Macroinvertebrate assessment report

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Approach to data analysis

Introduction

Assessment of freshwater bodies using macroinvertebrates is a widely used practice as they tend to be good indicators of the ecosystem's health (Rosenberg & Resh, 2018). The suitability of macroinvertebrates-based indicators to perform assessment of streams is based on the following principles:

- Well established sampling methodologies and procedures
- A relatively easy identification process
- Cost effective
- Ubiquity of species commonly found in most of freshwater bodies
- Relatively long-life cycles (around one year) to help assess changes over time
- Responsive to a wide variety of stressors with certain species reacting differently to different stressors.

The Auckland Council's River Ecology Monitoring Programme (REMP) is responsible for collecting macroinvertebrate data from the streams across the Auckland region on a yearly basis. The data analysis presented in this report makes use of a portion of the collected data between the years 2006 and 2016 with the aim of assessing the health of the involved streams while exploring the trends between land use and stream integrity.

Sites

The dataset obtained from the REMP contains macroinvertebrate data from the year 2006 to the year 2016. This data contains yearly records of a total of 109 sites scattered across the Auckland region but this particular analysis is focussed on a small subset of only 15 sites (fig. 1). The chosen subset is a good representative of the streams heterogeneous conditions throughout Auckland, particularly their diverse catchment land cover.

The sites (n=15) are classified into categories depending on their catchment land cover. The four land cover categories presented in this study are forestry (exotic forest), native, pasture and urban. Sites are assigned to a certain category according to their most dominant land use. The percentages and category for each site are presented in table 1. It is worth noting how some of the sites have relatively high percentages of different land uses (e.g. Matakana with 39.7% of native forest and 45.5% of urban land use) but only belong to one category. If this study was to include a larger dataset, this type of sites would likely have their own category, for example in the case of Matakana it could be "Urban with native forest" or "Urban low density".

Metrics

Since the dataset does not provide species counts but instead abundance codes, the number of metrics that can be calculated from the dataset is limited. The first two indices used in this study are the Macroinvertebrate Community Index (MCI) (Stark, 1985; Stark, 1993) and its semi-quantitative variant (SQMCI) (Stark, 1998). Both indices have been calculated from their hard-bottomed (HB) and soft-bottomed (SB) derivations (Stark & Maxted, 2007a; Stark et al., 2001; Stark & Maxted, 2007) and have been extensively used in New Zealand. (Death & Collier, 2010; Clapcott et al., 2016; Neale et al., 2017). Both the MCI and the SQMCI have been calculated for each stream included in this study using Microsoft Excel and the formulas provided by the Ministry for the Environment (2018) in their user guide website.

The other two indices are taxa richness (the number of different species counted) and the percentage of Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly) (%EPT). The %EPT is calculated by adding the total number of mayfly (E), stonefly (P) and caddisfly (T) species, dividing it by the total of identified species (taxa richness) and multiplying it by 100 (Land Air Water Aotearoa, 2018a). However, taxa richness can often be misleading as a high number of species does not necessarily imply a healthy freshwater body (i.e. taxa richness can be high on nutrient-enriched rivers and streams) (Land Air Water Aotearoa, 2018b). While %EPT is often a good indicator of stream health as it represents a sensitive group of species that are not very tolerant to water pollution, it can also be misleading in certain circumstances; some locations are known to have a low %EPT due to natural circumstances and not due to external stressors. Both %EPT and taxa richness have been calculated for each studied site using Microsoft Excel.

Land use

Linear regression is used to relate the percentage of the different land covers (native forest, forestry, pasture, urban) and the macroinvertebrate indices calculated for each site record. Pearson's correlation is used to establish the degree to which land cover is related to the different macroinvertebrate metrics. Minimum, maximum, mean and standard deviation are calculated for each site and presented using both tables and plots to improve visual understanding of the results.

A non-metric multidimensional scaling (NMDS) is applied to try to establish the different macroinvertebrate communities found at each site. Finding similarities and dissimilarities among sites can help confirm or deny the relationships between sites, such as land cover. Although this sort of technique is usually applied to samples with full species composition (Death & Collier, 2010; Belmar et al., 2013; McManamay et al., 2013), it is used in this study with values that translate into abundance codes (see table 2).

The counts that resulted from the conversion obviously differ from what the original samples might have been as the exact quantities for each macroinvertebrate species can not be replicated. But the NMDS is still useful as it shows the overall similarities among sites, in terms of macroinvertebrates community composition, even though if it is not 100% accurate.

All the data processing and calculations are done using R (2017). A detailed list of all used packages and a link to the Github code repository can be found in the appendix.

Temporal analysis

All macroinvertebrate indices for each land use category are analysed against the 10-year period from 2006 to 2016 using Spearman correlation coefficients. This technique seems appropriate for this specific case as the involved variables do not follow a linear relationship. Bar plots with standard deviations are used to provide a visual support to the analysis by land use types.

All metrics are analysed for each site during the period of 2006 to 2016 by using the Mann-Kendall trend test. This technique is a non-parametric trend test commonly used for water quality data analysis and is often applied to check if macroinvertebrates indices values increase or decrease over time (Stark & Fowles, 2006). Scattered plots with LOESS curves are also used as a visual support element to help analyse metrics trends for each site. Even though the analysis is performed on all sites, only a subset of them is used on the assessment section. The chosen subset of streams is a good representative of the four land cover types used to categorise all the streams in this study.

All the calculations are done using R (2017). A detailed list of all used packages and a link to the Github code repository can be found in the appendix.

Analysis of stream integrity and influence of land use

Basic statistics

Calculating the mean, minimum and maximum values for each metric and for each site starts showing an interesting division between site categories. The highest %EPT is recorded in West Hoe (native) while the lowest, which is 0.0, belongs to more than one site: Kumeu, Ngakaroa, Oteha, Puhinui and Vaughan Lower, all of which are classified as either pasture or urban. The highest taxa richness is 45 and is found in Hoteo (pasture). The lowest taxa richness is found in the Ngakaroa (pasture) and Oakley (urban) sites and has a value of 7. The best MCI value is found in West Hoe (native) and the worst one is in Otara (urban). A similar scenario happens when looking at SQMCI values; the highest is found in Matakana (pasture) and the lowest in Puhinui (urban).

The mean values for all four metrics on each site are found in table 2 and visually represented in the bars plot displayed in figure 3. The bars plot shows the division of categories as the bars are ordered from the highest to the lowest values, showing a trend that related the higher values to native and forestry categories while the lower values fall into urban and pasture categories, although there are exceptions. When all sites are combined by land use and the mean of all four metrics is calculated (figure 2), the trend appearing in figure 2 is reinforced, as native and forestry land uses capture the highest values while urban and pasture englobe the lowest values.

NDMS

The results from the NDMS analysis (figure 8) reveal the similarities between community composition among the sites. Native sites, especially Cascades and Opanuku, appear quite close to each other, which means they share a similar composition in terms of species abundance. In the case of these two native sites, this is confirmed by similarities with their SQMCI means (figure 3a). It is surprising to see West Hoe (native) quite far apart from both Cascades and Opanuku. But because West Hoe does have the best results (mean values) for the MCI, SQMCI and %EPT (figure 3a, 3b and 3c) it probably has a more sensitive and abundant macroinvertebrate species community. The nature of the bottom of the native streams also helps to identify why Cascades and Opanuku are related but West Hoe is not. While Cascades and Opanuku are hard-bottomed streams, West Hoe is soft-bottomed. The composition of the macroinvertebrate community can differ significantly from soft-bottomed to hard-bottomed freshwater bodies in low lands (Rawer-Jost et al., 2004), which explains the difference between West Hoe and the two other native sites.

On the other hand, the sites with a higher percentage of pasture, urban cover show a similar composition, with Puhinui being on the edge of the spectrum, likely as a result of consistently having some of the lowest scores for all macroinvertebrates metrics.

Mahurangi, the only site under the forestry category shares similarities with some of the best (in terms of indicators performance) pasture sites such as Matakana, Hoteo, and Wairoa. These similarities can be explained by the fact that even if they are classified as pasture sites, Matakana, Hoteo and Wairoa enjoy an important percentage of native and exotic forest on their catchments (table 1).

Land cover trends

To confirm the relationships between each macroinvertebrate metric and the different types of land cover, a simple regression is plotted for each metric (figures 4, 5, 6 and 7). The models resulting from the simple regression (table 4) are used to assess the statistical significance of the model, which leads to identify the strongest dependencies between analysed variables. A Pearson correlation test (table 3) is also performed as an alternative method to provide a secondary insight to the conclusions drawn from the regressions analysis.

MCI

The MCI stands out since it shows a high level of significance to all land use types in both the Pearson correlation test (table 3) and the linear regression model (table 4). For both native (table 4a) and forestry (table 4b) types the MCI displays a positive trend (the index increases as the percentage of native or exotic forest increases) but it completely reverses the trend for both urban (table 4d) and pasture (table 4c) land types (the index decreases as the percentage of urban or pasture land increases).

SQMCI

The SQMCI shows a similar pattern to the MCI but less significant, especially when analysed against pasture and forestry land use types. Both the Pearson correlation test and the linear regression model indicate that the SQMCI increases its value when the percentage of native land increases (table 5a) and decreases when the percentage of urban area increases (table 5d). Because the SQMCI shows a slightly lower level of significance than the MCI, it seems like a good idea to discard its use in the next section (temporal analysis). This decision is also supported by the results of applying a similar approach to Stark (1998); a Pearson correlation test (table 6b) and a linear regression model (table 6a) show a high level of significance and a positive relationship between both the MCI and the SQMCI. A scatter plot to visualize the linear model is also provided (figure 8).

%EPT

%EPT shows a strong response against the percentage of native and urban land. %EPT increases its value as the percentage of native forest cover also increases. But for urban land it does quite the opposite as it tends to decrease its value when the percentage of urban area in the catchment increases.

Taxa richness

The total number of taxa does not seem to be related to any of the land use types except for urban. Both the Pearson correlation test (table 3) and the linear regression model (table 5) show how an increase in the percentage of urban land coverage implies a decrease in taxa richness. Since this metric does not obtain high levels of significance in the performed tests it seems adequate to not include it in the next section (temporal analysis).

Analysis of temporal trends in stream integrity

Regional trends

The Spearman correlation tests do not provide any significant association between the MCI and %EPT values over the years when based on single records. Even if the analysis is focussed on land use categories the hypothetical associations are non-existent. However, the same test performed on the mean values for each year and land use type provides a different result. The native category presents a decline of the MCI in mean values from 2006 to 2016 while the urban category reveals an increase of the MCI in mean values for the same period.

Despite the lack of relevant results from most of the tests, a simple visual analysis to some of the provided plots helps to identify some facts (figures 10, 11, 12 and 13):

The Mahurangi site, which is the only site under the forestry category (exotic forest) presents in overall good water quality results for its MCI (between 100 and 119) across the years, without a clear increasing or declining trend. Its %EPT also does not show any visible trends although it shows relatively high values except for the year 2014, where the lowest %EPT for this site was recorded.

MCI and %EPT values for native forest sites (figure 11) show some of the highest results of the dataset similarly to the forestry scenario, although no obvious trends are detected from the plot other than a substantial variability in some of the years as represented by the standard deviation lines.

Pasture sites show moderate results for the MCI metric (figure 12a) although in the last five years, from 2011 to 1016, the average value stays below the good (80) threshold line. Both the MCI and the %EPT plots (figure 12) would present worst values if the percentage of pasture land was more homogenous across sites. For example, sites like Kumeu or Wairoa, despite being pasture sites, have a significant amount of native or exotic forest, which seems to be the reason why these sites perform better than for example Ngakaroa or Papakura, which are at the lower end of the spectrum of the pasture category.

Sites trends

The Kendall correlation tests (table 8) do not provide significant results for most of the analysed sites except for a few exceptions. The urban stream of Oakley shows an improvement of its MCI over time. Another urban site, Oteha, shows an increasing trend of its %EPT value while West Hoe, a native site, appears to be suffering a decline of its MCI over time. The scatter plots (figure 14) help to visualize the evolution of both MCI and %EPT metrics for each stream over the years thanks to the LOESS curve.

Overall assessment of ecological integrity of Auckland streams

Macroinvertebrate-based indices are measured for a variety of sites and, on average, the best performing sites were detected to be classified as native or forestry (table 2 and 3). Among all measured metrics, MCI stands out as the strongest since it has a significant relationship with the percentage of all four land use types in the catchment area (table 3 and figure 4, 5, 6 and 7). The MCI relationship is positive when related to native and forestry land uses (increases when the surface of native or exotic forest also increases) but negative when related to urban and pasture land cover (declines when urban and pasture areas grow). These findings are aligned with several examples in the literature such as Death & Collier (2010), Young & Collier (2009) and Quinn et al. (1997) that previously demonstrated how MCI, and other stream-health indicators, tend to decline when external stressors (e.g. urban development and vegetation clearing) are on the rise.

All metrics present an association with the percentage of urban land cover (table 3) which results in urban sites presenting some of the worst values of the whole dataset. The reasons for the low results of urban sites are likely to be sedimentation, heavy metal pollution and nutrients input along with changes in the flow and morphology of the streams that resulted from the growing urban intensity in the streams catchment areas (Larned et al., 2004; Walsh et al., 2005).

Overall, mean MCI values of seven sites (46% of the total number of sites) are above the fair level (80) of water quality. Among these seven sites, 14% were classified as forestry (Mahurangi), 43% as native (Opanuku, Cascades and West Hoe) and 43% as pasture (Wairoa, Hoteo and Matakana). The high results from the pasture sites can be explained by the high percentages of exotic and native forest in their catchments (table 1). The rest of the pasture and urban sites present consistently low values for all the measured macroinvertebrate indices.

The regional trends detect a decline in MCI values for native sites in the period from 2006 through 2016 while another increasing trend for the same metric is detected on urban sites. While Opanuku (figure 14h) and Cascades (figure 14a) MCI and %EPT values stay stable over the years, West Hoe (figure 14o) exhibits a steady decline of its MCI (table 8). The Orewa area, which comprises part of the catchment for the West Hoe stream, has been exposed to urban developments during recent years. Lack of sedimentation control on some of the developments (McGhie, 2018) might be the cause of this decline although further studies should be carried to properly evaluate the impact of the developments on the stream condition. Nevertheless, this case is a good example of how sites with high percentage of native forest on their catchment are not completely immune to external stressors.

Improvement of MCI values in urban areas over the years 2006 to 1016 are led by the Oakley site (figure 14g). The improvement on this type of sites is likely due to the restoration work carried out by the Auckland Council and community groups such as the Friends of Oakley Creek Te Auaunga. Riparian planting of native species, sedimentation control and measures against the input of pollutions and nutrients (generally man-made wetlands and ponds) are some of the strategies being implemented in the Oakley stream catchment area (Auckland Council, 2018). This sort of restoration programmes not only provide benefits to the stream and the fauna and flora it supports but also help to raise awareness among local communities and foster a sense of conservation ethic that becomes precious (Craig & Stewart, 1994). It is important to keep monitoring streams and areas where restoration programmes are in place to assess their effectiveness and ideally help improve their success in the future.

Forestry sites (Mahurangi) do not show any specific trend although the degree of variability between certain years is significant (figure 10b). These variations in the %EPT might occur because of harvesting activities, which are known to cause declines in stream health (Death et al., 2003). To better assess forestry sites, it is recommended to include harvesting data in the analysis as well as to make sure that monitoring is maintained, especially after logging operations.

The dataset obtained for this study could be expanded to include more sites. This would likely translate into more significant results when assessing regional trends and would provide a wider array of candidates to choose reference conditions from. With the current dataset, native sites are recommended to be used as reference sites and their scores to be used to effectuate comparisons with other sites. Ideally, reference sites would be available for hard-bottomed and soft-bottomed streams, but this study only provides one soft-bottom reference site, West Hoe. West Hoe would be an appropriate candidate for soft-bottomed reference streams if it was not going through a degrading trend. Cascades appears to be a minimally disturbed site since its catchment is inhabited and it has a 100% coverage of native forest, therefore a good candidate for hard-bottomed reference site.

Cascades is also arguably the best example of what ideal conditions in the Auckland region might look like, at least for hard-bottomed streams, also known as the best attainable condition (Stoddard et al., 2006; Clapcott et al., 2017).

Along with the expansion of the number of sites, the frequency of the surveys could be increased to help detect seasonal patterns in the data. It is known that changes in the temperature and the availability of light have an impact on freshwater ecosystems, therefore it would be appropriate to have results in different conditions encountered throughout a natural year. The land cover data could also be improved as the percentages of the different land use types are likely to change over time. Recent studies suggest that multiple resolutions of data using different scales may help assess the ecological integrity of streams (Kamarinas et al., 2016).

Other indicators could be measured and included in the dataset in order to improve the assessment of the streams. Decomposition rates of woody debris and leaf biomass (Sponseller et al., 2001; Little & Altermatt, 2018), fish-based indicators (Joy & Death, 2014) and ecosystem metabolism (Young & Collier, 2009) are known to be related to land use stressors and would provide a useful complement to the macroinvertebrate-based information already available.

Appendix 1 - Figures

Figure 1. Sites map

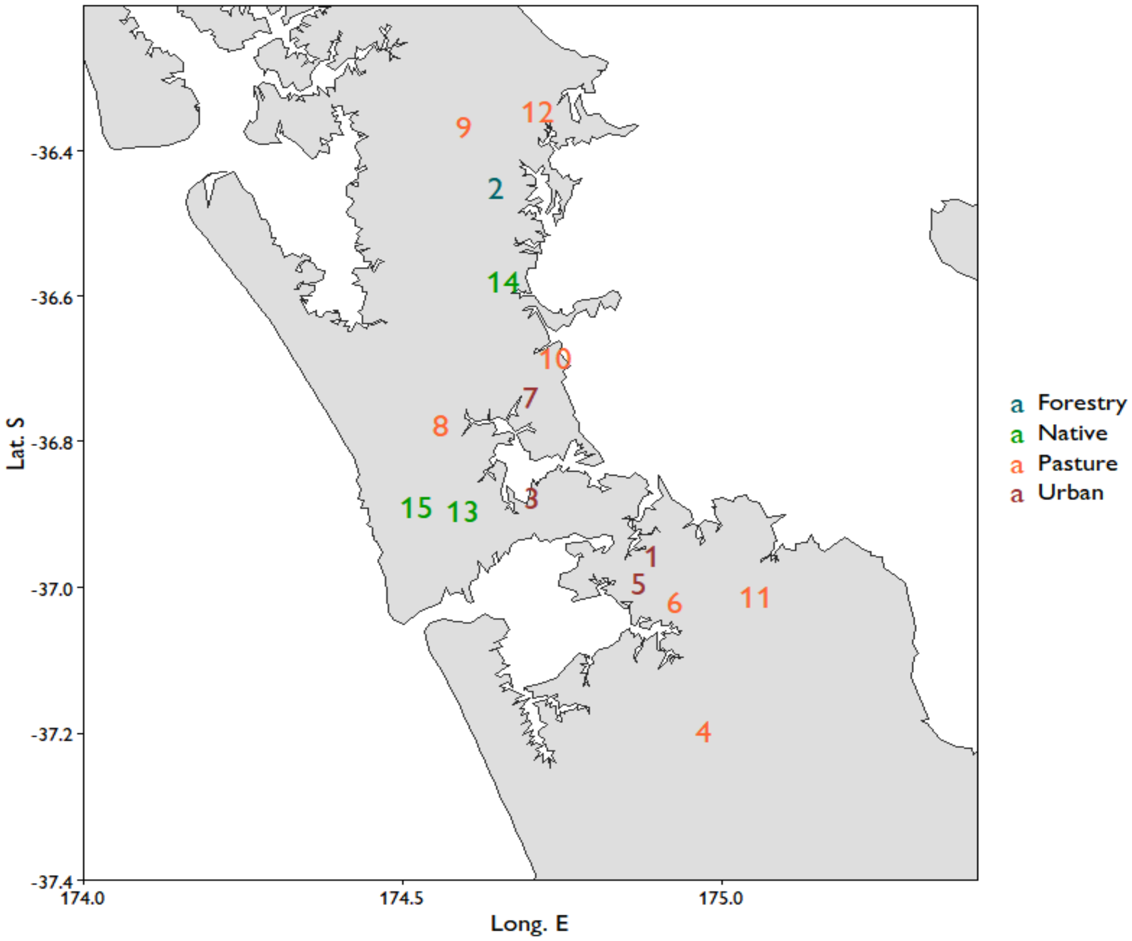


Fig. 1 The Auckland region with sample sites (n=15) included in this study shown. The colour represents the land cover classification of each site. Site names correspond as follows: (1) Otara, (2) Mahurangi, (3) Oakley, (4) Ngakaroa, (5) Puhinui, (6) Papakura, (7) Oteha, (8) Kumeu, (9) Hoteo, (10) Vaughan Lower, (11) Wairoa, (12) Matakana, (13) Opanuku, (14) West Hoe, (15) Cascades.

Figure 2. Mean metrics per land use category

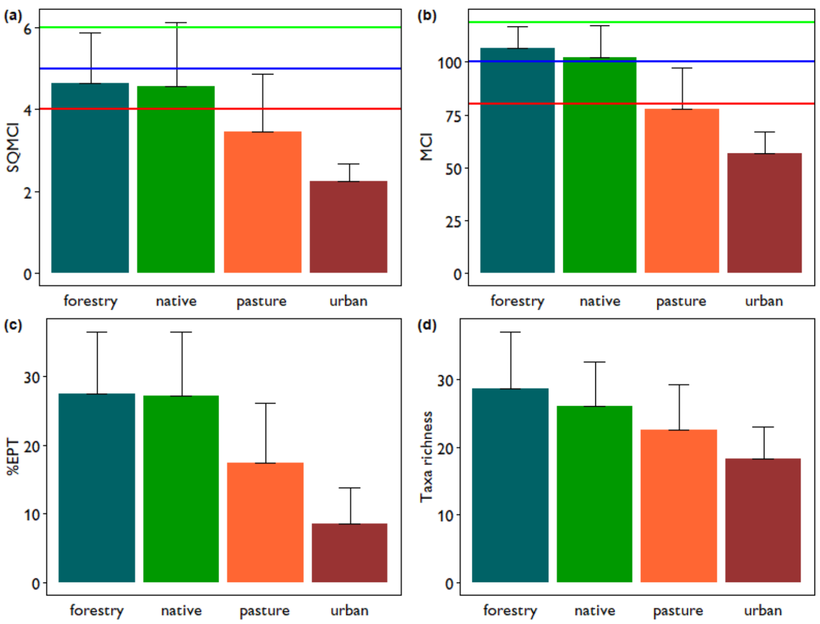


Fig. 2 Bar plots of mean values for all four macroinvertebrates metrics (SQMCI, MCI, %EPT and taxa richness) calculated for each land use category (forestry, native pasture and urban). The bars are filled with colours depending on the land use category (green: native, blue: forestry, orange: pasture, brown: urban). The line on top of each bar represents the standard deviation. The three coloured lines (red, blue, green) appearing on the MCI and SQMCI plots represent the thresholds for water quality status. SQMCI > 6 means clean water, 5-6 doubtful quality, 4-5 low pollution likely and < 4 substantial pollution (Stark, 1998). The MCI scores > 119 are considered excellent, 100-119 are considered good, 80-99 are considered fair, and < 80 are considered poor (Stark & Maxted, 2007b).

Figure 3. Mean values per metric per site

Fig. 3 Bar plots of mean values for all four macroinvertebrates metrics (SQMCI, MCI, %EPT and taxa richness) calculated for each site. The bars are filled with colours depending on the site's category (green: native, blue: forestry, orange: pasture, brown: urban). The line on top of each bar represents the standard deviation. The MCI and SQMCI plots display the threshold for water quality status. SQMCI > 6 means clean water, 5-6 doubtful quality, 4-5 low pollution likely and < 4 substantial pollution (Stark, 1998). The MCI scores > 119 are considered excellent, 100-119 are considered good, 80-99 are considered fair, and < 80 are considered poor (Stark & Maxted, 2007b).

Figure 4. Metrics vs Native Forest

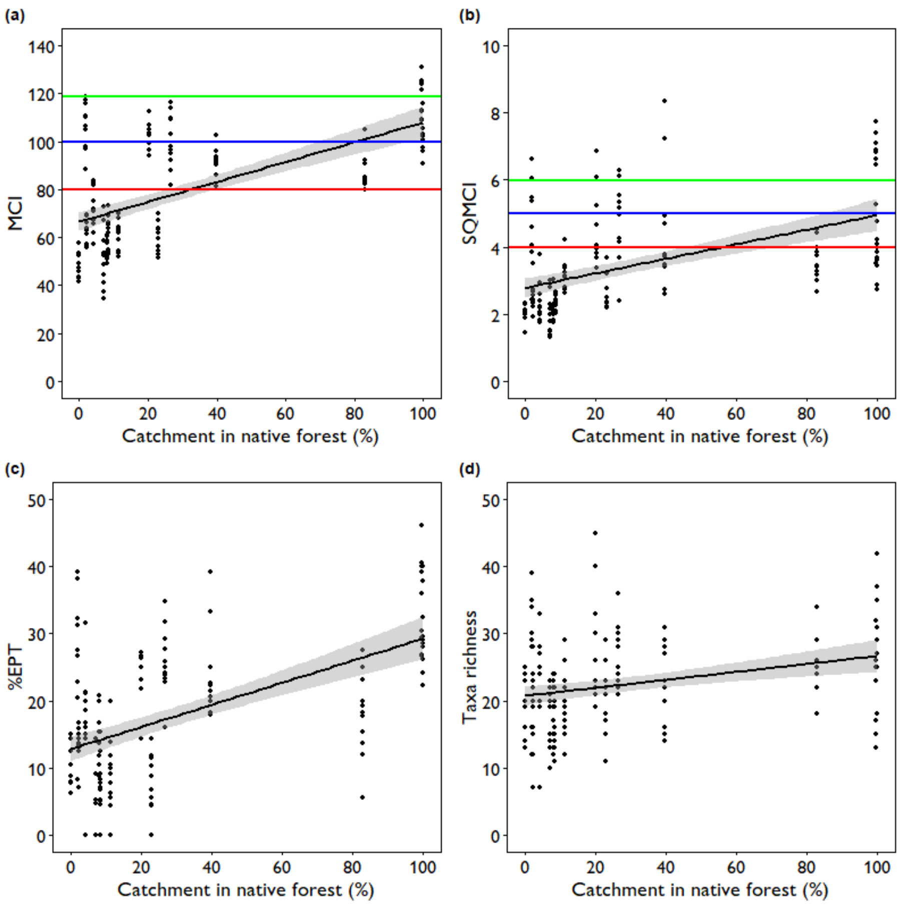


Fig. 4 Scatter plots for all macroinvertebrate indices against the percentage of native forest in the catchment area. A linear method is used to plot the best fit line (in black) and the 95% confidence intervals (in grey). MCI and SQMCI plots display the threshold lines that correspond with water quality levels. SQMCI > 6 means clean water, 5-6 doubtful quality, 4-5 low pollution likely and < 4 substantial pollution (Stark, 1998). The MCI scores > 119 are considered excellent, 100-119 are considered good, 80-99 are considered fair, and < 80 are considered poor (Stark & Maxted, 2007b).

Figure 5. Metrics vs Forestry (Exotic Forest)

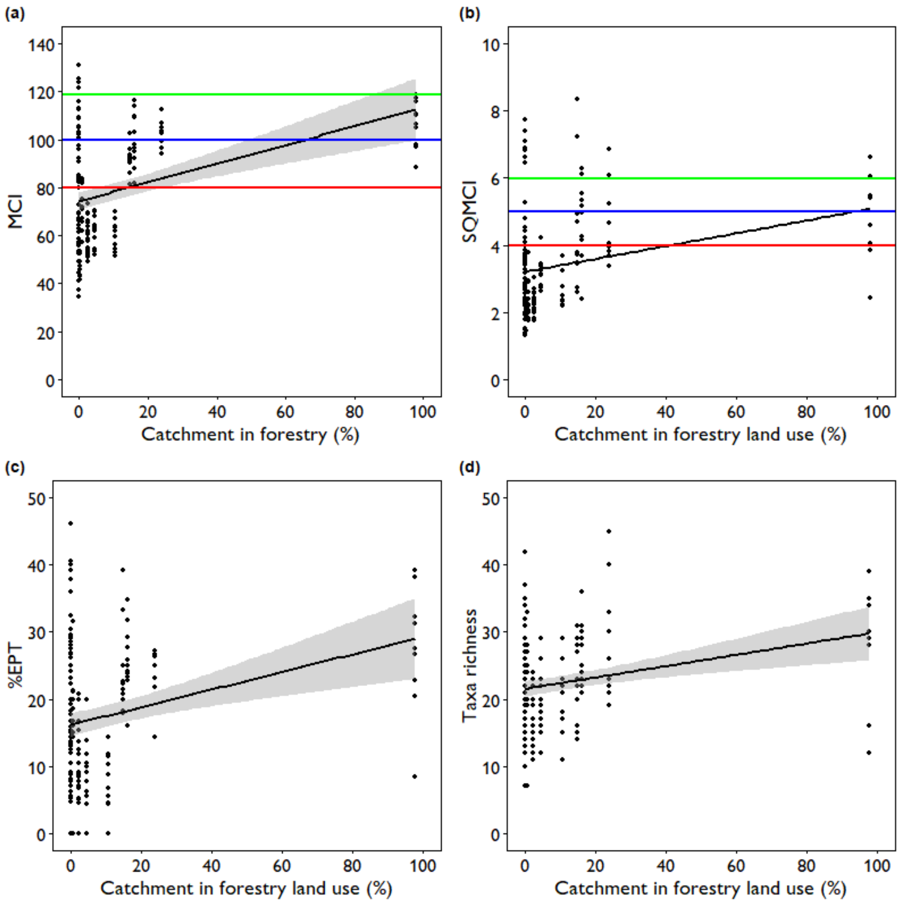


Fig. 5 Scatter plots for all macroinvertebrate indices against the percentage of forestry (exotic forest) in the catchment area. A linear method is used to plot the best fit line (in black) and the 95% confidence intervals (in grey). MCI and SQMCI plots display the threshold lines that correspond with water quality levels. SQMCI > 6 means clean water, 5-6 doubtful quality, 4-5 low pollution likely and < 4 substantial pollution (Stark, 1998). The MCI scores > 119 are considered excellent, 100-119 are considered good, 80-99 are considered fair, and < 80 are considered poor (Stark & Maxted, 2007b).

Figure 6. Metrics vs Pasture

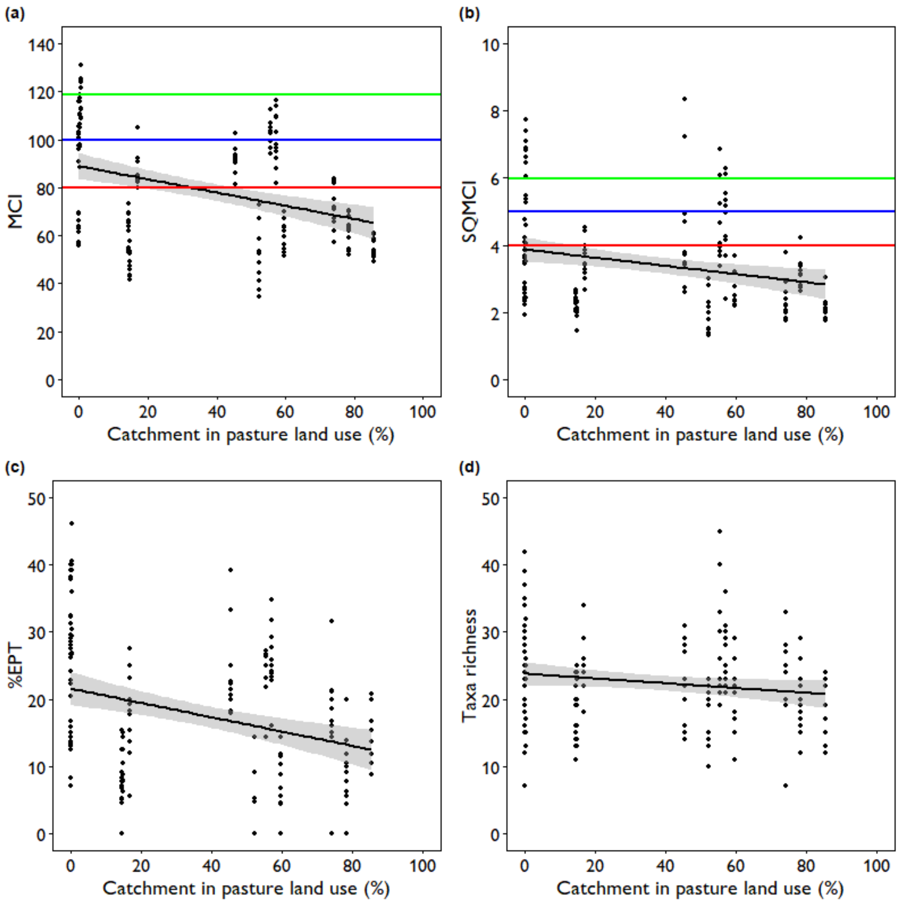


Fig. 6 Scatter plots for all macroinvertebrate indices against the percentage of pasture land in the catchment area. A linear method is used to plot the best fit line (in black) and the 95% confidence intervals (in grey). MCI and SQMCI plots display the threshold lines that correspond with water quality levels. SQMCI > 6 means clean water, 5-6 doubtful quality, 4-5 low pollution likely and < 4 substantial pollution (Stark, 1998). The MCI scores > 119 are considered excellent, 100-119 are considered good, 80-99 are considered fair, and < 80 are considered poor (Stark & Maxted, 2007b).

Figure 7. Metrics vs Urban

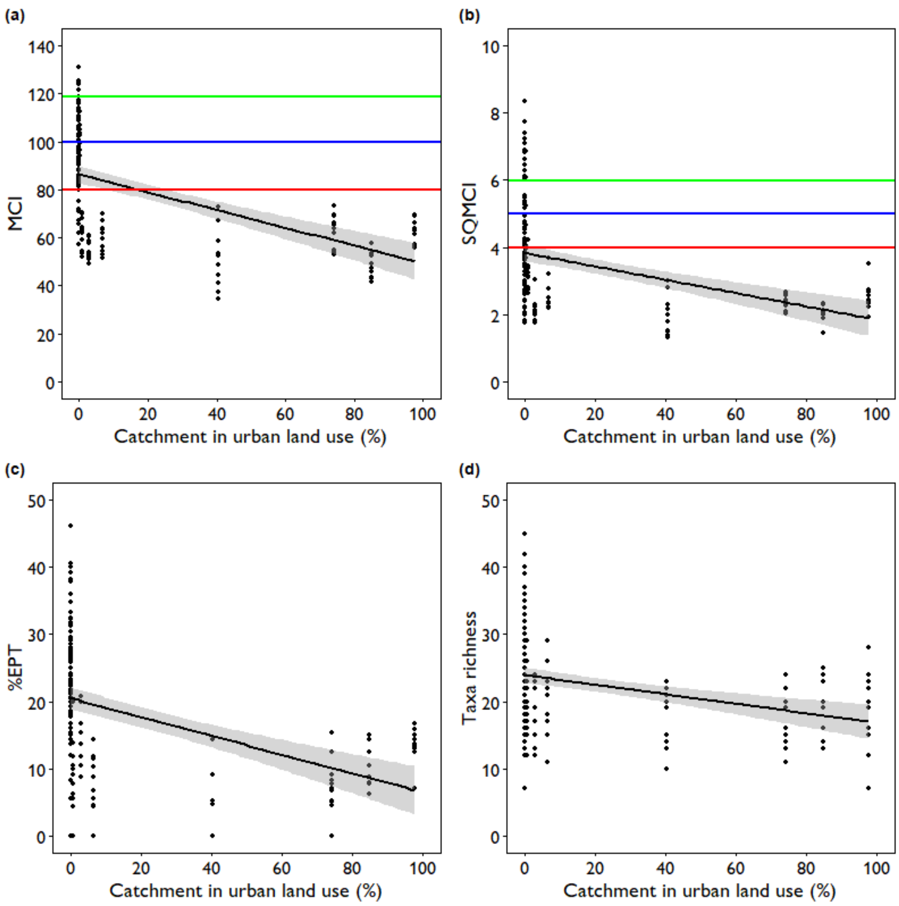


Fig. 7 Scatter plots for all macroinvertebrate indices against the percentage of urban land in the catchment area. A linear method is used to plot the best fit line (in black) and the 95% confidence intervals (in grey). MCI and SQMCI plots display the threshold lines that correspond with water quality levels. SQMCI > 6 means clean water, 5-6 doubtful quality, 4-5 low pollution likely and < 4 substantial pollution (Stark, 1998). The MCI scores > 119 are considered excellent, 100-119 are considered good, 80-99 are considered fair, and < 80 are considered poor (Stark & Maxted, 2007b).

Figure 8. SQMCI vs MCI

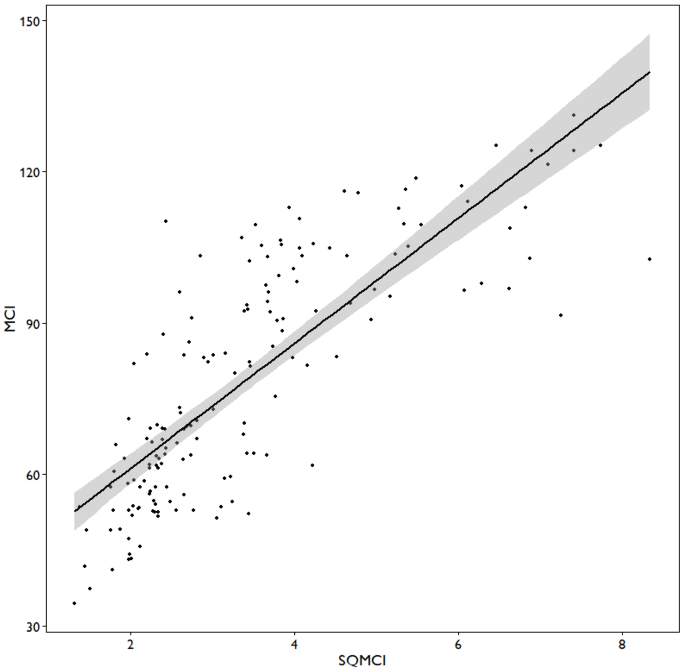


Fig. 8 Scatter plot of the MCI values against the SQMCI values for all sites from 2006 to 2016. A linear method is used to plot the best fit line (in black) and the 95% confidence intervals (in grey).

Figure 9. NDMS

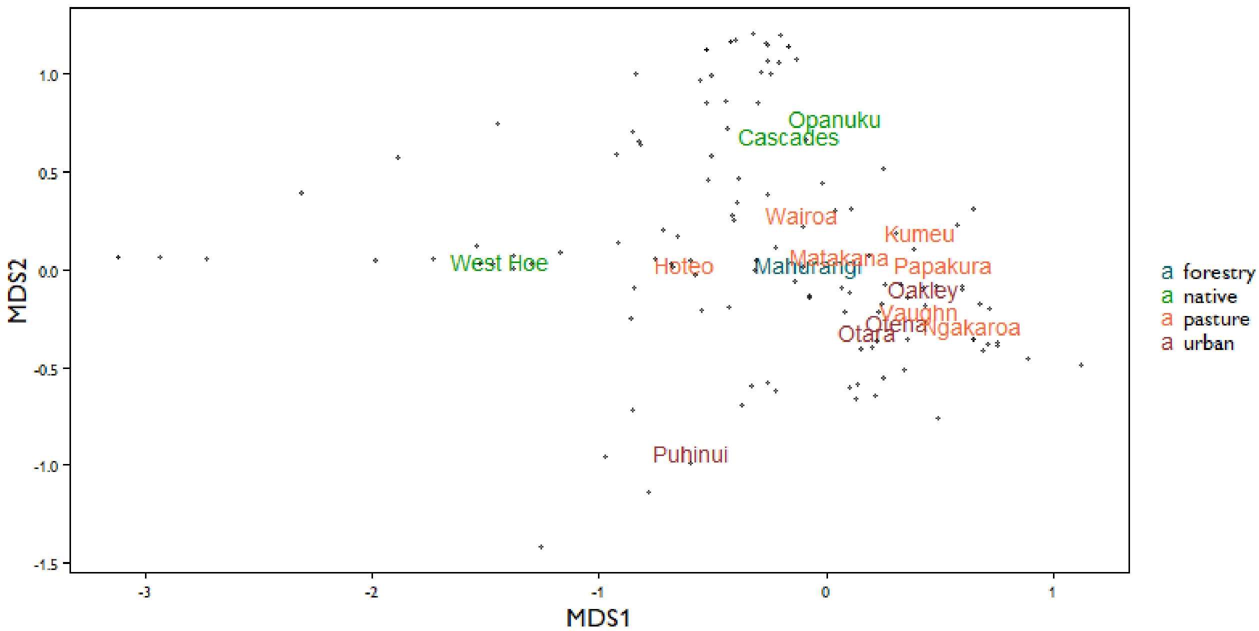


Fig. 9 Plot resulting from the NDMS execution. The black dots represent macroinvertebrate species and the name of the sites appear close if their species composition is similar or far apart if it is not. Each site label is coloured according to its land use category (green: native, blue: forestry, orange: pasture, brown: urban).

Figure 10. MCI and %EPT vs time - Forestry

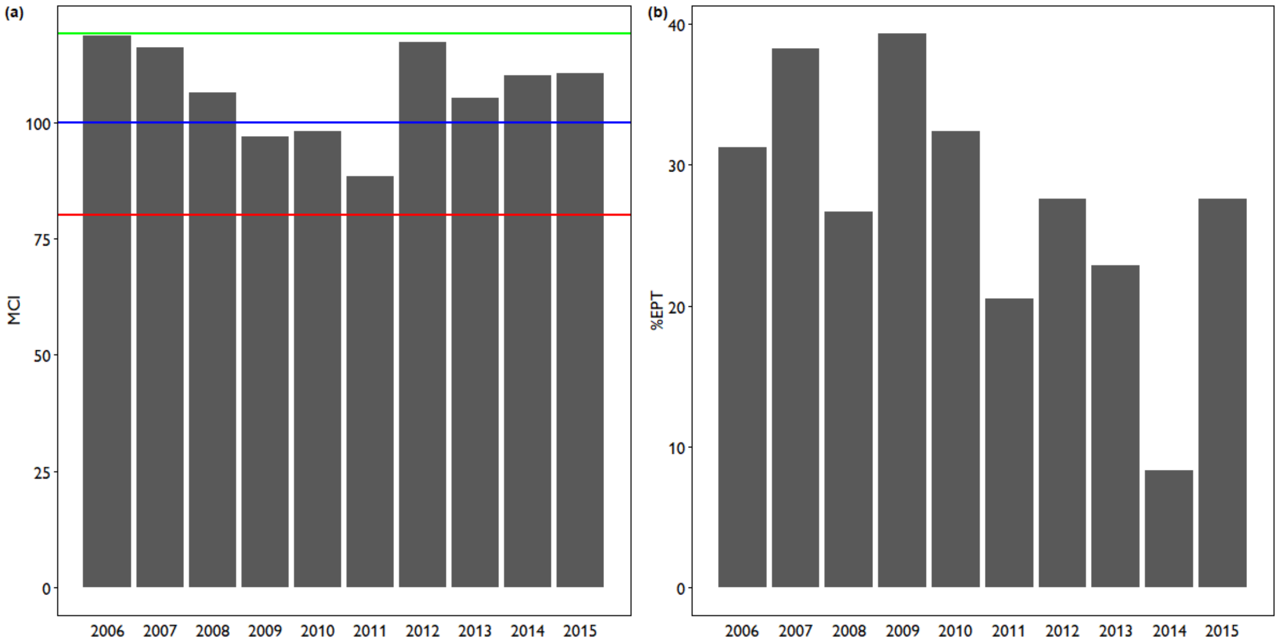


Fig. 10 Bar plots for the annual mean values of sites belonging to the forestry land use category from 2006 to 2016. The three coloured lines (red, blue, green) appearing on the MCI plot represent the thresholds for water quality status. The MCI scores > 119 are considered excellent, 100-119 are considered good, 80-99 are considered fair, and < 80 are considered poor (Stark & Maxted, 2007b). The standard deviation lines are missing since only one site is classified under the forestry category (Mahurangi).

Figure 11. MCI and %EPT vs time – Native

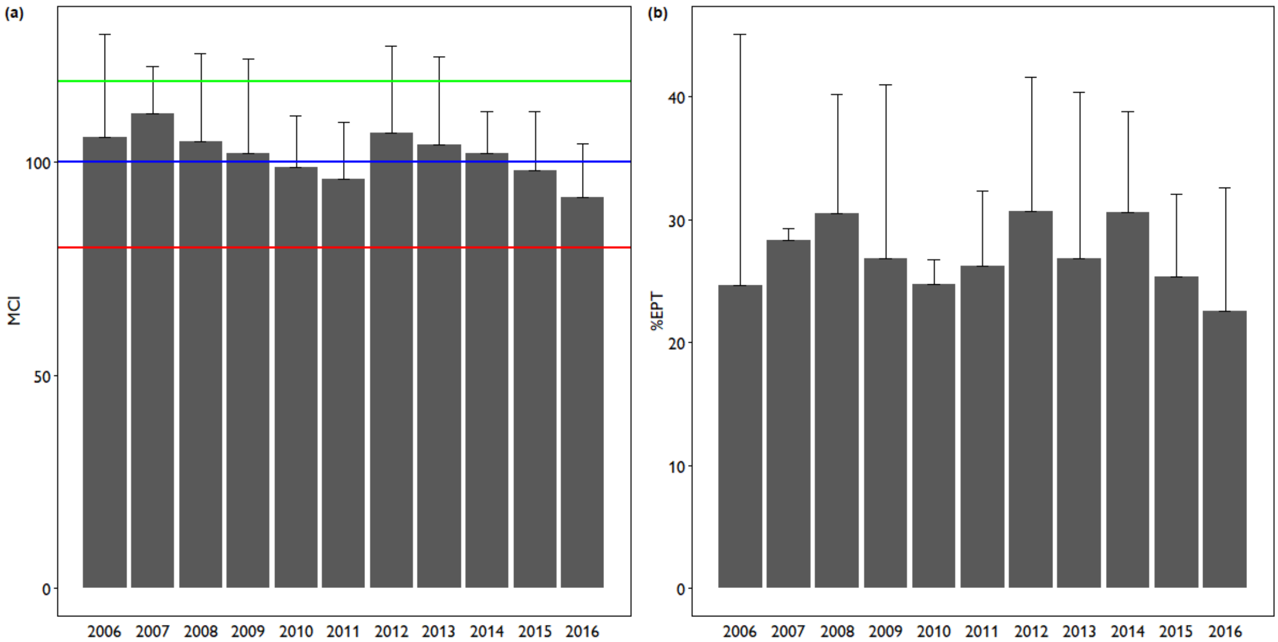


Fig. 11 Bar plots for the annual mean values of sites belonging to the native forest land use category from 2006 to 2016. The three coloured lines (red, blue, green) appearing on the MCI plot represent the thresholds for water quality status. The MCI scores > 119 are considered excellent, 100-119 are considered good, 80-99 are considered fair, and < 80 are considered poor (Stark & Maxted, 2007b). The lines on top of the bars represent the standard deviations.

Figure 12. MCI and %EPT vs time – Pasture

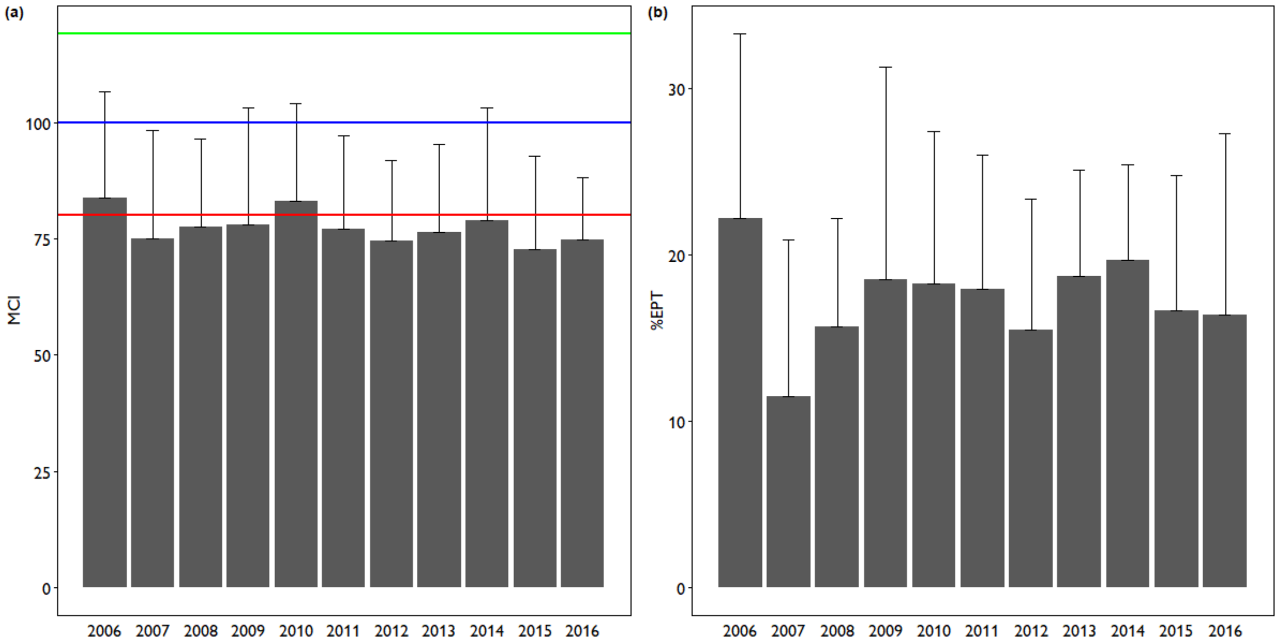


Fig. 12 Bar plots for the annual mean values of sites belonging to the pasture land use category from 2006 to 2016. The three coloured lines (red, blue, green) appearing on the MCI plot represent the thresholds for water quality status. The MCI scores > 119 are considered excellent, 100-119 are considered good, 80-99 are considered fair, and < 80 are considered poor (Stark & Maxted, 2007b). The lines on top of the bars represents the standard deviations.

Figure 13. MCI and %EPT vs time – Urban

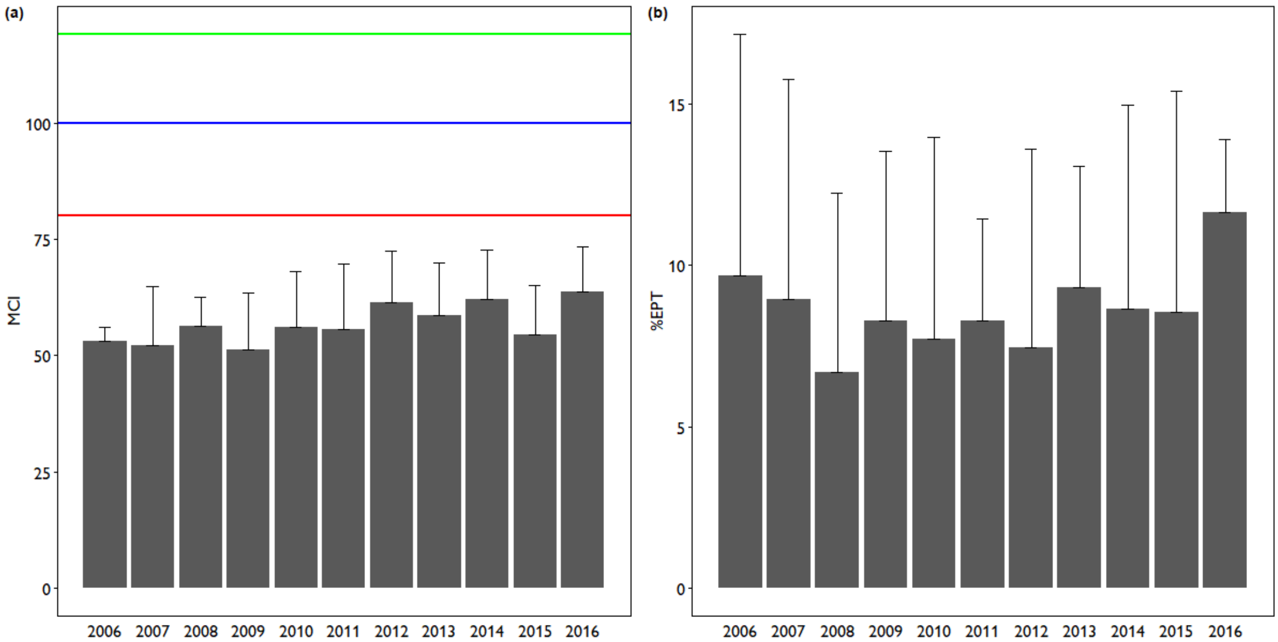
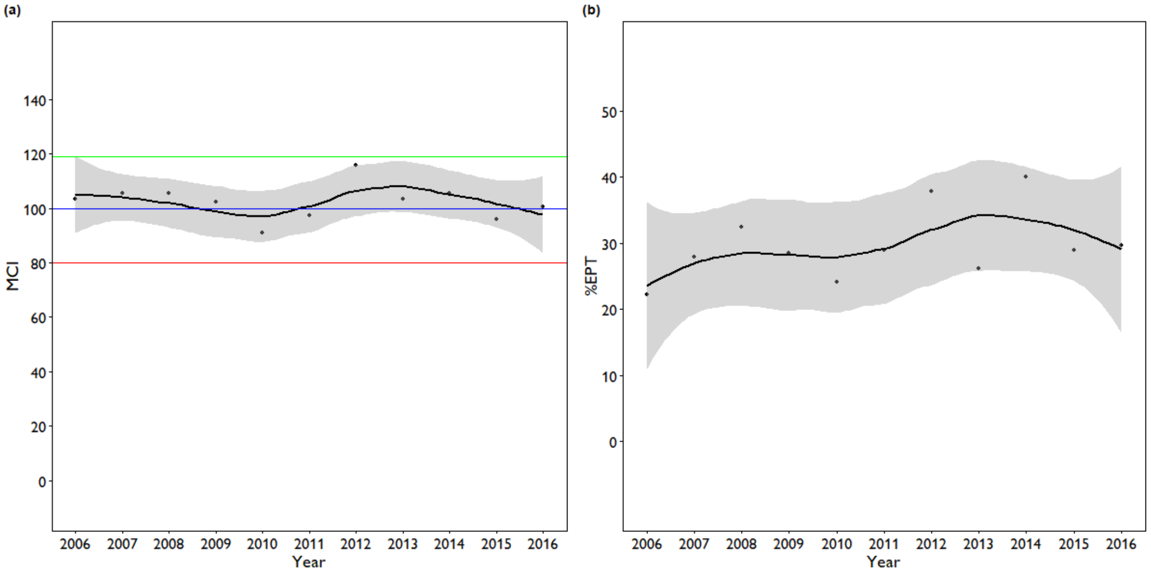


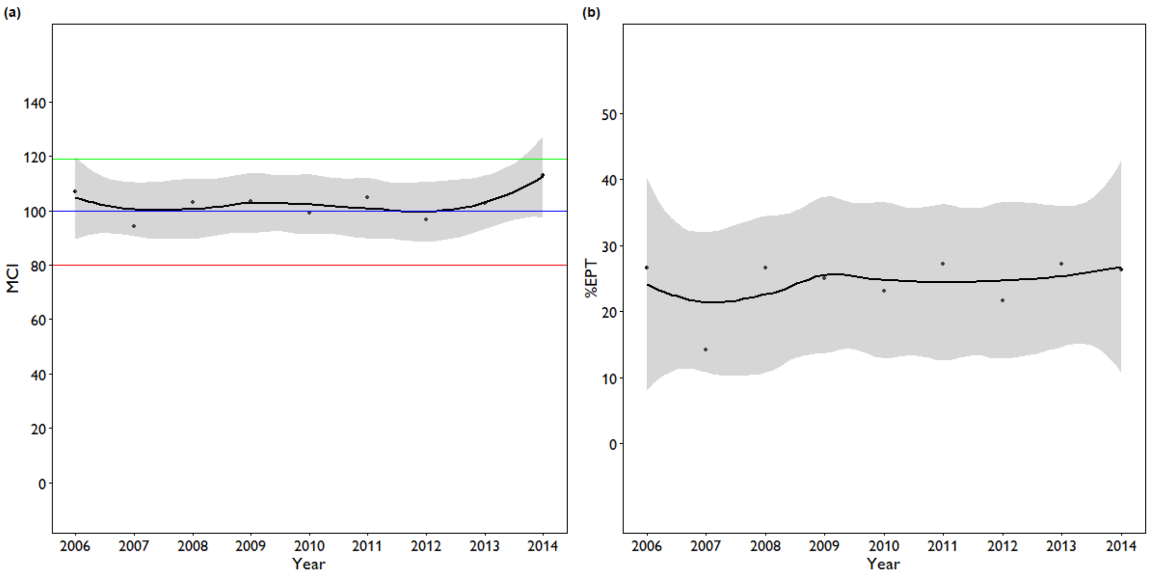
Fig. 13 Bar plots for the annual mean values of sites belonging to the pasture land use category from 2006 to 2016. The three coloured lines (red, blue, green) appearing on the MCI plot represent the thresholds for water quality status. The MCI scores > 119 are considered excellent, 100-119 are considered good, 80-99 are considered fair, and < 80 are considered poor (Stark & Maxted, 2007b). The lines on top of the bars represent the standard deviations.

Figure 14. MCI and EPT vs Time

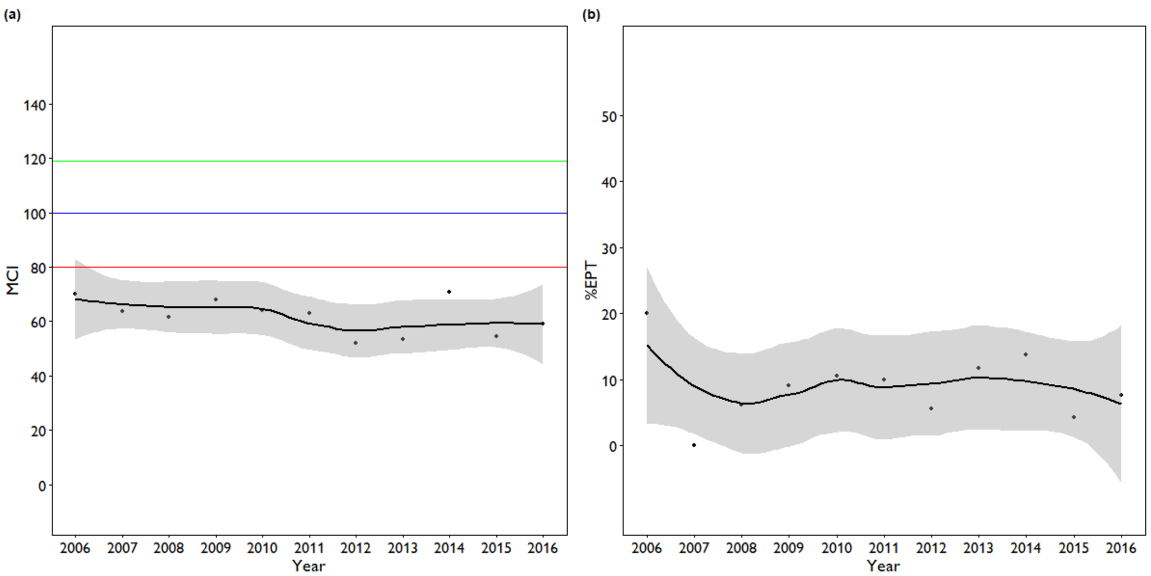
(a) Cascades



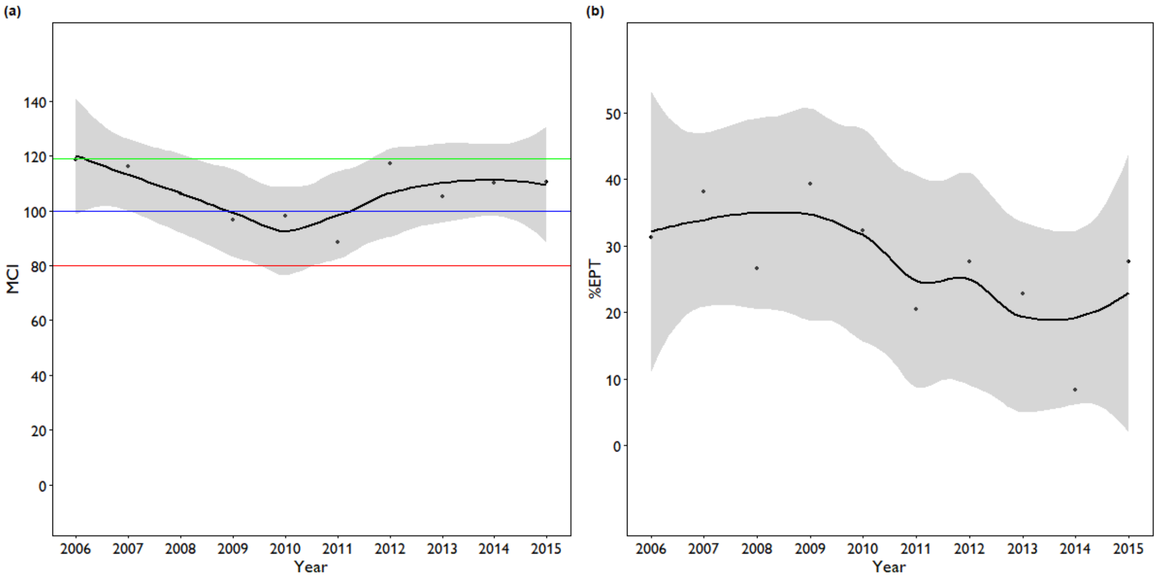
(b) Hoteo



(c) Kumeu



(d) Mahurangi



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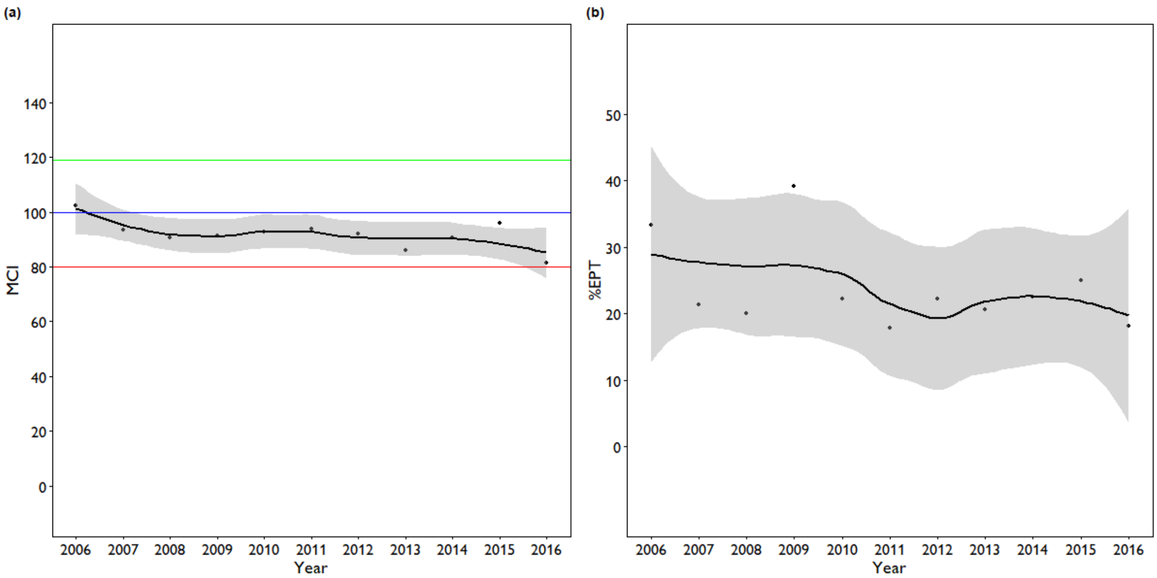

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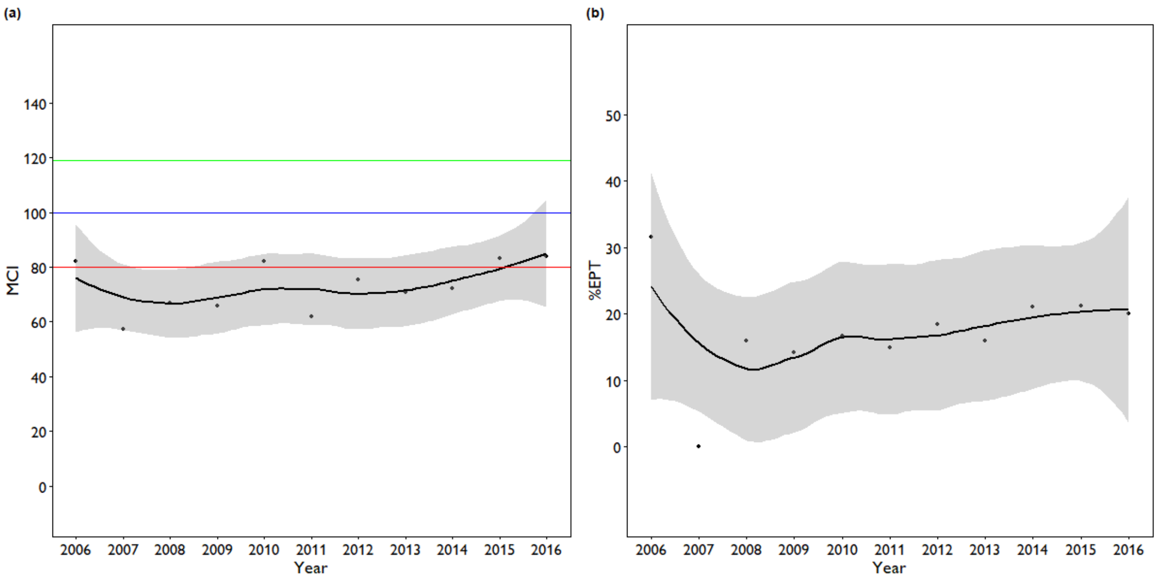

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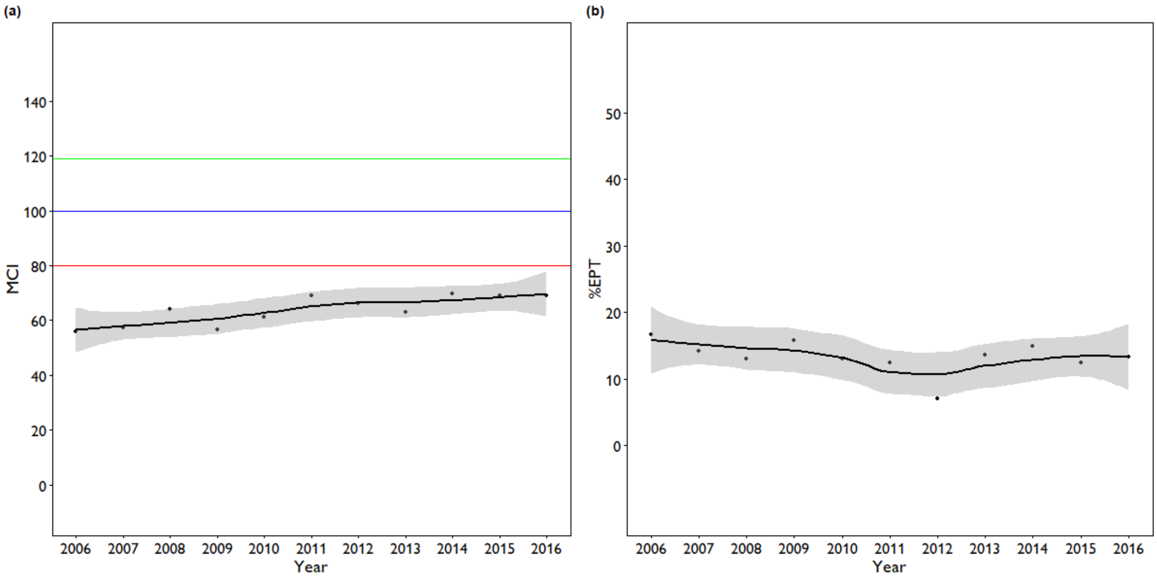
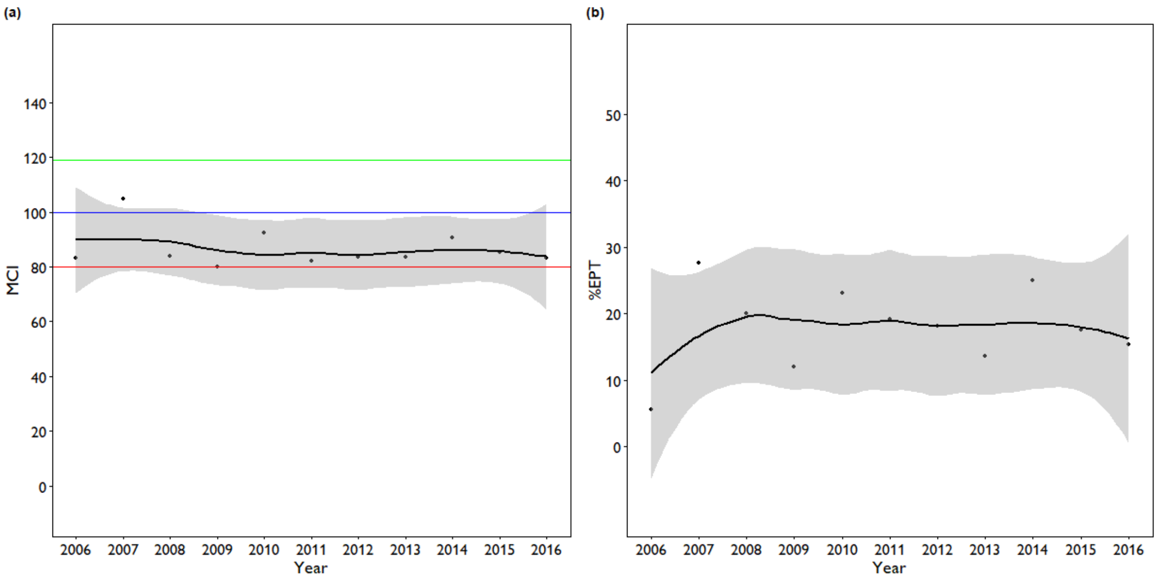
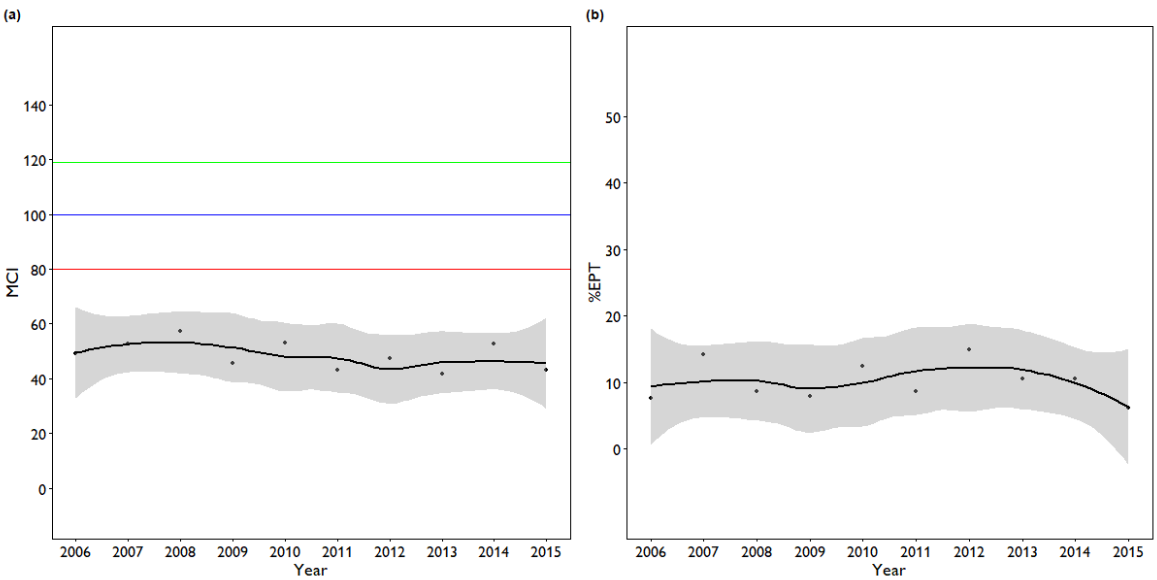


(h) Opanuku



(i) Otara



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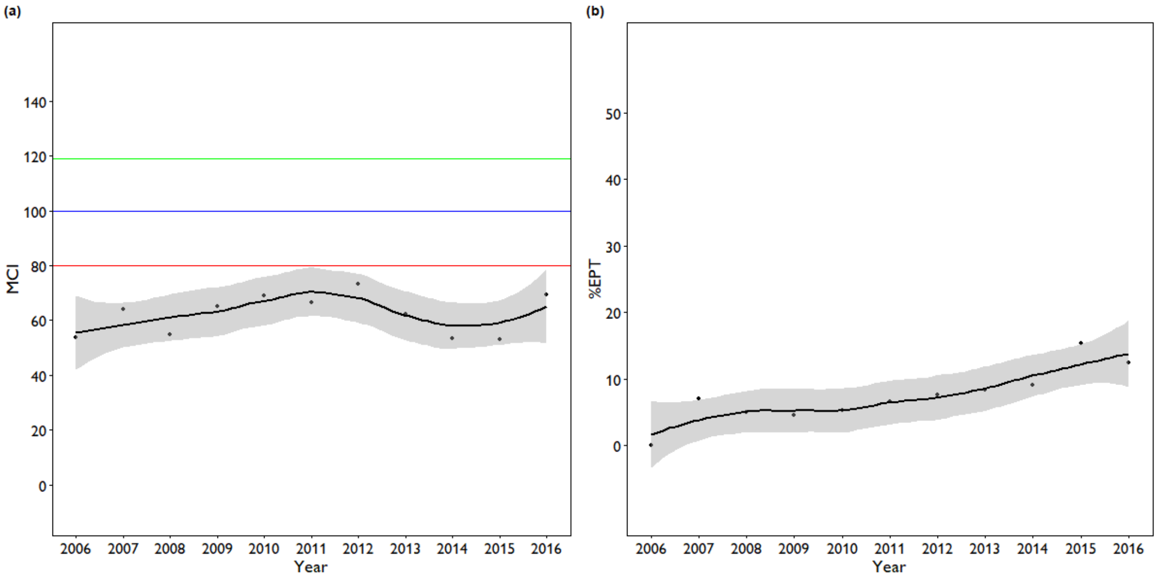
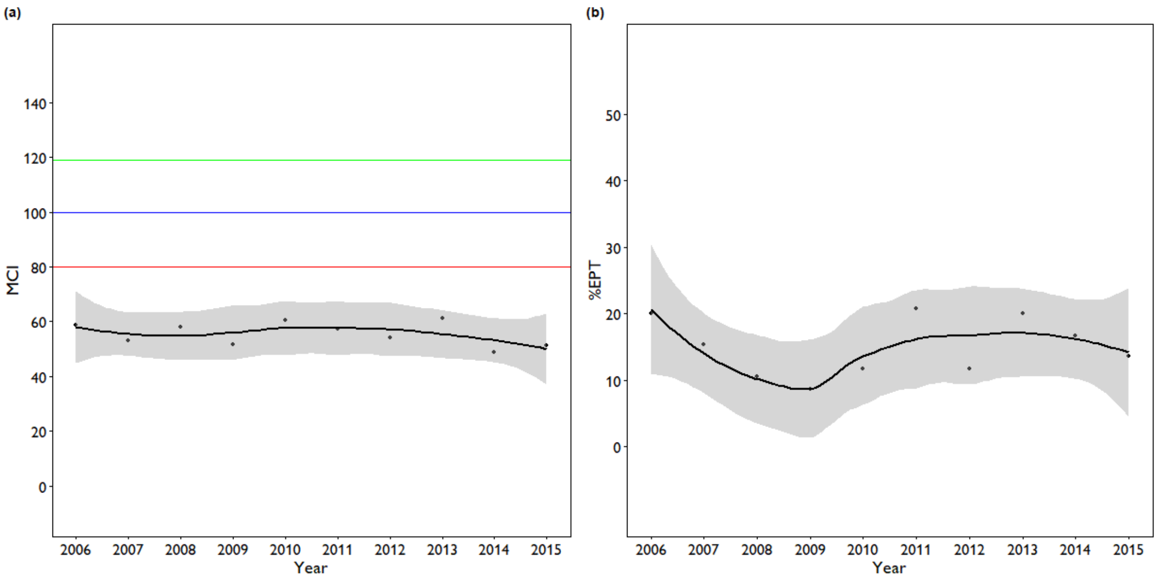
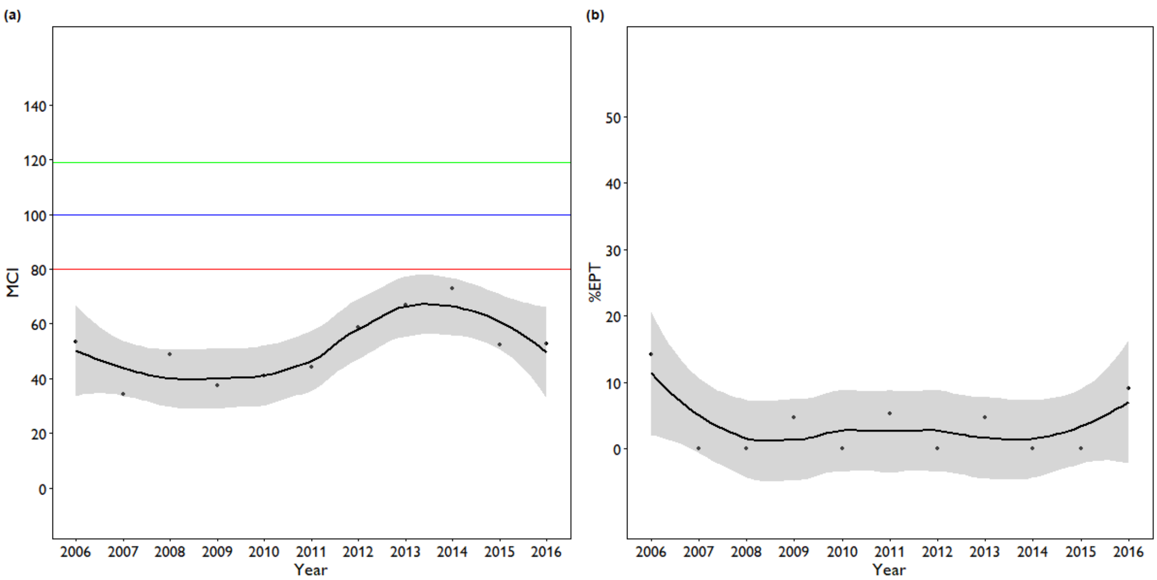


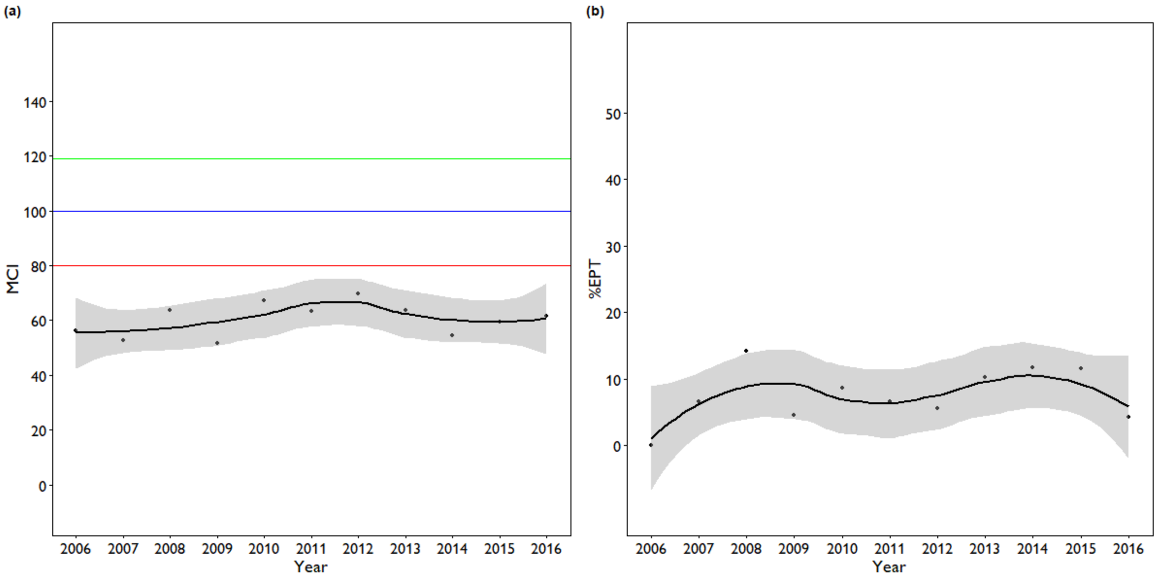
(k) Papakura



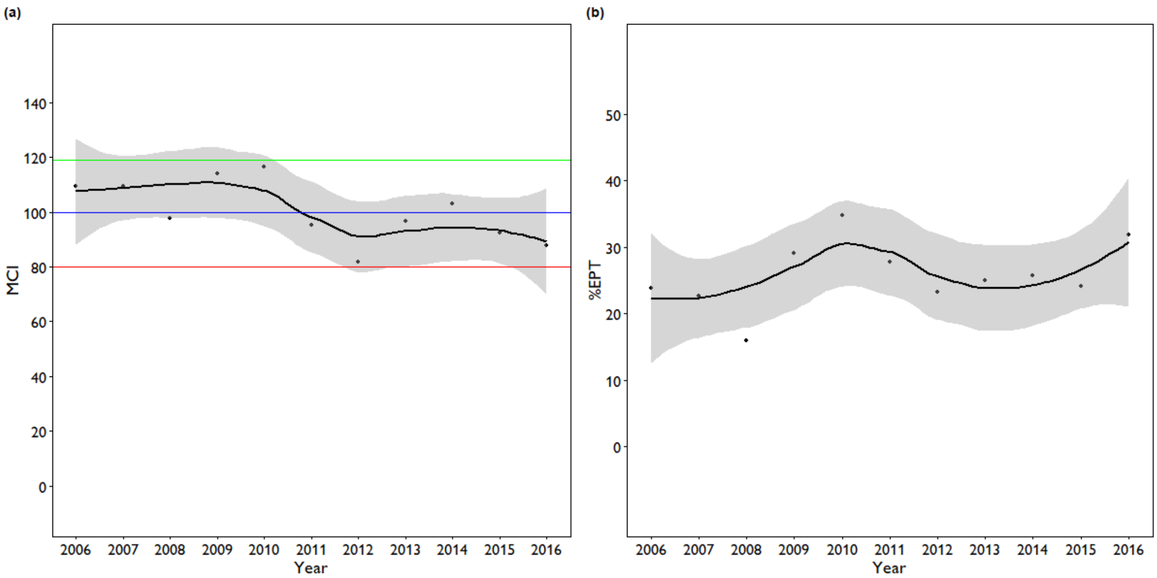
(l) Puhinui



(m) Vaughan Lower



(n) Wairoa



(o) West Hoe

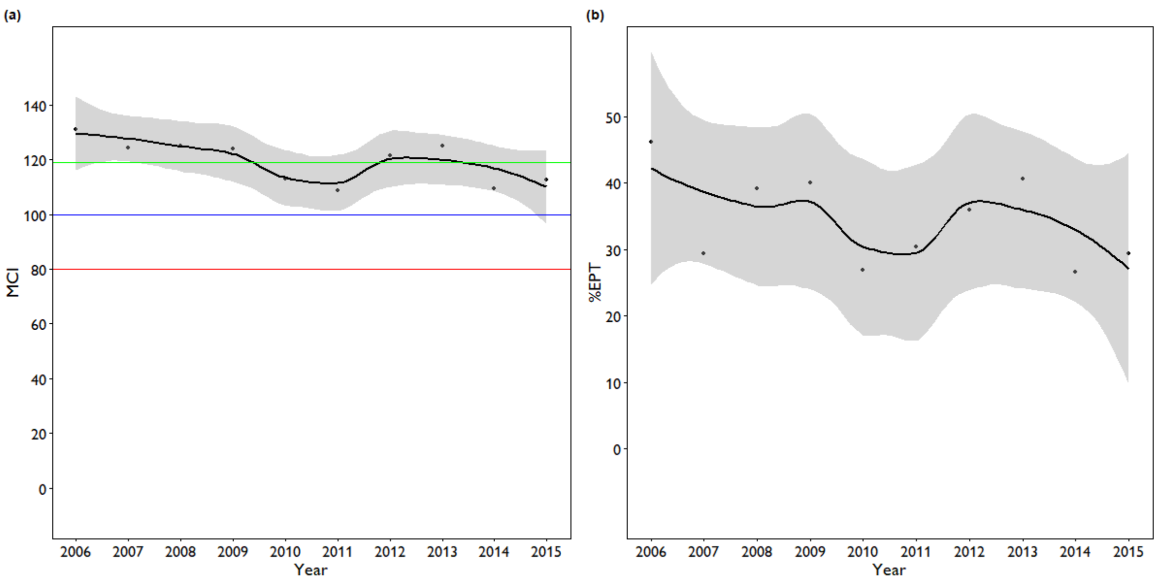


Fig. 14 Scatter plots for each site for both %EPT and MCI metrics values from 2006 to 2016. The MCI plots display three horizontal lines (green, blue, red) to represent scores > 119, which are considered excellent, 100-119, which are considered good, 80-99, which are considered fair, and < 80, which are considered poor (Stark & Maxted, 2007b). A LOESS (local regression) curve is plotted to predict the variability of the metrics along the years. A confidence interval set to 95% is displayed in grey. The limits on the Y axis have been expanded below zero and well above the maximum value to accommodate the confidence intervals, otherwise some of them would miss some sections since their values would go way off-limits.

Appendix 2 - Tables

Table 1. Sites land cover percentage and category

N	Name	Category	% Native	% Exotic forest	% Horticulture	% Pasture	% Urban	Bottom
1	Otara	Urban	0	0.2	0	14.9	84.0	S
2	Mahurangi	Forestry	1.9	97.9	0	0.2	0	S
3	Oakley	Urban	2.3	0	0	0	97.7	S
4	Ngakaroa	Pasture	4.2	0.8	20.8	74.2	0	S
5	Puhinui	Urban	7.1	0	0	52.4	40.5	S
6	Papakura	Pasture	8.1	2.5	0.9	85.6	2.9	S
7	Oteha	Urban	8.6	2.4	0.1	14.5	74.3	S
8	Kumeu	Pasture	11.4	4.5	4.8	78.4	0.9	S
9	Hoteo	Pasture	20.2	23.9	0.1	55.6	0.2	S
10	Vaughan Lower	Pasture	23.1	10.6	0	59.6	6.7	S
11	Wairoa	Pasture	26.7	16.1	0	57.2	0	S
12	Matakana	Pasture	39.7	14.8	0	45.5	0	S
13	Opanuku	Native	83	0	0	17	0	H
14	West Hoe	Native	99.6	0	0	0.4	0	S
15	Cascades	Native	100	0	0	0	0	H

Table 1 All sites with their respective land cover classification and the percentages of each type of land cover. The numbers in the first column correspond to the numbers displayed in the sites map (fig. 1). The last column indicates the nature of the bottom, S for soft and H for hard (rocky).

Table 2. Abundance codes

Abundance code	Counts (value)
Rare (R)	1
Common (C)	5
Abundant (A)	20
Very Abundant (VA)	100
Very very abundant (VVA)	500

Table 2 Abundance codes translated into numeric values. The translation from qualitative to quantitative values follows the thresholds set by Stark (1998).

Table 3. Basic calculations for each site

Site	**n**	**%EPT**				**TR**				**MCI**				**SQMCI**			
		Min	Max	Mean	Sd	Min	Max	Mean	Sd	Min	Max	Mean	Sd	Min	Max	Mean	Sd
Cascades	11	22.4	40.0	29.7	5.3	18	42	**30.8**	6.5	91.0	115.9	102.4	6.4	2.7	4.8	3.7	0.6
Hoteo	9	14.3	27.3	24.3	4.2	19	**45**	28.8	**9.0**	94.3	112.8	102.7	5.6	3.4	6.9	4.6	1.2
Kumeu	11	**0.0**	20.0	9.0	5.3	12	29	19.7	5.0	52.1	70.7	61.9	6.5	2.6	4.2	3.2	0.4
Mahurangi	10	8.3	39.3	27.5	**9.0**	12	39	28.6	8.5	88.4	118.6	106.8	9.9	2.4	6.6	4.6	1.2
Matakana	11	17.9	39.1	23.9	6.6	14	31	22.9	6.0	81.4	102.5	91.9	5.3	2.6	**8.3**	4.4	**1.8**
Ngakaroa	11	**0.0**	31.6	17.3	7.5	**7**	33	22.9	6.7	57.4	83.8	72.9	9.2	1.8	3.8	2.4	0.6
Oakley	11	7.1	16.7	13.4	**2.5**	**7**	28	19.0	6.0	56.0	69.7	63.8	5.3	1.9	3.5	2.5	0.4
Opanuku	11	5.6	27.6	17.9	6.2	18	34	25.2	4.1	80.0	104.8	86.7	7.0	2.7	4.5	3.6	0.6
Otara	10	6.2	15.0	10.2	2.9	13	25	19.6	4.2	41.8	**57.5**	**48.6**	5.3	1.4	**2.3**	**2.0**	**0.2**
Oteha	11	**0.0**	15.4	7.4	4.1	11	24	**16.5**	**4.1**	52.9	73.2	62.2	7.4	2.0	2.7	2.4	**0.2**
Papakura	10	8.7	20.8	14.9	4.3	12	24	17.7	4.2	49.0	61.2	55.5	**4.3**	1.8	3.1	2.1	0.4
Puhinui	11	**0.0**	**14.3**	3.5	4.8	10	**23**	17.9	4.2	**34.4**	72.8	51.2	**11.9**	**1.3**	3.0	2.0	0.6
Vaughan Lower	11	**0.0**	**14.3**	7.7	4.1	11	29	20.0	5.3	51.7	69.8	60.4	5.9	2.2	3.7	2.6	0.5
Wairoa	11	16.0	34.8	25.9	5.0	**21**	36	26.5	4.7	81.7	116.5	100.4	11.2	2.4	6.3	4.8	1.1
West Hoe	10	**26.7**	**46.2**	34.5	6.8	13	32	21.6	5.9	**108.7**	**131.2**	**119.5**	7.9	**3.5**	7.7	**6.5**	1.3

Table 3 Minimum, maximum, mean and standard deviation values for each defined metric and for each site. Third column (n) represents the number of samples available per site as some sites miss a certain year in the dataset. Minimum and maximum values for each column appear in bold.

Table 4. Metrics vs Land use. Pearson correlation tests

Native	*t-value*	*DF*	*p-value*	**Forestry**	*t-value*	*DF*	*p-value*
MCI	**9.593**	**157**	**2.2e-16**	MCI	**5.3403**	**157**	**3.204e-07**
SQMCI	**7.0608**	**157**	**5.05e-11**	SQMCI	3.9062	157	0.000139
%EPT	**8.0622**	**157**	**1.791e-13**	%EPT	3.8816	157	0.0001525
Taxa rich.	3.826	157	0.0001876	Taxa rich.	3.7246	157	0.0002724
Pasture	*t-value*	*DF*	*p-value*	**Urban**	*t-value*	*DF*	*p-value*
MCI	**-4.7833**	**157**	**3.944e-06**	MCI	**-8.0957**	**157**	**1.476e-13**
SQMCI	-3.1473	157	0.001972	SQMCI	**-6.3094**	**157**	**2.728e-09**
%EPT	-4.0745	157	7.3e-05	%EPT	**-6.5095**	**157**	**9.644e-10**
Taxa rich.	-1.9603	157	0.05173	Taxa rich.	**-4.6595**	**157**	**6.72e-06**

Table 4 The results of Pearson correlation tests: T-value, degrees of freedom (DF) and p-value for each pair of macroinvertebrate metric and land use type. A positive t-value indicates an increasing trend on the relationship among the two involved variables, while a negative t-value denotes a decreasing trend. A p-value lower than 0.05 is considered as a positive indicator of the validity of the tested relationship. The values in bold denote the most significant relationships.

Table 5. Metrics vs Land use: Linear regression summary

(a)

Native	*Estimate*	*Std. Err.*	*t-value*	*p-value*	*R-sq.*	*Adj. R-sq.*	*p-value*
(Intercept)	-40.92916	7.62922	-5.365	2.86-e07			
MCI	0.89078	0.09286	9.593	< 2e-16	**0.3695**	**0.3655**	**< 2.2e-16**
(Intercept)	-8.792	5.889	-1.493	0.137			
SQMCI	11.128	1.576	7.061	5.04e-11	**0.241**	**0.2362**	**5.04e-11**
(Intercept)	-2.0766	4.5146	-0.460	0.646			
%EPT	1.7761	0.2203	8.062	1.79e-13	**0.2928**	**0.2883**	**1.791e-13**
(Intercept)	-3.0161	8.8227	-0.342	0.732913			
Taxa rich.	1.4354	0.3752	3.826	0.000188	0.08529	0.07946	0.0001876

(b)

Forestry	*Estimate*	*Std. Err.*	*t-value*	*p-value*	*R-sq.*	*Adj. R-sq.*	*p-value*
(Intercept)	-19.94191	6.06191	-3.29	0.00124			
MCI	0.39401	0.07378	5.34	3.2e-07	**0.1537**	**0.1483**	**3.204e-07**
(Intercept)	-4.717	4.426	-1.066	0.288107			
SQMCI	4.626	1.184	3.906	0.000139	0.08858	0.08277	0.00013
(Intercept)	-0.6514	3.5168	-0.185	0.853284			
%EPT	0.6661	0.1716	3.882	0.000152	0.08756	0.08175	0.0001525
(Intercept)	-10.4816	6.0642	-1.728	0.085875			
Taxa rich.	0.9605	0.2579	3.725	0.000272	0.08119	0.07533	0.0002724

(c)

Pasture	*Estimate*	*Std. Err.*	*t-value*	*p-value*	*R-sq.*	*Adj. R-sq.*	*p-value*
(Intercept)	73.41245	7.92195	9.267	< 2e-16			
MCI	-0.46121	0.09642	-4.783	3.94e-06	**0.1272**	**0.1216**	**3.944e-06**
(Intercept)	53.739	5.786	9.288	< 2e-16			
SQMCI	-4.873	1.548	-3.147	0.00197	0.05935	0.05336	0.001972
(Intercept)	52.8770	4.5055	11.736	< 2e-16			
%EPT	-0.8958	0.2199	-4.075	7.3e-05	0.09563	0.08987	7.3e-05
(Intercept)	52.1495	8.0432	6.484	1.1e-09			
Taxa rich.	-0.6705	0.3420	-1.960	0.0517	0.02389	0.01767	0.05173

(d)

Urban	*Estimate*	*Std. Err.*	*t-value*	*p-value*	*R-sq.*	*Adj. R-sq.*	*p-value*
(Intercept)	83.40406	8.07377	10.330	< 2e-16			
MCI	-0.79555	0.09827	-8.096	1.48e-13	**0.2945**	**0.29**	**1.476e-13**
(Intercept)	55.591	6.040	9.204	< 2e-16			
SQMCI	-10.198	1.616	-6.309	2.73e-09	**0.2023**	**0.1972**	**2.728e-09**
(Intercept)	47.4299	4.7658	9.952	< 2e-16			
%EPT	-1.5138	0.2326	-6.509	9.64e-10	**0.2125**	**0.2075**	**9.644e-10**
(Intercept)	59.2421	8.6499	6.849	1.59e-10			
Taxa rich.	-1.7139	0.3678	-4.659	6.72e-06	**0.1215**	**0.1159**	**6.72e-06**

Table 5 The summary of all models resulting from a linear regression for each pair of macroinvertebrate metric and land use category. The values in bold denote the most significant relationships.

Table 6. SQMCI vs MCI: Linear regression summary and Pearson correlation test

(a) Linear regression model results

SQMCI	*Estimate*	*Std. Err.*	*t-value*	*p-value*	*R-sq.*	*Adj. R-sq.*	*p-value*
(Intercept)	-0.669667	0.252937	-2.648	0.00893			
MCI	0.051878	0.003079	16.851	**< 2e-16**	**0.644**	**0.6417**	**< 2e-16**

(b) Pearson correlation test results

SQMCI	*t-value*	*DF*	*p-value*
MCI	**-4.7833**	**157**	**3.944e-06**

Table 6 The results from the linear regression model (a) and the Pearson correlation test (b) for the SQMCI and the MCI values. The values in bold denote a significant relationship. Both p-values are well below 0.05 and both R-squared values (with and without adjustment) are close to 1.

Table 7. MCI and %EPT Spearman Correlation tests

(a) Regional (all sites)

Metric	*S*	*p-value*	*corr. coef.*
MCI	688160	0.7333	-0.02723278
%EPT	682810	0.8098	-0.01923506

(b) By land use

Metric	*Land use*	*S*	*p-value*	*corr. coef.*
MCI	Native	73613	0.4449	-0.09016295
%EPT	Native	67161	0.9636	0.005392939
MCI	Forestry	192	0.6567	-0.1636364
%EPT	Forestry	259.29	0.08441	-0.5714312
MCI	Pasture	73613	0.4449	-0.09016295
%EPT	Pasture	67161	0.9636	0.005392939
MCI	Urban	10098	0.125	0.2375701
%EPT	Urban	12364	0.672	0.06645128

(c) By land use using yearly means

Metric	*Land use*	*S*	*p-value*	*corr. coef.*
MCI	Native	366	**0.03085**	**-0.6636364**
%EPT	Native	244	0.7549	-0.1090909
MCI	Forestry	192	0.6567	-0.1636364
%EPT	Forestry	259.29	0.08441	-0.5714312
MCI	Pasture	340	0.08745	-0.5454545
%EPT	Pasture	222	0.9892	-0.009090909
MCI	Urban	72	**0.02807**	**0.6727273**
%EPT	Urban	172	0.5209	0.2181818

Table 7 The results from the Spearman correlation tests at 95% of confidence levels for all sites combined (a), for all four land use types (b) and all four land types based on yearly mean values (c) from 2006 to 2016. None of the correlation coefficients appear to be strong enough on the first two tables as all the values are close to 0, which denotes zero association between the two studied variables (variable x being time and variable y being MCI and %EPT). In the third table, bold values denote significant variable association.

Table 8. Kendall rank correlation test per site

Site	Category	Metric	Kendall corr. coef.	p-value
Cascades	Native	MCI	-0.1467952	0.5322
		%EPT	0.4036867	0.08581
Hoteo	Pasture	MCI	0.1111111	0.7614
		%EPT	0.1143324	0.6733
Kumeu	Pasture	MCI	-0.3090909	0.2183
		%EPT	0.01818182	1
Mahurangi	Forestry	MCI	-0.1111111	0.7275
		%EPT	-0.4045199	0.106
Matakana	Pasture	MCI	-0.3454545	0.1646
		%EPT	-0.1100964	0.6394
Ngakaroa	Pasture	MCI	0.3818182	0.121
		%EPT	0.3669879	0.1183
Oakley	Urban	**MCI**	**0.6**	**0.009946**
		%EPT	-0.3148688	0.183
Opanuku	Native	MCI	-0.03669879	0.8759
		%EPT	-0.09090909	0.7612
Otara	Urban	MCI	-0.3333333	0.2164
		%EPT	0.02273314	0.9282
Oteha	Urban	MCI	0.09090909	0.7612
		%EPT	**0.7818182**	**0.0003334**
Papakura	Pasture	MCI	-0.2444444	0.3807
		%EPT	0.06819943	0.7868
Puhinui	Urban	MCI	0.4181818	0.08656
		%EPT	-0.02159168	0.9316
Vaughan	Pasture	MCI	0.09090909	0.7612
		%EPT	0.183494	0.4349
Wairoa	Pasture	MCI	-0.4545455	0.06017
		%EPT	0.2363636	0.3587
West Hoe	Native	**MCI**	**-0.5111111**	**0.04662**
		%EPT	-0.2696799	0.2812

Table 8 The results from the Kendall rank correlation test performed for each site for both %EPT and MCI with the available values from 2006 to 2016. The correlation coefficient column displays a value between -1 and 1 which denotes the relevance of the association between the two studied variables (variable x being time and variable y being MCI and %EPT). Values in bold indicate a strong trend between variables.

Appendix 3 – R Code

All the code generated to plot all figures and perform all the statistical methods presented in this study is publicly available at this Github repository https://github.com/jordij/r-streams

R version: 3.4.3

Details:

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platform       x86_64-w64-mingw32
arch           x86_64
os             mingw32
system         x86_64, mingw32
status
major          3
minor          4.3
year           2017
month          11
day            30
svn rev        73796
language       R
version.string R version 3.4.3 (2017-11-30)
nickname       Kite-Eating Tree
```

List of R packages:

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Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows >= 8 x64 (build 9200)

Matrix products: default

locale:
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[3] LC_MONETARY=English_New Zealand.1252 LC_NUMERIC=C
[5] LC_TIME=English_New Zealand.1252

attached base packages:
[1] stats     graphics  grDevices utils     datasets  methods   base

other attached packages:
 [1] broom_0.4.4            southernMaps_0.0.0.9000 sp_1.2-7
 [4] measurements_1.2.0     bindrcpp_0.2.2          vegan_2.5-2
 [7] lattice_0.20-35        permute_0.9-4           cowplot_0.9.3
[10] ggplot2_2.2.1          extrafont_0.17          dplyr_0.7.4

loaded via a namespace (and not attached):
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.8-23
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