pasture	WD/L/SS	5	8	38	C2	Net/Trap
RAN114	TW	3	2	Scrub	CW/L/HS	10	27	2	C1	E-Fishing
RAN115	R	6	3	Pasture	CD/L/SS	7	63	95	C2	Net/Trap
RAN116	R	4	3	Pasture	CW/L/SS	12	173	137	C2	Net/Trap

[1]Unsuitable for application of Joy et al. (2013) protocols given large size. Backpack electric fishing of wadeable habitats present (eg, riffles and shallow runs) was undertaken.

[2]Unsuitable for application of Joy et al. (2013) protocols given large size. A combination of backpack electric fishing of wadeable habitat and netting/trapping of deeper water habitats (eg, pools and deep runs) was undertaken.

Table A1.2: Summary of habitat variables assessed at each of the 48 sites

Site ID	Rapid Habitat Assessment											Instream fine sediment cover
	Total score	Sed. cover	Invert. habitat divers.	Invert. habitat abund.	Fish habitat divers.	Fish habitat abund.	Hydraulic heterogeneity	Bank erosion	Bank vege.	Riparian width	Riparian shade	
RAN007	21	1	4	1	2	6	1	2	1	1	2	100
RAN008	50.5	1	8	1	8	7	2	3	3	10	7.5	100
RAN012	67.5	6	10	4	9	4	5	8	5.5	10	6	18.8
RAN017	30	1	2	1	4	2	3	8	3	4	2	80
RAN020	39	4	6	7	4	4	2	9	1	1	1	NA
RAN021	46.5	1	6	2	8	5	6	1	3.5	10	4	68
RAN023	57	3	10	1	10	9	4	4	4	9	3	NA
RAN024	63	1	6	1	9	10	2	6	8	10	10	100
RAN025	70.5	10	9	10	5	6	5	8.5	7	8	2	NA
RAN030	37	1	5	1	5	6	4	5	4	1	5	100
RAN031	58.5	1.5	10	5.5	10	6	7	4.5	7	1	6	64.5
RAN032	30.5	1	2	1	3	8	1	8	2.5	2	2	100
RAN035	42	1	10	1	10	3	9	5	1	1	1	NA
RAN036	27	9	9	8	10	6	7	8	5	6	1	NA
RAN037	33	1	2	1	1	9	2	10	3	3	1	98.8
RAN038	32.5	1	2	1	4	8	1.5	7.5	2	1.5	4	68
RAN041	85.5	10	10	9	10	9	10	8	6	9.5	4	2
RAN043	24	1	5	1	4	6	2	1	1	1	2	80
RAN050	44	5	5	7	4	8	3	6	2	1	3	65.5
RAN051	47	2	5	1	7	8	5	7	4	4	4	75.8
RAN052	53	1	10	1	10	6	2	4	5.5	6	7.5	88
RAN054	81	7	10	8	10	7	10	6	7	8	8	NA
RAN055	58	3	9	2	7	7	5	9	5	5	6	40
RAN063	64.5	9	7	6	6	6	8	9	5	5.5	3	5.8
RAN068	78.5	9	8	8	8	9	8	8	6	8	6.5	NA
RAN070	26	7	1	1	1	1	1	10	1	1	2	NA
RAN071	41.5	7	6	1	4	7	3	7	2.5	2	2	0
RAN072	52.5	1	6	1	8	9	1	6	3.5	9	8	100
RAN074	46	8	6	2	3	4	5	4	6	6	2	14
RAN076	42.5	1	2	1	4	9.5	1	6.5	5.5	3	9	100
RAN079	57.5	3	10	6.5	8.5	5.5	6.5	4.5	3.5	5	4.5	27.3
RAN080	78	9.5	9	8	9	7	5	9.5	6	10	5	19
RAN083	32	1	5.5	1	5	7	2	4.5	2	1	3	89.5
RAN084	97.5	9	10	9	10	10	10	10	10	9.5	10	7
RAN085	53.5	3	10	2.5	10	6	2	5.5	4	8.5	2	33.3
RAN086	86	8	7	6	9	9	9	9	9	10	10	21.3
RAN088	68	1	10	1	9	9.5	9	4	6	9.5	9	100
RAN089	68	9	10	5	9	8	5	5	6	6	5	0
RAN090	61	7	10	2	6	4	7	6.5	5.5	10	3	24
RAN092	65.5	7	10	5	8	6	7	8	2.5	10	2	43.9
RAN094	62.5	1	10	2	9	6	6	5.5	7	10	6	70
RAN096	43	2	6	2	6	8	3	3	3	2	8	100
RAN101	72.5	4	10	8	9	6	9	9	5	8	4.5	22
RAN111	59	9	9	6	10	9	3	6.5	2.5	1	3	0
RAN113	41	1	2	1	2	9	1	10	3	10	2	15
RAN114	91	9	10	9	10	9.5	9	9	8.5	9.5	7.5	1.25
RAN115	74.5	6	10	7	10	9	6	7	5.5	9	5	16.1
RAN116	28	1	6	2	6	5	2	2	2	1	1	34.8

Table A1.3: Summary of periphyton (PeriWCC) and macrophyte streambed cover and macroinvertebrate and Fish-IBI metrics

Site ID	PeriWCC	Macrophyte cover	MCI	QMCI	ASPM	Fish-IBI
RAN007	51.67	31.67	62.5	2.8	0.10	14
RAN008	NA	NA	70.4	3.8	0.19	32
RAN012	0	0	82.7	5.3	0.36	20
RAN017	NA	36.25	65.1	2.7	0.13	26
RAN020	NA	NA	73.7	3.5	0.20	0
RAN021	1.25	2.25	94.3	4.5	0.21	22
RAN023	NA	NA	82.5	4.1	0.17	24
RAN024	NA	60.5	92.8	3.9	0.21	32
RAN025	NA	NA	129.6	6.0	0.60	34
RAN030	NA	NA	53.8	4.1	0.10	32
RAN031	11.25	0.25	121.6	5.5	0.51	40
RAN032	NA	51	66.4	4.6	0.11	16
RAN035	NA	NA	71.8	2.8	0.16	32
RAN036	NA	NA	100.8	6.7	0.51	34
RAN037	NA	77.5	67.2	2.0	0.15	22
RAN038	0	0	108.6	5.5	0.37	22
RAN041	1.38	0	133.9	7.9	0.79	42
RAN043	NA	NA	84.2	4.0	0.21	50
RAN050	10.55	0	106.1	4.7	0.49	0
RAN051	8.88	46.25	98.1	3.7	0.33	22
RAN052	0	0	106.0	5.4	0.50	28
RAN054	NA	NA	122.4	6.9	0.65	34
RAN055	14.28	0.25	91.0	4.3	0.35	40
RAN063	12.5	0	103.8	4.6	0.47	34
RAN068	NA	NA	103.8	4.6	0.47	34
RAN070	NA	NA	98.3	4.4	0.48	14
RAN071	73.75	23.75	94.5	4.1	0.30	28
RAN072	NA	NA	80.0	4.4	0.30	30
RAN074	35.6	0.5	72.8	4.3	0.15	44
RAN076	NA	55	78.4	3.5	0.24	20
RAN079	11.25	0	51.7	4.3	0.09	22
RAN080	2.45	0.5	119.2	6.0	0.56	50
RAN083	2.5	80	121.4	7.4	0.62	26
RAN084	0.85	0	80.2	4.2	0.18	36
RAN085	52.75	0	141.5	7.8	0.73	36
RAN086	0	0	88.6	4.6	0.27	22
RAN088	2.5	0	110.0	3.7	0.51	32
RAN089	54.7	0	85.0	4.3	0.34	30
RAN090	56.25	0	115.2	5.6	0.58	34
RAN092	3.05	7.65	89.5	6.5	0.47	22
RAN094	0	0	94.8	3.6	0.26	22
RAN096	0	20	115.5	6.1	0.50	22
RAN101	63.75	0	86.7	4.6	0.19	28
RAN111	0	95	96.2	4.4	0.42	26
RAN113	0	98.5	109.3	6.2	0.54	18
RAN114	3.4	0	71.0	4.1	0.13	38
RAN115	0.39	26.05	127.5	6.2	0.62	20
RAN116	0.25	65	91.6	4.0	0.32	32

Appendix 2: Summary statistics from spsurvey for extent and categorical estimates

Table A2.1: Summary statistics for extent estimates of Rapid Habitat Assessment (RHA) total sum scores and individual variables within the RHA. 5th to 95th percentiles, mean and standard deviation are presented

Variable	5Pct	10Pct	25Pct	50Pct	75Pct	90Pct	95Pct	Mean	Std. Deviation
Rapid Habitat Assessment (total sum score)	26.59	29.06	32.57	46.01	62.88	73.73	81.02	50.08	18.22
Deposited sediment	1	1	1	2.11	6.46	8.60	8.96	3.86	3.24
Invertebrate habitat diversity	1.16	1.37	2.24	5.93	9.18	9.67	9.84	6.53	3.16
Invertebrate habitat abundance	1	1	1	1.41	6.58	7.58	8.09	3.65	3.02
Fish cover diversity	1	2.14	3.39	6.03	8.92	9.56	9.78	6.43	2.97
Fish cover abundance	1.71	3.03	5.37	6.40	8.09	8.82	9.17	6.68	2.22
Hydraulic heterogeneity	1	1.00	1.69	2.73	6.39	8.49	8.90	4.32	2.85
Bank erosion	1.10	2.87	4.89	7.10	8.56	9.19	9.72	6.77	2.40
Bank vegetation	1	1	2.05	2.94	5.09	6.06	7.00	3.81	2.08
Riparian width (potential)	1	1	1	3.49	8.43	9.67	9.83	4.89	3.55
Riparian shade	1	1	1.35	2.68	4.73	7.57	8.50	3.79	2.47

Table A2.2: Summary statistics for extent estimates of instream fine sediment cover, periphyton cover (as PeriWCC), macrophyte cover, macroinvertebrate metrics and Fish-IBI scores

Variable	5Pct	10Pct	25Pct	50Pct	75Pct	90Pct	95Pct	Mean	Std. Deviation
Instream fine sediment cover	0	0	18.96	65.71	90.94	99.36	99.68	55.15	37.22
Periphyton cover (PeriWCC)	0	0	0	2.45	14.00	57.66	61.82	16.58	24.34
Macrophyte cover	0	0	0	0.99	49.12	77.69	87.63	26.89	33.48
MCI score	62.94	65.27	71.27	90.73	106.19	117.43	123.72	90.33	20.65
QMCI score	2.22	2.48	3.07	4.33	5.48	6.20	6.72	4.35	1.44
ASPM	0.11	0.12	0.15	0.30	0.48	0.56	0.62	0.33	0.18
Fish-IBI	0	8.78	20.32	24.91	31.40	36.06	41.54	25.43	10.87

Table A2.3: Summary statistics for categorical estimates

Indicator	Class	NResp	Est.P	StdErr.P	LCB95Pct.P	UCB95Pct.P	Est.U	StdErr.U	LCB95Pct.U	UCB95Pct.U
Fine sed. NPS-FM	A	15	41.9	8.2	25.8	57.9	1,322.5	288.6	756.8	1,888.1
Fine sed. NPS-FM	B	5	8.7	3.5	1.8	15.6	275.3	104.6	70.4	480.2
Fine sed. NPS-FM	C	2	3.4	2.2	0	7.6	107.7	65.7	0	236.5
Fine sed. NPS-FM	D	18	46	8.5	29.4	62.7	1,453.6	314.7	836.8	2,070.3
Fine sed. NPS-FM	Total	40	100	0	100	100	3,159.0	271.0	2,627.9	3,690.1
PeriWCC	Excel.	24	75.4	7.4	60.9	89.9	1,683.6	229.1	1,234.6	2,132.7
PeriWCC	Fair	3	7.5	4	0	15.4	167.6	84.4	2.2	333.0
PeriWCC	Good	1	2.7	2.3	0	7.2	59.9	50.4	0	158.7
PeriWCC	Poor	3	14.4	7.4	0	28.8	321.1	177.6	0	669.3
PeriWCC	Total	31	100	0	100	100	2,232.3	223.1	1,795.1	2,669.5
PeriWCC PNRP objective	Compl.	25	78.1	7.6	63.2	93	1,743.6	228.7	1,295.3	2,191.8
PeriWCC PNRP objective	Exceeds	6	21.9	7.6	7	36.8	488.7	181.4	133.2	844.2
PeriWCC PNRP objective	Total	31	100	0	100	100	2,232.3	223.1	1,795.1	2,669.5
Macrophyte PNRP objective	Compl.	28	70.8	9.1	53.1	88.6	2,076.8	265.9	1,555.7	2,598.0
Macrophyte PNRP objective	Exceeds	8	29.2	9.1	11.4	46.9	854.7	303.9	259.0	1450.3
Macrophyte PNRP objective	Total	36	100	0	100	100	2,931.5	272.3	2,397.7	3,465.3
MCI PNRP	Excel.	2	2.5	1.5	0	5.5	95.5	57.8	0	208.7
MCI PNRP	Fair	19	32.9	6.4	20.3	45.5	1,255.2	230.2	804.1	1,706.4
MCI PNRP	Good	12	22.2	4.3	13.7	30.7	847.9	170.2	514.3	1,181.5
MCI PNRP	Poor	15	42.4	7.2	28.2	56.5	1,617.2	347.7	935.7	2,298.8
MCI PNRP	Total	48	100	0	100	100	3,815.9	291.7	3,244.1	4,387.7
MCI PNRP objective	Exceeds	34	75.3	4.5	66.5	84.1	2,872.5	303.5	2,277.6	3,467.4
MCI PNRP objective	Compl.	14	24.7	4.5	15.9	33.5	943.4	1,71.9	606.5	1,280.3
MCI PNRP objective	Total	48	100	0	100	100	3,815.9	2,91.7	3,244.1	4,387.7
MCI NPS-FM	A	2	2.5	1.5	0	5.5	95.5	57.8	0	208.7
MCI NPS-FM	B	9	12.2	3.2	5.9	18.5	466.3	109.3	252	680.6
MCI NPS-FM	C	15	36.6	7.2	22.5	50.6	1395.1	314.2	779.3	2010.9

Indicator	Class	NResp	Est.P	StdErr.P	LCB95Pct.P	UCB95Pct.P	Est.U	StdErr.U	LCB95Pct.U	UCB95Pct.U
MCI NPS-FM	D	22	48.7	6.9	35.2	62.2	1858.9	306.5	1258.1	2459.7
MCI NPS-FM	Total	48	100	0	100	100	3815.9	291.7	3244.1	4387.7
QMCI NPS-FM	A	6	8.5	3.1	2.4	14.6	323.1	109.9	107.7	538.4
QMCI NPS-FM	B	6	12.2	4.5	3.3	21	464.4	179.1	113.3	815.4
QMCI NPS-FM	C	9	20.4	5.6	9.4	31.4	777.3	226.3	333.8	1220.8
QMCI NPS-FM	D	27	59	6.3	46.6	71.4	2251.2	309.1	1645.3	2857
QMCI NPS-FM	Total	48	100	0	100	100	3815.9	291.7	3244.1	4387.7
ASPM NPS-FM	A	5	6.6	2.6	1.6	11.6	251	91.2	72.2	429.8
ASPM NPS-FM	B	14	29.7	6.7	16.6	42.9	1133.4	274.2	596	1670.8
ASPM NPS-FM	C	7	13.7	4.5	4.9	22.6	524.3	178.9	173.6	875
ASPM NPS-FM	D	22	50	6.9	36.4	63.5	1907.2	311.3	1297	2517.4
ASPM NPS-FM	Total	48	100	0	100	100	3815.9	291.7	3244.1	4387.7
Fish-IBI PNRP	Excel.	2	3.1	1.9	0	6.9	119.9	71.4	0	259.7
Fish-IBI PNRP	Fair	16	25.1	5	15.4	34.8	958.5	160	644.9	1272.1
Fish-IBI PNRP	Good	5	6.9	2.4	2.2	11.6	263.1	86.4	93.8	432.5
Fish-IBI PNRP	Poor	25	64.8	5.9	53.2	76.4	2474.4	378.1	1733.4	3215.5
Fish-IBI PNRP	Total	48	100	0	100	100	3815.9	291.7	3244.1	4387.7

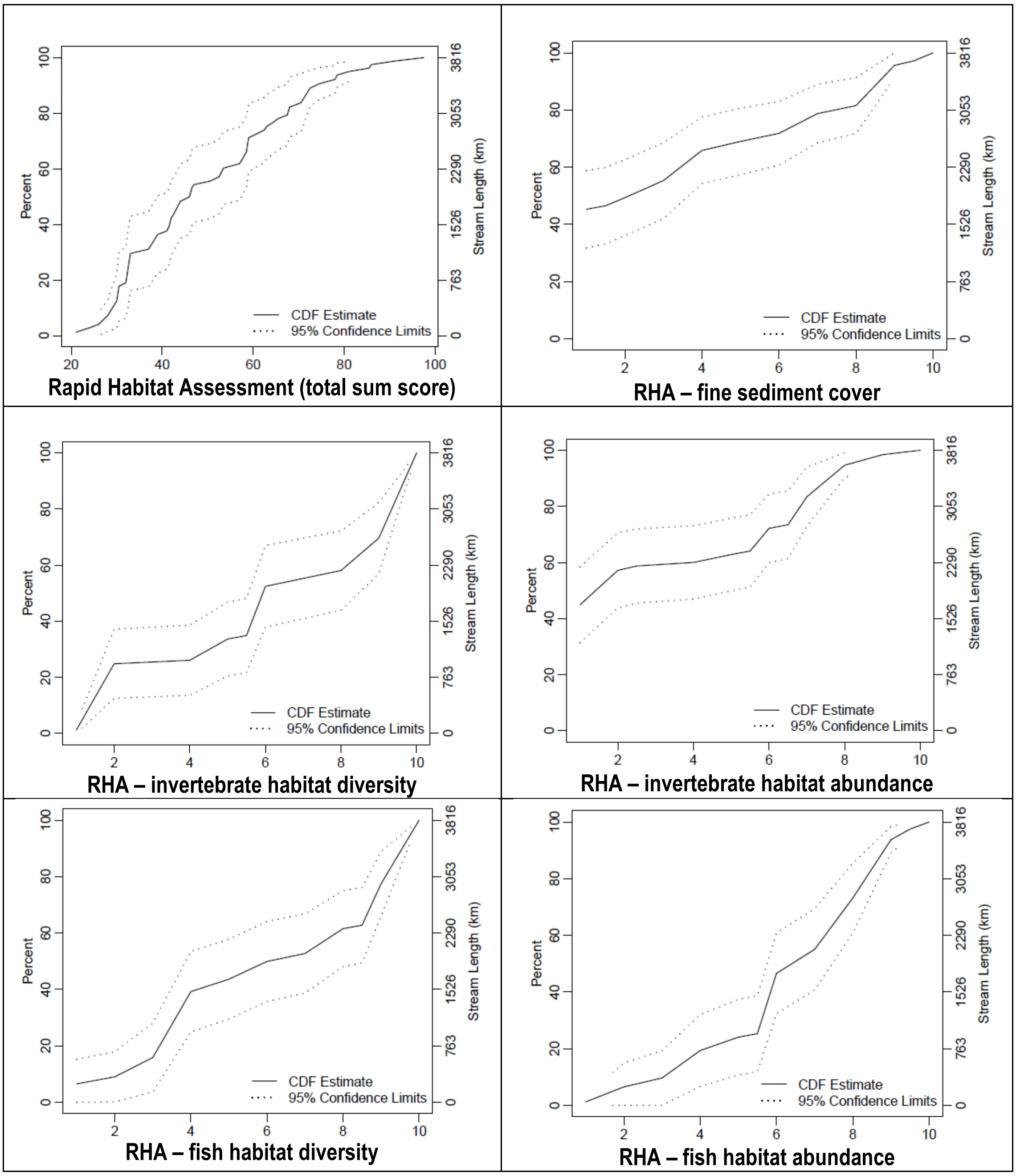

Figure A2.1: Cumulative frequency distributions of extent estimates calculated in spsurvey

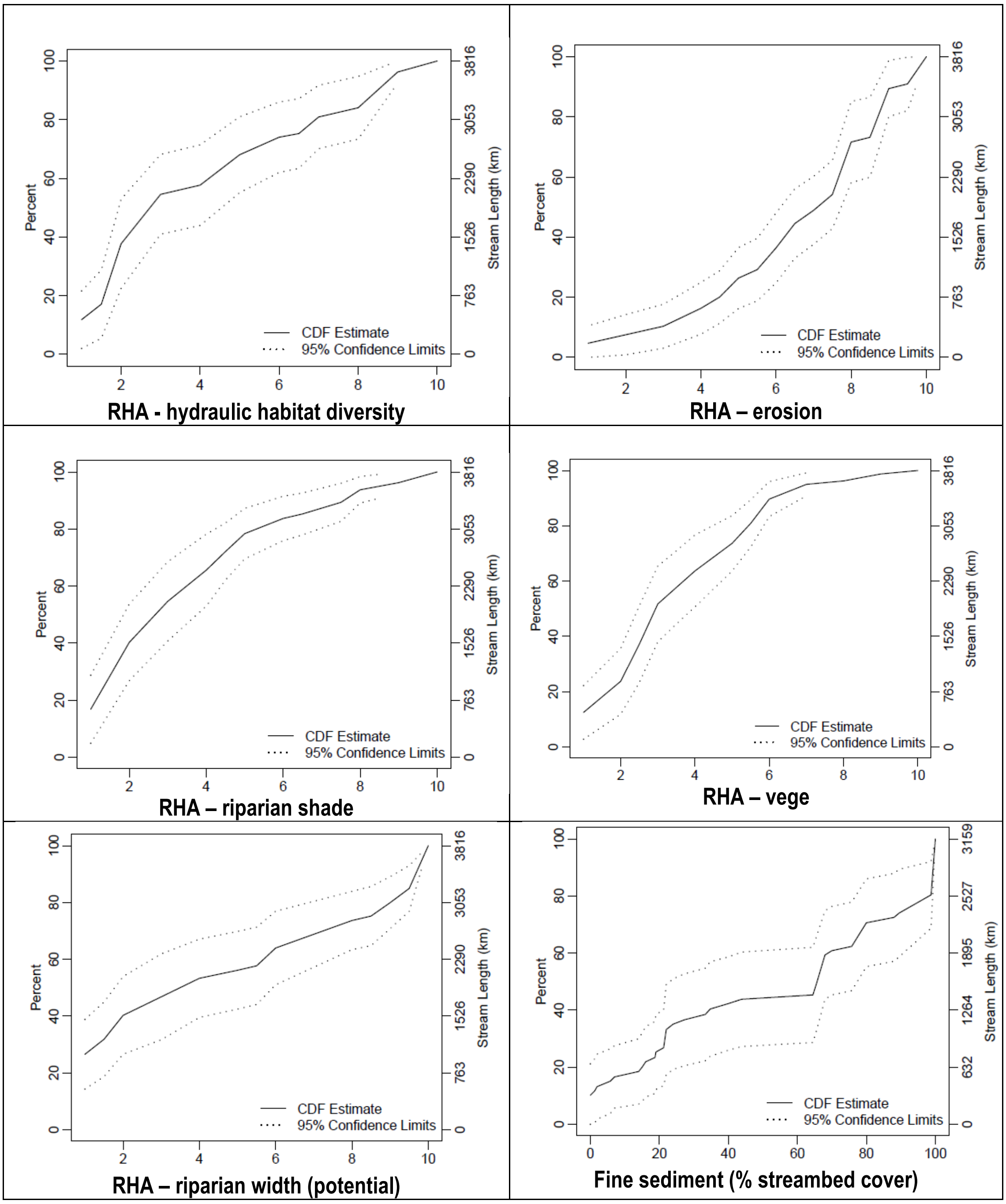

Figure A2.1. cont.: Cumulative frequency distributions of extent estimates calculated in spsurvey

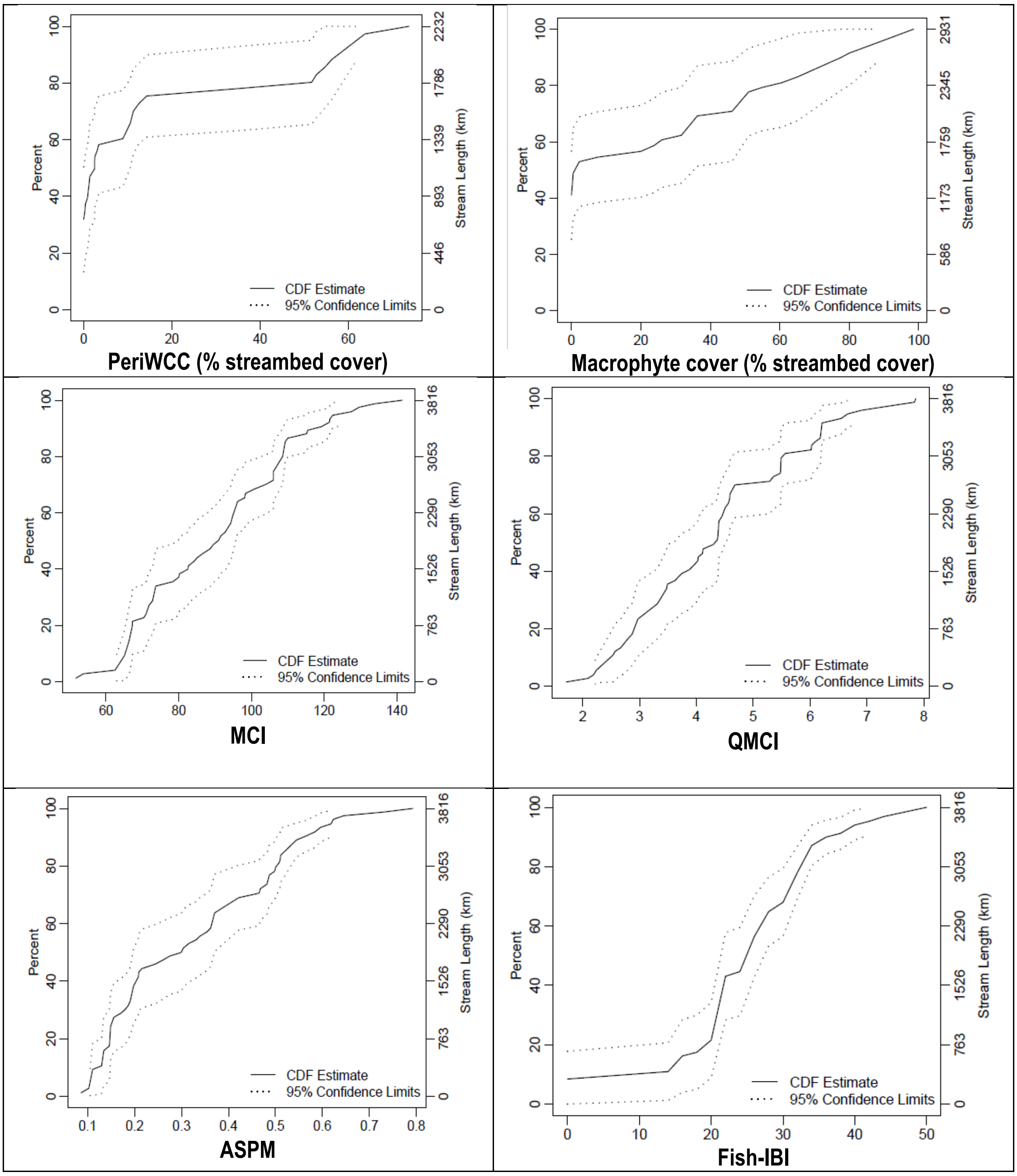

Figure A2.1. cont: Cumulative frequency distributions of extent estimates calculated in spsurvey

Appendix 3: Additional NPS-FM macroinvertebrate metric graphs: QMCI and ASPM

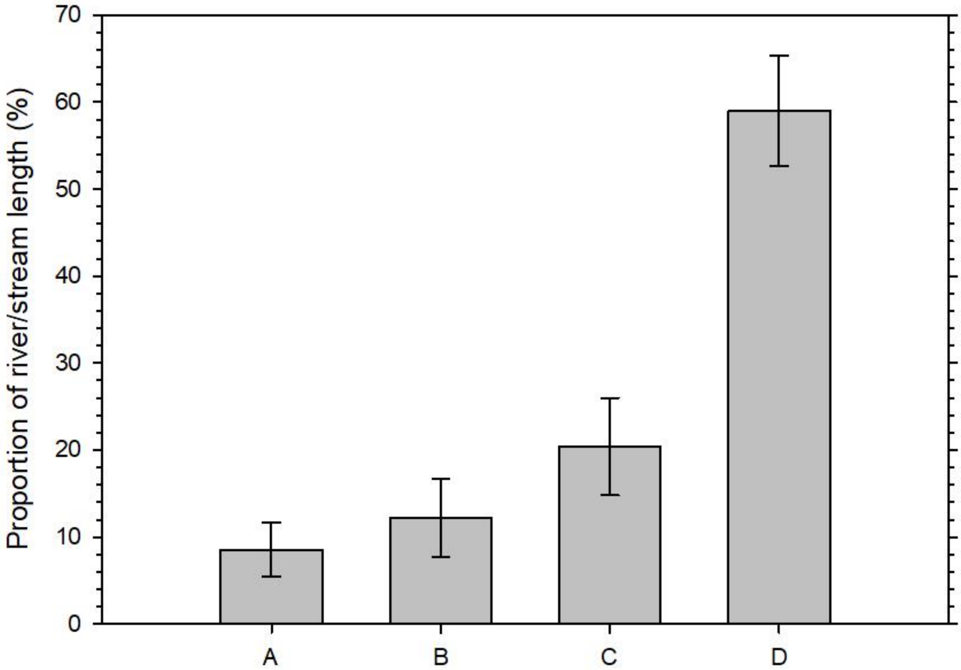

Figure A3.1: Estimates of the percentages (±1 SE) of river and stream length in the Wellington Region that fall within each of QMCI quality states proposed in the NPS-FM (MfE 2019)

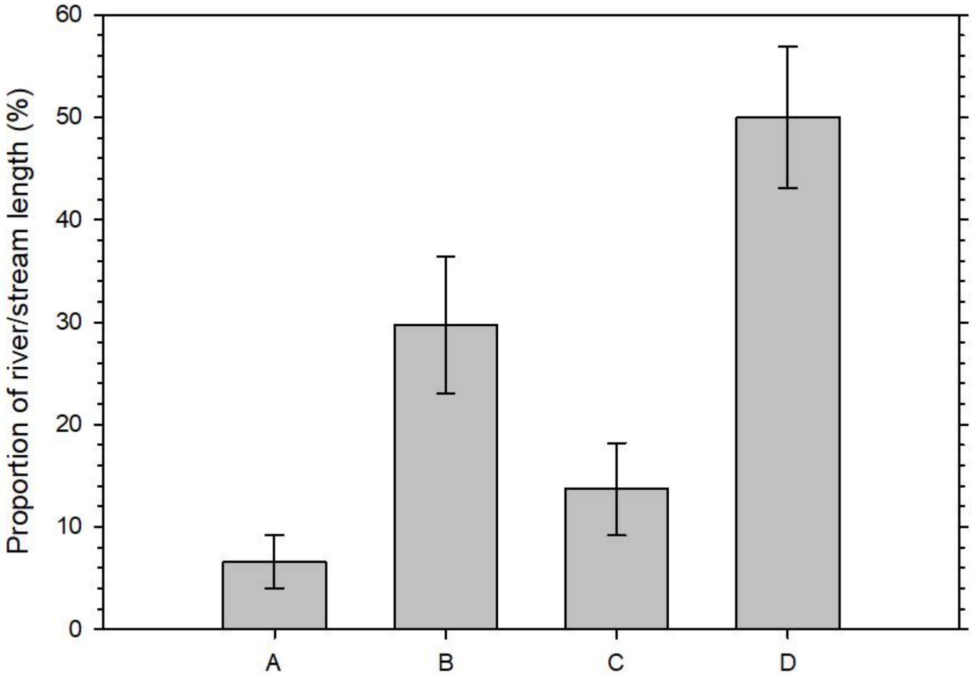

Figure A3.2: Estimates of the percentages (±1 SE) of river and stream length in the Wellington Region that fall within each of ASPM quality states proposed in the NPS-FM (MfE 2019)