NIWA
Taihoro Nukurangi

Analysis of stream responses to riparian management on the Taranaki ring plain

Prepared for Taranaki Regional Council

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Highlights

- Modelling of invertebrate metrics, a primary measure of stream health, and *E. coli*, a measure of swimmability (as defined in the National Policy Statement for Freshwater Management), in relation to upstream restoration indicates that the landscape-scale riparian restoration undertaken in the Taranaki region as part of the Riparian Management Programme has had a beneficial effect on water quality and downstream aquatic invertebrate communities.

- Twelve out of the fourteen invertebrate metrics included in the modelling analysis had detectable relationships with restoration at the region-wide scale, whereas the majority of previous post-restoration monitoring studies have reported a disappointing lack of detectable improvement in biodiversity. Invertebrate metrics including MCI, SQMCI, EPT richness and percent EPT had positive relationships with restoration across 59 sites, indicating that invertebrate communities improved with increasing restoration across the region over time.

- *E. coli* concentrations were found to have a negative relationship with restoration across 11 monitoring sites, indicating that *E. coli* concentrations decreased with increasing restoration. However, the percentage of 'swimmable' sites according to current NPS-FM criteria has remained consistently low (27%).

Executive summary

The Taranaki ring plain has 1800 dairy farms and nearly 13,000 km of stream bank outside the Egmont National Park boundaries (15,000 km total including stream banks within the National Park). The 13,000 km includes ephemeral and intermittent streams and drains as well as larger streams and rivers. To protect the ring plain waterways, the Taranaki Regional Council introduced a voluntary Riparian Management Programme (RMP) in the early 1990s, in which the council works with farmers to develop individual riparian management plans for their properties, and supplies native plants at cost for riparian plantings. Currently 99.5% of Taranaki dairy farms have riparian plans, and plan holders have fenced over 84% of all ring plain waterways and planted approximately 70%.

The objective of this study was to assess the relationships between the riparian fencing and planting undertaken in the Riparian Management Programme and stream health and recreational values in Taranaki streams. Stream health and recreational values were measured by macroinvertebrate metrics and *Escherichia coli* (*E. coli*) concentrations, respectively. To quantify the effects of the Riparian Management Programme, three different "restoration indices" of varying complexity were developed to represent the amount and ecological effects of riparian restoration. The first index was calculated as the simple proportion of upstream bank length fenced and/or planted, the second index weighted that proportion by age and type of restoration (fencing vs. planting), and the third index weighted the proportion by predicted shading effects of vegetation in relation to stream width. Multiple regression models were used to examine the relationships between three restoration indices and *E. coli* concentrations and invertebrate metrics. The 'swimmability' of Taranaki's *E. coli* monitoring sites was also assessed following the current National Policy Statement for Freshwater Management criteria for "Human Health for Recreation" (as amended in 2017) under various flow scenarios.

The modelling found overall positive relationships between several of the invertebrate metrics and restoration, including National and Taranaki versions of the MCI (macroinvertebrate community index) and SQMCI (semi-quantitative MCI) scores, and EPT richness (number of sensitive Ephemeroptera, Plecoptera, and Trichoptera species). An additional measure of community change based on dissimilarity to original composition also had a positive relationship with restoration, demonstrating that there has been a shift in stream invertebrate community composition since the Programme began. However, the site-to-site variability for all metrics was high, and for many sites it was not possible to determine the direction of the relationships between certain metrics and restoration. The modelling also found an overall negative relationship between restoration and *E. coli* concentrations across 11 monitoring sites, indicating that *E. coli* levels have decreased with increasing restoration. However, the percentage of swimmable sites (above or including the "C" attribute state in the NPS-FM) has remained low (27%) and largely unchanged since implementation of the RMP.

The restoration index calculated as the proportion of upstream bank length fenced and/or planted was the best fit for the MCI and SQMCI models, while the more complex indices based on vegetation age and type or predicted shading were better fits for other metrics, including species richness and percent EPT. The simple proportional restoration index 1 was also the best fit for *E. coli* concentrations both across all sites and when individual site relationships were considered.

Overall, the findings of this study indicate that the Taranaki Riparian Management Program has had beneficial effects on stream health and water quality for human health and recreation in the region. Many restoration studies are unable to detect any effect of restoration on invertebrate communities,

potentially due to the mismatch between scale of restoration, which is typically conducted at the reach scale, and scale of degradation, which usually occurs at the catchment scale, in conjunction with land use changes. The analysis in this study suggests that when restoration is also conducted at the landscape scale, detectable benefits on downstream communities and water quality do occur.

1 Introduction

1.1 Background

The Taranaki ring plain is one the most intensive dairy farming areas in New Zealand. The ring plain also contains approximately 13,000 kilometres of streambank outside the Egmont National Park boundary (Bedford 2015) and most dairy farms are crossed by at least one stream (TRC 2011). Although the water quality of Taranaki streams is generally very good because they have their source in the bush-covered Egmont National Park (TRC 2011), in the early 1990s the Taranaki Regional Council (hereafter "the Council" or "TRC") became concerned about the reduction in riparian vegetation along the edges of rivers and streams on the ring plain which had occurred over the past 170 years of dairy farming. Many waterways were also not fenced to keep cattle from entering the streams. Consequently, the Council introduced a voluntary initiative to support the region's farmers to fence and plant native vegetation on either side of the waterways on their properties, known as the Riparian Management Programme (RMP). The Taranaki Riparian Management Programme was applied to all waterways, including intermittent flows as well as permanent streams of any size, not just to the larger streams previously identified in various national programmes. The Programme has been widely adopted; currently over 11,000 km, or 84%, of all ring plain waterways are now fenced and over 8,500 km, or 70%, are planted (Bedford 2015). The RMP has been one of the largest and longest-running riparian planting and enhancement schemes on private land in New Zealand (TRC 2011). The Council now wishes to determine whether ecological and recreational values of Taranaki streams, such as stream ecosystem health and suitability for primary contact ('swimmability'), respectively, have improved over the course of the Programme. Both ecosystem health and human health for recreation are compulsory national values under the New Zealand National Policy Statement for Freshwater Management (NPS-FM) (MfE 2017).

Riparian fencing and planting are used widely in New Zealand and internationally for mitigating land use intensification effects on adjacent waterways and enhancing stream health (Greenwood, Harding et al. 2012). Fencing reduces stock access to the stream, thereby reducing bank erosion and sediment and faecal bacteria inputs, while plantings increase shading, reduce stream temperatures, intercept sediments, nutrients, and bacteria in run-off, increase inputs of leaves and wood, and enhance stream habitat (Parkyn, Davies-Colley et al. 2003; Wilcock, Betteridge et al. 2009; Greenwood, Harding et al. 2012). It is generally assumed that these improvements in water quality and habitat will in turn enhance biodiversity and ecological functions (Parkyn, Davies-Colley et al. 2003; Wilcock, Betteridge et al. 2009; Greenwood, Harding et al. 2012). However, this assumption is rarely tested, primarily due to lack of adequate post-restoration monitoring (Bernhardt, Palmer et al. 2005; Wortley, Hero et al. 2013) and empirical support to date has been equivocal (Parkyn, Davies-Colley et al. 2003; Greenwood, Harding et al. 2012; Collins, Doscher et al. 2013).

Macroinvertebrates (the aquatic insects, molluscs, crustaceans, and worms that live in streams) are commonly used as biological indicators of stream health due to their differing sensitivity to pollution and habitat conditions (Moore and Neale 2008; Wagenhoff, Shearer et al. 2016). The relative abundances of macroinvertebrate taxa collected from a monitoring site are used to calculate various metrics indicative of stream health, including the New Zealand-specific macroinvertebrate community index (MCI), and its semi-quantitative version, the SQMCI. The MCI and SQMCI calculate a community-wide score based on the sensitivity of the different species present to the effects of organic pollution and stream habitat conditions (Stark and Maxted 2007). The MCI has recently been included as an indicator of stream health in the latest NPS-FM (MfE 2017). The total taxon richness, or number of species, is also frequently used as an indicator of stream health, as degraded streams typically contain fewer species. The number and abundance of EPT taxa (Ephemeroptera, Plecoptera, and Trichoptera), which are known to be highly sensitive to pollution and/or stream degradation, are also commonly used as indicators of stream health; degraded streams typically have fewer EPT (Wagenhoff, Shearer et al. 2016). EPT metrics include EPT richness (number of EPT taxa) and percent EPT abundance, the percentage of total individuals which are EPT. In addition to organic enrichment, other factors known to affect macroinvertebrate community composition and abundance include temperature, flow, dissolved oxygen, and high amounts of fine sediment (Moore and Neale 2008). Taranaki Regional Council samples macroinvertebrates at fifty-nine sites twice per year as part of their 'State of the Environment Monitoring' (SEM) Programme. A 2014 analysis of long-term trends in the annual monitoring data found that MCI scores had improved at most sites across the region since 1995, when monitoring began (Bedford 2015).

Under the NPS-FM, Human Health for Recreation (popularly known as 'swimmability'[1]) in non-lake fed rivers is assessed using *Escherichia coli (E. coli*) bacteria. *E. coli* is an indicator of faecal contamination and the risk of exposure to other harmful water-borne pathogens, particularly *Campylobacter*, but also *Cryptosporidium* oocysts, *Giardia* cysts, Norovirus, other human enteric viruses, and/or *Salmonellae* (McBride and Soller 2017; MfE 2017). Faecal contamination of water by livestock or other animals can occur via direct deposition, runoff from pastoral land, and piped discharges from farms. Human contamination of water can occur due to leaking sewage pipes or septic tanks, poorly treated sewage, and overflow of storm water systems during heavy rain (McBride and Soller 2017). *E. coli* has also been found to naturalize (i.e. exist without a host) in some New Zealand environments (Perchec-Merien and Lewis 2013). Heavy rains and/or high flows are also known to increase *E. coli* concentrations via sediment mobilisation, in which in-channel stores may also be resuspended and/or transported (McKergow and Davies-Colley 2010). Taranaki Regional Council monitors *E. coli* levels monthly at 11 of the State of Environment Monitoring (SEM) sites across the region.

The combination of the Riparian Management Programme and the regular monitoring of macroinvertebrates and *E. coli* across Taranaki streams offers a unique opportunity to test the effect of riparian restoration on stream health and recreational values. The aim of this study was to assess the relationships between the riparian restoration (fencing and planting) undertaken in the Riparian Management Programme and MCI values and *E. coli* levels in Taranaki streams. To quantify the effects of the Riparian Management Programme, three different "restoration indices" were developed to represent the degree of riparian restoration which has occurred at each SEM monitoring site.

[1] It should be noted that while 'swimmability' in this report refers solely to protection from faecal contamination, in other contexts it can refer to a wider range of values, such as water clarity, algal growth, odour, etc.

1.2 Scope of the project

The project had four main objectives:

1) To assess the relationships between MCI scores and other invertebrate metrics and restoration conducted during the Riparian Management Programme.

2) To investigate whether riparian management is correlated with specific environmental variables (e.g., nutrients, water temperature) and whether those variables were in turn correlated with improved MCI scores and other measures of macroinvertebrate community change and stream health.

3) To assess the relationships between *E. coli* concentrations over time and restoration conducted during the Riparian Management Programme.

4) To determine whether each site meets the 'swimmability' standards defined by NZ, EU, and US criteria for *E. coli*.

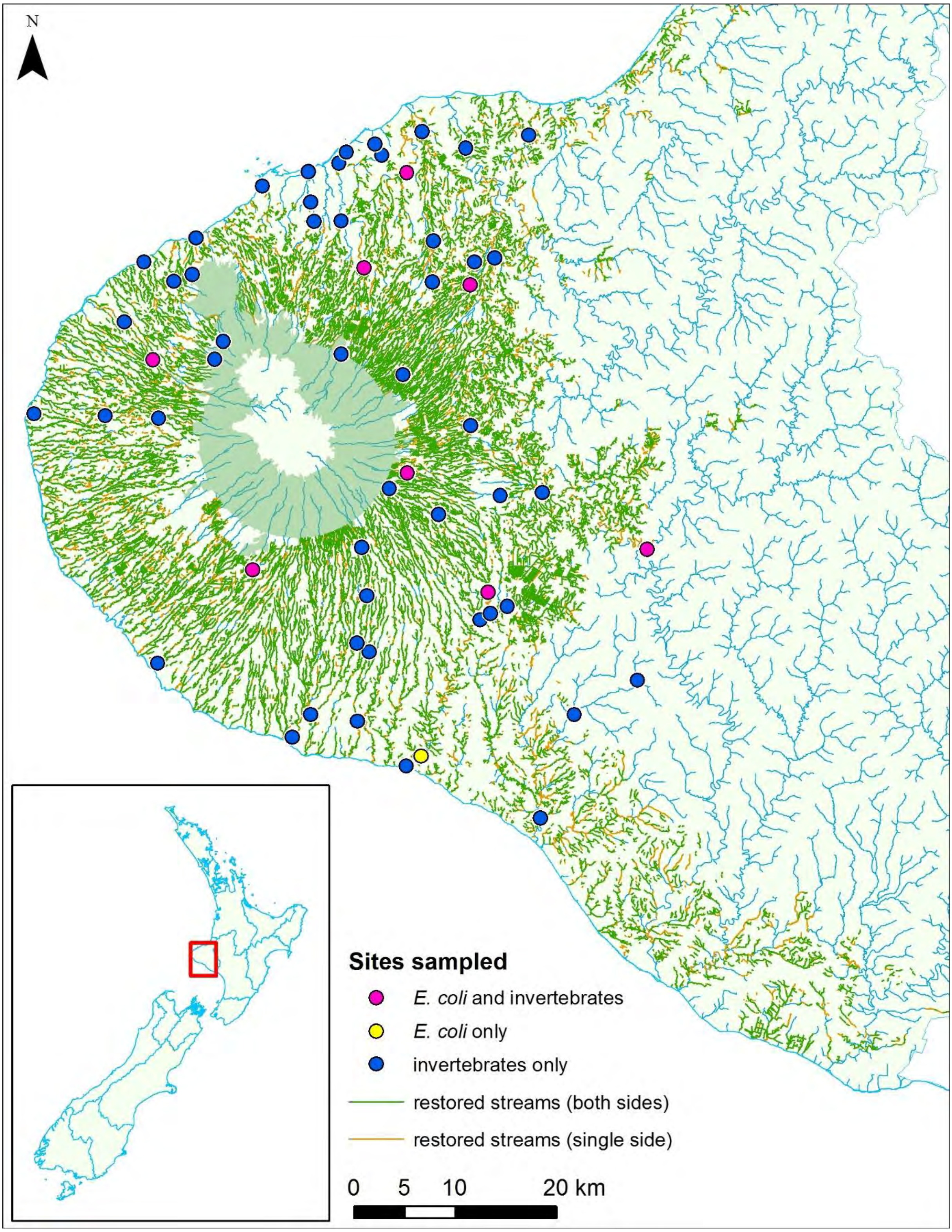

Figure 1-1: Location of invertebrate and *E. coli* sampling sites on the Taranaki Ring Plain. Sites at which both *E. coli* and invertebrates were sampled are represented by pink dots, sites were invertebrates only were sampled are represented by blue dots, and the site were only *E. coli* was measured is represented by a yellow dot. Stream restoration that has occurred during the Riparian Management Programme is shown in green - streams with both banks fenced and/or planted, or orange - one bank fenced and/or planted. Note that the map shows all restored streams in the region, whereas the analysis in this report only included streams within the upstream catchment of an invertebrate or *E. coli* monitoring site.

2 Methods

The Taranaki Regional Council provided 14-23 years of data (depending on site) from 60 SEM monitoring sites across the region (Figure 1-1). Fifty-nine of the sites were sampled twice annually for macroinvertebrates, a subset of 10 of those sites were also sampled monthly for *E. coli* and other physicochemical parameters, including nutrients, dissolved oxygen, turbidity, and temperature. One additional site was sampled for physicochemical parameters and *E. coli* but not macroinvertebrates, and therefore included in the *E. coli* analysis only.

Daily mean flow records were also provided for the eleven physicochemical monitoring sites. Five sites did not have a flow gauge at the same location the monitoring was conducted, in which case data from the nearest flow gauge was used instead. This approximation adds some extra uncertainty into the *E. coli* models, as the model framework assumes that the approximated flow corresponds to a specific date-site combination. In order to ensure any observed *E. coli*-flow relationships held without this added noise the models were also run for the subset of sites where flow measurements were taken at the same location (Appendix A; Table A-1). The *E. coli*-flow relationship remained positive in the paired-flow subset, therefore estimated flows were used to increase the number of sites, and therefore statistical power, in the modelling analysis.

2.1 GIS

Spatial data provided by the Council, including stream lines, fence lines and vegetation planted during the Riparian Management Programme, were matched to stream lines from the River Environment Classification (REC) national stream network database and a digital elevation map in ArcGIS. The combined data were then used to determine the length of fence and vegetation along each stream during each year the Riparian Management Program was implemented. This information was used to create 'restoration indices' for each stream upstream of a monitoring site, as described below.

However, in some cases the restoration data provided by Taranaki Regional Council was along farm drains or other streams too small to be included in the REC database. We tested two different methods to resolve this issue: 1) only including restoration that matched up to an REC stream segment and 2) creating our own stream network using the finest-scale digital elevation map (DEM) available, which had 2 km resolution. Because the 2 km DEM still excluded some of the drains and small streams included in the council dataset, we chose to use the restoration indices calculated using restoration along REC steam segments only for the modelling presented in the main body of this report. However, indices calculated using the two methods were highly correlated (Figure B-1), and analysis of a subset of models using the 2 km DEM-derived restoration indices confirmed that the overall results and general were similar between analyses using either set of indices (Appendix B, Appendix C). Therefore, we can be confident that the results presented using only restoration on REC streams are robust, even though restoration was slightly under-estimated by excluding drains and small streams that did not match up to an REC stream segment.

2.2 Restoration indices

Three restoration indices were trialled to represent the cumulative effect of the fencing and planting undertaken as part of the Riparian Management Programme. The restoration indices for each site are shown in Figure 2-1. All three indices similarly represent the degree of riparian restoration, but each is calculated differently to focus on a particular aspect or predicted effect of fencing and/or planting.

Index 1 was calculated as the simple proportion of upstream bank length restored, with fencing and planting given equal weight.

Index 2 was designed to be sensitive to the type of restoration implemented and reflect that restoration benefits increase over time as vegetation grows, then level off once maximum growth is reached. Therefore, this index was calculated as the proportion of upstream bank length restored, but with the length of each restored patch weighted by the type of restoration (fence, tall vegetation, or short vegetation) and how long it had been in place, so that the weighting increased over time since restoration. Tall vegetation weight was set to increase from 0 to 50% over the first 4 years and then from 50 to 100% over years 5 to 20; it was assumed that most streams would not be more than 3-4 meters wide and therefore shade would be close to maximum after 20 years (Parkyn, Collier et al. 2010). Short vegetation was assumed to have half the maximum benefit of tall vegetation, and to reach full height after 4 years. Consequently, short vegetation was weighted from 0 to 50% over the first 4 years, with no change thereafter. Fencing 'benefit,' was calculated following the same procedure as short vegetation, as fencing has been shown to result in rapid reductions in sediment exports (McKergow, Weaver et al. 2003), although little is currently known about fencing impacts on bank erosion rates (Hughes 2016), which will depend on stream size, bank height, and bank material.

Index 3 was designed to more accurately quantify the effects of stream shading by riparian vegetation by comparing shading to the relative width of the stream. Vegetation type and age were used to create a 'shading' function based on simulation modelling of re-forestation of riparian zones by Davies-Colley, Meleason et al. (2009). Tall vegetation shading was calculated as:

$$y = 1 - y_0 + a(1 - b^x)$$

where y is shading, y_0 is DIFN (diffuse non-interceptance, a measure of lighting; $0<y_0<1$), x is stream width, and a and b are the constants derived from the simulation modelling. Low vegetation shading was calculated as:

$$y = 1 - y_0 + \frac{a}{1 + (x/x_0)^b}$$

where again y is shading, x is the vegetation height/stream width ratio, y_0 is DIFN, and x_0, a, and b are constants from the simulation modelling (Davies-Colley, Meleason et al. 2009). Fencing was weighted from 0 to 1 over the first four years and as 1 thereafter. If the fencing 'benefit' was greater than the shading 'benefit,' then fencing alone was used to calculate the restoration index (multiplied by proportion of upstream reach restored) and vice versa.

Vegetation or fences that were already present prior to implementation of GIS management of Riparian Management Programme restoration data in 2001 were assigned the maximum benefit at time zero and given no further age weighting. The upstream length within the National Park was treated as pre-existing tall vegetation and assigned maximum benefit with no further age weighting. In effect, this represents the initial, or baseline, state at each site beginning in 2001.

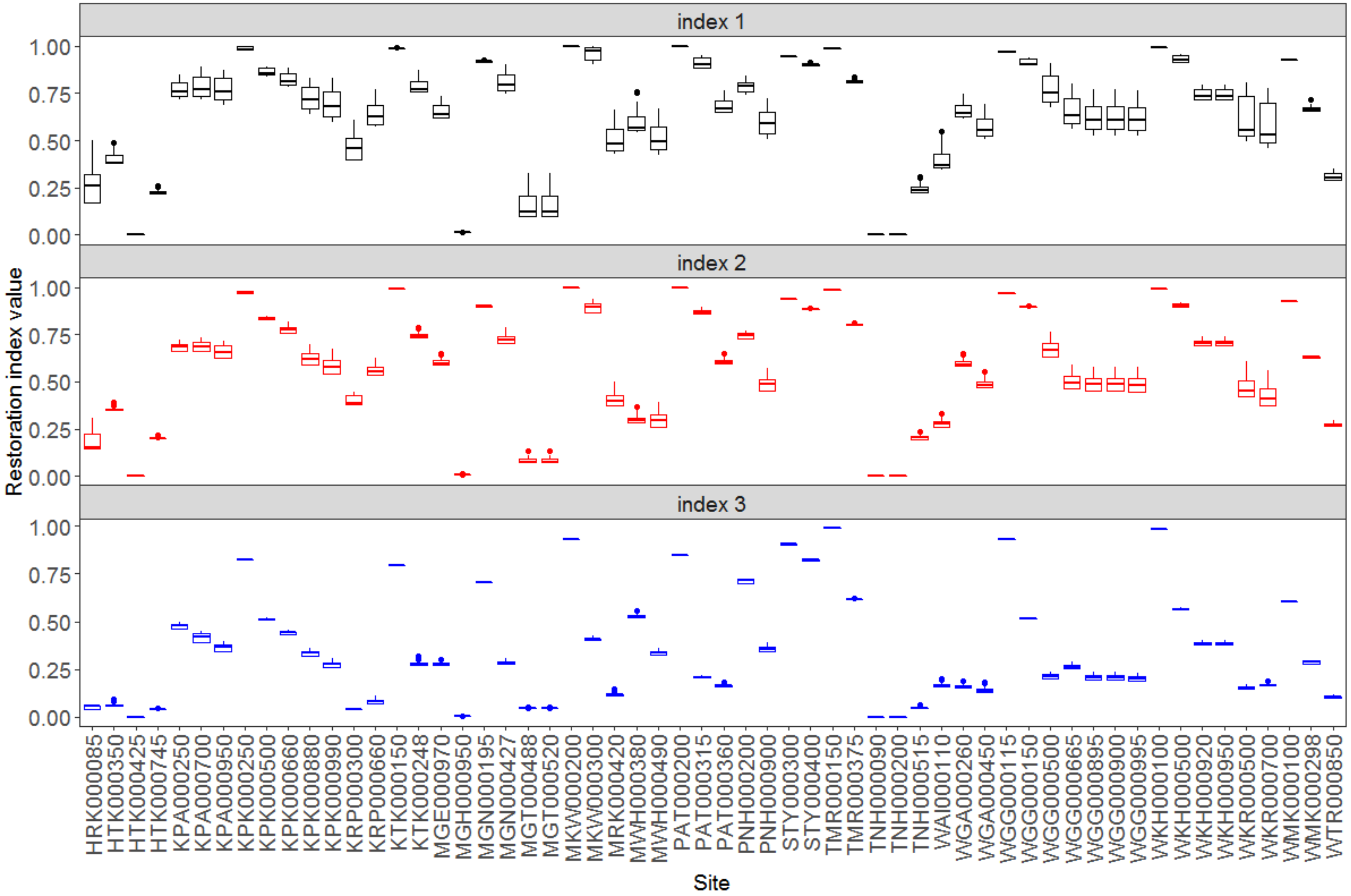

Figure 2-1: Restoration indices for each site over the Riparian Management Programme. Index 1 is the proportion of upstream streambank fenced and/or planted, index 2 is the upstream proportion weighted by type (fencing or planting) and age, index 3 incorporates age of vegetation to predict shading effects. The boxes show the range of index values over the course of the last 14-23 years; a straight line indicates no change in restoration, a large box indicates an increase in restoration over the period. The lower and upper edges of each box indicate the 25th and 75th quartile, respectively. The thick line in the middle is the median. The whiskers indicate data within 1.5 times the inter-quartile range (IQR; distance between 1st and 3rd quartiles). Points indicate outliers greater than 1.5 * IQR.

2.3 Invertebrates

Eight different metrics were calculated for each SEM sample: taxon richness (total number of taxa), EPT richness (number of sensitive Ephemeroptera, Plecoptera, and Trichoptera species), percent EPT richness, MCI (Macroinvertebrate Community Index) and semi-quantitative MCI (SQMCI). Two versions of the MCI and SQMCI were calculated, one using national MCI species tolerance values and the other using Taranaki region species tolerance values, which are slightly different to the National MCI for some species. The richness and abundance of forest specialist taxa (a subset of EPT taxa known to be found primarily in forested streams) in each sample were also calculated, along with community dissimilarity, a multivariate measure of change in species composition compared to the previous sampling, and total turnover, which can be broken down into two components, appearance and disappearance of species.

2.4 *E. coli*

Swimmability was assessed in relation to both New Zealand and international criteria for *E. coli*. The current New Zealand criteria, from the 2017 amendment to the National Policy Statement for Freshwater, includes four different attributes to assess long term swimmability: 1) the percent of *E. coli* counts that exceed 540 *E. coli*/100 mL, 2) the percent of *E. coli* counts that exceed 260 *E. coli*/100 mL, 3) the median *E. coli* concentration per 100 mL) and 4) the 95th percentile of *E. coli* per 100 mL (MfE 2017). There are five different attribute states, A-E, associated with different numeric values of each attribute and the corresponding risk of *Campylobacter* infection (Table 2-1). The swimmability threshold is the bottom of the “C” attribute state, which restricts median risks to be less than 1 infection per 1000 exposures (McBride and Soller 2017; MfE 2017). The previous recreational guidelines established by the Ministry of Health (MoH) in 2003 included both long-term grades based on the 95th percentile of E. coli per 100 mL and a surveillance criteria based on *E. coli* concentration per 100 mL of individual samples collected during routine (i.e. weekly) monitoring (MfE 2003). The European Union (EU) *E. coli* criteria are based on the 95th and 90th percentiles of *E. coli*/100 mL and include three grades, “Excellent”, “Good,” and “Sufficient” (Table 2-4) (EU Council 2006). The United States Environmental Protection Agency (US EPA) recommendation levels include two grades based on both the geometric mean of *E. coli*/100 mL and the 90th percentile for an estimated infection rate of 32 (Grade 1) or 36 (Grade 2) in 1000 (Table 2-5) (US EPA 2012). In general, the 2017 NPS grades for swimmability are less restrictive than the US EPA water quality criteria but comparable to the EU “Excellent” grade, although all three EU grades (Excellent”, “Good,” and “Sufficient”) are considered to be swimmable (McBride and Soller 2017). However, it should be noted that the NPS-FM requires that swimmability be assessed on the basis of year-round data at all flows, whereas the previous New Zealand MfE/MoH recreational guidelines and the EU and US EPA guidelines are based on swimmability during recognised bathing seasons only, and with provision that data be gathered only under conditions suitable for bathing (i.e. excluding high flows).

The criteria were applied over the entire dataset, for each site and year individually, and in accordance with the sampling methodology prescribed in the NPS-FM, namely using the previous five years’ data to calculate the current grade (MfE 2017). Swimmability was also compared using only samples collected on days where the mean daily flow was below the annual median flow, and excluding 3 days following a ‘significant’ river fresh, defined as either 3 times or 7 times the annual median flow, to reflect recommended practice of avoiding immersion for up to 3 days after a large rainfall/flow event (McBride and Soller 2017).

Table 2-1: New Zealand National Policy Statement for Freshwater Management criteria for human health and recreation (MfE 2017).

Attribute State	Numeric Attribute State				Narrative Attribute State
	% exceedances over 540 *E. coli*/100 mL	% exceedances over 260 *E. coli*/100 mL	Median concentration (*E. coli*/100 mL)	95th percentile of *E. coli*/100 mL	Description of risk of Campylobacter infection (based on *E. coli* indicator)
A (Blue)	<5%	<20%	≤130	≤540	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk) The predicted average infection risk is 1%*
B (Green)	5–10%	20–30%	≤130	≤1000	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk) The predicted average infection risk is 2%*
C (Yellow)	10–20%	20–34%	≤130	≤1200	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk) The predicted average infection risk is 3%*
D (Orange)	20–30%	>34%	>130	>1200	20-30% of the time, the estimated risk is ≥50 in 1000 (>5% risk) The predicted average infection risk is > 3%*
E (Red)	>30%	>50%	>260	>1200	For more than 30% of the time, the estimated risk is ≥50 in 1000 (>5% risk) The predicted average infection risk is >7%*

* The predicted average infection risk is the overall average infection to swimmers based on a random exposure on a random day, ignoring any possibility of not swimming during high flows or when a surveillance advisory is in place (assuming that the *E. coli* concentration follows a lognormal distribution). Actual risk will generally be less if a person does not swim during high flows.

Table 2-2: Ministry of Health grading guidelines for freshwater recreation (MfE/MoH 2003).

Microbiological Assessment Category	95th percentile (*E. coli*/100 mL)[a]
A	≤130
B	131–260
C	251–550
D	>550

[a] Calculated using the Hazen method

Table 2-3: Ministry of Health surveillance criteria for freshwater (MfE/MoH 2003).

Mode	*E. coli* concentration per 100 mL	Action
Acceptable Green	no samples >260 *E. coli*/100 mL	– Continue routine (e.g., weekly) monitoring
Alert Amber	single sample >260 and <550 *E. coli*/100 mL	– Increase sampling to daily (initial samples will be used to confirm if a problem exists – Consult the CAC to assist in identifying possible location of sources of faecal contamination – Undertake a sanitary survey and report on sources of contamination
Action Red	single sample >550 *E. coli*/100 mL	– Increase sampling to daily (initial samples will be used to confirm if a problem exists – Consult the CAC to assist in identifying possible location of sources of faecal contamination – Undertake a sanitary survey and report on sources of contamination – Erect warning signs – Inform public through the media that a public health problem exists

Table 2-4: European Union bathing water criteria for inland waters (EU Council 2006).

Criteria	Excellent Quality	Good Quality	Sufficient
E. coli (cfu/100 mL)	500*	1000*	900**

* Based on a 95-percentile evaluation

** Based on a 90-percentile evaluation

Table 2-5: United States Environmental Protection Agency criteria (US EPA 2012).

Criteria	Grade 1 Estimated Illness Rate 32/1000		Grade 2 Estimated Illness Rate 36/1000	
	GM (cfu/100 mL)	STV (cfu/100 mL)	GM (cfu/100 mL)	STV (cfu/100 mL)
E. coli	100	320	126	410

GM = geometric mean

STV = statistical threshold value – should not be exceed by more than 10% of samples (approximates the 90^{th} percentile)

2.5 Statistical modelling of macroinvertebrate indices and *E. coli*

Multiple regression modelling of *E. coli* and macroinvertebrate indices against the restoration indices was carried out in R (R Development Core Team 2008) using the R-INLA package (Rue, Martino et al. 2009) which uses integrated nested Laplace approximation (INLA) methodology to estimate regression parameters in a Bayesian setting. INLA methodology developed by Rue, Martino et al. (2009) is specifically designed to fit latent Gaussian models well-suited to account for spatial, temporal or spatio-temporal structure inherent in the data. We assumed a Poisson distribution for count data, including *E. coli* and invertebrate abundance and species richness. We assumed a gamma distribution for positively continuous variables, such as the MCI and QMCI metrics. We assumed a binomial distribution for proportional data, namely percent EPT, and a gaussian distribution for turnover and dissimilarity measures, as well as continuous physicochemical variables.

Because the goal of this study was to examine the relationships between *E. coli* concentrations and macroinvertebrate indices and restoration at both the regional and site scale, we constructed two models, one to test for overall relationships between *E. coli* and invertebrate responses and restoration across all sites, and the other to examine differences between sites. The first model included restoration index as a fixed main effect and site as a random intercept to account for the correlation between levels of *E. coli* or invertebrates at each site. The second model included restoration and site as random slopes; this enabled comparison of relationships between *E. coli* and invertebrates and restoration between individual sites while still accounting for the similarity between values within each site. The second invertebrate model also included a random intercept for site, similar to the first model, to account for different initial values of *E. coli* and invertebrate metrics. There were too few sites in the *E. coli* dataset for the random slope *E. coli* model to also be able to incorporate a random site intercept as well. All models except for the invertebrate dissimilarity metric models also included a random seasonality term, monthly for the *E. coli* data and bi-annually for the invertebrate data, to incorporate seasonal differences in response variables. The dissimilarity metrics were calculated as pairwise comparisons between sampling points, therefore the two seasonal samplings were averaged together to avoid confounding effects of within-year being more similar than between-year pairs. Flow was also included as an additional covariate in the *E. coli* model to account for the known effect of flow on *E. coli* concentrations (Larned, Snelder et al. 2015). The influence of other physicochemical variables on macroinvertebrate metric responses was also tested by including them as covariates and performing backwards stepwise model selection (Redding, Lucas et al. 2017).

The relationship between parameters and response variables was assessed by looking at the mean values and 95% credible intervals (the probability that the true value lies between those intervals) for each parameter; if the credible intervals for a parameter do not include zero, then it can be confidently inferred that the parameter has a positive or negative (indicated by the sign of the coefficient) effect on the response variable.

3 Results

3.1 Invertebrates

Boxplots of the raw data indicate that there were no strong patterns in invertebrate metric scores over time for all sites combined (Figure 3-1, Figure 3-2). Most metrics had similar distributions across years, with few outliers, except for forest taxa richness and abundance, which had large outliers in most years.

3.1.1 Relationship with restoration

As described in section 2.5, two sets of models were fit to each invertebrate metric, one with the three different restoration indices as fixed effects and one with the restoration indices as random slope terms. Site was included as a random intercept in both models to account for the fact that the response variables within each site will have more similar values than between sites. Model fit was assessed by comparing the model predictions to observed data, and the three models compared by DIC (Deviance Information Criterion, a relative measure of fit, or deviance, penalised by the number of parameters; the smaller the DIC the better the relative fit. Spiegelhalter, Best et al. 2002). Detailed plots and model parameter tables are presented here for the National SQMCI metric model to illustrate the information returned by each component of the models. National SQMCI was chosen because it is a commonly used metric and the results were representative of several other metrics. The results for the other metrics are summarized in Table 3-3.

All three restoration index models estimated a positive relationship between National SQMCI and restoration (i.e., SQMCI increased as restoration increased), indicated by the positive parameter coefficient and 95% credible intervals that did not include zero (Table 3-1). The National SQMCI model with restoration index one, the simple proportion of upstream length fenced/planted, had the lowest DIC score with restoration as a fixed effect. The index one model predicts that for every unit increase in the restoration index (i.e. from 0 to 100% planted), the National SQMCI score might increase by approximately 7 (Figure 3-3). However, it should be noted that one is the maximum value of the restoration index, and the largest change in restoration index in the dataset was 0.34, at site HRK000085 (Figure 2-1). For a change of 0.34 in restoration index, National SQMCI score might be predicted to increase by approximately 1.3 (Figure 3-3).

Figure 3-4 shows the seasonal random effect; the spring samples were higher than the baseline (i.e., expected value if there was no seasonal effect). The site-specific coefficients were quite variable, with many sites having either higher or lower National SQMCI scores than the baseline (Figure 3-5). Other sites had credible intervals that crossed zero, indicating similar scores to other sites. The predicted annual means are plotted with the observed data in Figure 3-6; all three models gave similar predicted National SQMCI metric scores.

Including restoration as a random slope improved the fit of all three models, indicating site-specific differences were an important source of variation (Table 3-1). The model with restoration index one also had the lowest DIC score with restoration as a random slope (Table 3-1). Figure 3-7 shows that National SQMCI scores were higher than the baseline in spring than summer in this model as well. The site-specific intercepts in the random slope models were either positive, indicating sites had higher scores than the baseline, or had credible intervals which crossed zero, indicating scores were similar to the baseline (Figure 3-8).

The site-specific restoration coefficients (slopes) are shown in Figure 3-9. Almost half (49%) of sites had a positive coefficient with a credible interval that did not include zero, indicating positive relationships between restoration and National SQMCI scores (i.e., SQMCI scores increased as the amount restoration increased). The remaining sites all had credible intervals which included zero, which means the direction of the relationship between restoration and National SQMCI cannot be confidently inferred for that site. No sites had negative relationships between restoration and National SQMCI. Finally, the model predictions plotted with the observed data are shown in Figure 3-10; again, all three restoration index models gave similar predictions.

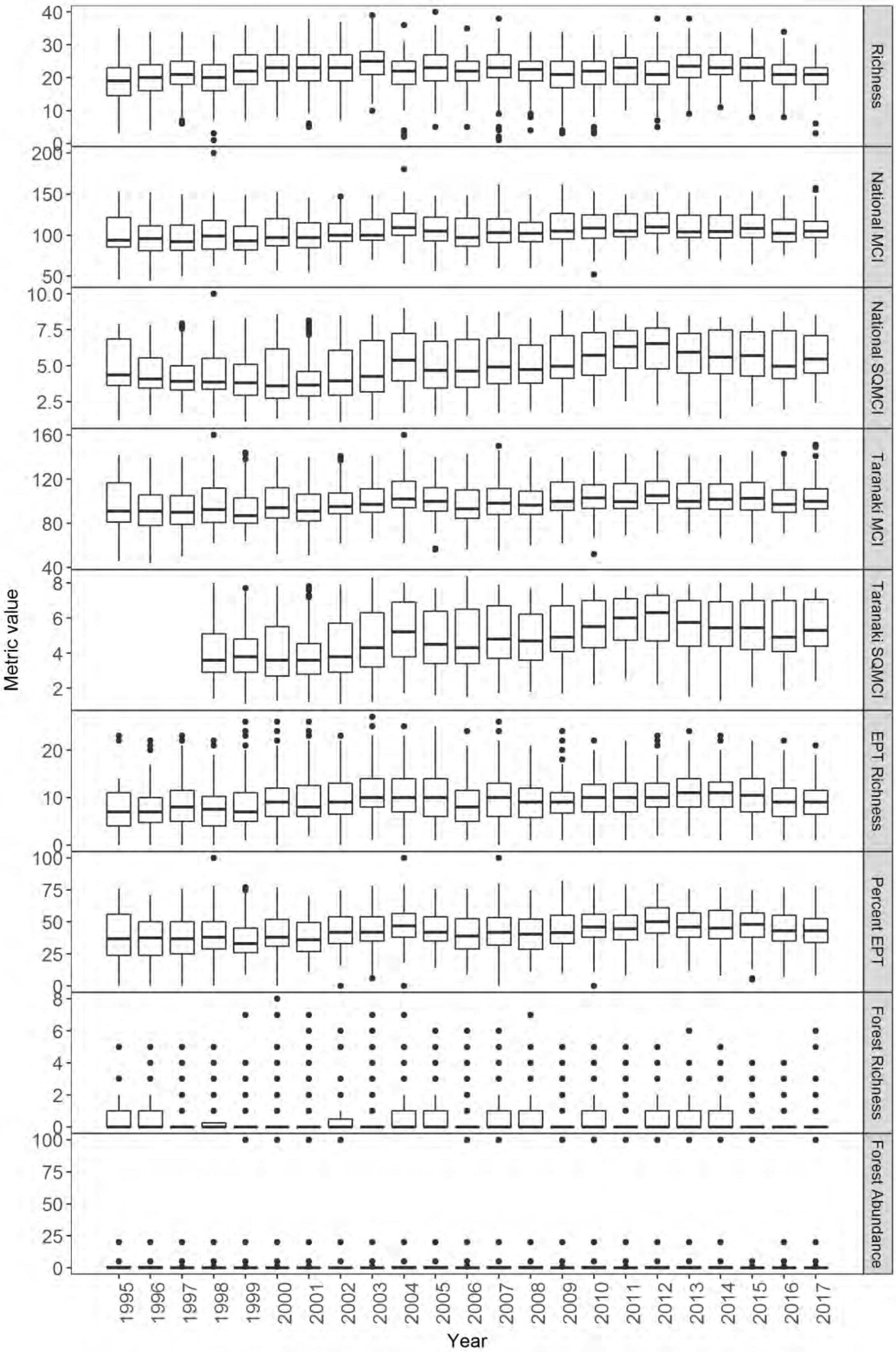

Figure 3-1: Invertebrate metric score distributions across all sites per year. The lower and upper edges of each box indicate the 25th and 75th quartile, respectively. The thick line in the middle is the median. The whiskers indicate data within 1.5 times the inter-quartile range (IQR; distance between 1st and 3rd quartiles). Points indicate outliers outside the IQR range.

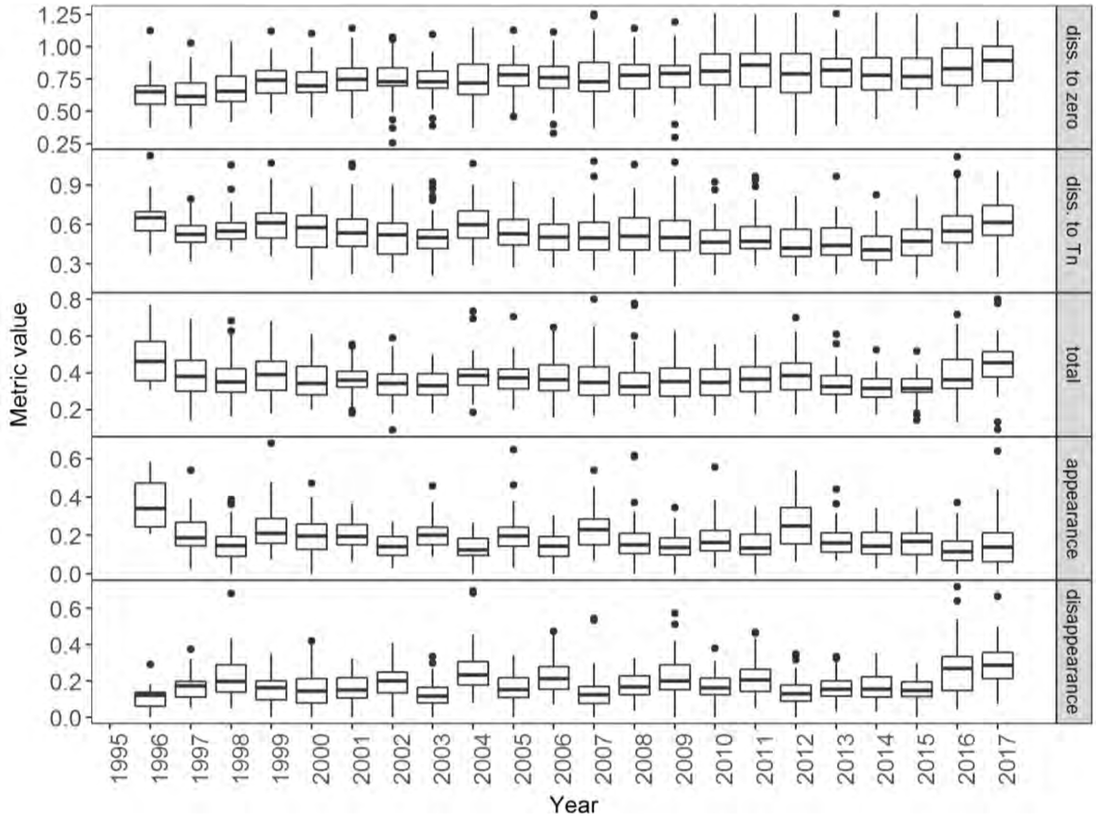

Figure 3-2: Invertebrate dissimilarity measure distributions across all sites per year. The lower and upper edges of each box indicate the 25th and 75th quartile, respectively. The thick line in the middle is the median. The whiskers indicate data within 1.5 times the inter-quartile range (IQR; distance between 1st and 3rd quartiles). Points indicate outliers outside the IQR range.

Table 3-1: Model parameter coefficients, standard errors, 95% credible intervals, and DIC scores for the National SQMCI models with each restoration index. Note that parameter means and quantiles are on the linear scale of the predictor (i.e., log scale).

Metric	Model	Restoration index	Parameter	Mean	Standard error of the mean	2.5% quantile	97.5% quantile	DIC[a]
National SQMCI	Restoration	Index 1	Intercept	0.6140	0.0875	0.4370	0.7804	**6904.71**
	Fixed effect		Restoration	1.5610	0.1053	1.3571	1.7685	
		Index 2	Intercept	-0.1590	0.1986	-0.5562	0.2170	6933.58
			Restoration	3.0914	0.2868	2.5244	3.6323	
		Index 3	Intercept	1.2799	0.0530	1.1699	1.3788	7189.86
			Restoration	0.9244	0.1176	0.7093	1.1726	
	Restoration	Index 1	Intercept	0.4282	0.1797	0.0613	0.7685	**6746.40**
	Random slope	Index 2	Intercept	-0.2320	0.2793	-0.7815	0.3150	6785.30
		Index 3	Intercept	1.5004	0.0465	1.4119	1.5943	7227.36

[a] DIC = Deviance Information Criterion, a relative measure of fit, or deviance, penalized by the number of parameters; the smaller the DIC the better the relative fit (Spiegelhalter, Best et al. 2002).

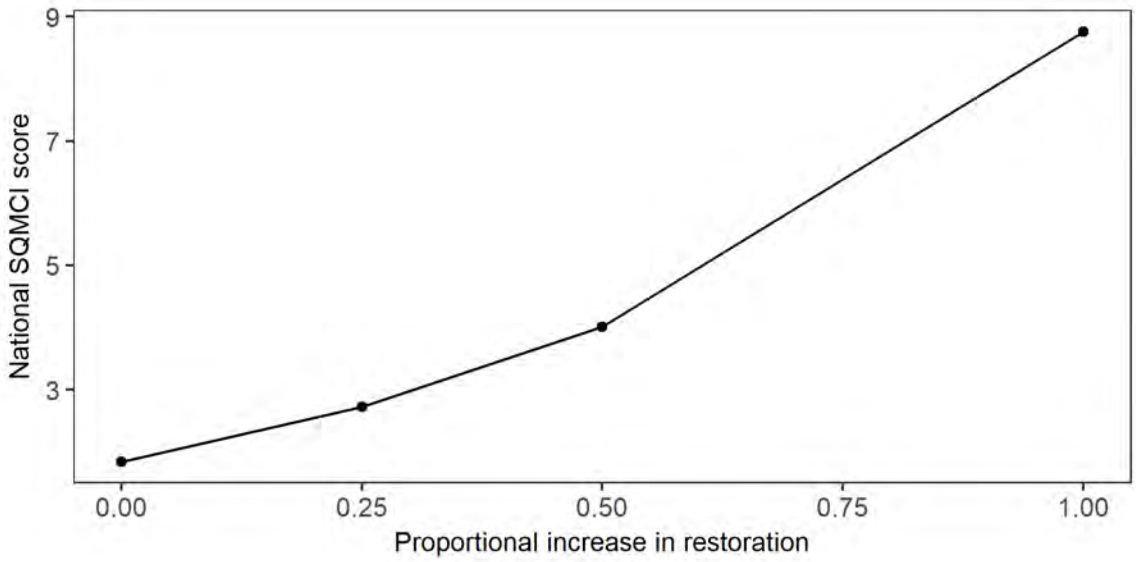

Figure 3-3: Predicted increases in National SQMCI scores with increasing restoration index values from the restoration index 1 fixed effect model.

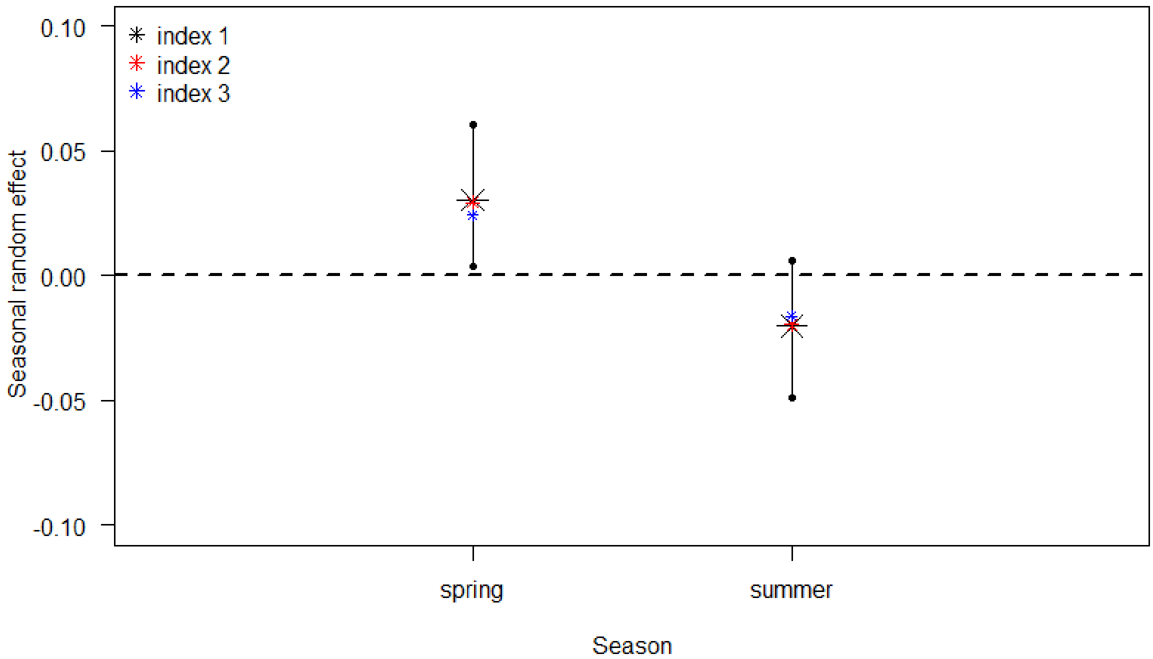

Figure 3-4: Posterior estimates and credible intervals for the seasonal effect in the National SQMCI with restoration as fixed effect models. The coefficients and credible intervals for restoration index 1, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively.

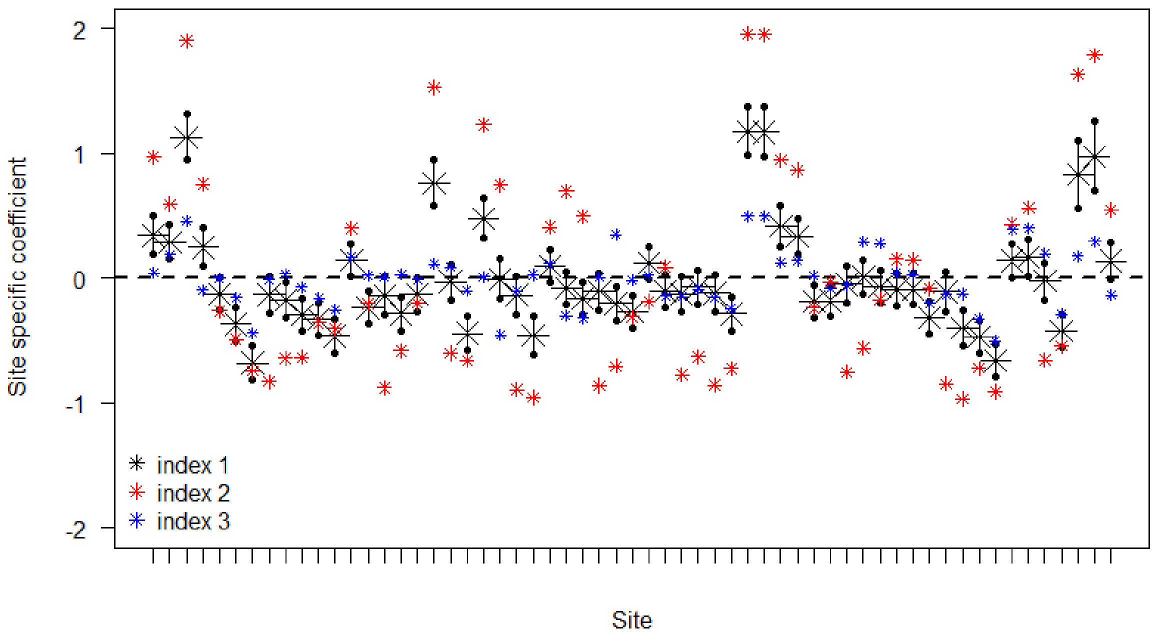

Figure 3-5: Site-specific intercepts for National SQMCI models with each restoration index as a fixed effect. The coefficients and credible intervals for restoration index 1, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively. Site names are ommitted for visual clarity.

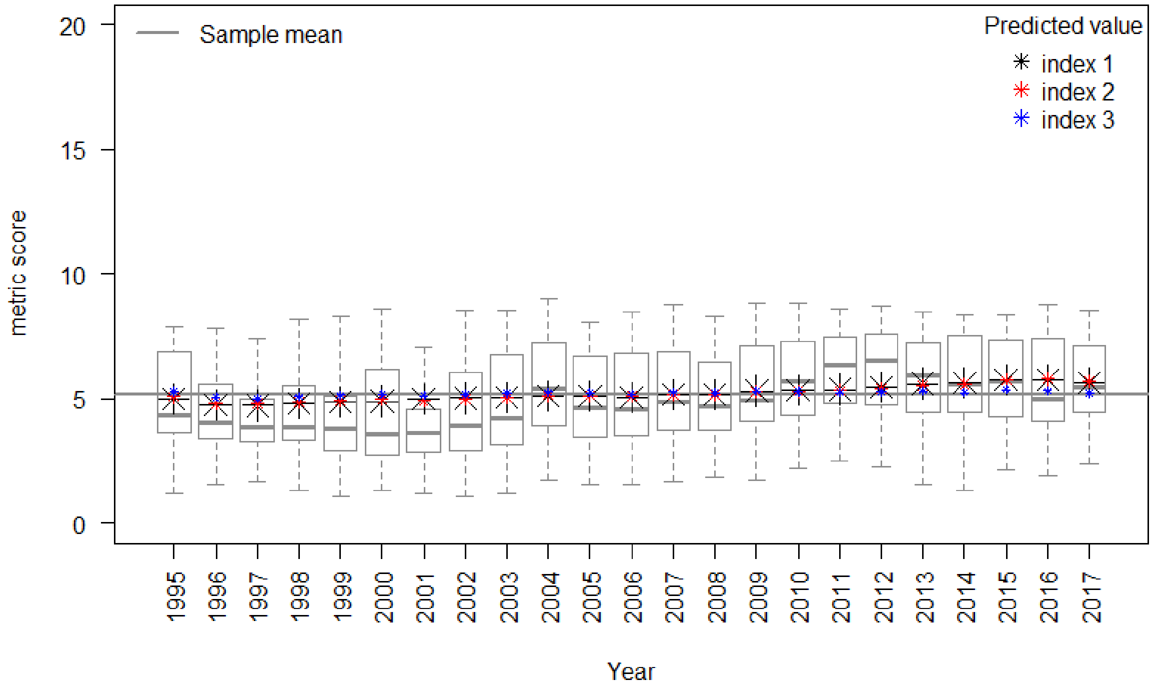

Figure 3-6: Predicted values from the National SQMCI with restoration as a fixed effect models plotted overtop the observed data distribution. The observed data is shown by the grey boxplots, the overall sample mean is shown by the grey line, predicted values and credible intervals for restoration index 1, the best fitting model, are shown largest and in black, and the predicted values from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively.

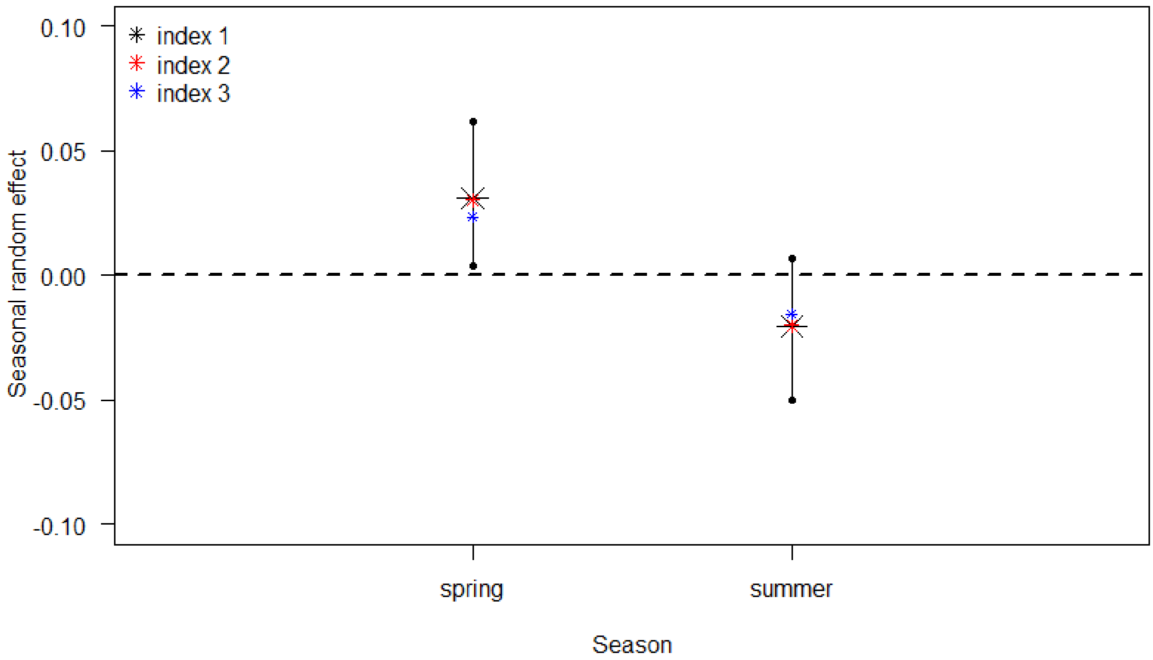

Figure 3-7: Posterior estimates and credible intervals for the seasonal effect in the National SQMCI with restoration as random slope models. The coefficients and credible intervals for restoration index 1, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively.

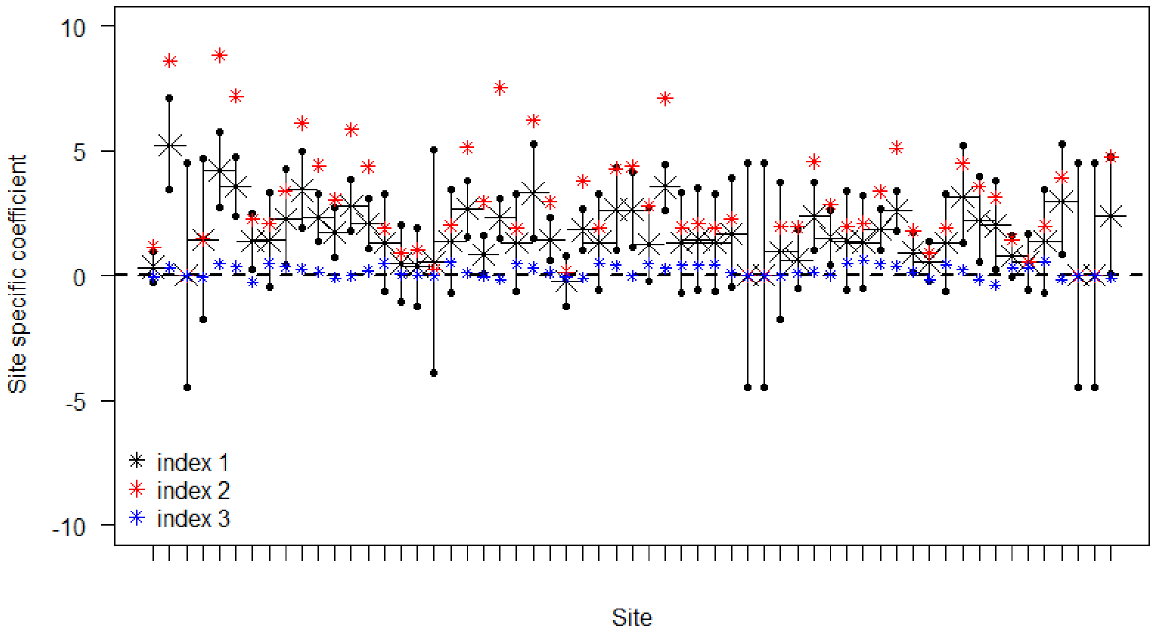

Figure 3-8: Site-specific intercepts for National SQMCI models with each restoration index as a random slope. The coefficients and credible intervals for restoration index 1, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively. Site names are omitted for visual clarity.

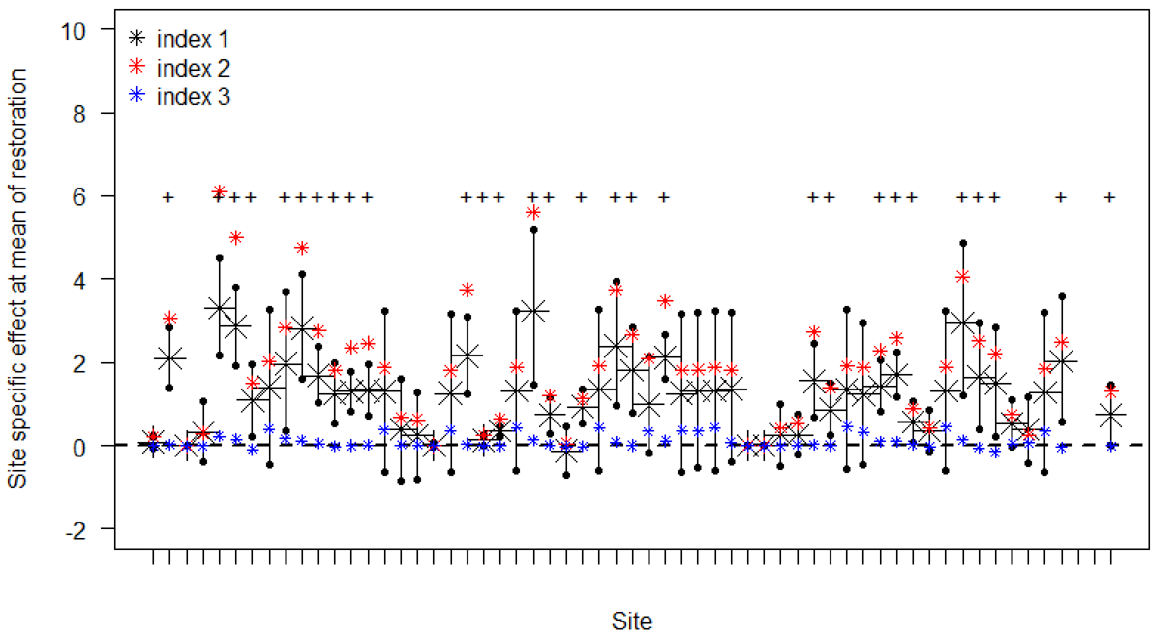

Figure 3-9: Site-specific restoration coefficients (slopes) for the National SQMCI models with each restoration index, evaluated at the mean of the restoration index at that site. '+' indicates sites with positive posterior means, indicating a positive relationship between restoration and National SQMCI scores, and '-' indicates a negative relationship. No sign indicates the credible intervals include zero and therefore direction of the relationship cannot be confidently inferred. The coefficients and credible intervals for restoration index 1, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively. Site names are ommitted for visual clarity.

Table 3-2: Posterior estimates for restoration index coefficients for the National SQMCI with restoration index 1 random slope model. A positive posterior mean with credible intervals that do not include zero indicates positive relationships between restoration and macroinvertebrate metric scores at that site. It is important to note that the coefficients and quantiles are at the scale of the linear predictor (i.e., log scale). A slope of 0 indicates the restoration index remained constant at that site, "--" indicates either that no restoration has been done upstream of this site or if so, data was not available.

Site	Intercept mean	Intercept 2.5% CI	Intercept 97.5% CI	Slope mean	Slope 2.5% CI	Slope 97.5% CI	Nat. SQMCI-Rest. Relationship
HRK000085	0.3328	-0.2742	0.9455	0.0908	-0.0748	0.2578	
HTK000350	5.2296	3.4204	7.0987	2.1015	1.3745	2.8525	+
HTK000425	0.0000	-4.4952	4.4883	0.0000	0.0000	0.0000	
HTK000745	1.4208	-1.7341	4.6600	0.3223	-0.3934	1.0572	
KPA000250	4.2070	2.7413	5.7305	3.3009	2.1509	4.4962	+
KPA000700	3.5478	2.3927	4.7256	2.8581	1.9276	3.8069	+
KPA000950	1.3717	0.2770	2.4741	1.0851	0.2191	1.9573	+
KPK000250	1.4140	-0.4596	3.3055	1.3995	-0.4549	3.2715	
KPK000500	2.2773	0.4091	4.2634	1.9663	0.3533	3.6813	+
KPK000660	3.4172	1.9318	4.9714	2.8221	1.5954	4.1056	+
KPK000880	2.3225	1.3966	3.2533	1.6858	1.0137	2.3614	+
KPK000990	1.7444	0.7495	2.7462	1.2553	0.5394	1.9763	+
KRP000300	2.8111	1.7961	3.8377	1.3013	0.8315	1.7766	+
KRP000660	2.0842	1.0998	3.0802	1.3331	0.7034	1.9701	+
KTK000150	1.3107	-0.6324	3.2547	1.2971	-0.6258	3.2208	
KTK000248	0.4798	-1.0546	2.0050	0.3827	-0.8411	1.5992	
MGE000970	0.3587	-1.2298	1.9368	0.2397	-0.8218	1.2943	
MGH000950	0.5260	-3.9079	5.0462	0.0063	-0.0469	0.0605	
MGN000195	1.3687	-0.6874	3.4236	1.2568	-0.6312	3.1438	
MGN000427	2.6605	1.5366	3.8051	2.1494	1.2414	3.0741	+
MGT000488	0.8424	0.1037	1.5960	0.1292	0.0159	0.2447	+
MGT000520	2.2954	1.5231	3.0846	0.3489	0.2315	0.4689	+
MKW000200	1.3156	-0.6122	3.2439	1.3156	-0.6122	3.2439	
MKW000300	3.3019	1.5033	5.3032	3.2259	1.4687	5.1812	+
MRK000420	1.4506	0.5903	2.3204	0.7339	0.2986	1.1740	+
MWH000380	-0.2145	-1.2071	0.7930	-0.1283	-0.7219	0.4742	
MWH000490	1.8304	1.0059	2.6583	0.9416	0.5175	1.3675	+
PAT000200	1.3424	-0.5856	3.2705	1.3424	-0.5856	3.2705	
PAT000315	2.6382	1.0402	4.3320	2.3964	0.9449	3.9351	+
PAT000360	2.6476	1.1638	4.1745	1.8063	0.7940	2.8479	+
PNH000200	1.2481	-0.2176	2.7095	0.9800	-0.1708	2.1276	
PNH000900	3.5392	2.6455	4.4386	2.1152	1.5811	2.6528	+
STY000300	1.3328	-0.6775	3.3502	1.2614	-0.6412	3.1707	
STY000400	1.4570	-0.5909	3.5295	1.3138	-0.5328	3.1826	
TMR000150	1.3228	-0.6256	3.2716	1.3054	-0.6174	3.2285	
TMR000375	1.6776	-0.4640	3.9234	1.3678	-0.3783	3.1988	
TNH000090	0.0000	-4.4952	4.4883	0.0000	0.0000	0.0000	
TNH000200	0.0000	-4.4952	4.4883	0.0000	0.0000	0.0000	

Site	Intercept mean	Intercept 2.5% CI	Intercept 97.5% CI	Slope mean	Slope 2.5% CI	Slope 97.5% CI	Nat. SQMCI-Rest. Relationship
TNH000515	0.9753	-1.7839	3.7585	0.2616	-0.4786	1.0083	
WAI000110	0.6362	-0.5362	1.8295	0.2580	-0.2175	0.7419	
WGA000260	2.3637	1.0392	3.7162	1.5488	0.6809	2.4350	+
WGA000450	1.5234	0.4342	2.6259	0.8693	0.2478	1.4984	+
WGG000115	1.3889	-0.5801	3.3597	1.3467	-0.5624	3.2577	
WGG000150	1.3455	-0.5159	3.2011	1.2320	-0.4724	2.9311	
WGG000500	1.8479	1.0406	2.6590	1.4280	0.8041	2.0548	+
WGG000665	2.5919	1.7841	3.4036	1.6994	1.1698	2.2317	+
WGG000895	0.9314	0.1263	1.7393	0.5798	0.0786	1.0827	+
WGG000995	0.5716	-0.2249	1.3715	0.3549	-0.1397	0.8515	
WKH000100	1.3339	-0.6098	3.2778	1.3208	-0.6038	3.2456	
WKH000500	3.1677	1.3145	5.2298	2.9488	1.2236	4.8683	+
WKH000920	2.2136	0.5327	3.9597	1.6465	0.3962	2.9454	+
WKH000950	2.0049	0.2828	3.7986	1.4961	0.2111	2.8346	+
WKR000500	0.7802	-0.0500	1.6053	0.5414	-0.0347	1.1140	
WKR000700	0.5612	-0.5927	1.6971	0.3912	-0.4132	1.1831	
WMK000100	1.3794	-0.6699	3.4277	1.2787	-0.6210	3.1775	
WMK000298	2.9838	0.8484	5.2884	2.0183	0.5739	3.5772	+
WNR000450	0.0000	-4.4952	4.4883	--	--	--	
WTR000540	0.0000	-4.4952	4.4883	--	--	--	
WTR000850	2.3699	0.0522	4.7401	0.7326	0.0161	1.4652	+

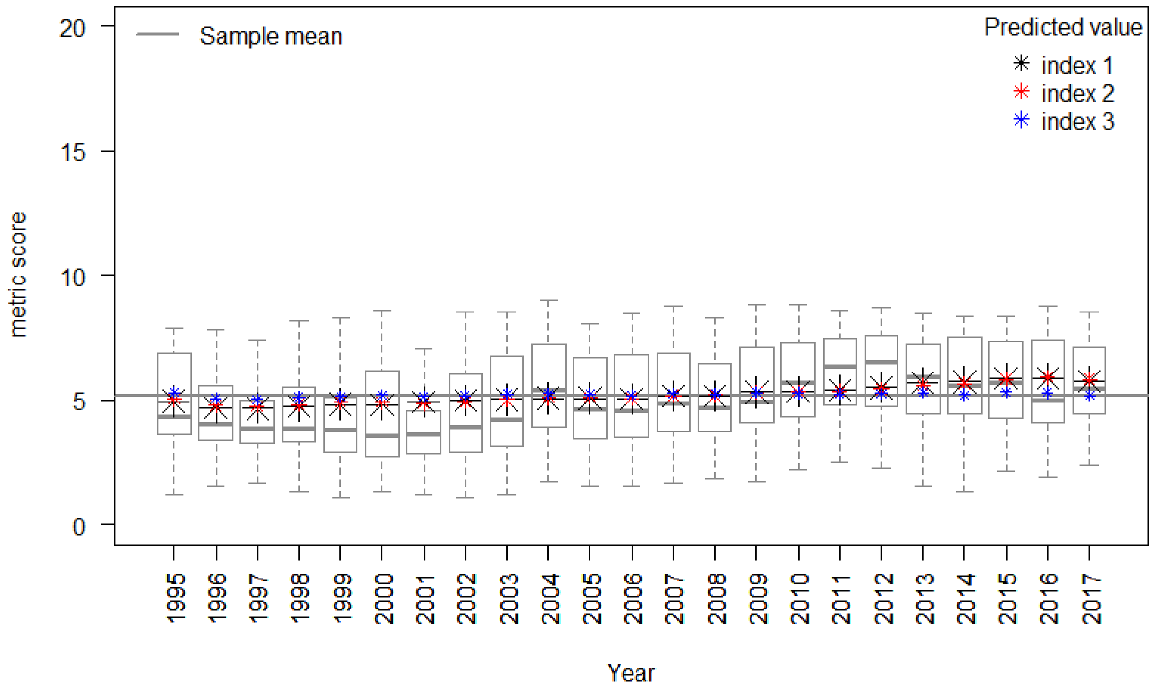

Figure 3-10: Predicted values for each National SQMCI restoration as random slope model plotted overtop the observed data distribution. The observed data is shown by the grey boxplots, the overall sample mean is shown by the grey line, predicted values and credible intervals for restoration index 1, the best fitting model, are shown largest and in black, and the predicted values from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively.

Out of the other metrics, National MCI, Taranaki SQMCI and MCI, EPT richness, percent EPT, forest species richness, forest species abundance, and dissimilarity to zero all also had overall positive relationships between restoration and metric values (Table 3-3). Dissimilarity to previous sampling (T_{n-1}, where T is time and n is time step number), total turnover, and the appearance component of species turnover all had overall negative relationships with restoration. The index with the best fitting restoration as fixed effect model varied between metrics. Index 1, the simple proportion of upstream length fenced and planted, was the best fitting model (chosen by lowest DIC score) for all the restoration as fixed effect models for National MCI, Taranaki SQMCI and MCI, EPT richness, and all turnover metrics except disappearance. Forest species richness and forest species abundance were best fit by the second index, in which restoration was weighted by type and age. Percent EPT and the disappearance turnover metric were equally well fit by the second index and the third index, which is weighted by predicted shading effects. This may mean that forest taxa and other EPT may not return in large numbers until riparian vegetation has become established, even though other metrics such as MCI and SQMCI appear to be driven more by the initial intervention rather than the age of restoration. On the other hand, as noted previously, all three index models had similar fits and give similar predictions. Therefore, differences between metrics could also simply be due to statistical artefact.

Table 3-3: Summary of model results for all invertebrate metric models with restoration indices as fixed effects and as random slopes. The best-fitting index was determined by lowest DIC score, and the direction by the sign of the restoration fixed effect coefficient if the 95% credible intervals did not include zero. 2-3 indicates models with indices 2 and 3 fit equally well, 1-3 indicates that all three models fit equally well. If no direction is given, the credible intervals for that parameter crossed zero and therefore the direction of the relationship cannot be confidently inferred. The percentage of sites with positive relationships between restoration and the given metric was determined by the number of sites with positive random slope coefficients with 95% credible intervals that did not include zero. There were no sites with negative relationships. If no percentage is given then credible intervals for all sites crossed zero.

Metric	Best-fitting Index Restoration fixed effect	Direction Restoration fixed effect	Best-fitting Index Restoration random slope	% positive relationships	% negative relationships
National SQMCI	1	+	1	49%	
National MCI	1	+	1	56%	
Taranaki SQMCI	1	+	1	47%	
Taranaki MCI	1	+	1	61%	
Richness	1		1		
EPT Richness	1	+	1-3		
Percent EPT	2-3	+	1-3		
Forest Richness	2	+	2	2%	
Forest Abundance	2	+	1	7%	
Dissimilarity to T_0	1	+	1		
Dissimilarity to T_{n-1}	1	-	1-3		
Total Turnover	1	-	1-3		
Appearance	1	-	1-3		
Disappearance	2-3		3		

3.1.2 Physicochemical covariates

The influence of physicochemical covariates on invertebrate metrics was examined via stepwise backwards selection of the best-fit models for each metric with a suite of physicochemical parameters included. However, these results must be interpreted with some caution, as only 10 sites had both invertebrate and physicochemical data.

Physicochemical parameters were chosen by the model selection procedure if their inclusion improved the overall fit of the model (indicated by DIC score). However, in many cases a parameter was included even though there was no clear relationship between that parameter and the metric (i.e., credible intervals included zero; Table 3-4). The direction of relationships which could be inferred, on the other hand, were for the most part consistent across metrics. For example, total phosphorus had a negative relationship with National SQMCI, National MCI and Taranaki SQMCI. Dissolved reactive phosphorus, DRP, had a negative relationship with abundance of forest taxa. Nitrate nitrogen (NO_3) had a positive relationship with National MCI and Taranaki MCI and a negative relationship with the appearance turnover metric. Ammoniacal nitrogen (NH_4) had a positive relationship with Taranaki SQMCI and abundance of forest taxa. The positive relationships between NO_3 and NH_4 and SQMCI and MCI metrics is rather unusual, as it is generally expected that nutrient enrichment will have a negative effect on sensitive taxa (Stark and Maxted 2007). It may be an artefact of the small sample size, or be due to associations with some other unmeasured effect or parameter. It is highly likely that both N and P are influenced by factors other than land use and restoration alone; for example the geology of Mt. Taranaki is known to release phosphorus, but because phosphorus is the limiting nutrient for most Taranaki streams, it is taken up quickly and concentrations are largely consistent throughout most of the catchment and higher only at the bottom. Nitrate, on the other hand, tends to increase throughout the length of catchment, even in mid-reaches where restoration has been greatest (Gary Bedford, personal communication). Turbidity had a negative relationship with species richness, but a positive relationship with National SQMCI and Taranaki SQMCI. Turbidity is generally expected to have a negative effect on invertebrates, because it can reduce primary production, or algal growth, a key food source for many invertebrates (Ryan 1991).

Restoration continued to have a positive relationship with National SQMCI and MCI, Taranaki SQMCI and MCI, EPT richness, and percent EPT, and dissimilarity to zero even with the addition of covariates. This suggests that the positive relationships between metrics and restoration were not related to other covariates relationship with invertebrates. However, the positive relationships between restoration and forest taxa abundance and richness were no longer observed in the covariate models. Likewise, the negative relationships between restoration and dissimilarity to T_{n-1}, total turnover, and appearance of new species, all became undetermined in the covariate models. These shifts could indicate that the observed relationships between restoration and forest invertebrates may be attributed to covariates rather than restoration alone. Again, however, the models were fit using only data from 10 sites, and therefore results may not be generalisable. Only one of the six physicochemical variables examined had a direct relationship with restoration, tested by running the restoration as a fixed effect models with the physicochemical parameter as the response variable compared to an intercept-only model without restoration (Table 3-5

Table 3-5). For most of the physicochemical variables, the intercept-only model was a better fit, indicating no relationship with restoration. Turbidity, however, had a negative relationship with restoration, indicating that water clarity improved with restoration.

Table 3-4: Parameter coefficients and DIC scores for invertebrate metric models with restoration as a fixed effect and selected physicochemical covariates. The fixed effect model indicates the overall relationship between parameters and metrics. '% sites' is the proportion of the ten sites which had a positive or negative relationship (direction indicated in brackets) with restoration in the corresponding random slope model. Parameters tested include DRP, dissolved reactive phosphorus (g/m^3); NH_4, ammoniacal nitrogen (g/m^3); NO_3, nitrate nitrogen (g/m^3); TN, total nitrogen (g/m^3); TP, total phosphorus (g/m^3); TURBIDITY, turbidity (NTU).

Metric	Restoration index	Parameter	Mean	Standard error of the mean	2.5% quantile	97.5% quantile	direction	DIC
National SQMCI	1	Intercept	0.1335	0.2587	-0.4073	0.6067		1389.00
		NH_4	0.2455	0.1642	-0.0668	0.5788		
		NO_3	-0.0282	0.0683	-0.1623	0.1059		
		TN	0.0161	0.0568	-0.0953	0.1277		
		TP	-1.1765	0.3299	-1.8211	-0.5259	-	
		TURBIDITY	0.0080	0.0029	0.0023	0.0138	+	
		Restoration	2.1526	0.2847	1.5982	2.7077	+	
National MCI	1	Intercept	4.2856	0.0699	4.1418	4.4174		3123.09
		DRP	0.1572	0.3095	-0.4501	0.7654		
		NH_4	0.0604	0.0526	-0.0416	0.1651		
		NO_3	0.0429	0.0152	0.0131	0.0727	+	
		TP	-0.1698	0.0791	-0.3244	-0.0137	-	
		Restoration	0.5784	0.0791	0.4276	0.7385	+	
Taranaki SQMCI	1	Intercept	0.2498	0.3136	-0.3894	0.8234		1223.68
		DRP	2.0111	1.0882	-0.1219	4.1513		
		NH_4	0.3921	0.1627	0.0815	0.7213	+	
		TP	-2.6613	0.5083	-3.6426	-1.6457	-	
		TURBIDITY	0.0215	0.0073	0.0075	0.0360	+	
		Restoration	1.9561	0.3803	1.2170	2.6783	+	
Taranaki MCI	1	Intercept	4.2514	0.0672	4.1129	4.3777		2997.20
		DRP	0.0750	0.2826	-0.4795	0.6302		
		NH_4	0.0673	0.0483	-0.0264	0.1631		
		NO_3	0.0367	0.0138	0.0096	0.0638	+	
		TP	-0.1405	0.0722	-0.2817	0.0020		
		Restoration	0.5502	0.0748	0.4076	0.7012	+	
Richness	1	Intercept	3.1346	0.1672	2.8059	3.4660		2425.91
		DRP	0.7085	0.7244	-0.7230	2.1215		
		NH_4	0.1403	0.1392	-0.1390	0.4082		
		NO_3	-0.0073	0.0627	-0.1303	0.1158		
		TN	-0.0625	0.0540	-0.1688	0.0432		
		TURBIDITY	-0.0047	0.0023	-0.0094	-0.0003	-	
		Restoration	-0.0976	0.1868	-0.4671	0.2681		

Metric	Restoration index	Parameter	Mean	Standard error of the mean	2.5% quantile	97.5% quantile	direction	DIC
EPT Richness	1	Intercept	1.5136	0.2543	0.9841	1.9857		2057.56
		DRP	-0.2288	1.1750	-2.5463	2.0675		
		NH_4	0.2704	0.2021	-0.1387	0.6557		
		NO_3	0.1087	0.0900	-0.0680	0.2851		
		TN	-0.0939	0.0753	-0.2421	0.0534		
		TURBIDITY	-0.0065	0.0037	-0.0141	0.0005		
		Restoration	1.0852	0.2970	0.5268	1.6937	+	
Percent EPT	2-3	Intercept	-0.8315	0.2641	-1.3579	-0.3207		586.51
		DRP	-2.0509	6.4821	-14.8641	10.5917		
		NH_4	0.8274	1.2677	-1.7018	3.2796		
		NO_3	-0.2855	0.2168	-0.7156	0.1361		
		TP	-3.0073	3.0524	-9.2150	2.7811		
		TURBIDITY	0.0145	0.0253	-0.0354	0.0641		
		Restoration	1.1194	0.3628	0.4161	1.8399	+	
Forest Richness	2	Intercept	-4.9152	1.4262	-7.8103	-2.1399		407.40
		DRP	2.5432	7.7960	-12.6424	17.9540		
		NO_3	-0.4276	0.6415	-1.7470	0.7768		
		TN	-0.4277	0.2758	-0.9806	0.1032		
		TP	-4.2543	4.4119	-13.8473	3.4611		
		Restoration	3.3820	1.9003	-0.4409	7.1317		
Forest Abundance	2	Intercept	-3.9900	2.1955	-7.8531	0.9281		931.32
		DRP	-25.4258	4.3648	-34.0166	-16.8811	-	
		NH_4	4.1168	0.9609	2.2934	6.0948	+	
		NO_3	-0.5555	0.3761	-1.3176	0.1606		
		Restoration	1.9880	3.0585	-5.0912	7.1093		
Dissimilarity to T_0	1	Intercept	0.2504	0.1732	-0.1091	0.5726		-342.29
		DRP	1.5863	0.8192	-0.0216	3.1971		
		NH_4	-0.4172	0.3763	-1.1572	0.3213		
		NO_3	-0.1123	0.0577	-0.2256	0.0010		
		TN	0.0609	0.0348	-0.0076	0.1293		
		TURBIDITY	-0.0009	0.0009	-0.0028	0.0009		
		Restoration	0.7934	0.1716	0.4483	1.1236	+	
Dissimilarity to T_{n-1}	1	Intercept	0.6157	0.0559	0.5221	0.7459		-135.11
		DRP	-0.2579	1.0412	-2.4245	1.6811		
		NH_4	-0.8310	0.5974	-2.0068	0.3406		
		NO_3	0.0449	0.0469	-0.0399	0.1473		
		TURBIDITY	0.0025	0.0015	-0.0004	0.0055		
		Restoration	-0.1184	0.0725	-0.2878	0.0031		

Metric	Restoration index	Parameter	Mean	Standard error of the mean	2.5% quantile	97.5% quantile	direction	DIC
Total Turnover	1	Intercept	0.3294	0.0543	0.2266	0.4423		-397.98
		DRP	0.6159	0.6650	-0.6914	1.9220		
		NH_4	-0.4554	0.3298	-1.1033	0.1923		
		NO_3	-0.0445	0.0413	-0.1253	0.0370		
		TN	0.0191	0.0296	-0.0390	0.0772		
		Restoration	0.0219	0.0684	-0.1205	0.1511		
Appearance	1	Intercept	0.1731	0.0242	0.1289	0.2252		-407.84
		DRP	0.4054	0.5045	-0.5887	1.3987		
		NH_4	0.1487	0.3220	-0.4839	0.7811		
		NO_3	-0.0688	0.0306	-0.1297	-0.0091	-	
		TN	0.0420	0.0275	-0.0121	0.0958		
		Restoration	-0.0046	0.0314	-0.0724	0.0525		
Disappearance	3	Intercept	0.1219	0.0350	0.0491	0.1890		-382.82
		DRP	0.2093	0.6070	-0.9922	1.3987		
		NH_4	-0.5104	0.3416	-1.1815	0.1607		
		NO_3	0.0254	0.0380	-0.0470	0.1026		
		TN	-0.0144	0.0298	-0.0729	0.0440		
		TURBIDITY	0.0013	0.0008	-0.0003	0.0030		
		Restoration	0.0746	0.0448	-0.0111	0.1680		

Table 3-5: Physicochemical variable relationships with restoration (index 1). The DIC intercept only indicates the fit of a model without restoration included, DIC restoration indicates whether the fit was improved by including restoration. The lower DIC value, indicating better fit, is in bold. Direction indicates whether the relationship was positive, negative, or undetermined.

Physicochemical variable	DIC intercept only	DIC restoration	Model parameter	Mean	Standard error of the mean	2.5% quantile	97.5% quantile	direction
DRP	**-13813.52**	-13811.81	Intercept	-0.0027	0.0073	-0.0170	0.0118	
			Restoration	0.0017	0.0067	-0.0115	0.0148	
NH_4	**-7201.53**	-7200.33	Intercept	-0.0019	0.0126	-0.0275	0.0221	
			Restoration	-0.0003	0.0150	-0.0290	0.0301	
NO_3	1356.58	**1354.54**	Intercept	-0.1098	0.2067	-0.5228	0.2972	
			Restoration	0.2163	0.1186	-0.0163	0.4490	
TN	**2638.44**	2638.85	Intercept	0.1720	0.2435	-0.3133	0.6518	
			Restoration	-0.2132	0.1529	-0.5133	0.0871	
TP	**-3561.30**	-3560.95	Intercept	0.0137	0.0202	-0.0260	0.0541	
			Restoration	-0.0175	0.0255	-0.0685	0.0325	
TURBIDITY	11194.48	**11170.21**	Intercept	10.1017	2.2992	5.5911	14.6283	

Physicochemical variable	DIC intercept only	DIC restoration	Model parameter	Mean	Standard error of the mean	2.5% quantile	97.5% quantile	direction
			Restoration	-15.2748	2.9911	-21.1479	-9.4060	-

3.2 *E. coli*

The raw data indicates that *E. coli* concentrations fluctuated from year to year with no consistent temporal pattern across all sites combined (Figure 3-11). *E. coli* concentrations in 1995 were substantially lower than other years, however we noted that effect was an artefact of only one sample taken in 1995. Therefore, the subsequent modelling of *E. coli* only included data from 1998 onwards, when regular monthly sampling was implemented across all sites (except MKW000300, where sampling began in 2003).

3.2.1 Swimmability

Three of the eleven Taranaki Region *E. coli* monitoring sites met NPS swimmability criteria when applied across the entire dataset (Table 3-6). Site STY000300, which is located on conservation land, was in the top A-Blue grade, while site PAT000200, which is located in a large catchment with mixed land use, was in the B-Green grade and site PNH000200, which is located in a primarily agricultural catchment, was in the C-Yellow grade. The remaining sites were below the minimum swimmability criteria (bottom of the C grade) for one or more attributes. Six sites were in the D-Orange grade and three were in the E-Red grade. The sites which fell in the D grade band were located in a variety of land uses, primarily large catchments with multiple impacts, but also land under intensive usage and in the eastern hill country. Of the three sites in the E grade band, two were located on agricultural land, but one was on conservation land (site MKW000300). Sites that were in the D or E grade tended to be in that grade across all attributes, whereas the B and C grade sites often met the median and % >260 *E. coli*/100 mL attributes but not the 95th percentile or % >540 *E. coli*/100 mL attribute. The 95th percentile criterion was the attribute which most frequently caused sites to fail to meet the NPS swimmability grading.

Yearly grades for each site calculated following the sampling procedure outlined in the NPS-FM (rolling calculation over previous five years) are included in Table 3-8. The percentage of swimmable sites has remained fairly constant since 2003, with 27% swimmable under the NPS-FM criteria, 9% swimmable under the MfE/MoH 2003 criteria, 27% and 18% swimmable under the US EPA mean and 90th percentile criteria, respectively, and 27% swimmable under the EU criteria (swimmable includes “Excellent,” “Good,” and “Sufficient” categories). Although the NPS-FM is considered less restrictive than the EU criteria (McBride and Soller 2017), both criteria resulted in the same number of swimmable sites for this dataset. Pre-2003 differences were most likely due to fewer number of sites sampled during those years rather than any changes in swimmability status.

Excluding samples taken during flows above the annual median or within three days following a rainfall event reduced the percentage of sites that exceeded the 95th percentile, % >540 *E. coli*/100 mL, and % >260 *E. coli*/100 mL attributes, but not the percentage of sites that exceed the median criteria (Table 3-7; Appendix D). Consequently, the overall grades of each site remained the same. The percentage of sites exceeding the MfE/MoH 2003 criteria also did not change when high flow days were excluded from the dataset. The percentage of sites which met the US EPA mean criteria decreased from 27% to 18% when above-median flows were excluded but the 90th percentile criteria remained the same. The percentage of sites that met the EU swimmability standards, on the other hand, increased from 27% to 81% when *E. coli* data from days with flow above annual median were excluded.

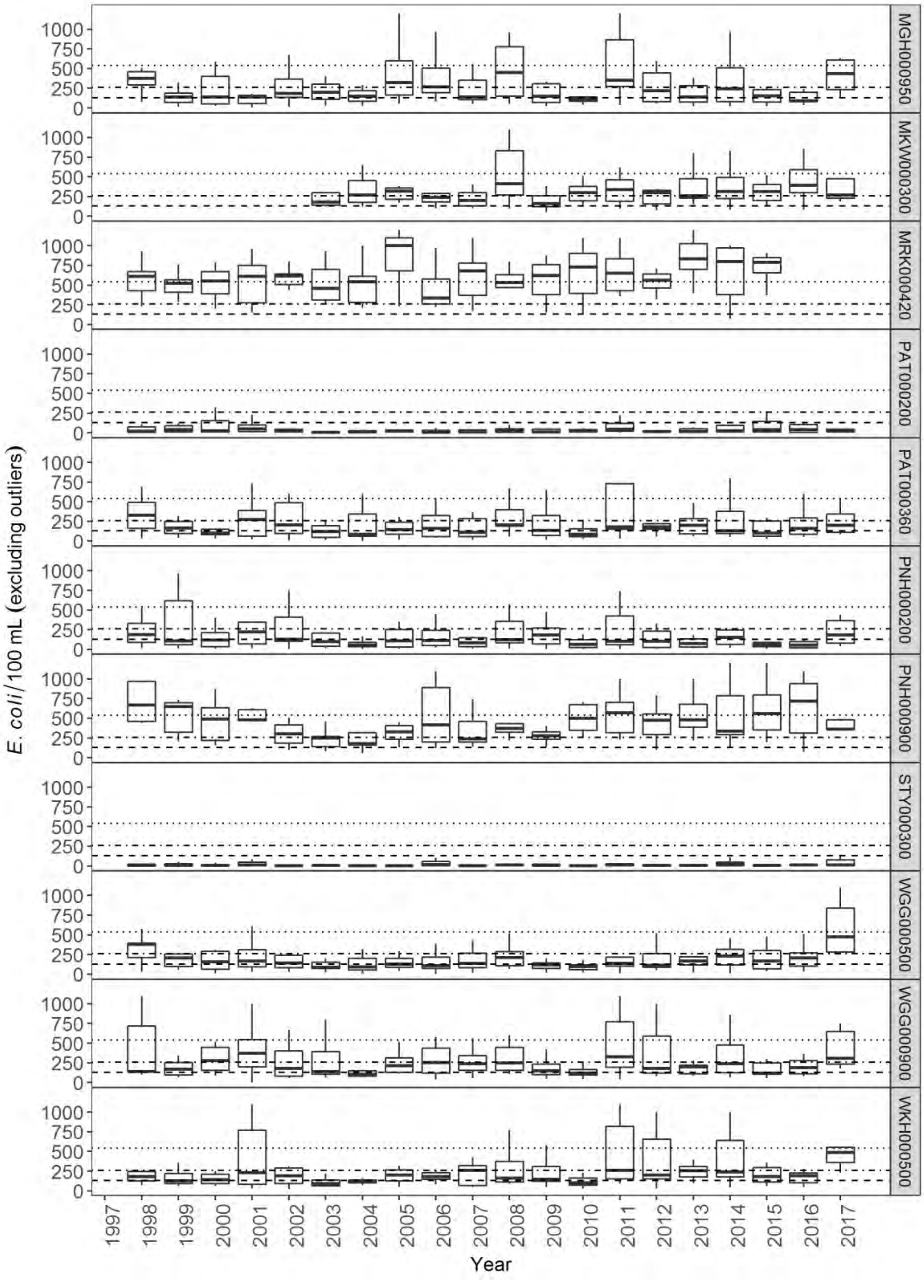

Figure 3-11: Distributions of *E. coli* concentrations grouped by site and year. The lower and upper edges of each box indicate the 25th and 75th quartile, respectively. The thick line in the middle is the median. The whiskers indicate data within 1.5 times the inter-quartile range (IQR; distance between 1st and 3rd quartiles). This plot excludes outliers (points >1.5 * IQR). The dashed line indicates the NPS median criteria for

swimmability, 130 *E. coli*/100 mL, the dot-dash line indicates the percent exceedance threshold of 260 *E. coli*/100 mL and the dotted line indicates the percent exceedance threshold of 540 *E. coli*/100 mL (also the 95th percentile threshold for the top category of swimmability. Note that the NPS grades all waters with the 95th percentile below 1200 E. coli/100 ML as swimmable, subject to all other criteria also being met).

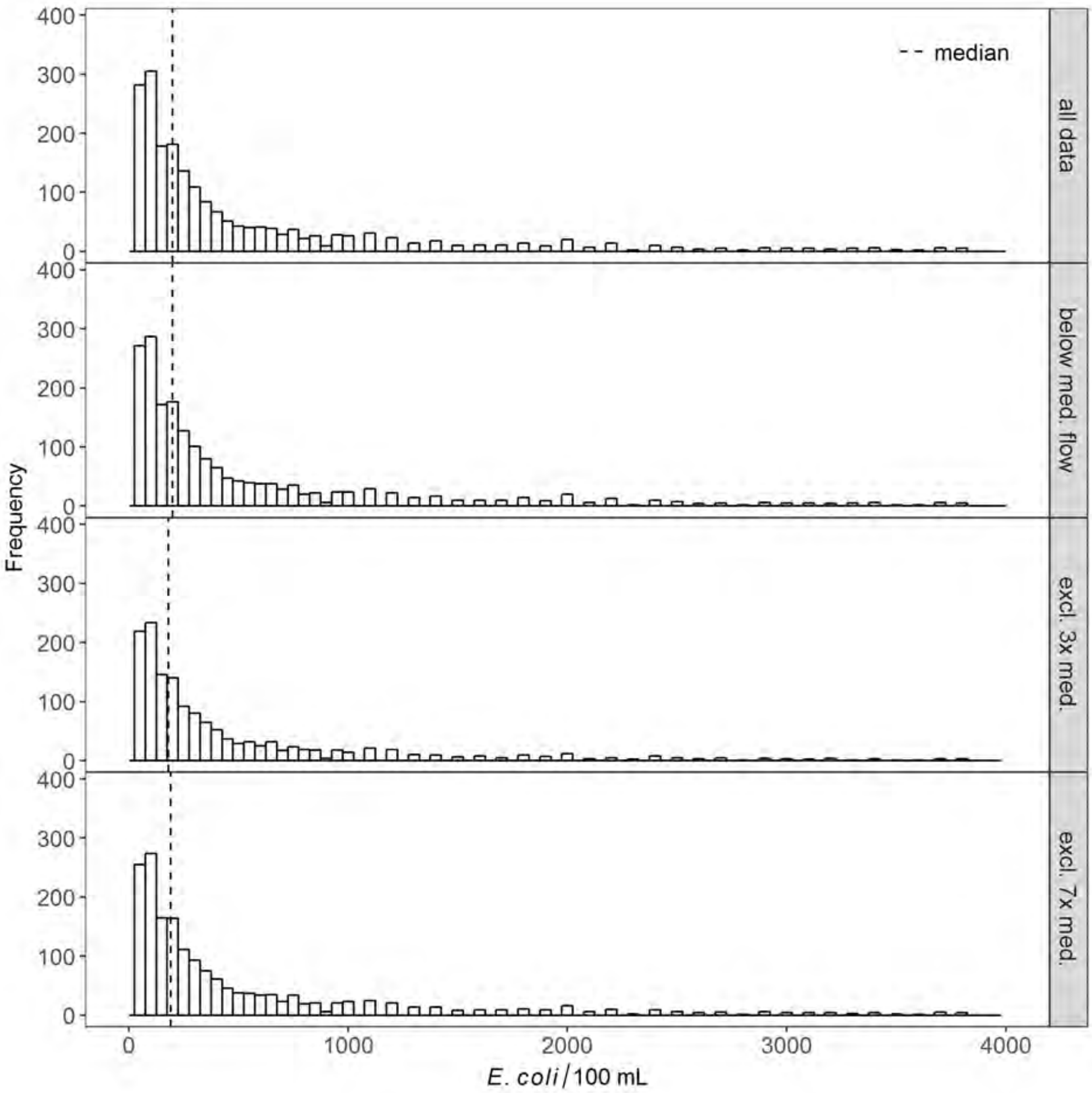

Figure 3-12: Distributions of *E. coli* concentrations per 100 mL for all Taranaki Region monitoring sites under various flow conditions between 1995 and 2017. The dashed lines indicate the median concentration for each dataset. Note that this plot excludes the 4% of data (outliers) which exceeded 4000 *E. coli*/100 mL.

Table 3-6: Swimmability for each monitoring site using the full data record (1995-2017) relative to the NPS-FM criteria. Median grades are listed as "A, B, C" because the median criteria is the same for the top three attribute states. Likewise, 95th percentile grades are listed as "D, E" because those two attribute states have the same 95th percentile criteria. In these situations when grades are equivalent, the attribute is considered to be in the highest grade, therefore a site with Median grade "A, B, C" can be considered grade "A" and a site with 95th Percentile grade "D, E" can be considered grade "D."

Site	n	Median value	95th percentile	% > 540/100 mL	% > 260/100 mL	Median grade	95th Percentile grade	% > 540/100 mL grade	% > 260/100 mL grade	Overall lowest grade
All	2547	200	3400	26.2	41.7	D-Orange	D, E	D-Orange	D-Orange	D-Orange
MGH000950	242	220	3300	28.5	45.0	D-Orange	D, E	D-Orange	D-Orange	D-Orange
MKW000300	168	325	4620	30.4	62.5	E-Red	D, E	E-Red	E-Red	E-Red
MRK000420	216	785	12000	71.8	91.7	E-Red	D, E	E-Red	E-Red	E-Red
PAT000200	242	21	573	5.4	7.9	A, B, C	B-Green	B-Green	A-Blue	B-Green
PAT000360	242	200	6095	25.2	42.2	D-Orange	D, E	D-Orange	D-Orange	D-Orange
PNH000200	242	100	1095	15.3	25.6	A, B, C	C-Yellow	C-Yellow	B-Green	C-Yellow
PNH000900	240	500	3200	47.1	76.7	E-Red	D, E	E-Red	E-Red	E-Red
STY000300	242	8	100	2.1	2.9	A, B, C	A-Blue	A-Blue	A-Blue	A-Blue
WGG000500	242	180	3290	19.4	36.0	D-Orange	D, E	C-Yellow	D-Orange	D-Orange
WGG000900	229	220	2060	23.1	41.1	D-Orange	D, E	D-Orange	D-Orange	D-Orange
WKH000500	242	210	3685	25.6	29.3	D-Orange	D, E	D-Orange	D-Orange	D-Orange

Table 3-7: Percentage of Taranaki *E. coli* monitoring sites which meet New Zealand NPS-FM and US and European criteria under various flow scenarios. Flow scenarios included all data, data only from days with mean daily flow at or below annual median flow, and data from at or below annual median and excluding samples taken within 3 days of a 3 times median or 7 times median flow. The percentages given for the US EPA and EU criteria are not inclusive, i.e. the percent which meets G2 criteria does not include those which also meet G1, and percentage of sites which meet the "good" criteria does not include those that also meet the "excellent" criteria. The 'Total' row gives the summed percentage of sites deemed swimmable under each set of criteria.

Approach	% swimmable All data	% swimmable Flow ≤ Median	% swimmable Flow ≤ Median Excluding 3 days post 3x median flow	% swimmable Flow ≤ Median Excluding 3 days post 7x median flow
NPS 2017 (A-C)				
Median	27%	27%	27%	27%
95th percentile	27%	73%	73%	73%
% >540/100 mL	36%	81%	81%	81%
% >260/100 mL	27%	73%	73%	73%
Total (lowest grade)	27%	27%	27%	27%
MfE/MoH 2003				
Grade (A-B)	9%	9%	9%	9%
US EPA				
Mean (Grade 1)	18%	18%	18%	18%
Mean (Grade 2)	9%	0%	9%	0%
Total Mean	27%	18%	27%	18%
90th percentile (G1)	18%	18%	18%	18%
90th percentile (G2)	0%	0%	0%	0%
Total 90th percentile	18%	18%	18%	18%
EU				
Excellent	9%	18%	18%	18%
Good	9%	27%	27%	27%
Sufficient	9%	36%	36%	36%
Total	27%	81%	81%	81%

Table 3-8: Percentage of Taranaki *E. coli* monitoring sites which meet New Zealand NPS-FM and overseas swimmability criteria based on the previous 5 years of monitoring data, as per the sampling procedure described in the NPS-FM. Note that both the US EPA categories and all three EU categories are deemed "swimmable." The percentages given for the US EPA and EU criteria are not inclusive, i.e. the percent which meets G2 criteria does not include those which also meet G1, and percentage of sites which meet the "good" criteria does not include those that also meet the "excellent" criteria.

Year	no. sites	NPS lowest grade	NPS median	NPS 95th percentile	NPS <20% exceed 540/100 mL	NPS <34% exceed 260/100 mL	MfE/MoH 2003 grade	US EPA Mean G1	US EPA Mean G2	US EPA 90th Percentile G1	US EPA 90th Percentile G2	EU excellent	EU good	EU sufficient
2000	10	30	30	30	40	40	10	20	0	20	0	10	20	0
2001	10	20	20	20	20	30	10	20	0	20	0	10	0	20
2002	10	20	20	20	20	30	10	20	0	10	10	10	0	10
2003	11	18	27	18	27	27	9	18	0	18	0	9	0	18
2004	11	18	27	18	36	45	9	18	0	18	0	9	0	27
2005	11	27	27	27	55	45	9	18	9	18	0	9	0	27
2006	11	27	27	18	45	45	9	18	0	18	0	9	0	18
2007	11	27	27	9	64	36	9	18	9	18	0	9	0	18
2008	11	27	27	27	64	36	9	18	9	18	0	9	18	0
2009	11	27	27	27	55	36	9	18	9	18	0	9	9	9
2010	11	27	27	27	45	36	9	18	9	18	0	9	9	9
2011	11	27	27	27	36	36	9	18	9	18	0	9	9	9
2012	11	27	27	27	36	36	9	27	0	18	0	18	9	0
2013	11	27	27	27	36	45	18	27	0	18	0	18	9	0
2014	11	27	27	27	36	36	9	27	0	18	0	18	9	0
2015	11	27	27	27	36	36	9	27	0	18	0	18	9	0
2016	11	27	27	27	36	27	9	27	0	18	0	18	9	0
2017	11	27	27	27	27	27	9	27	0	18	0	18	9	0

3.2.2 Relationship with restoration

As described in section 2.5, two sets of models were run, one with the three different restoration indices as fixed effects and one with the restoration indices as random slope terms. Flow was also added as a covariate (fixed effect) to account for the effect of flow on *E. coli* concentrations, which has been found to be a positive relationship (i.e., increased flow associated with increased *E. coli*) (Larned, Snelder et al. 2015). Model fit was assessed by comparing the model predictions to observed data, and the three models compared by DIC (Deviance Information Criterion, a relative measure of fit, or deviance, penalised by the number of parameters; the smaller the DIC the better the relative fit. Spiegelhalter, Best et al. 2002).

All three models estimated an overall positive relationship between *E. coli* concentrations and flow and an overall negative relationship *between E. coli* and restoration, indicated by the positive parameter coefficient for flow and the negative parameter coefficient for restoration, and 95% credible intervals that did not include zero (Table 3-9). The model with restoration index one, the unweighted proportion of upstream length fenced and/or planted, had the lowest DIC score out of the three fixed effect models. However, the range in DIC values was small, indicating that model fit was similar for the three indices.

The index one model predicts, on average, that for every unit increase in restoration (i.e. from 0 to 100% planted) when flow is held constant might decrease *E. coli* concentrations by 1130 *E. coli*/100 mL, or approximately 75% (Figure 3-13). However, it should again be noted that the largest increase in restoration index over the Riparian Management Programme was only 0.34, which the model predicts would decrease *E. coli* concentration by approximately 30% (Figure 3-13). Additionally, as mentioned, these estimates do not include flow effects on *E. coli* concentrations.

Figure 3-14 shows the random seasonal effect, which indicates that on average *E. coli* concentrations were lower in winter and higher in summer compared to the baseline (i.e., expected value if there was no seasonal effect). It is important to note, however, that because flow is a covariate in the model, this represents the seasonal effects with flow already taken into account, whereas other studies have reported that *E. coli* concentrations increase in conjunction with higher rainfall and elevated flows over winter (Larned, Snelder et al. 2015).

The site-specific random effects (intercepts) are shown in Figure 3-15. Three sites (MRK000420, PAT000360, and WKH000500) had positive coefficients, indicating that *E. coli* concentrations at these sites were higher than the baseline (i.e., expected value if there were no differences between sites). However, site MRK000420, which had the largest positive coefficient, has also undergone a simultaneous large increase in land use activity, namely new poultry farms and a deterioration in stock control, as well as restoration, resulting in an overall increase in pollution loads on the catchment (Gary Bedford, personal communication). Another three sites (MGH000950, PAT000200, and PNH000200) had negative coefficients, indicating that *E. coli* concentrations at these sites were lower than the baseline. The credible intervals for the remaining five sites crossed zero, indicating that *E. coli* concentrations were similar. The model predictions from the restoration as a fixed effect models plotted against the observed data are shown in Figure 3-16; all three models gave similar predictions of *E. coli* concentration.

The model with restoration index one, the simple proportion of upstream length fenced/planted, also had the lowest DIC with restoration as a random slope term. All three models also estimated a positive relationship between *E. coli* concentrations and flow (Table 3-9). Similar seasonal random effects were observed as in the restoration as fixed effect models; *E. coli* concentrations were lower in winter and higher in summer (Figure 3-14). Ten of the eleven sites had negative posterior means for the site-specific intercept, or slope, of restoration (Figure 3-18, Table 3-10), indicating that there was a negative relationship between restoration and *E. coli* at those sites (i.e., as restoration index increased, *E. coli* concentrations declined). The eleventh site, MRK000420 had a positive relationship between restoration and *E. coli*. The model predictions from the random slope models plotted against the observed data are shown in Figure 3-19; again, all three models gave similar predictions.

Table 3-9: Model parameter coefficients, standard errors, 95% credible intervals, and DIC scores for *E. coli* models with each restoration index. Note that coefficients (means) are on the scale of the linear predictor (log scale).

Model	Restoration index	Parameter	Mean	Standard error of the mean	2.5% quantile	97.5% quantile	DIC[a]
Restoration fixed effect	Index 1	Intercept	7.2935	0.3443	6.6520	7.9357	**4718818**
		Flow	0.0335	0.0000	0.0334	0.0336	
		Restoration	-1.3732	0.0128	-1.3983	-1.3480	
	Index 2	Intercept	8.1143	0.3681	7.4190	8.8097	4719888
		Flow	0.0335	0.0000	0.0335	0.0336	
		Restoration	-2.7619	0.0271	-2.8150	-2.7088	
	Index 3	Intercept	9.0279	0.5593	7.9323	10.1254	4723190
		Flow	0.0335	0.0000	0.0335	0.0336	
		Restoration	-6.6144	0.0795	-6.7705	-6.4585	
Restoration random slope	Index 1	Intercept	7.7703	0.2444	7.3160	8.2251	**4718629**
		Flow	0.0333	0.0000	0.0332	0.0333	
	Index 2	Intercept	8.2396	0.2476	7.7814	8.6976	4720486
		Flow	0.0334	0.0000	0.0333	0.0335	
	Index 3	Intercept	7.7265	0.2465	7.2683	8.1853	4728147
		Flow	0.0333	0.0000	0.0333	0.0334	

[a] DIC = Deviance Information Criterion, a relative measure of fit, or deviance, penalized by the number of parameters; the smaller the DIC the better the relative fit (Spiegelhalter, Best et al. 2002)

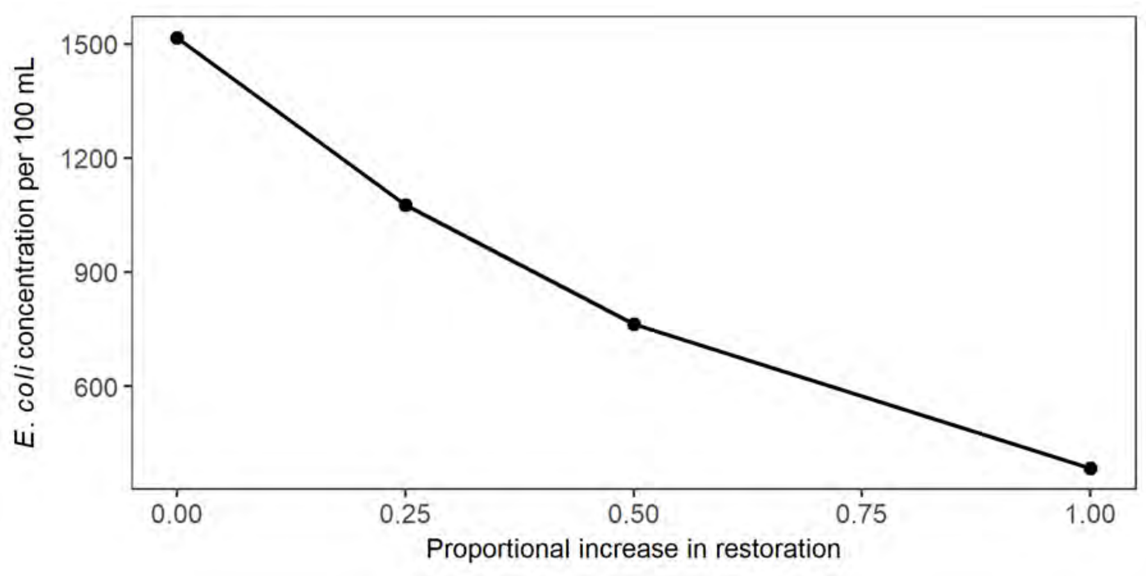

Figure 3-13: Predicted decreases in *E. coli* concentrations per 100 mL with increasing restoration index values from the restoration index 1 fixed effect model with flow held constant.

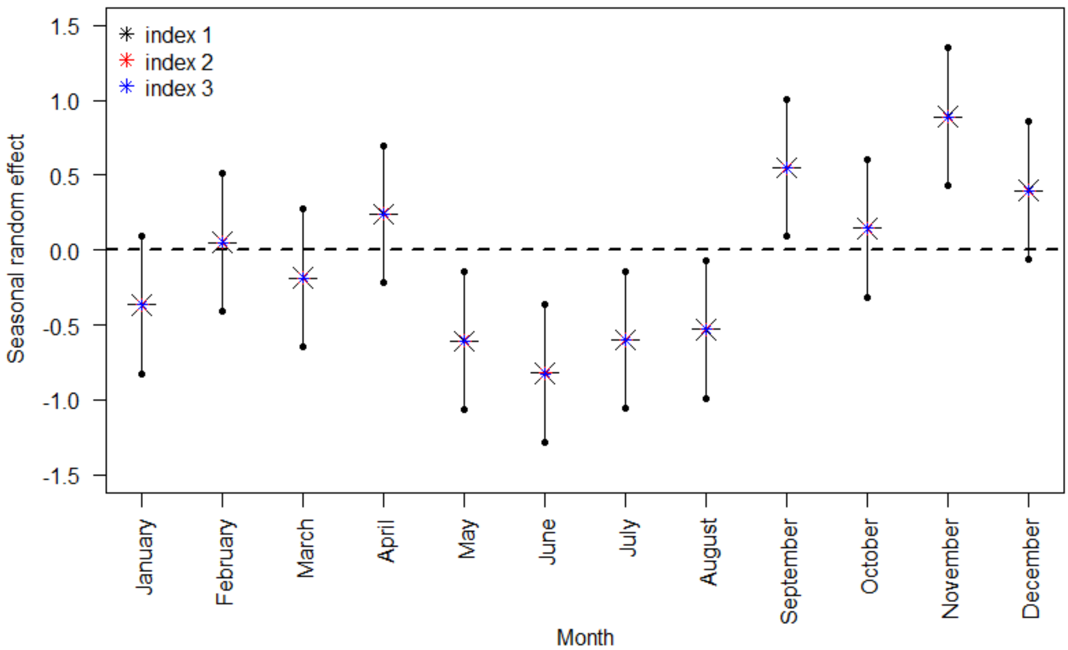

Figure 3-14: Posterior estimates and credible intervals for the seasonal (i.e., monthly) random effect in the restoration as a fixed effect models. The coefficients and credible intervals for restoration index 1, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively. The symbols for the three indices are superimposed when the coefficient values are very similar for each model.

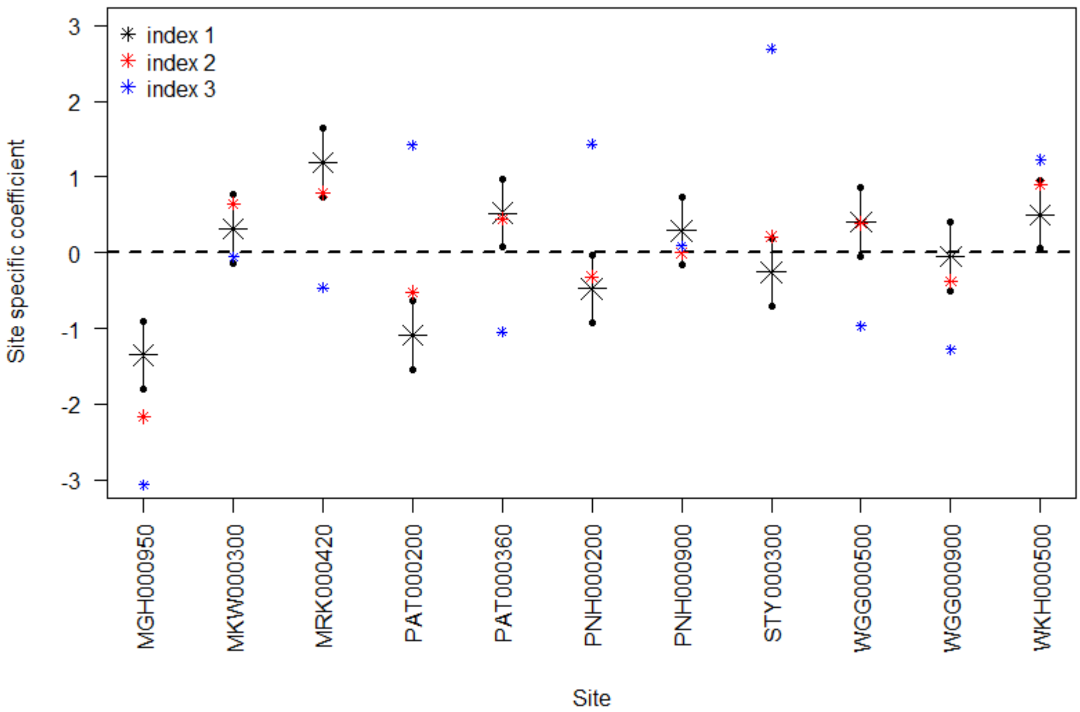

Figure 3-15: Site specific intercepts and credible intervals for *E. coli* models with restoration as a fixed effect. The coefficients and credible intervals for restoration index 1, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively.

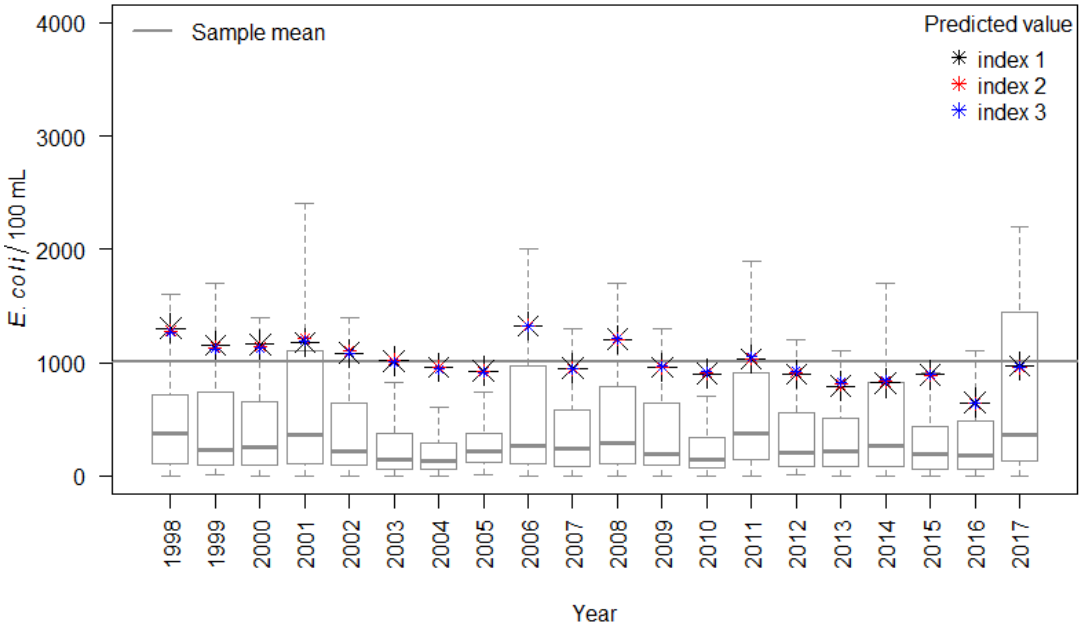

Figure 3-16: Predicted *E. coli* concentrations from the fitted fixed effect restoration models compared to observed values. Note that this plot does not show outliers, but the mean value (grey line) indicates their influence. The observed data is shown by the grey boxplots. The predicted values for the restoration index 1 model (the best-fitting model) are shown largest and in black, the predicted values from models with restoration indices 2 and 3 are shown in red and blue, respectively.

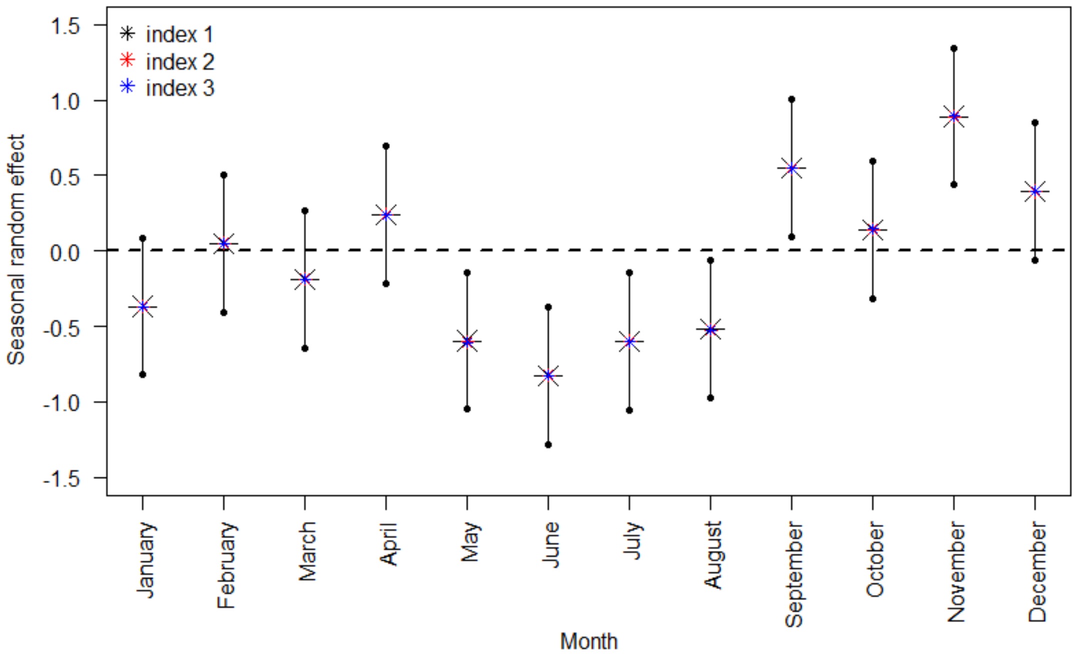

Figure 3-17: Posterior estimates and credible intervals for the seasonal (i.e. monthly) random effect in the restoration as a random slope models. The coefficients and credible intervals for restoration index 1, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively.

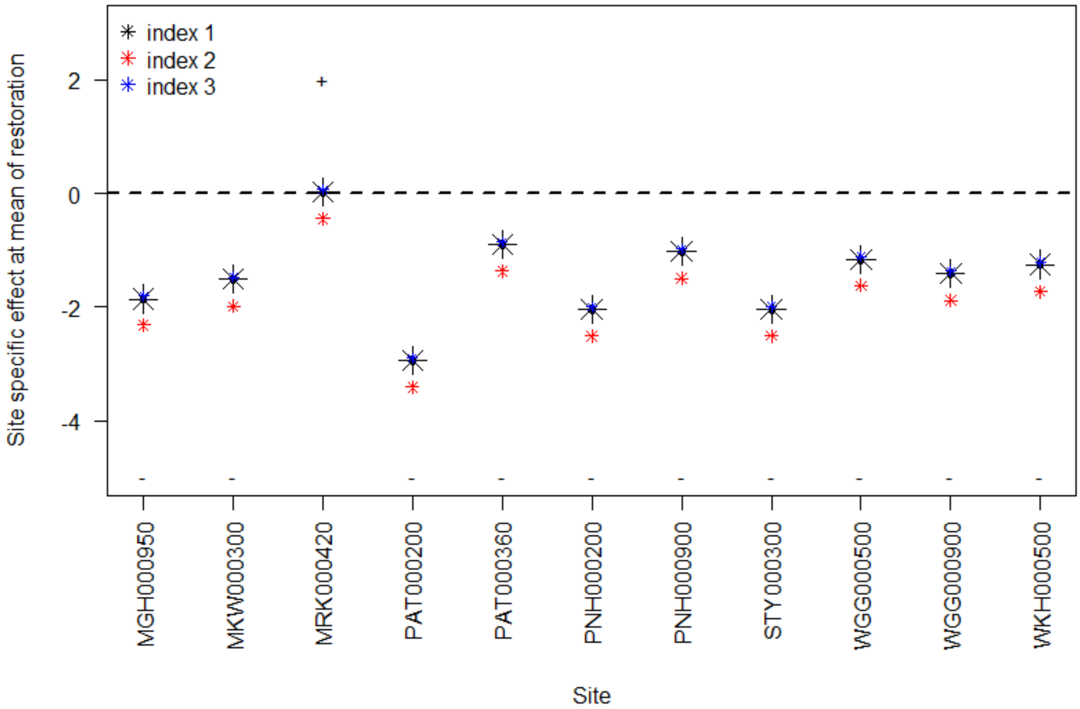

Figure 3-18: Site specific restoration coefficients (slopes) for the three restoration index models, evaluated at the mean of the restoration index at that site. A negative posterior mean with credible intervals that do not include zero indicates a negative relationship between restoration and *E. coli* concentration at that site, a positive posterior mean with credible intervals that do not include zero indicate a positive relationship between restoration and *E. coli* concentration at that site. The coefficients for restoration index 1, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively. The credible intervals for index 1 are too small to be visible on the plot.

Table 3-10: Posterior estimates for restoration index coefficients for the restoration index 1 random slope model. A negative posterior mean with credible intervals that do not include zero indicates a negative relationship between restoration and *E. coli* concentration at that site. A positive posterior mean with credible intervals that do not include zero indicates a positive relationship between restoration and *E. coli* concentration. It is important to note that the coefficients and quantiles are at the scale of the linear predictor (i.e., log scale), therefore a large negative value represents a smaller effect than a small negative value.

Site	Mean restoration coefficient (slope)	2.5% quantile	95.5% quantile
MGH000950	-1.8568	-1.8720	-1.8415
MKW000300	-1.5090	-1.5240	-1.4940
MRK000420	0.0250	0.0107	0.0392
PAT000200	-2.9382	-2.9557	-2.9208
PAT000360	-0.8965	-0.9112	-0.8819
PNH000200	-2.0406	-2.0564	-2.0249
PNH000900	-1.0243	-1.0390	-1.0096
STY000300	-2.0312	-2.0510	-2.0114
WGG000500	-1.1636	-1.1786	-1.1487
WGG000900	-1.4038	-1.4189	-1.3888
WKH000500	-1.2513	-1.2660	-1.2366

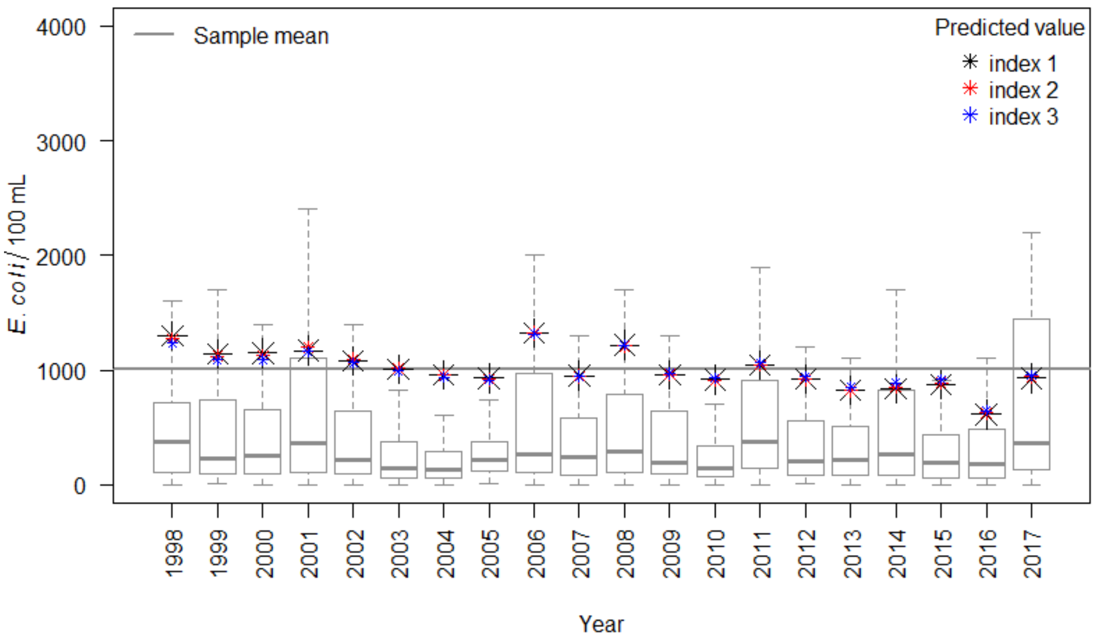

Figure 3-19: Predicted *E. coli* concentrations from the fitted random slope restoration models compared to observed values. Note that this plot does not show outliers, but the mean value (grey line) indicates their influence. The observed data is shown by the grey boxplots. The predicted values for the restoration index 1 model (the best-fitting model) are shown largest and in black, the predicted values from models with restoration indices 2 and 3 are shown in red and blue, respectively.

4 Discussion

From the multiple regression modelling results we can infer that the Taranaki's Riparian Management Program has had beneficial effects on stream ecosystem health and water quality for human health and recreation in the region. The modelling analysis found positive relationships between macroinvertebrate metric scores and restoration, and negative relationships between *E. coli* concentrations and restoration. However, note that that all statistical models are simplifications of actual processes, and do not attribute causation. In analyses like these we cannot rule out the possibility that the observed relationships have been influenced by other parameters not measured or included in the models. Moreover, there was considerable variability between sites, and for many sites it was not possible to infer any relationship between restoration and a given response variable.

Models with restoration index 1, the simple proportion of upstream bank length that has been fenced and/or planted, often had the lowest DIC scores, indicating better relative fit than models with restoration indices 2 and 3. Nonetheless, all three models had similar DIC scores and gave very similar predicted values for both invertebrate metrics and *E. coli*. From a practical perspective, this indicates that future analysis and/or prediction of ecological responses to restoration can use the simpler and easier index 1 approach without loss of accuracy. From an ecological perspective, this could indicate that the quantity (in this case, length) of restoration is a more important factor than the type or age of vegetation. The Taranaki dataset provides an ideal opportunity to continue exploring important questions on relative benefits of different restoration methods.

4.1 Invertebrates

Twelve out of the fourteen invertebrate metrics including in the modelling analysis were found to have a detectable relationship with restoration at the region-wide scale (restoration as a fixed effect across all sites). This is in itself an impressive result; the majority of post-restoration monitoring studies have reported a disappointing lack of detectable improvement in biodiversity (Parkyn, Davies-Colley et al. 2003; Palmer, Menninger et al. 2010; Louhi, Mykrä et al. 2011; Leps, Sundermann et al. 2016; Lorenz, Armin W., Haase et al. 2018). However, most riparian restoration projects focus on individual reaches, even though degradation typically occurs at the catchment-scale (Bernhardt and Palmer 2011; Lorenz, Armin and Feld 2013; Giling, Mac Nally et al. 2016). While it has been shown that upstream land use and riparian cover within a catchment can have stronger negative influences on downstream water quality and biota than immediately adjacent conditions (Dodds and Oakes 2008; Lorenz, Armin and Feld 2013; Giling, Mac Nally et al. 2016), there have been few opportunities to test the converse, i.e., whether upstream restoration can benefit downstream communities (but see Kail and Hering 2009, who showed that near-natural reaches upstream have a positive effect on downstream reaches). The Taranaki Regional Council Riparian Management data has provided a unique look at the cumulative influence of upstream restoration on downstream macroinvertebrate communities, in one of the first analyses of riparian restoration at the landscape scale.

MCI and SQMCI scores, EPT richness, percent EPT, and forest species richness and abundance all had positive relationships with restoration, indicating that presence and relative abundances of sensitive taxa and forest specialist taxa increased with restoration. Correspondingly, the relationship between restoration and dissimilarity to time zero, a measure of compositional change, was also positive, indicating that community composition has shifted away from the initial condition.

Which restoration index model had the best fit/lowest DIC score varied between metrics, suggesting that while upstream length fenced/planted may be sufficient to predict some invertebrate responses (namely MCI and SQMCI scores and EPT richness and percent EPT), other characteristics of invertebrate communities, particularly the richness and abundance of forest species, may be more dependent on type and age of restoration, or the amount of shading provided.

It was somewhat surprising that indices two and three, which both incorporated an age component, did not consistently outperform the simpler index 1. This may be because trying to include age added too much additional 'noise' into the analysis. Alternatively, it could indicate that age of restoration is not as important as previously thought in comparison to the effect of initial fencing/planting, which is captured in restoration index 1. It is generally expected that there will be a time lag between completion of restoration measures and ecological recovery, due to natural successional processes and/or hysteresis (Leps, Sundermann et al. 2016). For example, Parkyn, Davies-Colley et al. (2003) predicted the full effects of restoration would not be realized until vegetation had grown sufficiently to create a closed canopy. Conversely, a study of 44 river restoration projects in Germany found that restoration age was a poor predictor of community compositional change (Leps, Sundermann et al. 2016). Similarly, we found that incorporating age or predicted shading effects into the restoration index did not appear to improve the fit of the models to the observed invertebrate data. We are unable to tease apart temporal effects such as the effect of maturing vegetation versus the time lag involved in invertebrate recolonization in this study. Nevertheless, our results raise interesting questions about timescales of recovery, and highlight that additional analyses focused specifically on timing and rates of recovery in relation to upstream restoration would be worthwhile.

Again, note that observed relationships are correlational, not causal. We cannot rule out the possibility that restoration and invertebrates are both increasing due to unmeasured parameters. Furthermore, it is also important to note that the between site variability was also quite high, and it was not possible to infer a directional relationship for more than half the sites for any given metric. As mentioned above, this is not unusual in restoration studies, particularly those conducted at the reach scale. Nevertheless, our analysis suggests that the regional restoration approach fostered by the Taranaki Riparian Management Programme has succeeded in assuaging several of the commonly-blamed causes for lack of restoration effects on stream macroinvertebrates. The first of these, as mentioned above, is the mismatch between scales of restoration and degradation. The second is dispersal constraints leading to low recolonization. However, the Taranaki Ring Plain is an exceptional setting for a stream restoration programme in that restoration sites are potentially accessible from a prime source of diverse recolonists in Egmont (Taranaki) National Park. In addition, the Riparian Management Programme has resulted in establishment of many small sections of restored riparian vegetation scattered across the Ring Plain. These revegetated sections are suitable habitat for many species of flying adult invertebrates (Collier and Smith 1998; Petersen, Winterbottom et al. 1999; Petersen, Masters et al. 2004), and may serve as "stepping stones" connecting restored reaches to each other and to the National Park. Therefore, the combination of its unique landscape and landscape-level riparian management program has made Taranaki an ideal experiment for investigating the relationships between riparian restoration and stream ecological and recreational values. It is a rare situation internationally, and the results after the first 20 years are noteworthy.

4.2 *E. coli*

Although the modelling indicated that there has been a negative relationship between increasing restoration and *E. coli* concentrations at ten of the eleven monitoring sites, any changes in concentrations have not yet been large enough to result in an improvement in swimmability; the percentage of sites meeting current NPS swimmability criteria has remained low (27%) since 2000.

The percentage of swimmable Taranaki sites is lower than the national average; a recent analysis of 792 NRWQN and Regional Council monitoring sites found that 49% of sites nationwide met the median criteria ($\leq$130 *E. coli*/100 mL) and 31% of sites met the 95th percentile criteria (<540 *E. coli*/100 mL) (McBride and Soller 2017). However, the distribution of *E. coli* concentrations in Taranaki is very similar to the distribution observed from the national dataset (Figure 4-1). It is possible that the lower than average "pass rate" observed for Taranaki sites may be because the national dataset includes rivers and streams from a variety of land uses and catchment sizes, whereas the Taranaki data primarily comes from sites with pastoral land upstream.

The three different restoration index models generally gave very similar predicted values, which shows that weighting by age or restoration type may not be necessary to predict *E. coli* responses to restoration. In fact, the first restoration index, the unweighted proportion of upstream bank length fenced and/or planted, had the lowest DIC score for both restoration as a fixed effect and restoration as a random slope models. Ten of the eleven sites had negative site-specific relationships, further supporting the overall inference that upstream restoration is a possible strategy for managing downstream *E. coli* levels. The one site which showed a positive relationship between restoration and *E. coli* concentration, MRK000420, is located in a catchment with increasing land use activity likely to increase *E. coli* inputs (i.e. poultry farming), which may be obscuring or confounding any effects of riparian restoration.

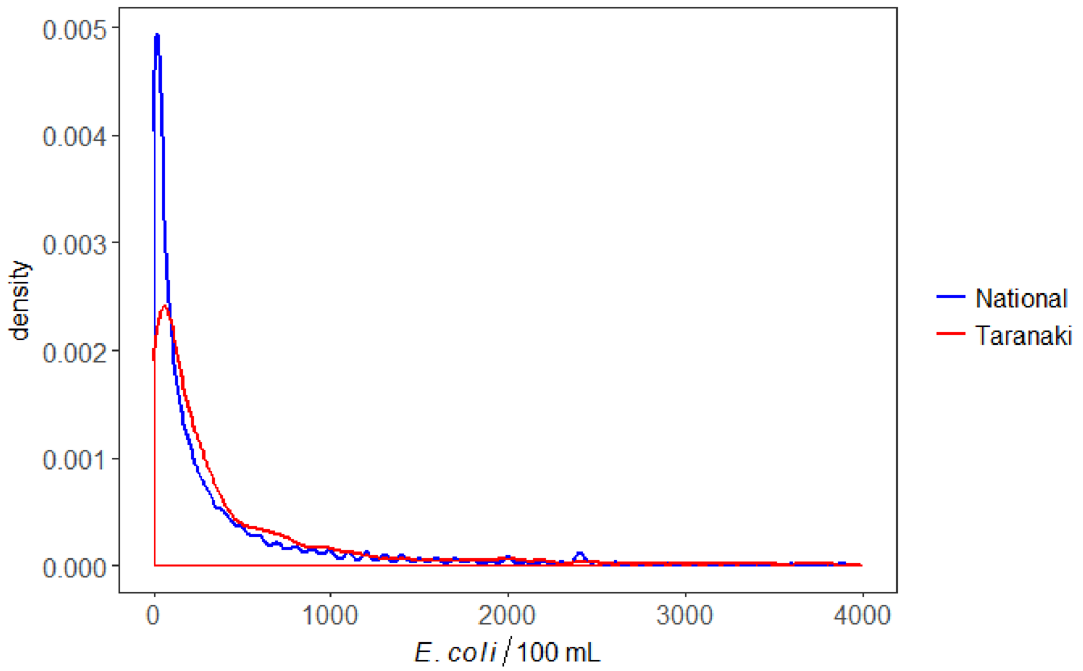

Figure 4-1: Distributions of Taranaki (red) and nation-wide (blue) *E. coli* concentrations. The national data comes from 792 NRWQN and Regional Council monitoring sites analysed in McBride and Soller (2017).

4.3 Conclusions

The results of our analysis indicate that the landscape-scale riparian restoration undertaken in the Taranaki region as part of the Riparian Management Programme has had a beneficial effect on water quality and downstream aquatic invertebrate communities, including improved invertebrate community composition and decreased *E. coli* concentrations.

5 Acknowledgements

Thank you to Katie Blakemore, Fiona Jansma, and Chris Lambert at Taranaki Regional Council for provision of relevant data. Thank you to Kathy Walter from NIWA for processing the flow data files.

6 Glossary of abbreviations and acronyms

DEM	Digital elevation model; a 3D representation of a terrain's surface created from elevation data.
DIC	Deviance Information Criterion; a calculation of fit, or deviance, penalized by the number of parameters. The smaller the DIC, the better the fit.
DIFN	Diffuse non-interceptance; a measure of available light.
E. coli	*Escherichia coli*, a bacteria commonly associated with faecal material and used as a human health indicator.
EPT	Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies); sensitive indicator taxa.
GIS	Geographic Information System; a system for capturing, storing, manipulating, managing, analysing, and presenting spatial or geographic data.
INLA	Integrated Nested Laplace Approximation; a computationally efficient method for fitting Bayesian models.
MCI	Macroinvertebrate Community Index; a measure of an invertebrate community's sensitivity to organic pollution.
NPS-FM	National Policy Statement for Freshwater Management.
REC	River Environment Classification; a database of catchment spatial attributes and river network descriptions for every segment of New Zealand rivers.
RMP	Riparian Management Programme.
SEM	State of the Environment monitoring; conducted by Regional Councils.
SQMCI	Semi-quantitative version of the MCI.
TRC	Taranaki Regional Council.

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Appendix A Flow estimate comparison for *E. coli* model

As noted in the Methods section, we had to use estimated flow measures for some sites, resulting in uncertainty not being propagated through the model correctly. In order to ensure that the positive *E. coli*-flow relationship held without this added noise, the models were run for the subset of sites where flow measurements were taken at the same location. A positive *E. coli*-flow relationship was still found, although the model with index 2 now has the lowest DIC. However, this change could be due either to the improvement in uncertainty or due a loss of information from excluding restoration data from 5 out of 11 sites.

Table A-1: Model parameter coefficients, standard errors, 95% credible intervals, and DIC scores for *E. coli* models using only data from sites with paired flow data. Note that coefficients (means) are on the scale of the linear predictor (log scale).

Model	Restoration index	Parameter	Mean	Standard error of the mean	2.5% quantile	97.5% quantile	DIC[a]
Restoration fixed effect	Index 1	Intercept	7.4392	0.4513	6.5641	8.3153	3634990
		Flow	0.0329	0.0000	0.0328	0.0330	
		Restoration	-1.2901	0.0146	-1.3188	-1.2615	
	Index 2	Intercept	8.2042	0.5801	7.0605	9.3479	**3634105**
		Flow	0.0330	0.0000	0.0329	0.0331	
		Restoration	-2.9608	0.0318	-3.0233	-2.8984	
	Index 3	Intercept	8.3403	0.7237	6.8999	9.7800	3636892
		Flow	0.0330	0.0000	0.0329	0.0331	
		Restoration	-7.8029	0.1032	-8.0056	-7.6004	

[a] DIC = Deviance Information Criterion, a relative measure of fit, or deviance, penalized by the number of parameters; the smaller the DIC the better the relative fit (Spiegelhalter, Best et al. 2002)

Appendix B *E. coli* modelling using 2 km DEM streams

As described in the Methods section, some of the restoration data provided by Taranaki Regional Council was along farm drains or other streams too small to be included in the REC national stream network data layer. We tested two different methods to resolve this issue: 1) only including restoration that matched up to an REC stream segment (the results presented in the main text of this report) and 2) creating our own stream network using the finest-scale digital elevation map (DEM) available, which had 2 km resolution. Because the 2 km DEM still did not include some of the drains and small streams included in the council dataset, we choose to use the restoration indices calculated using restoration along REC stream segments only for the modelling presented in the main body of the report. However, to confirm those results, we also conducted the modelling analysis using the restoration indices calculated using our 2 km DEM stream network. The resulting restoration indices were highly correlated (Figure B-1) and overall results and general conclusions of the *E. coli* modelling analysis were the same for both methods; there was a negative relationship between restoration and *E. coli* concentrations across all sites. Model parameters and plots are presented below.

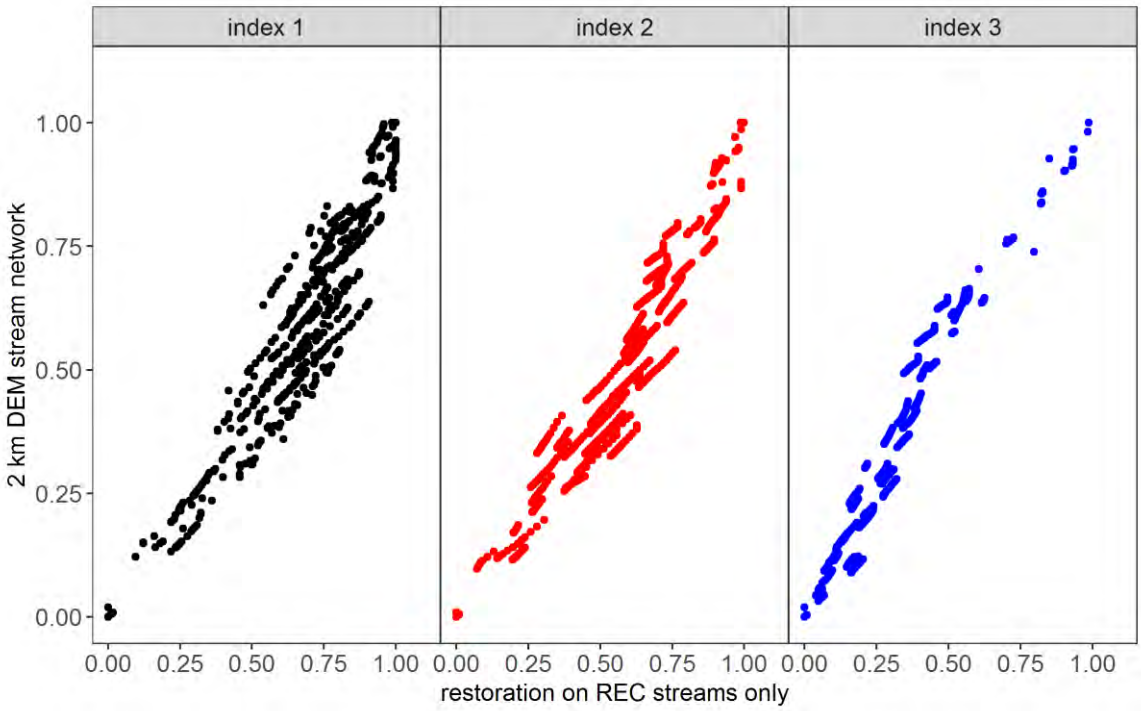

Figure B-1: Restoration index values calculated using only restoration along REC streams plotted against restoration index values calculated using a stream network derived from a 2 km resolution digital elevation map (DEM). The two sets of indices were highly correlated.

Table B-1: Model parameter coefficients, standard errors, 95% credible intervals, and DIC scores for *E. coli* models with each restoration index calculated using the 2 km DEM stream network. Note that coefficients (means) are on the scale of the linear predictor (log scale).

Model	Restoration index	Parameter	Mean	Standard error of the mean	2.5% quantile	97.5% quantile	DIC[a]
Restoration fixed effect	Index 1	Intercept	7.5571	0.3456	6.9129	8.2022	**4720851**
		Flow	0.0336	0.0000	0.0335	0.0337	
		Restoration	-1.8999	0.0195	-1.9381	-1.8617	
	Index 2	Intercept	8.8067	0.4357	7.9707	9.6436	4721008
		Flow	0.0336	0.0000	0.0336	0.0337	
		Restoration	-4.1568	0.0429	-4.2411	-4.0725	
	Index 3	Intercept	10.0362	0.7448	8.5659	11.5078	4723989
		Flow	0.0339	0.0000	0.0338	0.0340	
		Restoration	-8.3730	0.1050	-8.5791	-8.1672	
Restoration random slope	Index 1	Intercept	7.8647	0.2444	7.4104	8.3194	**4720765**
		Flow	0.0333	0.0000	0.0332	0.0334	
	Index 2	Intercept	8.5590	0.2454	8.1029	9.0158	4721579
		Flow	0.0335	0.0000	0.0334	0.0335	
	Index 3	Intercept	7.4566	0.2476	6.9966	7.9172	4730396
		Flow	0.0334	0.0000	0.0333	0.0335	

[a] DIC = Deviance Information Criterion, a relative measure of fit, or deviance, penalized by the number of parameters; the smaller the DIC the better the relative fit (Spiegelhalter, Best et al. 2002)

Table B-2: Model parameter coefficients, standard errors, 95% credible intervals, and DIC scores for *E. coli* 2 km DEM models using only data from sites with paired flow data. Note that coefficients (means) are on the scale of the linear predictor (log scale).

Model	Restoration index	Parameter	Mean	Standard error of the mean	2.5% quantile	97.5% quantile	DIC[a]
Restoration fixed effect	Index 1	Intercept	7.7252	0.5110	6.7269	8.7248	3634291
		Flow	0.0331	0.0000	0.0330	0.0332	
		Restoration	-2.0815	0.0225	-2.1257	-2.0373	
	Index 2	Intercept	8.8725	0.7731	7.3305	10.4138	**3633195**
		Flow	0.0332	0.0000	0.0331	0.0333	
		Restoration	-5.0229	0.0512	-5.1235	-4.9225	
	Index 3	Intercept	9.5016	1.1473	7.2006	11.8038	3634969
		Flow	0.0337	0.0000	0.0336	0.0338	
		Restoration	-11.9618	0.1357	-12.2283	-11.6956	

[a] DIC = Deviance Information Criterion, a relative measure of fit, or deviance, penalized by the number of parameters; the smaller the DIC the better the relative fit (Spiegelhalter, Best et al. 2002)

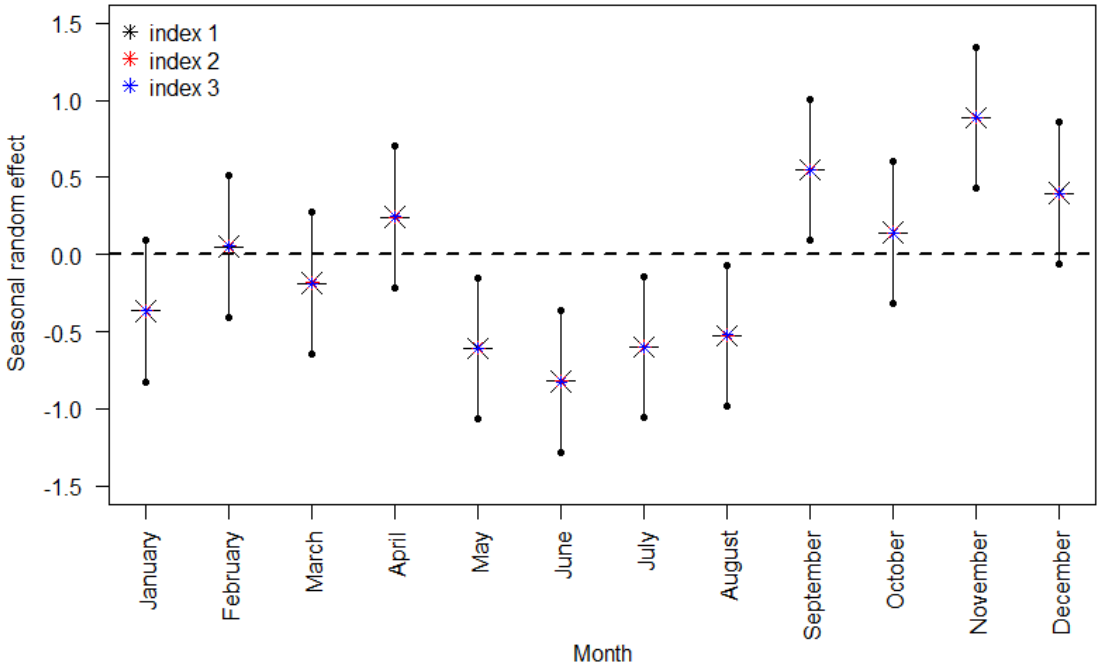

Figure B-2: Posterior estimates and credible intervals for the seasonal (i.e., monthly) random effect in the restoration as a fixed effect models. The coefficients and credible intervals for restoration index 3, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 1 and restoration index 3 models are shown in red and blue, respectively. The symbols for the three indices are superimposed when the coefficient values are very similar for each model.

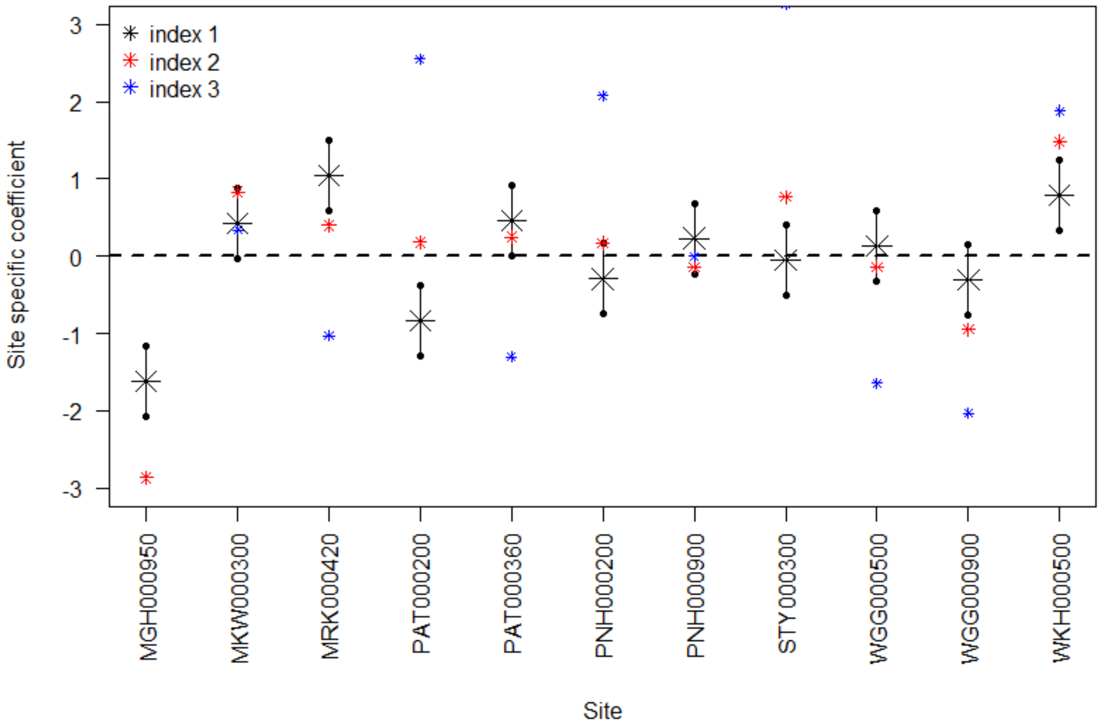

Figure B-3: Site specific intercepts and credible intervals for *E. coli* models with restoration as a fixed effect. The coefficients and credible intervals for restoration index 3, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 1 and restoration index 3 models are shown in red and blue, respectively.

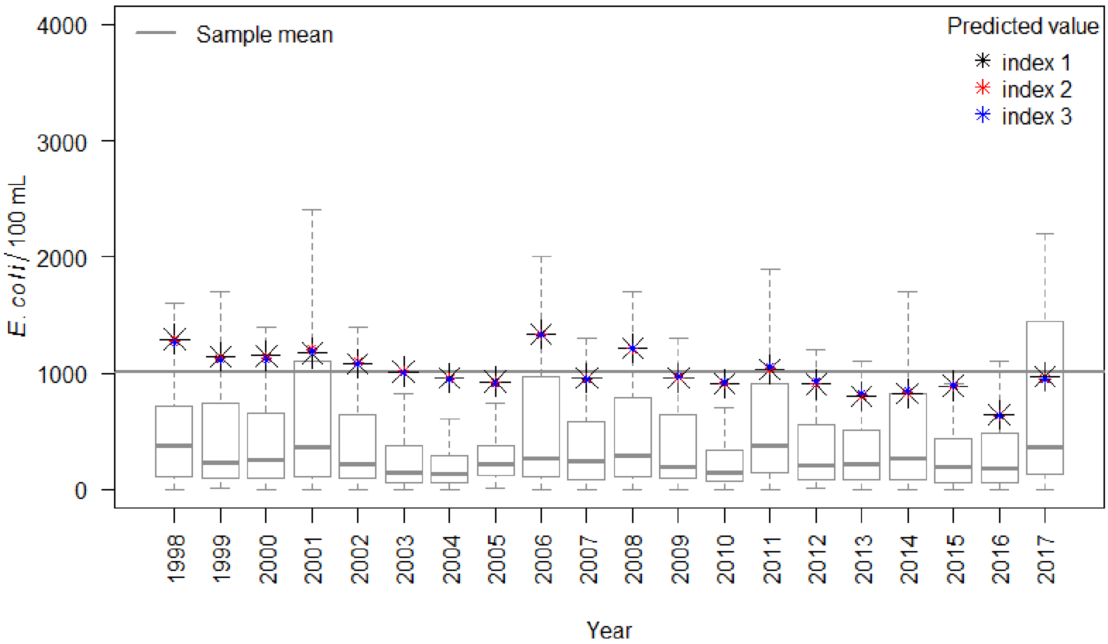

Figure B-4: Predicted *E. coli* concentrations from the fitted fixed effect restoration models compared to observed values. Note that this plot does not show outliers, but the mean value (grey line) indicates their influence. The observed data is shown by the grey boxplots. The predicted values for the restoration index 3 model (the best-fitting model) are shown largest and in black, the predicted values from models with restoration indices 1 and 3 are shown in red and blue, respectively.

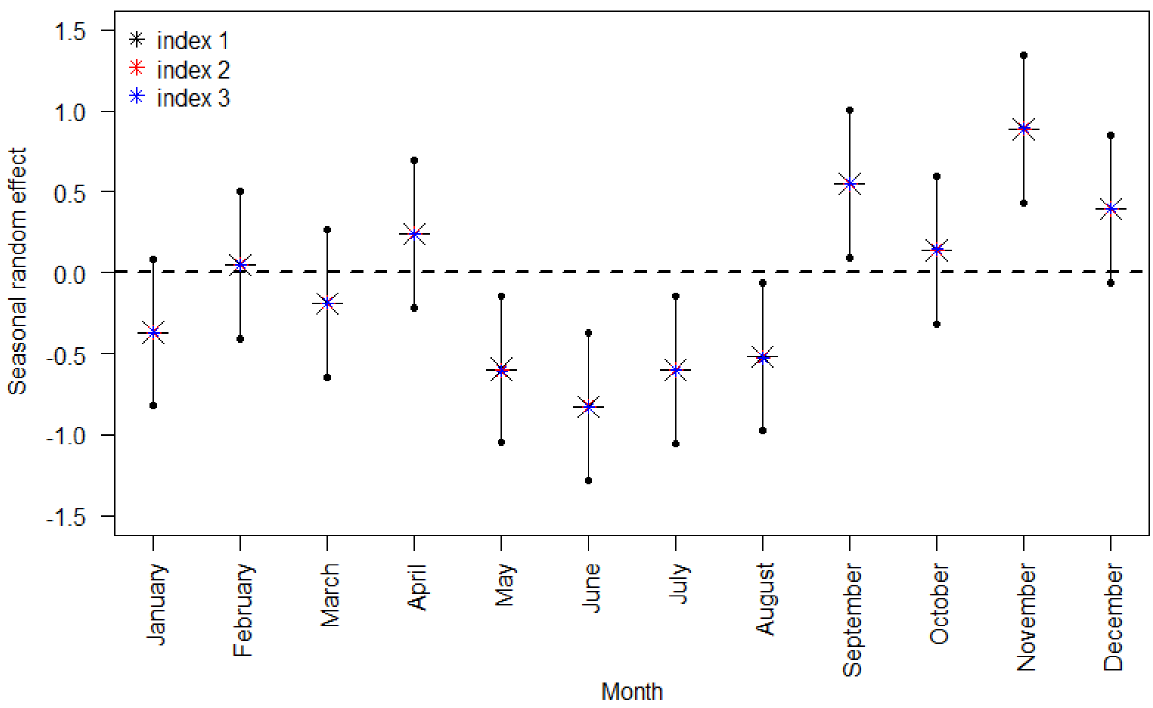

Figure B-5: Posterior estimates and credible intervals for the seasonal (i.e., monthly) random effect in the restoration as a random slope models. The coefficients and credible intervals for restoration index 1, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively.

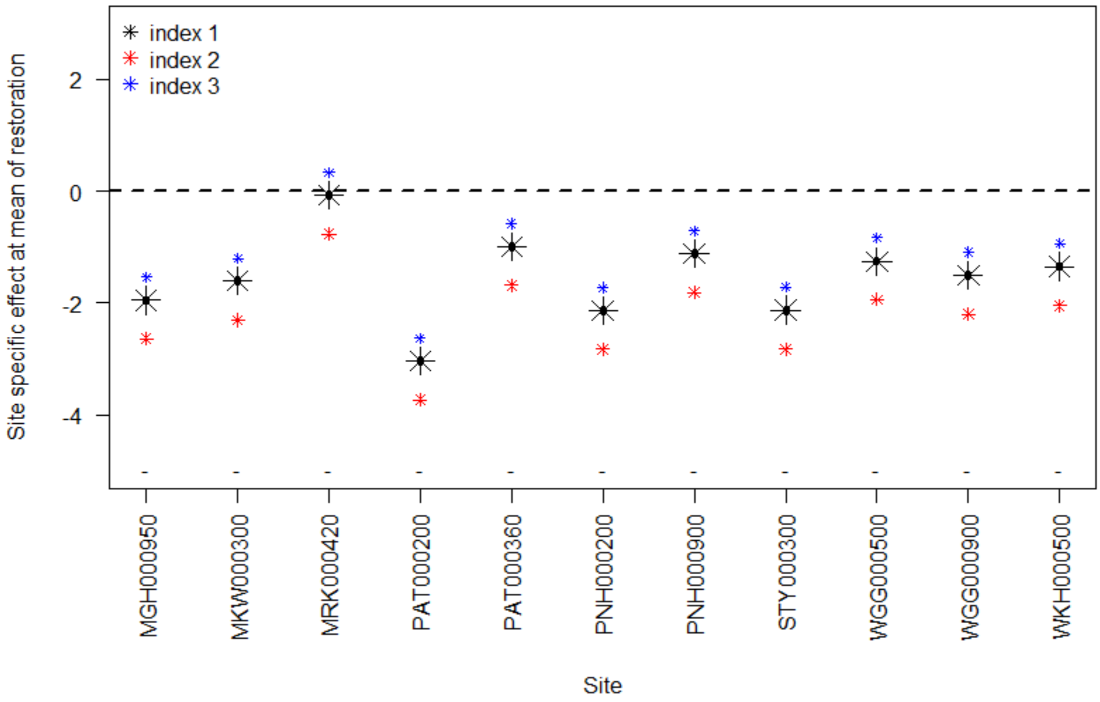

Figure B-6: Site specific restoration coefficients (slopes) for the three restoration as random slope models, evaluated at the mean of the restoration index at that site. A negative posterior mean with credible intervals that do not include zero indicates a negative relationship between restoration and *E. coli* concentration at that site, a positive posterior mean with credible intervals that do not include zero indicate a positive relationship between restoration and *E. coli* concentration at that site. The coefficients and credible intervals for restoration index 1, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively.

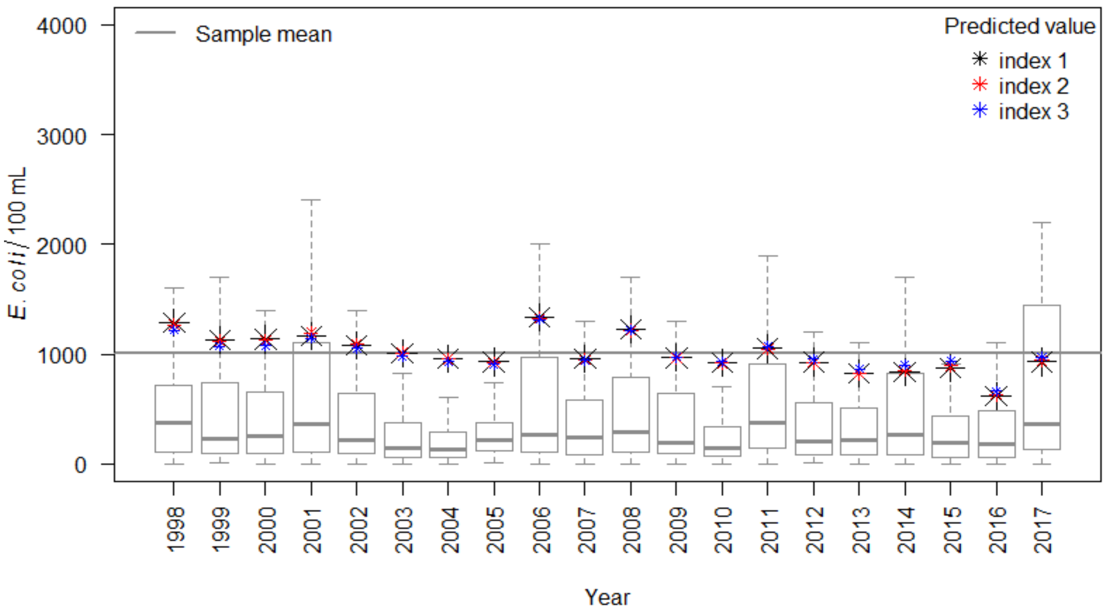

Figure B-7: Predicted *E. coli* concentrations from the fitted random slope restoration models compared to observed values. Note that this plot does not show outliers, but the mean value (grey line) indicates their influence. The observed data is shown by the grey boxplots. The predicted values for the restoration index 1 model (the best-fitting model) are shown largest and in black, the predicted values from models with restoration indices 2 and 3 are shown in red and blue, respectively.

Appendix C Invertebrate modelling using 2 km DEM streams

The invertebrate modelling analysis using National SQMCI as a response variable was also conducted using the restoration indices calculated using our 2 km DEM stream network to confirm the REC-only results presented in the main text of this report. The overall results and general conclusions were the same for both methods; there was a positive relationship between restoration and National SQMCI metric scores across all sites. Model parameters and plots are presented below. Because the National SQMCI results were similar for both sets of models, we infer the other invertebrate metric models will also be similar across the two restoration index calculation methods.

Table C-1: Model parameter coefficients, standard errors, 95% credible intervals, and DIC scores for National SQMCI models with each restoration index. Note that coefficients (means) are on the scale of the linear predictor (log scale).

Model	Restoration index	Parameter	Mean	Standard error of the mean	2.5% quantile	97.5% quantile	DIC[a]
Restoration fixed effect	Index 1	Intercept	0.2933	0.1328	0.0234	0.5427	**6918.61**
		Restoration	2.2819	0.1848	1.9252	2.6435	
	Index 2	Intercept	-0.8745	0.3027	-1.4866	-0.3067	6944.13
		Restoration	4.7646	0.4711	3.8403	5.6627	
	Index 3	Intercept	1.3125	0.0518	1.2071	1.4114	7208.86
		Restoration	0.7755	0.1053	0.5773	0.9924	
Restoration random slope	Index 1	Intercept	0.1150	0.2336	-0.3625	0.5567	**6762.68**
	Index 2	Intercept	1.5011	0.0549	1.3979	1.6121	7225.57
	Index 3	Intercept	1.5344	0.0480	1.4459	1.6338	7235.63

[a] DIC = Deviance Information Criterion, a relative measure of fit, or deviance, penalized by the number of parameters; the smaller the DIC the better the relative fit (Spiegelhalter, Best et al. 2002).

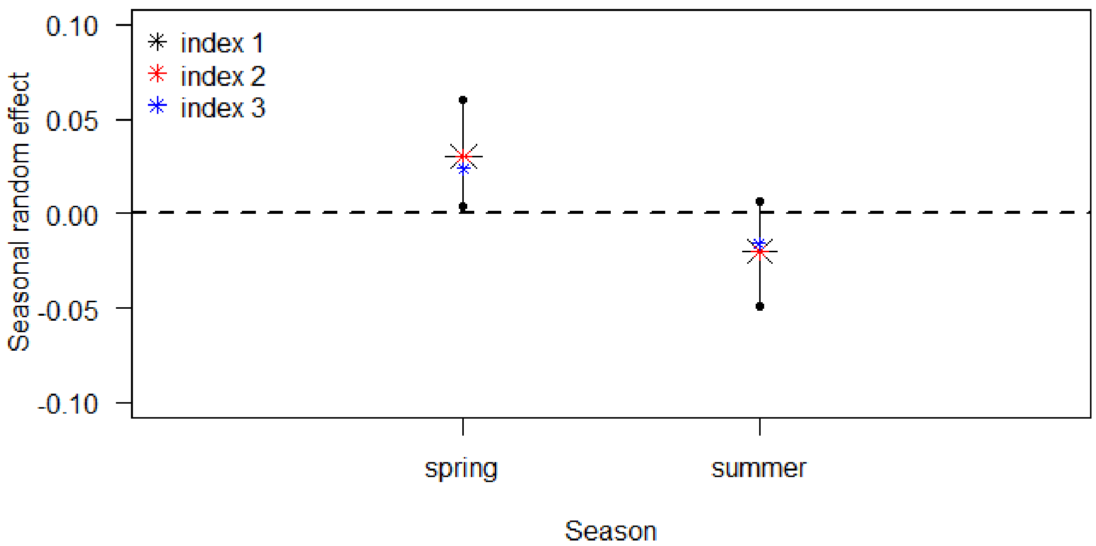

Figure C-1: Posterior estimates and credible intervals for the seasonal random effect in the restoration as a fixed effect models. The predicted values for the restoration index 1 model (the best-fitting model) are shown largest and in black, the predicted values from models with restoration indices 2 and 3 are shown in red and blue, respectively.

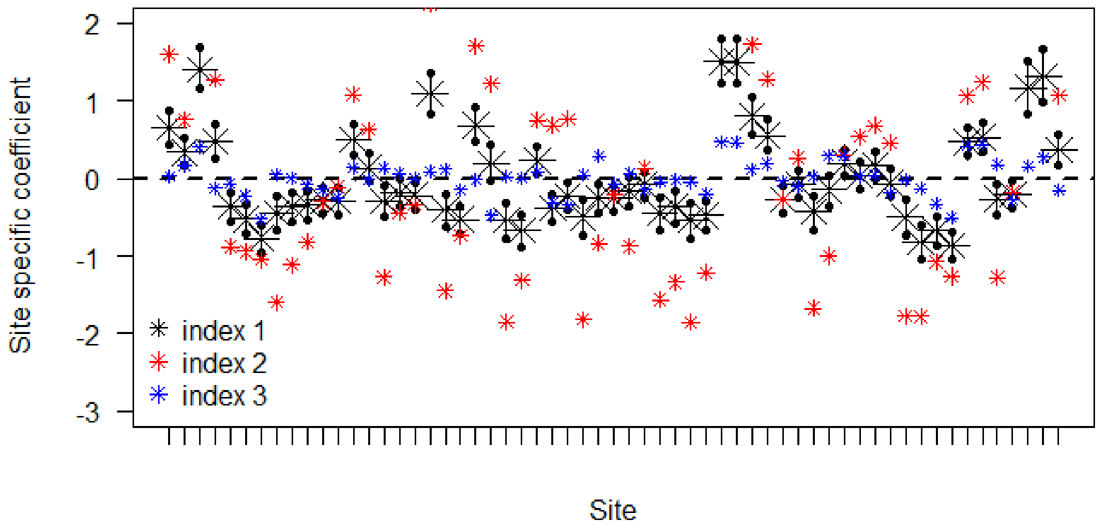

Figure C-2: Site specific intercepts and credible intervals for National SQMCI models with restoration as a fixed effect. The predicted values for the restoration index 1 model (the best-fitting model) are shown largest and in black, the predicted values from models with restoration indices 2 and 3 are shown in red and blue, respectively.

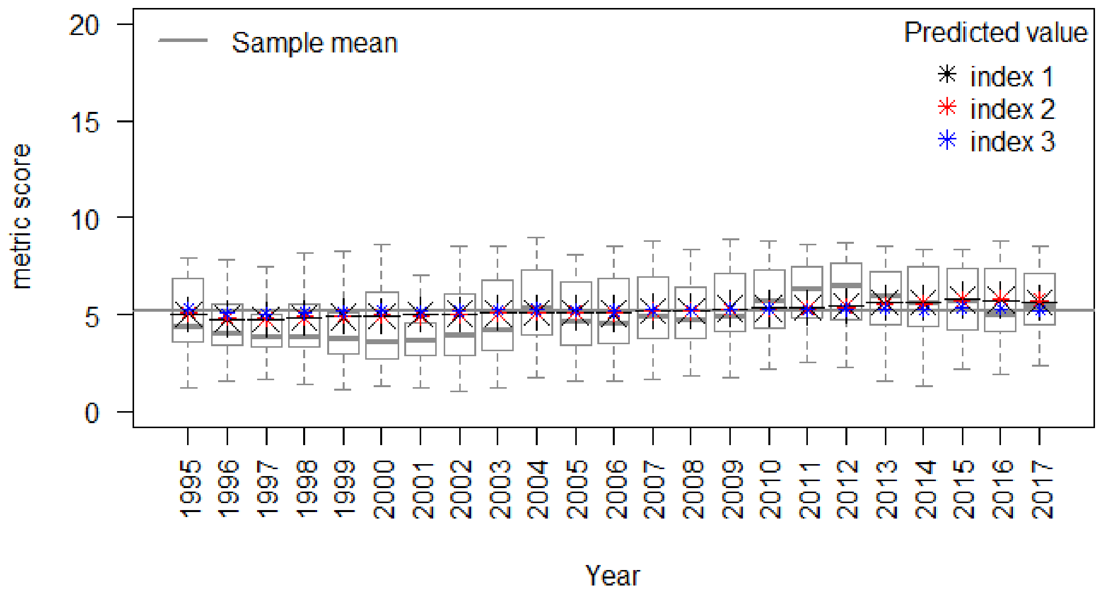

Figure C-3: Predicted National SQMCI metric values from the fitted fixed effect restoration models compared to observed values. The observed data is shown by the grey boxplots. The predicted values for the restoration index 3 model (the best-fitting model) are shown largest and in black, the predicted values from models with restoration indices 1 and 3 are shown in red and blue, respectively.

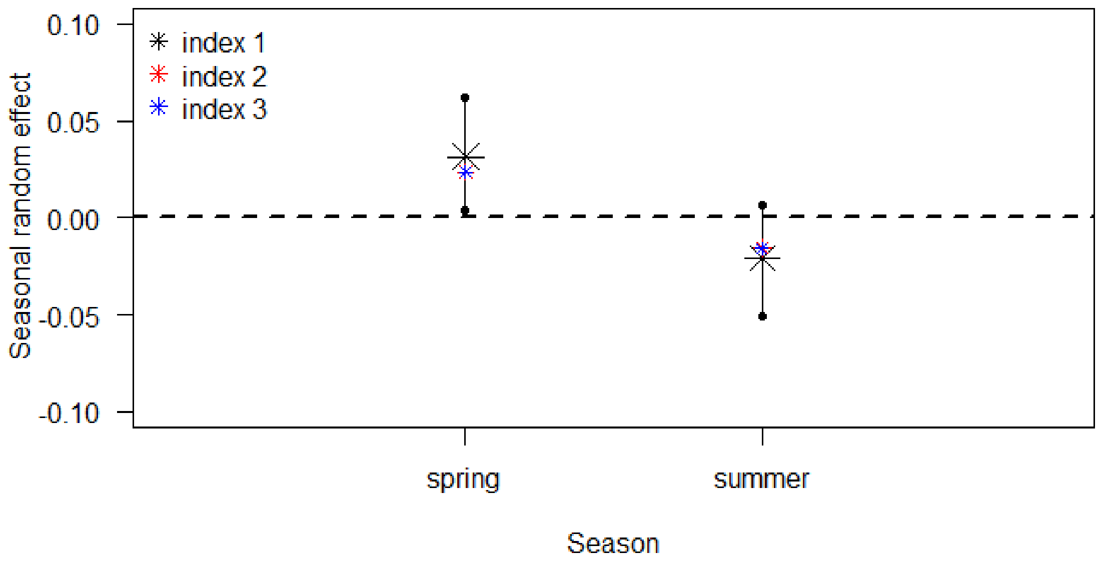

Figure C-4: Posterior estimates and credible intervals for the seasonal random effect in the restoration as a random slope models. The predicted values for the restoration index 3 model (the best-fitting model) are shown largest and in black, the predicted values from models with restoration indices 1 and 3 are shown in red and blue, respectively.

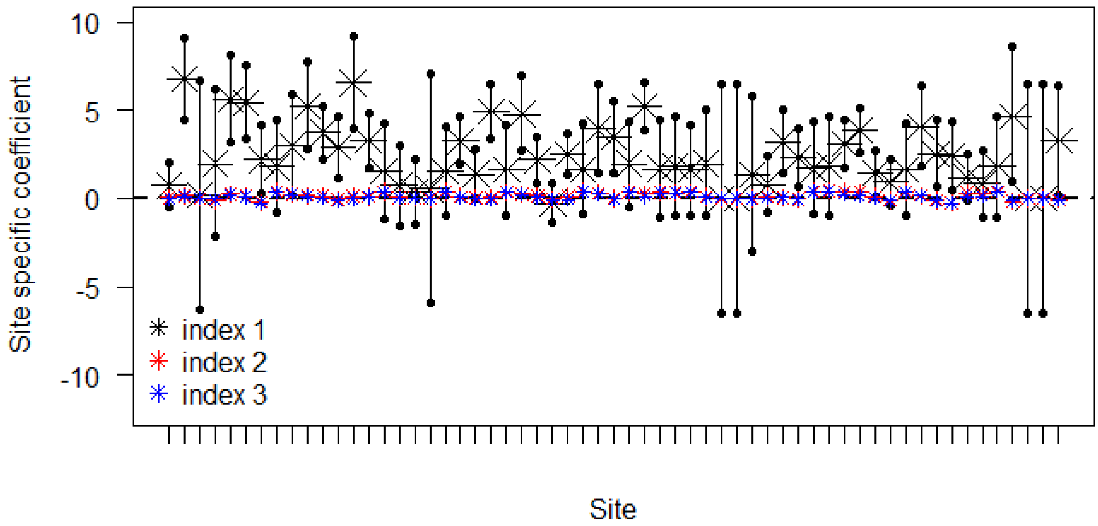

Figure C-5: Site specific intercepts and credible intervals for National SQMCI models with restoration as a random slope. The predicted values for the restoration index 3 model (the best-fitting model) are shown largest and in black, the predicted values from models with restoration indices 1 and 3 are shown in red and blue, respectively.

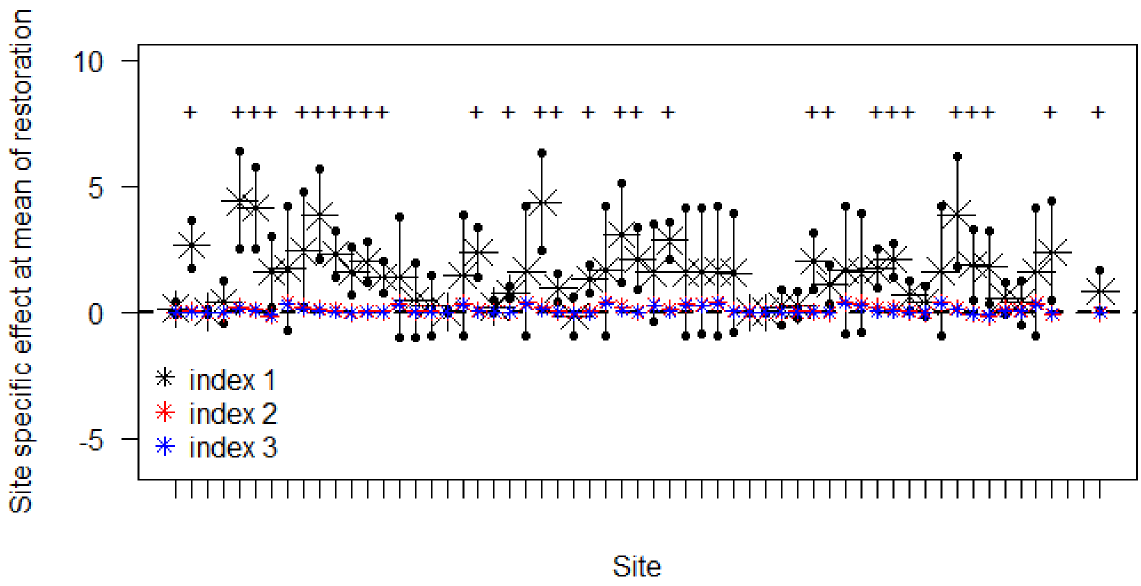

Figure C-6: Site specific restoration coefficients (slopes) for the three restoration index models, evaluated at the mean of the restoration index at that site. A negative posterior mean with credible intervals that do not include zero indicates a negative relationship between restoration National SQMCI metric values at that site, a positive posterior mean with credible intervals that do not include zero indicate a positive relationship between restoration and National SQMCI scores at that site. The coefficients and credible intervals for restoration index 1, the best fitting model, are shown largest and in black, and the coefficients from the restoration index 2 and restoration index 3 models are shown in red and blue, respectively.

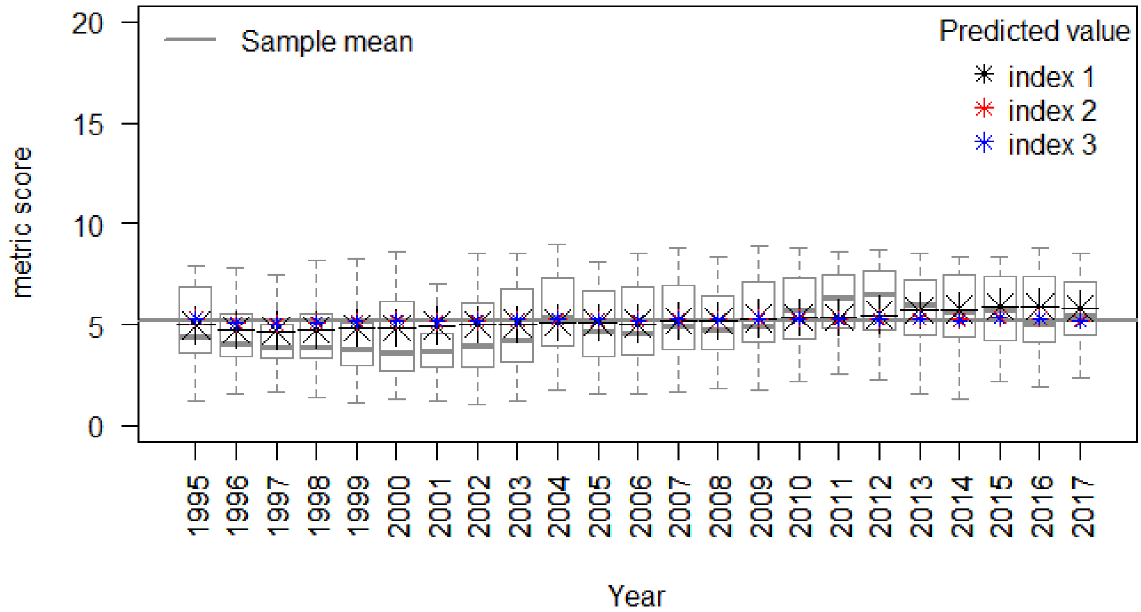

Figure C-7: Predicted National SQMCI metric values from the fitted random slope restoration models compared to observed values. The observed data is shown by the grey boxplots. The predicted values for the restoration index 1 model (the best-fitting model) are shown largest and in black, the predicted values from models with restoration indices 2 and 3 are shown in red and blue, respectively.

Table C-2: Posterior estimates for restoration index coefficients for the National SQMCI with restoration index 1 random slope model. A positive posterior mean with credible intervals that do not include zero indicates positive relationships between restoration and macroinvertebrate metric scores at that site. It is important to note that the coefficients and quantiles are at the scale of the linear predictor (i.e., log scale). A slope of 0 indicates the restoration index remained constant at that site, "--" indicates either that no restoration has been done upstream of this site or if so, data was not available.

Site	Intercept mean	Intercept 2.5% CI	Intercept 97.5% CI	Slope mean	Slope 2.5% CI	Slope 97.5% CI	Nat. SQMCI-Restoration Relationship
HRK000085	0.7428	-0.5021	2.0038	0.1414	-0.0956	0.3815	
HTK000350	6.7798	4.4824	9.1448	2.6757	1.7690	3.6090	+
HTK000425	0.1843	-6.3276	6.7079	0.0035	-0.1212	0.1285	
HTK000745	1.9719	-2.1168	6.1494	0.3923	-0.4211	1.2233	
KPA000250	5.5860	3.1953	8.1441	4.3836	2.5075	6.3911	+
KPA000700	5.4169	3.3404	7.5860	4.1243	2.5434	5.7759	+
KPA000950	2.1918	0.2834	4.1294	1.5828	0.2047	2.9820	+
KPK000250	1.8056	-0.7880	4.4301	1.7252	-0.7530	4.2329	
KPK000500	2.9690	0.2377	5.8837	2.4191	0.1937	4.7939	+
KPK000660	5.2452	2.8392	7.7917	3.8264	2.0711	5.6840	+
KPK000880	3.7272	2.2190	5.2461	2.3027	1.3709	3.2410	+
KPK000990	2.8962	1.2041	4.6022	1.6147	0.6713	2.5658	+
KRP000300	6.5470	3.9216	9.2322	1.9953	1.1952	2.8136	+
KRP000660	3.3089	1.7765	4.8601	1.3735	0.7374	2.0174	+
KTK000150	1.5677	-1.1423	4.2536	1.3864	-1.0102	3.7616	
KTK000248	0.7246	-1.5765	3.0183	0.4661	-1.0140	1.9414	
MGE000970	0.3801	-1.4719	2.2278	0.2431	-0.9415	1.4251	
MGH000950	0.5354	-5.9377	7.0902	0.0034	-0.0374	0.0447	
MGN000195	1.5646	-0.9745	4.0901	1.4660	-0.9131	3.8324	
MGN000427	3.2540	1.9133	4.6096	2.3770	1.3976	3.3672	+
MGT000488	1.3983	-0.0094	2.8280	0.2179	-0.0015	0.4407	
MGT000520	4.9303	3.4328	6.4544	0.7644	0.5322	1.0007	+
MKW000200	1.6268	-0.9388	4.1987	1.6268	-0.9388	4.1987	
MKW000300	4.7890	2.6930	7.0153	4.3263	2.4328	6.3374	+
MRK000420	2.1820	0.8610	3.5187	0.9414	0.3714	1.5181	+
MWH000380	-0.2501	-1.3656	0.8837	-0.1707	-0.9320	0.6030	
MWH000490	2.5171	1.3869	3.6577	1.3120	0.7229	1.9065	+
PAT000200	1.6546	-0.9113	4.2261	1.6546	-0.9113	4.2261	
PAT000315	3.9262	1.4874	6.5197	3.0775	1.1658	5.1103	+
PAT000360	3.4692	1.4321	5.5562	2.0909	0.8631	3.3487	+
PNH000200	1.9637	-0.4481	4.3892	1.5752	-0.3594	3.5210	
PNH000900	5.2206	3.8379	6.6174	2.8321	2.0820	3.5898	+
STY000300	1.6838	-1.0342	4.4157	1.5673	-0.9626	4.1103	
STY000400	1.8272	-0.9668	4.6537	1.6171	-0.8556	4.1186	

Site	Intercept mean	Intercept 2.5% CI	Intercept 97.5% CI	Slope mean	Slope 2.5% CI	Slope 97.5% CI	Nat. SQMCI-Restoration Relationship
TMR000150	1.6228	-0.9425	4.1945	1.6228	-0.9425	4.1945	
TMR000375	1.9804	-0.9908	5.0482	1.5523	-0.7766	3.9567	
TNH000090	0.0000	-6.5295	6.5196	0.0000	0.0000	0.0000	
TNH000200	0.0000	-6.5295	6.5196	0.0000	0.0000	0.0000	
TNH000515	1.3484	-3.0464	5.7926	0.2153	-0.4865	0.9250	
WAI000110	0.8079	-0.8034	2.4454	0.2612	-0.2598	0.7907	
WGA000260	3.2277	1.4384	5.0500	2.0153	0.8981	3.1530	+
WGA000450	2.3062	0.6885	3.9421	1.1147	0.3328	1.9054	+
WGG000115	1.7052	-0.9194	4.3369	1.6575	-0.8937	4.2158	
WGG000150	1.8721	-0.9291	4.6798	1.5691	-0.7788	3.9226	
WGG000500	3.0967	1.7170	4.4836	1.7143	0.9505	2.4820	+
WGG000665	3.8782	2.6367	5.1286	2.0752	1.4108	2.7442	+
WGG000895	1.4387	0.1285	2.7559	0.6594	0.0589	1.2630	+
WGG000995	0.9272	-0.3699	2.2321	0.4219	-0.1683	1.0157	
WKH000100	1.6472	-0.9379	4.2381	1.6327	-0.9297	4.2008	
WKH000500	4.0397	1.8559	6.4156	3.8847	1.7847	6.1695	+
WKH000920	2.5390	0.6510	4.4648	1.8748	0.4807	3.2967	+
WKH000950	2.3994	0.4553	4.3865	1.7773	0.3372	3.2493	+
WKR000500	1.2046	-0.1425	2.5429	0.5670	-0.0671	1.1970	
WKR000700	0.8282	-1.0980	2.7263	0.3797	-0.5034	1.2500	
WMK000100	1.8139	-1.0221	4.6609	1.6001	-0.9017	4.1116	
WMK000298	4.6368	0.9424	8.6380	2.3577	0.4792	4.3921	+
WNR000450	0.0000	-6.5295	6.5196	--	--	--	
WTR000540	0.0000	-6.5295	6.5196	--	--	--	
WTR000850	3.2640	0.1635	6.4184	0.8314	0.0417	1.6350	+

Appendix D Swimmability tables

Please see supplementary Excel files.

(To obtain these files, please email info@trc.govt.nz with 'request for NIWA swimmabilty files' in the subject line.)