Investigating drivers of temporal patterns in freshwater macroinvertebrates metrics in Taranaki

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Executive summary

Regional councils are required to monitor freshwater macroinvertebrate communities as part of the Ecosystem Health attribute under the National Policy Statement for Freshwater Management (NPS-FM). If a degrading trend in macroinvertebrate metrics is detected, councils must develop an action plan to identify and mitigate key stressors contributing to the decline.

Taranaki Regional Council (TRC) has observed variable trends in Macroinvertebrate Community Index (MCI) values across its 67 State-of-the-Environment (SOE) monitoring sites. While long-term data (28 years) indicate improving trends at many sites, the most recent annual monitoring report found that the number of sites exhibiting degrading MCI trends over the past 10 years was more than twice that observed over the long term. As a result, TRC commissioned NIWA to investigate potential drivers of these declines.

Like all SOE monitoring networks designed to meet the different national and regional reporting needs of specific variables (e.g., nutrients, *E. coli*, periphyton), there was comparatively limited spatial and temporal overlap between observed macroinvertebrate data and observed data for potential proximate environmental stressors. These data were supplemented with more distal indicators of potential stressors and observed variables for nearby locations or time periods. Additional temporal data included flow metrics from nearby catchments, interpolated climate conditions based on a network of national climate stations (NIWA Virtual Climate Station Network, VCSN) and water quality and periphyton measurements available for subsets of the macroinvertebrate monitoring sites (19 and 12 sites, respectively). Indicators of catchment characteristics for each site were provided by TRC and included upstream catchment area, number of dairy effluent consents and the proportion of the upstream network that had riparian fencing and vegetation.

Many of the site-level characteristics (such as catchment descriptors, proportion of the upstream network with mitigation actions applied, site average climate, macroinvertebrate metric and local environmental conditions) were correlated. For example, sites with a higher proportion of upstream natural land cover, which were predominantly sites at or near the boundary of Te Papa-Kura-o-Taranaki, unsurprisingly also had fewer dairy discharge consents, larger substrate, more average rainfall and cooler temperatures as well as fewer days since a flow event at least three times the long-term median, when compared to sites with a lower proportion of upstream natural land cover.

Temporal trends in six macroinvertebrate metrics were analysed using data from biannual spring/summer samples and for annual summer-only samples for three time periods; long-term: 1995–2023, and two decades: 2003–2013 and 2013–2023. Sites with >85% of sampling dates with data were included in the trend analyses for each time period. This resulted in 1,752 different trend analyses, which are summarised in spreadsheets provided with this report. Key results for macroinvertebrate metric trends were:

- Five of the six macroinvertebrate metrics, apart from taxa richness, showed largely consistent trend directions within sites and periods. Taxa richness may behave differently to other macroinvertebrate metrics as it summarises taxa that are both tolerant and sensitive to a range of stressors.
- Using summer-only samples (TRC's most recent sampling regime), compared to biannual spring and summer sampling, resulted in similar trend directions for most

sites, metrics and time periods but commonly with reduced certainty in the trend direction, as would be expected given the smaller sample size.

- From the available data there were no significant differences in average macroinvertebrate metric scores, environmental conditions, or catchment characteristics observed in sites with increasing compared to decreasing long-term (1995–2023) trends in the MCI values.

- Sites where trend direction varied (increasing one decade and decreasing in the other) differed from sites with increasing trends in both decades in average antecedent rainfall, but not in any of the other available catchment characteristics or site-average environmental conditions. This is likely to be a spurious correlation and not causative as the likely proximate cause of rainfall impacts on macroinvertebrate communities (DaysSinceFRE3, a measure of the frequency of high flows) did not show a similar pattern.

- Average antecedent rainfall was significantly lower and the number of days since a flow event greater than three times the long-term median flow was significantly higher in the 2013–2023 period than the 2003–2013. Longer periods between high river flows could have contributed to the higher prevalence of declining MCI trends in the 2013–2023 period than the earlier decade.

Potential drivers of temporal changes in MCI within sites were analysed using linear models of stressors and MCI values across the long-term (1995–2023) period at each site. This was done for two data sets: 1) the full 67 sites and 2) a subset of 19 sites with additional paired water quality data (including dissolved oxygen, nutrient concentrations and turbidity). Key results were:

- Across both datasets, the variables correlated with MCI in the highest percentage of sites were antecedent average rainfall, high-flow events (flows >3× median long-term flow), water and air temperature, and a categorical visual cover estimate of periphyton mats recorded at the time of macroinvertebrate samples. When correlated, MCI values were generally higher when there was higher recent rainfall, relatively recent flow events, when air and/or water temperature was cooler and when periphyton mat coverage was less widespread.

- The Southern Oscillation Index (SOI), a climate variable indicating the intensity of El Niño or La Niña events, showed correlations with MCI in only two sites. The few correlations may reflect a mismatch of scale between this climate indicator and proximate stressors affecting macroinvertebrates. Antecedent rainfall was linked to MCI. In addition, the more proximate variables also related to MCI (recent flows, water temperature and periphyton cover) are known to be influenced by climate, suggesting that climate is likely to influence macroinvertebrate communities, perhaps particularly during prolonged periods with high temperatures, low rainfall and reduced river flows.

- Further investigation of the relationship between periphyton, measured as percent cover or biomass, and MCI trends was somewhat limited by availability of numeric periphyton data. The numeric periphyton biomass (chlorophyll *a*) data available for 12 sites between 2018 and 2023 showed no relationship with MCI at any site. In addition, there was no obvious relationship between the frequency of periphyton mat or filament cover category assigned during times of increasing or decreasing MCI trends in the four sites that had identifiable trends in both decades. Although we found no evidence for periphyton effect on MCI in this smaller dataset, the results from the categorical periphyton data assigned at the 67 sites over a longer time period (between 1995–2023) provides some evidence that high periphyton biomass may be impacting macroinvertebrate communities at least some of the time in the sites with decreasing MCI trends.

The management implications of this project include:

- Both rainfall and air temperature were directly linked to changes in MCI values and while climate conditions are beyond council control, local actions could help mitigate the effects of climate on the more proximate potential stressors identified (water temperature, river flow and periphyton). These approaches could be targeted to key areas and could include:
  - Shading, with the aim to reduce water temperatures and limit light available in areas with the potential for high periphyton growth.
  - Management of water abstractions to prevent prolonged or extreme low-flow conditions.
  - Riparian planting to limit fine sediment inputs, maintain habitat quality, and control periphyton growth.
  - Potentially nutrient management to minimize periphyton growth and prevent toxic nutrient concentrations. Note though that observed nutrient concentrations were positively correlated when showing a relationship with MCI and not acting as a direct stressor of macroinvertebrate communities.
- Moving from biannual to summer-only macroinvertebrate monitoring will likely lead to detection of similar trend directions within specific time periods but is expected to reduce confidence in the trend direction, particularly over shorter time periods.

Data availability and the co-occurrence of multiple stressors within sites were challenges within this analysis, as is common to all multiple stressor analyses. If more robust identification of key drivers affecting macroinvertebrate communities is a priority for TRC, we recommend:

1. Where possible, aligning monitoring of potential stressors with macroinvertebrate monitoring sites, at least for a subset of locations.
2. Continuing, and potentially expanding, periphyton percent cover and/or biomass monitoring. A larger numeric periphyton dataset will allow more robust investigations of the relationship between periphyton and macroinvertebrate metric scores.
3. Depending on council priorities, additional potential investigations could include:
   - Compilation of any additional council periphyton monitoring data from nuisance periphyton monitoring programmes or catchment specific investigations to further investigate the potential role of high periphyton biomass in impacting macroinvertebrate communities.

- Collection of additional data or use of expert and local knowledge in combination with existing data to investigate whether key stressors vary between representative case studies for different types of rivers (e.g., high gradient small headwater streams within Te Papa-Kura-o-Taranaki will likely have different stressors to lower gradient larger waterways with more agricultural inputs further downstream).

1 Background

Regional Councils have statutory responsibilities to manage New Zealand's waterways under the Resource Management Act 1991 (RMA) and the National Policy Statement for Freshwater Management 2020 (NPS-FM). The NPS-FM requires regional councils to monitor and report on a range of freshwater attributes for water quality and ecosystem health, including macroinvertebrates.

Under the NPS-FM, sites that show degrading temporal trends in macroinvertebrate attributes trigger development of an action plan to identify key stressors and attempt to improve macroinvertebrate communities. A detailed understanding of regional-specific stressors affecting macroinvertebrate communities is required to support in this process. However, this may be challenging for several reasons. First, the common annual to bi-annual frequency of macroinvertebrate monitoring means that >10 years of data are generally required to detect trends with confidence (Larned et al. 2020). Second, identifying the key cause of trends in macroinvertebrate metrics is complicated due to the frequent presence of multiple interacting stressors. Third, there is often a shortage of adequate paired temporal monitoring data where both the potential stressors and macroinvertebrate metrics have been consistently monitored over time at the same sites. Furthermore, separating the influence of proximate anthropogenic causes from climate variability is difficult because climate variation may amplify or counteract the effects of other drivers, such as land use and land management (Snelder et al. 2022a). Thus, disentangling the impact of individual stressors on macroinvertebrate communities is likely to be a significant challenge for councils. However, understanding the relative role of different environmental conditions, and their ability to be managed is beneficial for selecting management actions that are effective in protecting or remediating freshwater ecological health.

While data from council State-of-the-Environment (SOE) monitoring networks would ideally assist in identifying potential causes of any ecological changes (e.g., in macroinvertebrate communities), the networks were not designed for this purpose. Rather, SOE monitoring networks are designed to monitor the current state and trends of individual indicators of ecosystem health, such as deposited fine sediment, water quality, periphyton and macroinvertebrates. Due to differences in the most appropriate locations to monitor different variables, and the costs associated with monitoring, the locations at which data for macroinvertebrates, water quality, periphyton, flow, water temperature and deposited fine sediment are collected do not often align spatially or temporally, or if they do, only at a subset of sites. These spatially and temporally patchy datasets causes technical difficulties when using the data in statistical analyses or models to attempt to identify potential stressors of ecological values, or to determine quantitative relationships between individual stressors and ecological values (such as macroinvertebrate metrics).

Taranaki Regional Council (TRC) established its freshwater SOE monitoring programme in 1995, with the goal of reporting on the state and any trends in the health of the region's freshwater bodies. A suite of variables are monitored as part of the network, including periphyton, water quality, river flow, deposited fine sediment and macroinvertebrates. In common with other councils, data are available for different variables at different spatial locations and over different time periods.

In their latest annual Freshwater Macroinvertebrate State of the Environment monitoring report (2019–2023; TRC 2024), TRC observed that the number of monitored sites exhibiting degrading Macroinvertebrate Community Index (MCI) trends over the last 10 years was more than twice that observed over the long-term (28 years of monitoring data). The report contained a recommendation that analyses should be conducted on the monitoring data held by the council to explore the potential drivers of temporal changes in macroinvertebrate communities within the region.

TRC engaged NIWA to fulfil the requirements of the recommendation in the TRC 2024 report. In brief, the goals of this report are to:

1. Briefly summarise the temporal and spatial data readily available for potential proximate stressors of macroinvertebrates at macroinvertebrate SOE monitoring sites using observed and modelled data, as provided by TRC and from readily accessible sources.
2. To investigate whether sites that show degrading or improving trends in macroinvertebrate metrics differ in key contributing attributes.
3. Investigate relationships between temporal patterns in macroinvertebrate metrics and potential key stressors, including climatic conditions.

In addition to this report excel spreadsheets summarising the results of macroinvertebrate metric trend analyses are provided (see Section 3 for further details).

2 Potential stressors of freshwater macroinvertebrates and data availability

2.1 Potential stressors of macroinvertebrates

Potential stressors of macroinvertebrate communities can occur at multiple, interacting spatial scales from global (e.g., climate patterns) to proximate (local, in-stream) scales. There is a comparatively common suite of potential proximate (local, in-stream) anthropogenic stressors that impact macroinvertebrate communities and the metrics calculated from them (such as the MCI; Figure 2-1). These include inputs of fine sediment, nutrients or other contaminants, changes to river flow regimes, excess periphyton growth and alterations to instream or riparian habitat, which are more common with more intensive catchment land use (Figure 2-1; Collier et al. 2014, Nguyen et al. 2024). These stressors can have direct as well as indirect (e.g., through impacts on periphyton growth) effects on macroinvertebrate communities (Figure 2-1).

Deposited fine sediment is unstable, provides poor refugia from floods, can abrade soft body parts and smother habitat for macroinvertebrates (Burdon et al. 2013).

Excess periphyton growth smothers the interstitial spaces between stones that many sensitive macroinvertebrates use as habitat. Moreover, thick periphyton mats or long filaments are likely poor food resources for many macroinvertebrates (Tonkin et al. 2013). High periphyton biomass forms under conditions of sufficient light and nutrients while warm water temperatures speed growth and a lack of scouring floods allows high biomass or cover to develop (Biggs and Kilroy 2000).

Macroinvertebrates may also be directly negatively affected by high water temperatures, which reduce dissolved oxygen concentrations leading to physiological stress. Periods of low rainfall and/or excess water abstraction can contribute to and exacerbate low flow magnitude and duration. Nuisance periphyton blooms can occur in unshaded reaches with sufficient nutrients during particularly hot dry summers when river flows are low and stable and water temperatures are warm. Excess periphyton growth can also contribute to low dissolved oxygen concentrations (Biggs and Kilroy 2000), further stressing macroinvertebrates.

The influence of proximate drivers on macroinvertebrate communities within a particular stream may also be affected by more distal catchment-scale parameters such as the stream length, slope, geology, land cover, and the number, magnitude and frequency of water abstractions in the upstream catchment (Larned et al. 2020). Broader scale climate patterns can also impact river flow regimes (the frequency, magnitude, duration, timing and predictability of high and low flows) and water temperature (e.g., Birk et al. 2020) and amplify or counteract the effects of other stressors, such as nutrient or deposited fine sediment inputs (Snelder et al. 2022a). Global influences include climatic cycles, such as the Southern Oscillation Index (SOI) — an indicator of El Niño or La Niña weather conditions — which has previously been linked to temporal changes in water quality in New Zealand rivers (Snelder et al. 2022a).

Identifying the key potential stressors of macroinvertebrate communities and the scales at which they are influenced can assist in designing targeted effective management actions to mitigate or reduce stressor impacts. For example, some of the stressors of macroinvertebrates can be influenced by management actions (at least to some degree), whiles others may not be able to be managed locally, and many will be influenced by factors that both can and cannot be directly managed. For example, river flow regimes may be impacted by both climatic conditions, which are beyond the control of local management actions, and by conditions that may, at least in theory, be able to be managed, such as the impact of water abstractions on river flow. Some management actions can also target several potential stressors. For example, excluding stock using fencing and planting riparian vegetation are likely to influence multiple potential proximate stressors, e.g., reducing fine sediment and nutrient inputs, increasing stream shade and lowering water temperature, thereby reducing the likelihood of excess periphyton growth. Disentangling the relative influence of both stressors and mitigations as drivers of macroinvertebrate communities is a common goal of regional councils, particularly as required under the NPS-FM, but one that is challenging (e.g., Birk et al. 2000).

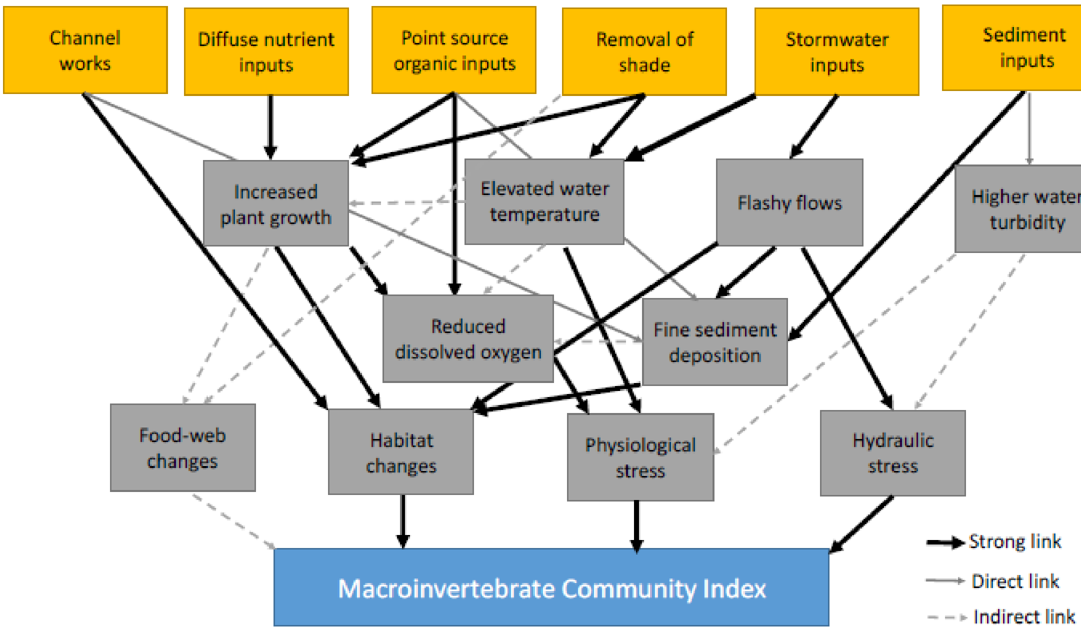

Figure 2-1: Pathways through which potential stressors (orange) influence the MCI (from Collier et al. 2014).

2.2 Data availability

TRC established their SOE monitoring network with the aim to report on state and trends in freshwater health (TRC 2024). Across this network, variables associated with water quality, periphyton, freshwater habitat and macroinvertebrate communities are sampled and measured.

However, because council SOE monitoring networks are not designed primarily to identify drivers of ecological changes but to meet multiple purposes in a cost-effective manner, site locations and monitoring frequency are often optimised for individual variables (e.g., nutrient concentrations, *E.coli* concentrations or periphyton cover). As a result, the water quality, periphyton, and macroinvertebrate monitoring programmes are not fully aligned in time or space.

Spatial or temporal gaps in observed data for potential proximate stressors of macroinvertebrate communities may be filled in several ways by using:

1. Observed data for proximate stressors from nearby spatial locations or similar time periods (e.g., data from a flow gauge from elsewhere in the catchment or a nearby catchment);
2. Predicted data for proximate stressors for the site/period of interest using models based on available data (e.g., predicted river flows based on observed flows in nearby or similar catchments or from rainfall data);
3. Data from distal variables that are hypothesised to impact proximate stressors on macroinvertebrate communities (e.g., observed or predicated rainfall or air temperature, which may influence river flows or water temperature);
4. Catchment characteristics that may affect proximate drivers within the catchment (e.g., upstream slope, catchment size, land cover, number/magnitude of water abstractions or effluent discharges could influence river flow, nutrient and deposited fine sediment inputs, etc).

TRC worked with NIWA to find data that both directly measured and served as indicators of the likely proximate stressors of macroinvertebrate communities. A summary of the data compiled for this report is provided in the following sections.

2.2.1 Macroinvertebrate data

Macroinvertebrate monitoring has been undertaken since 1995, but the number and location of sites has changed over time to fulfil changing regional and national monitoring requirements and policy (TRC 2024). Currently, macroinvertebrate surveys are undertaken annually in summer at 67 sites on 36 rivers and streams. Prior to 2022/2023, samples were collected biannually, in spring and summer. The sampling methodology has remained similar over time, and details of macroinvertebrate sampling sites and collection methods can be found in TRC (2024).

Macroinvertebrate data were available for 2852 samples from 67 sites on 36 rivers sampled between 1995 and 2023. Samples were assigned to a water year (June to May) rather than a calendar year to prevent samples collected during the same summer period (December to March) being split into different years. Sites were sampled between one and three times per water year for a total of 3–55 samples per site (Figure 2-2). Thirty two (48%) of the sites were sampled in all 28 water years, a further 20 sites (30%) were sampled for between 20 and 27 water years, six sites (9%) were sampled for between five and sixteen years and 9 sites (13%) for fewer than 5 years (Figure 2-2).

Samples were collected in all seasons, although predominantly in Spring and Summer (Spring: 1,083 samples, Summer: 1,184, Winter: 3, Autumn: 582). Note that we extended the definition of summer to include March.

Macroinvertebrate community indices were calculated by TRC and provided for this report. To calculate the Macroinvertebrate Community Index (MCI), freshwater taxa are assigned tolerance values that indicate their sensitivity to organic pollution. There is a set of national tolerance values (Clapcott et al. 2017) utilised in the NPS-FM; Taranaki has also developed their own regionally-derived tolerance values for freshwater taxa, which are commonly used in region-specific reporting, including identification of temporal trends (e.g., TRC 2024).

TRC provided pre-calculated macroinvertebrate metric values for the following indices:

- MCI-regional: Macroinvertebrate Community Index calculated using Taranaki regional tolerance values. Based on taxa presence/absence. Values range from 80 to 140. Lower values are designed to indicate a community more impacted by organic pollution. See Stark and Maxted (2007) for further information.
- SQMCI-regional: a semi-quantitative variant of the MCI, which incorporates the abundance of taxa reported in coded abundance categories (e.g., rare, common, abundant, very abundant).
- ASPM: Average Score Per Metric. Calculated from normalised scores of %EPT, MCI and EPT richness. Higher values indicate communities with higher ecological integrity. See Collier (2008) for further information.
- Percent EPT individuals (%EPT): percentage of individuals that are Ephemeroptera, Plecoptera, Trichoptera. These taxa are sensitive to organic pollution.
- Number EPT taxa (EPT): the number of EPT taxa present.
- Taxa richness: the count of macroinvertebrate taxa identified in the sample. Taxa are identified to different taxonomic levels, commonly to family or genera.

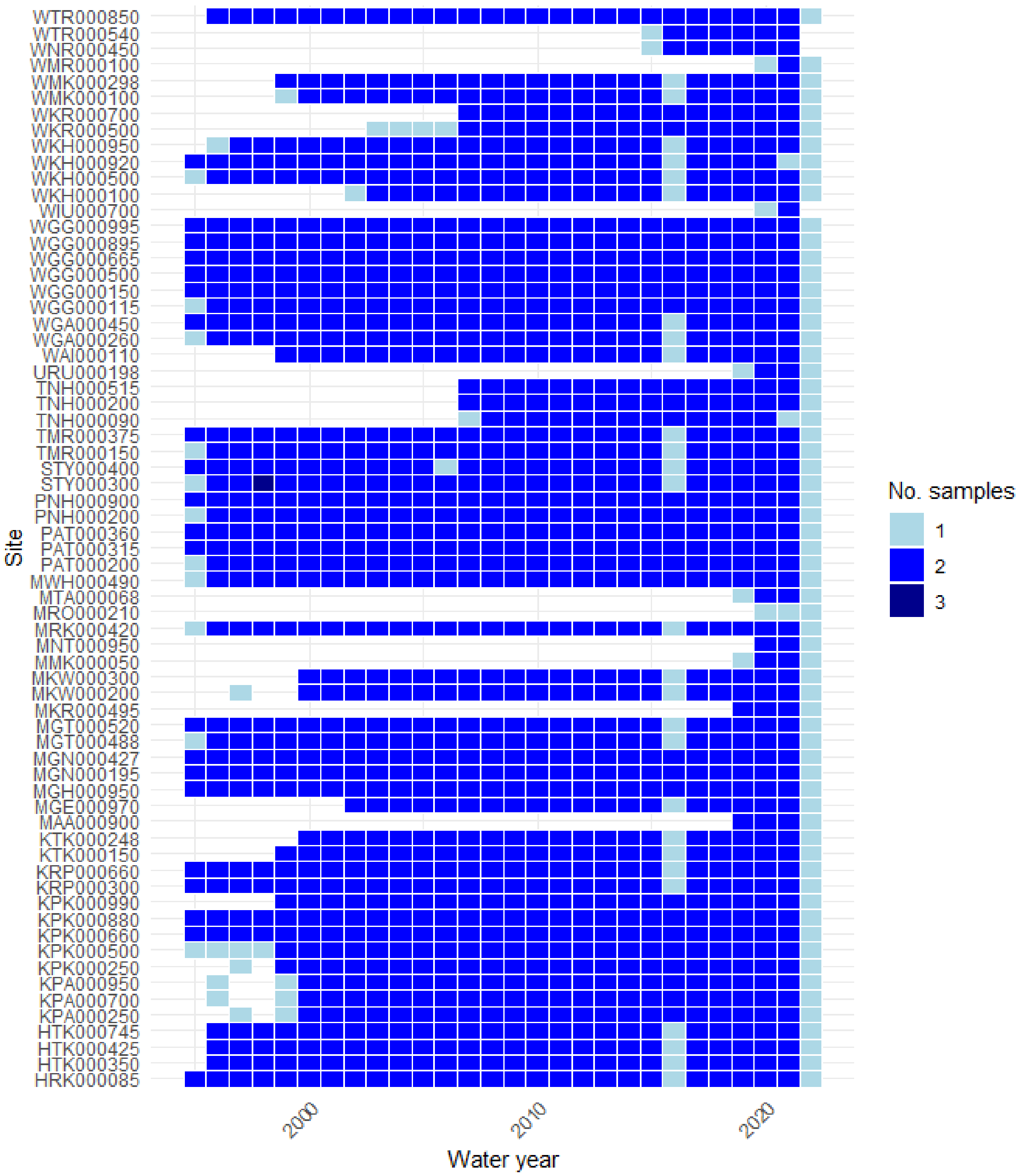

Figure 2-2: Number of macroinvertebrate samples collected per water year for 67 State-of-the-Environment monitoring sites in the Taranaki region between 1995 and 2023. Water years run from June to May.

2.2.2 Local temporal variables

Environmental monitoring data were provided by TRC for a range of periphyton, water quality and habitat variables. Some variables were collected at the same location and time as the macroinvertebrate samples and others were from separate water quality or periphyton monitoring networks with variable spatial and temporal overlap with the macroinvertebrate data.

Data collected with macroinvertebrate samples

Data that were collected at the same time and location as the macroinvertebrate samples included:

- Spot water temperature.
- Visual assessments of the percentage cover of bed substrate classes (including sand, silt, cobble, fine gravel, bedrock).
- Reach scale meta-data with categories for a range of variables including:
  - Periphyton mats coverage (none, slippery, patchy, widespread)
  - Periphyton filaments coverage (none, patchy, widespread)
  - Macrophytes (none, edge only, on edge and bed)
  - Bank stability (stable, mostly stable, highly unstable)
  - Bed shading (None, partial, complete).

The substrate index (SI) was calculated from the percentage cover of substrate categories using the equation from Harding et al. (2009):

$$SI = 0.08 * bedrock + 0.07 * boulder + 0.06 * cobble + 0.05 * coarse\_gravel + 0.04 * fine\_gravel + 0.03 * (sand + silt)$$

River flow

Individual flow recorders were located on the Mangaoraka, Waiongana, Pūnehu, Kapoaiaia, and Waiokura Streams, as well as the Waiwhakaiho, Manganui, Pātea, Mangaehu, Waingongoro, Kaūpokonui, Waitara, and Whenuakura Rivers. TRC provided the number of days since a flow greater than three times the median long-term flow (DaysSinceFRE3) at a site for each of the sampling occasions for all macroinvertebrate sites. For sites with flow recorders in the catchment this was calculated from the flows at this recorder. For other sites the metric was calculated using recorders in nearby catchments. Note that TRC sampling protocols precluded macroinvertebrate sample collection within seven to 14 days after a FRE3 or larger event, depending on the type and source of the waterway, as high flows disturb macroinvertebrate communities.

Water quality monitoring sites

Water quality variables were sampled at 19 of the macroinvertebrate sampling sites, generally monthly, over variable time periods depending on the site and variable (Figure 2-3). Key water quality variables to include in analyses were identified based on data availability and likelihood of being a driver (or influencing a driver) of macroinvertebrate communities, based on previous research and expert knowledge (e.g., Collier et al. 2014). The water quality variables provided by TRC and that were prioritised for inclusion related to water chemistry (e.g., conductivity, dissolved oxygen), turbidity and nutrient concentrations (total nitrogen, dissolved inorganic nitrogen, total phosphorus, and dissolved reactive phosphorus; Figure 2-3).

Some data related to periphyton were also provided by TRC with this data set (chlorophyll *a,* and percentage cover of periphyton; Figure 2-3). See Section 4.1 for how the variables were summarised and temporally aligned with the macroinvertebrate sampling dates.

Additional periphyton data

As well as the categorical estimates of periphyton cover collected at the time of macroinvertebrate sample collection, chlorophyll *a* biomass samples were collected monthly at 12 of the macroinvertebrate sites starting in 2018 (Figure 2-3). Water quality variables (see paragraph above) were also monitored at 11 of the 12 periphyton sites. The numeric periphyton data were not available over long contiguous time periods for many sites (Figure 2-3) but were used in a separate analysis of periphyton and MCI at the subset of sites and the shorter time period (2018–2023; see Section 4.2.3).

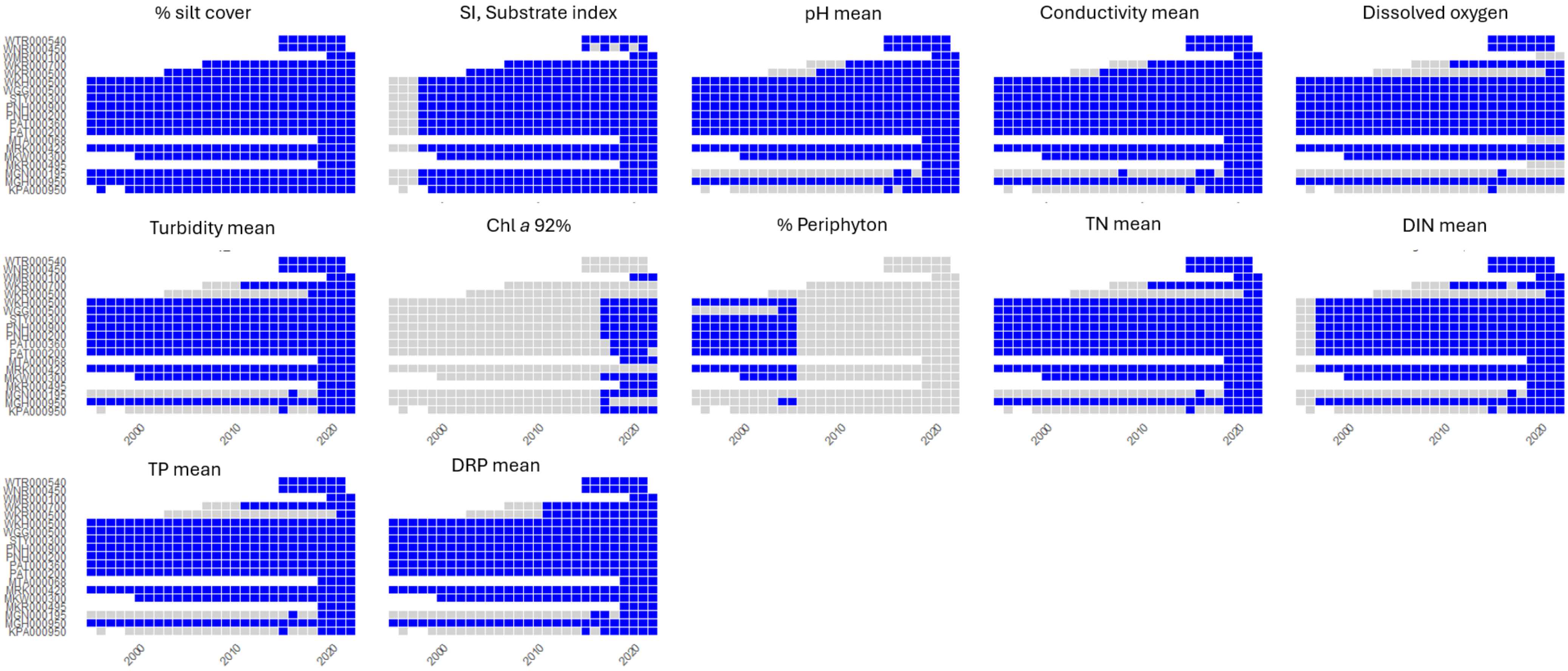

Figure 2-3: Subset of Taranaki macroinvertebrate sites at which selected water quality and periphyton data were also available yearly between 1995 and 2023. Each row is a site, with year on the x axis. Grey indicates years for which macroinvertebrate data exists and blue indicates those years that also have at least one record of the water quality variable in the three months prior (see Section 4.1 for how variables were summarised for analyses). Substrate silt and SI (a summary substrate index) were calculated from percent cover of different substrate class data collected during macroinvertebrate sampling (see Section 2.2.2 for calculation of SI). Periphyton data were available at 12 sites (See Section 2.2). TN = total nitrogen, DIN = dissolved inorganic nitrogen, TP = total phosphorus, DRP = dissolved reactive phosphorus.

2.2.3 Distal temporal variables: climate

Two methods were used to quantify temporal climate conditions. First, broad scale cyclical climate patterns were indicated by the Southern Oscillation Index (SOI). The SOI is an indicator of the El Niño Southern Oscillation (ENSO), which is the movement of warm equatorial water across the Pacific Ocean and associated changes in atmospheric pressure. Second, data for spatially explicit and proximate potential climatic drivers of macroinvertebrate community composition, such as rainfall, air temperature and soil moisture, were extracted from the NIWA Virtual Climate Station Network (VCSN).

Monthly average SOI values (1995 to 2023) were downloaded from the Australian Government Bureau of Meteorology[1]. The SOI typically ranges from –30 to 30 and is quasi-periodic with a typical period of 3–7 years. El Ninō conditions are defined as an SOI less than –8 over 3 months and La Ninã conditions are defined as an SOI > 8.

Data from the VCSN[2] (air temperature, rainfall and soil moisture) were extracted to provide measures of predicted climatic conditions over the sampling period. The VCSN provides daily estimates across an approximately five metre grid over New Zealand. Estimates are based on spatial interpolation of actual data observations made at 150 automatic climate stations. Macroinvertebrate sampling sites were matched to the nearest VSCN site (Figure 2-4) and rainfall, soil moisture and air temperature were summarised (average and maximum values) over the three months prior to each macroinvertebrate sampling date.

[1] http://www.bom.gov.au/climate/enso/soi/
[2] Data available here: Virtual Climate Network (VCSN) timeseries | NIWA DataHub

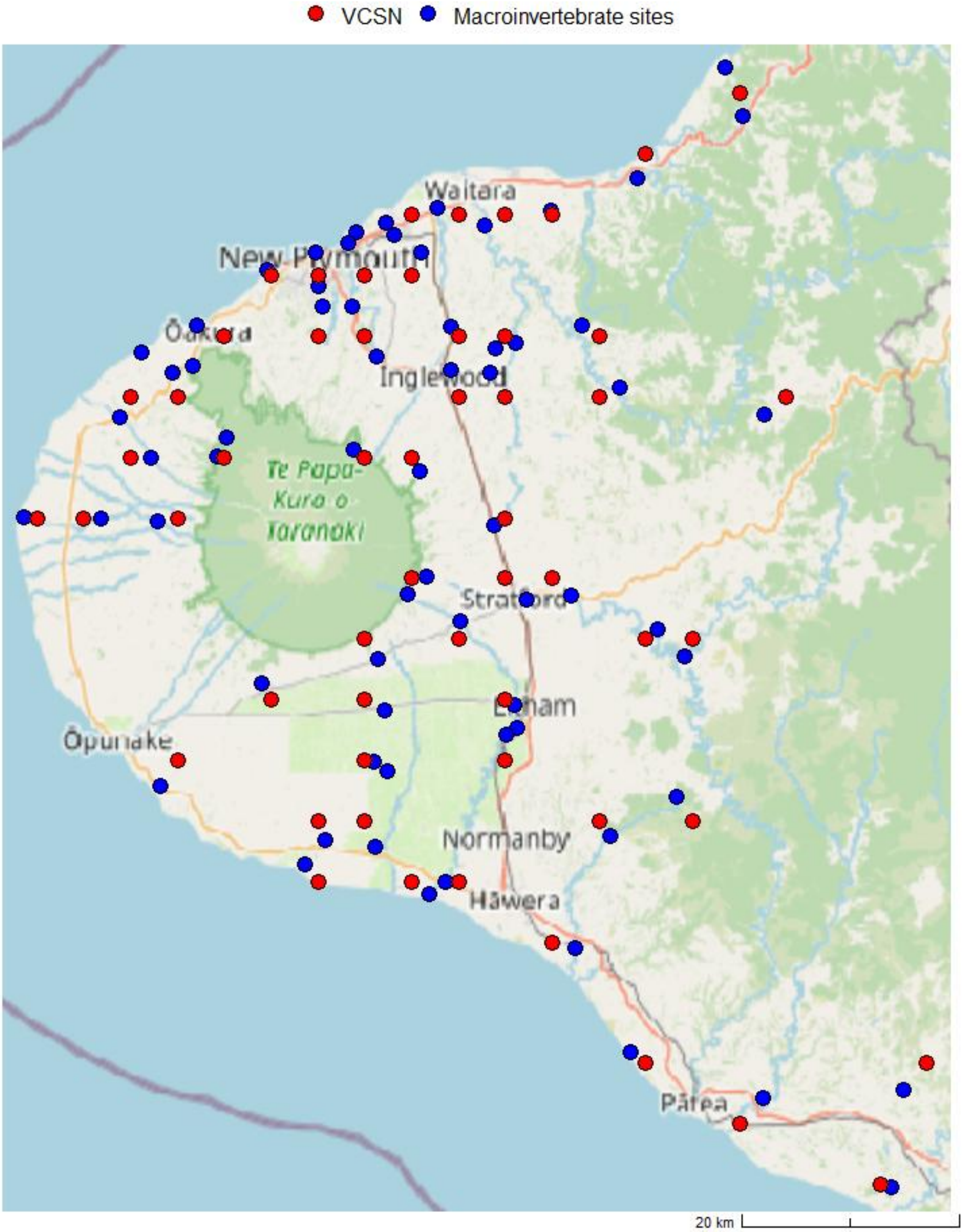

Figure 2-4: Locations of macroinvertebrate sampling sites (blue) and matched nearest Virtual Climate Station Network site (VCSN, red).

2.2.4 Spatial site data

Site characteristics were summarised using one-off measurements of a variety of parameters provided by TRC (for details see Table 2-1):

- Upstream catchment area.

- Percentage of upstream catchment in natural land cover classes.
- Number of consents to discharge dairy effluent.
- Percentage of upstream stream bank fenced.
- Percentage of upstream stream bank vegetated.

2.2.5 Between-site correlations

Pairwise corelations were used to investigate whether selected site characteristics (see Section 2.2.4) or site-summarised environmental conditions and macroinvertebrate metrics (see Table 2-1) were correlated between sites. For example, it was expected that sites that were within Te Papa-Kura-o-Taranaki would have higher upstream natural land cover, cooler temperatures and fewer dairy consents than sites outside of the National Park. Variables with multiple years of data (e.g., macroinvertebrate metrics and measured environmental variables) were summarised for a site as the average of values paired with macroinvertebrate sampling dates. Values paired with macroinvertebrate samples were either mean or 92nd percentile values over the three months prior to macroinvertebrate sample (Table 2-1). Two location variables were included in pairwise correlations: Easting = site spatial location co-ordinate (NZTM) and Northing = spatial location coordinate (NZTM).

Many of the variables were highly correlated (Table 2-1), as expected. Average air temperature from the VCSN and spot water temperature collected at the time of macroinvertebrate samples monitoring values were significantly positively correlated (r = 0.65). Most of the macroinvertebrate metrics were also significantly positively correlated.

All macroinvertebrate metrics were likely to be higher in sites where there was more rainfall, cooler temperatures and higher soil moisture (Table 2-1). For all macroinvertebrate metrics, except taxa richness, values were also commonly higher in sites with smaller upstream catchment areas, fewer dairy consents, a higher percentage of natural land cover, less deposited fine sediment and larger substrate (Table 2-1).

In addition, sites with a larger catchment area were also more likely to have more dairy effluent discharge consents, to have a higher percentage of bank vegetation and to have warmer water temperatures (Table 2-1).

Sites with more upstream natural land cover, which were predominantly sites with upstream area within the national park, unsurprisingly also had fewer dairy discharge consents, larger substrate, more average rainfall and cooler temperatures as well as fewer days since a flow event at least three times the long-term median than sites with lower upstream natural land cover (Table 2-1).

Table 2-1: Description of site characteristics and summary of pairwise Pearson correlations between them. Significant pairwise correlations (α = 0.05) between sites are listed, with the direction (positive or negative) of the correlation indicated in superscript. Averaged annual values were used for variables with multiple years of data (e.g., macroinvertebrate metrics, environmental variables). VCSN annual data were the annual average of average conditions in the 3 months prior to a macroinvertebrate collection date. Substrate index (SI) was calculated using the equation in Harding et al. (2009). Water temperature from the VCSN and spot monitoring values were significantly positively correlated (r = 0.65). Easting = spatial location co-ordinate (NZTM), northing = spatial location coordinate (NZTM).

Variable	Description	Correlations
Macroinvertebrate metrics		
MCI	Macroinvertebrate Community Index calculated using Taranaki regional tolerance values. MCI scores range from 80 to 140. Lower scores are designed to indicate a community more impacted by organic pollution. Stark and Maxted (2007).	TR^+, $\%EPT^+$, $ASPM^+$, avg_rain^+, avg_temp^-, $soil\_M^+$, $catcharea^-$, dairy $consent^-$, natural $land^+$, $easting^-$, $\%silt^-$, SI^+
%EPT	Percentage of individuals that are Ephemeroptera, Plecoptera, Trichoptera. These taxa are sensitive to organic pollution	TR^+, MCI^+, $ASPM^+$, avg_rain^+, avg_temp^-, $soil\_M^+$, $catcharea^-$, dairy $consent^-$, natural $land^+$, $easting^-$, $\%silt^-$, SI^+
ASPM	Average Score Per Metric. Calculated from normalised scores of %EPT, MCI and EPT richness. Higher scores indicate communities with higher ecological integrity. (Collier (2008).	TR^+, MCI^+, $\%EPT^+$, avg_rain^+, avg_temp^-, $soil\_M^+$, $catcharea^-$, dairy $consent^-$, natural $land^+$, $easting^-$, $\%silt^-$, SI^+
TR	Taxa richness. The number of taxa in a sample.	MCI^+, $\%EPT^+$, $ASPM^+$, avg_rain^+, avg_temp^-, $soil\_M^+$, SI^+
Virtual climate station network (VCSN) data		
Avg_rain	Average rainfall over 3 months prior to macroinvertebrate sample at nearest VCSN station.	TR^+, MCI^+, $\%EPT^+$, avg_temp^-, $soil\_M^+$, natural $land^+$, $Northing^+$, $\%silt^-$, SI^+
Avg_temp	Average air temperature over 3 months prior to macroinvertebrate sample at nearest VCSN station.	TR^-, MCI^-, $\%EPT^-$, $ASPM^-$, avg_rain^-, $soil\_M^-$, $DaysSinceFre3^-$, SI^-
Soil_M	Average soil moisture content over 3 months prior to macroinvertebrate sample at nearest VCSN station.	TR^+, MCI^+, $\%EPT^+$, $ASPM^+$, avg_rain^+, avg_temp^-, natural $\_land^+$, $\%silt^-$, SI^+, $Easting^-$
Catchment characteristics		
Catcharea	Upstream catchment area from the sampling site	$temperature^+$, Dairy $consents^+$, % bank $vege^-$

Variable	Description	Correlations
Dairy consent	Total number of consents to discharge dairy effluent to land and/or water in the upstream catchment	MCI$^-$, temperature$^+$, catch area$^+$, natural land$^-$
% bank fence	Percentage of stream bank protected by fencing (existing and completed) in the upstream catchment	Days since FRE3$^+$, % bank vege$^+$, Northing$^-$
% bank vege	Percentage of stream bank vegetated (existing and completed) in the upstream catchment	Temperature$^-$, catch area$^-$, % bank fence$^+$, SI$^-$
Natural land	Percentage of upstream catchment in “natural” landcover class according to the Land Cover Database (LCDB)[3]	MCI$^+$, %EPT$^+$, ASPM$^+$, avg_rain$^+$, temp$^-$, soil_M$^+$, DaysSinceFre3$^-$, catcharea$^-$, dairy consent$^-$, %silt$^-$, SI$^+$
Environmental monitoring data from TRC		
DaysSinceFre3	For each macroinvertebrate sampling date, the number of days since a flow >3 times the median long-term flow. For sites without flow recorders in the catchment this was estimated from the nearest catchment with a flow recorder. See Table 3-2 for list of catchments with flow recorders.	avg_temp$^-$, % bank fence$^+$, natural land$^-$, Northing$^-$
Substrate Index; SI	Summary of substrate size. Larger number indicates larger substrate. Calculated from percent cover of each size class recorded on macroinvertebrate sampling dates. SI = 0.08* bedrock + 0.07*boulder + 0.06*cobble + 0.05*coarse_gravel + 0.04*fine_gravel + 0.03* sand + silt. From Harding et al. (2009).	TR$^+$, MCI, %EPT$^+$, ASPM$^+$, avg_rain$^+$, avg_temp$^-$, soil_M$^+$, % bank vege$^-$, dairy consent$^-$, natural land$^+$, Easting$^-$, Northing$^+$, %silt$^-$
%_silt	Percentage cover of deposited fine sediment recorded during habitat assessment at macroinvertebrate monitoring sites.	MCI$^-$, %EPT$^-$, ASPM$^-$, soil_M$^-$, natural land$^-$, SI$^-$, Easting$^+$

[3] Data provided by TRC. LCDB available here: LCDB v5.0 - Land Cover Database version 5.0, Mainland, New Zealand | LRIS Portal

3 Macroinvertebrate metric trends

3.1 Data Preparation

Seasonal patterns in water temperature and frequency, as well as magnitude and duration of high and low river flows, can impact macroinvertebrate communities and resultant metrics (Stark and Phillips 2009). Assessments for seasonality can be made during trend assessments (See Section 3.2) but require data to be relatively evenly distributed across the seasons and time period being analysed.

Most samples were collected by TRC were in summer (1,184, 42%) and spring (1,083, 38%), with an additional 515 samples (18%) collected during March. The NPS-FM macroinvertebrate attributes require that samples are collected during summer months (November 1st to April 30th). For trend analyses samples collected during spring (September to November, inclusive) and summer (December to March, inclusive) were retained for analysis. The definition of summer was extended to better align with the NPS-FM recommendations and to incorporate the samples collected during March. This retained 98 % (2,782) of the samples provided by TRC.

3.2 Methods

3.2.1 Trend analyses

Trends were calculated for two seasonal periods: both spring and summer samples (spring-summer) and for summer samples only. Summer only samples were analysed separately as TRC has recently changed from bi-annual macroinvertebrate sampling (spring and summer) to annual summer only sampling.

Sites were retained for trend analysis within each temporal range if they had data for >85 % of sampling occasions possible (e.g., 85% of biannual samples for the relevant period for the spring-summer dataset).

Trends were calculated across three time periods (see Figure 3-1):

- The full 28-year data set (1995 to 2023).
- 2003 to 2013.
- 2013 to 2023.

For each of the six (three time periods times two seasons) datasets, trend analyses were undertaken for sites with sufficient data for the following macroinvertebrate metrics (see Section 2.2 and Table 2-1 for further details):

- ASPM; average score per metric.
- Percent EPT; percentage of individuals that were Ephemeroptera, Plecoptera or Trichoptera, which are commonly sensitive to organic pollution.
- EPT; the number of EPT taxa.
- Taxa richness; the total number of taxa.

- MCI regional; Macroinvertebrate Community Index, calculated using tolerance values specific to Taranaki.
- SQMCI regional; the semi-quantitative variant of the MCI.

Trends were calculated using the method of Snelder et al. (2021). Briefly, the trend magnitude is calculated using the Sen slope (or Theil–Sen) estimator (SSE). SSE is the median of all possible slopes of a non-parametric regression between observations and is expressed as the rate of change of the variable per year. SSE is relatively robust to non-normal data, missing values and small data sets, which are common in environmental monitoring data.

For the data sets containing spring and summer samples, a Kruskall Wallis test was used to assess whether there were consistent seasonal differences. In the case of a significant (i.e., $p \leq 0.05$) test the seasonal version of the SSE was used, where the median of all inter-observation slopes was calculated within each season.

Confidence in the trend direction was assigned based on the probability that calculated trend direction is correct (i.e., matches the estimated true trend) using either the Kendall S or its seasonal variant. Kendall S is calculated by evaluating all pairs of observations and whether the difference between them is positive (concordant) or negative (discordant). Kendall S is the difference between number of concordant and discordant pairs. One of nine categories was assigned based on the confidence that the trend was decreasing from 'virtually certain' (confidence 99–100%) to 'exceptionally unlikely' (confidence 0–1%).

3.2.2 Comparison of trend direction between sites

We used mixed effects models (MEM) to test whether there were consistent environmental differences between sites that showed 1) increasing or 2) decreasing trends in MCI values or 3) sites at which insufficient data allowed trend calculation. Trend direction was the predictor variable for separate MEM models of macroinvertebrate metric state, average environmental conditions over time and catchment characteristics (variables tested are listed in Table 2-1). A random intercept term for river was included in models to account for similarities in macroinvertebrate community metrics between sites located on the same river.

These analyses were conducted to analyse the difference in macroinvertebrate metric state for:

1. sites that showed increasing, decreasing trends, or were not able to be assessed due to a lack of data over the 28-year period.
2. sites that showed a consistent increase in MCI in both recent decades (2003–2013 and 2013–2023) and for those that showed inconsistent trend directions between the two decades (increasing in one and decreasing in the other).

3.3 Results and discussion

3.3.1 Trend direction and confidence

In total 1,752 trend analyses were run (six macroinvertebrate metrics, two sampling frequencies (summer only and spring and summer) across three time periods (two decades and full 28 years) and between 42 and 53 sites, depending on the period analysed (Table 3-1).

Over the 28 year period (1995 to 2023) the majority of sites (74%) showed an increasing trend in MCI values, with a moderate to high certainty that the trend direction was not decreasing (Table 3-1, Figure 3-2 and Figure 3-5). This matched the results of TRC (2024) where 75% of sites showed an increasing long-term trend. The percentage of sites showing decreasing trends (26%) was higher than observed in TRC (2024, 14%). This discrepancy is likely due to the data filtering rules we implemented**.** In this analysis, trends were only undertaken on sites with >85% of years with data between 1995-2023, resulting in 42 sites. Whereas in TRC (2024) fifty-six sites with macroinvertebrate data for at least 10 years were analysed for long term trends, with six of the sites having indeterminate trends. Temporal trends in MCI between 2003 and 2013 were also commonly increasing at most sites (~70%, similar to TRC (2024)), albeit with a slightly lower confidence in the trends direction than for the longer term data set (Table 3-1**,** Figure 3-3, Figure 3-6).

A higher prevalence of sites with decreasing trends was observed between 2013 and 2023 (approximately 40% of sites, of varying likelihood; again similar to TRC (2024); Table 3-1, Figure 3-4, Figure 3-7).

The different macroinvertebrate metrics showed similar patterns in trend direction and likelihood across sites within each time period (Figure 3-2, Figure 3-3, Figure 3-4). However, one exception was taxa richness, which more commonly showed the opposite trend to other metrics. Taxa richness is not always a strong indicator of stream health because it includes taxa that become more prevalent under impacted conditions, as well as those that are more sensitive (Wagenhoff et al. 2016). For example, both high and low levels of flow disturbance can reduce richness, and mild nutrient-enriched rivers with small increases in periphyton growth can potentially support higher taxa richness than pristine waterways.

Analysing sites using samples collected only in summer versus those collected in spring or summer generally had little impact on trend direction results within sites (Table 3-1, Figure 3-2, Figure 3-3, Figure 3-4). However, the certainty in trend direction was often reduced in the summer only data sets, as would be expected given the smaller sample size (Figure 3-2, Figure 3-3, Figure 3-4). Further investigation of the impact of using summer only versus summer and spring data on trend confidence and direction could be made using the results provided as excel spreadsheets along with this report.

Figure 3-1: Macroinvertebrate Community Index (MCI) scores over time at 67 State of the Environment monitoring sites in Taranaki. Red shading indicates the 2003–2013 decade and blue shading indicates the 2013–2023 decade during which trends were calculated, if sufficient data were available. Trends were also calculated between 1995 and 2023, for sites with sufficient data. Note the y axis scale differs between sites.

Table 3-1: Number of sites with increasing, decreasing or indeterminate trend direction (grey shading) and within different categories of declining trend likelihood MCI for three different time periods. Columns indicate different sets of sites with sufficient data for analyses over the full 28 years, and in two 10-year periods (2003 to 2013 and 2013 to 2023). Two datasets were analysed for all time periods; summer only samples and both summer and spring samples. MCI was calculated using TRC regional tolerance values.

	1995–2023 summer/spring	1995–2023 summer only	2003–2013 summer/spring	2003–2013 summer only	2013–2023 summer/spring	2013–2023 summer only
Decreasing	11 (26%)	5 (12%)	12 (24%)	12 (24%)	22 (42%)	22 (42%)
Increasing	31 (74%)	37 (88%)	36 (71%)	35 (69%)	27 (51%)	28 (53%)
Indeterminate			3 (5%)	4 (8%)	4 (8%)	3 (6%)
Exceptionally unlikely decreasing	24	19	3	1		
Extremely unlikely decreasing	2	5	10	9	5	3
Very unlikely decreasing	4	4	4	2	1	6
Unlikely decreasing	3	6	11	15	13	12
As likely as not	6	5	15	16	19	19
Likely decreasing	3	2	8	7	9	7
Very likely decreasing					1	6
Extremely likely decreasing		1		1	3	
Exceptionally likely decreasing						
Virtually certain					2	
Total number sites	**42**	**42**	**51**	**51**	**53**	**53**

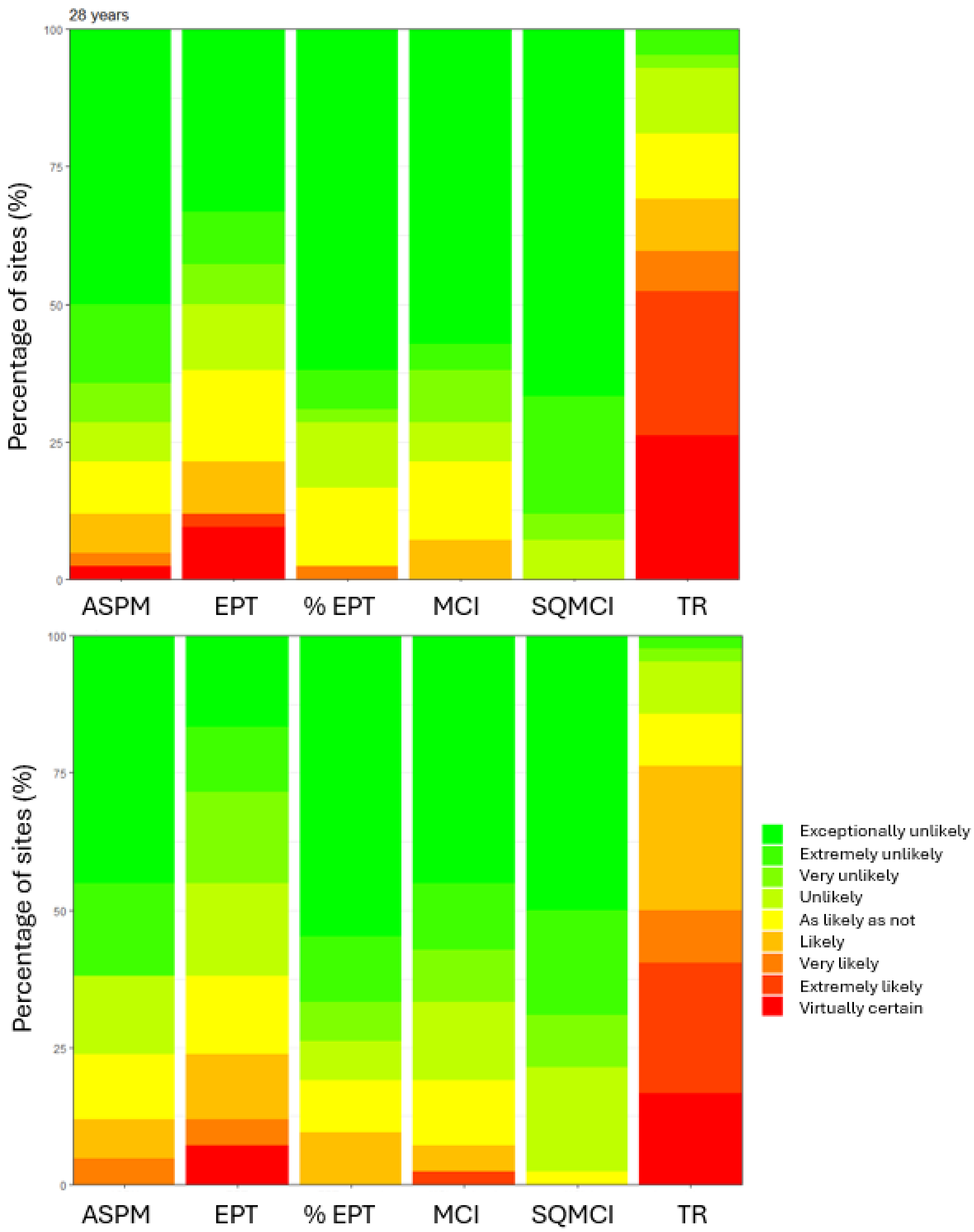

Figure 3-2: The proportion of sites in different likelihood of declining trend categories for multiple macroinvertebrate metrics between 1995 and 2023 using spring and summer samples (top) and summer only samples (bottom). Macroinvertebrate metrics are defined in Section 2.2.1 and Table 2-1 and the number of sites in each trend likelihood category is listed in Table 3-1.

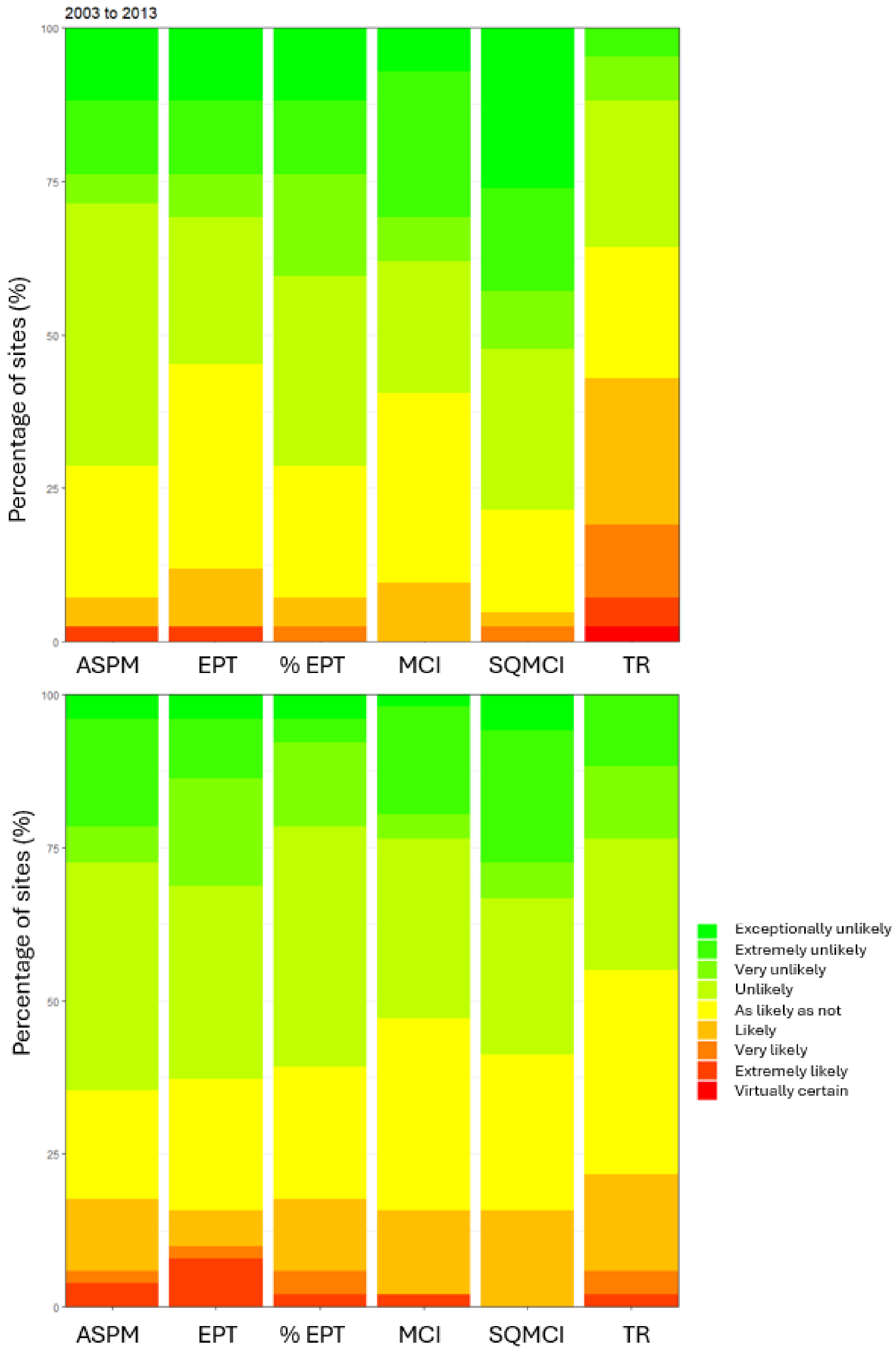

Figure 3-3: The proportion of sites in different likelihood of declining trend categories for multiple macroinvertebrate metrics between 2003 and 2013 using spring and summer samples (top) and summer only samples (bottom). Macroinvertebrate metrics are defined in Section 2.2.1 and Table 2-1 and the number of sites in each trend likelihood category is listed in Table 3-1.

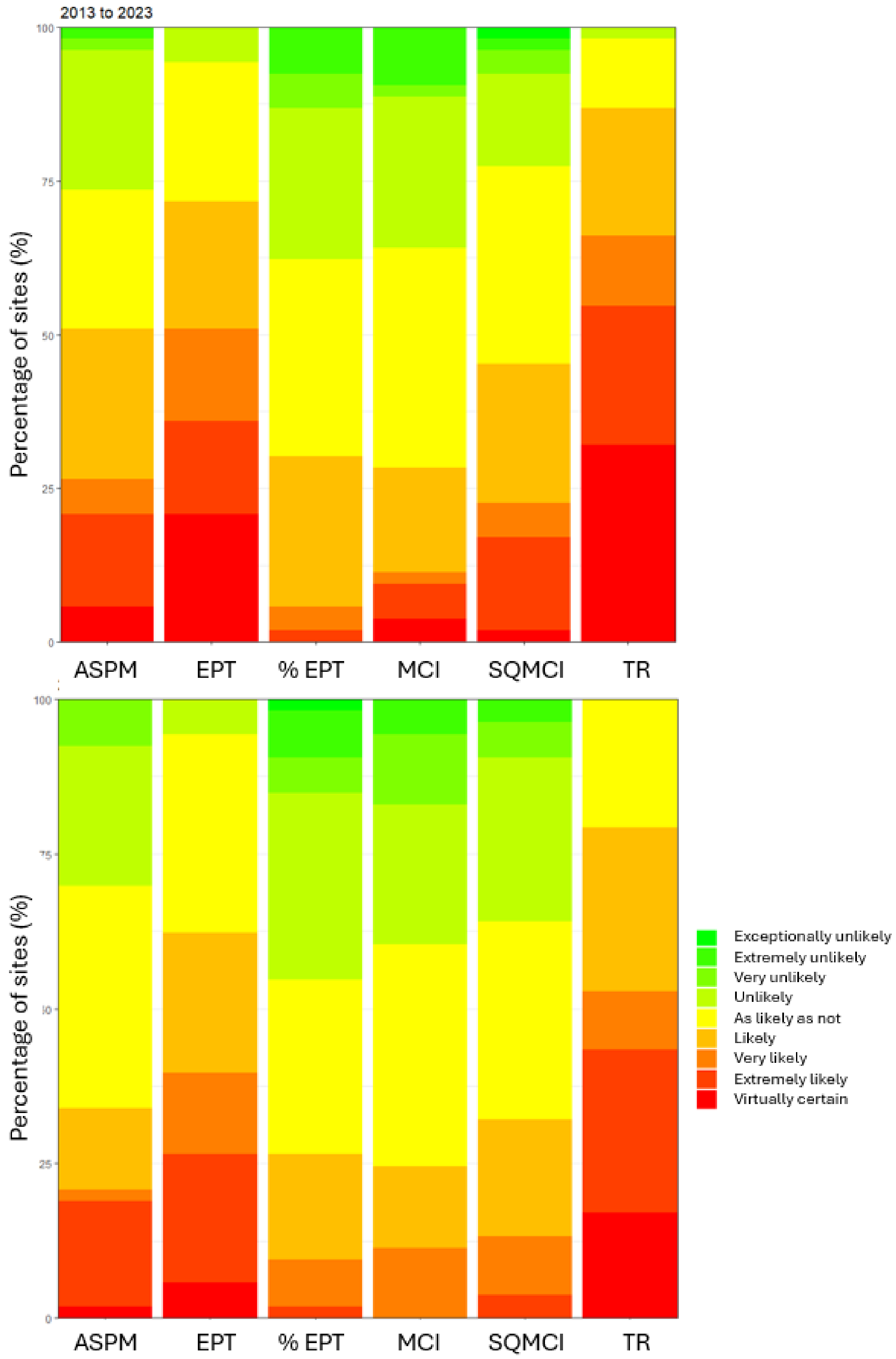

Figure 3-4: The proportion of sites in different likelihood of declining trend categories for multiple macroinvertebrate metrics between 2013 and 2023 using spring and summer samples (top) and summer only samples (bottom). Macroinvertebrate metrics are defined in Section 2.2.1 and Table 2-1 and the number of sites in each trend likelihood category is listed in Table 3-1.

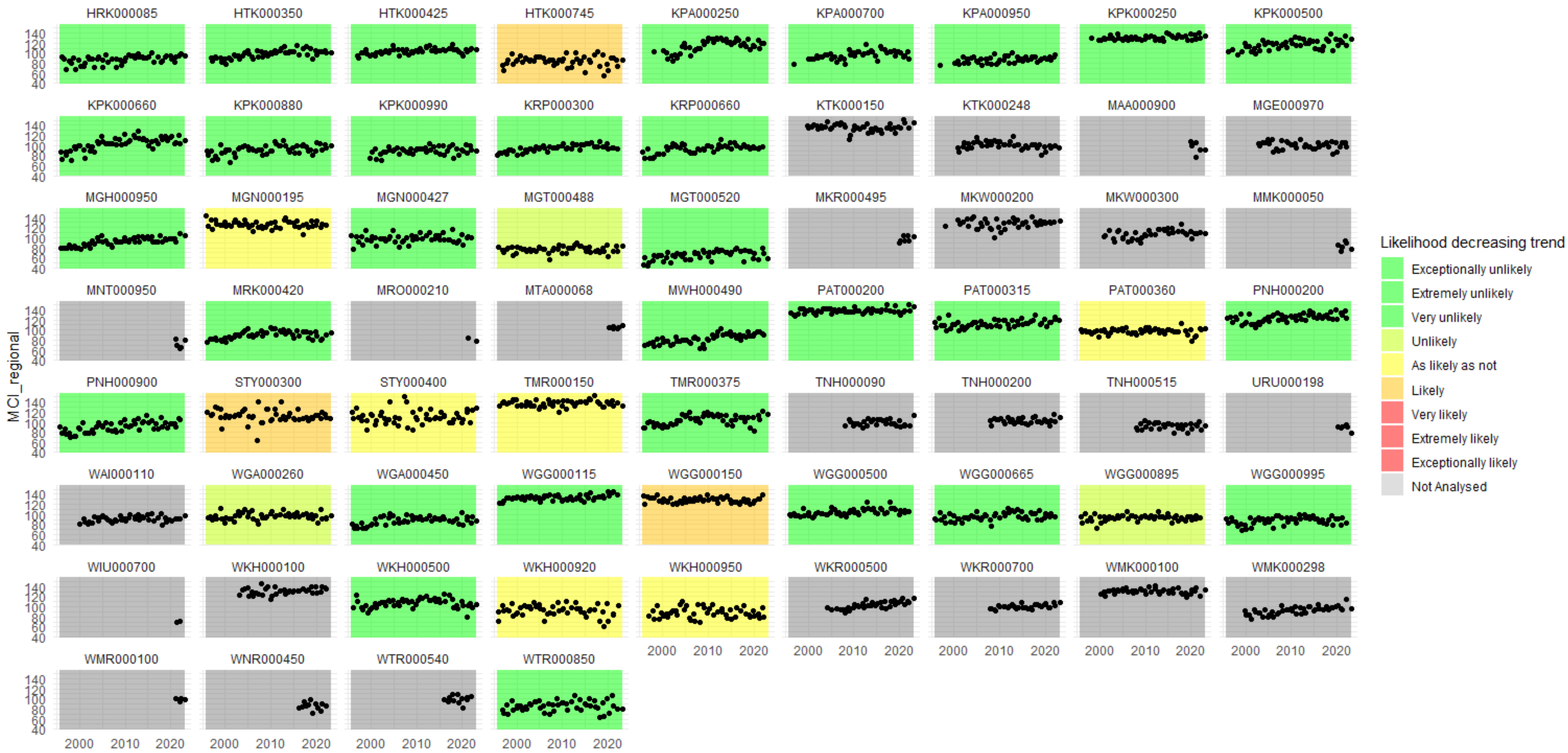

Figure 3-5: MCI scores over time in 67 TRC State of the Environment monitoring sites between 1995 and 2023. Samples collected in both spring and summer are included. Site backgrounds are colour coded according to categories indicating likelihood of a declining trend in MCI. Sites with grey backgrounds did not meet data requirements for trend analysis (data for >85% of sampling periods). MCI was calculated using TRC regional tolerance values.

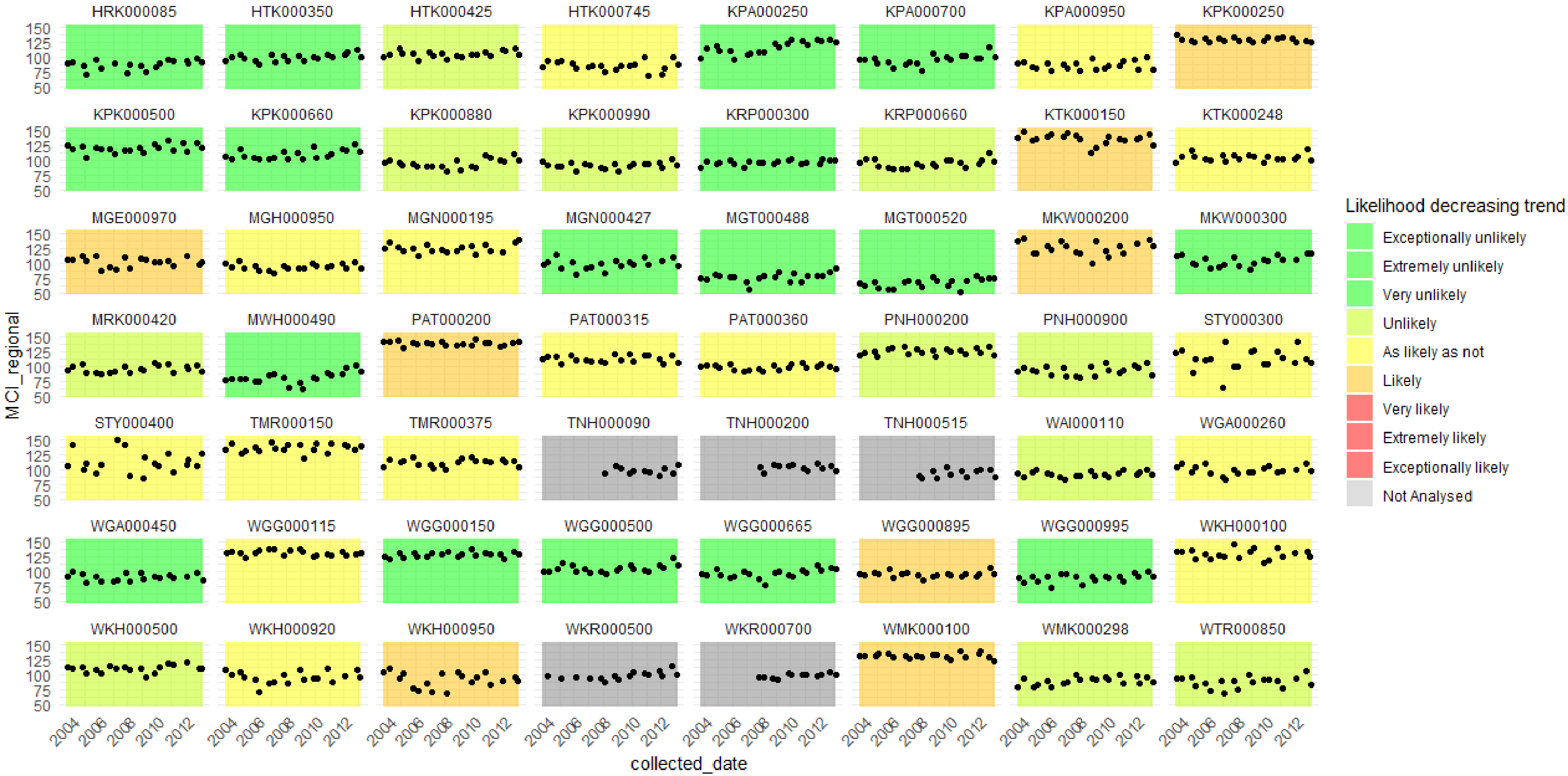

Figure 3-6: MCI scores over time in 67 TRC State of the Environment monitoring sites between 2003 and 2013. Samples collected in spring and summer are included. Site backgrounds are colour coded according to categories indicating likelihood of a declining trend in MCI. Sites with grey backgrounds did not meet data requirements for trend analysis (data for >85% of sampling periods). MCI was calculated using TRC regional tolerance values.

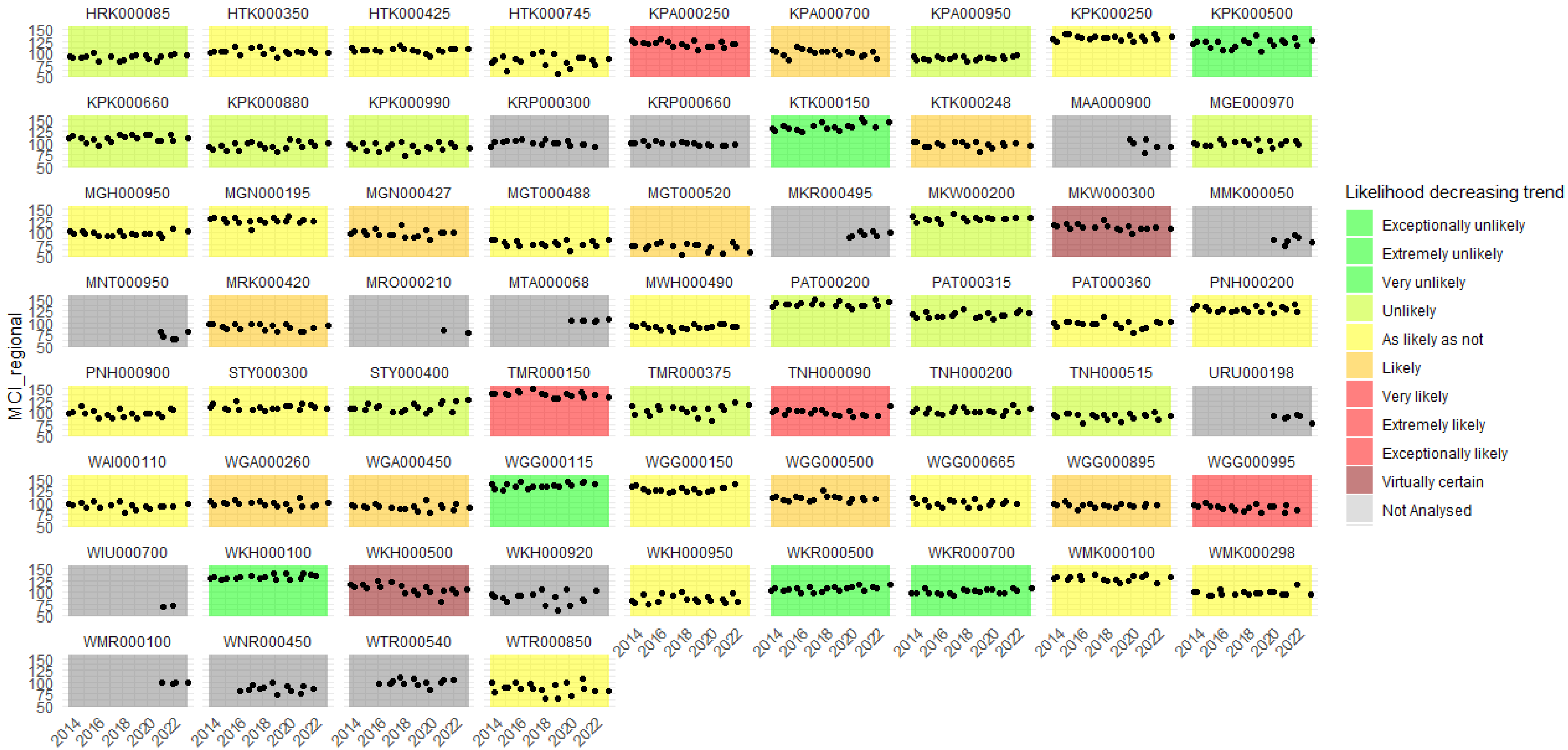

Figure 3-7: MCI scores over time in 67 TRC State of the Environment monitoring sites between 2013 and 2023. Samples collected in spring and summer are included. Site backgrounds are colour coded according to categories indicating likelihood of a declining trend in MCI. Sites with grey backgrounds did not meet data requirements for trend analysis (data for >85% of sampling periods). MCI was calculated using TRC regional tolerance values.

3.3.2 Comparison of trend direction between sites

Long-term trends

Over the 28-year period, increasing trends (of varying certainty) were observed in the majority of sites (35 of the 43 sites with sufficient data), and decreasing trends in relatively few (six sites; Table 3-2). Insufficient data prevented trend analyses at 25 sites (Table 3-2). No significant differences in macroinvertebrate metrics, average environmental conditions or catchment characteristics were identified between sites with increasing or decreasing trends, or those where trend analyses were not possible. Sites that showed increasing or decreasing long-term MCI trends were distributed across the Taranaki region (Figure 3-10).

Table 3-2: Summary of trend direction and likelihood of a decreasing trend in MCI over three time periods (1995–2023, 2003–2013 and 2013–2023) for 67 sites. Trend directions are shaded according to five composite confidence in decreasing trend categories. Red = virtually certain and exceptionally likely declining, orange = very likely to likely decreasing, yellow = as likely as not, dark green = unlikely and very unlikely declining, bright green = exceptionally and extremely unlikely declining. The change category summarises sites that showed increases in both decades (IncInc), at a confidence level equal or high than 'more likely as not' in at least one decade and those that showed an increase in one decade and decrease in the other (IncDec), at a more than likely as not confidence level. See main text for rationale of confidence levels chosen. Blank trend direction cells were unable to be assessed due to insufficient macroinvertebrate data for trends. Sites in bold are water quality monitoring sites.

Site	No. invert samples 1995-2023	1995 to 2023	2003 to 2013	2013 to 2023	Change category
HRK000085	54	Increasing	Increasing	Increasing	IncInc
KPK000500	51	Increasing	Increasing	Increasing	IncInc
KPK000660	54	Increasing	Increasing	Increasing	IncInc
KPK000880	55	Increasing	Increasing	Increasing	IncInc
KPK000990	47	Increasing	Increasing	Increasing	IncInc
HTK000425	52	Increasing	Increasing	Increasing	IncInc
MWH000490	54	Increasing	Increasing	Increasing	IncInc
STY000400	53	Increasing	Increasing	Increasing	IncInc
KPA000950	47	Increasing	Increasing	Increasing	IncInc
WTR000850	53	Increasing	Increasing	Increasing	IncInc
HTK000350	52	Increasing	Increasing	Indeterminate	-
WGG000665	55	Increasing	Increasing	Indeterminate	-
TMR000375	54	Increasing	Indeterminate	Increasing	-
PAT000315	55	Increasing	Indeterminate	Increasing	-
MGH000950	55	Increasing	Increasing	Increasing	-
PNH000200	54	Increasing	Increasing	Decreasing	-
PNH000900	55	Increasing	Increasing	Decreasing	-
MGT000488	53	Increasing	Increasing	Decreasing	-
WGG000115	54	Increasing	Decreasing	Increasing	-
KPK000250	48	Increasing	Decreasing	Increasing	-
WGA000260	53	Increasing	Increasing	Decreasing	-

Site	No. invert samples 1995-2023	1995 to 2023	2003 to 2013	2013 to 2023	Change category
KPA000700	47	Increasing	Increasing	Decreasing	IncDec
MGN000427	55	Increasing	Increasing	Decreasing	IncDec
MGT000520	54	Increasing	Increasing	Decreasing	IncDec
MRK000420	53	Increasing	Increasing	Decreasing	IncDec
WGA000450	54	Increasing	Increasing	Decreasing	IncDec
WGG000500	55	Increasing	Increasing	Decreasing	IncDec
KPA000250	47	Increasing	Increasing	Decreasing	IncDec
WKH000500	53	Increasing	Increasing	Decreasing	IncDec
WGG000995	55	Increasing	Increasing	Decreasing	IncDec
PAT000200	54	Increasing	Decreasing	Increasing	IncDec
WGG000895	55	Increasing	Decreasing	Decreasing	-
KRP000300	54	Increasing	Increasing	-	-
KRP000660	54	Increasing	Increasing	-	-
PAT000360	55	Increasing	Increasing	Decreasing	-
WGG000150	55	Decreasing	Increasing	Decreasing	-
STY000300	54	Decreasing	Increasing	Increasing	-
HTK000745	52	Decreasing	Decreasing	Decreasing	-
MGN000195	55	Decreasing	Increasing	Indeterminate	-
TMR000150	53	Decreasing	Increasing	Decreasing	-
WKH000920	53	Decreasing	Indeterminate	-	-
WKH000950	51	Indeterminate	Decreasing	Increasing	-
WMK000298	46	-	Increasing	Increasing	IncInc
WAI000110	46	-	Increasing	Indeterminate	-
MKW000300	44	-	Increasing	Decreasing	IncDec
WKR000500	35	-	Decreasing	Increasing	IncDec
MGE000970	40	-	Decreasing	Increasing	IncDec
MKW000200	45	-	Decreasing	Increasing	IncDec

Site	No. invert samples 1995-2023	1995 to 2023	2003 to 2013	2013 to 2023	Change category
KTK000150	46	-	Decreasing	Increasing	IncDec
WKH000100	39	-	Decreasing	Increasing	-
KTK000248	44	-	Decreasing	Decreasing	-
WMK000100	45	-	-	Decreasing	-
TNH000090	29	-	-	Decreasing	-
WKR000700	31	-	-	Increasing	-
TNH000200	31	-	-	Increasing	-
TNH000515	31	-	-	Increasing	-
MAA000900	7	-	-	-	-
MKR000495	7	-	-	-	-
MMK000050	6	-	-	-	-
MNT000950	5	-	-	-	-
MRO000210	3	-	-	-	-
MTA000068	6	-	-	-	-
URU000198	6	-	-	-	-
WIU000700	3	-	-	-	-
WMR000100	4	-	-	-	-
WNR000450	13	-	-	-	-
WTR000540	13	-	-	-	-

Trends in 2003–2013 and 2013–2023

Sites were grouped into two categories of trend direction over the two decades. Sites that consistently showed increasing MCI trends in both decades (at a confidence level equal or high than 'more likely as not' in at least one decade) were categorised as IncInc sites (Table 3-2). Sites that showed an increasing MCI trend in one decade and a decreasing trend in the other decade, at a more than likely as not confidence level, were categorised as IncDec (Table 3-2). The IncDec category did not include sites with 'as likely as not' trend confidences to increase the confidence that decreasing trends were actually present.

Eleven sites showed increasing trends in MCI-regional values in both 2003–2013 and 2013–2023, while 15 sites had an increase in MCI in one decade and a decrease in the other (Table 3-2). Most of sites that showed inconsistent trend directions between the two time periods increased in the earlier decade and decreased during 2013–2023 (10 sites out of 15), apart from PAT000200, WKR000500, MGE000970, MKW000200 and KTK000150. Four of the sites that showed increasing trends in both decades were on the Kaūpokonui River, with the rest predominantly near the north and western coast (Figure 3-10).

Of the variables representing average macroinvertebrate state, average environmental conditions and catchment characteristics listed in Table 2-1, MEM showed that only average rainfall was consistently different between sites that showed consistent increases in MCI and those that increased in one decade and decreased in the other. Average rainfall (the average of three months antecedent rainfall to each macroinvertebrate sampling date) was higher in sites that showed differing trend directions over the two decades (MEM glm: $F_{1, 6} = 6.3$, $p = 0.04$, Figure 3-8, Figure 3-9). This difference is likely to be spurious and due to correlations with other, unmeasured between-site differences, particularly since differences in flow regime (e.g., the average time since a flow event greater than three times the long-term median flow) did not differ significantly between the sites that showed differing trends (Figure 3-9). In general, sites with higher rainfall also had cooler average air temperature, more upstream natural land and larger substrate (Table 2-1, Section 2.2.4). See Section 2.4.4 for further discussion of correlations of site characteristics between sites.

The number of days since a flood event at least three times the long-term median flow at a site was significantly higher in the 2013–2023 period than the 2003–2013 and the 1995–2023 period (MEM: $F_{2, 4170} = 4.7$, $P = 0.009$, Figure 3-9). The average antecedent rainfall was also significantly lower in the 2013–2023 period than the 2003–2013 decade (MEM log10 antecedent rain: $F_{2, 4170} = 8.4$, $P < 0.001$, Figure 3-9). The lower rainfall on average and general longer time since a recent flood event could have contributed to the higher prevalence of declining MCI trends in the 2013–2023 period than the earlier decade.

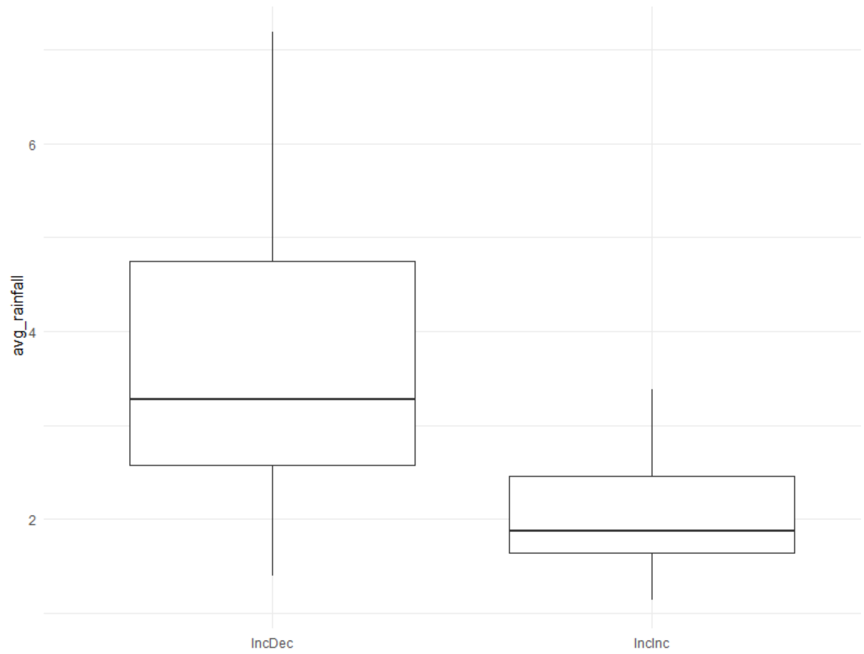

Figure 3-8: Box and whisker plot of the annual average of the average rainfall in three months prior to macroinvertebrate samples. IncInc sites had increasing MCI trends in both 2003–2013 and 2013–2023. IncDec sites had increasing MCI trends in one decade and decreasing trends in the other.

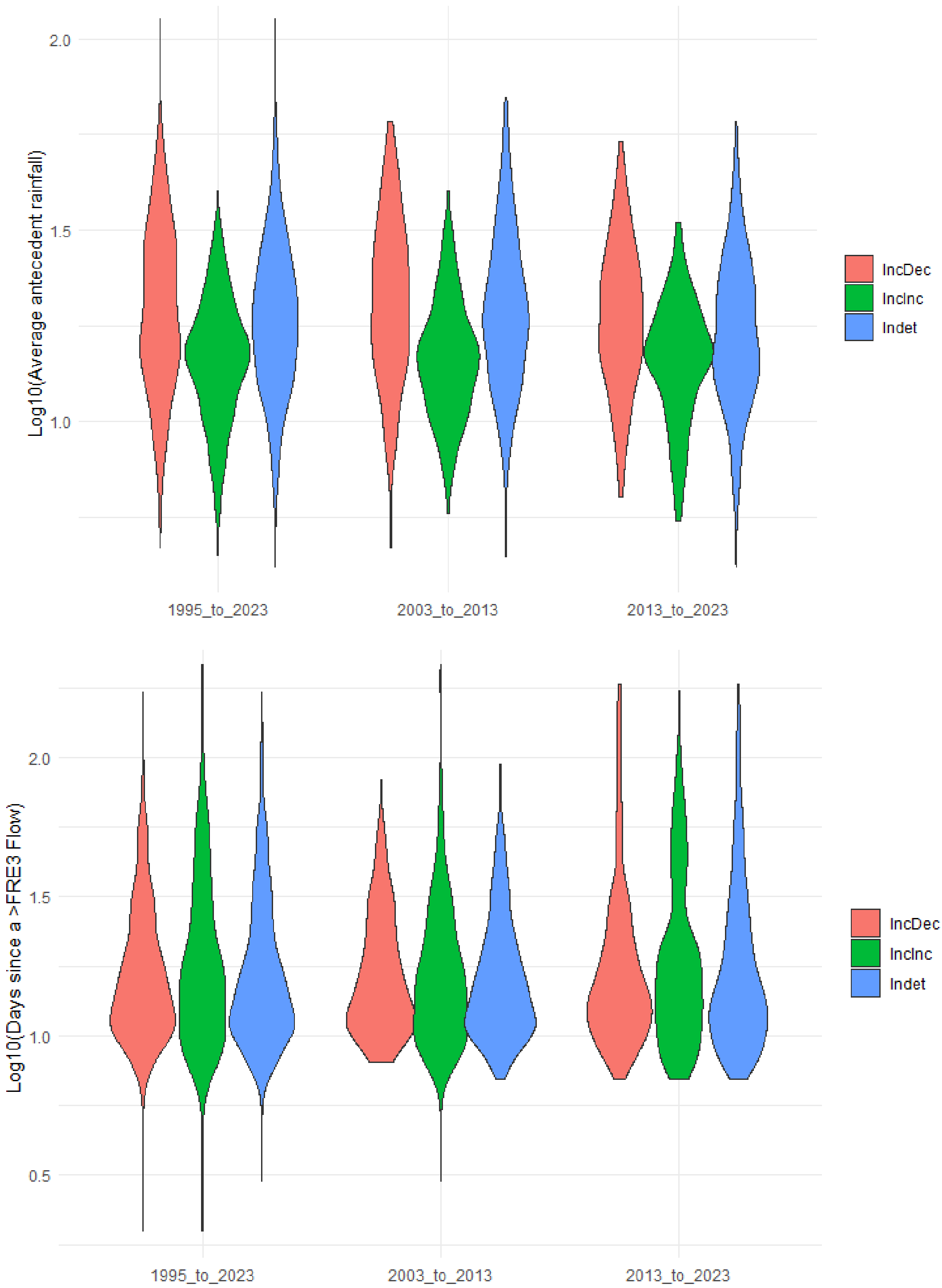

Figure 3-9: Violin plots showing the distribution of log10 transformed average annual rainfall in the three months prior to a macroinvertebrate sample collection (top) and average annual number of days since a flow at least three times the long-term median flow at a site prior to macroinvertebrate samples (bottom) across three time periods (1995—2003, 2003—2013 and 2013—2023) in sites that had varying trends in MCI in the decades 2003—2013 and 2013—2023. DecInc = decreasing MCI trend in the earlier decade and increasing trend in the later, IncDec = increasing trend and then decreasing trend, IncInc = increasing trend in both decades, Indet = sites not assigned IncDec, DecInc or IncInc. See Table 3-2 for list and number of sites in each trend category.

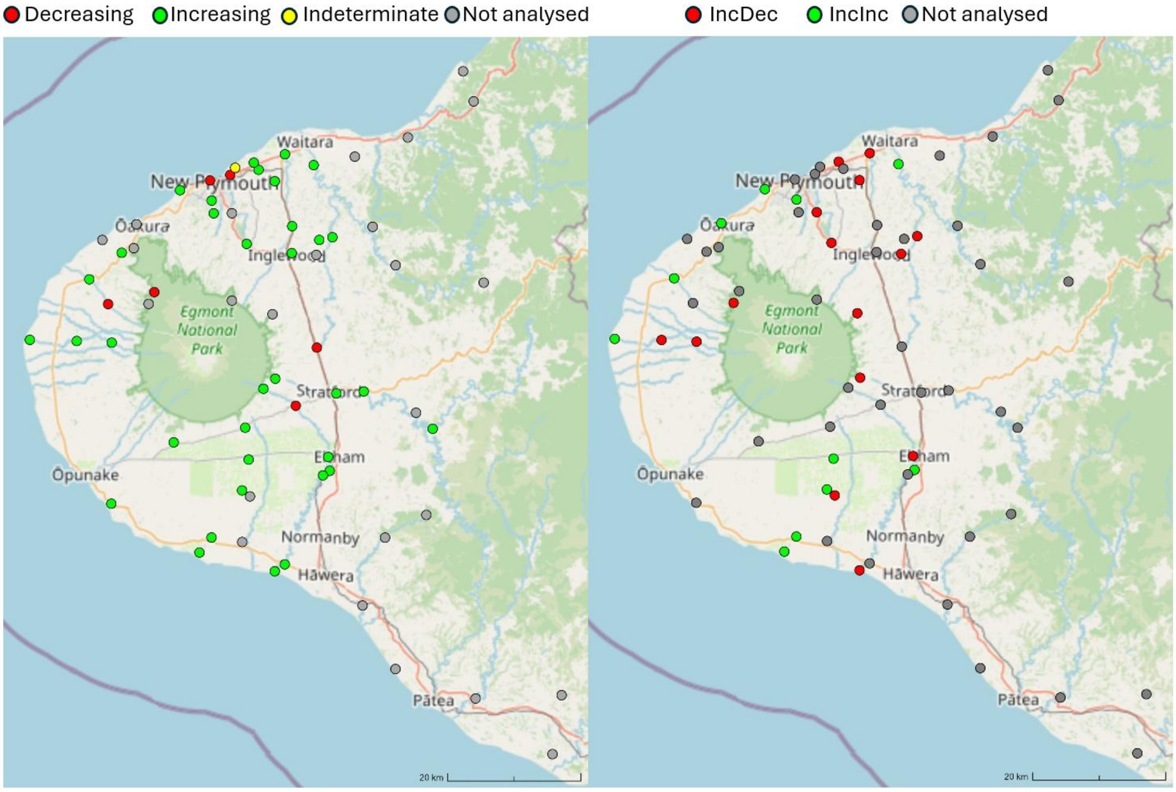

Figure 3-10: Maps of Taranaki macroinvertebrate monitoring sites showing long-term (1995 to 2023) trends in MCI-regional values (left) and comparisons of short-term trends between 2003—2013 and 2013—2023 (right). IncInc = sites that showed increasing MCI trends in both time periods. IncDec = sites that had an increasing trend in one decade and a decreasing trend in the other. Grey points show sites with insufficient data for trend analysis (left) or that either had insufficient data or did not have determinate trends during both short-term time periods (right).

4 Correlations between potential stressors and MCI values

In this section correlations and relationships between potential stressors and MCI values over time were investigated both separately for individual sites and together across all sites with sufficient data. All seasonal macroinvertebrate sample data were included in correlations, i.e., not just samples collected during spring and summer.

4.1 Methods

Two datasets were created:

1. Broad dataset: the 67 sites with temporal macroinvertebrate monitoring.
2. Water quality dataset: nineteen macroinvertebrate sites that had additional water quality data, as well as limited periphyton data.

4.1.1 Data available

Temporal environmental data for the broad dataset were largely collected during the macroinvertebrate sample collection, supplemented by the virtual climate data (Table 4-1). Data for additional variables were available for a subset of sites (19 sites) at which water quality data were also collected (Table 4-1). Temporal categorical periphyton data were available for the broad data set. Numeric periphyton percentage cover and biomass (chlorophyll *a*) data were also available for a subset of the water quality sites (11 sites), but only over relatively short time periods (between 2018 and 2023 for biomass data; Table 4-1, Figure 2-3) and were not able to be included in correlation analyses. See Section 4.2.3 for an investigation of periphyton state in sites that show increasing or decreasing MCI trends.

Water quality and periphyton data were collected on different dates and at different frequencies (commonly monthly) than the macroinvertebrate samples. Each water quality variable was summarised as the mean or 92nd percentile value over the three months prior to each macroinvertebrate sampling date at a site (see Table 4-1).

Table 4-1: Variables used as predictors of MCI and their data source (67-site broad macroinvertebrate dataset or 19-site subset with additional water quality parameter information).

Variable name	Description	Data set
SOI	Southern Oscillation Index, pressure differential in the South Pacific.	Broad data set
Avg_rain	Average daily rainfall over 3 months prior to macroinvertebrate sample at nearest VCSN station.	Broad data set
Avg_temp	Average air temperature over 3 months prior to macroinvertebrate sample at nearest VCSN station.	Broad data set
Avg_SoilM	Average soil moisture content over 3 months prior to macroinvertebrate sample at nearest VCSN station.	Broad data set
Water temp	Spot water temperature data collected at same time as macroinvertebrate samples.	Broad data set

Variable name	Description	Data set
DaysSinceFre3	Number of days since a flow event ≥ three times the median long-term flow at a site for each macroinvertebrate sampling date. Calculated from nearby catchments for those without a flow recorder.	Broad data set
%silt	Visual estimates of percent silt cover on the stream bed collected during macroinvertebrate sampling.	Broad data set
SI	Substrate index, calculated from percent cover estimates of substrate size classes. See Section 2.2 for more detail.	Broad data set
Periphyton_mat category	One of four cover categories recorded for periphyton mat coverage during macroinvertebrate sampling.	Broad data set
Water temperature	Average water temperature over three months prior to macroinvertebrate sampling.	Water quality sites
Turbidity	Turbidity (92^{nd} percentile) in the three months prior to macroinvertebrate sampling.	Water quality sites
Dissolved oxygen	Average dissolved oxygen saturation over three months prior to macroinvertebrate sampling.	Water quality sites
Dissolved reactive phosphorus (DRP)	Average DRP over three months prior to macroinvertebrate sampling.	Water quality sites
Dissolved inorganic nitrogen (DIN)	Average DIN over three months prior to macroinvertebrate sampling.	Water quality sites

4.1.2 Analyses

Within each site, for both the 67- and 19-site datasets, the relationship between MCI and individual environmental variables over time within each site was assessed using separate linear models for each variable and each site. The full temporal period was utilised for each site (the data available between 1995–2023).

To test the importance of key stressors across all rivers, mixed effects models were run with a combination of stressors identified in the separate linear models above and a random intercept term of site nested within river. These models were run for the three trend time periods (1995–2023, 2003–2013 and 2013–2023) to identify if similar parameters were predictors of MCI in each time period.

4.2 Results and discussion

4.2.1 Potential stressors over time

Plots of temporal patterns in several potential stressors with temporal data (SOI, average air temperature, days since a FRE3 flow event and the substrate index) in all 67 sites are shown in Appendix A. Appendix B has plots of DIN over time within the 19 sites in the water quality dataset.

4.2.2 MCI correlations with potential stressors

Broad data set

Climatic conditions (SOI) were significantly (positively) correlated with MCI values over time in only two sites (PAT000315 and WIU000700), of which the latter had only three sampling occasions (Table 4-3).

Average antecedent air temperature was correlated with MCI values in 17 sites, of which 15 sites showed a negative relationship between air temperature and MCI (Figure 4-1; Table 4-3). Average antecedent rainfall was significantly and positively correlated with MCI in 22 sites (Table 4-3; Figure 4-2). The number of days since a flow event at least three times the median long-term flow for a site was negatively correlated with MCI in 12 sites (Figure 4-3, Table 4-3). Seven of these 12 sites also had positive correlations between MCI and average antecedent rainfall.

The percentage cover of fine silt at a site was not correlated with MCI values in any sites (Table 4-3). Percentage silt cover did not vary greatly over time within sites (generally less than ± 5 to 10%). However, temporal changes in the substrate index were correlated with MCI in 10 sites (Table 4-3). Seven sites showed an expected positive relationship, with higher MCI values when substrate size was generally larger. Larger substrate is generally more stable during flow events with potentially more availability of larger interstitial spaces as habitat for macroinvertebrates. Small substrate, particularly sand and silt, are unstable in flow events and are not preferred habitat for many macroinvertebrate taxa, including many of the sensitive EPT taxa. Three sites showed an unexpected negative relationship between substrate size and MCI (Figure 4-4).

The amount of periphyton recorded during macroinvertebrate sampling was significantly associated with different MCI values in 21 sites, with 16 sites of the 21 sites having lower MCI values when periphyton mats were 'widespread' rather than 'slippery', 'patchy' and/or 'none' (Figure 4-5, Table 4-3). Interestingly, a few sites were observed to have MCI values that were higher when periphyton was 'widespread' rather than 'patchy' or 'slippery', which is counterintuitive if periphyton is acting as a stressor on macroinvertebrate communities (Figure 4-5).

It should be noted that some of these predictor variables are also likely to be correlated within at least some of the sites (See section 3.2.2 for correlations between site average environmental variables). Care must be used when interpreting causation from the correlations identified here.

Water quality data set

The additional variables in the water quality data set that were not already investigated in the broad data set were DIN, DRP, turbidity, average water temperature from water quality collections (in comparison to spot measurements taken at the time of macroinvertebrate sampling) and dissolved oxygen concentrations (Table 4-1).

Across the 19 sites, turbidity was a poor indicator of MCI values, with a significant correlation at only one site, and that in a counter-intuitive direction with higher MCI values when turbidity was higher in the previous three months (Table 4-3, Table 4-4, Figure 4-10). High turbidity values in this site likely relate to recent high flow events, which were commonly linked to higher MCI values in the broader dataset (see Section 4.2.1).

Similar to air temperature in the broad dataset, average water temperature in the three months prior to macroinvertebrate samples was correlated with MCI values in several (five of 19) sites (Table

4-3 and Table 4-4). MCI values were lower in all five sites when antecedent water temperature had been higher (Figure 4-8).

Antecedent dissolved oxygen concentrations were correlated with MCI values in three sites, all of which also had significant correlations with water temperature (Table 4-3 and Table 4-4). However, one of the sites had only three dissolved oxygen data values available (WKR000500), and one showed a counter intuitive relationship with higher MCI values when DO was lower (Figure 4-9).

The dissolved nutrient variables DIN and DRP had significant correlations with MCI values in seven and two sites, respectively (Table 4-3 and Table 4-4). In all cases DIN and MCI correlations were positive (Figure 4-7), which is unexpected if DIN is acting as a stressor. However, it is important to note that the relationship between observed instream nutrient concentrations and periphyton biomass can be complex (this is discussed further in section 4.2.3). DIN concentrations can become toxic to macroinvertebrates at very high concentrations and periphyton growth can be limited by low DIN concentrations. See Appendix B for temporal trends in DIN. DRP was positively correlated with MCI in one site and negatively in the other (Figure 4-6).

Maximum nitrate concentrations in 15 of the 19 sites were within the values for Band A and Band B of the nitrate toxicity attribute in the NPS-FM (based on annual medians; Table 4-2). These band assignments are based on maximum values, not the annual medians required by the NPS-FM and are likely to be over-estimates of the sites true nitrate toxicity band. However, Band A and Band B indicate effects of nitrate toxicity on fewer than 95% of species. Only four of the sites had values that placed them in nitrate attribute bands that indicated potential toxic effects on more than 20% of taxa, and in only two of the sites nitrate concentrations ranged across more than two bands over time. Dissolved nutrients do not seem to be acting as direct stressors of macroinvertebrate communities in these sites.

Table 4-2: Mean, minimum and maximum nitrate concentrations (NO_3 mg/L) from samples at water quality sites. The NPS-FM nitrate toxicity attribute band is based on comparing measured minimum and maximum values in the sites with the median annual value of monthly sampling in the NPS-FM and thus is indicative only.

Site code	No. samples	Mean	Minimum	Maximum	Indicative NPS-FM attribute bands
PAT000200	354	0.02	0.00	0.14	Band A
STY000300	353	0.03	0.00	0.11	Band A
PNH000200	353	0.06	0.01	0.68	Band A
MGH000950	355	0.12	0.00	0.43	Band A
WKH000500	364	0.12	0.00	0.47	Band A
MGN000195	46	0.15	0.02	0.65	Band A
WTR000540	115	0.20	0.00	0.49	Band A
KPA000950	36	0.25	0.00	0.77	Band A
MKW000300	266	0.30	0.01	0.92	Band A

Site code	No. samples	Mean	Minimum	Maximum	Indicative NPS-FM attribute bands
MTA000068	30	0.32	0.08	0.85	Band A
WNR000450	116	0.35	0.07	0.72	Band A
MKR000495	31	0.36	0.09	0.85	Band A
WMR000100	30	0.57	0.06	1.20	Band A to Band B
MRK000420	354	0.84	0.05	1.73	Band A to Band B
PAT000360	354	0.90	0.21	1.54	Band A to Band B
PNH000900	353	1.08	0.07	4.40	Band A to Band C
WGG000500	378	1.19	0.13	2.87	Band A to Band C
WKR000500	56	3.21	1.77	4.70	Band B to Band C
WKR000700	162	3.28	1.59	5.20	Band B to Band C

Table 4-3: Summary of number of Taranaki sites with correlations between temporal MCI and potential stressors between 1995–2023. The broad data set has 67 sites and the water quality data set has 19 sites. Variables are ordered from the highest percentage of sites with correlations with MCI to the least.

Variable	Data set	No. of sites with MCI correlations	Description
Dissolved inorganic nitrogen (DIN)	Water quality sites	37% (7 / 19)	All positive correlations.
Avg_rain	Broad data set	33% (22 / 67)	All positive correlations.
Periphyton_mat category	Broad data set	31% (21 / 67)	16 sites had lower MCI when mats widespread.
Water temperature	Water quality sites	26% (5 / 19)	All negative correlations.
Air temperature	Broad data set	25% (17 / 67)	Negative correlation in 15 sites.
DaysSinceFre3	Broad data set	18% (12 / 67)	All negative correlations.
Dissolved oxygen	Water quality sites	16% (3 / 19)	Same sites with water temperature correlations. Two positive, one negative correlation.
SI	Broad data set	15% (10 / 67)	Seven positive, 3 negative correlations.
Dissolved reactive phosphorus (DRP)	Water quality sites	10% (2 / 19)	One positive, one negative correlation.
Turbidity	Water quality sites	5% (1 / 19)	Positive correlation. Likely spurious.
SOI	Broad data set	3% (2 / 67)	Likely spurious. One site only had 3 data points.
%silt	Broad data set	0	

Table 4-4: Results of individual linear models for each environmental variable within a site over time (1995–2023) for the water quality dataset (19 sites). The number of invertebrate samples and variables with significant linear relationships (and the direction) are indicated. * Note that the number of paired water quality variable samples varies by parameter and may be considerably lower than the macroinvertebrate sample number. See Figures 4-6 to 4-10 for number of data points per water quality variable. MCI trend results for each site for 2003–2013 and 2013–2023 are in the last column (see Section 3 for more details). IncInc = increasing MCI trend in both decades, IncDec = increasing and decreasing trend in each decade. The bold sites have periphyton monitoring data also available.

Site	No. Invert samples*	Sig. correlations	Trend category 2003–2013 and 2013–2023
KPA000950	47	$Temp^-$	IncInc
MGH000950	55	-	-
MGN000195	55	$Temp^-$ $DaFRE3^-$	-
MKR000495	7	-	-
MKW000300	44	DIN^+ $DaFRE3^-$	IncDec
MRK000420	53	DIN^+ $Temp^-$ DO^+	IncDec
MTA000068	6	-	-
PAT000200	54	DRP^+	IncDec
PAT000360	55	-	-
PNH000200	54	DIN^+ DRP^- $DaFRE3^-$	-
PNH000900	55	$Turbidity^+$ DIN^+ $Temp^-$ DO^-	-
STY000300	54	-	-
WGG000500	55	-	IncDec
WKH000500	53	DIN^+	IncDec
WKR000500	35	$Temp^-$ DO^-	IncDec
WKR000700	31	DIN^+	-
WMR000100	4	-	-
WNR000450	13	-	-
WTR000540	13	DIN^+	-

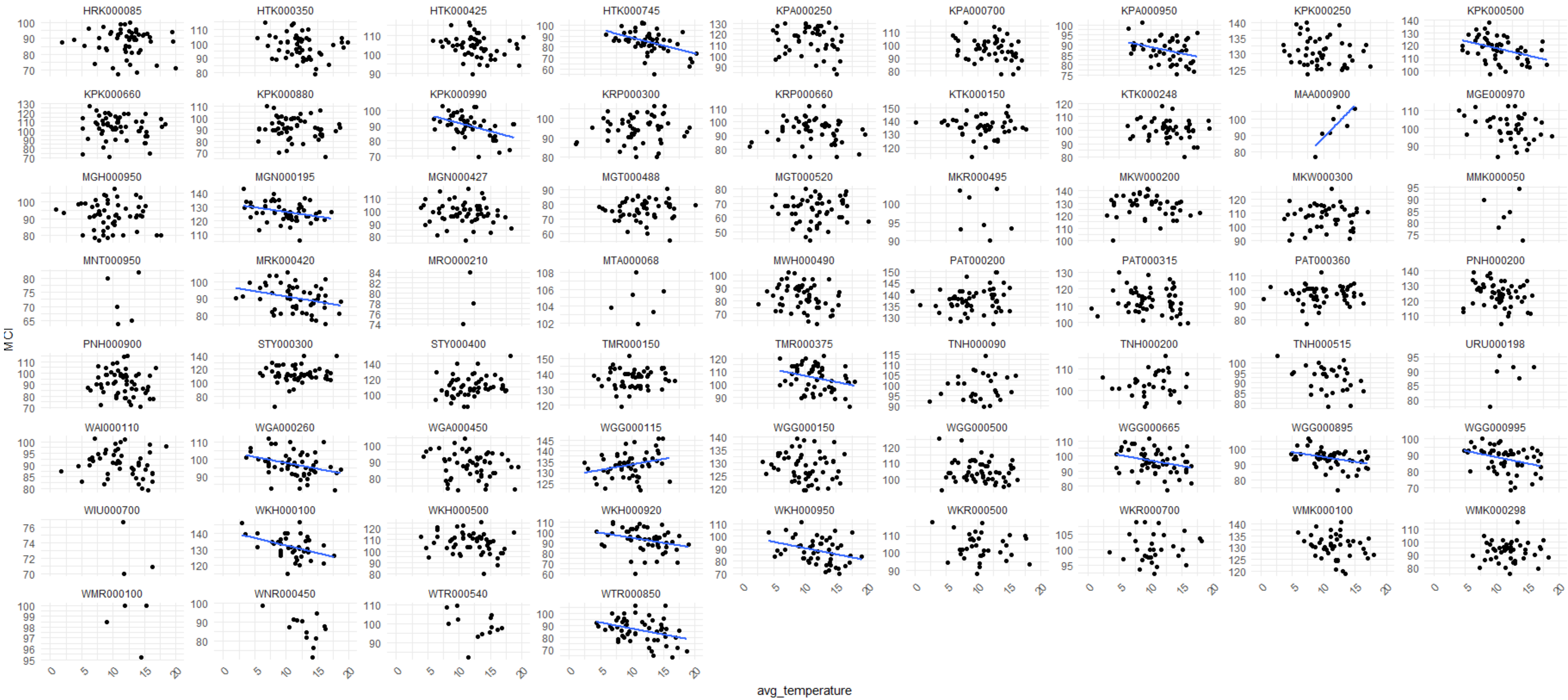

Figure 4-1: Plots of MCI values against average air temperature in the prior three months for 67 macroinvertebrate monitoring sites. Air temperature data from the NIWA virtual climate station network. Fitted lines (blue) added to sites with a significant linear correlation (alpha = 0.05).

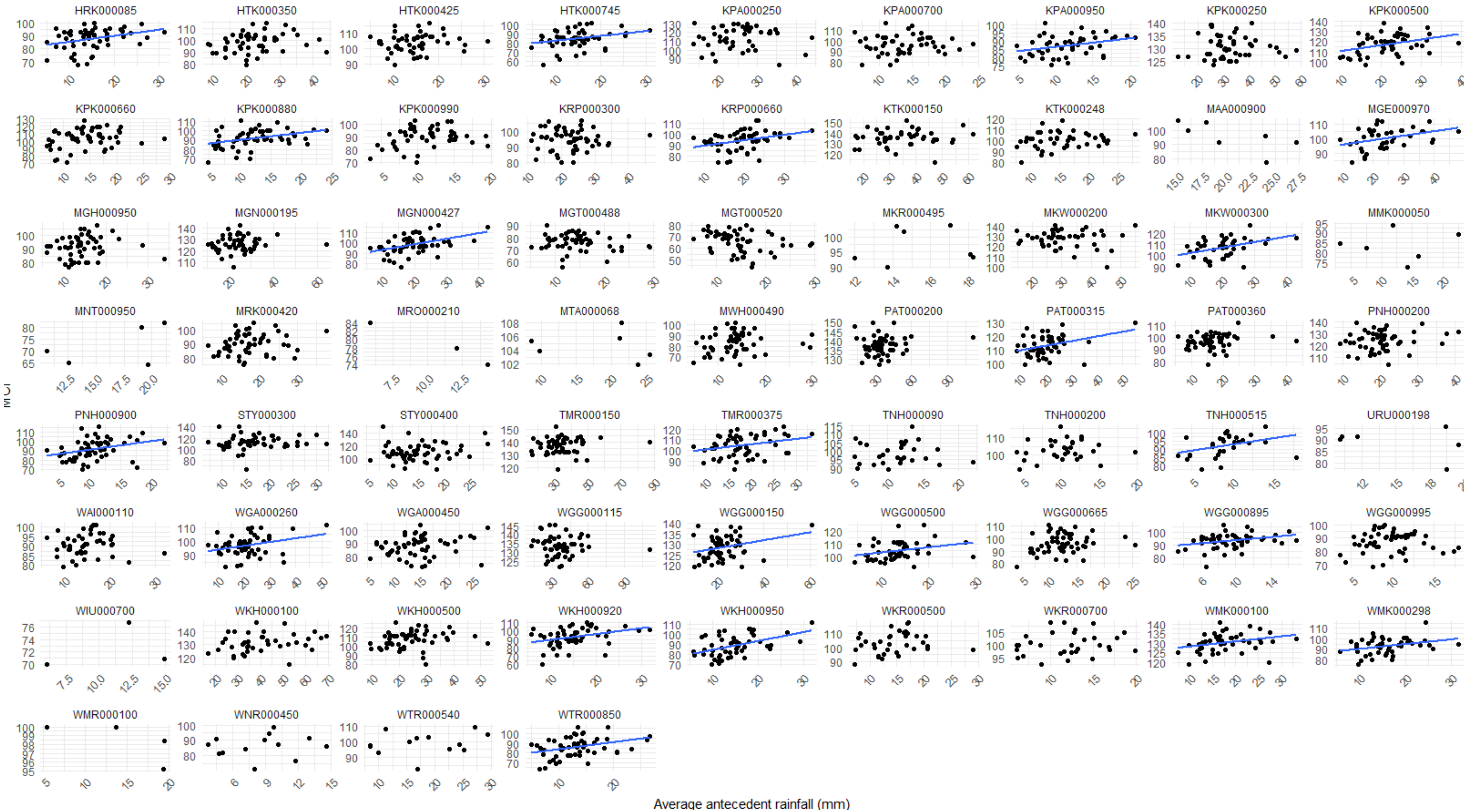

Figure 4-2: Plots of MCI values against average rainfall in the prior three months for 67 macroinvertebrate monitoring sites. Rainfall data from the NIWA virtual climate station network. Fitted lines (blue) added to sites with a significant linear correlation (alpha = 0.05).

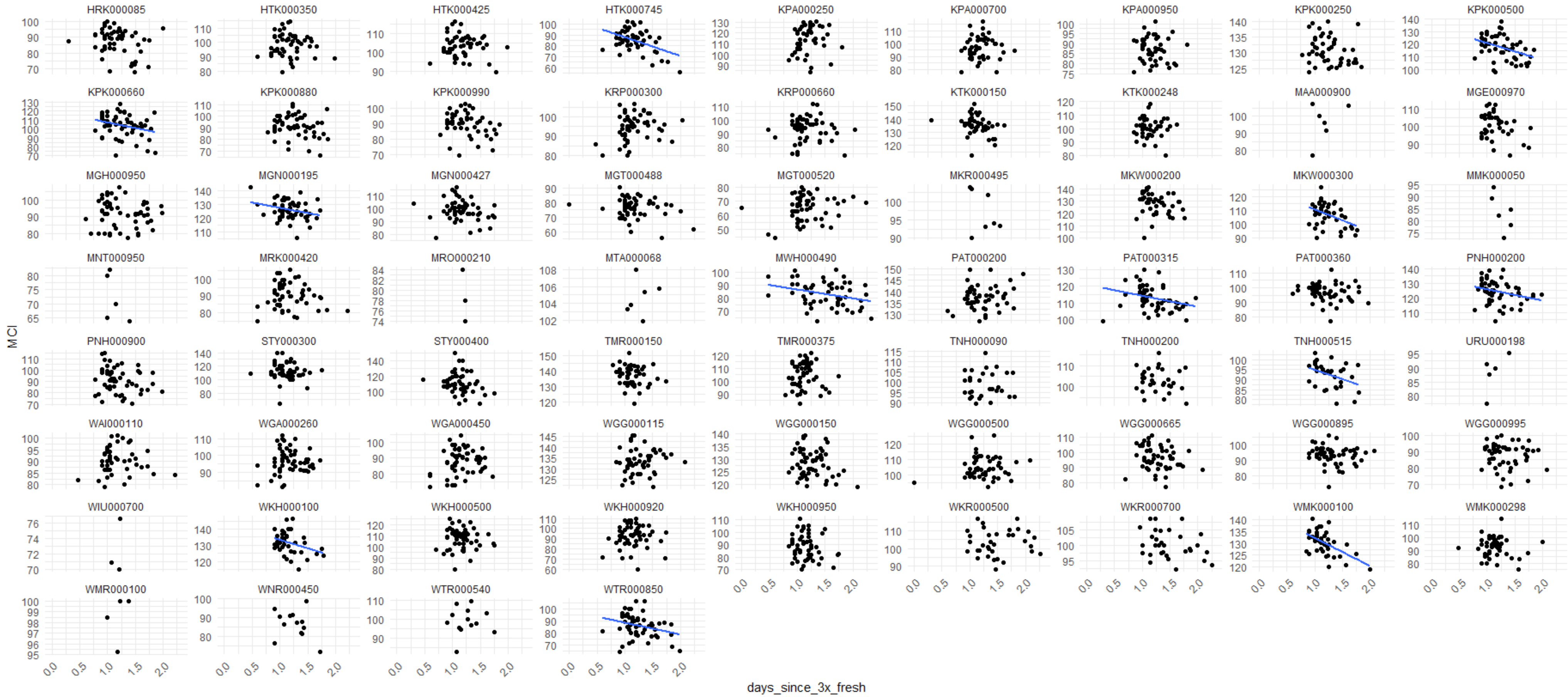

Figure 4-3: Plots of MCI values against log10 transformed number of days since a flow event greater than three times the long-term median flow for each site for 67 macroinvertebrate monitoring sites. Fitted lines (blue) added to sites with a significant linear correlation (alpha = 0.05).

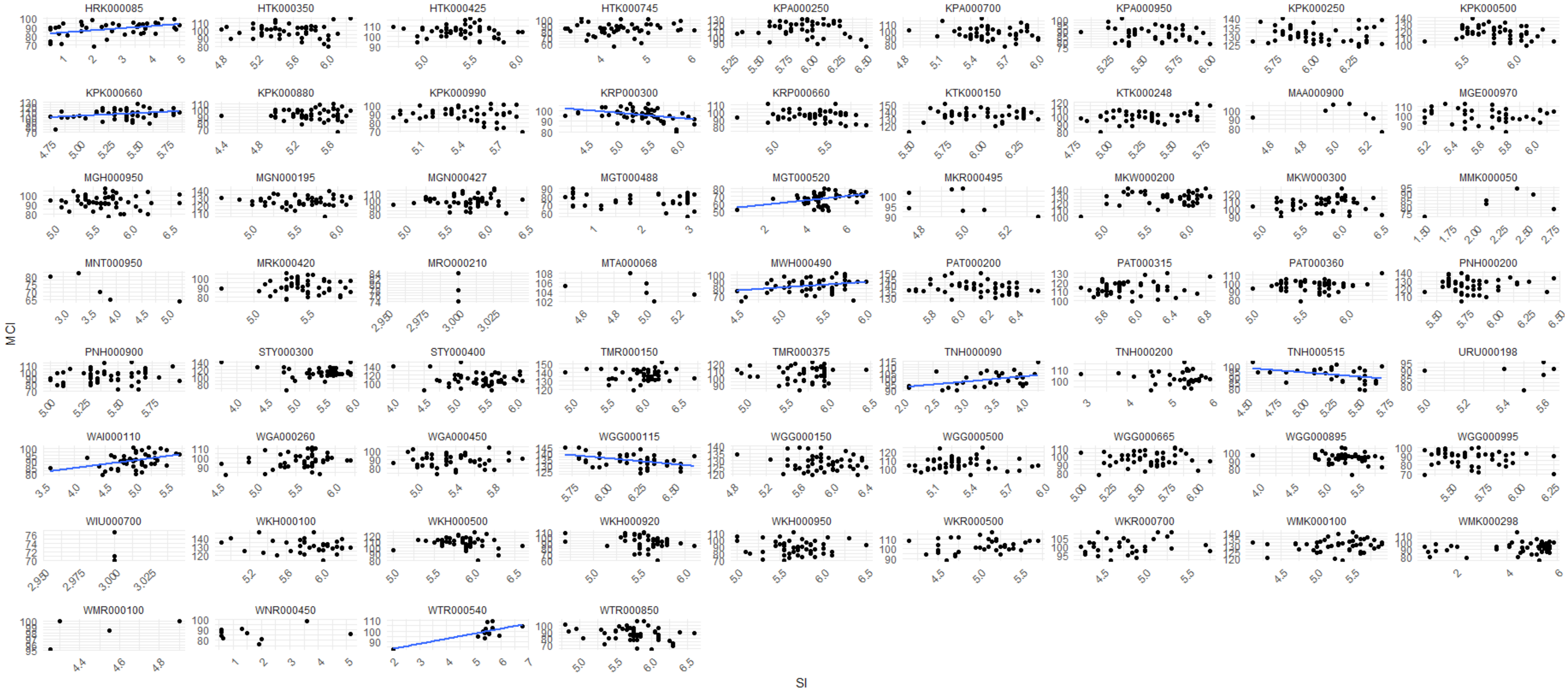

Figure 4-4: Plots of MCI values against substrate size (SI) for 67 macroinvertebrate monitoring sites. Higher SI indicates larger substrate. Fitted lines (blue) added to sites with a significant linear correlation (alpha = 0.05).

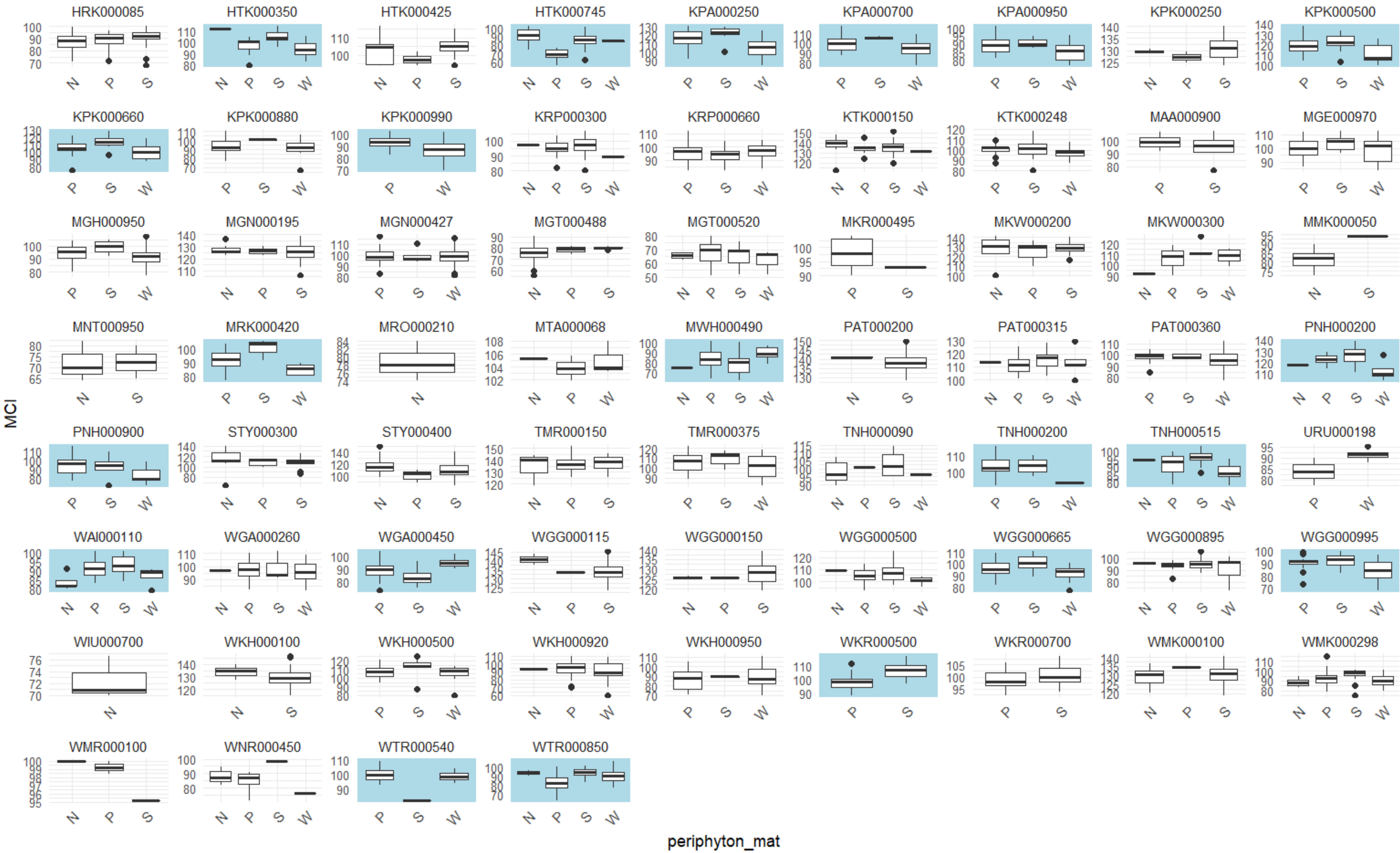

Figure 4-5: Box and whisker plots of MCI values when different categories of cover of periphyton mats were present at each macroinvertebrate monitoring site with records available between 1995 and 2023. N = none, P = patchy, S = slippery, W = widespread. Note different y axis limits per site. Blue shading indicates sites where a significant difference in MCI values was observed between periphyton categories.

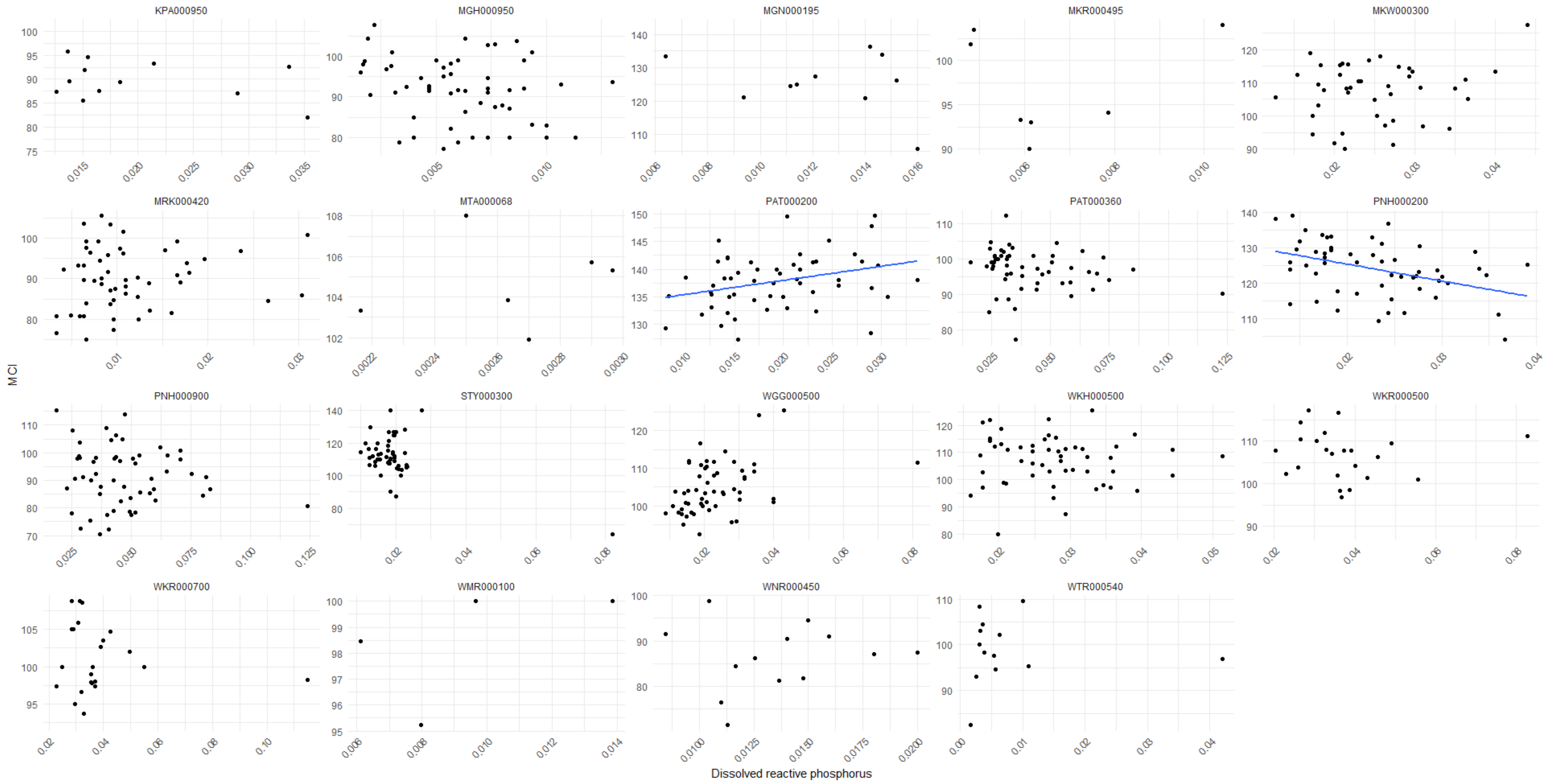

Figure 4-6: Plots of MCI values and mean dissolved reactive phosphorus in the three months prior for 19 macroinvertebrate monitoring sites. Fitted lines (blue) are added to sites with a significant linear correlation (alpha = 0.05).

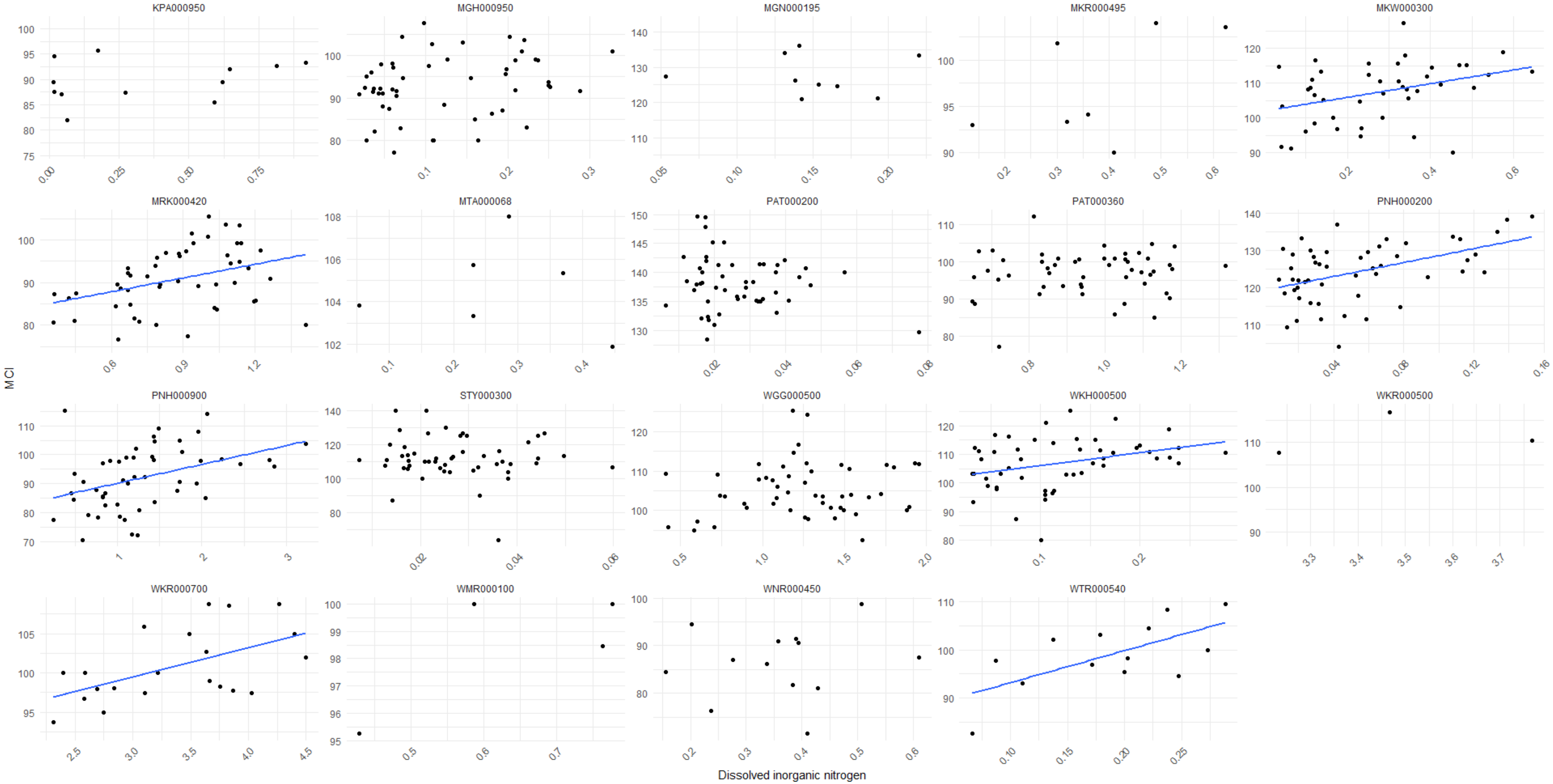

Figure 4-7: Correlations between MCI and mean dissolved inorganic nitrogen concentration in the three months prior for 19 macroinvertebrate monitoring sites. Fitted model lines (blue) show for sites with significant correlations.

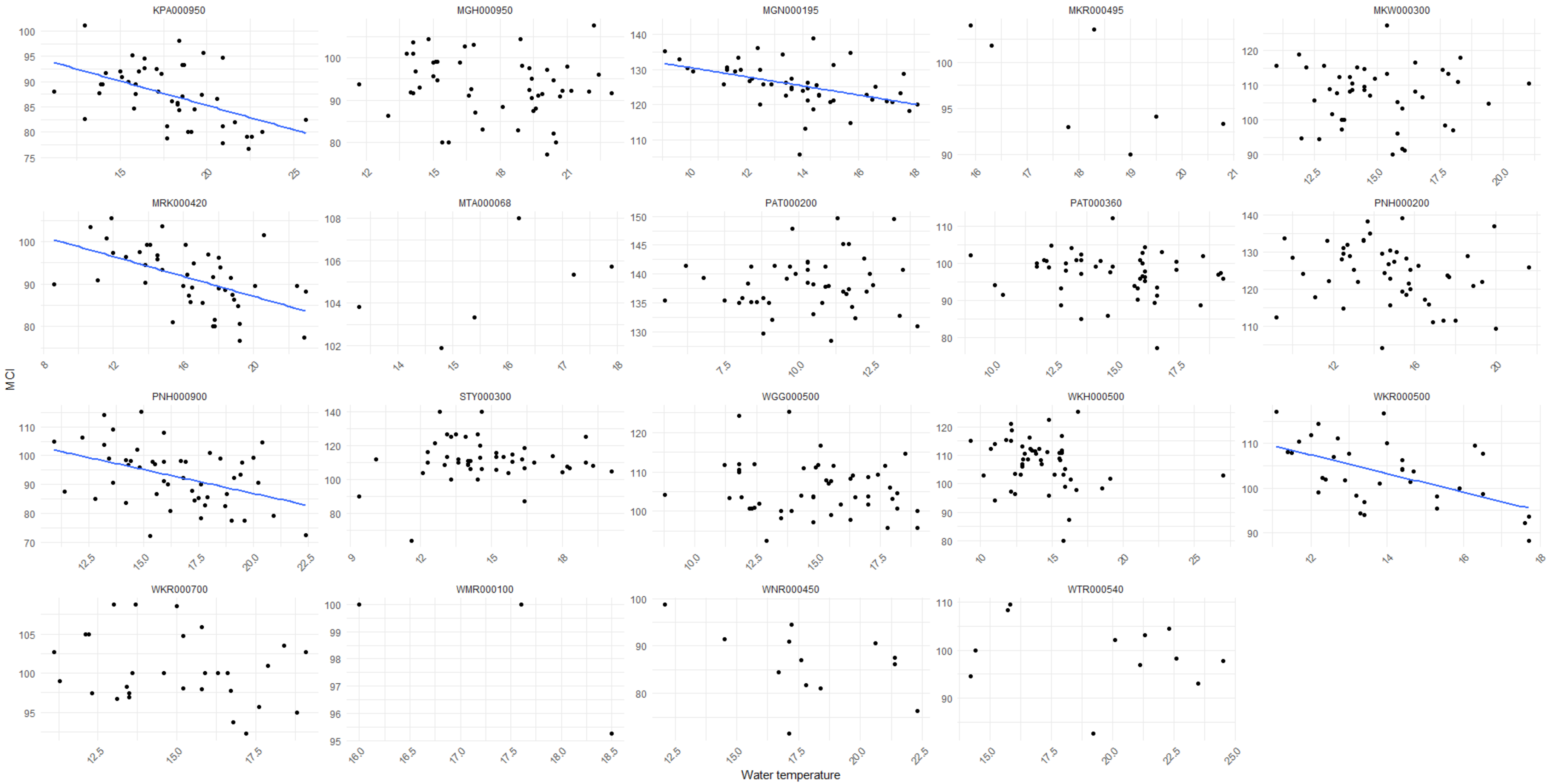

Figure 4-8: Plots of MCI values and spot water temperature in the three months prior for 19 macroinvertebrate monitoring sites. Fitted lines (blue) are added to sites with a significant linear correlation (alpha = 0.05).

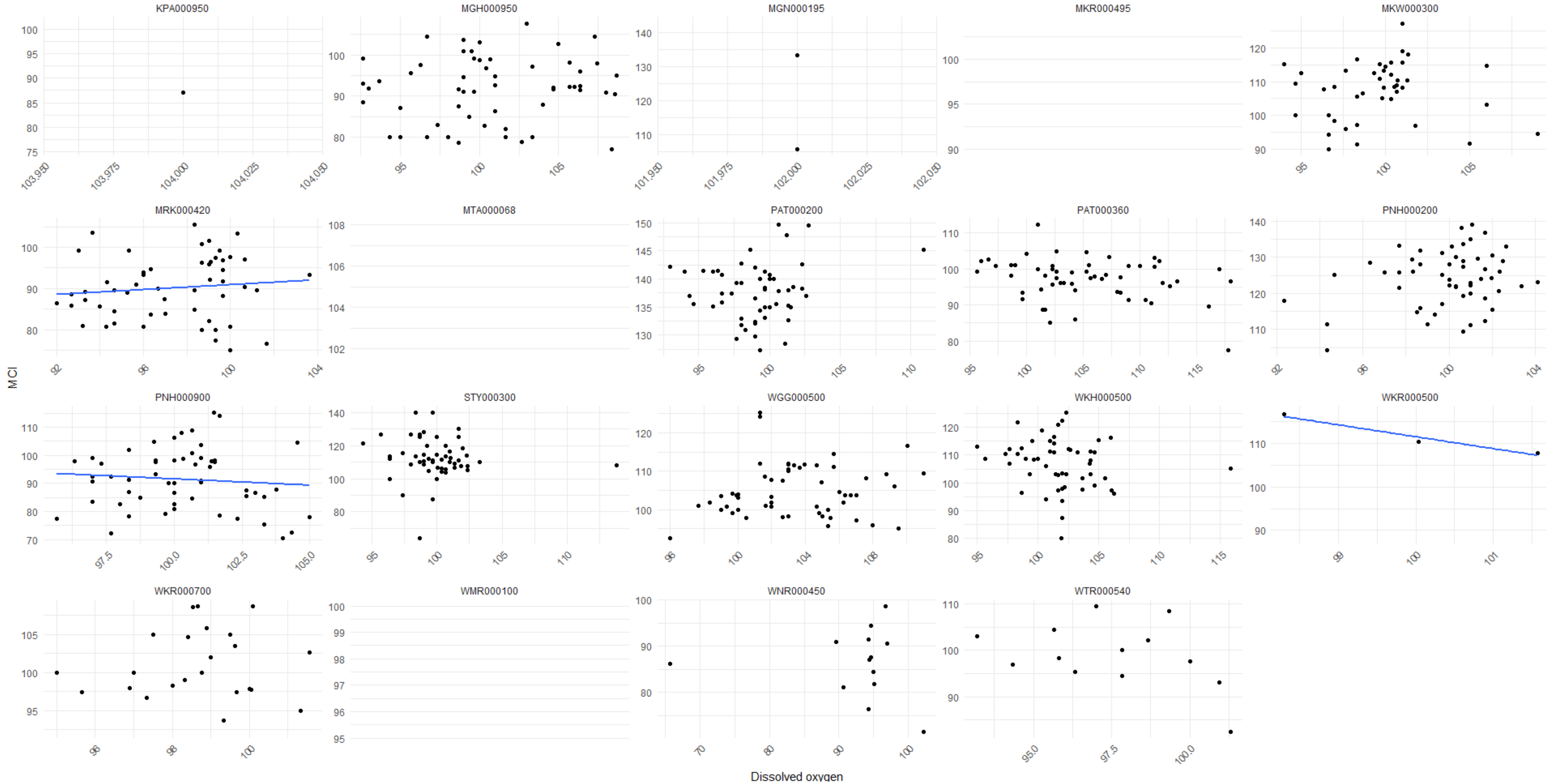

Figure 4-9: Plots of MCI values and mean dissolved oxygen concentration (% saturation) during the three months prior for 19 macroinvertebrate monitoring sites. Fitted lines (blue) are added to sites with a significant linear correlation (alpha = 0.05).

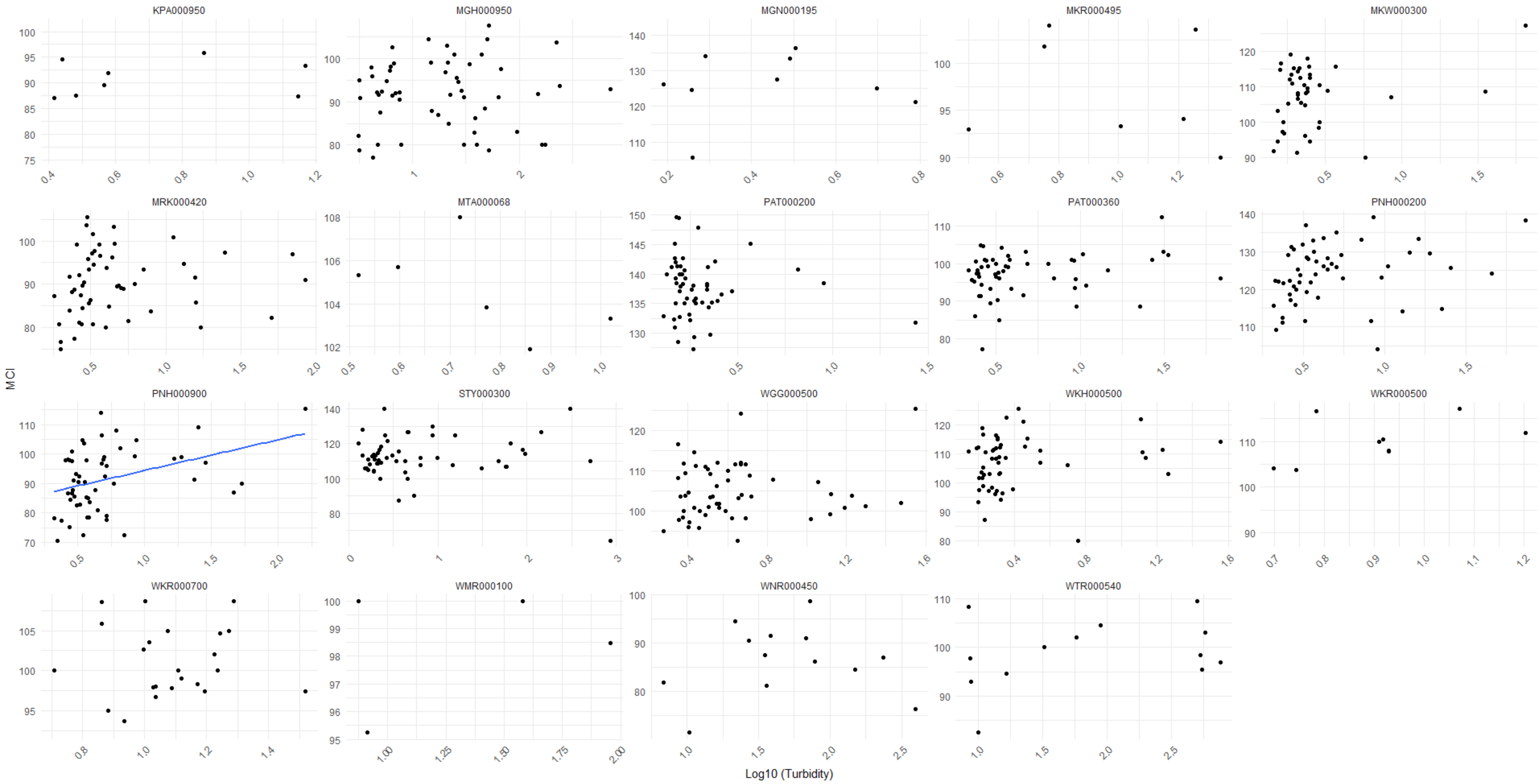

Figure 4-10: Plots of MCI values and log10 transformed 92nd percentile turbidity in the three months prior for 19 macroinvertebrate monitoring sites. Fitted lines (blue) are added to sites with a significant linear correlation (alpha = 0.05).

4.2.3 Investigation of periphyton as a potential stressor of macroinvertebrate communities

MCI values differed significantly with periphyton mat cover categories in 31% of the 67 sites (Table 4-3, with MCI values commonly lower when periphyton coverage was categorised as 'widespread' (Table 4-3; Figure 4-5). As discussed previously, periphyton biomass has the potential to mechanistically contribute to the decline in MCI values because commonly associated changes in growth form with higher biomass (i.e., thick mats or high filament cover) alter macroinvertebrate community composition (Tonkin et al. 2014), by reducing both habitat and food quality.

Periphyton growth is highest when water temperatures are warm, sufficient nutrient and light levels are present and when there is sufficient time between scouring floods for periphyton to accumulate (Biggs and Kilroy 2000). MCI was higher in some sites where there had been a more recent flow event (daysSinceFRE3, Table 4-3), potentially indicating that regular scour of periphyton by flows may help maintain higher MCI values in these sites.

MCI levels were higher when water or air temperatures were cooler in approximately a quarter of sites in both datasets (Table 4-3). Cooler water temperatures may have a physiological benefit for sensitive macroinvertebrates by helping maintain high DO concentrations. Cooler water temperatures may also slow periphyton growth. Nitrate concentrations were unlikely to be having toxic effects on many macroinvertebrates, apart from occasionally in two sites (Table 4-2). Dissolved inorganic nitrogen (DIN) concentrations were correlated with MCI values in 37% percent of the 19 sites with DIN data. Interestingly, DIN was positively associated with MCI values indicating it wasn't acting directly as a stressor on macroinvertebrates in those sites. A negative relationship between nutrient concentrations and MCI could be expected if high DIN was supporting higher periphyton biomass, which was in turn negatively impacting macroinvertebrate communities. However, observed relationships between instream nutrient concentrations and periphyton can be complicated by the fact that nutrient concentrations and periphyton standing crop at any one time are the product of several interacting factors. Nutrient concentrations are commonly influenced by river flows, particularly the relative contribution of rainwater, overland runoff and groundwater, with their differing potential nutrient concentrations. Periphyton standing crop measured at any one time is influenced by the time for periphyton accrual since a scouring flood, grazing rates of macroinvertebrates and light and nutrient availability (Biggs and Kilroy 2000).

To further investigate the potential role of high periphyton cover in reducing MCI values in some sites, we utilised the numeric periphyton data from the water quality and periphyton monitoring sites. The numeric periphyton data were from 12 periphyton monitoring sites, which overlaps with 11 of the water quality monitoring sites (see Table 4-4, Section 2.2 and Figure 2-3). The periphyton sites had chlorophyll *a* concentration data between 2018 and 2023 (with different sites having different lengths of records), as well as some periphyton coverage data from 1995 to 2006. Several approaches were attempted to investigate potential influences of periphyton biomass/cover on MCI values by:

1. Plotting periphyton biomass between 2018 and 2023 in the 12 sites and visualising these patterns in the context of the direction of trend in MCI values at those sites between 2013 and 2023.
2. Using linear models to investigate whether MCI values were associated with periphyton biomass in the 12 sites between 2018 and 2023.

3. Visualising whether the annual measures of periphyton coverage categories available for the full period (1995–2023) were consistently higher in the decades with decreasing MCI trends than in the decade with increasing MCI trends.

Methods

Monthly periphyton biomass data were summarised as the 92nd percentile of the available biomass data in the three months prior to macroinvertebrate samples.

Scatter plots of the summarised periphyton biomass values over time for the 12 sites were created, with the direction of MCI trends in 2013–2023 indicated on the plots (trend information available in Table 4-3). Separate linear models of MCI predicted by periphyton biomass were run for each site and viewed graphically.

The categorical periphyton cover data collected at the same time as macroinvertebrate samples was available for both decades that MCI trends were analysed over (2003–2013 and 2013–2023). This data was used to test the hypothesis that cover of filaments and/or mats would be higher during time periods in which MCI was decreasing than in time periods in which MCI was increasing. The percentage of records of periphyton mats in the four cover categories (none, slippery, patchy, widespread) were visualised for both the 2003–2013 and 2013–2023 decades in sites that showed consistently increasing trends in both decades (IncInc, one site) and those with increasing trends in 2003–2013 and decreasing trends in 2013–2023 (IncDec, three sites). The four periphyton cover categories are a coarser measure of periphyton cover/biomass than chlorophyll *a,* but the only long-term temporal indicator of periphyton cover/biomass that was available for all these sites.

Results

Of the 12 sites with periphyton biomass (chlorophyll *a*) data available two sites showed an increasing trend in MCI in 2013–2023 and six sites a decreasing trend (at a confidence level of ‘as likely or not’ or higher; Table 4-4. One site had an indeterminate MCI trend and three sites had insufficient macroinvertebrate data to calculate MCI trends for 2013–2023 (Figure 4-10). From the MCI trend directions assigned over both decades (IncInc vs IncDec, see Table 4-4), one periphyton site showed increasing MCI trends in both decades (IncInc) and four sites had increasing MCI trends in 2003–2013 and decreasing MCI trends in 2013–2013 (IncDec, Table 4-4).

Periphyton biomass was not consistently lower in sites that had increasing or decreasing MCI trends (Figure 4-11). For example, both STY000300 and PNH000200 had consistently low periphyton biomass, below the NPS-FM periphyton attribute Band A / Band B boundary, indicating rare periphyton blooms, but showed increasing and decreasing trends in MCI in 2013–2023, respectively. Note that the NPS-FM attribute bands are indicative only, as the NPS-FM requires calculation of the 92nd percentile of monthly measurements over three years. Sites MKW000300 and WGG000500 both had decreasing MCI trends over the 2013–2023 decade and both showed patterns of increasing periphyton biomass between 2018 and 2023, with several biomass values within NPS-FM Band C, indicating occasional nuisance periphyton blooms (Figure 4-11). It is possible that high periphyton biomass may be negatively impacting macroinvertebrate communities in these sites at least some of the time. However, no sites showed significant relationships between MCI and periphyton biomass (Figure 4-12). Further collection of periphyton biomass data, particularly a longer temporal record, will allow more robust investigation of the relationship between periphyton biomass and macroinvertebrate community metrics. Similarly, using metrics other than MCI (such as %EPT abundance), although correlated with MCI, may provide better resolution of the potential impacts of periphyton biomass on macroinvertebrate communities.

One potential anomaly between the long term categorical periphyton data and the 2018 to 2023 numerical periphyton biomass data was observed. The longer term categorical periphyton cover data for site KPA000950 (consistently increasing MCI trends) suggest that periphyton cover was often higher than that indicated by the chlorophyll *a* data (commonly Band A, occasionally Band B, between 2018 and 2023. Periphyton mat coverage was 'patchy' in KPA000950 during the 2022 and 2023 macroinvertebrate samples (potentially matching the 2022 and 2023 chlorophyll *a* data) but commonly more 'widespread' earlier in the decade (Figure 4-13). Macroinvertebrate and periphyton samples are often collected in different habitat types as part of monitoring procedures (commonly riffle habitat for macroinvertebrates and runs for periphyton). At this site the periphyton and macroinvertebrate sampling locations are approximately 20 metres apart and physical differences (e.g., shade, substrate size, hydraulic conditions) between the sampling locations may mean that periphyton biomass and/or cover routinely differs between the locations. In addition, the periphyton biomass data is summarised over the antecedent three months so it is not unexpected that it does not align perfectly with one-off cover categories assigned at the time of macroinvertebrate sample collection. Further investigation of the relationship between antecedent periphyton biomass data and the spot categories could help identify the sites/times of year in which one-off categories may or may not be good estimators of longer term periphyton biomass at the macroinvertebrate sample collection locations.

The sites that showed consistently increasing or increasing and then decreasing MCI trend in the two decades (2003–2013 and 2013–2023) demonstrated no clear pattern of a higher prevalence of records of lower periphyton cover categories during time periods of increasing MCI compared to time periods with decreasing MCI trends (Figure 4-14).

Summary

The relatively recent start of consistent numeric periphyton biomass precluded the use of numeric periphyton data in more in-depth investigations of drivers of MCI trends in 2003–2013 and 2013–2023. Although periphyton biomass was not correlated with MCI values in any of the sites between 2018 and 2023, over the longer term (1995–2023) many sites did show significantly lower MCI values when periphyton cover was classified as 'Widespread'. Although results were mixed, there is potential for periphyton to negatively impact macroinvertebrate communities in at least some of the sites some of the time. Further investigation of the relationship between the spot periphyton categories assigned during macroinvertebrate sample collection and any antecedent summaries of numeric periphyton biomass may further understanding of the consistency of these two measures.

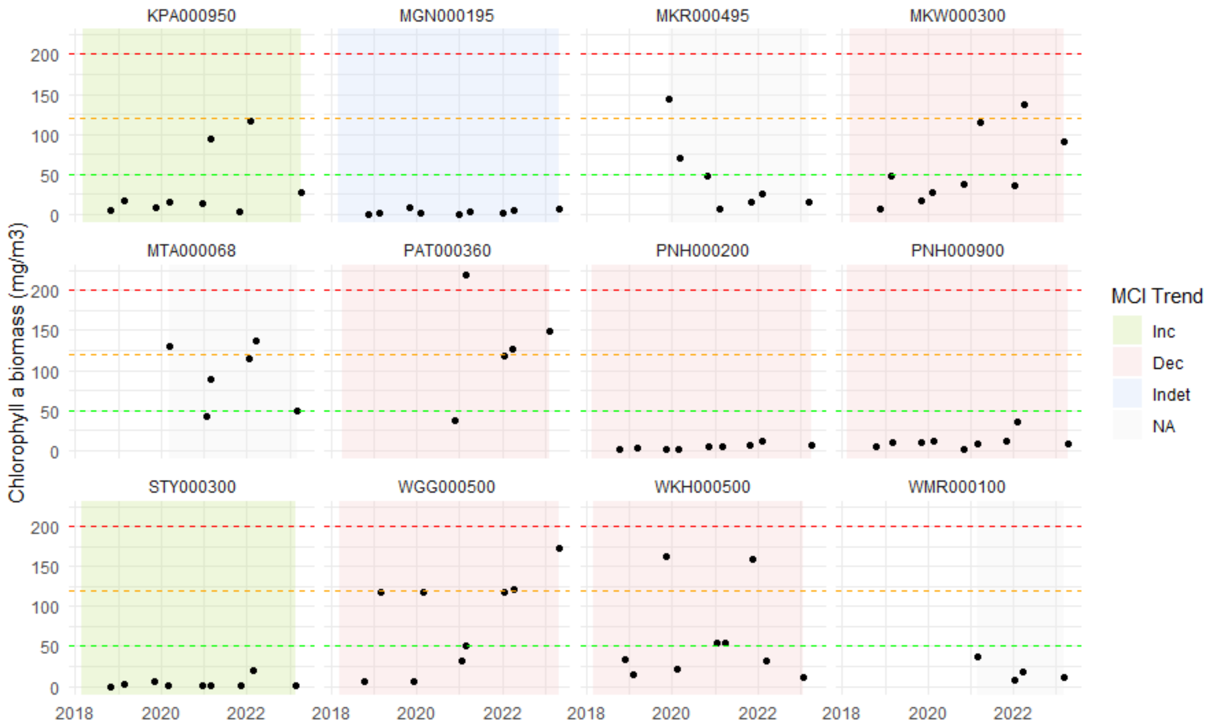

Figure 4-11: 92nd percentile chlorophyll *a* (mg/m^3) biomass in the three months prior to macroinvertebrate sampling dates in the periphyton monitoring sites. Monthly chlorophyll *a* data were available from 2018 to 2023. Background shading of plots indicates the direction of MCI trend between 2013 and 2023 in the sites. Increasing and decreasing trends with certainties of 'as likely as not' and higher were assigned to an increasing or decreasing direction. NA indicates sites with insufficient macroinvertebrate samples to assign a trend direction. NPS-FM periphyton attribute bands thresholds are shown by dashed line (Band A/B boundary = green, Band B/C boundary = orange, Band C/D boundary = red).

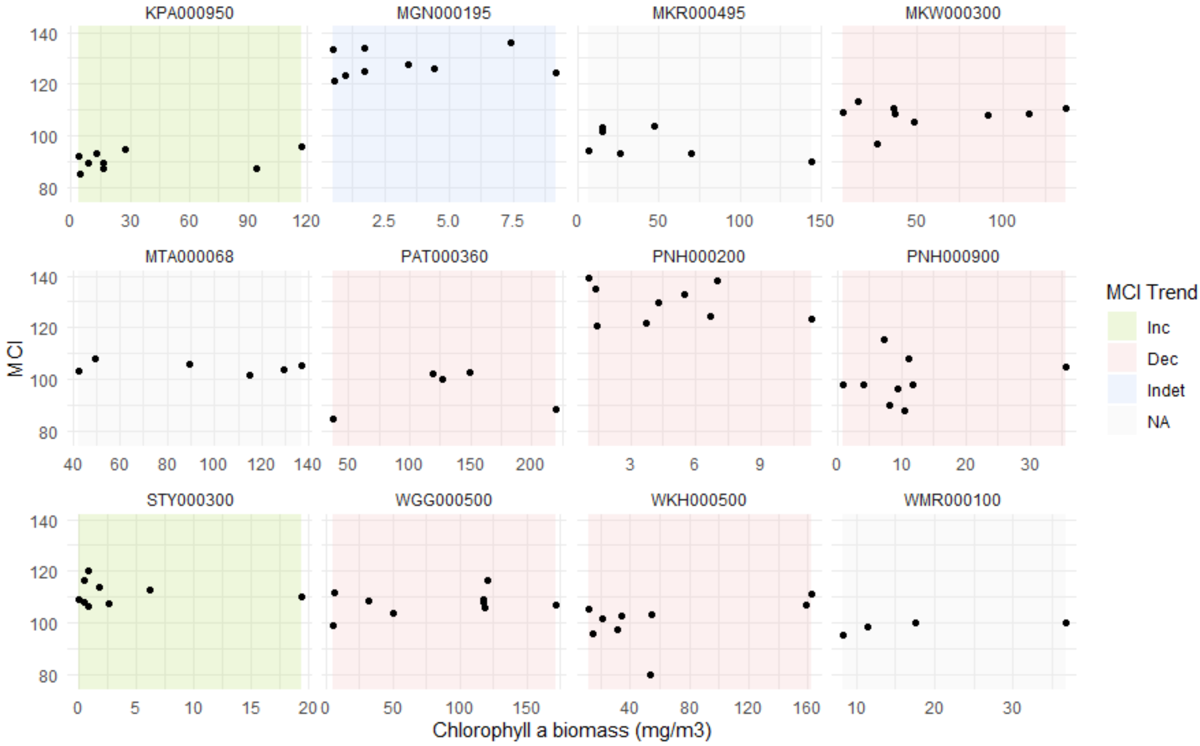

Figure 4-12: Relationships between MCI scores and 92nd percentile chlorophyll *a* (mg/m^3) biomass (summarised over the three months prior to macroinvertebrate sampling). Monthly chlorophyll *a* data were available from 2018 to 2023. Background shading of plots indicates the direction of MCI trend between 2013 and 2023 in the sites. Increasing and decreasing trends with certainties of 'as likely as not' and higher were assigned to an increasing or decreasing direction. NA indicates sites with insufficient macroinvertebrate samples to assign a trend direction. None of the relationships were significant at α=0.05 when tested with linear models.

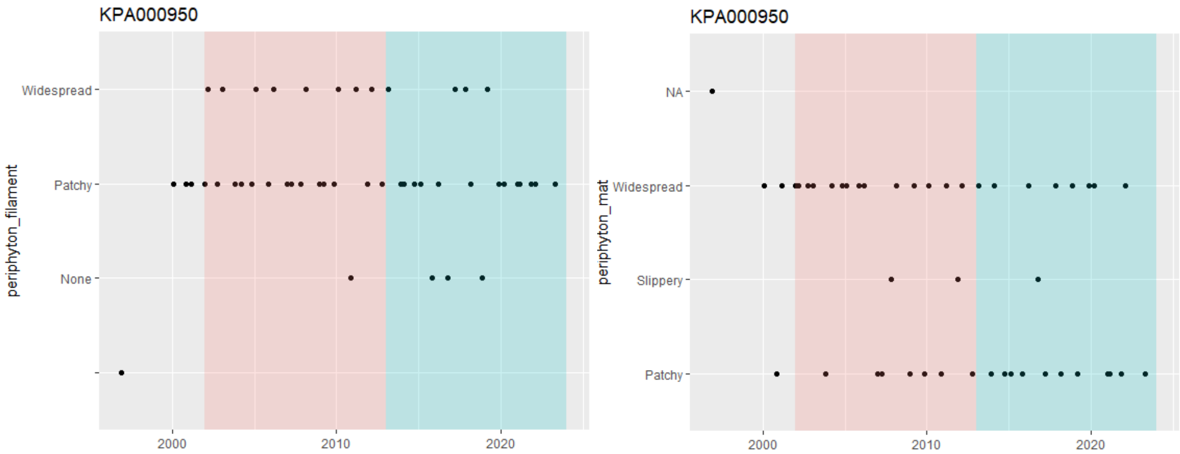

Figure 4-13: Periphtyon cover categories recorded for filaments (left) and mats (right) during macroinvertebrate sample collections. The red rectangle indicates the 2003–2013 and the blue the 2013–2023 time periods. This site showed increasing MCI trends in both decades.

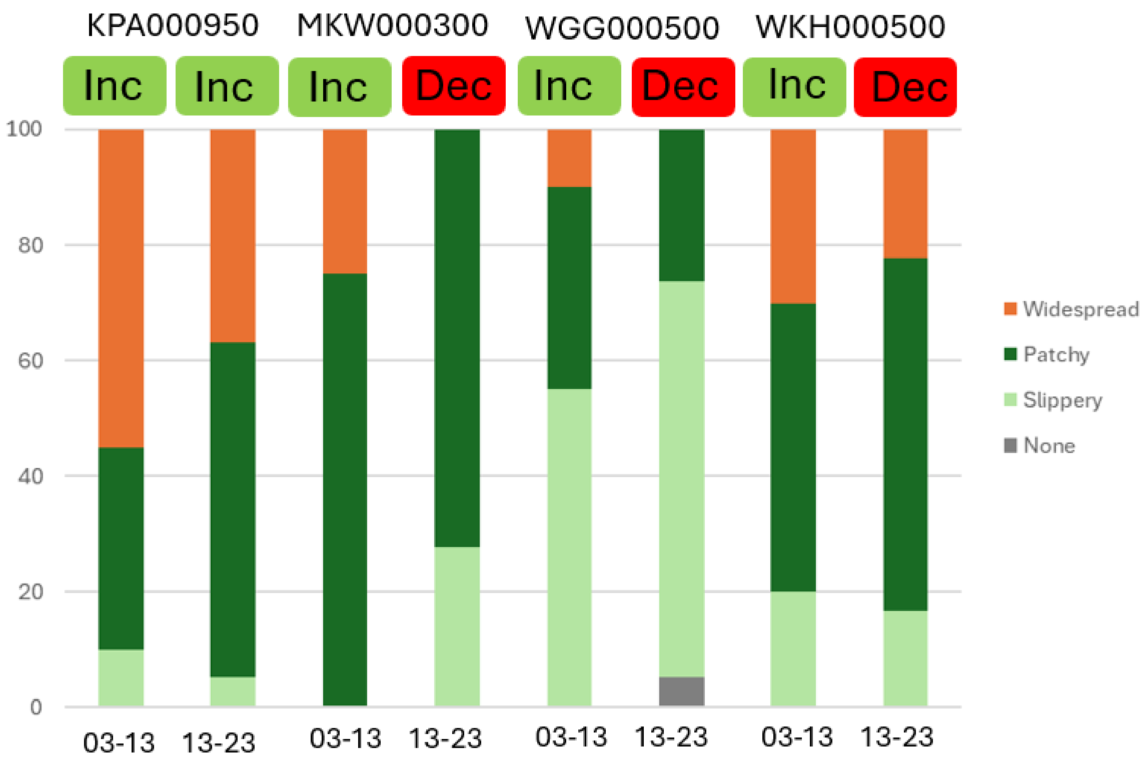

Figure 4-14: The percentage of records for periphyton mats coverage from biannual sampling in four different categories (none, slippery, patchy and widespread) from two decades (2003–2013 and 2013–2023) in five sites. These four sites had either consistently increasing MCI trends in both decades (KPA000950) or increasing MCI trends in 2003–2013 and decreasing trends in 2013–2023 (other four sites). The red and green boxes indicate whether MCI trends were increasing (Inc) or decreasing (Dec) within each site for that time period.

4.2.4 Are there common stressor-MCI relationships to the three time periods?

To investigate whether similar stressors were associated with MCI values during the three trend time periods (the two decades; 2003–2013, 2013–2023 and the long-term (1995–2023)), we conducted mixed effects models for each period separately. Site nested within river was included as a random intercept term in all models to account for similarities of sites on the same river.

The variables chosen to include in the mixed effects models of stressor relationships across all sites were those from the broad data set that had the most common correlations with MCI at a site (see Section 4.2.2): average antecedent rainfall, daysSinceFRE3 (log10 transformed), water temperature, substrate index and the categorical periphyton mats parameter.

Across all three time periods, average antecedent rainfall, DaysSinceFRE3, water temperature and periphyton mats coverage had strong significant relationships with MCI (Table 4-5). These relationships were all in an expected direction, with lower MCI values occurring after longer periods without a flow event, when there had been less recent rainfall, water temperatures were higher and periphyton mats were more widespread.

Substrate size was strongly related with MCI in the earlier decadal period (2003–2013), less strongly related over the long-term period (1995–2023) and not significantly related to MCI during the 2013–2023 decade (Table 4-5).

Table 4-5: Results from mixed effects linear model on all sites over three time periods (1995–2023, 2003–2013 and 2013–2023). DF = degrees of freedom, F = F-statistic, p = significance. Grey shaded boxes are significant at alpha = 0.05.

	DF	F	P	Direction
1995–2023				
Log10 (DaysSinceFRE3)	1, 2159	79.6	<0.001	Negative
Avg_rain	1, 2159	28.4	<0.001	Positive
Water temperature	1, 2159	93.1	<0.001	Negative
Substrate Index	1, 2159	6.1	0.01	Positive
Periphyton mats	3, 2159	17.9	<0.001	Common: widespread < other categories
2003–2013				
Log10 (DaysSinceFRE3)	1, 950	40.4	<0.001	Negative
Avg_rain	1, 950	25.1	<0.001	Positive
Water temperature	1, 950	42.5	<0.001	Negative
Substrate Index	1, 950	22.6	<0.001	Positive
Periphyton mats	3, 950	8.8	<0.001	Common: widespread < other categories
2013–2023				

	DF	F	P	Direction
Log10 (DaysSinceFRE3)	1, 944	48.5	<0.001	Negative
Avg_rain	1, 944	36.4	<0.001	Positive
Water temperature	1, 944	45.1	<0.001	Negative
Substrate Index	1, 944	0.4	0.5	-
Periphyton mats	3, 944	8.8	<0.001	Common: widespread < other categories

5 Summary

The key points from the analyses above are summarised below.

Trends in macroinvertebrate metrics

Results from 1,752 trend analyses on macroinvertebrate metrics are summarised in the report and provided as separate spreadsheets. Key findings were:

- The proportion of sites showing increasing and decreasing trends during the three time periods analysed (1995–2023, 2003–2013, 2013–2023) were generally similar to that reported by TRC (2024).
- Over the long-term (1995–2023), almost three quarters of sites showed an increasing trend in MCI. Temporal trends in MCI between 2003 and 2013 were also commonly increasing at most sites (~70%), albeit with a slightly lower confidence in trend direction than for the longer-term data set. Similar to TRC (2024), a higher prevalence of sites with decreasing trends was observed between 2013 and 2023 (approximately 40% of sites).
- Most macroinvertebrate metrics (ASPM, %EPT, MCI, SQMCI, EPT taxa) showed similar patterns in trend direction and likelihood within a site and over the same period.
- Trend directions in taxa richness were occasionally different from other metrics, which is not unexpected. Taxa richness includes taxa that are both sensitive and tolerant to different stressors and thus is not always a good indicator of environmental conditions.
- Trends analysed using summer only samples were generally in the same direction as trends from combined spring/summer datasets, although confidence in the trend direction was often reduced.
- Sites that showed increasing or decreasing long-term (1995–2023) MCI trends were distributed across the Taranaki region and no significant and likely causative differences in average environmental conditions or catchment characteristics were identified between sites with increasing or decreasing MCI trends.
- Antecedent average rainfall and the number of days since a flow event at least three times the long-term median were generally lower in the 2013–2023 decade than in 2003–2013 decade. This matches with a higher prevalence of decreasing MCI trends in 2013–2023. Results of site-specific relationships between MCI and rainfall and river flow are summarised below.

Temporal correlations between MCI and potential stressors

- Broad-scale air pressure (SOI) conditions were not commonly correlated with temporal values of MCI (correlated in two of 67 sites).
- Antecedent air and spot water temperature were positively correlated with each other. In approximately a quarter of sites in both the broad 67-site dataset (air temperature) and the 19-site water quality dataset (water temperature), MCI values were higher when air and water temperatures were lower.

- Antecedent average rainfall was positively correlated with MCI values in 33% of sites (22 / 67) and MCI values were higher in 18% of sites (12 / 67) when there was a more recent flow event exceeding three times the long-term median flow at a site.
- Turbidity (1 site), DRP (2 sites) and dissolved oxygen concentrations (3 sites) were not commonly correlated with MCI values.
- Dissolved inorganic nitrogen was positively correlated with MCI in 7 / 19 sites. DIN is unlikely to be directly acting as a stressor of macroinvertebrates due to the positive direction of the relationships. However, nutrients may still impact macroinvertebrate communities at very high (toxic) concentrations or, in sites with sufficient light and a lack of frequent scouring floods, by promoting excess periphyton growth (although this would result in a negative MCI – DIN relationship, which was not observed). Instream DIN concentrations are influenced by contributions of the magnitude of river flow and the sources contributing (e.g., groundwater with potentially high concentration or rain). Some of the observed DIN correlations may be influenced by recent rainfall and river flow conditions.

Potential role of periphyton

- In 31 % of the 67 sites (21 sites), MCI values differed depending on the periphyton coverage category assigned at the time of sampling. In the majority of those sites, MCI values were lower when periphyton mats were 'widespread'. Excess periphyton growth can impact macroinvertebrate communities by smothering habitat, reducing food quality and, if water temperatures are high, potentially causing physiological stress by reducing daytime DO concentrations. Excess periphyton growth occurs under conditions of sufficient light and nutrients, when water temperatures are warmer and in the absence of scouring flows.
- Numeric periphyton biomass (chlorophyll *a*) data were available for 12 sites between 2018 and 2023 showed no relationship with MCI at any site.
- There was no obvious relationship between the frequency of periphyton mat or filament cover category assigned during times of increasing or decreasing MCI trends in sites that showed consistently increasing MCI trends in both decades or sites that had increasing MCI trends in 2003–2013 (one site) and decreasing MCI trends in 2013–2023 (three sites).
- Further investigation of the relationship between spot periphyton cover categories assigned at the time of macroinvertebrate sample collection and antecedent numeric periphyton biomass/cover data to assess the consistency of the methods may be beneficial.
- Although results were mixed, there is some evidence that high periphyton biomass may be impacting macroinvertebrate communities at least some of the time in the sites with decreasing MCI trends.

Common stressors of MCI in 2003–2013 and 2013–2023?

- Antecedent average rainfall, water temperature, days since a FRE3 or larger flow event and periphyton coverage were commonly significantly related to temporal MCI patterns in all three periods (long term, 2003–2013 and 2013–2023). The directions of the relationships were indicative that these variables, apart from rainfall (positive correlation), were stressors of macroinvertebrate communities.

- Substrate size was positively correlated with MCI in 2003–2013 but not in 2013–2023.

Management implications

Shifting from biannual to summer-only macroinvertebrate monitoring is likely to still facilitate detection of trends in the same direction across most sites and time periods, albeit with lower confidence in the trend direction.

While we could not identify site characteristics that differed between sites with increasing and decreasing MCI trends over recent decades, we did identify potential proximate stressors that were commonly correlated with MCI values within a site. The most commonly identified proximate variables correlated with temporal change in MCI values within a site were variables that may be able to be managed locally (within the catchment) to some degree, but that are also likely to be impacted by climate; the frequency of high-flow events (flows exceeding three times the median long-term flow), water and air temperature, and periphyton cover. MCI was also correlated with antecedent rainfall in almost a third of sites, and average rainfall was lower in the later decade (2013–2023), which had a higher proportion of decreasing MCI trends. The paucity of correlations directly between MCI and SOI indicates that this parameter may not be representative of proximate stressors on macroinvertebrate communities. Regardless, macroinvertebrate communities are likely to be negatively impacted in sites where long dry summers with reduced rainfall lead to fewer scouring flows, higher water temperatures and perhaps increased periphyton biomass.

While climate itself is beyond the council's control, measures that reduce water temperatures (such as shading), maintaining flows that disturb the bed substrate (such as managing water abstractions) and riparian planting to reduce fine sediment and nutrient inputs and create shade could help preserve stony bed substrate as good habitat and mitigate excessive periphyton growth and support macroinvertebrate communities. Although MCI correlations with observed nutrient concentrations were positive and nitrate concentrations did not commonly exceed the national bottom line for nitrate toxicity, reduction of nutrient inputs, if they are associated with reductions in periphyton growth and of nutrient concentrations below toxic thresholds, will also benefit macroinvertebrates.

Recommendations for future work

Data availability and the co-occurrence of multiple stressors within sites were challenges within this analysis, as is common to all multiple stressor analyses. If more robust identification of key drivers affecting macroinvertebrate communities is a priority for TRC, we recommend:

1. Where possible, aligning monitoring of potential stressors with macroinvertebrate monitoring sites, at least for a subset of locations.
2. Continuing, and potentially expanding, periphyton percent cover and/or biomass monitoring. A larger numeric periphyton dataset will allow more robust investigations of the relationship between periphyton and macroinvertebrate metric scores.
3. Depending on council priorities, additional potential investigations could include:
    - Compilation of any additional council periphyton monitoring data, i.e., from nuisance periphyton monitoring programmes or catchment specific investigations to further investigate the potential role of high periphyton biomass in impacting macroinvertebrate communities.

- Collection of additional data or use of expert and local knowledge in combination with existing data to investigate whether key stressors vary between representative case studies from different types of rivers (e.g., high gradient small headwater streams within Te Papa-Kura-o-Taranaki will likely have different stressors to lower gradient larger waterways with more agricultural inputs further downstream).

6 Acknowledgements

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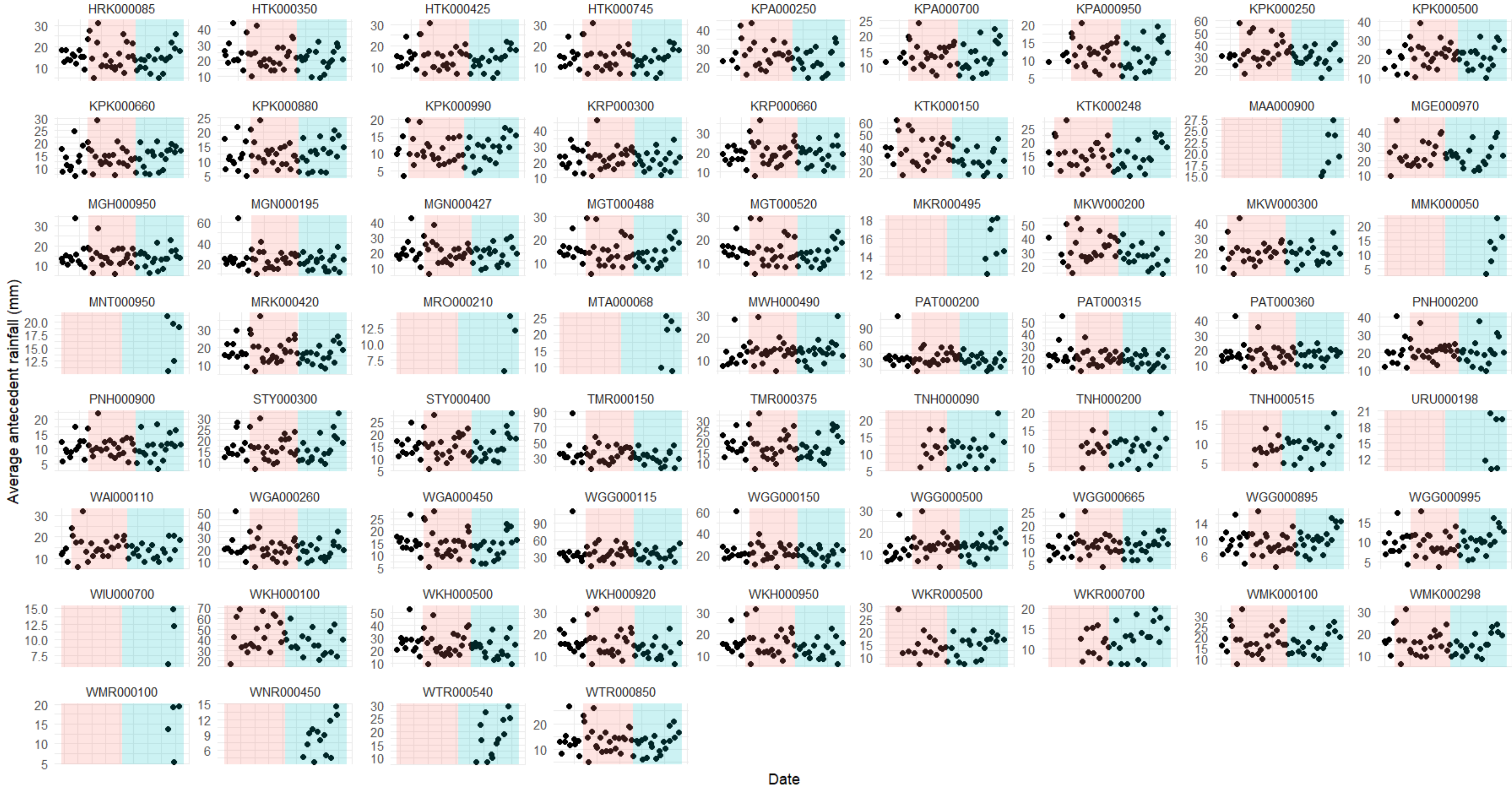
Appendix A Temporal patterns in potential stressors for 67 site dataset

For the following plots potential stressors of macroinvertebrate communities are shown over time in each of the 67 macroinvertebrate monitoring sites. Red and blue boxes indicate the two decadal time periods over which short term macroinvertebrate metric trends were examined (2003–2013 and 2023, respectively). The full time period for trend analyses (1995 to 2023) is indicated by x axis limits.

7.1 Southern Oscillation Index (SOI)

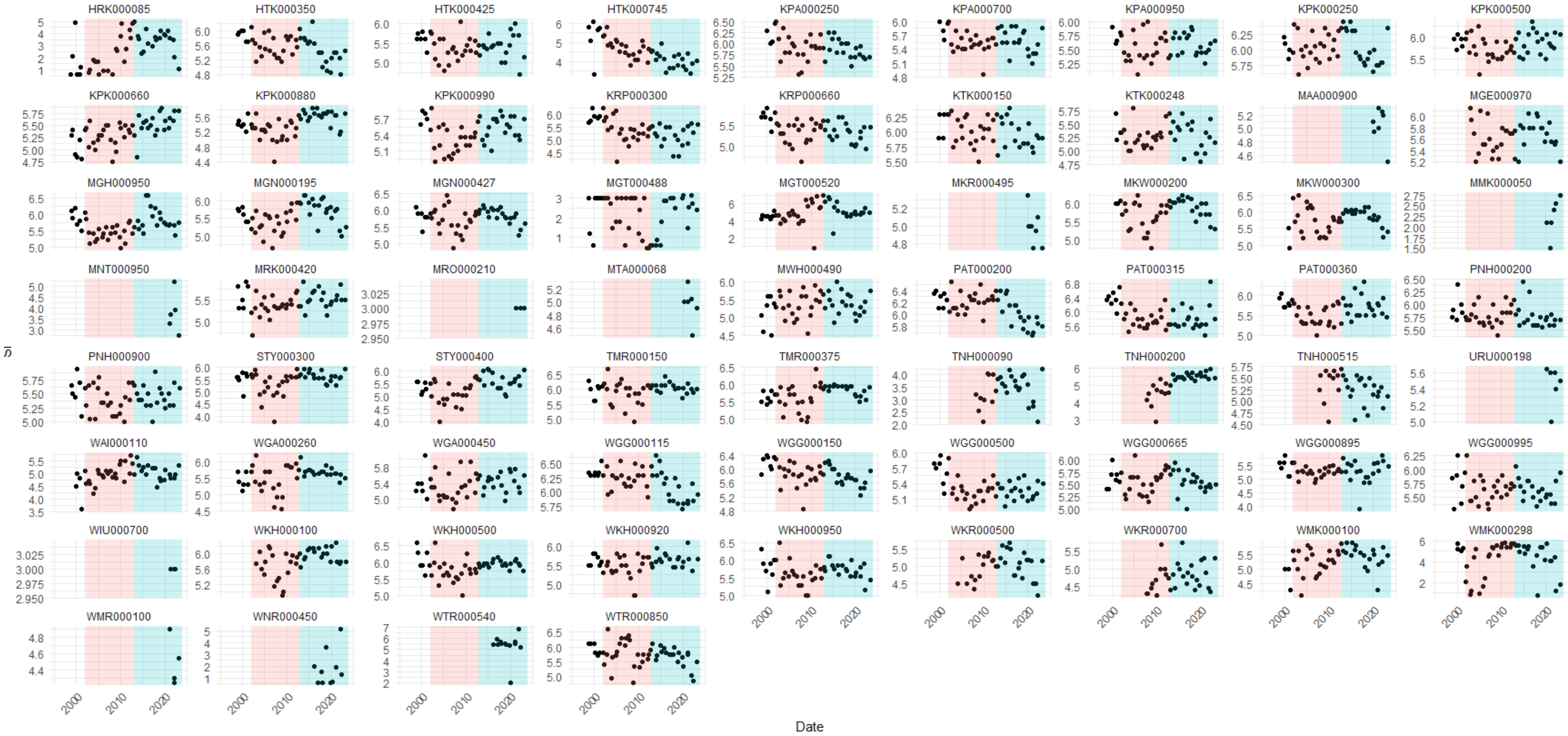
7.2 Average antecedent rainfall (NIWA virtual climate station network)



7.3 Average antecedent air temperature (NIWA virtual climate station network)

7.4 Number of days since a flow event at least three times the median long-term flow at a site (DaysSinceFRE3)

7.5 Substrate Index (SI)



Appendix B Temporal patterns in potential stressors for 19 site dataset

For the following plots potential stressors of macroinvertebrate communities are shown over time in each of the 19 macroinvertebrate monitoring sites with water quality data available. Red and blue boxes indicate the two decadal time periods over which short term macroinvertebrate metric trends were examined (2003–2013 and 2023, respectively). The full time period for trend analyses (1995 to 2023) is indicated by x axis limits.

7.6 Dissolved inorganic nitrogen