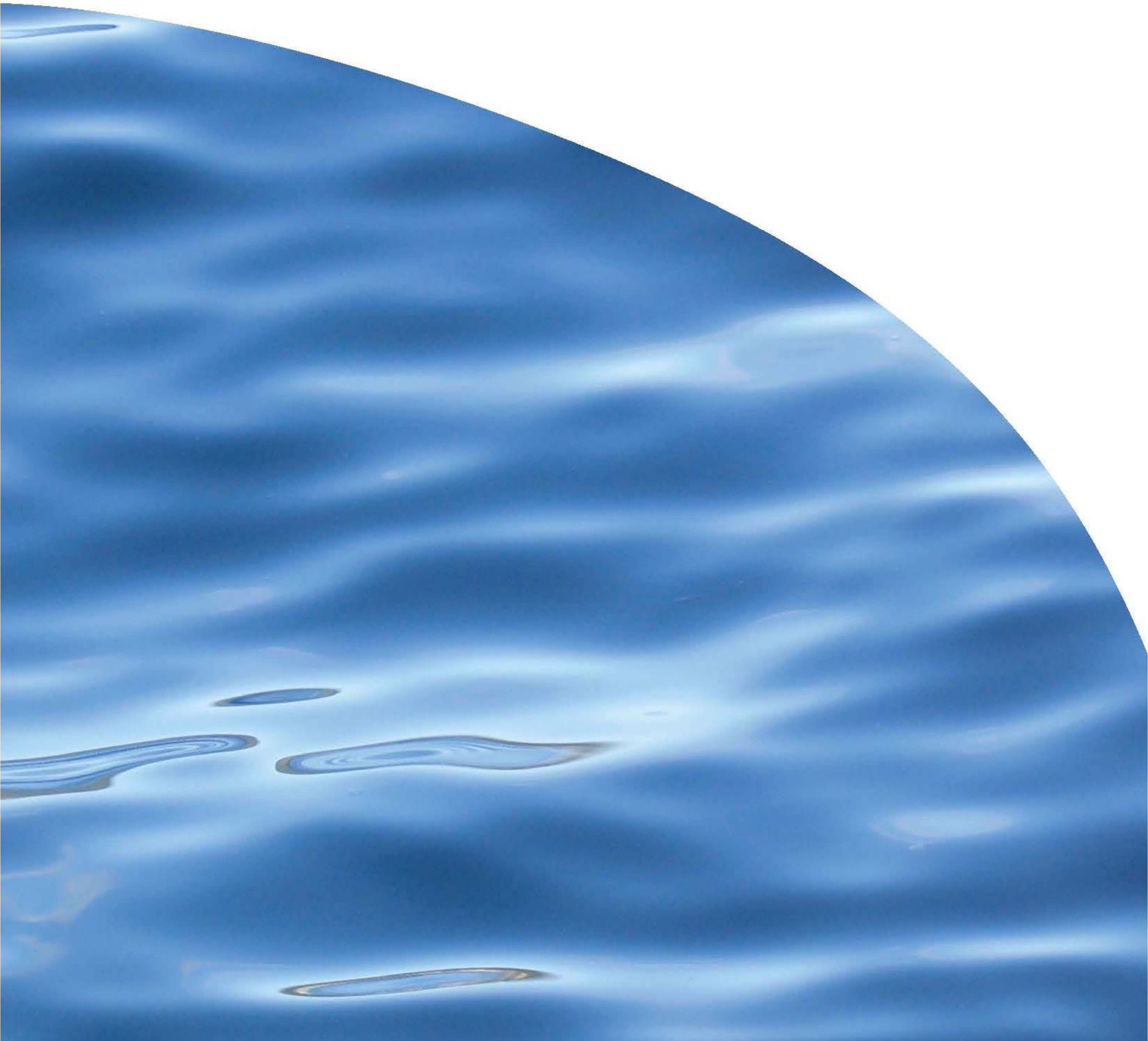
REPORT NO. 2503

TECHNICAL REPORT OF MACROINVERTEBRATE COMMUNITY INDEX PREDICTIONS FOR THE WELLINGTON REGION



TECHNICAL REPORT OF MACROINVERTEBRATE COMMUNITY INDEX PREDICTIONS FOR THE WELLINGTON REGION

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Prepared for Greater Wellington Regional Council

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1. INTRODUCTION

1.1. Background

Greater Wellington Regional Council (GWRC) is currently reviewing its five regional plans and is developing a single new integrated plan for the Wellington region. A discussion document (Regional Plan Working Document for Discussion or WDFD) was released to key stakeholders in August 2013 and a Draft Regional Plan is expected to be released around September 2014.

Macroinvertebrates have been identified as a key indicator of river and stream ecosystem health in Schedule H of the WDFD. However, due to a lack of robust information on variation in reference condition (natural state) of macroinvertebrate metrics in the Wellington region, numeric thresholds[1] were not included. The purpose of this project is to develop a predictive model of contemporary macroinvertebrate metric scores specific to the Wellington region that could then be used to inform numeric thresholds for the Macroinvertebrate Community Index (MCI) to be included in the Draft Regional Plan. A model developed specifically for the Wellington region is likely to provide greater accuracy than the national model (Clapcott *et al.* 2013) as additional data not used in the development of the national model will be used. Predictions from the regional model can then be used in combination with existing reference data to identify reference thresholds for selected classes in the region.

1.2. Project scope

The purpose of this project is to:

- Develop a model of contemporary MCI scores specific to the Wellington region based on MCI data from 290 sites across the region.
- Compare the accuracy of predictions from the regional model with that from the national model.
- Use the outputs from the regional model along with existing reference data as the basis for MCI thresholds for classes in the Wellington region in four bands — ‘excellent’, ‘good’, ‘fair’ and ‘poor’.

The methods for identification of MCI thresholds should be, as far as possible, consistent with any likely future guidance from the National Objectives Framework.

[1] In this instance, ‘thresholds’ refers to numeric guideline values that can be used to differentiate between specific states of ecological quality, such as reference or ‘excellent’, ‘good’, ‘fair’ or ‘poor’ quality.

2. METHODS

2.1. Source data

Data was provided by Greater Wellington Regional Council compiled from a range of projects conducted over the last 15 years. Data included MCI scores for 290 sites in the Wellington region; scores were either an average of MCI scores from three replicates or a score from a single replicate at sites sampled on a single occasion, or 5 year medians from routine monitoring sites (Table 1). The 290 sites were relatively representative of the environmental variation observed the Greater Wellington region (Table 2). Sites sampled and model outputs are summarised by two levels of river classification. The first level is the GWRC FENZ[2] classification that is based on the FENZ classification and documented in Warr (2009). The second is the Regional Plan River Class (RP River Class) which is a further condensed version of the GWRC FENZ classification (Table 2).

Table 1. Summary of Macroinvertebrate Community Index (MCI) sample data analysed in this project.

Project ID*	Number of sites	Year collected	MCI score	MCI range
A	55	2005-2013	5-yr median	72–148
B	15	1999-2013	5-yr median	66–141
C	8	2010	Single sample	73–138
D	3	2003-2007	5-yr median	83–114
E	29	2001	Single sample	63–155
F	57	2003/2004	Single sample	56–153
G	8	2007/2008	Single sample	93–134
H	14	2006	Single sample	71–120
I	78	2001	Single sample	76–173
J	15	2011/2012	Single sample	65–131
K	8	2012	Single sample	80–113

*Project details:

A. GWRC Rivers State of the Environment (RSoE) monitoring
B. GWRC Historic RSoE monitoring
C. GWRC Mangatarere Stream investigation
D. GWRC Riparian restoration monitoring
E. Kingett Mitchell REC verification study
F. Kingett Mitchell Wellington City urban stream study
G. GWRC Wellington city urban stream samples
H. Kingett Mitchell Wairarapa urban streams study
I. Massey University samples
J. GWRC additional sampling
K. GWRC Pahaoa River investigation

[2] Freshwater Ecosystems of New Zealand (FENZ) geo-database

Table 2. Distribution of sample data sites in relation to Greater Wellington Regional Council (GWRC) river classification.

RP River class	GW FENZ class	No. of sample sites	%	No. stream segments total	%	Length stream segments total	%
1	C7	82	28.3	2979	16.6	1729.1	14.2
	C10	1	0.3	1562	8.7	923.6	7.6
	UR	1	0.3	705	3.9	355.7	2.9
		[84]	*[29.0]*	*[5246]*	*[29.2]*	*[3008.4]*	*[24.7]*
2	C5	74	25.5	4553	25.4	3076.4	25.3
	C1	4	1.4	450	2.5	279.0	2.3
	C6b	3	1.0	22	0.1	13.7	0.1
		[81]	*[27.9]*	*[5025]*	*[28.0]*	*[3369.2]*	*[27.7]*
3	C8	25	8.6	2699	15.03	1868.7	15.3
4	C6a	31	10.7	475	2.64	429.9	3.5
5	C6c	11	3.8	252	1.40	200.9	1.6
6	A	58	20.0	4258	23.7	3299.1	27.1
	B	0	0.0	5	0.0	3.4	0.0
		[58]	*[20]*	*[4263]*	*[23.7]*	*[3302.5]*	*[27.1]*
TOTAL		290	100.0	17960	100.00	12179.6	100.00

*Description of RP River Classes:

1. Steep gradient, hard sedimentary
2. Moderate gradient and coastal, hard sedimentary
3. Moderate gradient, soft sedimentary
4. Low gradient, large, draining ranges
5. Low gradient, large, draining plains and eastern Wairarapa
6. Low gradient, small

2.1. Predictive model development

We investigated two model approaches recently used to predict contemporary and reference values for stream metrics: boosted regression tree (Clapcott *et al.* 2013) and linear regression (Unwin *et al.* 2010).

2.1.1. Boosted regression tree model

Boosted regression tree (BRT) models were developed using the training data set (n = 290) and 18 environmental predictor variables from the LCDB3[3] and FENZ[2] database (Table 3). Boosted regression tree model-fitting parameters, such as the

[3] New Zealand's Landcover Database v3.0 (LCDB3)

tree complexity and learning rate, were tuned manually with the aim of improving the percentage of deviance explained by the model. A number of alternative models were investigated, such as modelling transformed MCI, including or excluding RP River Class category, and automated simplification of the model by the removal of variables with low contribution. Additionally, we used a leave-one-out cross validation approach which allowed us to independently test the predictive performance of the models and assess model consistency and bias.

Table 3. Variables from boosted regression tree (BRT) and linear regression models developed to predict the Macroinvertebrate Community index (MCI).

Variable	**Description**	**BRT relative importance**	**Significance in linear model (p)**
NativeVeg	Native vegetation cover in the catchment (%)	59.60	< 0.001
Urban	Urban impervious cover in the catchment (%)	8.40	< 0.05
SEGJANAIRT	Segment summer air temperature (°C)	5.30	< 0.001
SEGSLOPESQ	Segment slope (°), square-root transformed	4.62	< 0.001
USDAYSRAIN	Days/year with rainfall in the catchment greater than 25 mm	4.49	
USPHOSPHOR	Average phosphorus concentration of rocks in the catchment, 1 = very low to 5 = very high	2.45	
SEGRIPSHAD	Segment riparian shade (proportional)	2.31	
PastoralHeavy	Pastoral heavy cover in the catchment (%)	2.28	<0.05
ExoticVeg	Exotic vegetation cover in the catchment (%)	1.79	
USCALCIUM	Average calcium concentration of rocks in the catchment, 1 = very low to 4 = very high	1.63	
SEGFLOWSTA	Annual low flow/annual mean flow (ratio)	1.62	
SEGLFLOW4T	Mean annual 7-day low flow (m^3/s), fourth-root transformed	1.40	
DailyAll	The proportion of flow remaining after surface water allocation	1.24	< 0.05
USHARDNESS	Average hardness of rocks in the catchment, 1 = very low to 5 = very high	0.96	
SEGMINTNOR	Segment winter air temperature (°C), normalised with respect to SEGJANAIRT	0.82	
LOCSED	Weighted average of proportional cover of bed sediment using categories of: 1 = mud; 2 = sand; 3 = fine gravel; 4 = coarse gravel; 5 = cobble; 6 = boulder; 7 = bedrock	0.60	
LOCHAB	Weighted average of proportional cover of local habitat using categories of: 1 = still; 2 = backwater; 3 = pool; 4 = run; 5 = riffle; 6 = rapid; 7 = cascade	0.40	
PastoralLight	Pastoral light cover in the catchment (%)	0.09	

The best-performing model was one that modelled logit-transformed MCI, where:

$$logit(MCI) = \log(\frac{MCI/200}{1 - MCI/200})$$

All 18 predictor variables were retained in this best performing model which explained 65.9% of the deviance in MCI data and had a cross validation coefficient of 0.818 (se = 0.021). The proportion of native vegetation in the catchment explained over half of the deviance in MCI data and had a strong positive relationship with MCI (Figure 1).

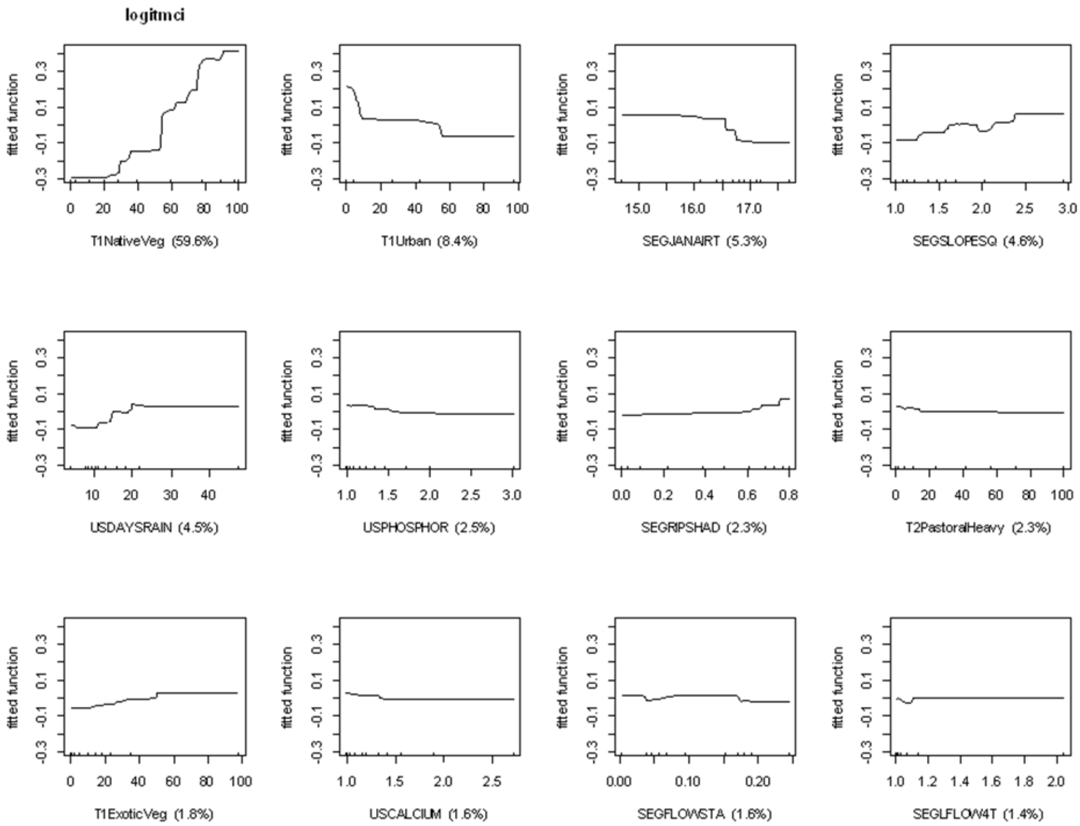

Figure 1. Shape of the relationships between Macroinvertebrate Community Index (MCI) and individual environmental predictors in order of model importance (12 most important variables shown) from a boosted regression tree (BRT) model. Note the rug plots on the x-axis show the distribution of training data and the y-axis scale shows the marginal contribution of each predictor in logit-transformed units to mean MCI.

We compared predictions for the 290 site training dataset from the regional BRT model and the national model from Clapcott *et al.* (2013). Firstly, the regional model shows excellent predictive accuracy (Nash-Sutcliffe efficiency [NSE] = 0.82) and effectively no bias, and the root mean square deviation (RMSD) was 11.05 suggesting a standard deviation of 21.6 MCI units for the model (Figure 2) . In comparison, predictions from the national model versus the observed values from 290 sites had good predictive accuracy (NSE = 0.69), low bias (0.89) and the RMSD was 14.41 suggesting a standard deviation of 28.2 MCI units.

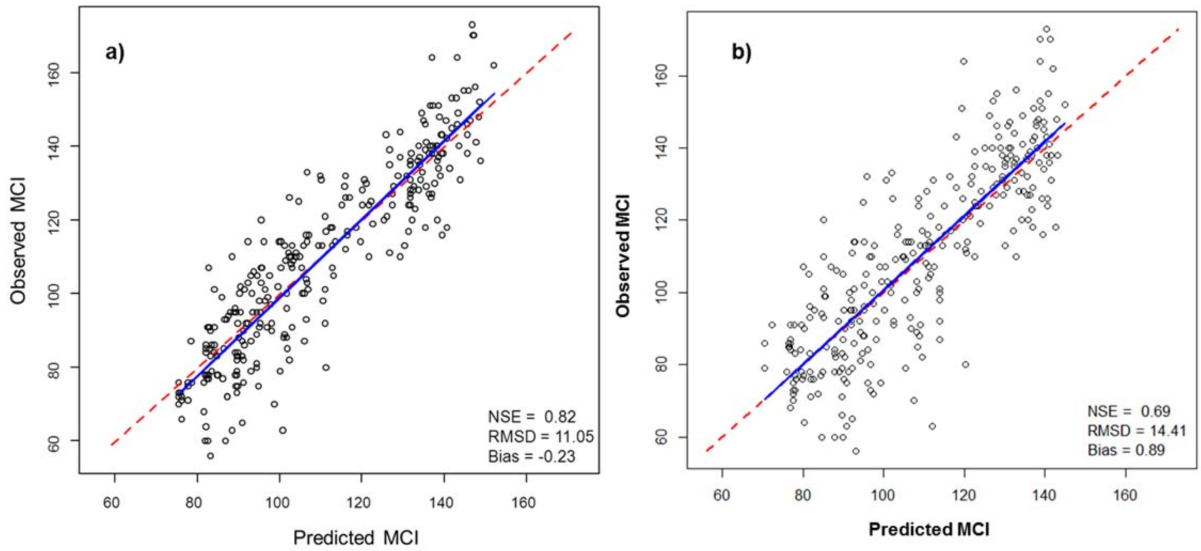

Figure 2. Correlations between observed and predicted values from the boosted regression tree (BRT) a) regional model and b) national model for contemporary Macroinvertebrate Community Index (MCI). N = 290. The dashed line is the 1:1 line and the blue line is the line of best fit. Model performance statistics are explained in text.

The relationships between predicted and observed MCI values from the BRT model using a leave-one-out approach showed good model validation (Figure 3) in terms of:

- the Nash-Sutcliffe efficiency (NSE = 0.67) statistic which indicates how well the plot of observed versus predicted fits the 1:1 line, where values greater than 0 are satisfactory but values greater than 0.5 indicate good model performance,
- root mean squared deviation (RMSD = 14.73) is an estimate of model uncertainty (overall departure between observed and predicted values), where smaller values indicate lower uncertainty than large values,
- bias (Bias = -0.07) which measures the average tendency of the predicted values to be larger or smaller than the observed, where positive values indicate model underestimation and negative values indicate overestimation bias.

These model diagnostics can be interpreted as indicative of a very good predictive model (within the training data range), with 95th percent confidence intervals of < 29 MCI units, and effectively no bias (< 0.1 MCI unit). The difference between the potential predictive performance (Coefficient of variation [CV] correlation of 0.82) and the validation model performance (NSE = 0.67) suggests that the model could be improved by increasing sample N within the environmental range of the training data.

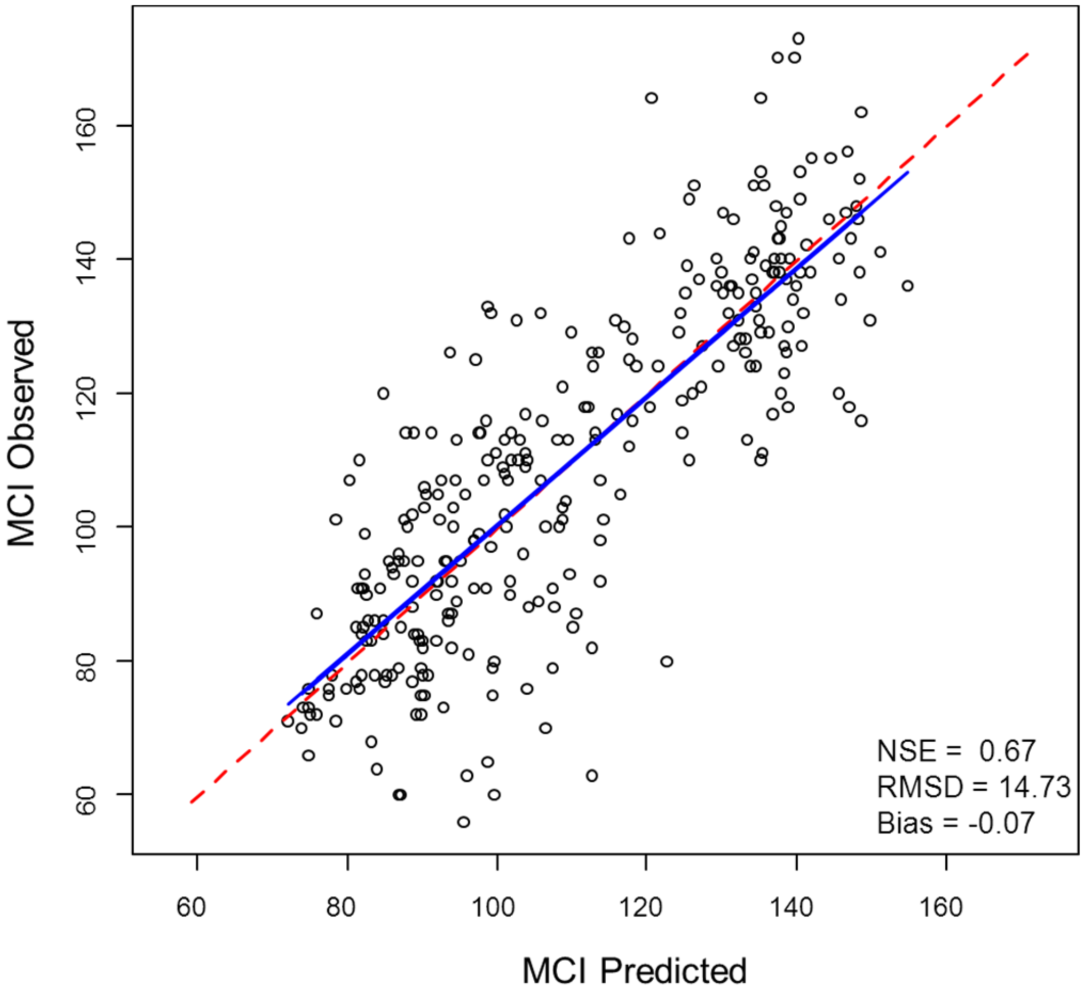

Figure 3. Correlations between observed and predicted values from the boosted regression tree (BRT) leave-one-out validation model for contemporary Macroinvertebrate Community Index (MCI). The dashed line is the 1:1 line and the blue line is the line of best fit. Model performance statistics are explained in text.

2.1.2. Linear model

We explored linear models to provide a comparison to the BRT approach and to test an alternative approach to predicting reference state (discussed below). Linear models were developed using the training dataset (n = 290) and a selection of the 18 environmental predictor variables from the LCDB3 and FENZ database (Table 3). Initially we trialled general additive models (GAM) to allow for up to three-way interactions between smoother functions of all predictors. Inspection of the resultant GAM model suggested that only low-order smoothing functions were being fitted, meaning there was little justification for moving away from a standard linear regression. Therefore we developed a linear model using manual predictor selection informed by variance inflation factor (VIF) and the Akaike information criterion (AIC) value. We used backward selection (‘step’ function in core R package ‘stats’; R Core Team, 2013) to inform the most parsimonious model. The 'step' function sequentially removes the least significant predictor variable until the model with the lowest AIC value is reached. We also explicitly investigated the potential for interactions of interest (e.g. between *NativeVeg* and environmental descriptors). The ‘best’ model contained seven predictor variables (Table 3) as well as an interaction between *Urban* and *NativeVeg* and had an adjusted R^2-value of 0.70 ($p < 0.001$).

The relationships between predicted and observed MCI values from the linear model using a leave-one-out approach showed good model validation (Figure 4) in terms of:

- the Nash-Sutcliffe efficiency (NSE = 0.70),
- root mean squared deviation (RMSD = 14.2), and
- bias (Bias = -0.22).

These model diagnostics can be interpreted as indicative of a very good predictive model, with 95th percent confidence intervals of < 28 MCI units, and effectively no bias (<0.3 MCI units).

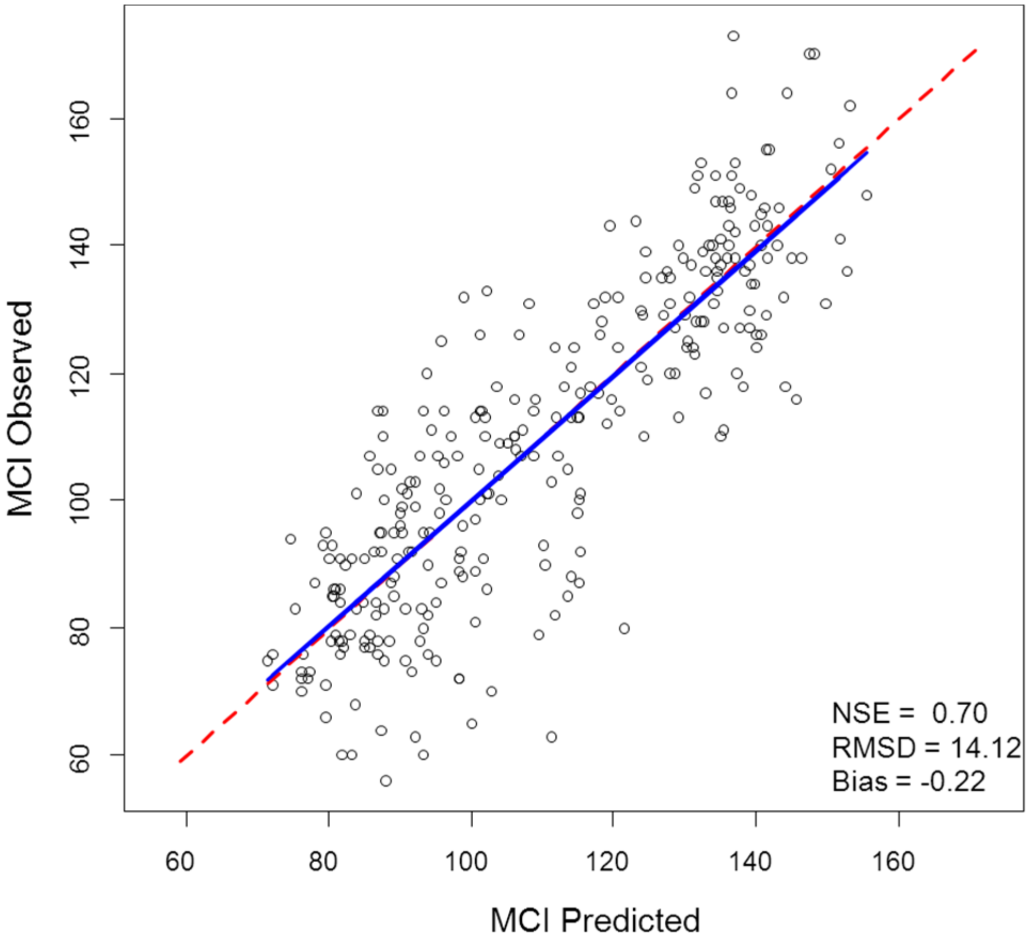

Figure 4. Correlations between observed and predicted values from the linear leave-one-out validation model for contemporary Macroinvertebrate Community Index (MCI). The dashed line is the 1:1 line and the blue line is the line of best fit. Model performance statistics are explained in text.

2.1.3. Predicting reference state

To predict expected reference MCI values for the Wellington reaches, the land-use variables were reset to values representative of no human pressure (0 for *DailyAll*, *PastoralHeavy*, *PastoralLight*, *Urban* and *ExoticVeg* and 100 for *NativeVeg*). The BRT and linear model were then used to predict MCI values in the absence of land-use pressure. Boosted regression tree models do not 'extrapolate' beyond the fitted range of predictor variables. So if the resetting of land use creates sites with a combination of characteristics beyond that which was in the training set, BRT models can only suggest the MCI value for the most similar site. By contrast, linear regressions can extend the trend observed along gradients of predictive conditions, and propose an MCI value outside the range experienced in the training set. A comparison of BRT and linear model reference predictions illustrates how BRT predictions are truncated to a value observed in the training data set (Figure 5).

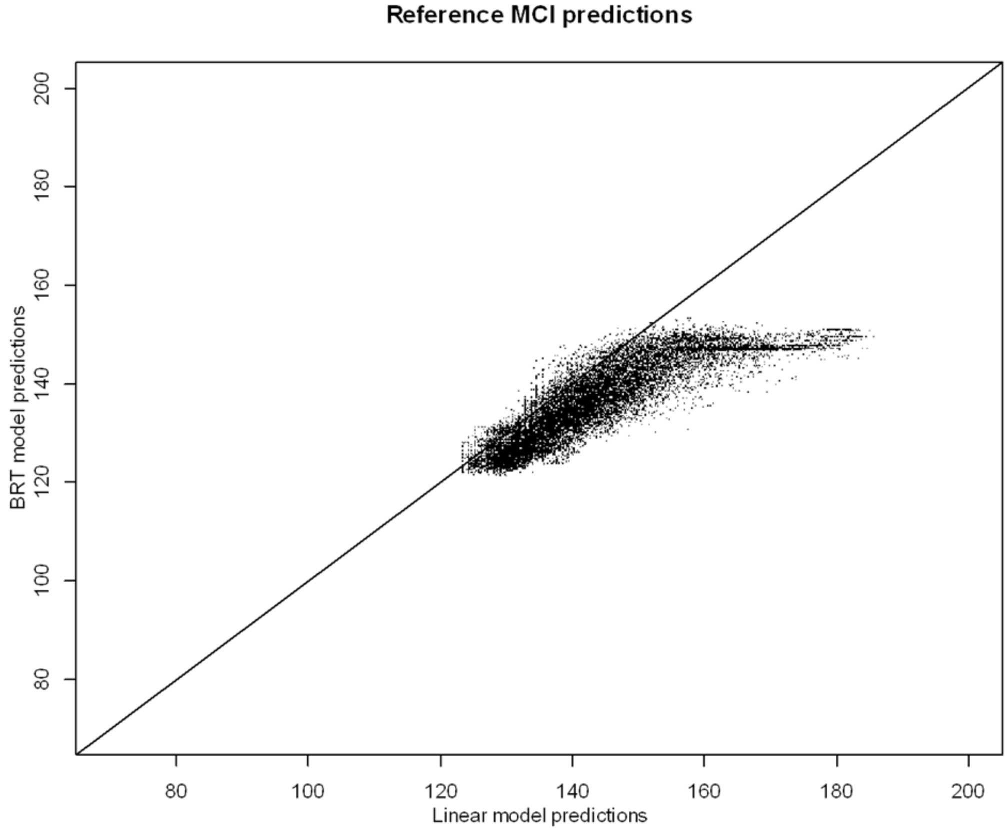

Figure 5. Correlation of predicted reference Macroinvertebrate Community Index (MCI) values from the boosted regression tree (BRT) and linear models.

A leave-one-out cross validation illustrates the weakness of both model approaches for accurately predicting reference[4] MCI values on a site-by-site basis (Figure 6). The NSE values reflect the limited validation data set, whereas the RMSD is consistent with that observed for contemporary models. Improved model performance is likely to be gained by increasing N, especially in the reference range.

[4] 'Reference' sites having no human pressure (0 for *DailyAll*, *PastoralHeavy*, *PastoralLight*, *Urban* and *ExoticVeg* and 100 for *NativeVeg*)

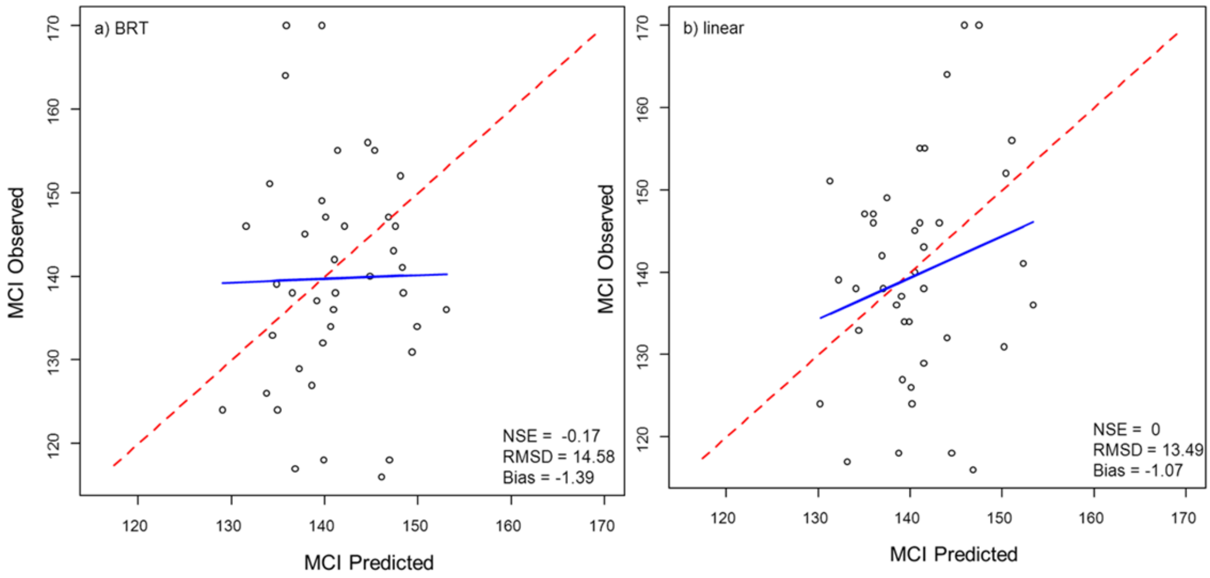

Figure 6. Correlations between observed and predicted values from the a) boosted regression tree (BRT) and b) linear leave-one-out validation model for reference Macroinvertebrate Community Index (MCI). The dashed line is the 1:1 line and the blue line is the line of best fit. Model performance statistics are explained in text.

3. MACROINVERTEBRATE COMMUNITY INDEX PREDICTIONS FOR GREATER WELLINGTON

3.1. Output

The output from the BRT and linear models was used to predict MCI values for all stream segments in the Wellington region and to calculate summaries by two levels of stream classification: GWRC FENZ Class and RP River Class (Appendix 1). Boxplots for RP River Class summaries are shown in Figure 7 and Figure 8, and for GWRC FENZ Class see Appendix 2. In terms of contemporary predictions the modelled output distributions mirror the observed, with significantly different ranges of values within the six RP River Classes (Figure 7). For reference predictions, there is a distinct tendency for higher values to occur at streams with lower temperature and higher slopes. This is particularly evident for linear model predictions because *SEGJANAIRT* and *SEGSLOPESQ* were the primary variables driving this model in the absence of land-use pressure (Figure 8). The BRT model incorporated more environmental variation leading to generally lower reference predictions at sites characterised as soft sedimentary (Figure 8).

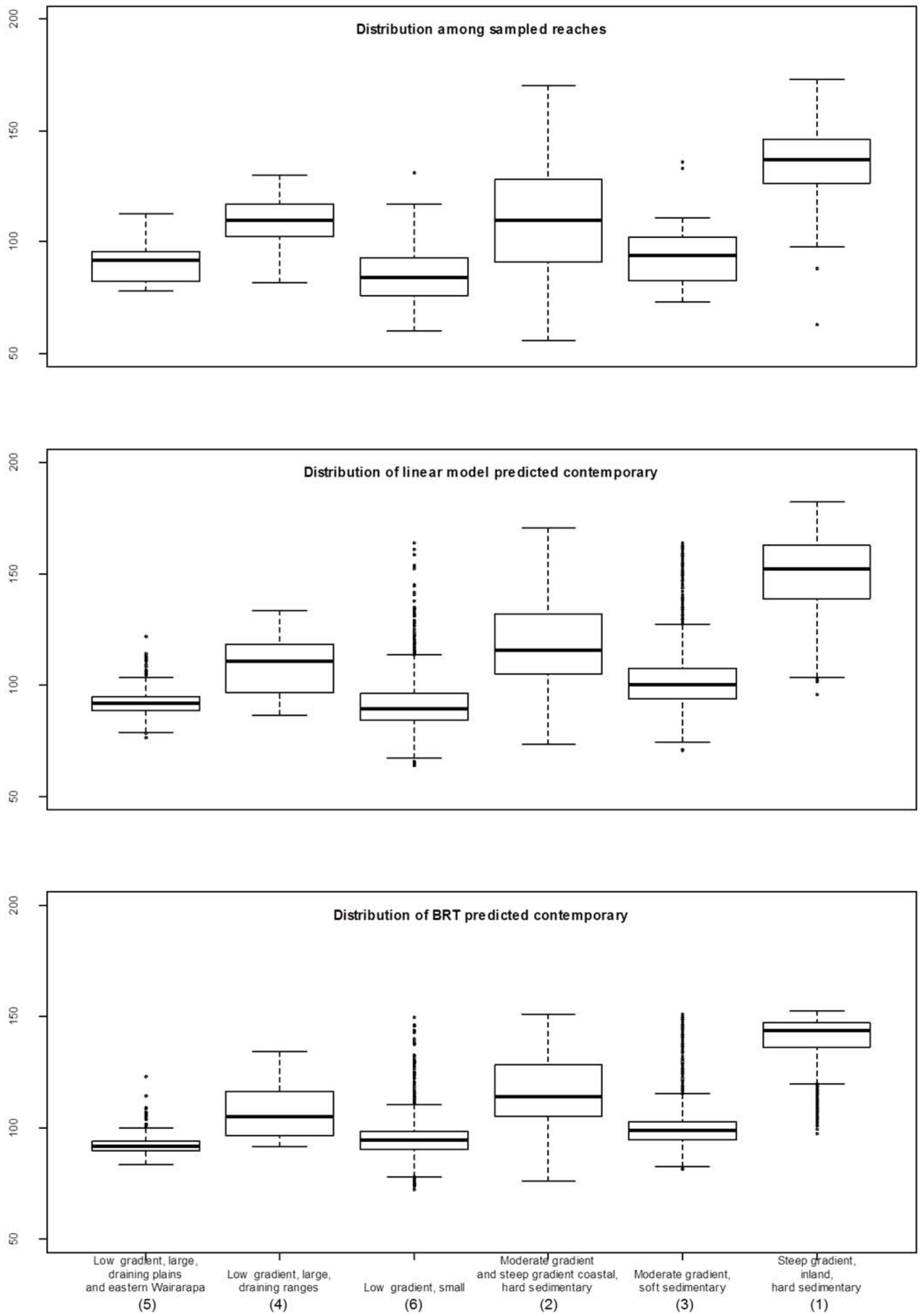

Figure 7. Boxplots showing measured Macroinvertebrate Community Index (MCI) and contemporary MCI from linear and boosted regression tree (BRT) model predictions grouped by RP River Class.

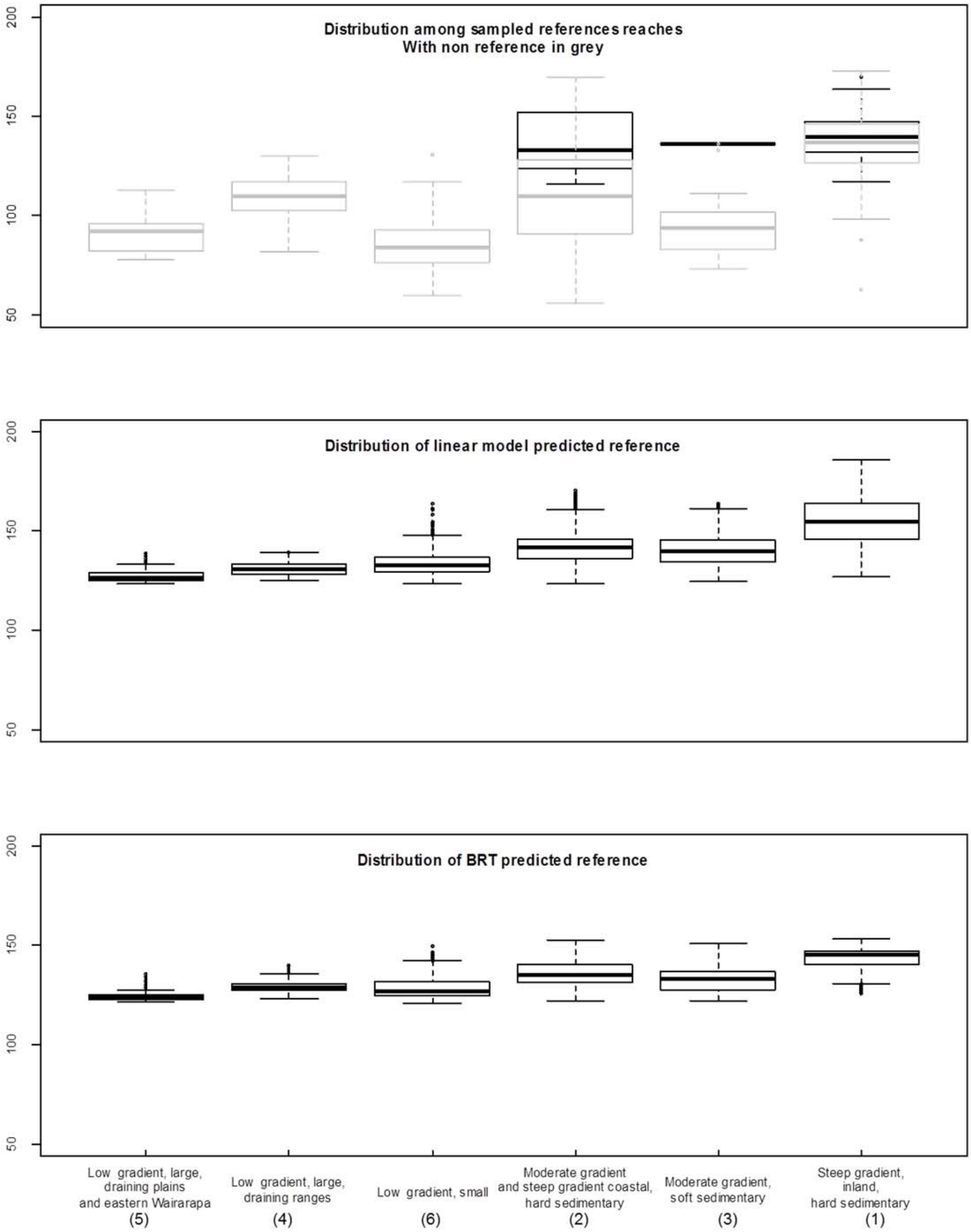

Figure 8. Boxplots showing measured Macroinvertebrate Community Index (MCI) and reference MCI from linear and boosted regression tree (BRT) model predictions grouped by RP River Class.

3.2. Management bands

Three alternative ways to determine management bands for MCI are discussed below.

3.2.1. Deviation from reference approach

Bands are determined by applying a set deviance from reference approach. For example, if the expected reference MCI value for a site was 130, then bands could be within 20 MCI units of the reference value or within 20% of the reference value (either approach is valid given the normal distribution of MCI data); within 20 MCI units = 'Excellent' (MCI >130), 'Good' (110-129), 'Fair' (90-109) or 'Poor' (<90), or within 20% 'Excellent' (MCI >130), 'Good' (104-129), 'Fair' (78-104) or 'Poor' (<78). However, this approach could lead to very low bottom lines where there are low-scoring reference sites and this may not give sufficient environmental protection.

3.2.2. Ratio of observed to expected (reference)

The ratio of observed to expected ($MCI_{O/E}$) requires a robust estimate of reference on a site by site basis. The current predictive models, whilst very good in terms of explaining deviance in MCI have an RMSD (predictive error) of approximately 15 MCI units. Which means 80% confidence is only achieved when bands are 28 MCI units wide. $MCI_{O/E}$ could be calculated using an average E or reference value for a given stream class. However, using the average reference conditions for stream classes still means there could be large variation between that statistic and the actual reference condition of a particular site. Hence, at the site level, using average reference predictions for different stream classes could have the effect of allowing more degradation (if the average reference value is lower than the actual reference value) or less degradation (if the average is greater than the actual) when compared to using an accurate site-specific reference value. In reality, an average / quantile reference value for a given stream class is the best available option in the absence of site-specific reference values.

3.2.3. Adoption of existing quality classes

Four quality classes were assigned by Stark and Maxted (2007b) to the MCI to denote 'Excellent' (MCI ≥ 120), 'Good' (100–119), 'Fair' (80–99) or 'Poor' (< 80) conditions indicative of different levels of pollution. The 'Poor' threshold of 80 was calculated as halfway between the 'Excellent' threshold of 120 and the theoretical MCI minimum of 40. Stark and Maxted (2007a) tested these boundaries for soft-bottomed streams and found they corresponded well for the MCI_{sb} which provided greater discrimination of effects for urban and moderate-high intensity rural land uses. Wright-Stow and Winterbourn (2003) proposed that 'fuzzy' rather than fixed boundaries would provide more certainty in assigning quality classes, such that 'Excellent' would become > 125, 'Good' 105–115, 'Fair' 85–95 and 'Poor' < 75, and intermediate values would have intermediate class assignments (*e.g.* 96–114 would be 'Good-fair'). These fuzzy classes were originally proposed by Stark (1985) and were later replaced by the fixed boundaries, although the concept of fuzzy boundaries was supported by Stark and Maxted (2007b).

The assigning of management band thresholds has been discussed as part of the proposed inclusion of MCI as a NOF variable (NZFSS submission 4 February 2014 — http://freshwater.science.org.nz/pdf/NZFSS_amendments_to_the_NPS_FM.pdf). The proposed national bands are the default quality classes assigned by Stark and Maxted (2007b) but an important aspect is noted: "…the statistic used (*e.g*. summer value, monthly mean, 3-year rolling mean) will need to be determined." Analysis of regional data provides improved resolution for the definition of band thresholds for GWRC, and the MCI statistic could be defined by analysis of reference site variability. Analysis of year-to-year variability in MCI values at reference sites in the Waikato region (Clapcott unpublished data) suggests a 3-year rolling mean would be appropriate. This reduces the likelihood that a site will be assigned to the wrong band due to sampling error or natural deviation in MCI values due to climatic influences.

At the regional level, the definition of an 'Excellent' threshold is best defined firstly by the measured MCI value at reference sites by stream class. The number of measured sites required per class can be informed by the variability observed in environmental descriptors. For example, predictive models suggest greater environmental variability in RP River Classes 1, 2 and 3 compared to lower variability in RP River Classes 4 and 5. Data from at least three sites per class could be used in a power analysis to determine the minimum number of sites required to characterise reference state.

Secondly, an 'Excellent' threshold could be defined by the modelled contemporary MCI value for sites that meet a set of land-use filters and thirdly, by the modelled reference value by stream class. In this project we used a set of land-use filters that allowed for a reference data set greater than 10% of the total data set, *i.e.* 40 out of 290 sites. As such, filters were conservative allowing up to 15% non-native vegetation in the catchment and 5% light pasture, but no heavy pasture and no urban development or surface water allocation. Note: using a land-use restriction of 90% native forest reduced the reference data set to 24 sites.

The average or the 25th percentile value could be used to inform a reference threshold. The latter would mean accepting that 25% of all reference sites would fall below the 'Excellent' threshold (compared to 50% for the mean value). The definition of remaining thresholds could be achieved by the equal distribution of data from the 'Excellent' threshold down to a lower limit determined by either the 5th percentile of measured or modelled data. The latter would mean accepting that measured data may not represent the true range of conditions present in any given class.

3.2.4. RP River Class 1

Summary model statistics for RP River Class 1 (Steep gradient, inland, hard sedimentary) are provided in Table 4. Data suggest an ‘Excellent’ threshold of 130 to 140 and a ‘Fair’ threshold of 110. Accepting an ‘Excellent’ threshold at 140 would suggest a ‘Good’ threshold halfway at 125 — thresholds at 140, 125, 110.

Table 4. Summary Macroinvertebrate Community Index (MCI) statistics for RP River Class 1. *from the contemporary model for sites with native vegetation > 85%, light pasture < 5%, heavy pasture = 0%, urban = 0%, surface water allocation = 0.

Reference	**N**	**min**	**5th**	**25th**	**50th**	**75th**	**95th**	**max**
measured	35	117	118	**132**	140	147	158	170
brt 85%*	3100	127	138	**144**	147	147	149	152
linear 85%*	3100	129	138	**149**	157	165	173	182
brt	5250	126	135	**141**	146	147	150	153
linear	5250	127	136	**146**	155	164	176	186
Contemporary	**N**	**min**	**5th**	**25th**	**50th**	**75th**	**95th**	**max**
measured	84	63	**110**	127	137	146	161	173
brt	5250	97.3	**115**	136	144	147	149	152
linear	5250	95.6	**120**	139	152	163	174	182

3.2.5. RP River Class 2

Summary model statistics for RP River Class 2 (Moderate gradient and coastal, hard sedimentary) are provided in Table 5. Data suggest an ‘Excellent’ threshold of 130 and a ‘Fair’ threshold between 70 and 90; 80 would be in line with the proposed national C/D threshold for hard-bottomed streams (NZFSS submission 4 February 2014). Accepting an ‘Excellent’ threshold at 130 would suggest a ‘Good’ threshold approximately halfway at 105 — thresholds at 130, 105, and 80. Note the wider range (minimum to maximum values) in observed and predicted contemporary values for RP River Class 2 compared to RP River Class1. This is likely to reflect the greater range of both environmental and land use gradients in RP River Class 2.

Table 5. Summary Macroinvertebrate Community Index (MCI) statistics for RP River Class 2. *from the contemporary model for sites with native vegetation > 85%, light pasture < 5%, heavy pasture = 0%, urban = 0%, surface water allocation = 0

Reference	**N**	**min**	**5th**	**25th**	**50th**	**75th**	**95th**	**max**
measured	4	116	118	**128**	133	143	165	170
brt 85%*	723	127	129	**134**	139	144	148	151
linear 85%*	723	122	132	**140**	145	151	161	171
brt	5020	122	126	**131**	135	140	146	153
linear	5020	123	130	**137**	142	146	154	171
Contemporary	**N**	**min**	**5th**	**25th**	**50th**	**75th**	**95th**	**max**
measured	81	56	**70**	91	110	128	143	170
brt	5020	76.1	**98.2**	105	114	128	143	151
linear	5020	73.6	**92.9**	105	116	132	150	171

3.2.6. RP River Class 3

Summary model statistics for RP River Class 3 (Moderate gradient, soft sedimentary) are provided in Table 6. Data suggest an 'Excellent' threshold of 130 and a 'Fair' threshold of 80. Accepting an 'Excellent' threshold at 130 would suggest a 'Good' threshold approximately halfway at 115 – thresholds at 130, 105, and 80.

Table 6. Summary Macroinvertebrate Community Index (MCI) statistics for RP River Class 3. *from the contemporary model for sites with native vegetation > 85%, light pasture < 5%, heavy pasture = 0%, urban = 0%, surface water allocation = 0

Reference	**N**	**min**	**5th**	**25th**	**50th**	**75th**	**95th**	**max**
measured	1	136	136	**136**	136	136	136	136
brt 85%*	72	128	130	**139**	146	148	150	151
linear 85%*	72	132	134	**145**	155	159	162	164
brt	2700	122	123	**127**	133	137	142	151
linear	2700	124	129	**134**	140	145	153	164
Contemporary	**N**	**min**	**5th**	**25th**	**50th**	**75th**	**95th**	**max**
measured	25	73	**75**	83	94	102	129	136
brt	2700	81.6	**89.5**	94.6	98.7	103	117	151
linear	2700	70.8	**87.6**	93.6	99.9	107	125	164

3.2.7. RP River Class 4

Summary model statistics for RP River Class 4 (Low gradient, large, draining ranges) are provided in Table 7. Data suggest an ‘Excellent’ threshold of 120 to 130 and a ‘Fair’ threshold of 90. Accepting an ‘Excellent’ threshold at 130 would suggest a ‘Good’ threshold approximately halfway at 110 — thresholds at 130, 110, and 90. The utility of model predictions is illustrated in this and following RP River Classes where there are no measured data from reference sites.

Table 7. Summary Macroinvertebrate Community Index (MCI) statistics for RP River Class 4. *from the contemporary model for sites with native vegetation > 85%, light pasture < 5%, heavy pasture = 0%, urban = 0%, surface water allocation = 0

Reference	**N**	**min**	**5th**	**25th**	**50th**	**75th**	**95th**	**max**
measured	0							
brt 85%*	2	131	131	**131**	131	132	132	132
linear 85%*	2	129	129	**129**	129	129	129	129
brt	475	123	125	**128**	129	131	135	140
linear	475	125	127	**129**	131	133	136	139
Contemporary	**N**	**min**	**5th**	**25th**	**50th**	**75th**	**95th**	**max**
measured	31	82	**87.5**	102	110	117	126	130
brt	475	91.9	**94.1**	96.6	105	116	127	134
linear	475	86.7	**91.1**	96.8	111	118	126	134

3.2.8. RP River Class 5

Summary model statistics for RP River Class 5 (Low gradient, large, draining plains and eastern Wairarapa) are provided in Table 8. Data suggest an ‘Excellent’ threshold of 110 to 120 and a ‘Fair’ threshold of 80. Accepting an ‘Excellent’ threshold at 110 would suggest a ‘Good’ threshold approximately halfway at 95 — thresholds at 110, 95, and 80. Accepting an ‘Excellent’ threshold at 120 would suggest a ‘Good’ threshold approximately halfway at 100 — thresholds at 120, 100, and 80. None of the 249 river segments in RP River Class 5 are described by the chosen land use filters, suggesting only ‘best available’ reference sites would be available to validate model predictions and inform ‘Excellent’ thresholds.

Table 8. Summary Macroinvertebrate Community Index (MCI) statistics for RP River Class 5. *from the contemporary model for sites with native vegetation > 85%, light pasture < 5%, heavy pasture = 0%, urban = 0%, surface water allocation = 0

Reference	**N**	**min**	**5th**	**25th**	**50th**	**75th**	**95th**	**max**
measured	0							
brt 85%*	0							
linear 85%*	0							
brt	249	122	122	**123**	124	125	130	136
linear	249	123	124	**125**	126	129	133	138
Contemporary	**N**	**min**	**5th**	**25th**	**50th**	**75th**	**95th**	**max**
measured	11	78	**78**	82.5	92	96	108	113
brt	249	83.6	**88.9**	89.9	91.9	94.2	105	123
linear	249	76.3	**84.6**	88.3	92	94.6	109	122

3.2.9. RP River Class 6

Summary model statistics for RP River Class 6 (Low gradient, small) are provided in Table 9. Data suggest an ‘Excellent’ threshold of 120 and a ‘Fair’ threshold of 70. Accepting an ‘Excellent’ threshold at 120 would suggest a ‘Good’ threshold approximately halfway at 95 – thresholds at 120, 95, and 70. However, unless these are true soft-bottomed streams (which may be hard to determine) it would be more protective to adopt the proposed national C/D threshold for hard-bottomed streams of 80 (NZFSS submission 4 February 2014). Thresholds would then be 120, 100, and 80.

Table 9. Summary Macroinvertebrate Community Index (MCI) statistics for RP River Class 2. *from the contemporary model for sites with native vegetation > 85%, light pasture < 5%, heavy pasture = 0%, urban = 0%, surface water allocation = 0

Reference	**N**	**min**	**5th**	**25th**	**50th**	**75th**	**95th**	**max**
measured	0							
brt 85%*	15	128	128	**131**	143	145	149	149
linear 85%*	15	129	129	**132**	145	156	162	164
brt	4260	121	123	**125**	127	132	137	149
linear	4260	123	127	**129**	132	137	143	164
Contemporary	**N**	**min**	**5th**	**25th**	**50th**	**75th**	**95th**	**max**
measured	58	60	**64.8**	76	84.5	92.5	110	131
brt	4260	72.5	**82.8**	90.4	94.4	98.6	106	149
linear	4260	64	**74.1**	84.2	89.5	96	108	164

3.1. Future work

To validate the reference predictions from current models and to develop predictive models with less error requires MCI data from more sites. Improvements are likely to be achieved by acquiring data from sites currently underrepresented in the training data, such as in GWRC FENZ classes B, C1, C10, C8, UR.

To determine the most appropriate MCI statistic would require an analysis of temporal variability in MCI data from representative reference sites.

4. REFERENCES

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5. APPENDICES

Appendix 1. Summaries of measured and modelled Macroinvertebrate Community Index (MCI) values for the Wellington region.

A1.1. Measured contemporary Macroinvertebrate Community Index (MCI).

RP River Class	Description	GW FENZ Class	N	min	5th	25th	50th	75th	95th	max
1	*Steep gradient, hard sedimentary*	C7	31	82	87.5	102	110.0	117.0	126.0	130.0
		C10	1	148	148.0	148	148.0	148.0	148.0	148.0
		UR	1	151	151.0	151	151.0	151.0	151.0	151.0
			84	*63*	*110.0*	*127*	*137*	*146*	*161*	*173.0*
2	*Moderate gradient and coastal, hard sedimentary*	C5	74	56	69.2	89.5	110.0	128.0	141.0	153.0
		C1	4	101	103.0	112	124.0	142.0	164.0	170.0
		C6b	3	70	72.1	80.5	91.0	102.0	112.0	114.0
			81	*56*	*70.0*	*91*	*110*	*128*	*143*	*170.0*
3	*Moderate gradient, soft sedimentary*	C8	25	73	75.0	83	94.00	102.0	129.0	136.0
4	*Low gradient, large, draining ranges*	C6a	31	82	87.5	102	110.00	117.0	126.0	130.0
5	*Low gradient, large draining plains and eastern Wairarapa*	C6c	11	78	78.0	82.5	92.00	96.0	108.0	113.0
6	*Low gradient, small*	A	58	60	64.8	76	84.5	92.5	110.0	131.0
		B	-	-	-	-	-	-	-	-
			58	*60*	*64.8*	*76*	*84.5*	*92.5*	*110.0*	*131.00*

A1.2. Boosted regression tree (BRT) modelled contemporary Macroinvertebrate Community Index (MCI).

RP River Class	Description	GW FENZ Class	N	min	5th	25th	50th	75th	95th	max
1	*Steep gradient, hard sedimentary*	C7	2980	97.3	110.0	131	139.0	145.0	149.0	152.0
		C10	1560	109	140.0	146	147.0	148.0	149.0	152.0
		UR	705	118	131.0	138	145.0	147.0	149.0	152.0
			5250	*97.3*	*115.0*	*136*	*144*	*147*	*149*	*152.0*
2	*Moderate gradient and coastal, hard sedimentary*	C5	4550	76.1	98.1	105	113.0	126.0	141.0	151.0
		C1	450	87.9	101.0	111	132.0	144.0	149.0	151.0
		C6b	22	89.7	92.4	96.1	99.9	100.0	107.0	117.0
			5020	*76.1*	*98.2*	*105*	*114*	*128*	*143*	*151.0*
3	*Moderate gradient, soft sedimentary*	C8	2700	81.6	89.5	94.6	98.70	103.0	117.0	151.0
4	*Low gradient, large, draining ranges*	C6a	475	91.9	94.1	96.6	105.00	116.0	127.0	134.0
5	*Low gradient, large draining plains and eastern Wairarapa*	C6c	249	83.6	88.9	89.9	91.90	94.2	105.0	123.0
6	*Low gradient, small*	A	4260	72.5	82.8	90.4	94.4	98.6	106.0	149.0
		B	5	89.4	90.4	94.5	97.4	98.9	101.0	102.0
			4260	*72.5*	*82.8*	*90.4*	*94.4*	*98.6*	*106.0*	*149.00*

A1.3. Boosted regression tree (BRT) modelled contemporary Macroinvertebrate Community Index (MCI) at sites with restricted land-use pressure (Natveg >85%, SWA = 0, Urban = 0, HeavyPastoral = 0, LightPastoral <5%)

RP River Class	Description	GW FENZ Class	N	min	5th	25th	50th	75th	95th	max
1	*Steep gradient, hard sedimentary*	C7	1470	127	136.0	141	144.0	147.0	149.0	152.0
		C10	1370	137	143.0	147	147.0	148.0	150.0	152.0
		UR	257	133	140.0	147	147.0	148.0	150.0	152.0
			3100	*127*	*138.0*	*144*	*147*	*147*	*149*	*152.0*
2	*Moderate gradient and coastal, hard sedimentary*	C5	544	127	129.0	133	138.0	142.0	146.0	149.0
		C1	179	127	135.0	142	145.0	147.0	149.0	151.0
		C6b	-	-	-	-	-	-	-	-
			723	*127*	*129.0*	*134*	*139*	*144*	*148*	*151.0*
3	*Moderate gradient, soft sedimentary*	C8	72	128	130.0	139	146.00	148.0	150.0	151.0
4	*Low gradient, large, draining ranges*	C6a	2	131	131.0	131	131.00	132.0	132.0	132.0
5	*Low gradient, large draining plains and eastern Wairarapa*	C6c	-	-	-	-	-	-	-	-
6	*Low gradient, small*	A	15	128	128.0	131	143.0	145.0	149.0	149.0
		B	-	-	-	-	-	-	-	-
			15	*128*	*128.0*	*131*	*143*	*145.0*	*149.0*	*149.00*

A1.4. Linear modelled contemporary Macroinvertebrate Community Index (MCI).

RP River Class	Description	GW FENZ Class	N	min	5th	25th	50th	75th	95th	max
1	*Steep gradient, hard sedimentary*	C7	2980	95.6	116.0	131	141.0	150.0	160.0	171.0
		C10	1560	118	149.0	157	162.0	167.0	172.0	177.0
		UR	705	129	144.0	162	170.0	175.0	179.0	182.0
			5250	*95.6*	*120.0*	*139*	*152*	*163*	*174*	*182.0*
2	*Moderate gradient and coastal, hard sedimentary*	C5	4550	73.6	92.6	104	114.0	130.0	146.0	158.0
		C1	450	84.2	97.6	121	141.0	155.0	163.0	171.0
		C6b	475	86.7	91.1	96.8	111.0	118.0	126.0	134.0
			5020	*73.6*	*92.9*	*105*	*116*	*132*	*150*	*171.0*
3	*Moderate gradient, soft sedimentary*	C8	2700	70.8	87.6	93.6	99.90	107.0	125.0	164.0
4	*Low gradient, large, draining ranges*	C6a	475	86.7	91.1	96.8	111.00	118.0	126.0	134.0
5	*Low gradient, large draining plains and eastern Wairarapa*	C6c	249	76.3	84.6	88.3	92.00	94.6	109.0	122.0
6	*Low gradient, small*	A	4260	64	74.0	84.2	89.5	96.0	108.0	164.0
		B	5	82.4	83.1	85.8	96.5	102.0	105.0	106.0
			4260	*64*	*74.1*	*84.2*	*89.5*	*96.0*	*108.0*	*164.00*

A1.5. Linear modelled contemporary Macroinvertebrate Community Index (MCI) at sites with restricted land-use pressure (Natveg >85%, SWA = 0, Urban = 0, HeavyPastoral = 0, LightPastoral <5%)

RP River Class	Description	GW FENZ Class	N	min	5th	25th	50th	75th	95th	max
1	*Steep gradient, hard sedimentary*	C7	1470	129	135.0	143	149.0	155.0	162.0	171.0
		C10	1370	143	152.0	158	163.0	167.0	172.0	177.0
		UR	257	130	150.0	165	171.0	175.0	179.0	182.0
			3100	*129*	*138.0*	*149*	*157*	*165*	*173*	*182.0*
2	*Moderate gradient and coastal, hard sedimentary*	C5	544	122	131.0	138	144.0	147.0	154.0	158.0
		C1	179	134	142.0	151	156.0	160.0	165.0	171.0
		C6b	-	-	-	-	-	-	-	-
			723	*122*	*132.0*	*140*	*145*	*151*	*161*	*171.0*
3	*Moderate gradient, soft sedimentary*	C8	72	132	134.0	145	155.00	159.0	162.0	164.0
4	*Low gradient, large, draining ranges*	C6a	2	129	129.0	129	129.00	129.0	129.0	129.0
5	*Low gradient, large draining plains and eastern Wairarapa*	C6c	-	-	-	-	-	-	-	-
6	*Low gradient, small*	A	15	129	129.0	132	145.0	156.0	162.0	164.0
		B	-	-	-	-	-	-	-	-
			15	*129*	*129.0*	*132*	*145*	*156.0*	*162.0*	*164.00*

A1.6. Measured reference Macroinvertebrate Community Index (MCI).

RP River Class	Description	GW FENZ Class	N	min	5th	25th	50th	75th	95th	max
1	*Steep gradient, hard sedimentary*	C7	34	117	118.0	132	140.0	147.0	159.0	170.0
		C10								
		UR	1	151	151.0	151	151.0	151.0	151.0	151.0
			35	*117*	*118.0*	*132*	*140*	*147*	*158*	*170.0*
2	*Moderate gradient and coastal, hard sedimentary*	C5	2	132	132.0	132	133.0	134.0	134.0	134.0
		C1	2	116	119.0	130	143.0	156.0	167.0	170.0
		C6b	-	-	-	-	-	-	-	-
			4	*116*	*118.0*	*128*	*133*	*143*	*165*	*170.0*
3	*Moderate gradient, soft sedimentary*	C8	1	136	136.0	136	136.00	136.0	136.0	136.0
4	*Low gradient, large, draining ranges*	C6a	-	-	-	-	-	-	-	-
5	*Low gradient, large draining plains and eastern Wairarapa*	C6c	-	-	-	-	-	-	-	-
6	*Low gradient, small*	A	-	-	-	-	-	-	-	-
		B	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	-

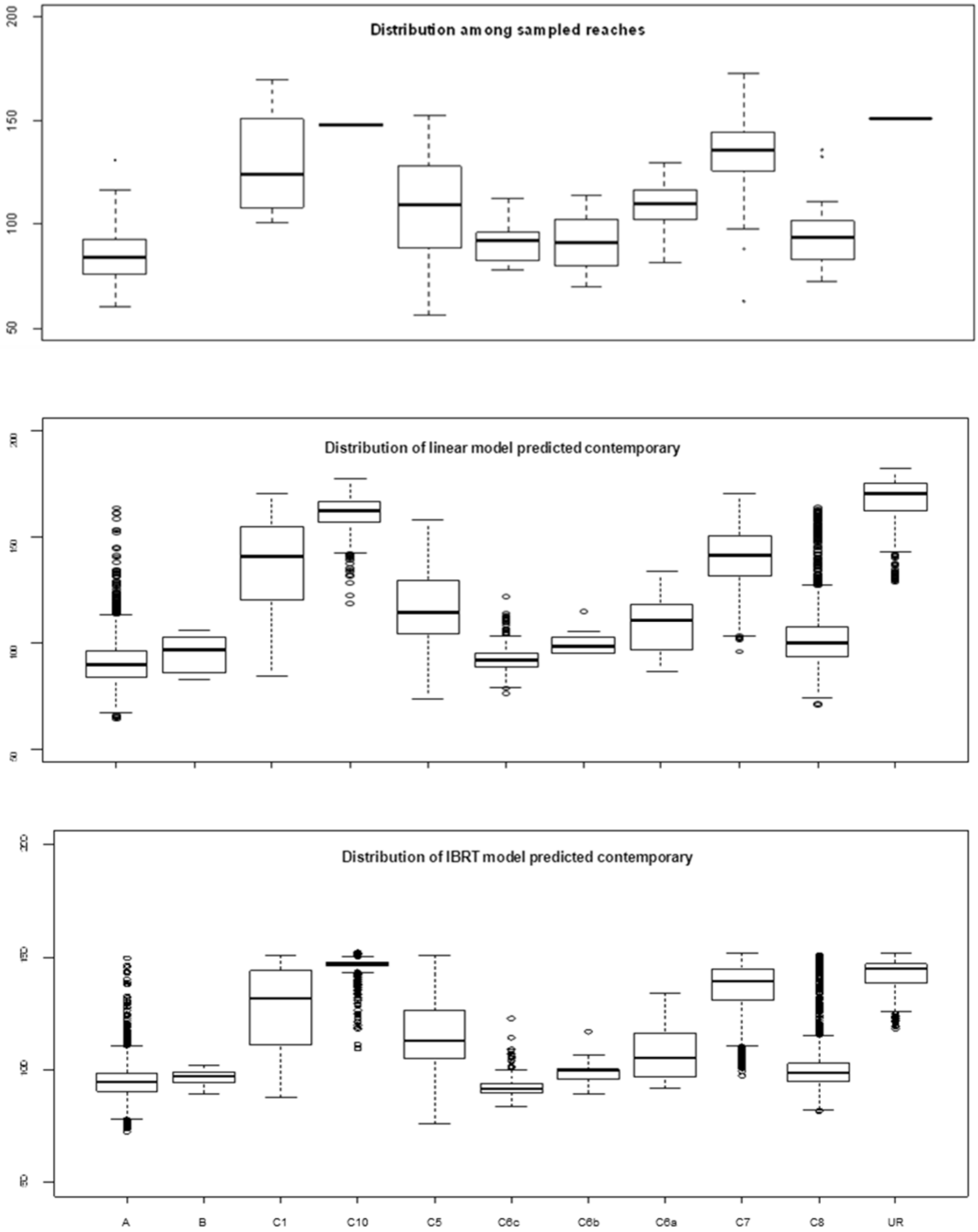
A1.7. Boosted regression tree (BRT) modelled reference Macroinvertebrate Community Index (MCI.

RP River Class	Description	GW FENZ Class	N	min	5th	25th	50th	75th	95th	max
1	*Steep gradient, hard sedimentary*	C7	2980	126	133.0	138	143.0	146.0	149.0	153.0
		C10	1560	135	142.0	147	147.0	148.0	150.0	153.0
		UR	705	133	137.0	145	147.0	149.0	151.0	152.0
			5250	*126*	*135.0*	*141*	*146*	*147*	*150*	*153.0*
2	*Moderate gradient and coastal, hard sedimentary*	C5	4550	122	126.0	131	135.0	140.0	145.0	152.0
		C1	450	125	130.0	134	142.0	145.0	149.0	153.0
		C6b	22	125	125.0	127	128.0	128.0	131.0	133.0
			5020	*122*	*126.0*	*131*	*135*	*140*	*146*	*153.0*
3	*Moderate gradient, soft sedimentary*	C8	2700	122	123.0	127	133.00	137.0	142.0	151.0
4	*Low gradient, large, draining ranges*	C6a	475	123	125.0	128	129.00	131.0	135.0	140.0
5	*Low gradient, large draining plains and eastern Wairarapa*	C6c	249	122	122.0	123	124.00	125.0	130.0	136.0
6	*Low gradient, small*	A	4260	121	123.0	125	127.0	132.0	137.0	149.0
		B	5	126	126.0	127	134.0	135.0	135.0	135.0
			4260	*121*	*123.0*	*125*	*127*	*132.0*	*137.0*	*149.00*

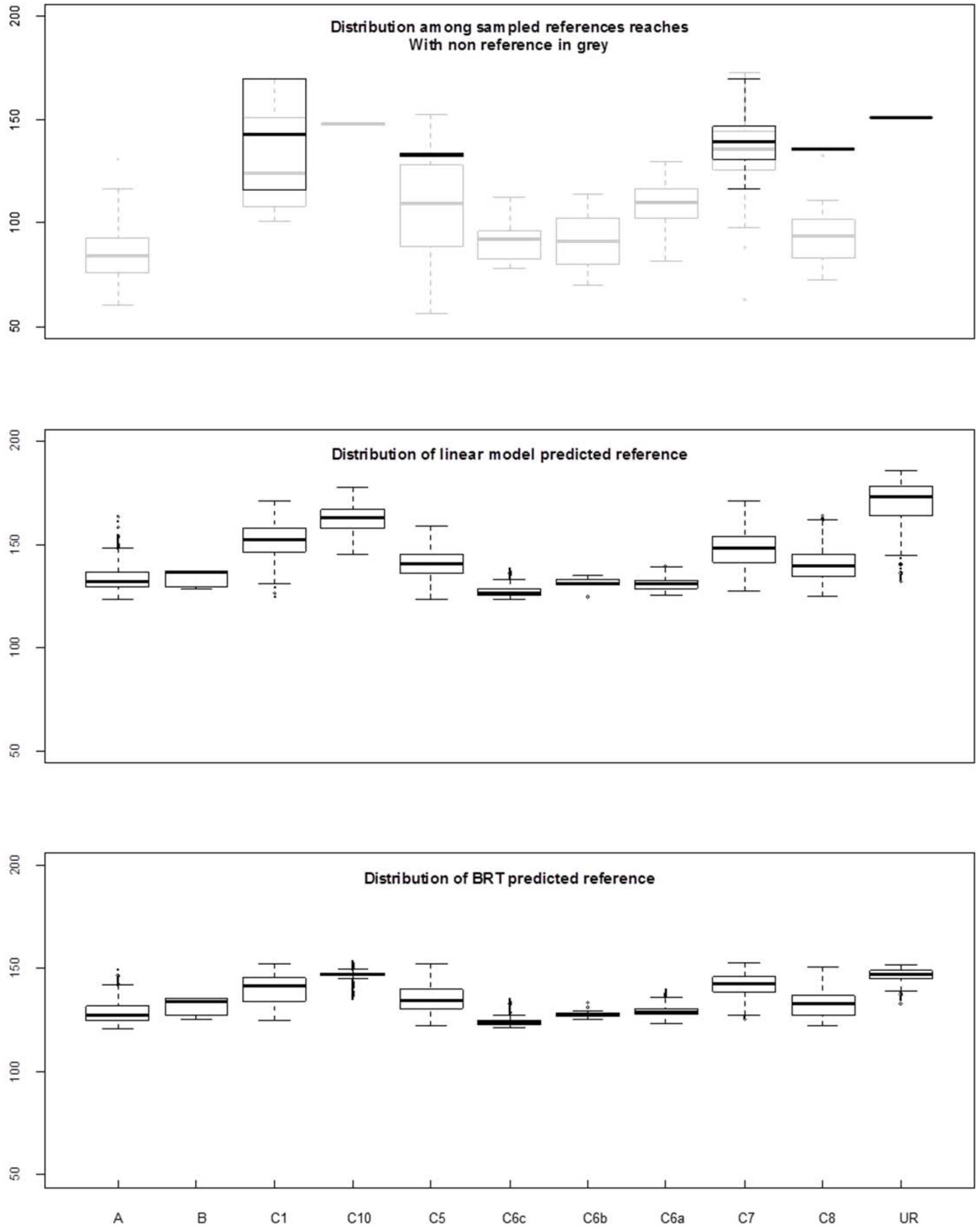
A1.8. Linear modelled contemporary Macroinvertebrate Community Index (MCI).

RP River Class	Description	GW FENZ Class	N	min	5th	25th	50th	75th	95th	max
1	*Steep gradient, hard sedimentary*	C7	2980	127	134.0	141	148.0	153.0	161.0	171.0
		C10	1560	145	152.0	158	163.0	167.0	173.0	178.0
		UR	705	132	147.0	164	173.0	178.0	182.0	186.0
			5250	*127*	*136.0*	*146*	*155*	*164*	*176*	*186.0*
2	*Moderate gradient and coastal, hard sedimentary*	C5	4550	123	129.0	136	141.0	145.0	151.0	159.0
		C1	450	125	138.0	146	152.0	158.0	164.0	171.0
		C6b	22	124	124.0	130	131.0	133.0	134.0	135.0
			5020	*123*	*130.0*	*137*	*142*	*146*	*154*	*171.0*
3	*Moderate gradient, soft sedimentary*	C8	2700	124	129.0	134	140.00	145.0	153.0	164.0
4	*Low gradient, large, draining ranges*	C6a	475	125	127.0	129	131.00	133.0	136.0	139.0
5	*Low gradient, large draining plains and eastern Wairarapa*	C6c	249	123	124.0	125	126.00	129.0	133.0	138.0
6	*Low gradient, small*	A	4260	123	127.0	129	132.0	137.0	143.0	164.0
		B	5	129	129.0	129	136.0	136.0	136.0	136.0
			4260	*123*	*127.0*	*129*	*132*	*137.0*	*143.0*	*164.00*

Appendix 2. Boxplots of measured and modelled Macroinvertebrate Community Index (MCI) values for the Wellington region grouped by Greater Wellington Regional Council (GWRC) FENZ class. Note: FENZ = Freshwater Ecosystems of New Zealand geo-database.



A2.1. Boxplots showing measured Macroinvertebrate Community Index (MCI) and contemporary MCI from linear and boosted regression tree (BRT) models predictions grouped by GWRC FENZ Class.



A2.2. Boxplots showing measured Macroinvertebrate Community Index (MCI) and reference MCI from linear and boosted regression tree models predictions grouped by GWRC FENZ Class.