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Macroinvertebrate Biotic Indices for the Northland Region

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Macroinvertebrate Biotic Indices for the Northland Region

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

INTRODUCTION

Biological monitoring using macroinvertebrates has been undertaken in New Zealand for well over 55 years (*e.g.*, Hirsch 1958), but it was the development of the Macroinvertebrate Community Index (MCI) in the mid-1980s – a simple tool for summarising complex biomonitoring data – that has dominated consent biomonitoring and regional state of the environment monitoring programmes in the last 30 years.

A preliminary version of the MCI (the IHQI, or Invertebrate Habitat Quality Index) was included in the Taranaki ringplain freshwater biological report (Taranaki Catchment Commission 1984), but it was the Water and Soil Miscellaneous Publication prepared under secondment in 1984 to the Water Quality Centre (Hamilton) (Stark 1985) that proposed New Zealand's Macroinvertebrate Community Index (MCI) and its quantitative variant (QMCI) for assessing organic enrichment in stony riffles[1]. The concept was derived from the United Kingdom's Biological Monitoring Working Party Score System (BMWP 1978), although genera are mainly used for scoring in New Zealand indices in contrast to families for the BMWP Score System. The MCI is analogous to the Average Score Per Taxon (ASPT) variant of the BMWP Score System (Armitage *et al.* 1983).

Subsequent research funded by the Public Good Science Fund through the Foundation for Research, Science and Technology focused on characterising the performance and precision of the MCI and QMCI (Stark 1993b).

Stark (1993b) used macroinvertebrate data from both the North and South Islands to investigate the influences of sampling method, water depth, current velocity, and substratum on the MCI and QMCI. When calculated from macroinvertebrate samples collected by hand-net or Surber sampler from stony riffles, the MCI and QMCI are independent of depth, velocity, and substratum; a major advantage when assessing water pollution or enrichment. The statistical precision of MCI and QMCI values obtained in these ways was defined, along with two methods for detecting statistically significant differences between index values (Stark 1993b).

A more cost-effective variant of the QMCI called the Semi-Quantitative Macroinvertebrate Community Index, or SQMCI was developed in 1998 (Stark 1998). The SQMCI uses a five-point scale of coded abundances (*i.e.* Rare, Common, Abundant, Very Abundant, Very Very Abundant). This index produces values very similar to the QMCI, but at less than 40% of the cost, due to reduced numbers of replicate samples being required to achieve the desired precision, and savings in macroinvertebrate sample processing time. Stark (1998) also re-evaluated the statistical precision of the MCI and QMCI from hand-net and Surber samples, based on a larger sample database than was previously available. Similar information was provided for the SQMCI.

[1] Riffle: a shallow part of a stream or river with broken water flow.

Stark & Maxted (2004[2], 2007a) developed new biotic indices for assessing the health of soft-bottomed (SB) streams. These indices are analogous to the MCI, SQMCI and QMCI, which were developed for hard-bottomed (HB) streams, and are denoted by the addition of "-sb" to the respective index names (*i.e.*, MCI-sb, SQMCI-sb and QMCI-sb). New Zealand appears to be the only country with qualitative, semi-quantitative and quantitative versions of the same biotic index, and different versions for HB and SB streams (Stark 1985, 1993b, 1998; Stark & Maxted 2004, 2007a).

Stark & Phillips (2009) found that HB and SB versions of the MCI, SQMCI, and QMCI showed modest by statistically significant seasonal variation with seasonal means generally within ±3% to ±5% of annual mean values. They concluded that seasonal variability was unlikely to confound interpretation of biomonitoring results based on the MCI (and variants) and does not need to be considered.

Finally, Suren et. al (2010) developed a biotic index for assessing the health of freshwater wetlands in the South Island.

The original MCI (Stark 1985) was developed primarily using data from Taranaki RingPlain streams (although tolerance values[3] (TVs) have been added subsequently by professional judgement for taxa not present in the data set used for index development). Similarly, the MCI-sb was developed primarily using data from SB streams in the Auckland region (Stark & Maxted 2004, 2007a). Never-the-less, these indices have been applied nationwide but there has always some uncertainty regarding whether or not biotic indices derived using data from one region would perform just as well in other regions or throughout New Zealand. The most up-to-date published list of TVs for the HB and SB versions of the MCI (and variants) was provided by Stark & Maxted (2007b).

Conceptually, it seems likely that biotic indices may perform best when applied to the region from which the data used to develop them were derived. Furthermore, applying a single biotic index (like the MCI) over a wide geographical range (such as throughout NZ) may inevitably involve some compromise. The standard interpretation, for example, may not apply equally in all regions, and some taxa may differ biogeographically in their pollution tolerances depending on, for example, water temperature.

Chessman (2003) recognised that Australia's MCI-equivalent biotic index (SIGNAL) was developed primarily using data from south-eastern Australia (Chessman 1995), and although it was applied subsequently nationwide, there were concerns about the applicability in other regions and, of course, there were taxa present in other regions that were not present in the south-east. Consequently, Chessman (2003), when developing SIGNAL2, derived what he called 'grades' (= TVs) for taxa separately for 24 different regions of Australia. For the

[2] Note that the MCI-sb described by Stark & Maxted (2004) is a preliminary version that is **not** the same as the final version (Stark & Maxted 2007). We simplified the tolerance value derivation process and derived tolerance values to the nearest 0.1 (rather than integers) to improve the performance of the MCI-sb and to reduce the possibility of confusion between the HB (integer) and SB (nearest 0.1) tolerance values.

[3] Tolerance values or taxon scores range from 0 (or 1) to 10 and are assigned to invertebrate taxa. They reflect their tolerance of organic enrichment or pollution. Taxa with low numbers are more tolerant than those with high numbers.

national SIGNAL2 index, these regional grades were averaged and standard errors were calculated (as a measure of confidence in the averaged national grades).

In this report I describe the development and performance testing of biotic indices using data collected from HB and SB streams in the Northland Region. Tolerance values were derived using the same iterative rank correlation method developed by Bruce Chessman (2003) that I used for developing the MCI-sb (Stark & Maxted 2007a) and the South Island Wetland Biotic Index (Suren *et al.* 2010). The expectation is that biotic indices developed for a specific region should perform better than an index developed elsewhere.

DATA SETS

Macroinvertebrates

Northland Regional Council (NRC) supplied two macroinvertebrate datasets for development of regional biotic indices – one for HB streams and another for SB streams.

Soft-bottomed stream macroinvertebrate data

Data from 183 samples collected annually from SB streams in the Northland Region between 1998 and 2013 inclusive were provided for analysis (Appendix 1). These samples were collected from 20 different sites and contained a total of 99 different macroinvertebrate taxa (identified at the generic level (at best)). Ninety of these taxa were present also in the HB stream dataset.

Hard-bottomed stream macroinvertebrate data

Data from 292 samples collected annually from HB streams in the Northland Region between 1998 and 2013 inclusive were provided for analysis (Appendix 2). These samples were collected from 33 different sites and contained a total of 125 different macroinvertebrate taxa (identified at the generic level (at best)). Ninety of these taxa were present also in the SB stream dataset.

Data reduction was required in order to reduce the effective number of samples to be included in subsequent analyses – the Chessman Process has an absolute practical limit of about 235 samples. It was decided not to eliminate data from the analyses (since this may affect the reliability of the analyses), but rather data from adjacent sampling occasions (years) were combined together. The resultant dataset comprising 150 ‘samples’ by 125 taxa was subjected to further analyses.

Environmental data

NRC supplied environmental data for 14 SB and 25 HB streams. These data comprised the following:-

- Pfankuch (1975) Habitat Quality Index (2005 – 2012 inclusive)
- Pfankuch (1975) Stability Index (2005 – 2012 inclusive)
- Clapcott *et al.* (2013) Rapid Habitat Assessment Index (2013)
- Land cover (based on LCDB3) with the following categories
    - Native forest (NATIVE)
    - Exotic forest (EXOTIC)
    - Scrub (SCRUB)
    - Low producing grassland (LOGRASS)
    - Lake and pond (LAKEPOND)
    - High producing grassland (HIGRASS)
    - Orchard/vineyard/crops (HORT)
    - Urban (URBAN)
- Median values of water quality variables for the period 2007 – 2011
    - % dissolved oxygen saturation (%DOsat)
    - Dissolved Reactive Phosphorus (DRP) g/m^3-P (DRP)
    - *E. coli* MPN/100ml
    - Ammoniacal Nitrogen (NH4) g/m^3-N
    - Nitrate – Nitrite Nitrogen g/m^3-N (NNN)
    - Turbidity (NTU)
- Perrie (2007) Water Quality Index (WQI (1))
- Wilkinson (2007) Water Quality Index (WQI (2))

A composite land-use variable (which Stark & Maxted (2007a) found useful when testing the performance of the MCI-sb) was created also. This was the percentage of the catchment that was developed (DEVPER) and comprised the sum of LOGRASS, HIGRASS, HORT, and URBAN.

DATA ANALYSES

Calculation of the MCI, QMCI, and SQMCI

Macroinvertebrate Community Index (MCI) tolerance values were derived by Stark (1985, 1993, 1998) for assessing organic enrichment of HB streams based on sampling macroinvertebrates from riffle (preferably) or run habitats, by Stark & Maxted (2007a) for SB streams, and by Suren *et al.* (2010) for South Island wetlands. For all indices, taxon scores or tolerance values (TV) (between 0 or 1 and 10) assigned to taxa (usually genera) of freshwater macroinvertebrates based upon their relationship to the degree of organic enrichment are used to calculate the biotic indices. Taxa that are characteristic of un-enriched conditions score more highly than taxa that may be found predominantly in polluted conditions. Different lists of tolerance values are used for HB streams, SB streams, and wetlands (Table 1), but the equations for the calculating MCI, SQMCI, and QMCI values are the same (only differing in the list of scores used).

The MCI is calculated as follows:-

$$MCI = \frac{\sum_{i=1}^{i=S} a_i}{S} \times 20$$

where S = the total number of taxa in the sample, and a_i is the TV for the ith taxon (Table 1). The MCI ranges from 0 (when no taxa are present) to 200 (when all taxa score 10 points each) although MCI scores < 40 or > 150 are rare.

The QMCI is calculated from count data as follows:-

$$QMCI = \sum_{i=1}^{i=S} \frac{(n_i \times a_i)}{N}$$

where S = the total number of taxa in the sample, n_i is the abundance for the ith scoring taxon, a_i is the TV for the ith taxon (Table 1) and N is the total of the coded abundances for the entire sample.

The macroinvertebrate data collected by NRC are relative abundance data, so the QMCI, which requires count data, is not considered further in this report.'

The SQMCI is calculated in a similar manner to the QMCI except that coded abundances (assigned to the R, C, A, VA and VVA abundance classes) are substituted for actual counts: *i.e.,*

$$SQMCI = \sum_{i=1}^{i=S} \frac{(n_i \times a_i)}{N}$$

where S = the total number of taxa in the sample, n_i is the coded abundance for the ith scoring taxon (*i.e.*, R=1, C=5, A=20, VA=100, VVA=500), a_i is the TV for the ith taxon (Table 1) and N is the total of the coded abundances for the entire sample. The QMCI and SQMCI indices range from 0 to 10.

The interpretation of MCI and SQMCI values (and their SB stream variants) is given in Table 2. The QMCI has the same interpretation as the SQMCI. Four quality classes were provided by Stark (1998) corresponding to different levels of organic pollution (enrichment). In recognition of the fact that biotic indices, even those developed primarily to reflect organic enrichment, can respond to other forms of disturbance (*e.g.*, sedimentation, toxic pollution), Stark & Maxted (2007a) suggested that sites should be assigned to quality classes on an excellent – good – fair – poor scale (Table 2).

Table 1 Taxon-specific tolerance values (TV) for use with the MCI, SQMCI, and QMCI for HB and SB streams and South Island wetlands (W) (Stark & Maxted 207, Suren *et al*. 2010).

	HB	SB	W
COELENTERATA			
Hydra	3	1.6	3
PLATYHELMINTHES	3	0.9	4
RHABDOCOELA	3	0.9	-
BRYOZOA	-	4.0	-
NEMATODA	3	3.1	7
NEMATOMORPHA	3	4.3	-
NEMERTEA	3	1.8	-
OLIGOCHAETA	1	3.8	4
POLYCHAETA	-	6.7	-
HIRUDINEA	3	1.2	4
TARDIGRADA	-	4.5	9
CRUSTACEA			
Amphipoda	5	5.5	7
Calanoida	-	-	5
Chydoridae	-	-	7
Cladocera	5	0.7	-
Cyclopoida			4
Copepoda	5	2.4	-
Daphniidae	-	-	3
Halicarcinus	-	5.1	-
Harpacticoida	-	-	9
Helice	-	6.6	-
Ilyocryptidae	-	-	7
Isopoda	5	4.5	6
Macrothricidae	-	-	7
Moinidae	-	-	1
Mysidae	-	6.4	-
Ostracoda	3	1.9	5
Paracalliope	5	-	-
Paraleptamphopus	5	-	-
Paranephrops	5	8.4	8
Paranthura	-	4.9	-
Paratya	5	3.6	8
Tenagomysis	-	-	5
Tanaidacea	4	6.8	-
INSECTA			
Ephemeroptera			
Acanthophlebia	7	9.6	-
Ameletopsis	10	10.0	-
Arachnocolus	8	8.1	-
Atalophlebioides	9	4.4	-
Austroclima	9	6.5	10
Austronella	7	4.7	-
Coloburiscus	9	8.1	-
Deleatidium	8	5.6	9
Ichthybotus	8	9.2	-
Isothraulus	8	7.1	-
Mauiulus	5	4.1	-
Neozephlebia	7	7.6	8
Nesameletus	9	8.6	8
Oniscigaster	10	5.1	7
Rallidens	9	3.9	-
Siphlaenigma	9	-	-
Tepakia	8	7.6	-
Zephlebia	7	8.8	9
Plecoptera			
Acroperla	5	5.1	8
Austroperla	9	8.4	10
Cristaperla	8	-	10
Halticoperla	8	-	-
Megaleptoperla	9	7.3	8
Nesoperla	5	5.7	-
Spaniocerca	8	8.8	-
Spaniocercoides	8	-	10
Stenoperla	10	9.1	-
Taraperla	7	8.3	7
Zelandobius	5	7.4	6
Zelandoperla	10	8.9	-
Megaloptera			
Archichauliodes	7	7.3	-
Odonata			
Aeshna	5	1.4	8
Anisoptera	5	6.0	-
Antipodochlora	6	6.3	-
Austrolestes	6	0.7	5
Odonata (continued)			
Hemianax	-	1.1	-
Hemicordulia	5	0.4	7
Ischnura	-	3.1	-
Procordulia	6	3.8	7
Uropetala	5	0.4	-
Xanthocnemis	5	1.2	6
Hemiptera			
Anisops	5	2.2	5
Corixidae	-	-	7
Diaprepocoris	5	4.7	7
Microvelia	5	4.6	6
Saldidae	5	3.9	8
Sigara	5	2.4	4
Coleoptera			
Antiporus	5	3.5	4
Berosus	5	-	8
Copelatus	5	3.7	-
Dytiscidae	5	0.4	-
Elmidae	6	7.2	8
Enochrus	5	2.6	-
Hydraenidae	8	6.7	10
Hydrophilidae	5	8.0	6
Lancetes	-	-	6
Liodessus	5	4.9	5
Onychohydrus	5	-	9
Podaena	8	-	-
Ptilodactylidae	8	7.1	10
Rhantus	5	1.0	6
Scirtidae	8	6.4	8
Staphylinidae	5	6.2	4
Neuroptera			
Kempynus	5	-	-
Diptera			
Anthomyiidae	3	6.0	-
Aphrophila	5	5.6	-
Austrosimulium	3	3.9	6
Calopsectra	4	-	-
Ceratopogonidae	3	6.2	7
Chironominae	-	-	6
Chironomidae	2	3.8	-
Chironomus	1	3.4	4
Cladopelma	-	-	5
Corynocera	-	-	4
Corynoneura	2	1.7	4
Cryptochironomus	3	-	10
Culex	3	-	-
Culicidae	3	1.2	4
Dasyhelea	-	-	9
Diptera indet.	3	2.9	-
Dixidae	4	7.1	-
Dolichopodidae	3	8.6	-
Empididae	3	5.4	9
Ephydridae	4	1.4	3
Eriopterini	9	7.5	8
Forcipomyiinae	-	-	8
Harrisius	6	4.7	10
Hexatomini	5	6.7	-
Kiefferulus	-	-	6
Limnophora	3	4.5	-
Limonia	6	6.3	9
Lobodiamesa	5	7.7	-
Maoridiamesa	3	4.9	-
Mischoderus	4	5.9	8
Molophilus	5	6.3	7
Muscidae	3	1.6	6
Nannochorista	7	-	-
Neocurupira	7	-	-
Neolimnia	3	5.1	5
Nothodixa	4	9.3	-
Orthocladiinae	2	3.2	7
Parochlus	8	-	-
Parachironomus	-	-	8
Paradixa	4	8.5	6
Paralimnophila	6	7.4	9
Paratanytarsus	-	-	2
Diptera (continued)			
Paucispinigera	6	7.7	9
Pelecorhyncidae	9	-	-
Peritheates	7	-	-
Podonominae	8	6.4	8
Polypedilum	3	8.0	8
Psychodidae	1	6.1	7
Scatella	7	-	-
Sciomyzidae	3	3.0	-
Stratiomyidae	5	4.2	4
Syrphidae	1	1.6	7
Tabanidae	3	6.8	5
Tanypodinae	5	6.5	8
Tanytarsini	3	4.5	-
Tanytarsus	3	-	8
Thaumaleidae	9	8.8	-
Tipulidae	5	3.4	-
Zelandotipula	6	3.6	8
Trichoptera			
Alloecentrella	9	-	-
Aoteapsyche	4	6.0	-
Beraeoptera	8	7.0	-
Confluens	5	7.2	-
Conuxia	8	-	-
Costachorema	7	7.2	-
Cryptobiosella	9	-	
Diplectrona	9	-	-
Ecnomina	8	9.6	-
Edpercivalia	9	6.3	-
Ecnominidae	8	-	10
Helicopsyche	10	8.6	10
Hudsonema	6	6.5	6
Hydrobiosella	9	7.6	-
Hydrobiosis	5	6.7	8
Hydrochorema	9	-	-
Hydroptilidae	-	-	6
Kokiria	9	-	-
Neurochorema	6	6.0	-
Oecetis	6	6.8	7
Oeconesidae	9	6.4	10
Olinga	9	7.9	5
Orthopsyche	9	7.5	-
Oxyethira	2	1.2	6
Paroxyethira	2	3.7	5
Philorheithrus	8	5.3	-
Plectrocnemia	8	6.6	6
Polyplectropus	8	8.1	7
Psilochorema	8	7.8	9
Pycnocentrella	9	-	8
Pycnocentria	7	6.8	9
Pycnocentrodes	5	3.8	10
Rakiura	10	-	-
Synchorema	9	-	-
Tiphobiosis	6	9.3	-
Triplectides	5	5.7	5
Triplectidina	5	-	6
Zelandoptila	8	7.0	-
Zelolessica	10	6.5	-
Lepidoptera			
Hygraula	4	1.3	5
Collembola	6	5.3	7
ACARINA	5	5.2	9
ARACHNIDA			
Dolomedes	5	6.2	-
MOLLUSCA			
Gundlachia = Ferrissia	3	2.4	4
Glyptophysa = Physastra	5	0.3	3
Gyraulus	3	1.7	2
Hyridella	3	6.7	8
Latia	3	6.1	-
Lymnaeidae	3	1.2	4
Melanopsis	3	1.9	-
Physa = Physella	3	0.1	2
Potamopyrgus	4	2.1	3
Sphaeriidae	3	2.9	4

Table 2 Interpretation of MCI-type biotic indices.

Stark & Maxted (2007b) quality class	Stark (1998) descriptions	MCI MCI-sb	SQMCI SQMCI-sb
Excellent	Clean water	> 119	>5.99
Good	Doubtful quality or possible mild pollution	100–119	5.00–5.99
Fair	Probable moderate pollution	80–99	4.00–4.99
Poor	Probable severe pollution	< 80	< 4.00

BIOTIC INDICES FOR NORTHLAND STREAMS

Derivation of tolerance values (taxon scores)

During the development of the MCI, Stark (1985) assigned TVs using a weighting procedure based upon the relative percentage occurrence of taxa at three site groups differing in enrichment status (*i.e.*, clean and unenriched, slight to moderate pollution, moderate to gross pollution). Assignment of sites to the three site groups was fairly subjective – based upon knowledge of catchment land-use and the existence of diffuse and point-source discharges. TVs for less common taxa for which this procedure was unreliable (Stark 1985), or those taxa added subsequently (Stark 1993, 1998) were assigned by professional judgment. Prior to 1985, TVs for most of biotic indices that had been developed overseas had been assigned by professional judgment.

In Australia, however, Bruce Chessman devised a procedure whereby TVs could be derived objectively from a taxa by site data matrix provided the sites covered a wide (preferably a full) range of disturbance or stream health (Chessman *et al*. 1997). This procedure was improved subsequently by Chessman (2003).

The iterative rank correlation process described by Chessman (2003) was used to derive TVs for 99 taxa collected from SB streams and 125 taxa collected from HB streams in the Northland region. All available macroinvertebrate data were used because the resulting TVs are likely to be more reliable than if a subset of the data were used, and to ensure that no taxa were omitted. (To derive scores for taxa omitted or not encountered in the data set, one must either repeat the iterative process using a data set containing the additional taxa, or assign the scores by professional judgement. Alternatively, a TV from one of the existing MCI-type indices could be 'adopted', or taxa without TVs could be omitted from index calculation).

The level of taxonomic resolution (*i.e.*, primarily generic) used for the existing MCI, SQMCI and QMCI was retained.

The iterative score derivation process proceeded separately for the SB and HB datasets as follows. For HB streams, MCI values (using existing MCI TVs - Table 1) were calculated on an Excel spreadsheet. Spearman rank correlations (Rs) were calculated between the MCI values and the abundances of all taxa across all sites/samples using STATISTICA 64 version 12. Since it is mathematically impossible for rare taxa with few occurrences to achieve large positive or negative correlations (Chessman *et al.* 1997), each Rs was expressed as a proportion of the maximum possible Rs for a taxon recorded from the same proportion of samples. The taxon with the highest positive adjusted Rs was assigned a TV of 10, and that with the lowest negative adjusted Rs was assigned a TV of 1. The remaining taxa were assigned integer TVs between these extremes in proportion to their adjusted Rs values. The resulting TVs were pasted back into the Excel spreadsheet and a new set of MCI values were calculated. This procedure was repeated until the TVs stabilized (*i.e.*, there was no change in the TVs for any of the taxa from one iteration to the next).

The procedure for SB streams was the same, except that MCI-sb TVs were used initially, and the derived TVs were not integers between 1 and 10, but rather were assigned to the nearest 0.1. The fact that HB stream TVs are integers and SB stream TVs are not, serves to reduce the possibility of the wrong list of TVs being applied to the other stream type.

At this point, we have four sets of TVs – (i) the original MCI TVs (Stark & Maxted 2007b), (ii) the original MCI-sb TVs (Stark & Maxted 2007b), (iii) NRC-MCI TVs for HB streams, and (iv) NRC-MCI-sb TVs for SB streams. Biotic indices were calculated for the SB and HB sample data using each of the four sets of TVs. Rank correlations between the resulting biotic indices and environmental variables, and between the biotic indices themselves, were calculated in order to determine the relationship between the NRC indices and the original indices and whether new indices were more highly correlated with environmental data that the original MCI and SQMCI (and their SB stream variants).

The apparent circularity of the iterative process developed by Chessman (2003) deserves some comment. In theory, the process requires that all sites (or samples) in the dataset are ordered initially from best to worst in terms of an environmental gradient[4]. For most existing biotic indices (including the MCI) this normally has been an enrichment gradient. Ideally, this would be done independently of the biological data, but if there was an easy way of doing this perhaps there would be no need for biotic indices? Chessman (2003) used SIGNAL (the Australian MCI equivalent) to determine the initial site order noting that SIGNAL was well-proven as an indicator of stream health in Australia. Likewise, I used the MCI and MCI-sb to determine the initial site orders, because in New Zealand the MCI and MCI-sb correlate well with indicators of enrichment (*e.g.*, Quinn & Hickey 1990a, Stark & Maxted 2007a,b).

Testing the performance of the new indices

Spearman Rank Correlations between biotic indices and between biotic indices and environmental variables were undertaken using STATISTICA 12 (StatSoft 2013). When multiple correlations are undertaken, there is a chance that some significant results could occur by chance. The Benjamini-Hochberg false discovery rate (B-H FDR), which controls the overall Type-I error rate, was applied to correct for this effect (Benjamini & Hochberg 1995).

[4] In practice, the process should converge on the same solution irrespective of the starting condition (Bruce Chessman, *pers. comm.*) – it could just take longer.

All graphs and other analyses presented in this report were produced by STATISTICA version 12.

RESULTS AND DISCUSSION

Derivation of Tolerance Values

Chessman's (2003) iterative rank correlation procedure provided stable TVs from the 7th to the 8th iteration for HB data and from the 10th to the 11th iteration for SB data. These TVs are summarised on Table 3 along with existing MCI and MCI-sb TVs for comparison. Also shown on this table are the numbers of samples that each taxon was recorded in.

The Chessman Process assigns TVs to taxa based up their distribution across whatever environmental gradient(s) is (are) present within the data set subjected to analysis. Poor results may be obtained if the gradient does not cover a wide range of river health. Also, the distributions of taxa that are poorly represented in the dataset may not reflect their relationships to the environmental gradient accurately, so their TVs may be least reliable.

Taxa with least representation in the data set are indicated on Table 3. In the SB stream dataset there were 17 taxa present in only single samples (red highlight), eight taxa present in two samples (orange), and two taxa present in three samples (yellow). Equivalent numbers for the HB dataset were 12, 6, and 10 respectively (Table 3). These are the taxa whose TVs *may* be least reliable.

Testing the performance of the new indices

The use of biotic indices to measure river health is primarily a ranking exercise. For example, is Site A in better condition than Site B etc.? Consequently, it makes sense to use rank correlation analyses to explore the performance of the NRC versions of the MCI. Appendix 3 presents the results of Spearman Rank correlation analyses that compare how similar the eight biotic indices (*viz*., MCI, MCI-sb, SQMCI, SQMCI-sb, NRC-MCI, NRC-MCI-sb, NRC-SQMCI, NRC-SQMCI-sb) ranked sites in order of river health and the similarity of the site rankings based on each of these indices to rankings determined independently from habitat, land-use, and water quality data.

Comparison of NRC indices with original indices

Table 4 summarises descriptive statistics for eight biotic and three habitat quality indices for streams and rivers in the Northland region based on samples collected between 1998 and 2013 inclusive. Comparison of the ranges of the original indices (*i.e.*, MCI, MCI-sb, SQMCI-SQMCI-sb) (Table 4)with the usual interpretation of these indices (Table 2) confirms that the streams from which samples have been collected cover a full range of river health from poor to excellent.

Table 3 TVs for the NRC-MCI-sb and NRC-MCI compared with original MCI-sb and MCI TVs. The number of SB (total 183) and HB (total 292) samples is given for each taxon. Red highlight indicates taxa present only in single samples, orange in two samples, and yellow in three samples.

	MCI-sb	NRC MCI-sb	No. of samples	MCI	NRC MCI	No. of samples		MCI-sb	NRC MCI-sb	No. of samples	MCI	NRC MCI	No. of samples
Acanthophlebia	9.6	9.3	1	7	8	41	Lymnaeidae	1.2	2	12	3	4	14
Acarina	5.2	4.8	13	5	6	47	*Maoridiamesa*	4.9	2.4	1	3	7	25
Acroperla	5.1	-	-	5	6	1	*Mauiulus*	4.1	9	34	5	7	74
Adversaeshna	1.4	5.5	13	5	2	1	*Megaleptoperla*	7.3	9.4	1	9	8	14
Amarinus	5.1	5.4	84	3	3	20	*Melanopsis*	1.9	8.4	6	3	4	18
Ameletopsis	10	-	-	10	8	23	Mesoveliidae	-	-	-	5	1	1
Amphipoda	5.5	4.7	90	5	3	106	*Microvelia*	4.6	2.7	7	5	4	7
Anisops	2.2	1.4	8	5	2	8	*Mischoderus*	5.9	9.8	2	4	6	32
Anthomyiidae	6	-	-	3	2	1	*Molophilus*	6.3	-	-	5	3	3
Antipodochlora	6.3	-	-	6	4	12	Muscidae	1.6	7.7	3	3	5	110
Antiporus	3.5	2.8	9	5	2	1	Mysidae	6.4	6.6	5	5	8	1
Aphrophila	5.6	3.1	2	5	7	119	**NEMATODA**	3.1	4.4	4	3	7	7
Arachnocolus	8.1	5.4	1	8	8	3	**NEMERTEA**	1.8	4.1	12	3	5	54
Archichauliodes	7.3	9.7	6	7	8	182	*Neozephlebia*	7.6	8.3	6	7	7	36
Atalophlebioides	4.4	-	-	9	9	11	*Nesameletus*	8.6	-	-	9	8	47
Austroclima	6.5	9	7	9	7	26	*Neurochorema*	6	-	-	6	7	56
Austrolestes	0.7	3.1	10	6	1	5	*Nothodixa*	9.3	3.3	1	5	8	1
Austronella	4.7	9.6	7	7	6	3	*Oecetis*	6.8	8.1	9	6	5	7
Austroperla	8.4	-	-	9	9	18	Oeconesidae	6.4	-	-	9	7	4
Austrosimulium	3.9	7.7	69	3	6	131	**OLIGOCHAETA**	3.8	5	55	1	4	183
Beraeoptera	7	-	-	8	8	28	*Olinga*	7.9	9.9	6	9	9	58
Ceratopogonidae	6.2	4	2	3	8	1	*Oniscigaster*	5.1	5.9	1	10	7	7
Chironominae	4.7	5.6	59	2	6	144	Orthocladiinae	3.2	5.4	87	2	6	196
Chironomus	3.4	2.9	5	1	2	2	**OSTRACODA**	1.9	2.5	19	3	4	58
Cladocera	0.7	2.4	14	5	2	5	*Oxyethira*	1.2	4.9	104	2	4	178
Collembola	5.3	3.9	12	6	3	9	*Paradixa*	8.5	4.9	17	4	5	6
Coloburiscus	8.1	10	7	9	8	120	*Paralimnophila*	7.4	1	1	6	8	15
Conuxia	8	9.3	1	8	4	3	*Paranephrops*	8.4	5.7	11	5	5	14
Copepoda	2.4	2.9	13	5	3	8	*Paratya*	3.6	7.1	85	5	3	121
Corynoneura	1.7	4.4	3	2	-	-	*Paroxyethira*	3.7	2.8	36	2	3	19
Costachorema	7.2	-	-	7	7	21	*Physella*	0.1	2.6	84	3	1	93
Culex	3	7	1	3	8	1	**PLATYHELMINTHES**	0.9	3.6	36	3	4	70
Deleatidium	5.6	8.4	7	8	8	157	*Plectrocnemia*	6.6	-	-	8	6	10
Diaprepocoris	4.7	3.4	1	5	-	-	Podonominae	6.4	9	1	8	-	-
Dolichopodidae	8.6	-	-	3	5	2	**POLYCHAETA**	6.7	-	-	3	4	1
Dytiscidae	0.4	2.5	9	5	5	3	*Polypedilum*	8	5.3	13	3	7	10
Ecnomina / Zelandoptila	8.3	8.7	8	8	7	6	*Polyplectropus*	8.1	7.8	6	8	5	29
Elmidae	7.2	7.9	22	6	7	222	*Potamopyrgus*	2.1	5.8	180	4	3	266
Empididae	5.4	4.5	1	3	6	12	*Psilochorema*	7.8	9.7	4	8	8	66

	MCI-sb	NRC MCI-sb	No. of samples	MCI	NRC MCI	No. of samples		MCI-sb	NRC MCI-sb	No. of samples	MCI	NRC MCI	No. of samples
Ephydridae	1.4	5.6	1	4	4	10	Psychodidae	6.1	1.7	4	1	3	4
Eriopterini	7.5	7.7	5	9	8	53	Ptilodactylidae	7.1	-	-	8	6	12
Ferrissia	2.4	3.9	42	3	4	73	*Pycnocentria*	6.8	9.1	44	7	7	80
Gyraulus	1.7	2.6	5	3	1	59	*Pycnocentrodes*	3.8	9.5	30	5	7	166
Harrisius	4.7	10	2	6	-	-	*Rallidens*	3.9	-	-	9	8	28
Helicopsyche	8.6	9.5	2	10	7	35	*Rhantus*	1	1.1	1	5	-	-
Hemicordulia	0.4	1.1	14	5	1	9	Saldidae	3.9	1.1	1	5	-	-
Hexatomini	6.7	9.3	1	5	6	25	Sciomyzidae	3	5.4	1	3	2	2
HIRUDINEA	1.2	2.8	18	3	3	49	Scirtidae	6.4	-	-	8	8	5
Hudsonema	6.5	8.5	45	6	5	75	*Sigara*	2.4	1.8	50	5	2	29
Hydra	1.6	4.7	5	3	3	3	*Siphlaenigma*	-	-	-	9	7	5
Hydraenidae	6.7	2.3	2	8	7	23	*Spaniocerca*	8.8	-	-	8	8	3
Hydrobiosella	7.6	-	-	9	7	7	Sphaeriidae	2.9	4.2	31	3	3	17
Hydrobiosis	6.7	8.2	32	5	7	164	Staphylinidae	6.2	4.1	5	5	4	4
Hydrochorema	-	-	-	9	6	4	*Stenoperla*	9.1	-	-	10	10	23
Hydrophilidae	8	4	26	5	5	9	Stratiomyidae	4.2	-	-	5	5	2
Hydropsyche - Orthopsyche	7.5	9.5	2	9	5	16	Tabanidae	6.8	-	-	3	9	19
Hydropsyche -Aoteapsyche	6	8.5	16	4	6	204	Tanaidacea	6.8	-	-	4	4	1
Hydroptilidae	2.5	1	2	2	3	2	Tanypodinae	6.5	5.3	50	5	7	112
Hygraula	1.3	5.2	17	4	1	4	Tanytarsini	4.5	6.1	20	3	6	34
Hyridella	6.7	1.3	1	3	-	-	*Tepakia*	7.6	-	-	8	5	2
Ichthybotus	7.1	-	-	8	9	14	*Triplectides*	5.7	6.1	118	5	5	98
Ischnura	3.1	4.4	2	4	-	-	*Triplectidina*	-	-	-	5	8	1
Isopoda	4.5	-	-	5	4	3	*Xanthocnemis*	1.2	2.3	92	5	1	50
Isothraulus	7.1	-	-	8	7	3	*Zelandobius*	7.4	-	-	5	7	17
Latia	6.1	8.6	17	3	6	65	*Zelandoperla*	8.9	-	-	10	9	19
Limonia	6.3	4.2	1	6	2	10	*Zelandotipula*	3.6	-	-	6	2	4
Liodessus	4.9	4.5	4	5	-	-	*Zephlebia*	8.8	8.2	128	7	6	157

Table 4 Descriptive statistics for eight biotic and three habitat indices for streams and rivers in Northland.

	N	Min.	10th	25th	Mean	Median	75th	90th	Max.	Std Dev.
MCI	290	57	75.6	82.5	96.9	94.2	109.2	121.8	148	17.8
MCI-sb	183	32	56.0	66.0	80.5	79.0	96.0	107.0	122	19.3
NRC-MCI	290	50	76.9	95.0	109.7	110.7	126.7	137.8	151	22.5
NRC-MCI-sb	183	60	81.0	93.0	110.0	109.0	128.0	143.0	156	22.9
SQMCI	290	1.57	2.96	3.65	4.60	4.37	5.49	6.63	8.21	1.36
SQMCI-sb	183	0.64	2.13	2.35	3.13	2.76	3.71	4.70	7.42	1.11
NRC-SQMCI	290	1.89	3.25	4.17	5.29	5.43	6.34	7.13	8.13	1.42
NRC-SQMCI-sb	183	2.77	4.74	5.38	5.64	5.73	6.02	6.40	7.90	0.80
Pfankuch habitat	127	20.0	44.0	57.0	70.4	70.0	81.0	99.0	122.0	19.9
Pfankuch stability	117	32.0	50.0	67.0	83.8	84.0	102.0	114.0	135.0	23.2
Rapid Habitat	38	51.5	76.0	92.0	119.7	103.3	158.5	174.0	201.5	38.4

Figure 1 shows the distribution of MCI, MCI-sb, NRC-MCI, and NRC-MCI-sb values for samples collected from the Northland region between 1998 and 2013 inclusive. The new NRC-MCI TVs produce an index with a median value of 111 compared with the original MCI median of 94 – an increase of 17 units. Similarly, the range has increased from 91 (*i.e.*, 57 – 148) for the MCI to 101 (*i.e.*, 50 – 151) for the NRC-MCI.

The median NRC-MCI-sb value of 109 is 30 units higher than the median MCI-sb of 79 and the range has increased slightly from 90 to 96 units.

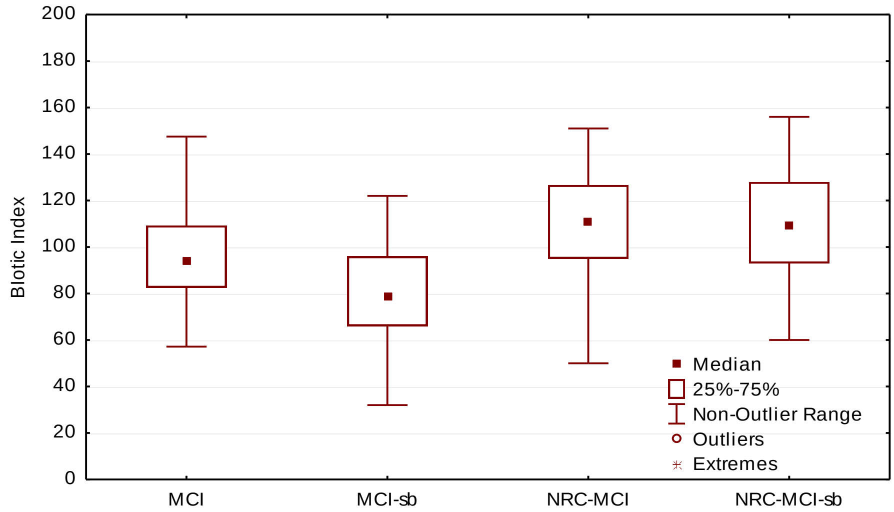

Figure 1 Distribution of MCI, MCI-sb, NRC-MCI, and NRC-MCI-sb values for samples collected from the Northland region (1998 – 2013).

The increased ranges of the NRC versions of the MCI and MCI-sb provided for greater discrimination between sites in terms of river health.

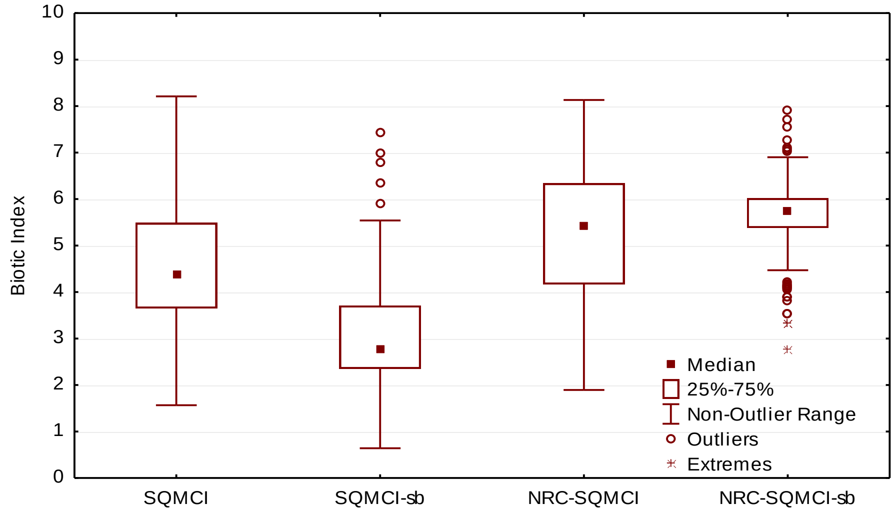

Figure 2 Distribution of SQMCI, SQMCI-sb, NRC-SQMCI, and NRC-SQMCI-sb values for samples collected from the Northland region (1998 – 2013).

The median NRC-SQMCI and NRC-SQMCI-sb values of 5.43 and 5.73 are also higher than the original SQMCI/SQMCI-sb values of 4.38 and 2.76 (Figure 2). The increase in the median SQMCI-sb value is particularly marked. In the case of the SQMCI indices, however, there has been a reduction in the range for both SB (-24%) and HB (-6%) variants compared with the original indices.

Table 5 compares the quality class classifications of the original and NRC versions of the MCI and SQMCI for HB and SB streams. In all cases, but especially for the SB indices, the NRC versions resulted in fewer sites being assigned to the poor stream quality class and greater numbers of sites being assigned to the excellent quality class. Ideally, this result should be evaluated by people familiar with the streams themselves to decide whether or not the NRC versions provide a more realist stream health assessment than the original indices.

Table 5 Comparative distributions of samples in quality classes in Northland's HB (top) and SB (bottom) streams using original and NRC versions of the MCI and SQMCI.

Quality	MCI		NRC-MCI		SQMCI		NRC-SQMCI	
Class	N	%	N	%	N	%	N	%
Poor	44	15.2	34	11.7	96	33.1	66	22.8
Fair	134	46.2	58	20.0	100	34.5	53	18.3
Good	75	25.9	83	28.6	47	16.2	73	25.2
Excellent	37	12.8	115	39.7	47	16.2	98	33.8
	290		290		290		290	
	MCI-sb		NRC-MCI-sb		SQMCI-sb		NRC-SQMCI-sb	
	N	%	N	%	N	%	N	%
Poor	92	50.3	14	7.7	151	82.5	9	4.9
Fair	54	29.5	53	29.0	17	9.3	19	10.4
Good	34	18.6	52	28.4	11	6.0	104	56.8
Excellent	3	1.6	64	35.0	4	2.2	51	27.9
	183		183		183		183	

Relationships to environmental data

Appendix 3 lists the rank correlations between indices and environmental variables from strongest to weakest. There were 172 correlations in total with 44 of them statistically significant (*i.e.*, P < 0.05) when taken at face value. Application of the B-H FDR procedure eliminated the weakest nine of these, deeming that when 172 correlations are run in one batch these seven significant results could have occurred by chance. Thus, 35 statistically significant results remain.

Table 6 Results of Spearman Rank Correlation testing between biotic indices and environmental variables. Red text indicates statistically significant results with bold results remaining significant after application of the B-H FDR procedure. Red italics denote statistically significant results at face value that were not strong enough to avoid elimination by the B-H FDR procedure. Non-significant results have been omitted from this table but are shown in Appendix 3. Shaded rows denote correlations between the indices.

	(N	Spearman (R)	t(N-2)	p-value	Order	Critical value
MCI vs DEVPER	**19**	**-0.776998**	**-5.08916**	**0.000091**	**9**	**0.002616**
MCI vs HIGRASS	**19**	**-0.762950**	**-4.86610**	**0.000145**	**11**	**0.003198**
MCI vs HORT	**19**	**-0.777809**	**-5.10260**	**0.000088**	**8**	**0.002326**
MCI vs LAKEPOND	**19**	**-0.768004**	**-4.94431**	**0.000123**	**10**	**0.002907**
MCI vs NATIVE	**19**	**0.667252**	**3.69365**	**0.001802**	**25**	**0.007267**
MCI vs NNN	**18**	**-0.675620**	**-3.66562**	**0.002089**	**28**	**0.00814**
MCI vs NRC-MCI	**24**	**0.863023**	**8.01309**	**0.000000**	**2**	**0.000581**
MCI vs NRC-SQMCI	**24**	**0.842907**	**7.34786**	**0.000000**	**4**	**0.001163**
MCI vs SQMCI	**24**	**0.848815**	**7.53048**	**0.000000**	**3**	**0.000872**
MCI vs URBAN	*19*	*-0.518849*	*-2.50246*	*0.022833*	*38*	*0.011047*
MCI vs WQI (2)	*18*	*-0.580879*	*-2.85447*	*0.011474*	*36*	*0.010465*
MCI-sb vs NRC-MCI-sb	**16**	**0.827306**	**5.51045**	**0.000077**	**7**	**0.002035**
MCI-sb vs NRC-SQMCI-sb	**16**	**0.675995**	**3.43238**	**0.004044**	**30**	**0.008721**
MCI-sb vs Rapid Habitat	*13*	*0.600553*	*2.49106*	*0.029979*	*41*	*0.011919*
MCI-sb vs SQMCI-sb	**16**	**0.712814**	**3.80280**	**0.001940**	**26**	**0.007558**
NRC-MCI vs DEVPER	**19**	**-0.742532**	**-4.57075**	**0.000271**	**13**	**0.003779**
NRC-MCI vs HIGRASS	**19**	**-0.708261**	**-4.13660**	**0.000690**	**19**	**0.005523**
NRC-MCI vs HORT	**19**	**-0.837948**	**-6.33065**	**0.000008**	**5**	**0.001453**
NRC-MCI vs LAKEPOND	**19**	**-0.723622**	**-4.32278**	**0.000462**	**16**	**0.004651**
NRC-MCI vs NATIVE	**19**	**0.677505**	**3.79790**	**0.001437**	**21**	**0.006105**
NRC-MCI vs NH4	**18**	**-0.607966**	**-3.06295**	**0.007435**	**34**	**0.009884**
NRC-MCI vs NNN	**18**	**-0.736952**	**-4.36101**	**0.000485**	**17**	**0.004942**
NRC-MCI vs NRC-SQMCI	**24**	**0.921637**	**11.13989**	**0.000000**	**1**	**0.000291**
NRC-MCI vs URBAN	**19**	**-0.676304**	**-3.78549**	**0.001477**	**22**	**0.006395**
NRC-MCI vs WQI (2)	**18**	**-0.675802**	**-3.66744**	**0.002081**	**27**	**0.007849**
NRC-MCI-sb vs NRC-SQMCI-sb	**16**	**0.868093**	**6.54332**	**0.000013**	**6**	**0.001744**
NRC-SQMCI vs DEVPER	**19**	**-0.734533**	**-4.46312**	**0.000342**	**15**	**0.00436**
NRC-SQMCI vs HIGRASS	**19**	**-0.710838**	**-4.16697**	**0.000646**	**18**	**0.005233**
NRC-SQMCI vs HORT	**19**	**-0.756129**	**-4.76389**	**0.000180**	**12**	**0.003488**
NRC-SQMCI vs LAKEPOND	**19**	**-0.704669**	**-4.09482**	**0.000755**	**20**	**0.005814**
NRC-SQMCI vs NATIVE	**19**	**0.600263**	**3.09445**	**0.006582**	**33**	**0.009593**
NRC-SQMCI vs NH4	*18*	*-0.480423*	*-2.19112*	*0.043590*	*44*	*0.012791*
NRC-SQMCI vs NNN	**18**	**-0.641198**	**-3.34229**	**0.004134**	**32**	**0.009302**
NRC-SQMCI vs URBAN	**19**	**-0.667991**	**-3.70103**	**0.001774**	**24**	**0.006977**
NRC-SQMCI vs WQI (2)	*18*	*-0.491736*	*-2.25892*	*0.038202*	*43*	*0.0125*
SQMCI vs DEVPER	**19**	**-0.626316**	**-3.31255**	**0.004117**	**31**	**0.009012**
SQMCI vs DO	*18*	*-0.575161*	*-2.81238*	*0.012517*	*37*	*0.010756*
SQMCI vs HIGRASS	**19**	**-0.629825**	**-3.34326**	**0.003853**	**29**	**0.00843**
SQMCI vs HORT	*19*	*-0.498919*	*-2.37362*	*0.029665*	*40*	*0.011628*
SQMCI vs LAKEPOND	**19**	**-0.584718**	**-2.97182**	**0.008553**	**35**	**0.010174**
SQMCI vs NATIVE	*19*	*0.487719*	*2.30346*	*0.034151*	*42*	*0.012209*
SQMCI vs NRC-MCI	**24**	**0.605876**	**3.57209**	**0.001702**	**23**	**0.006686**
SQMCI vs NRC-SQMCI	**24**	**0.673190**	**4.27001**	**0.000312**	**14**	**0.00407**
SQMCI-sb vs NRC-MCI-sb	*16*	*0.552691*	*2.48142*	*0.026397*	*39*	*0.011337*

The statistically significant results (including those eliminated by the B-H FDR) are summarised on Table 6. The 'Order' column ranks the correlations from strongest to weakest.

All but two correlations between indices were statistically significant following the B-H FDR procedure. The exceptions were SQMCI-sb vs NRC-MCI-sb, which was statistically significant at face value only (P = 0.026), and SQMCI-sb vs NRC-SQMCI-sb which was not statistically significant (P = 0.119) (Appendix 3). The six of the seven strongest correlations were between the indices themselves (*viz.*, NRC-MCI vs NRC-SQMCI, MCI vs NRC-MCI, MCI vs SQMCI, MCI vs NRC-SQMCI, NRC-MCI-sb vs NRC-SQMCI-sb, MCI-sb vs NRC-MCI-sb) (Table 6).

Before examining the correlations of various indices with environmental variables, we should first determine whether or not the NRC versions have better performance than the original indices.

We should expect positive rank correlations between biotic indices and the following environmental variables:-

- Pfankuch (1975) Habitat Quality Index (2005 – 2012 inclusive)
- Pfankuch (1975) Stability Index (2005 – 2012 inclusive)
- Clapcott *et al.* (2013) Rapid Habitat Assessment Index (2013)
- % Land cover of Native forest (NATIVE)
- % Land cover of Scrub (SCRUB)
- % dissolved oxygen saturation (%DOsat)
- Perrie (2007) Water Quality Index (WQI (1))

and negative rank correlations with the following environmental variables:-

- % Land cover of Exotic forest (EXOTIC)
- % Land cover of Low producing grassland (LOGRASS)
- % Lake and pond (LAKEPOND)
- % Land cover of High producing grassland (HIGRASS)
- % Land cover of Orchard/vineyard/crops (HORT)
- % Land cover of Urban (URBAN)
- % Land cover of LOGRASS+HIGRASS+HORT+URBAN (DEVPER)
- Dissolved Reactive Phosphorus (DRP) g/m^3-P (DRP)
- *E. coli* MPN/100ml
- Ammoniacal Nitrogen (NH4) g/m^3-N
- Nitrate – Nitrite Nitrogen g/m^3-N (NNN)
- Turbidity (NTU)
- Wilkinson (2007) Water Quality Index (WQI (2))

HB streams

Table 7 summarises the performance of the MCI and the NRC-MCI. The MCI has six statistically significant correlations with environmental variables (following B-H FDR) compared with nine for the NRC-MCI. Overall, the NRC-MCI had a greater number of correlations (13/20) that were stronger than those for the MCI (although not all were statistically significant). Of the statistically significant correlations, the NRC-MCI bettered the MCI in five. The four correlations that were stronger for the MCI than the NRC-MCI were also highly significant for the NRC-MCI (Table 7). All statistically significant correlations were consistent with expectations (*i.e.*, positive or negative). The strongest (-ve) correlation was between the NRC-MCI and the percentage of horticultural land in the catchment. Overall, we can conclude that the NRC-MCI is likely to perform better than the MCI in assessing the health of HB streams in the Northland region.

Table 7 Evaluation of the performance of the NRC-MCI vs MCI. The table shows Rs values. Red text shows statistically significant Spearman Rank Correlations (with italics non-significant after application of the B-H FDR procedure). Green highlights indicate which of these indices performed better. Environmental variables in parentheses should have negative correlations with biotic indices.

	MCI	NRC-MCI
Pfankuch habitat	0.069390	0.306239
Pfankuch stability	0.244054	0.021200
Rapid Habitat	-0.066755	0.090510
NATIVE	**0.667252**	**0.677505**
(EXOTIC)	-0.186128	-0.168717
SCRUB	0.093064	0.028120
(LOGRASS)	-0.226913	-0.200704
(LAKEPOND)	**-0.768004**	**-0.723622**
(HIGRASS)	**-0.762950**	**-0.708261**
(HORT)	**-0.777809**	**-0.837948**
(URBAN)	*-0.518849*	**-0.676304**
(DEVPER)	**-0.776998**	**-0.742532**
DO	-0.413856	-0.281255
(DRP)	-0.048171	-0.129920
(ECOLI)	-0.225207	-0.389665
(NH4)	-0.444143	**-0.607966**
(NNN)	**-0.675620**	**-0.736952**
(Turbidity)	-0.205274	-0.289705
WQI (1)	0.064377	-0.037526
(WQI (2))	*-0.580879*	**-0.675802**

Table 8 summarises the comparative performance of the SQMCI and NRC-SQMCI. The NRC-SQMCI had higher correlations for most variables (15/20) and with eight statistically significant at face value and only one eliminated by the B-H FDR procedure. As with the MCI and MCI-sb, all statistically significant correlations were consistent with expectations (*i.e.*, positive or negative). Land-use variables were most highly correlated with the NRC-SQMCI with the strongest (-ve) correlation with the percentage of horticultural land in the catchment. NNN (nitrate-nitrite) was the water quality variable that showed the strongest relationship to the NRC-SQMCI (as it did also for the NRC-MCI). Once again, it is likely that the NRC-SQMCI will perform better than the SQMCI for evaluating the health of HB streams in the Northland region. [The same is likely to be true of the QMCI if quantitative macroinvertebrate data are available.]

Table 8 Evaluation of the performance of the NRC-SQMCI vs SQMCI. The table shows Rs values. Red text shows statistically significant Spearman Rank Correlations (with italics non-significant after application of the B-H FDR procedure). Green highlights indicate which of these indices performed better. Environmental variables in parentheses should have negative correlations with biotic indices.

	SQMCI	NRC-SQMCI
Pfankuch habitat	0.052655	0.211589113
Pfankuch stability	0.087810	0.214470313
Rapid Habitat	0.007021	0.010096576
NATIVE	*0.487719*	**0.600263331**
(EXOTIC)	-0.236842	-0.157964035
SCRUB	0.145614	0.114085136
(LOGRASS)	-0.328647	-0.157362774
(LAKEPOND)	**-0.584718**	**-0.70466915**
(HIGRASS)	**-0.629825**	**-0.710838155**
(HORT)	*-0.498919*	**-0.756128592**
(URBAN)	-0.383926	**-0.667990904**
(DEVPER)	**-0.626316**	**-0.73453276**
DO	*-0.575161*	*-0.403756809*
(DRP)	0.104612	-0.068033033
(ECOLI)	-0.159959	-0.377904026
(NH4)	-0.114686	-0.480422884
(NNN)	-0.465428	**-0.641197814**
(Turbidity)	-0.136364	-0.277002621
WQI (1)	0.176713	0.094556645
(WQI (2))	-0.302530	-0.491735537

SB streams

Table 9 summarises the comparative performance of the MCI-sb and NRC-MCI-sb. The NRC-MCI-sb has higher correlations for most variables (12/20) but none of them is statistically significant. The environmental variables that had the strongest relationships to the NRC-MCI-sb were the Rapid Habitat Assessment (P = 0.097) and the percentage of urban land in the catchment (P = 0.099). However, neither the MCI-sb nor the NRC-MCI-sb had strong relationships with environmental variables, which raises some doubt concerning their utility for assessing the health of SB streams in the Northland region.

Table 10 summarises the comparative performance of the SQMCI-sb and NRC-SQMCI-sb. There is little to choose between these two indices as there were no statistically significant correlations with environmental variables. The SQMCI-sb had higher correlations for most variables (11/20 vs 9/20), but given that none was significant it is a dubious advantage. As with the MCI-sb and NRC-MCI-sb, the two variants of the SQMCI do not appear to be very good measures of the health of SB streams in the Northland region.

The apparent poor performance of SB versions of the MCI and SQMCI (both original and NRC) will be discussed later in this report.

Table 9 Evaluation of the performance of the NRC-MCI-sb vs MCI-sb. The table shows Rs values. Red italic text shows one statistically significant Spearman Rank Correlation that became non-significant after application of the B-H FDR procedure. Green highlights indicate which of these indices performed better. Environmental variables in parentheses should have negative correlations with biotic indices.

	MCI-sb	NRC-MCI-sb
Pfankuch habitat	0.363437	0.196036
Pfankuch stability	-0.223815	-0.231533
Rapid Habitat	*0.600553*	0.479341
NATIVE	0.10793	0.288547
(EXOTIC)	-0.099119	-0.063877
SCRUB	-0.008811	0.134362
(LOGRASS)	-0.044053	0.167401
(LAKEPOND)	-0.174009	-0.376653
(HIGRASS)	-0.048458	-0.096917
(HORT)	-0.114704	-0.428748
(URBAN)	-0.112459	-0.458655
(DEVPER)	0.006608	-0.019824
DO	0.116869	-0.061742
(DRP)	0.264901	0.266004
(ECOLI)	0.392071	0.174009
(NH4)	0.296893	-0.030136
(NNN)	0.110132	-0.185022
(Turbidity)	0.046307	0
WQI (1)	0.419252	0.299466
(WQI (2))	-0.167401	-0.40749

Table 10 Evaluation of the performance of the NRC-SQMCI-sb vs SQMCI-sb. The table shows Rs values. Green highlights indicate which of these indices performed better, but there were no statistically significant correlations. Environmental variables in parentheses should have negative correlations with biotic indices.

	SQMCI-sb	NRC-SQMCI-sb
Pfankuch habitat	0.226374	0.204396
Pfankuch stability	-0.462046	-0.257426
Rapid Habitat	0.368132	0.472527
NATIVE	-0.156044	0.27033
(EXOTIC)	-0.261538	-0.081319
SCRUB	-0.16044	0.243956
(LOGRASS)	-0.12967	-0.037363
(LAKEPOND)	-0.243956	-0.345055
(HIGRASS)	0.292308	-0.2
(HORT)	-0.177789	-0.248904
(URBAN)	-0.352035	-0.354236
(DEVPER)	0.274725	-0.125275
DO	0.011001	-0.039604
(DRP)	0.378856	0.259913
(ECOLI)	0.503297	0.371429
(NH4)	0.175962	0.035638
(NNN)	0.257143	-0.213187
(Turbidity)	-0.052805	0.074808
WQI (1)	0.450509	0.318728
(WQI (2))	-0.120879	-0.305495

Exploring some of the better relationships

The percentage of developed land in the catchment (DEVPER which comprises the sum of grassland, horticultural, and urban land-use) and the concentration of nitrate – nitrite nitrogen in the stream are two environmental variables that have amongst the highest rank correlations with the MCI and SQMCI (and the NRC variants) in HB streams (Table 7, Table 8).

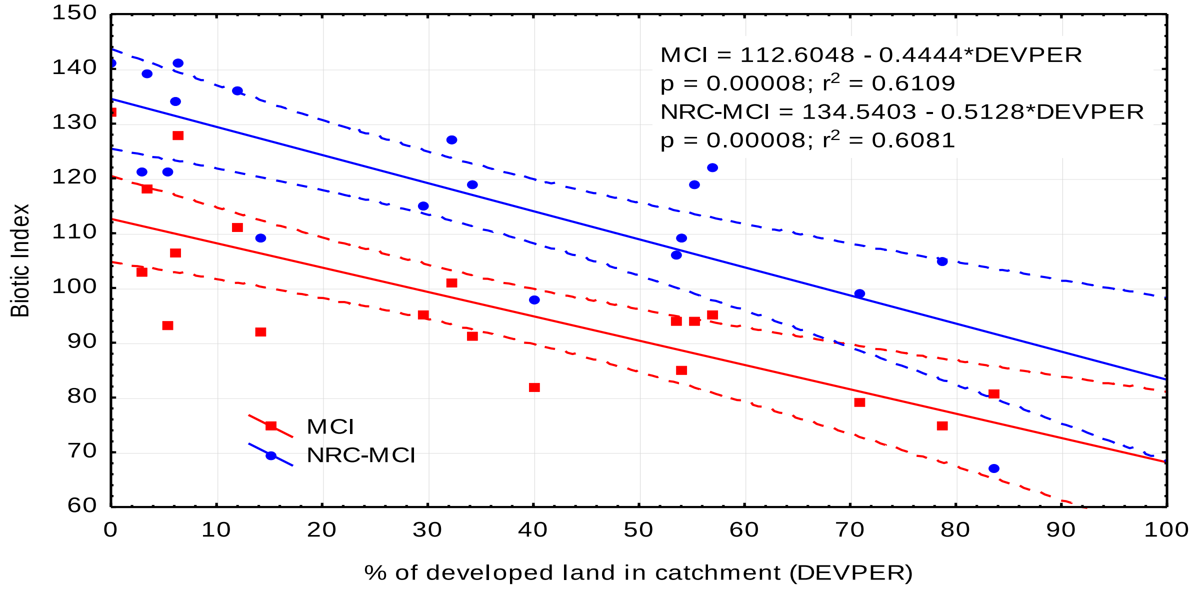

Figure 3 Linear regressions between MCI and NRC-MCI and the percentage of developed land in the catchment. Dashed lines are 95% confidence limits about the slopes of the regression lines.

The biotic index vs DEVPER regression is slightly stronger for the MCI than the NRC-MCI (Figure 3), but both indices seem to respond strongly to catchment development. With very few exceptions, NRC-MCI values were higher than MCI values for samples collected from Northland's HB streams.

If we interpret these indices using the criteria of Stark & Maxted (2007b) (see Table 2), we see that, on average, when 30% of more of the catchment is developed, then stream health is unlikely to achieve excellent status (> 119) when rated by the NRC-MCI. However, on average, the MCI vs DEVPER relationship suggests that even in an entirely natural catchment, excellent stream health is likely to be achieved at only 5% of sites (Figure 3). Conceptually, it would be desirable for any entirely natural catchment to support excellent stream health, so in this respect (at least) the NRC-MCI provides a better stream health assessment than the MCI for HB streams in Northland. The confidence limits around the NRC-MCI vs DEVPER regression suggest that excellent stream health is a virtual certainty in a catchment that has no urban, horticultural, or agricultural development. At the other extreme, the NRC-MCI indicates that stream health need not be poor (NRC-MCI<80) in a fully developed catchment, but that a fair or good result should be possible (in at least 50% of cases).

The situation with the SQMCI and NRC-SQMCI is practically identical to that for the MCI/NRC-MCI (Figure 4). I consider that the NRC-MCI and NRC-SQMCI provide a more realistic view of stream health than the original indices.

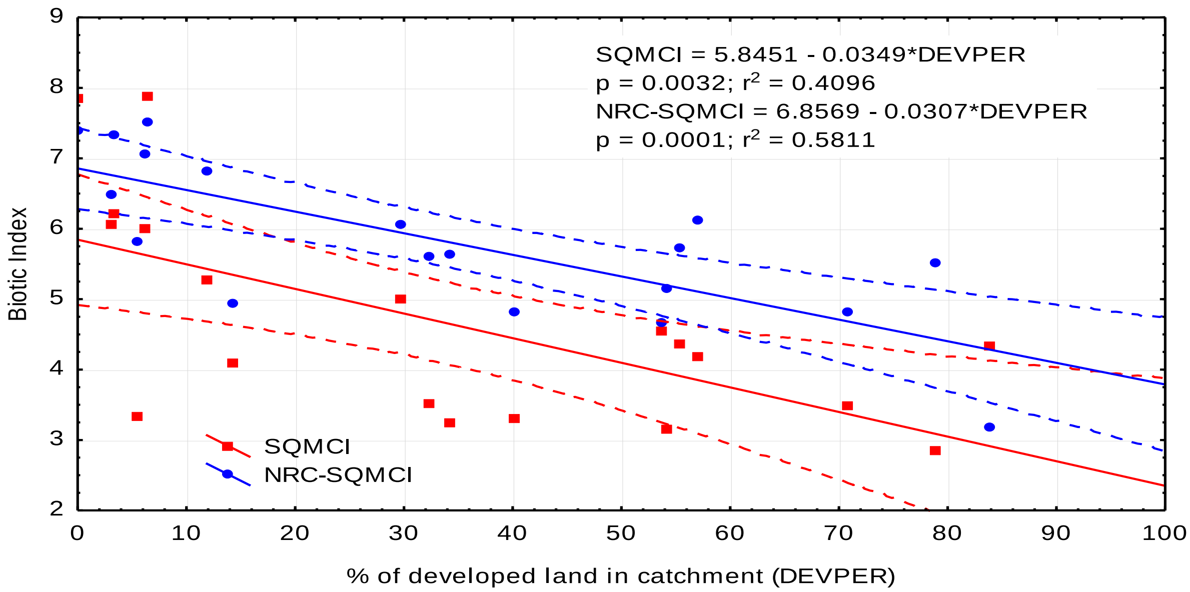

Figure 4 Linear regressions between SQMCI and NRC-SQMCI and the percentage of developed land in the catchment. Dashed lines are 95% confidence limits about the slopes of the regression lines.

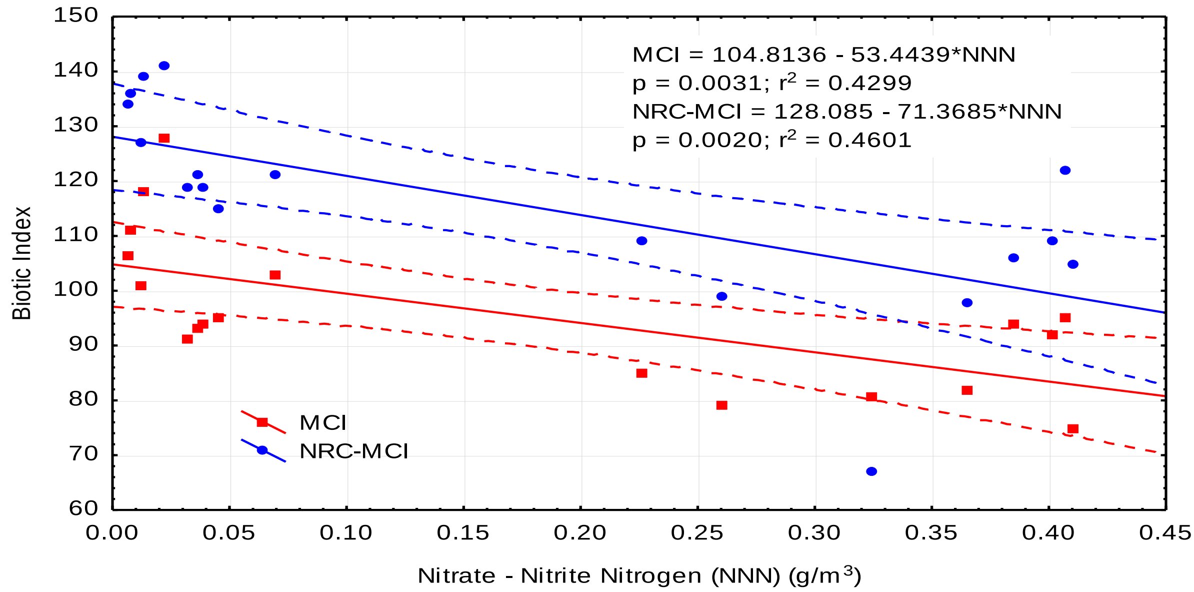

Figure 5 Linear regressions between MCI and NRC-MCI and the concentration of nitrate – nitrite nitrogen in the river water. Dashed lines are 95% confidence limits about the slopes of the regression lines.

The NRC-MCI has a stronger correlation with nitrate-nitrite nitrogen than the MCI based on data from Northland's HB streams (Figure 5). On average, excellent stream health (NRC-MCI > 119) is likely at a median NNN concentration of 0.1 g/m^3 or less. The result for the NRC-SQMCI is identical with excellent stream health (NRC-SQMCI > 5.99) corresponding to the same median NNN concentration (Figure 6).

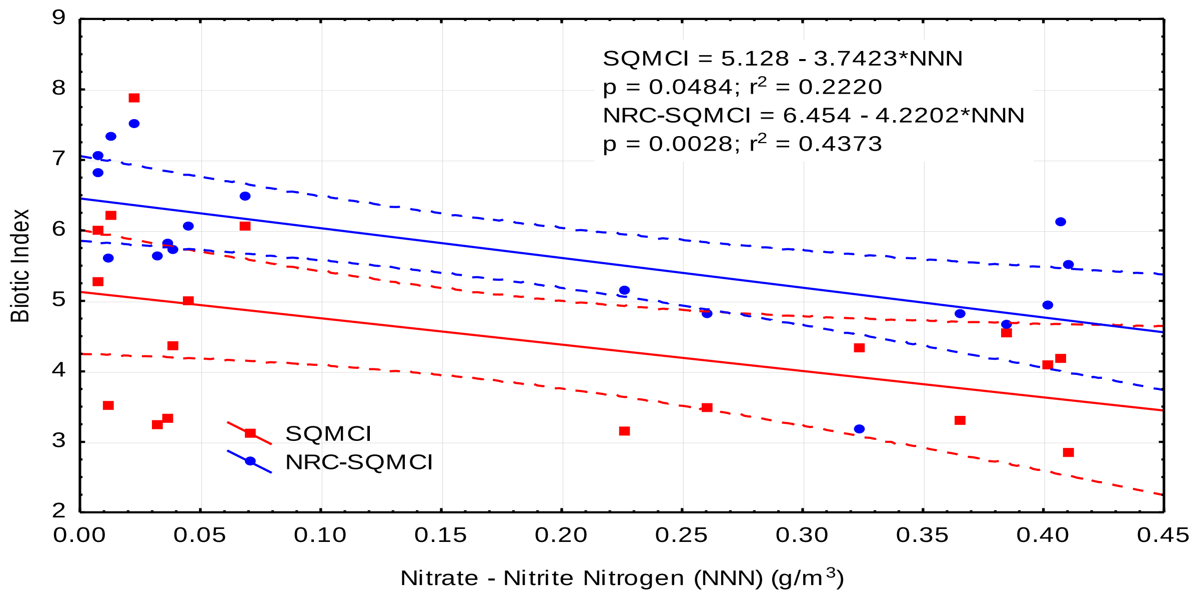

Figure 6 Linear regressions between SQMCI and NRC-SQMCI and the concentration of nitrate – nitrite nitrogen in the river water. Dashed lines are 95% confidence limits about the slopes of the regression lines.

Summary of stream health in the Northland region

Table 11 summarises median biotic index values for SB and HB streams in the Northland region based on data from 2007 – 2011 inclusive. It is clear from this table that, on average, the NRC versions of the indices result in better stream health assessments for most sites.

The assessments based on median (2007 – 2011) NRC-MCI values are presented also on the map of the Northland region (Figure 7).

Table 11 Stream health assessments for Northland streams based on median values (2007 – 2011) for a variety of biotic indices. Green = excellent, Yellow = Good, Orange = Fair, Red = Poor.

Site No.	Site Name	N	MCI	MCI-sb	NRC-MCI	NRC-MCI-sb	SQMCI	SQMCI-sb	NRC-SQMCI	NRC-SQMCI-sb
	Soft-bottom streams									
100007	Waiharakeke @ Stringer Rd walking bridge	5		103		148		4.65		6.88
100281	Mangahahuru @ Apotu Rd	5		76		94		2.66		5.67
100370	Awanui u/s Waihoe Channel	5		80		112		2.45		6.01
101038	Mangakahia @ Titoki	5		100		120		2.98		5.86
101625	Mangere @ Knight Rd	5		75		94		2.95		5.63
101752	Waitangi @ Watea	5		61		75		2.41		3.89
101753	Wairua @ Purua	5		76		98		2.26		5.16
102248	Waiotu @ SH1	5		75		101		2.39		5.84
102249	Whakapara River @ cableway	5		91		134		2.48		5.95
102257	Manganui @ Mitaitai Rd	5		69		98		2.69		5.62
105008	Ruakaka @ Flyger Rd Bridge	5		117		145		4.70		6.50
107045	Otarao Stream @ Mangakahia	2		84		109		3.79		5.34
108941	Waipao @ Draffin Rd bridge	4		102		144		3.68		6.34
108977	Paparoa @ Walking bridge	4		78		109		2.70		5.85
108979	Oruru @ Oruru Rd	4		75		132		2.38		6.06
109020	Utakura @ 177 Horeke Rd	4		71		93		2.36		5.82
	Hard-bottom streams									
100194	Hatea @ Mairpark walking bridge	3	94		106		4.54		4.66	
100237	Mangaharuru @ Main Rd	5	103		121		6.05		6.49	
100363	Awanui R @ FNDC P/S (take) by SH1	5	94		119		4.38		5.72	
101524	Waipapa @ Waipapa Landing	4	81		67		4.33		3.17	
101530	Kerikeri @ Stone store	4	75		105		2.86		5.52	
101751	Waipapa @ Forest Ranger	5	118		139		6.22		7.33	
102256	Kaihu @ Gorge	5	85		109		3.14		5.14	
102258	Opouteke @ Suspension	5	93		121		3.35		5.83	
102674	Kaeo River @ Dip Rd	5	95		115		5.00		6.06	
103178	Waitangi @ Waimate	5	99		96		4.39		5.48	
103304	Waipoua @ SH12	5	128		141		7.87		7.53	
103307	Mangakahia us of Twin Bridges	2	100		123		4.72		6.04	
105231	Punakitere @ Loop Rd bridge	5	95		122		4.18		6.11	
105532	Victoria @ Thompsons Bridge	5	111		136		5.28		6.81	
105672	Waiarohia @ 2nd Avenue	5	82		98		3.32		4.81	
105674	Waiarohia @ Russell Rd Bridge (Nth)	5	90		106		4.25		5.54	
105677	Waiarohia @ Kamo Tributary Culvert	5	70		80		2.61		3.53	
107773	Waiarohia @ Whau Valley	5	92		109		4.09		4.94	
108978	Mangamuka @ Iwiatua Rd	4	107		133		6.00		7.06	
109021	Hakaru @ Topuni Creek Farm	4	79		99		3.50		4.81	
109096	Mangakahia @ Twin Bridges	5	91		119		3.24		5.65	
109098	Waimamaku @ SH12	4	101		127		3.52		5.61	
109100	Ngunguru @ Waipoka Rd	3	90		88		4.21		3.03	
110370	Pukenui u/s Ridge Track Crossing	1	132		141		7.84		7.39	

Figure 7 Stream health assessment based on 2007 – 2011 median values of the NRC- MCI. Green = excellent, Yellow = Good, Orange = Fair, Red = Poor.

CONCLUSIONS

HB and SB stream datasets from the Northland region were used to derive TVs for regional versions of the MCI and SQMCI using an iterative Spearman rank correlation developed originally by Bruce Chessman (2003) in Australia and used previously in NZ to develop indices for SB streams in Auckland (Stark & Maxted 2007a) and for South Island wetlands (Suren et al. 2010). In all cases, the method relies on having macroinvertebrate data from a range of water bodies including the best and worst in the region. Furthermore, the macroinvertebrate taxa within the dataset must respond to an environmental gradient that is a measure of stream health. If this is not the case, then the performance of the resulting indices may be sub-optimal. In real-world data sets, it is possible (and maybe even likely) that macroinvertebrates are responding to a variety of different gradients or stressors, not all necessarily acting in the same direction, so any biotic index developed using this method should be ground-truthed to provide assurance that the results make sense.

TVs derived for HB streams using the Chessman Process produced NRC versions of the MCI and SQMCI that, in general, performed better than the original MCI and SQMCI when applied to macroinvertebrate data from HB streams in Northland. The NRC versions of the MCI and SQMCI had strong rank correlations with environmental variables such as the percentage of the catchment in various types of land-use, and some water quality variables. In addition, the NRC versions provided a more realistic distribution of sites across the excellent, good, fair, and poor quality classes. In contrast the original MCI and SQMCI underestimated stream health by about 20%. The NRC versions had expanded ranges compared with the original indices too, which is a positive outcome and may help discriminate better between sites.

However, assessing the health of SB streams in the Northland regions seems problematical. The existing MCI-sb and SQMCI-sb and the NRC versions did not have any statistically significant rank correlations with any of the environmental variables tested. There are several possible explanations for this, but without further investigation it is difficult to determine for certain why this is the case.

Firstly, as already noted, the Chessman Process for deriving TVs for taxa relies on the dataset covering a full range of river health from the best to the worst. If this is not the case, then the derived TVs may be unreliable. The fact that MCI-sb values ranged from 32 to 122 for Northland's SB streams provides some support for the view that SB stream data do not cover the full range of river health since pristine SB streams (*i.e.*, MCI-sb > 119) seem to be under-represented in the data set. However, why the MCI-sb which was developed in the Auckland region (immediately south of Northland) and performs well there, performs so poorly in Northland remains a mystery that warrants further investigation.

Taken at face value, the relatively poor correlations between environmental variables and biotic indices from SB streams suggest that these indices perform poorly as measures of SB stream health. However, this might not be the case. The assumption inherent in testing the performance of biotic indices by correlations with environmental variables such as habitat quality indices, indicators of catchment development, or water quality parameters, is that there is a measure of cause and effect involved. In other words, the water quality, habitat quality, or land-use activities within the catchment influence the character of macroinvertebrate communities. Indeed, this is the fundamental basis for biotic indices – that the communities present are a product of their environment.

In SB streams, however, perhaps many of these environmental factors play a lesser role in dictating macroinvertebrate community composition than they do for HB streams. Maybe the character of macroinvertebrate communities in SB streams is determined primarily by the nature of instream habitat and not so closely linked to the wider catchment? For example, in HB streams we know that the kinds of invertebrates that can persist in a stream when it becomes inundated by fine sediments are fairly tolerant. They have comparatively low TVs. Fine sedimentation can cause decreases in biotic indices in HB streams that mirrors enrichment effects. In SB streams the most sensitive invertebrates (*i.e.*, those with the highest TVs) tend to be present on hard substrates – such as woody debris – and streams dominated entirely by fine sediments generally have quite poor communities dominated by taxa with comparatively low TVs.

So if a pristine SB stream only has mobile fine sediments in it (and no woody debris or other hard substrates), then the macroinvertebrate community may not include many sensitive taxa resulting in a low biotic index score. Conversely, a poorer quality SB stream with some hard substrate present may support a few sensitive taxa that inflate the biotic index value. If this is occurring in SB streams, then a SB macroinvertebrate dataset is unlikely to embody an unambiguous gradient that may be strongly correlated with stream health. I suspect, therefore, that the character of SB stream invertebrate communities may depend most on the nature of the substrate and, especially, on the presence or absence of hard elements such as large woody debris. Consequently, it may not be too surprising that SB stream biotic indices do not show correlations with environmental variables that are as strong as those for HB streams. In HB streams the substrate generally is suitable for supporting assemblages of sensitive (*i.e.*, high TVs) macroinvertebrate taxa unless conditions are degraded by activities (such as enrichment, pollution, or sedimentation) occurring in the catchment upstream. In addition to variation between streams in their physical character, we also have the issue of how representative of what is present in the stream any macroinvertebrate samples are. It can be much easier to collect representative samples from stony riffles than from SB streams with their more heterogeneous habitats comprising soft substrates, aquatic macrophytes, and/or woody debris.

RECOMMENDATIONS

I recommend that NRC adopts the TVs developed from the HB stream dataset for calculating MCI, SQMCI, and QMCI in the Northland region. To avoid any confusion the resulting indices should be referred to in a manner that distinguishes them from the original versions of these indices (*e.g.*, NRC-MCI, NRC-SQMCI, NRC-QMCI).[5] The NRC versions of the MCI can be applied to historical datasets and do not require any changes to be made in future to data collection or processing protocols.

The above discussion concerning the assessment of SB stream health is somewhat speculative, but there may be a way forward. Firstly, it needs to be confirmed that the SB stream data does indeed cover the full range of stream health. This can only be confirmed by field inspection and knowledge of the range of SB stream types in the Northland region. I understand that pristine SB streams may be under-represented in the dataset (Carol Nicholson, *pers. comm.*). If that is the case, then additional sites should be sampled to address this deficiency. The Chessman Process could then be repeated on the expanded data set.

I doubt that a lot of additional data would be needed – the important thing is that the samples contain as many taxa as possible that are characteristic of top-quality SB stream habitats. A one-off survey of perhaps a dozen top quality reference sites probably would be sufficient. Sampling over time (years) would not be essential - the main advantage of more samples or sampling over time is the increased probability of including more taxa.

If there are some really poor quality SB sites in the region that have not been sampled, then the collection of additional samples from them could help reinforce that opposite end of the environmental gradient.

Secondly, it could be helpful to record the nature of the habitat sampled in SB streams. Was it all fine sediment, or did the sample include vegetation sweeps, and/or brushings from hard substrates such as logs? If samples from different streams vary in terms of the habitats sampled, then this alone will affect biotic index values and could confound stream health assessments. Ideally one should compare like with like – but this can be problematical for SB streams.

Thirdly, the Chessman iterations involved rank correlations between MCI values (rather than SQMCI nor QMCI value) and relative abundances of taxa in the dataset because Stark & Maxted (2007a) found the iterations based on the MCI performed best when developing the MCI-sb. However, it could be that for Northland SB streams, running the iterations on SQMCI values may produce a better result. This cannot, however, be guaranteed – the Chessman Process is an objective procedure – the result obtained depends entirely on the characteristics of the data used in the analysis.

[5] As the first draft of this report was being finalised, Alastair Suren (Environment Bay of Plenty) initiated the preparation of an Envirolink proposal aimed at revising the MCI (and variants) for HB and SB streams in New Zealand. An R-script for running the Chessman Process has already been developed. Should the application for funding proceed, it is likely that TVs will be derived separately for HB and SB streams in different regions of NZ based on data held in NIWA's national database.

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Appendix 1 Macroinvertebrate sampling sites and dates for hard-bottomed streams in the Northland Region.

Site Location	Site Code	Sampling date															
Hatea River u/s Mair Park Bridge	**100194**	-	-	-	-	-	-	-	-	-	-	-	Apr-09	12-Jan-10	02-Mar-11	12-Feb-12	19-Jan-13
Mangahahuru Stream @ end of Main Rd	**100237**	-	-	-	-	-	-	-	-	Mar-06	Mar-07	Jan-08	Apr-09	10-Jan-10	04-Mar-11	12-Feb-12	27-Jan-13
Awanui River @ FNDC watertake	**100363**	Mar-98	Feb-Mar-99	-	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	18-Jan-10	09-Mar-11	13-Feb-12	29-Jan-13
Waipapa Stream@ Waipapa Landing	**101524**	-	-	-	-	-	-	-	-	-	-	Jan-08	Apr-09	13-Jan-10	08-Mar-11	14-Feb-12	29-Jan-13
Kerikeri River @ stone store bridge	**101530**	-	-	-	-	-	-	-	-	-	-	Jan-08	Apr-09	13-Jan-10	08-Mar-11	14-Feb-12	29-Jan-13
Waipapa River @ Forest Ranger	**101751**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	19-Jan-10	08-Mar-11	13-Feb-12	29-Jan-13
Kaihu River @ gorge	**102256**	-	-	-	-	-	-	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	19-Jan-10	07-Mar-11	20-Feb-12	21-Jan-13
Opouteke River @ suspension bridge	**102258**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	14-Jan-10	07-Mar-11	20-Feb-12	21-Jan-13
Kaeo River @ Dip Rd Bridge	**102674**	-	-	-	-	-	-	-	-	-	Mar-07	Jan-08	Apr-09	18-Jan-10	09-Mar-11	13-Feb-12	29-Jan-13
Waitangi River @ Waimate Rd	**103178**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	17-Jan-10	08-Mar-11	14-Feb-12	29-Jan-13
Waipoua River @ SH12 Rest Area	**103304**	-	-	-	-	-	-	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	19-Jan-10	07-Mar-11	20-Feb-12	21-Jan-13
Mangakahia River u/s of Twin Bridges	**103307**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	-	-	-	-	-
Harris dam u/s	**104584**	Mar-98	-	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	-	-	-	-	-	-	-
Punakitere River @ Taheke Recorder	**105231**	-	-	-	-	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	19-Jan-10	07-Mar-11	20-Feb-12	21-Jan-13
Victoria River @ Thompsons Bridge	**105532**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	18-Jan-10	09-Mar-11	13-Feb-12	29-Jan-13
Waiarohia Stream @ Rust Ave Bridge	**105672**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	10-Jan-10	01-Mar-11	11-Feb-12	19-Jan-13
Waiarohia Stream @ Russell Rd Bridge (Sth)	**105673**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	-	-	-	-	-	-	-	-	-	-
Waiarohia Stream @ Russell Rd Bridge (Nth)	**105674**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	10-Jan-10	01-Mar-11	11-Feb-12	-
Waiarohia Stream @ 96 W. Hills Dr.	**105675**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	-	-	-	-	-	-	-	-	-	-
Waiarohia Stream @ 27A Huia St.	**105676**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	-	-	-	-	-	-	-	-	-	-
Waiarohia Stream @ Kamo Tributary Culvert	**105677**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	10-Jan-10	01-Mar-11	11-Feb-12	19-Jan-13
Waiarohia Stream @ Provan Bridge	**105679**	Mar-98	Feb-Mar-99	-	Mar-01	Mar-02	Mar-03	-	-	-	-	-	-	-	-	-	-
Waihoihoi Stream @ Artillery Rd	**106488**	-	-	-	-	Mar-02	-	-	-	-	-	-	-	-	-	-	-
Ruahuia Stream @ Viaduct	**106991**	-	-	-	-	-	-	Mar-04	Mar-05	Mar-06	-	-	-	-	-	-	-
Waiarohia Stream @ Whau Valley Rd Bridge	**107773**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	10-Jan-10	01-Mar-11	11-Feb-12	19-Jan-13
Mangamuka River @ Iwiatua Rd Bridge	**108978**	-	-	-	-	-	-	-	-	-	-	Jan-08	Apr-09	18-Jan-10	09-Mar-11	13-Feb-12	29-Jan-13
Hakaru River @ Topuni Creek Farm	**109021**	-	-	-	-	-	-	-	-	-	-	Jan-08	Apr-09	11-Jan-10	02-Mar-11	16-Feb-12	20-Jan-13
Mangakahia River d/s of Twin Bridges	**109096**	-	-	-	-	-	-	-	-	-	-	Jan-08	Apr-09	14-Jan-10	07-Mar-11	20-Feb-12	21-Jan-13
Waimamaku River @ SH12	**109098**	-	-	-	-	-	-	-	-	-	-	Jan-08	Apr-09	19-Jan-10	07-Mar-11	20-Feb-12	21-Jan-13
Ngunguru River @ Waipoka Rd	**109100**	-	-	-	-	-	-	-	-	-	-	Jan-08	Apr-09	10-Jan-10	-	-	-
Pukenui Stream u/s Ridge Track crossing	**110370**	-	-	-	-	-	-	-	-	-	-	-	-	-	06-Mar-11	12-Feb-12	19-Jan-13
Otaika Stream @ Otaika Valley Rd	**110431**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16-Feb-12	20-Jan-13
Ngunguru River @ Coalhill Lane	**110603**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10-Feb-12	26-Jan-13

Appendix 2 Macroinvertebrate sampling sites and dates for soft-bottomed streams in the Northland Region.

Site Location	Site Code	Sampling dates															
Waiharakeke Stream @ Stringers Rd Bridge	**100007**	-	-	-	-	-	-	-	-	-	Mar-07	Jan-08	Apr-09	13-Jan-10	8-Mar-11	14-Feb-12	29-Jan-13
Mangahahuru Stream @ Apotu Rd Bridge	**100281**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	10-Jan-10	6-Mar-11	12-Feb-12	29-Jan-13
Awanui River u/s Waihue Channel	**100370**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	18-Jan-10	9-Mar-11	13-Feb-12	29-Jan-13
Mangakahia River @ Titoki Bridge	**101038**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	9-Jan-10	1-Mar-11	20-Feb-12	21-Jan-13
Mangere River @ Knight Rd Bridge	**101625**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	9-Jan-10	5-Mar-11	11-Feb-12	22-Jan-13
Waitangi River @ Watea	**101752**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	13-Jan-10	8-Mar-11	14-Feb-12	29-Jan-13
Wairua River @ Purua	**101753**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	9-Jan-10	5-Mar-11	11-Feb-12	21-Jan-13
Waiotu River @ SH1 Bridge	**102248**	-	-	-	-	-	-	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	17-Jan-10	9-Mar-11	14-Feb-12	29-Jan-13
Whakapaka River @ cableway	**102249**	Mar-98	Feb-Mar-99	Mar-00	Mar-01	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	17-Jan-10	9-Mar-11	14-Feb-12	29-Jan-13
Manganui River @ Mititai Rd	**102257**	-	-	-	-	Mar-02	Mar-03	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	Apr-09	11-Jan-10	2-Mar-11	16-Feb-12	20-Jan-13
Ruakaka River @ Flyger Road	**105008**	-	-	-	-	-	-	-	-	-	Mar-07	Jan-08	Apr-09	11-Jan-10	2-Mar-11	16-Feb-12	20-Jan-13
Otarao Stream @ Mangakahia	**107045**	-	-	-	-	-	-	Mar-04	Mar-05	Mar-06	Mar-07	Jan-08	-	-	-	-	-
Otarao Stream trib. @ Coxhead Rd	**107046**	-	-	-	-	-	-	Mar-04	-	-	-	-	-	-	-	-	
Tarakiekie Stream @ Norvil Rd	**107047**	-	-	-	-	-	-	Mar-04	-	-	-	-	-	-	-	-	
Otarao Stream @ Norvil Rd	**107048**	-	-	-	-	-	-	Mar-04	Mar-05	Mar-06	-	-	-	-	-	-	-
Otarao Stream @ Wares property	**107748**	-	-	-	-	-	-	Mar-04	Mar-05	Mar-06	-	-	-	-	-	-	-
Waipao Stream @ Draffin Rd	**108941**	-	-	-	-	-	-	-	-	-	-	Jan-08	Apr-09	9-Jan-10	1-Mar-11	11-Feb-12	21-Jan-13
Paparoa Stream @ walking bridge	**108977**	-	-	-	-	-	-	-	-	-	-	Jan-08	Apr-09	11-Jan-10	2-Mar-11	-	-
Oruru River @ Oruru Rd	**108979**	-	-	-	-	-	-	-	-	-	-	Jan-08	Apr-09	18-Jan-10	9-Mar-11	13-Feb-12	29-Jan-13
Utakura River @ Okaka Rd Bridge	**109020**	-	-	-	-	-	-	-	-	-	-	Jan-08	Apr-09	19-Jan-10	8-Mar-11	14-Feb-12	29-Jan-13

Appendix 3 Results of Spearman Rank Correlation testing between biotic indices and environmental variables. Results have been ordered from lowest to highest P value. Red text indicates statistically significant results with bold results remaining significant after application of the Benjamini-Hochberg False Discovery Rate procedure. Red italics denote statistically significant results at face value that were not strong enough to avoid elimination by the Benjamini-Hochberg FDR procedure. Shaded rows denote correlations between indices.

	(N	Spearman (R)	t(N-2)	p-value	Order	Critical value
NRC-MCI vs NRC-SQMCI	**24**	**0.921637**	**11.13989**	**0.000000**	**1**	**0.000291**
MCI vs NRC-MCI	**24**	**0.863023**	**8.01309**	**0.000000**	**2**	**0.000581**
MCI vs SQMCI	**24**	**0.848815**	**7.53048**	**0.000000**	**3**	**0.000872**
MCI vs NRC-SQMCI	**24**	**0.842907**	**7.34786**	**0.000000**	**4**	**0.001163**
NRC-MCI vs HORT	**19**	**-0.837948**	**-6.33065**	**0.000008**	**5**	**0.001453**
NRC-MCI-sb vs NRC-SQMCI-sb	**16**	**0.868093**	**6.54332**	**0.000013**	**6**	**0.001744**
MCI-sb vs NRC-MCI-sb	**16**	**0.827306**	**5.51045**	**0.000077**	**7**	**0.002035**
MCI vs HORT	**19**	**-0.777809**	**-5.10260**	**0.000088**	**8**	**0.002326**
MCI vs DEVPER	**19**	**-0.776998**	**-5.08916**	**0.000091**	**9**	**0.002616**
MCI vs LAKEPOND	**19**	**-0.768004**	**-4.94431**	**0.000123**	**10**	**0.002907**
MCI vs HIGRASS	**19**	**-0.762950**	**-4.86610**	**0.000145**	**11**	**0.003198**
NRC-SQMCI vs HORT	**19**	**-0.756129**	**-4.76389**	**0.000180**	**12**	**0.003488**
NRC-MCI vs DEVPER	**19**	**-0.742532**	**-4.57075**	**0.000271**	**13**	**0.003779**
SQMCI vs NRC-SQMCI	**24**	**0.673190**	**4.27001**	**0.000312**	**14**	**0.00407**
NRC-SQMCI vs DEVPER	**19**	**-0.734533**	**-4.46312**	**0.000342**	**15**	**0.00436**
NRC-MCI vs LAKEPOND	**19**	**-0.723622**	**-4.32278**	**0.000462**	**16**	**0.004651**
NRC-MCI vs NNN	**18**	**-0.736952**	**-4.36101**	**0.000485**	**17**	**0.004942**
NRC-SQMCI vs HIGRASS	**19**	**-0.710838**	**-4.16697**	**0.000646**	**18**	**0.005233**
NRC-MCI vs HIGRASS	**19**	**-0.708261**	**-4.13660**	**0.000690**	**19**	**0.005523**
NRC-SQMCI vs LAKEPOND	**19**	**-0.704669**	**-4.09482**	**0.000755**	**20**	**0.005814**
NRC-MCI vs NATIVE	**19**	**0.677505**	**3.79790**	**0.001437**	**21**	**0.006105**
NRC-MCI vs URBAN	**19**	**-0.676304**	**-3.78549**	**0.001477**	**22**	**0.006395**
SQMCI vs NRC-MCI	**24**	**0.605876**	**3.57209**	**0.001702**	**23**	**0.006686**
NRC-SQMCI vs URBAN	**19**	**-0.667991**	**-3.70103**	**0.001774**	**24**	**0.006977**
MCI vs NATIVE	**19**	**0.667252**	**3.69365**	**0.001802**	**25**	**0.007267**
MCI-sb vs SQMCI-sb	**16**	**0.712814**	**3.80280**	**0.001940**	**26**	**0.007558**
NRC-MCI vs WQI (2)	**18**	**-0.675802**	**-3.66744**	**0.002081**	**27**	**0.007849**
MCI vs NNN	**18**	**-0.675620**	**-3.66562**	**0.002089**	**28**	**0.00814**
SQMCI vs HIGRASS	**19**	**-0.629825**	**-3.34326**	**0.003853**	**29**	**0.00843**
MCI-sb vs NRC-SQMCI-sb	**16**	**0.675995**	**3.43238**	**0.004044**	**30**	**0.008721**
SQMCI vs DEVPER	**19**	**-0.626316**	**-3.31255**	**0.004117**	**31**	**0.009012**
NRC-SQMCI vs NNN	**18**	**-0.641198**	**-3.34229**	**0.004134**	**32**	**0.009302**
NRC-SQMCI vs NATIVE	**19**	**0.600263**	**3.09445**	**0.006582**	**33**	**0.009593**
NRC-MCI vs NH4	**18**	**-0.607966**	**-3.06295**	**0.007435**	**34**	**0.009884**
SQMCI vs LAKEPOND	**19**	**-0.584718**	**-2.97182**	**0.008553**	**35**	**0.010174**
MCI vs WQI (2)	*18*	*-0.580879*	*-2.85447*	*0.011474*	*36*	*0.010465*
SQMCI vs DO	*18*	*-0.575161*	*-2.81238*	*0.012517*	*37*	*0.010756*
MCI vs URBAN	*19*	*-0.518849*	*-2.50246*	*0.022833*	*38*	*0.011047*
SQMCI-sb vs NRC-MCI-sb	*16*	*0.552691*	*2.48142*	*0.026397*	*39*	*0.011337*
SQMCI vs HORT	*19*	*-0.498919*	*-2.37362*	*0.029665*	*40*	*0.011628*
MCI-sb vs Rapid Habitat	*13*	*0.600553*	*2.49106*	*0.029979*	*41*	*0.011919*
SQMCI vs NATIVE	*19*	*0.487719*	*2.30346*	*0.034151*	*42*	*0.012209*
NRC-SQMCI vs WQI (2)	*18*	*-0.491736*	*-2.25892*	*0.038202*	*43*	*0.0125*
NRC-SQMCI vs NH4	*18*	*-0.480423*	*-2.19112*	*0.043590*	*44*	*0.012791*
SQMCI vs NNN	18	-0.465428	-2.10343	0.051602	45	0.013081
MCI vs NH4	18	-0.444143	-1.98288	0.064820	46	0.013372
SQMCI-sb vs ECOLI	14	0.503297	2.01764	0.066560	47	0.013663
MCI vs DO	18	-0.413856	-1.81847	0.087762	48	0.013953
SQMCI-sb vs Pfankuch stability	14	-0.462046	-1.80478	0.096246	49	0.014244
NRC-SQMCI vs DO	18	-0.403757	-1.76531	0.096585	50	0.014535
NRC-MCI-sb vs Rapid Habitat	13	0.479341	1.81146	0.097433	51	0.014826
NRC-MCI-sb vs URBAN	14	-0.458655	-1.78798	0.099037	52	0.015116
NRC-SQMCI-sb vs Rapid Habitat	13	0.472527	1.77825	0.102981	53	0.015407
SQMCI vs URBAN	19	-0.383926	-1.71435	0.104636	54	0.015698
SQMCI-sb vs WQI (1)	14	0.450509	1.74805	0.105968	55	0.015988
NRC-MCI vs ECOLI	18	-0.389665	-1.69243	0.109942	56	0.016279
SQMCI-sb vs NRC-SQMCI-sb	16	0.405882	1.66170	0.118792	57	0.01657
NRC-SQMCI vs ECOLI	18	-0.377904	-1.63269	0.122056	58	0.01686

NRC-MCI-sb vs HORT	14	-0.428748	-1.64399	0.126101	59	0.017151
MCI-sb vs WQI (1)	14	0.419252	1.59972	0.135644	60	0.017442
NRC-MCI-sb vs WQI (2)	14	-0.407490	-1.54574	0.148121	61	0.017733
MCI-sb vs ECOLI	14	0.392071	1.47638	0.165596	62	0.018023
SQMCI vs LOGRASS	19	-0.328647	-1.43474	0.169502	63	0.018314
SQMCI-sb vs DRP	14	0.378856	1.41811	0.181603	64	0.018605
NRC-MCI-sb vs LAKEPOND	14	-0.376653	-1.40849	0.184364	65	0.018895
NRC-SQMCI-sb vs ECOLI	14	0.371429	1.38580	0.191021	66	0.019186
MCI-sb vs Pfankuch habitat	14	0.363437	1.35139	0.201497	67	0.019477
NRC-MCI vs Pfankuch habitat	19	0.306239	1.32638	0.202257	68	0.019767
NRC-SQMCI-sb vs URBAN	14	-0.354236	-1.31220	0.214000	69	0.020058
SQMCI-sb vs Rapid Habitat	13	0.368132	1.31317	0.215857	70	0.020349
SQMCI-sb vs URBAN	14	-0.352035	-1.30289	0.217060	71	0.02064
SQMCI vs WQI (2)	18	-0.302530	-1.26961	0.222379	72	0.02093
NRC-SQMCI-sb vs LAKEPOND	14	-0.345055	-1.27352	0.226949	73	0.021221
NRC-MCI vs Turbidity	18	-0.289705	-1.21074	0.243576	74	0.021512
NRC-MCI vs DO	18	-0.281255	-1.17235	0.258219	75	0.021802
NRC-SQMCI vs Turbidity	18	-0.277003	-1.15313	0.265792	76	0.022093
NRC-SQMCI-sb vs WQI (1)	14	0.318728	1.16486	0.266712	77	0.022384
NRC-SQMCI-sb vs WQI (2)	14	-0.305495	-1.11140	0.288170	78	0.022674
NRC-MCI-sb vs WQI (1)	14	0.299466	1.08728	0.298270	79	0.022965
MCI-sb vs NH4	14	0.296893	1.07703	0.302642	80	0.023256
SQMCI-sb vs HIGRASS	14	0.292308	1.05883	0.310526	81	0.023547
NRC-MCI-sb vs NATIVE	14	0.288547	1.04396	0.317079	82	0.023837
SQMCI vs EXOTIC	19	-0.236842	-1.00512	0.328931	83	0.024128
MCI vs Pfankuch stability	18	0.244054	1.00665	0.329083	84	0.024419
SQMCI-sb vs DEVPER	14	0.274725	0.98976	0.341830	85	0.024709
NRC-SQMCI-sb vs NATIVE	14	0.270330	0.97266	0.349919	86	0.025
MCI vs LOGRASS	19	-0.226913	-0.96064	0.350196	87	0.025291
NRC-MCI-sb vs DRP	14	0.266004	0.95591	0.357981	88	0.025581
MCI-sb vs DRP	14	0.264901	0.95164	0.360055	89	0.025872
SQMCI-sb vs EXOTIC	14	-0.261538	-0.93867	0.366411	90	0.026163
MCI vs ECOLI	18	-0.225207	-0.92458	0.368920	91	0.026453
NRC-SQMCI-sb vs DRP	14	0.259913	0.93241	0.369507	92	0.026744
NRC-SQMCI-sb vs Pfankuch stability	14	-0.257426	-0.92285	0.374268	93	0.027035
SQMCI-sb vs NNN	14	0.257143	0.92176	0.374812	94	0.027326
NRC-SQMCI vs Pfankuch habitat	19	0.211589	0.89261	0.384525	95	0.027616
NRC-SQMCI-sb vs HORT	14	-0.248904	-0.89025	0.390832	96	0.027907
NRC-SQMCI vs Pfankuch stability	18	0.214470	0.87832	0.392770	97	0.028198
SQMCI-sb vs LAKEPOND	14	-0.243956	-0.87142	0.400625	98	0.028488
NRC-SQMCI-sb vs SCRUB	14	0.243956	0.87142	0.400625	99	0.028779
NRC-MCI vs LOGRASS	19	-0.200704	-0.84471	0.410002	100	0.02907
MCI vs Turbidity	18	-0.205274	-0.83896	0.413850	101	0.02936
NRC-MCI-sb vs Pfankuch stability	14	-0.231533	-0.82446	0.425765	102	0.029651
SQMCI-sb vs Pfankuch habitat	14	0.226374	0.80508	0.436435	103	0.029942
MCI-sb vs Pfankuch stability	14	-0.223815	-0.79550	0.441776	104	0.030233
MCI vs EXOTIC	19	-0.186128	-0.78108	0.445500	105	0.030523
NRC-SQMCI-sb vs NNN	14	-0.213187	-0.75588	0.464303	106	0.030814
SQMCI vs WQI (1)	18	0.176713	0.71815	0.483018	107	0.031105
NRC-SQMCI-sb vs Pfankuch habitat	14	0.204396	0.72332	0.483346	108	0.031395
NRC-MCI vs EXOTIC	19	-0.168717	-0.70576	0.489899	109	0.031686
NRC-SQMCI-sb vs HIGRASS	14	-0.200000	-0.70711	0.493004	110	0.031977
NRC-MCI-sb vs Pfankuch habitat	14	0.196036	0.69252	0.501790	111	0.032267
NRC-SQMCI vs EXOTIC	19	-0.157964	-0.65958	0.518358	112	0.032558
NRC-SQMCI vs LOGRASS	19	-0.157363	-0.65701	0.519971	113	0.032849
SQMCI vs ECOLI	18	-0.159959	-0.64818	0.526061	114	0.03314
NRC-MCI-sb vs NNN	14	-0.185022	-0.65220	0.526570	115	0.03343
SQMCI-sb vs HORT	14	-0.177789	-0.62585	0.543135	116	0.033721
SQMCI-sb vs NH4	14	0.175962	0.61921	0.547352	117	0.034012
MCI-sb vs LAKEPOND	14	-0.174009	-0.61212	0.551878	118	0.034302
NRC-MCI-sb vs ECOLI	14	0.174009	0.61212	0.551878	119	0.034593
SQMCI vs SCRUB	19	0.145614	0.60685	0.551970	120	0.034884
MCI-sb vs WQI (2)	14	-0.167401	-0.58820	0.567307	121	0.035174
NRC-MCI-sb vs LOGRASS	14	0.167401	0.58820	0.567307	122	0.035465
SQMCI-sb vs SCRUB	14	-0.160440	-0.56307	0.583753	123	0.035756
SQMCI vs Turbidity	18	-0.136364	-0.55060	0.589515	124	0.036047
SQMCI-sb vs NATIVE	14	-0.156044	-0.54726	0.594235	125	0.036337
NRC-MCI vs DRP	18	-0.129920	-0.52412	0.607378	126	0.036628
NRC-SQMCI vs SCRUB	19	0.114085	0.47348	0.641897	127	0.036919

NRC-MCI-sb vs SCRUB	14	0.134362	0.46970	0.646989	128	0.037209
SQMCI vs NH4	18	-0.114686	-0.46179	0.650448	129	0.0375
SQMCI-sb vs LOGRASS	14	-0.129670	-0.45302	0.658619	130	0.037791
NRC-SQMCI-sb vs DEVPER	14	-0.125275	-0.43741	0.669582	131	0.038081
SQMCI vs DRP	18	0.104612	0.42076	0.679529	132	0.038372
SQMCI-sb vs WQI (2)	14	-0.120879	-0.42183	0.680607	133	0.038663
MCI-sb vs DO	14	0.116869	0.40764	0.690717	134	0.038953
MCI-sb vs HORT	14	-0.114704	-0.39999	0.696195	135	0.039244
MCI-sb vs URBAN	14	-0.112459	-0.39206	0.701891	136	0.039535
MCI vs SCRUB	19	0.093064	0.38539	0.704731	137	0.039826
MCI-sb vs NNN	14	0.110132	0.38384	0.707808	138	0.040116
NRC-SQMCI vs WQI (1)	18	0.094557	0.37993	0.708994	139	0.040407
NRC-MCI vs Rapid Habitat	19	0.090510	0.37472	0.712503	140	0.040698
MCI-sb vs NATIVE	14	0.107930	0.37608	0.713424	141	0.040988
SQMCI vs Pfankuch stability	18	0.087810	0.35260	0.728989	142	0.041279
MCI-sb vs EXOTIC	14	-0.099119	-0.34506	0.736023	143	0.04157
NRC-MCI-sb vs HIGRASS	14	-0.096917	-0.33732	0.741705	144	0.04186
MCI vs Pfankuch habitat	19	0.069390	0.28679	0.777738	145	0.042151
NRC-SQMCI-sb vs EXOTIC	14	-0.081319	-0.28263	0.782275	146	0.042442
MCI vs Rapid Habitat	19	-0.066755	-0.27585	0.785988	147	0.042733
NRC-SQMCI vs DRP	18	-0.068033	-0.27276	0.788524	148	0.043023
NRC-SQMCI-sb vs Turbidity	14	0.074808	0.25987	0.799370	149	0.043314
MCI vs WQI (1)	18	0.064377	0.25804	0.799665	150	0.043605
NRC-MCI-sb vs EXOTIC	14	-0.063877	-0.22173	0.828254	151	0.043895
SQMCI vs Pfankuch habitat	19	0.052655	0.21740	0.830483	152	0.044186
NRC-MCI-sb vs DO	14	-0.061742	-0.21429	0.833919	153	0.044477
MCI vs DRP	18	-0.048171	-0.19291	0.849457	154	0.044767
SQMCI-sb vs Turbidity	14	-0.052805	-0.18318	0.857716	155	0.045058
MCI-sb vs HIGRASS	14	-0.048458	-0.16806	0.869334	156	0.045349
MCI-sb vs Turbidity	14	0.046307	0.16058	0.875094	157	0.04564
MCI-sb vs LOGRASS	14	-0.044053	-0.15275	0.881132	158	0.04593
NRC-MCI vs WQI (1)	18	-0.037526	-0.15021	0.882477	159	0.046221
NRC-SQMCI-sb vs DO	14	-0.039604	-0.13730	0.893071	160	0.046512
NRC-SQMCI-sb vs LOGRASS	14	-0.037363	-0.12952	0.899093	161	0.046802
NRC-SQMCI-sb vs NH4	14	0.035638	0.12353	0.903731	162	0.047093
NRC-MCI vs SCRUB	19	0.028120	0.11599	0.909023	163	0.047384
NRC-MCI-sb vs NH4	14	-0.030136	-0.10444	0.918545	164	0.047674
NRC-MCI vs Pfankuch stability	18	0.021200	0.08482	0.933459	165	0.047965
NRC-MCI-sb vs DEVPER	14	-0.019824	-0.06869	0.946371	166	0.048256
NRC-SQMCI vs Rapid Habitat	19	0.010097	0.04163	0.967278	167	0.048547
SQMCI-sb vs DO	14	0.011001	0.03811	0.970226	168	0.048837
MCI-sb vs SCRUB	14	-0.008811	-0.03052	0.976153	169	0.049128
SQMCI vs Rapid Habitat	19	0.007021	0.02895	0.977244	170	0.049419
MCI-sb vs DEVPER	14	0.006608	0.02289	0.982113	171	0.049709
NRC-MCI-sb vs Turbidity	14	0.000000	0.00000	1.000000	172	0.05