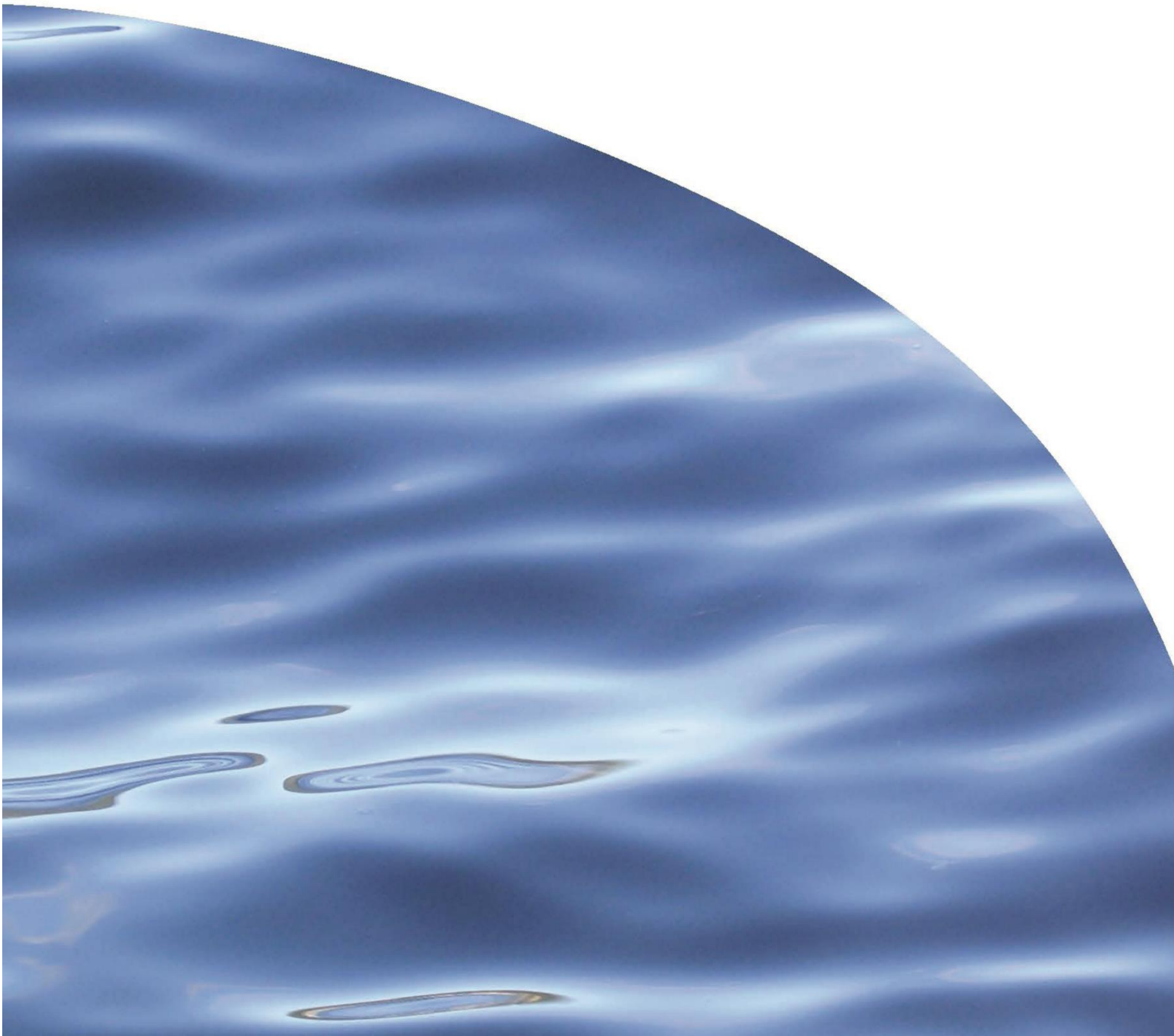
REPORT NO. 2994

TECHNICAL REPORT ON DEVELOPING A DEPOSITED SEDIMENT CLASSIFICATION FOR NEW ZEALAND STREAMS



TECHNICAL REPORT ON DEVELOPING A DEPOSITED SEDIMENT CLASSIFICATION FOR NEW ZEALAND STREAMS

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Prepared for Ministry for the Environment

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EXECUTIVE SUMMARY

One step towards the development of a sediment attribute for inclusion in the National Objectives Framework is knowledge of where attribute management bands should be applicable. A stream with naturally high deposited sediment volumes should not unnecessarily be categorised as degraded. Degraded streams should be identified as those where human activity is responsible for increasing deposited sediment from expected natural levels, to a degree that impacts the stream's values. As such, knowledge of the natural or reference condition is needed for any given stream. Reference condition can be estimated from sites with minimal land use or predicted from the relationship between sediment and land use. Reference condition will vary across the country due to natural environmental gradients such as the source and nature of the sediment (e.g. geology, soil), the delivery of the sediment (e.g. erosion, rainfall, elevation) and the ability of the stream to retain sediment (e.g. slope, flow). Understanding and classifying this variation is needed to determine where sediment attribute bands should be applied.

We explored a large body of data which describes the state of fine sediment deposited on the streambed to develop a classification of New Zealand streams based on variation in reference condition. The data was compiled from regional council application of standardised methods at their monitoring networks, research datasets, as well as observations recorded in the New Zealand freshwater fisheries database (NZFFB).

Reference sites were generally unrepresentative of the full range of environmental variation in the river network so we developed predictive models using flexible spatial regression models to predict reference condition for all stream segments. We then used a classification and regression tree (CART) model approach to partition sites by their environmental similarity into a number of classes. These classes were combined based on similarity in their sediment values into a small number of groups. We plotted these groupings to ascertain where in New Zealand levels of low, medium, or high sediment levels can be expected to occur naturally. Results suggest that the majority of New Zealand streams (>85%) can be expected to have less than 20% fine sediment cover. Higher sediment cover is generally expected in areas of the stream network at low elevation and on distinct geologies such as volcanic-acidic and alluvium.

This information forms the basis of a sediment classification for New Zealand streams. However, we recommend that a regional verification is needed to refine model predictions. We also recommend that the classification be revisited once sediment attribute bands have been developed based on the relationship between sediment and ecological responses.

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1. INTRODUCTION

1.1. Background

1.1.1. Fine deposited sediment in streams

Streams across the country vary in the amount of fine sediment deposited on their streambeds (Clapcott et al. 2011). This variation is due to natural environmental gradients such as the source and nature of the sediment (e.g. geology, soil), the delivery of the sediment (e.g. erosion, rainfall, elevation) and the ability of the stream to retain sediment (e.g. slope, flow). These environmental variables influence sediment in streams spatially but also temporally. According to the 'stable channel balance' premise, sediment accumulation occurs when the product of sediment load and sediment size is greater than the product of slope and discharge (Lane 1955). As such, for example, we might expect sediment retention to be greater during long periods of low flow (Table 1).

Land cover is also a factor that effects the amount of deposited fine sediment in streams; land clearance can accelerate erosion and the delivery of sediment, and alter stream flows and the retention of sediment (Leopold 1956; Leopold et al. 1964). Land use and land management practices can further influence sediment in streams (Woods et al. 2006b). For example, fenced or vegetated riparian strips can buffer the delivery of sediment (Table 1). As such, deposited sediment can be viewed as a function of natural environmental variability and land cover and land use.

Table 1. Conceptual relationships between land cover, land use, descriptors of natural environmental variability and deposited fine sediment in streams.

Variable	Influences on stream sediment
Land cover or land use	
Native vegetation cover	Less land erosion, buffered flows
Pastoral heavy cover	Increased erosion due to historic and current land management activities, bank slumping
Pastoral light cover	Increased erosion mainly due to historical land clearance
Urban land cover	Increased delivery from storm flows; decreased retention in concrete lined channels or regularly ‘cleaned’ streams
Exotic vegetation cover	Increased erosion due to roading and vegetation clearance; increased retention due to change in flow regime
Surface water allocation	Increased retention due to decreased flows
Environmental descriptor	
Elevation	Surrogate for generally higher rainfall (increased delivery of sediment) and larger grain size (less fine sediment); also freeze-thaw processes; influences what vegetation can grow and hence erosion potential
High rainfall events	Increased erosion and sediment delivery; indirectly vegetation type if not actively managed
Upstream slope	Higher slopes lead to increased sediment delivery
Upstream geology	Different geologies will be more susceptible to erosion and sediment transport
Natural sediment load	As a function of rainfall, lithology and slope; where higher loads should lead to higher instream sedimentation
Segment slope	Lower slopes retain more sediment due to influence on stream power[1]
Riparian vegetation	Buffers sediment delivery; reduces bank erosion
Mean flow	Lower flows retain more sediment due to influence on stream power
Low flow	Prolonged low flows can increase sediment accumulation
Flood flow	Floods flush sediment from the streambed and can scour banks, increase sediment delivery downstream
Flow stability	More stable flows increase sediment accumulation

1.1.2. Classification systems for assessing stream health

Classification systems provide a way to group sites with similar environmental characteristics. Classes are defined by similarity within groups and dissimilarity among groups. Classification systems provide a framework for freshwater assessment, ensuring appropriate management bands, or guidelines, are applied to appropriate stream classes. A classic example are Upland and Lowland classes for water quality guidelines (ANZECC 2000). In this example, guidelines are based on percentile distributions from reference sites in Upland or Lowland streams.

[1] Stream power predicts the rate of streambed erosion as a function of gravity, discharge and slope.

A classification system could be developed at the habitat, site, segment or catchment scale. It is important to understand the variation within each of these scales to assess the robustness of any given classification and its application. For example, the catchment scale has been proposed as the most suitable scale for the management of sediment (Owens 2008), but sediment deposition and erosion can occur at the habitat scale as they are controlled by shear stress, roughness and turbulence at the stream boundary layer. The River Environment Classification (Snelder & Biggs 2002) and following Freshwater Environments of New Zealand (Leathwick et al. 2010) provide a segment scale framework for the development of a sediment classification. A wide selection of environmental measurements (calculated or predicted) are available for every stream segment (the length of stream between tributary confluences).

To assess the state of deposited sediment, and hence Ecosystem Health[2], requires knowledge of reference state to provide a yardstick with which to measure current state. Reference state can be defined by the absence of a change in land cover due to human land use. Reference condition can be estimated from sites with minimal land use (as in the ANZECC guidelines for water quality example) or predicted from the relationship between sediment and land use (Hawkins 2010). Both approaches need to take into account natural environmental variability.

1.2. Aim and scope

The aim of this research was to develop a national classification system to define different classes or types of streams to which specific management bands for deposited sediment may be justifiably applied. The research was conducted as part of the Ministry for the Environment (MfE)-funded project 'Sediment Stage 2 - Sediment Thresholds'. This report is intended to provide input into the Phase 1b report prepared by NIWA and the Cawthron Institute (Cawthron) for MfE.

The scope of the research was to explore variation in the state of deposited sediment at reference sites to determine stream classes: first, by examining spatial variation of sites determined as reference by a set of land cover rules; secondly, by examining the spatial variation in reference state for all stream segments in the country predicted using spatial regression. This process was repeated using different sets of collated data, which included different measures of fine sediment. Here we present results for one dataset (*% cover B*) in the main text while other results are appended.

[2] The Ecosystem Health of streams is described by the structural and functional components present and their resilience to change. Deposited sediment is a component of stream structure and contributes to Ecosystem Health by defining the habitat available for benthic organisms and stream functions such as groundwater exchange and nutrient transformations. As such, an assessment of deposited sediment is an important component of Ecosystem Health assessment.

2. DATA

2.1. Sediment data

Deposited fine sediment is defined by Clapcott et al. (2011) as inorganic particles deposited on the streambed that are less than 2 mm in size. 'Sediment' henceforth refers to deposited fine sediment, unless stated otherwise.

An existing database compiled for the Sediment Stage 1 project included 628 unique sites where sediment had been measured using the standardised methods (Table 2) in Clapcott et al. (2011).

Table 2. Description of methods used to sample sediment.

Sediment method (metric)	Description
Bankside visual assessment (% cover)	A rapid qualitative visual assessment of the % of fine (2 < mm) sediment covering the streambed in a run habitat. Also known as SAM1.
Instream visual assessment (% cover)	The average % cover of fine sediment covering the streambed in a run habitat calculated from a minimum of 20 stratified views using an underwater viewer. Also known as SAM2.
Wolman count (% fine)	The proportion of particles less than 2mm in diameter recorded from a Wolman walk, or the measurement of a minimum of 100 particles picked up throughout a run habitat. Also known as SAM3.
Suspendable inorganic sediment (SIS; g/m^2)	The average amount of inorganic fine sediment entrapped and covering the streambed in a run habitat calculated from a minimum of 5 corers in a run habitat. Also known as SAM4.
Suspendable benthic sediment volume (SBSV, l/m^2)	Same as SIS but sediment volume rather than weight is recorded.
Shuffle score (0-5)	An average qualitative assessment of the size and duration of a sediment plume resuspended when disturbing the streambed at 3 sites within a run habitat. Also known as SAM5.

This Stage 1 database was manually checked for accuracy of NZReach numbers and a significant number of errors were corrected. The errors were mainly due to incorrect spatial link conducted during the Stage 1 project. Some NZReach assignments from a previous project, Sediment Assessment Methods, were also corrected. The suspended inorganic sediment (SIS) values for up to 50 sites were incorrectly assigned and this was also corrected during this data checking stage.

New data compiled in response to the request to regional councils in July 2016 included 1364 unique sites where deposited sediment had been observed using the methods described above. Additionally, data collected using a new rapid habitat assessment method (Table 3) were compiled. New data were assigned an NZReach based on matching site names or site ID numbers with the Stage 1 corrected dataset.

Table 3. Description of qualitative habitat assessment method used to sample sediment.

Sediment method (metric)	Description
Rapid habitat assessment component 1 (RHA100)	A rapid qualitative visual assessment of the % of fine (2< mm) sediment covering the streambed in a run habitat scored in the field on a scale of 1-10 and converted to % cover using guidelines provided on field sheets: 1 = 75, 2 = 60, 3 = 50, 4 = 40, 5 = 30, 6 = 20, 7 = 15, 8 = 10, 9 = 5, 10 = 0.

Stage 1 and Stage 2 data were combined and summarised (Table 4).

Table 4. Number of unique sites where there are sediment data for each sampling method.

Sediment measure (metric)	Level 1 no. of sites
RHA100	660
SAM1 (% cover)	666
SAM2 (% cover)	448
SAM3 (% fines)	633
SAM4 (SIS)	251
SAM 4(SBSV)	71
SAM5 (Shuffle score)	160

Methods RHA100, SAM1 and SAM2 provide equivalent measures of the sediment cover of the streambed surface within a run habitat (Hicks et al. 2016). As such, these data were combined and averaged for each NZReach to provide a *'% cover A'* measure for further analysis. Within-site variability was not examined further at this stage.

In addition, sediment data from 10,379 unique records were sourced from the New Zealand Freshwater Fish Database (NZFFD) as described in Hicks et al. (2016). Briefly, data entries that had been 'approved' in the database were extracted, excluding lake, wetland, pond or reservoir water body type records. Sediment information was entered into the NZFFD as either %mud/silt or %sand. These two categories were summed and multiple replicate observations for each NZReach were combined by averaging to give a measure equivalent to '%cover'. However, whereas all previous sediment samples were collected from run habitat, information on where sediment data were collected from was not recorded for NZFFD, so we labeled these as 'reach' samples. Subsequently, a second dataset for investigation of spatial variation in sediment was a combination of samples from the NZFFD at the reach scale and RHA100, SAM1 and SAM2 at the run scale (*% cover B*).

SAM4 provides a measure of sediment entrapped within the top 10 cm of the streambed. Compared to surface cover of sediment, this measure is likely to better relate to sediment loads via the 'frozen bedload' hypothesis[3] (Hicks et al. 2016), as well as affecting different aspects of stream ecology. As such, these data were explored further as '*SIS*', or 'suspendable inorganic sediment'. Multiple replicate observations were averaged for each NZReach.

2.2. Land cover and environmental predictors

We used the following upstream catchment land cover rules to define reference sites:

- > 90% native vegetation
- < 5% exotic vegetation
- < 10% pastoral heavy
- 0% urban.

This selection was based on *a priori* expectations of the relationship between land use and sediment delivery and retention in streams. For each sediment measure this resulted in a reduction of sites available to explore spatial variation compared to the full set of surveyed data (Table 5).

Table 5. Number of reference sites and total number of sites for each sediment measure.

Sediment variable	Reference sites	All sites
% cover A	94	1393
% cover B	1144	8482
SIS	27	160

NZReach identifiers were used to compile environmental data for regression analyses. Primary environment gradients of interest included reach-scale and catchment-scale stream descriptors (Table 6). Variables were chosen based on their

[3] A hypothesis promoted by John Dymond, the 'frozen bedload' hypothesis, is that SIS should relate to the suspended sediment concentration on a flood recession at the flow when bedload stops moving (which can be indexed by a flood statistic such as ¼ the mean annual flood discharge).

likely mechanistic relationship to sediment in streams. This excluded variables such as eastings, northings, and temperature, which may correlate well to sediment but have no mechanistic relationship to sediment delivery or retention in streams. Extensive exploratory analysis was also conducted of the relationship between environmental variables and sediment measures to inform variable selection.

Variables were transformed where necessary to meet the assumptions of normality for linear regression including:

- Logit transformation of *% cover A*, *% cover B*
- Log transformation of *SIS*, *Catchment sediment load*, *Stream power*, *Segment slope*, *USDaysRain*, *Specific mean flow*, *Specific low flow*
- Square-root transformation of *Elevation*.

Table 6. Mean and range of variables used in regression analysis. N = 8482 sites from the *% cover B* dataset.

Variable	Description	Mean (range)	Source
Response variable			
% cover A	The average cover of sediment on the streambed in a run habitat (%); logit transformed	25 (0–100)	Current project
% cover B	The average cover of sediment on the streambed in a run habitat or at a reach scale (%); logit transformed	24 (0–100)	Current project
SIS	The average amount of inorganic fine sediment entrapped and covering the streambed in a run habitat (g/m^2); log transformed	540 (1.1–11000)	Current project
Predictor variable			
Native cover	The cover of native vegetation in the upstream catchment including indigenous forest, broadleaf forest, manuka/kanuka, fernland, subalpine shrubs and alpine grass (%)	63 (0–100)	LCDB3
Exotic cover	The cover of exotic vegetation in the upstream catchment including exotic forest, deciduous hardwoods, forest-harvested, gorse and mixed exotic shrubs (%)	8.6 (0–100)	LCDB3
Pastoral heavy cover	The cover of pastoral vegetation in the upstream catchment including high producing exotic grassland, short rotation crops, orchards, vineyards or other perennial crops (%)	31 (0–100)	LCDB3
Pastoral light cover	The cover of pastoral vegetation in the upstream catchment including low producing grassland, tussock and depleted grass (%)	19 (0–100)	LCDB3
Urban cover	The cover in the upstream catchment of urban parkland, built up areas, transport infrastructure, mines or dumps (%)	0.61 (0–100)	LCDB3
Surface water allocation	The low flow remaining after the upstream consented daily water allocation (not including groundwater abstractions or flow restrictions on allocations) is deducted (proportion)	0.03 (0–1)	MfE 2006
Catchment sediment load	Predicted sediment load for the total upstream catchment (t/y) as a function of rainfall, lithology and slope; log transformed	5.7 (-3.9 –17)	WRENZ model; Hicks et al. 2011
Specific stream power	Product of the density of water (1000 kg m^3), acceleration due to gravity (9.8 m/s^2), mean flow (m^3/s), and segment slope (degrees), per unit width at mean annual low flow (m); log transformed	-2.4 (-6 –7.6)	Current project using Booker 2010

Table 6. continued

Variable	**Description**	**Mean (range)**	**Source**
Elevation	Average segment elevation (masl); square-root transformed	19 (0–53)	REC1
USSlope	Average slope in the catchment (degrees)	17 (0–55)	REC1
Segment slope	Average segment slope (degrees); log transformed	0.31 (-5.3 – 4.1)	REC1
USHardness	Average hardness of rocks in the catchment, 1 = very low to 5 = very high	3.3 (0–5)	FENZ; Leathwick et al. 2003
USCalcium	Average calcium concentration of rocks in the catchment, 1 = very low to 4 = very high	1.5 (0–4)	FENZ; Leathwick et al. 2003
USDaysRain	Days / year with rainfall in the catchment > 25 mm; log transformed	2.5 (0–4.9)	FENZ
Specific mean flow	Mean annual flow divided by catchment area ($m^3/s/km^2$); log transformed	-3.6 (-5 –5)	Woods et al. 2006a
Specific low flow	Mean annual 7-day low flow divided by catchment area ($m^3/s/km^2$); log transformed	-5.5 (-8 –2)	FENZ; Pearson 1995
Flow stability	Mean annual low flow / mean annual flow (ratio)	0.19 (0–0.63)	FENZ; Pearson 1995
FRE3	Average number of floods per year (based on the mean daily flow) exceeding three times the median flow	15 (1.8–4.1)	Booker 2013
GEOLOGY	Categorical REC classification at the geology level	NA	REC1
Riparian shade	Average segment shade estimated from vegetation cover, height and stream width (proportion)	0.53 (1–0.8)	FENZ; Leathwick et al. 2005

3. EXPLORING VARIATION AT REFERENCE SITES

We explored the distribution of sites in the *% cover B* dataset (including RHA100, SAM1, SAM2 and NZFFD data) at a national spatial scale (Figure 1) and across continuous environmental gradients (Figure 2) to assess their representativeness. Spatially, there was a lack of the reference sites for the eastern seaboard, especially Canterbury and the Southern Alps (Figure 1). There was significantly less sediment observed at reference sites compared to non-reference sites (Figure 2). Despite visually appearing quite similar, there was also a significant difference between distributions for most environmental gradients when tested with a Kolmogorov-Smirnov test (Conover 1971); reference sites differed compared to the national network for all gradients except *USHardness* and *USCalcium* (Figure 2). These explorations suggest the *% cover B* dataset, despite being 10-fold larger than the *% cover A* dataset (see Appendix 1), may not be suitable for developing a representative sediment classification (Figure 2).

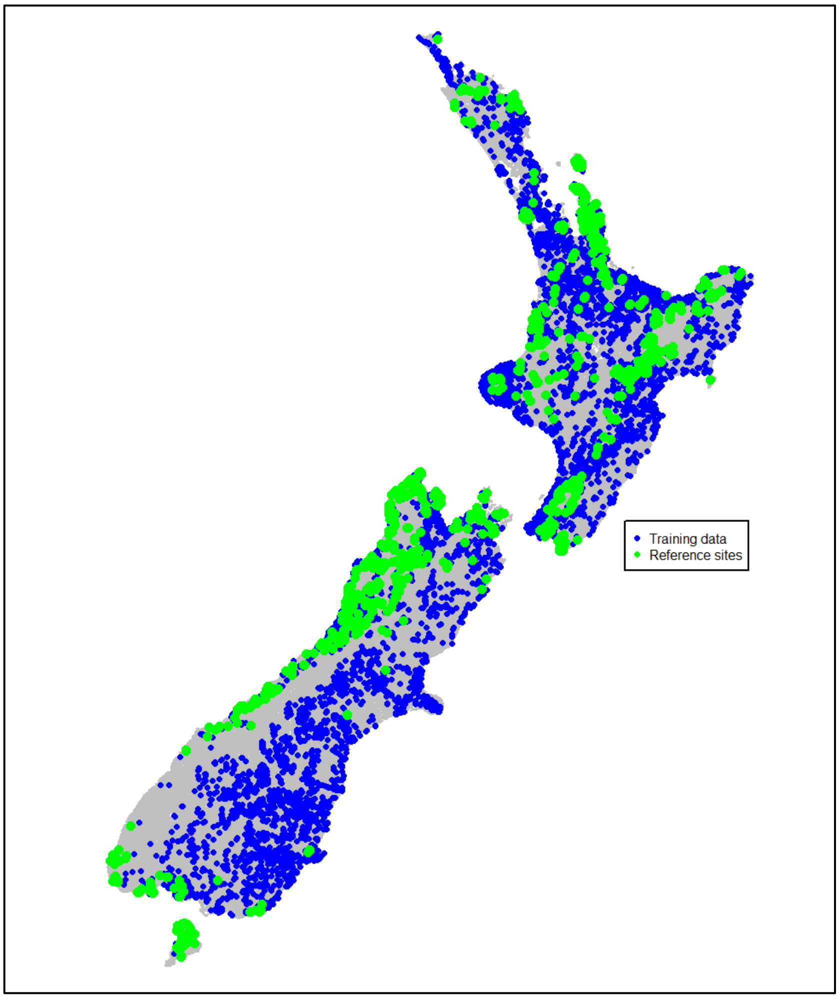

Figure 1. Distribution of reference sites and all surveyed (training) sites where *% cover B* data was collected.

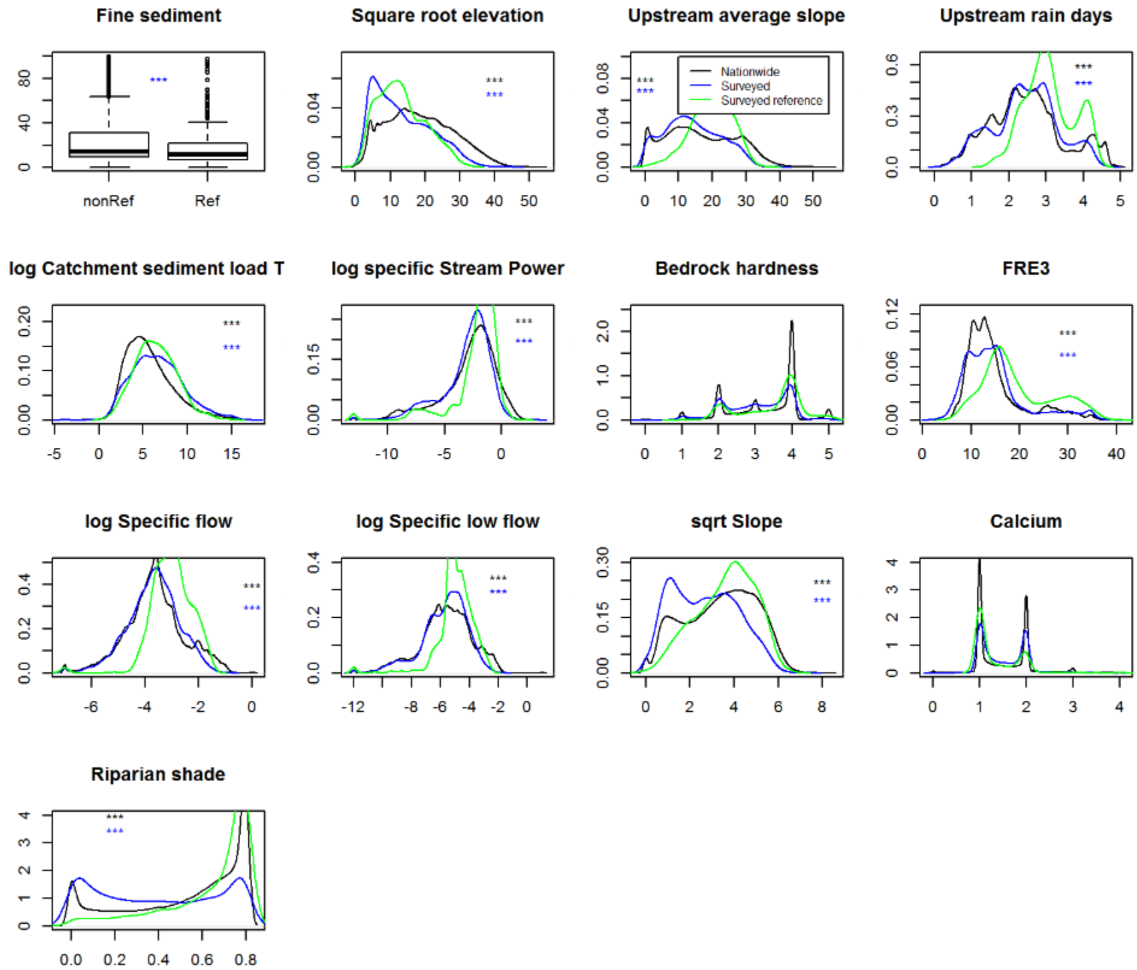

Figure 2. The distribution of reference sites and all sites in the *% cover B* dataset, relative to all stream segments in New Zealand, across continuous gradients of environmental descriptors. Stars in the top right indicate significance of the difference between the distributions of the reference sites and nationwide (black) or non-reference (blue), according to a Kolmogorov Smirnov test: *** = 0.001, ** = 0.01, * = 0.05.

4. PREDICTING REFERENCE CONDITION FOR ALL STREAM SEGMENTS

We chose to estimate sediment reference state for all stream segments using a flexible spatial regression approach—boosted regression trees (BRT; Elith et al. 2008). This machine learning method fits relationships of arbitrary form. That is, the relationship is not constrained to being linear, or quadratic, or logistic or geometric, but may rise and fall to best fit the training data. Overfitting is avoided by internal cross-validation. The model consists of many individual weak predictors, whose combined ability is a strong predictor.

We fitted the model using the *% cover B* dataset, in two steps. First we modelled sediment as a function of land cover (*Native vegetation*, *Exotic vegetation*, *Pastoral heavy*, *Pastoral light*, *Urban*, *Surface water allocation*). This preferentially assigns the effect on sediment to the land cover variables, rather than to environmental variables where they may be collinear. Variables were only retained in this step if they showed a logical relationship with sediment (necessary for resetting values to zero) and their inclusion significantly improved the percentage of deviance explained.

Then we modelled the residual variation in the land cover model using environmental variables. All environmental variables were retained in this step. Together these two steps can be used to predict contemporary sediment levels. We tested the performance of the two-step model by plotting the observed (surveyed) data against the predicted (modelled) data and calculating the following statistics:

- the Nash-Sutcliffe efficiency (NSE) statistic which indicates how well the plot of observed versus predicted fits the 1:1 line, where values greater than 0 are satisfactory but values greater than 0.5 indicate good model performance (Nash & Sutcliffe 1970)
- root mean squared deviation (RMSD) is an estimate of model uncertainty (overall departure between observed and predicted values), where smaller values indicate lower uncertainty than large values (Piñeiro et al. 2008)
- bias (Bias) which measures the average tendency of the predicted values to be larger or smaller than the observed, where positive values indicate model underestimation and negative values indicate overestimation bias.

To estimate reference state, we

1. reset all land cover variables to zero to estimate the average sediment value in the absence of anthropogenic pressures using the first step of the model
2. added the fitted functions from the second step of the model to the average sediment value to estimate the range in sediment values across the country as a function of environmental variability alone.

We tested the performance of reference predictions using the statistics described above. For BRT analyses, we used the *gbm* library of Ridgeway (2006) supplemented by scripts from Elith et al. (2008) in R (R Core Team 2014).

Four land cover variables (*Pastoral heavy cover*, *Exotic vegetation cover*, *Urban*, and *Native vegetation cover*) explained 6.3% of the variability in *% cover B* data and *Pastoral heavy cover* was the most important predictor variable (Figure 3). Environmental variables explained 17.6% of the residual variation in sediment and *Elevation* was the most important predictor variable (Figure 4).

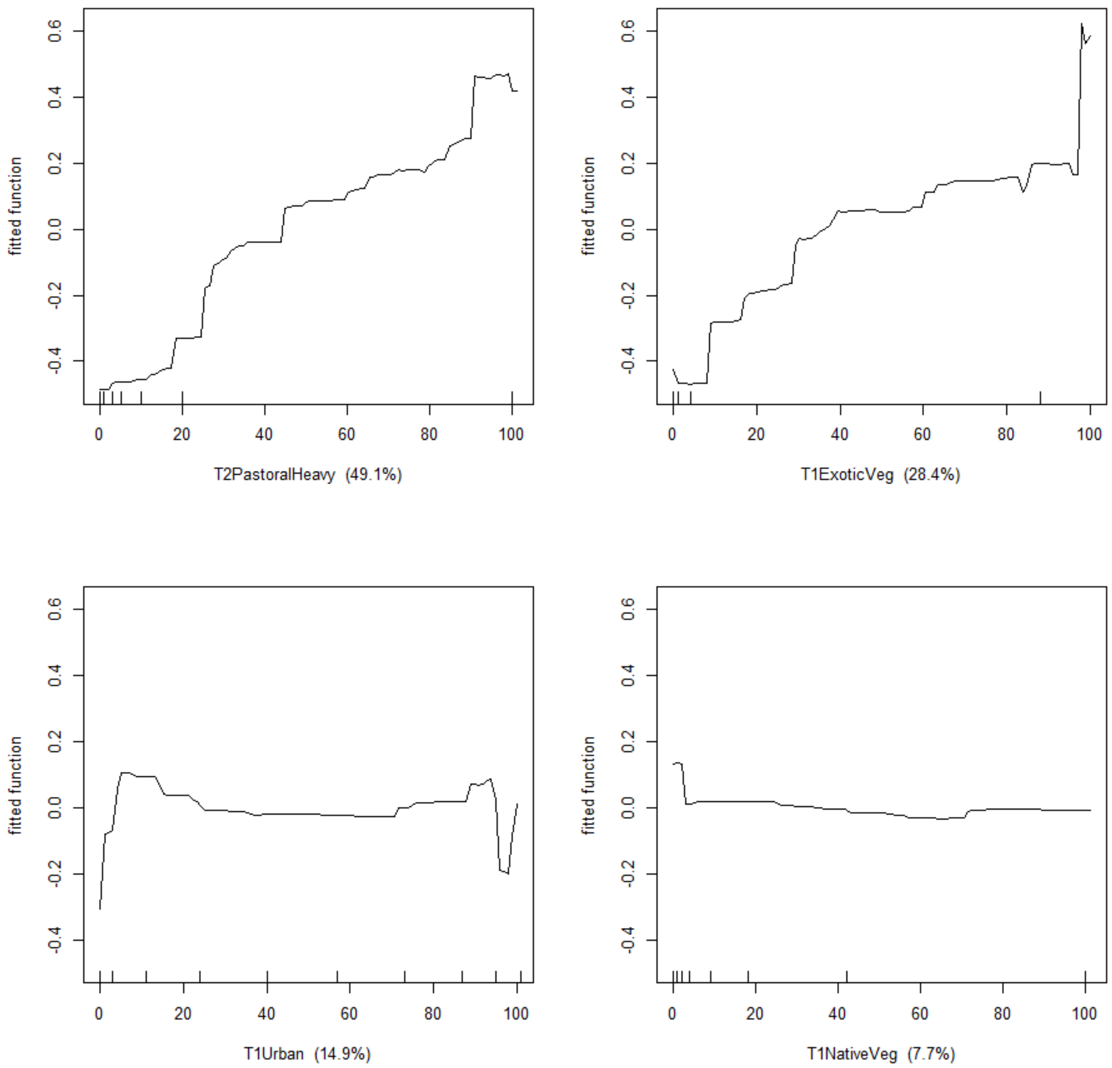

Figure 3. Shape of the relationship between land cover variables and logit transformed sediment cover *(% cover B*). The relative contribution of each predictor is given in parentheses. The y-scale shows the marginal contribution of each predictor to the mean sediment value.

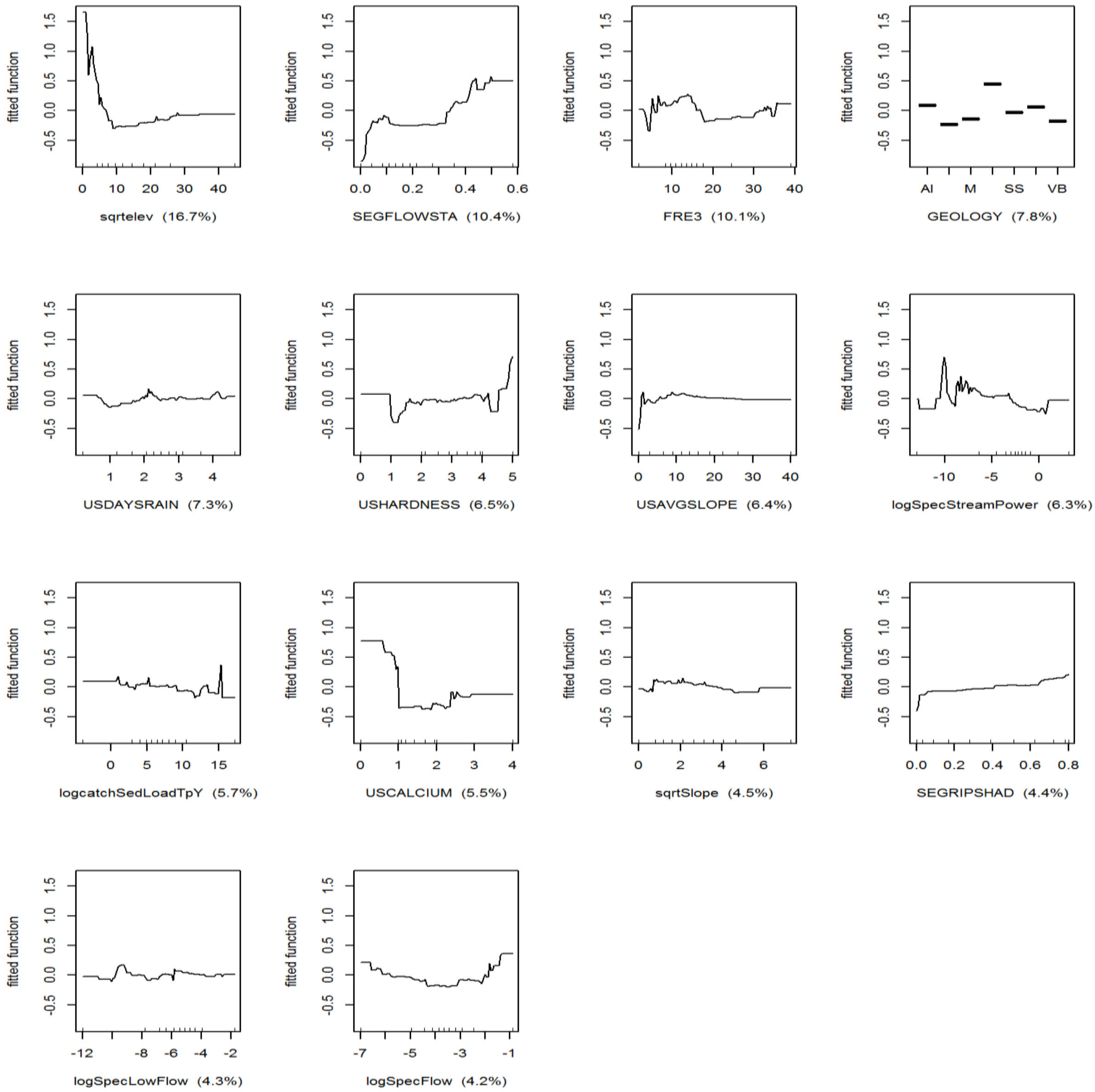

Figure 4. Shape of the relationship between environmental variables and variation in logit transformed sediment cover (*% cover B*) not explained by land cover. The relative contribution of each predictor is given in parentheses.

There was a good correlation (R = 0.51) between sediment cover observed at 8482 sites and values predicted by the two step BRT model of the *% cover B* dataset (Figure 5a). The NSE statistic suggested fair-good model performance (0.46) and there was effectively no model bias.

There was also a good correlation (0.5) between predicted reference state and observed sediment values at 1144 reference sites defined by land cover rules (Figure 5b). Other model performance statistics confirmed a fair-good predictive model: NSE = 0.46 and low bias suggested slight underestimation of sediment cover.

We predicted contemporary and reference state for all stream segments in New Zealand and viewed the map to assess if predictions seemed reasonable (Figure 6). The distribution of sediment at a national scale seems rational. For example, higher sediment values in Stewart Island and Northland were retained in reference predictions.

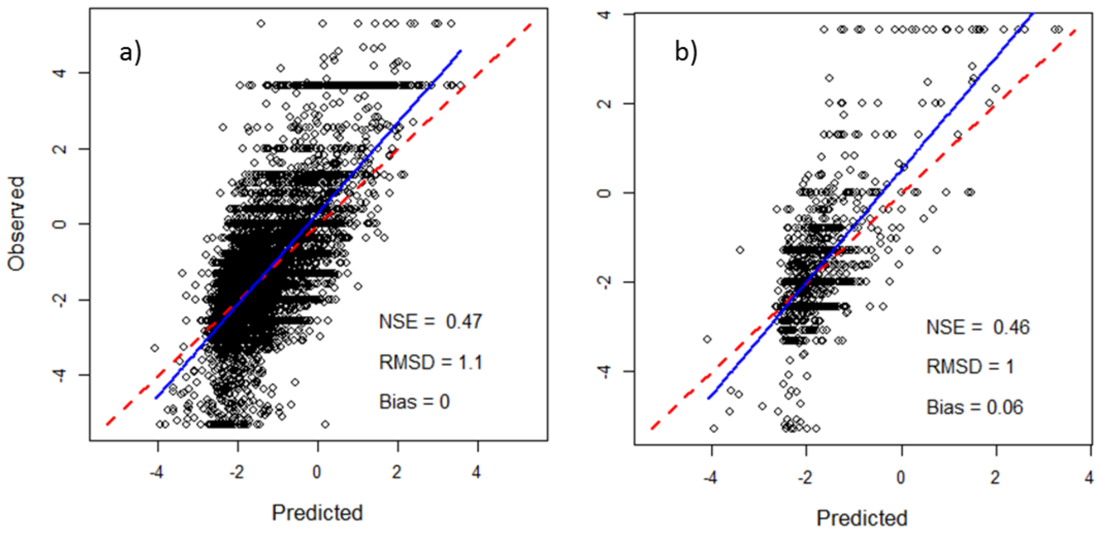

Figure 5. Scatterplots of the relationship between logit transformed observed and predicted values from a two-step BRT model for sediment cover (*% cover B*) at (a) all surveyed sites and (b) reference sites only. The dashed line is the 1:1 line and the blue line is the line of best fit. Model performance statistics are explained in text.

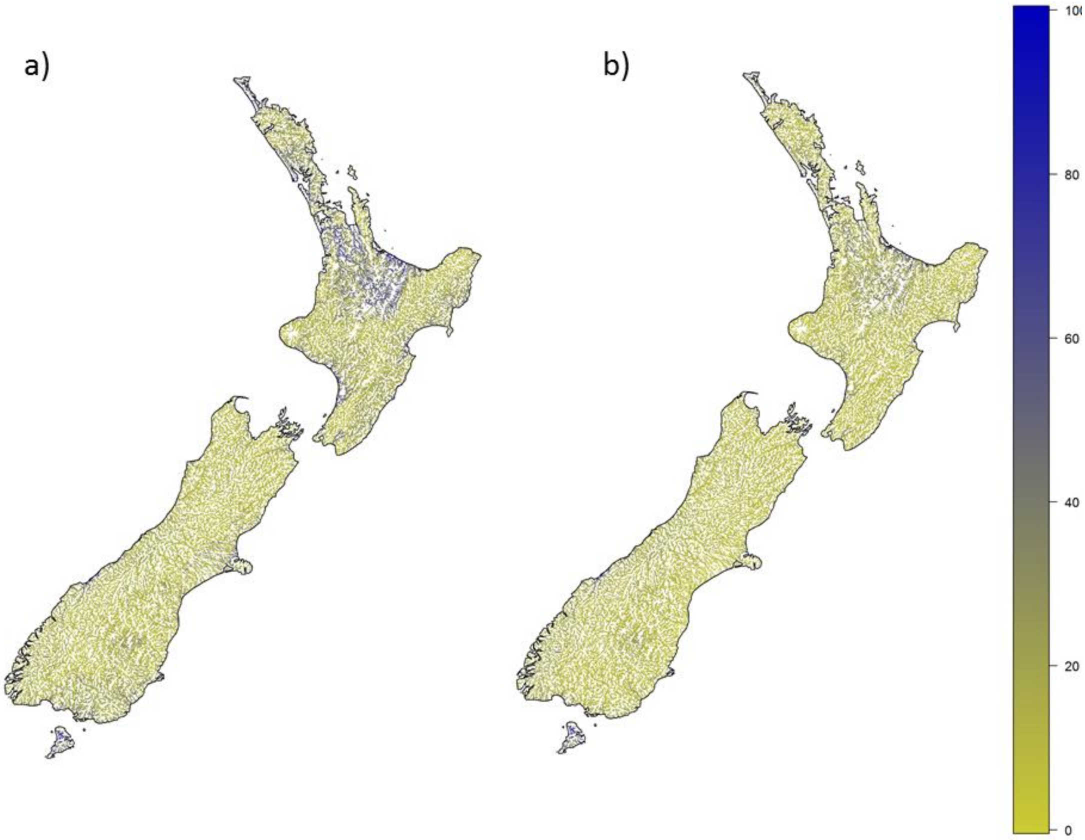

Figure 6. Map showing predicted (a) contemporary and (b) reference sediment cover from a two-step model of the *% cover B* dataset.

5. EXPLORING STREAM CLASSIFICATIONS

We used a Classification and Regression Tree (CART) method (De'ath & Fabricius 2000) to divide reference sites into a small number of categories, such as high, medium and low deposited sediment. The CART divides the training data into a small number of groups that are each internally similar (lower intra-group variance) but distinct from one another (higher inter-group variance). The division into groups is based on the environmental predictor variables, while the group variability is based on the response variable. For instance, streams divided into highland and lowland groups might exhibit quite different sediment distributions. Those groups may be further subdivided by the same or another predictor variable, and any subsequent variables can be different between groups. Thus a classification tree is built up, with all cases sorting into one of the 'leaf' nodes of the tree.

Here we developed a CART model for the:

i) *% cover B* reference site dataset (n = 1144)

ii) Nationwide predictions of sediment reference state from the two-step BRT model of *% cover B* (n = 576,273)

iii) Nationwide predictions of sediment reference state from Clapcott et al. (2011).

See appendices for CART of other datasets. CART models for all sediment datasets were developed on native units (i.e. not transformed). Each NZReach segment was weighted equally. We used the 'rpart' library (R Core Team 2014) to conduct CART analyses. We did not restrict the number of splits or resulting categories that the model could result in. CART performance was assessed using the predicted residual error sum of squares or 'PRESS' statistic, calculated using hold-one-out validation during model building.

5.1. Reference dataset

The PRESS statistic suggested poor CART model performance using the *% cover B* reference site dataset (R^2 = 0.14, n = 1144). The initial split at the head of the tree was made based on *Elevation* (≥ 18.5 m). Below that one group was split by *USSlope*, the other by flood flows *(FRE3)* (Figure 7).

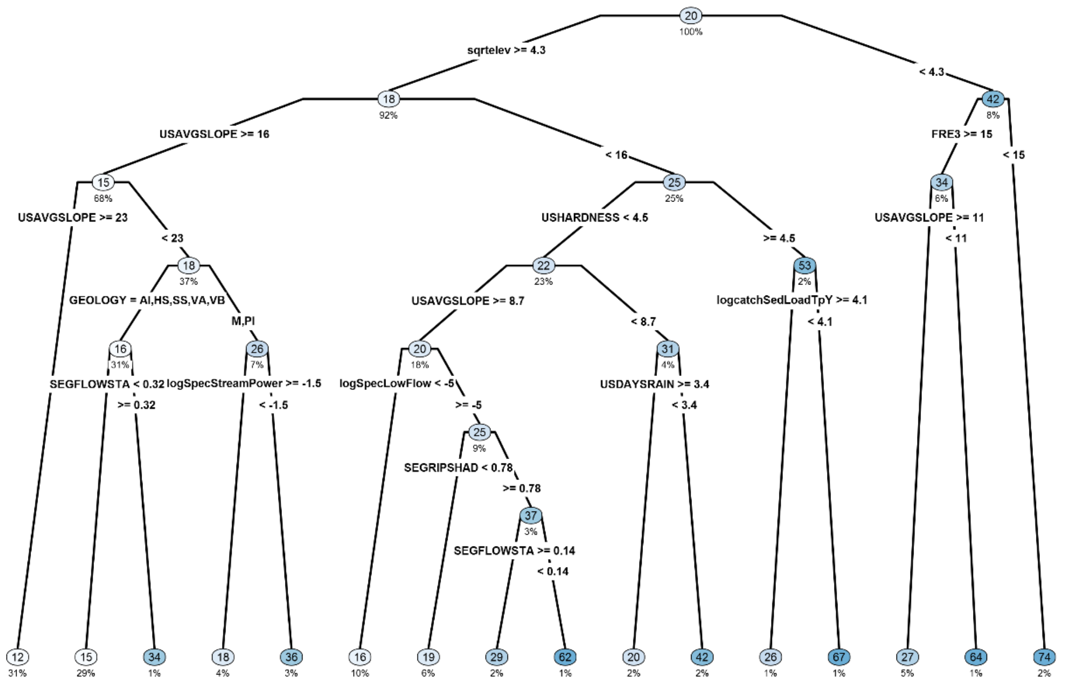

Figure 7. Decision tree structure for a classification tree model of observed sediment at reference sites from the *% cover B* dataset. Each node is labelled by the average sediment value for the group and beneath each node is the percentage of the training data. At each intermediate node is the condition that determines whether the case goes to the left or right child node.

The CART resulted in 16 classes with overlapping distributions (Figure 8). We manually assembled classes based on similar medians and distributions into three groups (Table 7). The largest group (69.1% of the stream network) had a median sediment cover value of 12%. The two categories above that had medians of 21% (26.4% of the stream network) and 83% (4.5% of the stream network). Mapped, it appears that the majority of the country should have less than 20% sediment cover in streams (Figure 9). Highest sediment cover is predicted for Group 3 streams located in low-lying areas of the country. Above 20% sediment cover is further predicted for many streams in Northland, Auckland, Waikato, Bay of Plenty, West Coast and numerous coastal streams around the country.

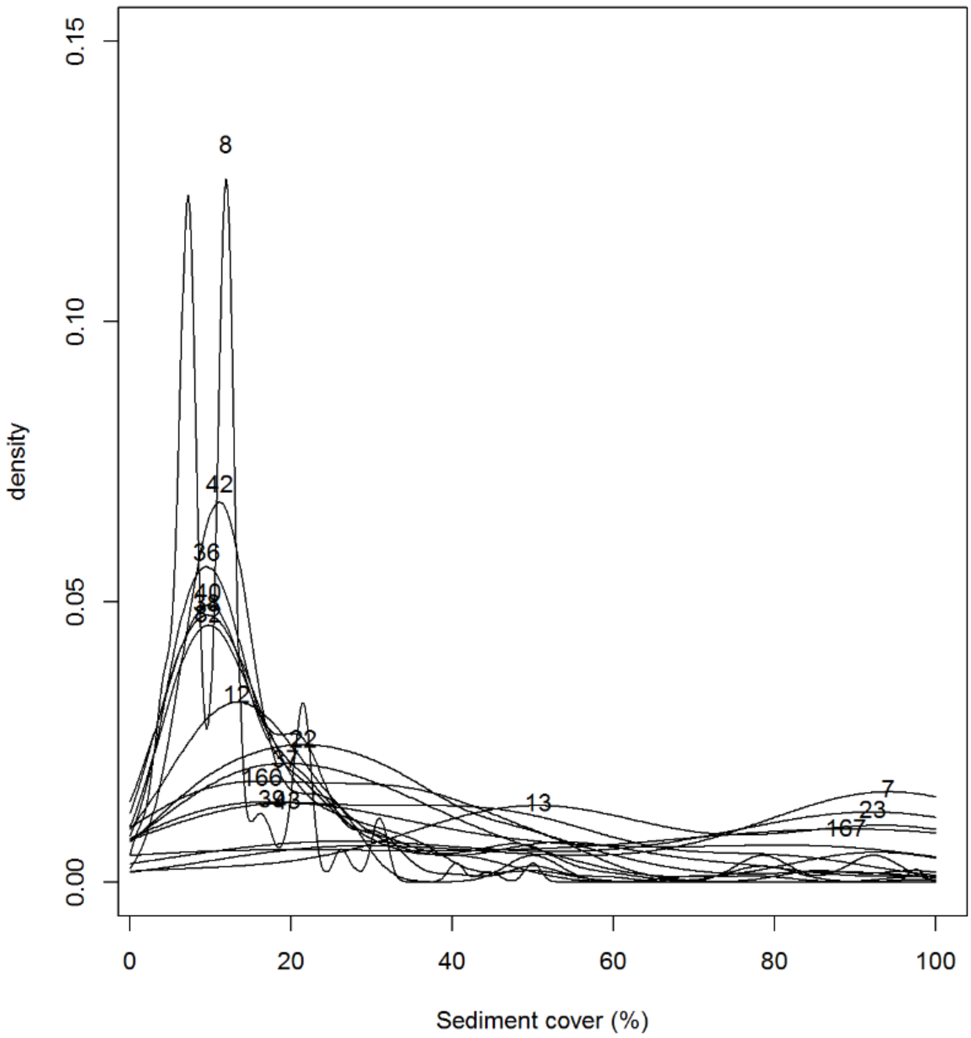

Figure 8. Distribution of sediment classes from a CART of reference sites in the *% cover B* dataset.

Table 7. Summary of sediment cover values for each lumped Group from a CART of reference sites in the *% cover B* database.

Group	Group statistics	% network	Class ID	Class medians
1	Min: 0.5	69.1%	8	12.4
	25%: 7.2		36	15.1
	Median: 12		40	16.5
	75%: 18.3		38	18.3
	Max: 97.5		82	19.4
	SD: 18.4		42	20.5
2	Min: 1.2	26.4%	22	25.6
	25%: 12		12	26.6
	Median: 21.5		166	28.9
	75%: 32.5		37	33.8
	Max: 97.5		39	36.1
	SD: 26.4		43	41.9
3	Min: 7.2	4.5%	167	61.7
	25%: 45.2		13	63.9
	Median: 83.2		23	66.7
	75%: 97.5		7	73.5
	Max: 97.5			
	SD: 31.3			

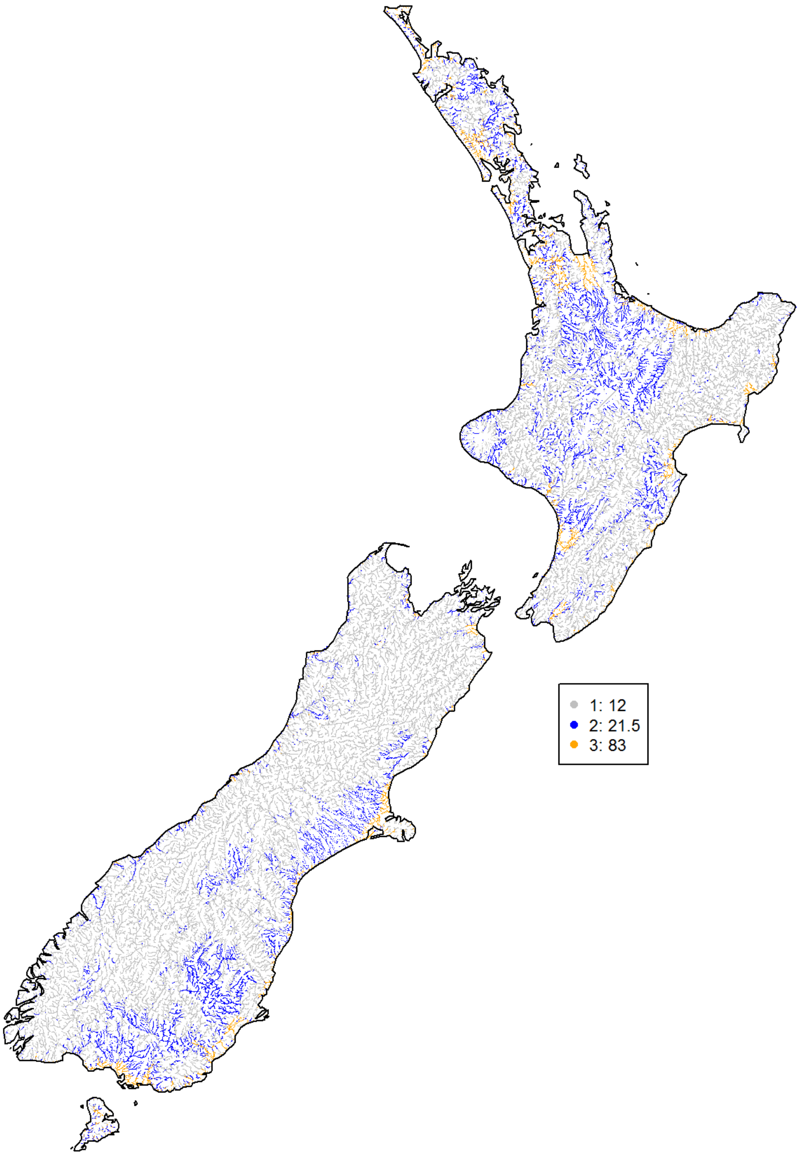

Figure 9. Map of Groups from a sediment classification based on reference sites in the *% cover B* dataset. Legend provides median sediment cover for each Group.

5.2. Predicted reference from the *% cover B* dataset

The PRESS statistic suggested good CART model performance (R^2 = 0.50) for the nationwide reference state 2-step BRT predictions (n = 576,118) from the *% cover B* dataset. The initial split at the head of the tree was made based on *Elevation* (≥ 31 m). Below that one group was split by *Geology*, the other by *USHardness.* The subsequent four child nodes were further split by flow and slope variables (Figure 10).

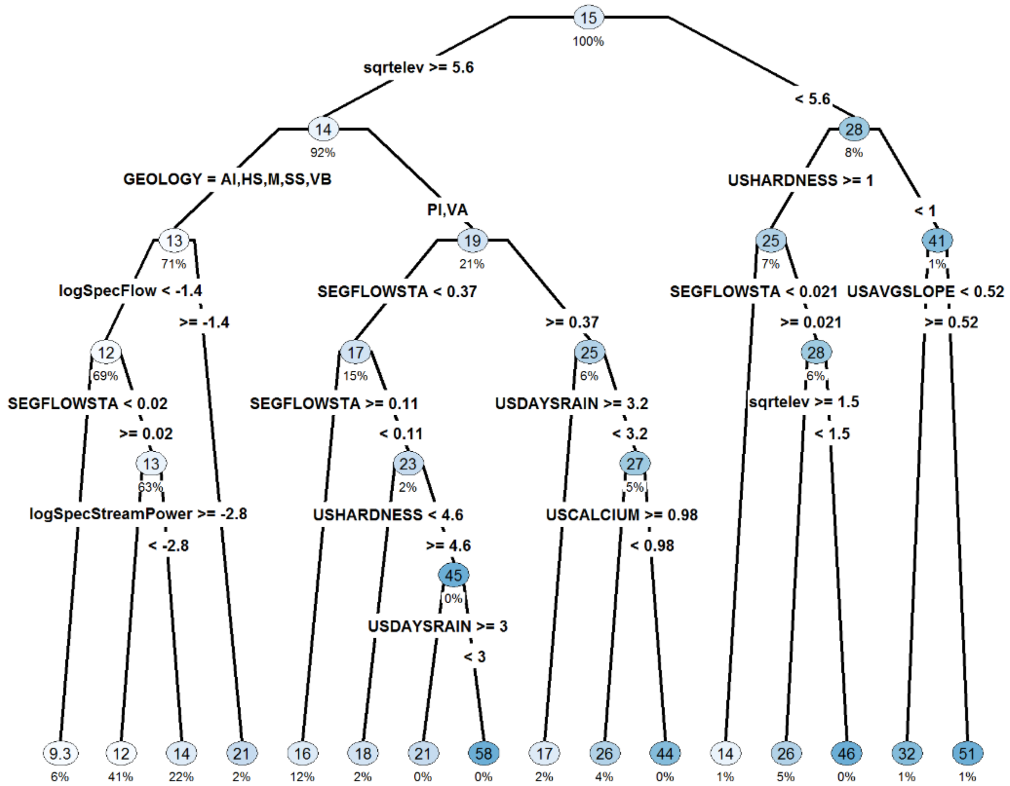

Figure 10. Decision tree structure for a classification tree model of reference sediment predictions from the *% cover B* dataset. Each node is labelled by the average sediment value for the group and beneath each node is the percentage of the training data. At each intermediate node is the condition that determines whether the case goes to the left or right child node.

The CART resulted in 16 classes with overlapping distributions (Figure 11). We manually assembled classes based on similar medians and distributions into three groups (Table 8). The largest group (85.5% of the stream network) had a median sediment cover value of 12%. The two categories above that had medians of 23% (13% of the stream network) and 49% (1% of the stream network). Mapped, it appears that the majority of the country should have less than 20% sediment cover in streams (Figure 12). Highest sediment cover is predicted for Group 3 streams located in Northland, West Coast, Stewart Island, parts of Waikato and Bay of Plenty. Above 20% sediment cover is predicted for many streams in Northland, Auckland, Waikato, Bay of Plenty, West Coast and numerous coastal streams around the country.

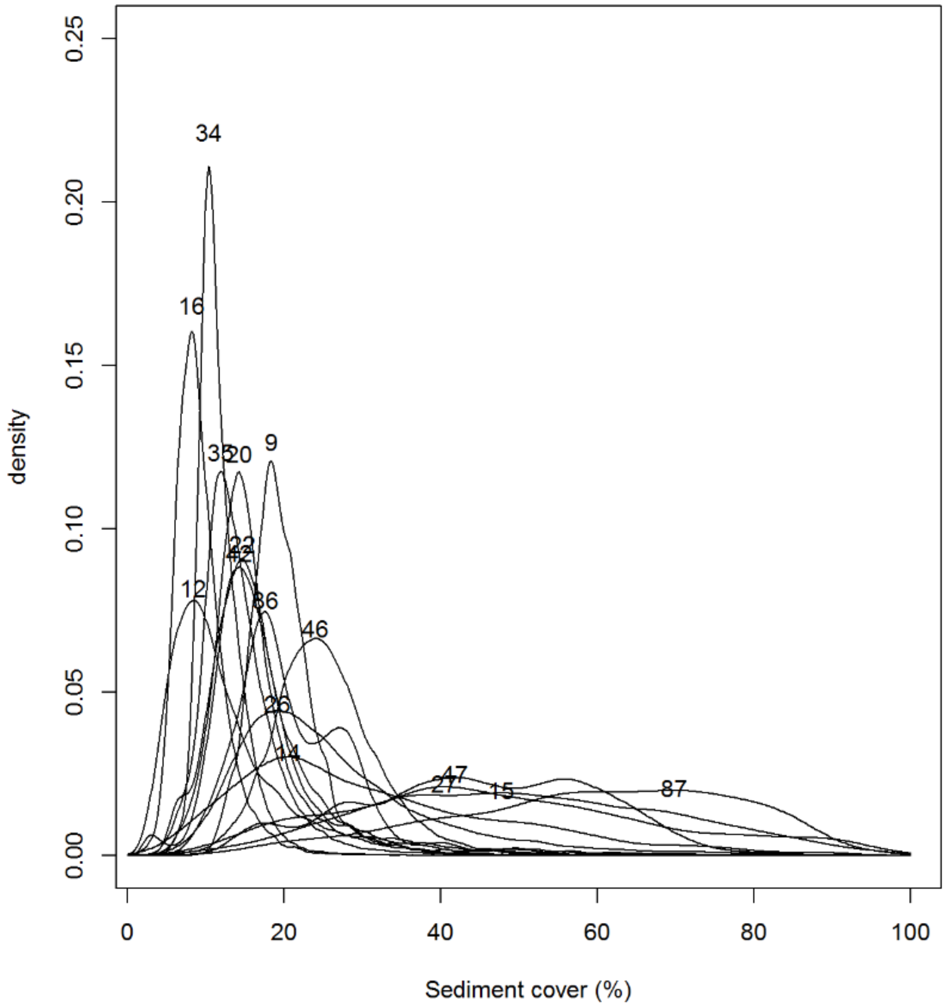

Figure 11. Distribution of sediment classes from a CART of reference sediment predictions based on the *% cover B* dataset.

Table 8. Summary of sediment cover values for each lumped group from a CART of reference sediment predictions based on the *% cover B* database.

Group	Group statistics	% network	Class ID	Class medians
1	Min: 1.5	85.5%	16	8.8
	25%: 10.8		12	10.7
	Median: 12.1		34	11.2
	75%: 14.9		35	13.3
	Max: 94.8		20	14.9
	SD: 5.1		22	15.2
			42	15.9
2	Min: 2.3	12.9%	9	19.2
	25%: 18.4		86	19.5
	Median: 22.9		26	23.3
	75%: 29.1		46	24.8
	Max: 96.6		14	27.5
	SD: 10.7			
3	Min: 5.2	1.5%	47	44.8
	25%: 36.0		27	45.2
	Median: 49.3		15	49.6
	75%: 63.1		87	60.9
	Max: 98.3			
	SD: 18.7			

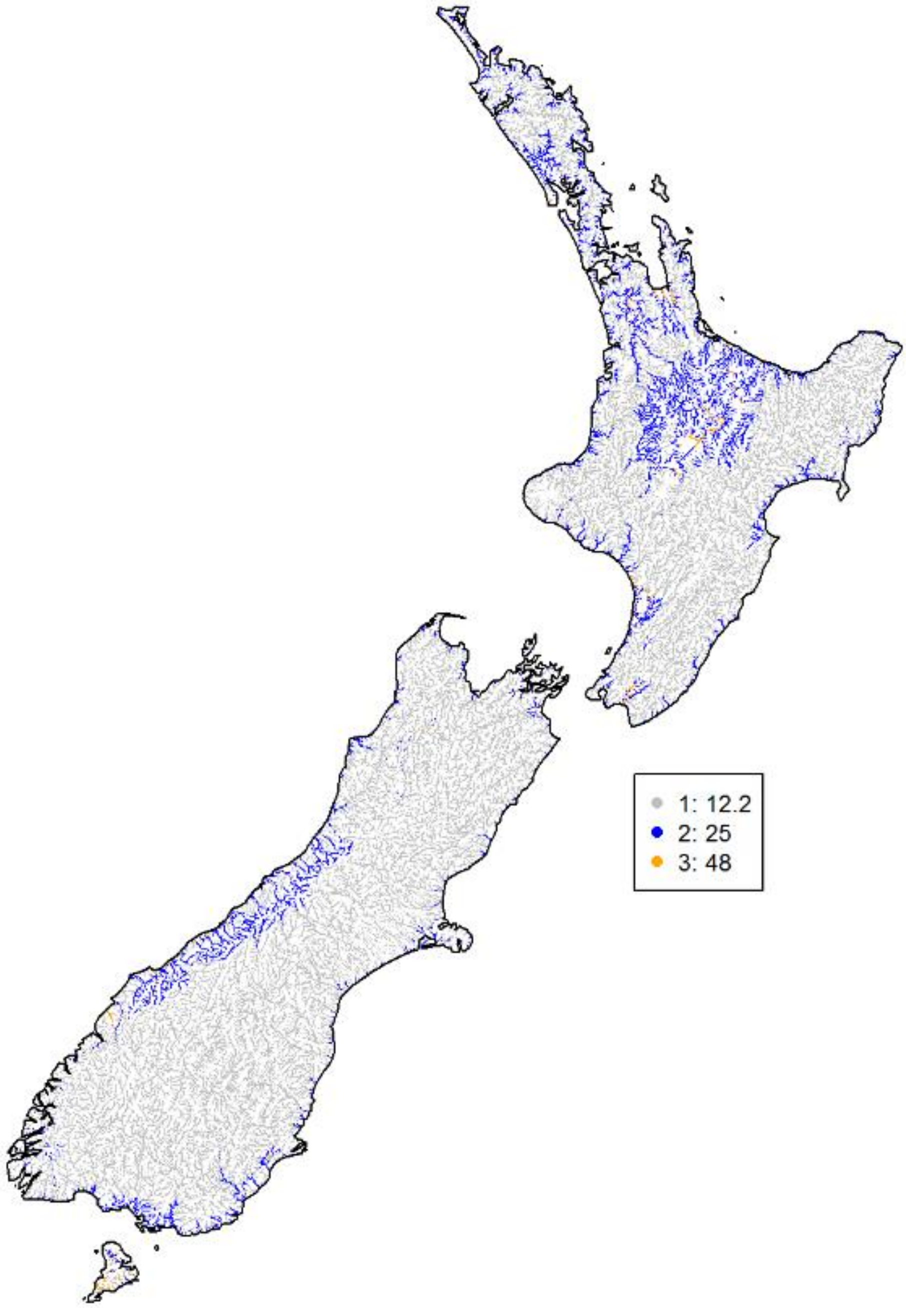

Figure 12. Map of Groups from a sediment classification based on predictions of reference condition from the *% cover B* dataset. Legend provides median sediment cover for each Group.

5.3. Predicted reference from Clapcott et al. (2011)

While good predictive model performance was achieved using the *% cover B* dataset it was not as good as that previously observed by Clapcott et al. (2011). They used the NZFFDB records post-1990 as a training dataset and, land cover and environmental variables extracted from FENZ based on LCDB1. We used a similar reset land cover approach but were only able to explain 7% plus 18% of variation in sediment data using recent land cover (LCDB3) and selected environmental variables respectively. Clapcott et al. (2011) explained 26% of the variance in sediment using area-weighted native vegetation cover, predicted logN concentration calculated from CLUES, and area-weighted impervious land covers, and explained a total 42% of the variance by adding environmental variables. Environmental variables were not chosen based on their potential mechanistic link to sediment, but instead included to provide the most optimal model in terms of predictive performance, which was assessed by 10-fold cross-validation error of 0.64 (i.e. very good model performance).

We performed an independent test of the Clapcott et al. (2011) sediment predictions by comparing their predicted values with observed values from the *% cover A* dataset (n = 94). There was a moderate correlation between observed and predicted contemporary sediment (R = 0.36, n = 1393) as well as observed and predicted reference sediment (R = 0.30, n = 94).

Based on the good predictive model performance observed by Clapcott et al. (2011) we decided to develop a CART based on their nationwide predictions of sediment reference values. The resulting PRESS statistic suggested good CART model performance (R^2 = 0.32) for the Clapcott et al. (2011) nationwide reference state predictions. The initial split at the head of the tree was made based on *Specific stream power* (0.05). Below that one group was split by *USSlope*, the other by *USDaysRain* (Figure 13).

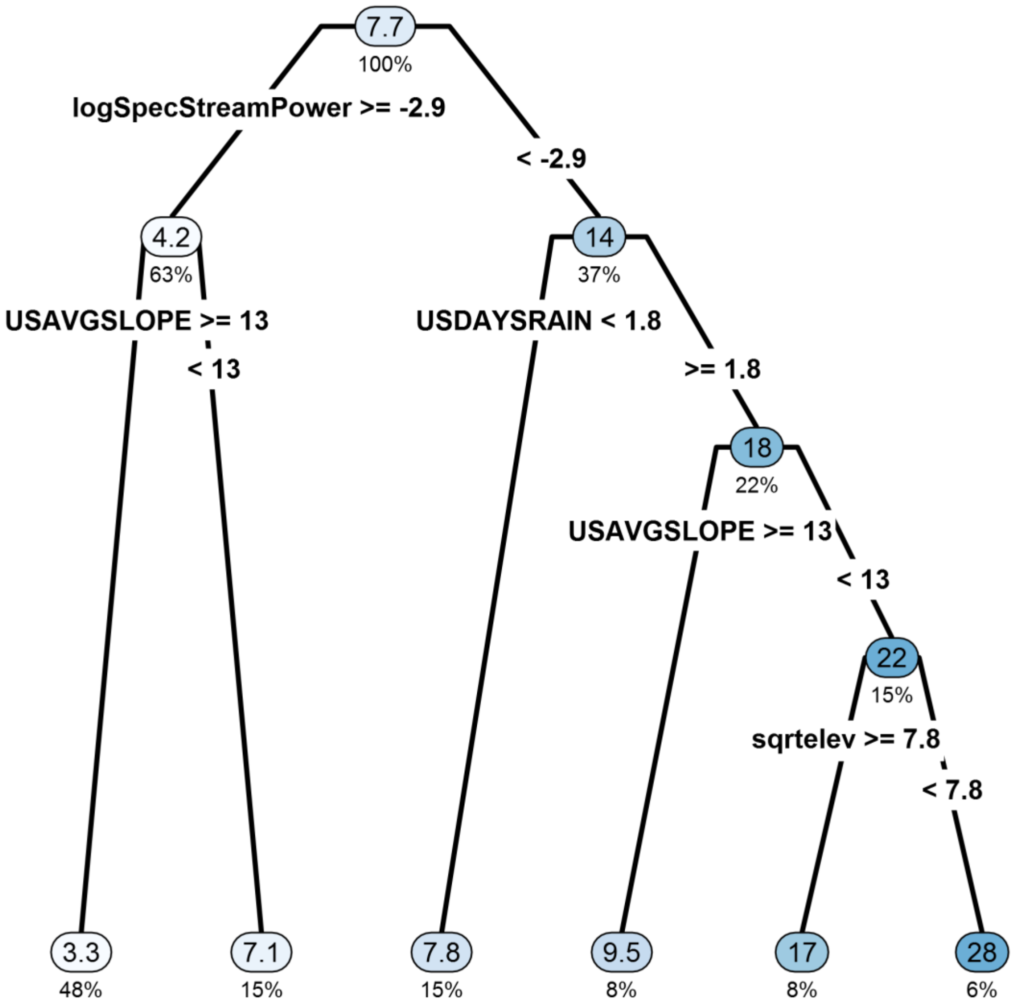

Figure 13. Decision tree structure for a classification tree model of reference sediment predictions from Clapcott et al. (2011). Each node is labelled by the average sediment value for the group and beneath each node is the percentage of the training data. At each intermediate node is the condition that determines whether the case goes to the left or right child node.

The CART resulted in 6 classes with strongly overlapping distributions (Figure 14). We manually assembled classes based on similar medians and distributions into two groups (Table 9). The largest group (93.7% of the stream network) had a median sediment cover value of 3%. The other category had a median of 24% (6.3% of the stream network) and 48% (1% of the stream network). Mapped, it appears that the majority of the country should have less than 20% sediment cover in streams (Figure 15). Above 20% sediment cover is predicted for many streams in Northland, Auckland, Waikato, Bay of Plenty, and numerous coastal streams around the country.

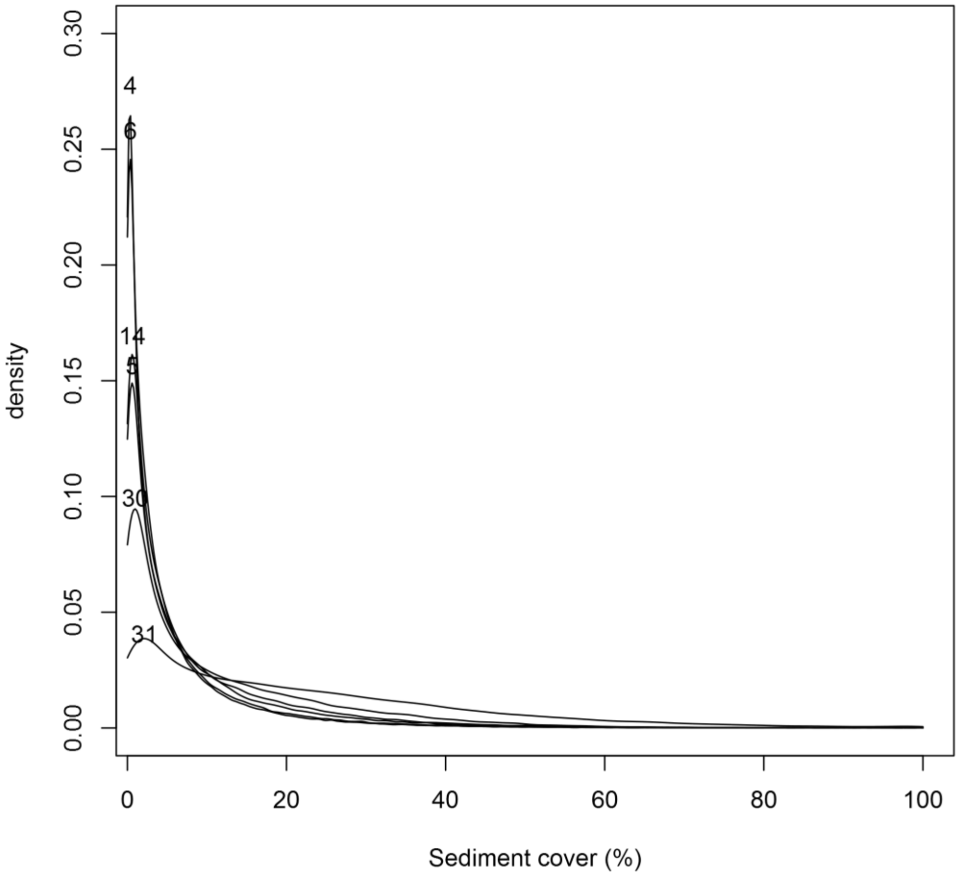

Figure 14. Distribution of sediment classes from a CART of reference sediment predictions based Clapcott et al. (2011).

Table 9. Summary of sediment cover values for each lumped group from a CART of reference sediment predictions from Clapcott et al. (2011).

Group	Group statistics	% network	Class ID	Class medians
1	Min: 0	93.7%	4	1.7
	25%: 0.7		5	3.7
	Median: 2.8		6	3.8
	75%: 8.5		14	5.6
	Max: 100		30	13.9
	SD: 10.1			
2	Min: 0	6.3%	31	24.1
	25%: 5.2			
	Median: 24.1			
	75%: 32.3			
	Max: 100			
	SD: 20.0			

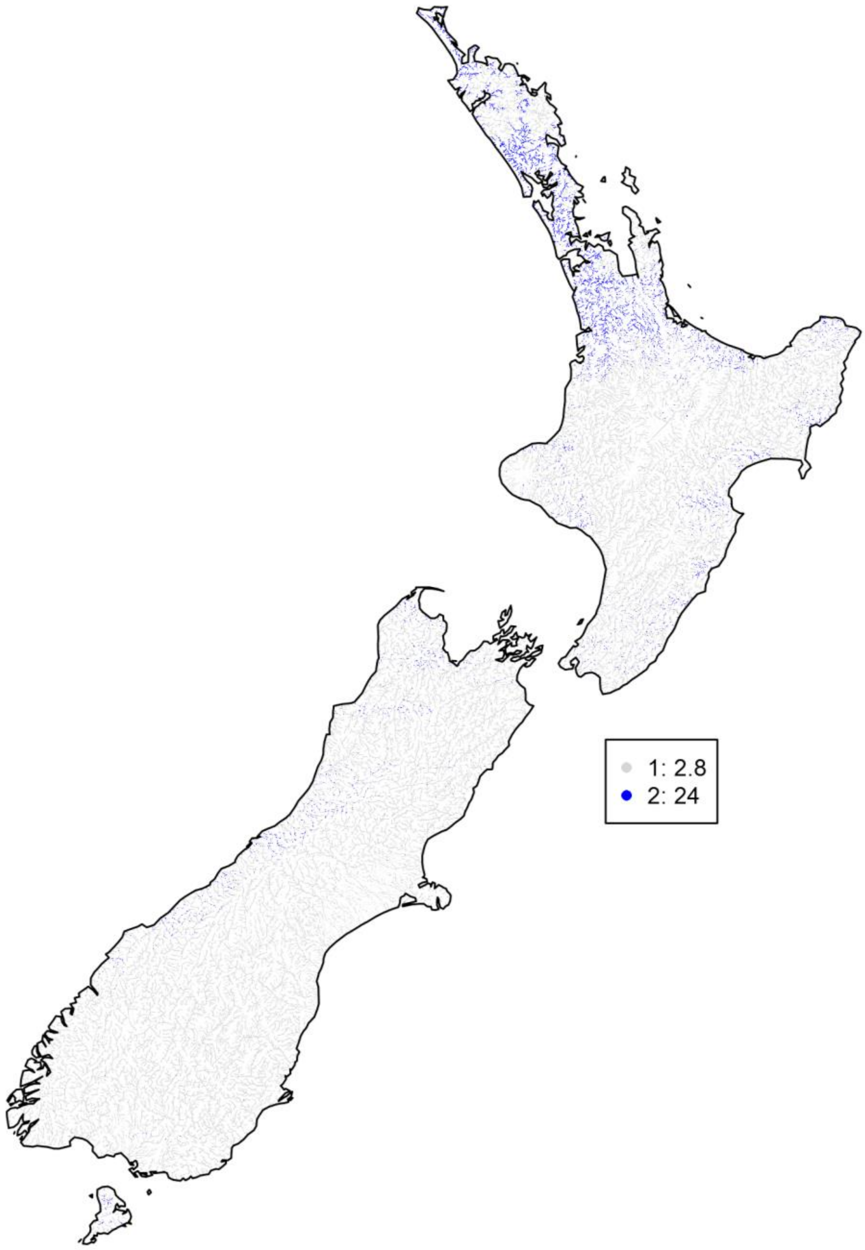

Figure 15. Map of Groups from a sediment classification based on predictions of reference condition from Clapcott et al. (2011).

6. SUMMARY OF REFERENCE CONDITION BY REC

6.1. Reference site dataset

We grouped nationwide reference site data from the *% cover B* dataset by the various components of the REC classification: climate, source of flow, geology, and land cover. Testing for difference between pairs within these categories suggests that few have distinct sediment values (Figure 16). The majority of REC groupings average less than 20% sediment.

- For Climate, all class medians are less than 16%, except for warm-dry climates where there was only 1 site (WD = 97%)
- For Source of Flow, all class medians are less than 15%, except for lake-fed streams (Lk = 27.5%) and no representation in glacial mountain streams
- For Geology, all class medians are less than 20%
- For Land cover, all class medians are less than or equal to 15%, except wetlands (W = 83%) and no class representation for those land covers excluded by our rules: exotic forests, pasture, and urban streams.

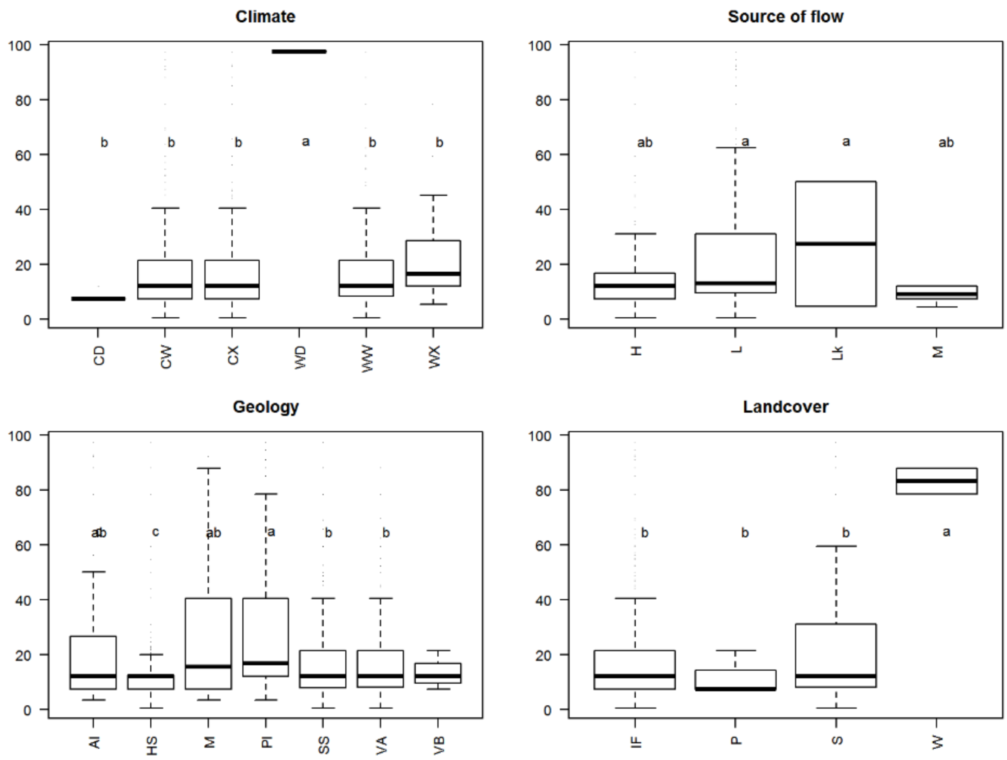

Figure 16. Box plots of sediment at reference sites in the *% cover B* dataset grouped by REC groups Climate, Source of flow, Geology, and Land cover. Letters indicate a significant difference between groups (Tukey's $p < 0.05$).

6.2. Predicted reference from the *% cover B* dataset

We grouped nationwide reference state predictions from the *% cover B* dataset by the various components of the REC classification: climate, source of flow, geology, and land cover. Testing for difference between pairs within these categories suggests that the bulk of them have distinct sediment values (Figure 17). The majority of REC groupings average less than 15% sediment.

- For Climate, all class medians are less than 15% except warm dry (WD = 16.4%)
- For Source of Flow, all class medians are less than 15% except lakes (Lk = 15.2%) and glacial mountain (GM = 16.3%)
- For Geology, all class medians are less than 15% except plutonic (Pl = 16.4%) and volcanic-acidic (VA = 17.1%)
- For Land cover, all class medians are less than 15% except mines and dumps (M = 17%), urban (U = 17%) and wetlands (W = 27.7%).

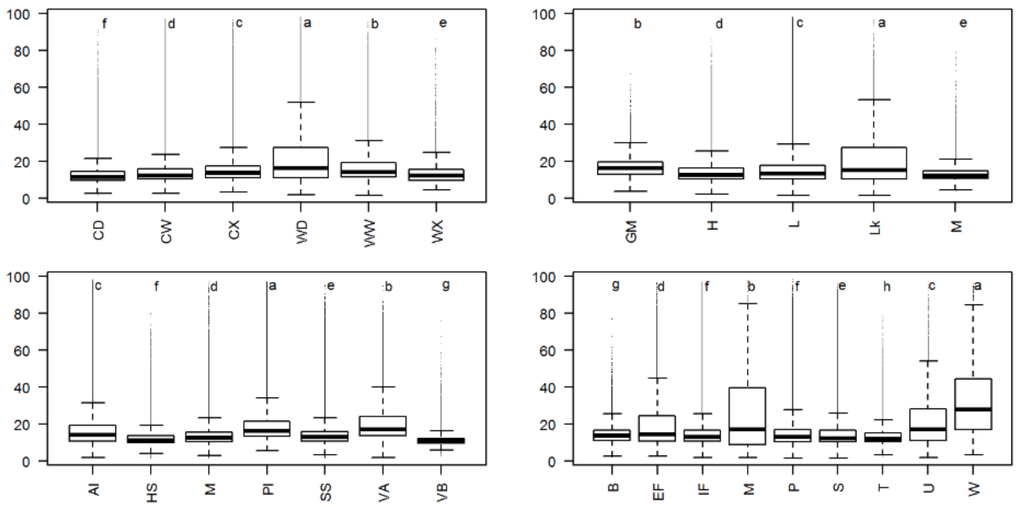

Figure 17. Box plots of sediment reference state predicted from the *% cover B* dataset grouped by REC groups Climate, Source of flow, Geology, and Land cover. Letters indicate a significant difference between groups (Tukey's $p < 0.05$).

6.3. Predicted reference from Clapcott et al. (2011)

We grouped nationwide reference state predictions from Clapcott et al. (2011) by the various components of the REC classification: Climate, Source of flow, Geology, and Land cover. Testing for difference between pairs within these categories suggests that the bulk of them have distinct sediment values (Figure 18). All REC groupings average less than 15% sediment, except Land cover mines and dumps (M = 17%), and wetlands (W = 21.7%).

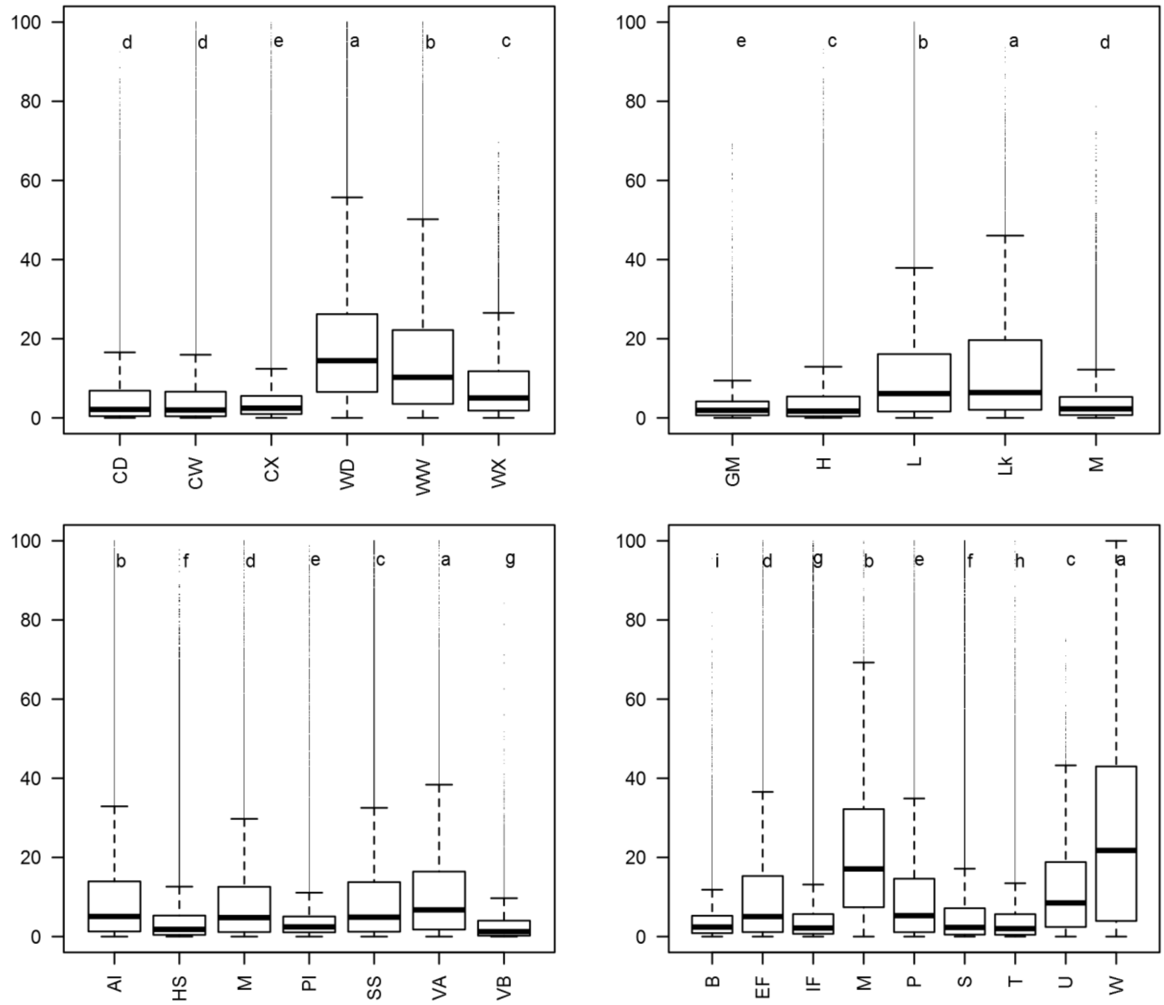

Figure 18. Box plots of sediment at reference sites from Clapcott et al. (2011) grouped by REC groups Climate, Source of flow, Geology, and Land cover. Letters indicate a significant difference between groups (Tukey's $p < 0.05$).

7. SUMMARY AND RECOMMENDED SEDIMENT CLASSIFICATION

Streams vary across the country in the amount of fine sediment deposited on their streambeds. The observed average percentage of fine sediment cover at reference sites defined by land cover rules ranged from 1% to 97.5%. Despite low model performance, a CART partitioned sites into classes which showed meaningful spatial patterns at the national scale. We grouped these classes and the resulting three Groups were defined by average sediment values of 12%, 21% and 83%. Standard deviation within the Groups suggest it may not be possible to discriminate the first two groups which together account for 95% of all stream segments nationally.

We were able to attribute a moderate amount of the national-scale variation to land cover and natural environmental gradients at the segment scale using flexible spatial regression. Unexplained variation may be due to finer scale processes that affect sediment distribution such as velocity and bed roughness, sediment quality such as organic content and particle size, or temporal variation, none of which were accounted for in our models. As such, our ability to accurately estimate reference condition was restricted by the strength of explanatory models and a lack of representative reference sites. However, examination of four different data sets provided a body of evidence from which some inferences can be made.

The reference value of 15% sediment cover appears to be a natural break in the distribution of predicted sediment values for the country. Reference predictions based on the *% cover A* and *% cover B* datasets, as well as Clapcott et al. (2011) predictions, suggest that the majority of streams in New Zealand would naturally have less than 15% sediment cover. The CART analyses further grouped these predictions into similar classes that when mapped provide reasonable spatial patterns at a national scale. There are some predictions however that do not make sense, such as high sediment cover in the Southern Alps. We think this illustrates that the model does not perform well at the extreme ends of environmental ranges, e.g. high altitudes. This would be expected when using a BRT model as they are built on average values and cannot extrapolate beyond the training data range.

The grouping of reference data by REC classes shows most class medians are below either 20% (observed data) or 15% (predicted data) sediment cover. Exceptions include streams in warm dry climates, with lake-fed or glacial mountain source of flow, or plutonic and volcanic-acidic geologies. However, the 75%-iles of many groups do range higher than 20% or 15% respectively. So using REC classes alone may not be the most sensitive discrimination of sediment distributions for management. Higher reference values predicted for mines and dumps, and urban suggests these land covers are not fully accounted for in the predictive models.

We recommend that a combination CART analyses of *% cover B* reference site data and *% cover B* reference predictions are used to inform a two Group classification of New Zealand streams. However, we do not recommend the CART model output be used in isolation to inform the classification. Instead it seems reasonable to use this classification as a basis for regional verification of exceptions to the < 20% sediment cover class. According to the *% cover B* data, the bulk of such exceptions appear to be located in areas that we would expect to see high sediment cover naturally due to low slope, low elevation and erodible geologies such as north of Kaipara, the Volcanic Plateau, and wetland areas for example.

We think the next steps include:

1. Development of sediment attribute bands. Once we know what levels of sediment biota are responsive to, we can look closer at the sediment cover percentages that best delineate Groups. Current models suggest somewhere between 15% and 20% would differentiate between Group 1 and Group 2. Furthermore, confirmation or otherwise, of biota sensitivity to high levels of deposited sediment would determine the necessity and potential sediment cover level for Group 3.
2. Revisit the classification at a regional scale. We think our analyses are limited to some degree by data representativeness and accuracy at a national scale. Collecting more data at identified under-representative environmental gradients may help. In the meantime, we think the quickest route to defining a sediment classification for NOF application is to use expert knowledge at a regional scale to confirm Group membership.

8. ACKNOWLEDGEMENTS

Thanks to Doug Brooker and Craig Depree (NIWA) for providing constructive feedback on early iterations of data exploration and model development.

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10. APPENDICES

Appendix 1. *% Cover A*

Exploring variation at reference sites

We explored the distribution of sites in the *% cover A* dataset (including RHA100, SAM1 and SAM2 data) at a national spatial scale (Figure A1.1) and across continuous environmental gradients (Figure A1.2) to assess their representativeness. Large areas of the country have no observations including Stewart Island and very few reference sites located in the South Island (Figure A1.1). There was a significant difference between distributions for most environmental gradients when tested with a Kolmogorov-Smirnov test (Conover 1971); reference sites differed compared to the national network for all gradients except USHardness and USCalcium (Figure A1.2). These explorations suggest the *% cover A* dataset may not be suitable for developing a representative sediment classification, but data could be used to predict reference condition for all stream segments to develop a stream classification.

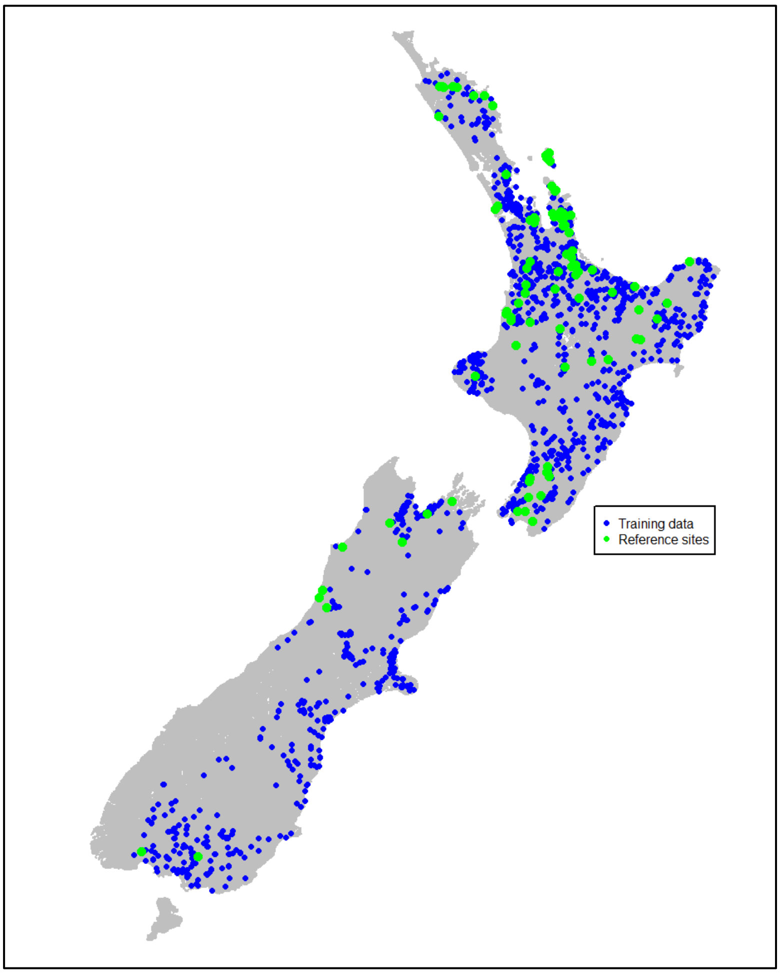

Figure A1.1. Distribution of reference sites and all surveyed (training) sites where *% cover A* data were collected.

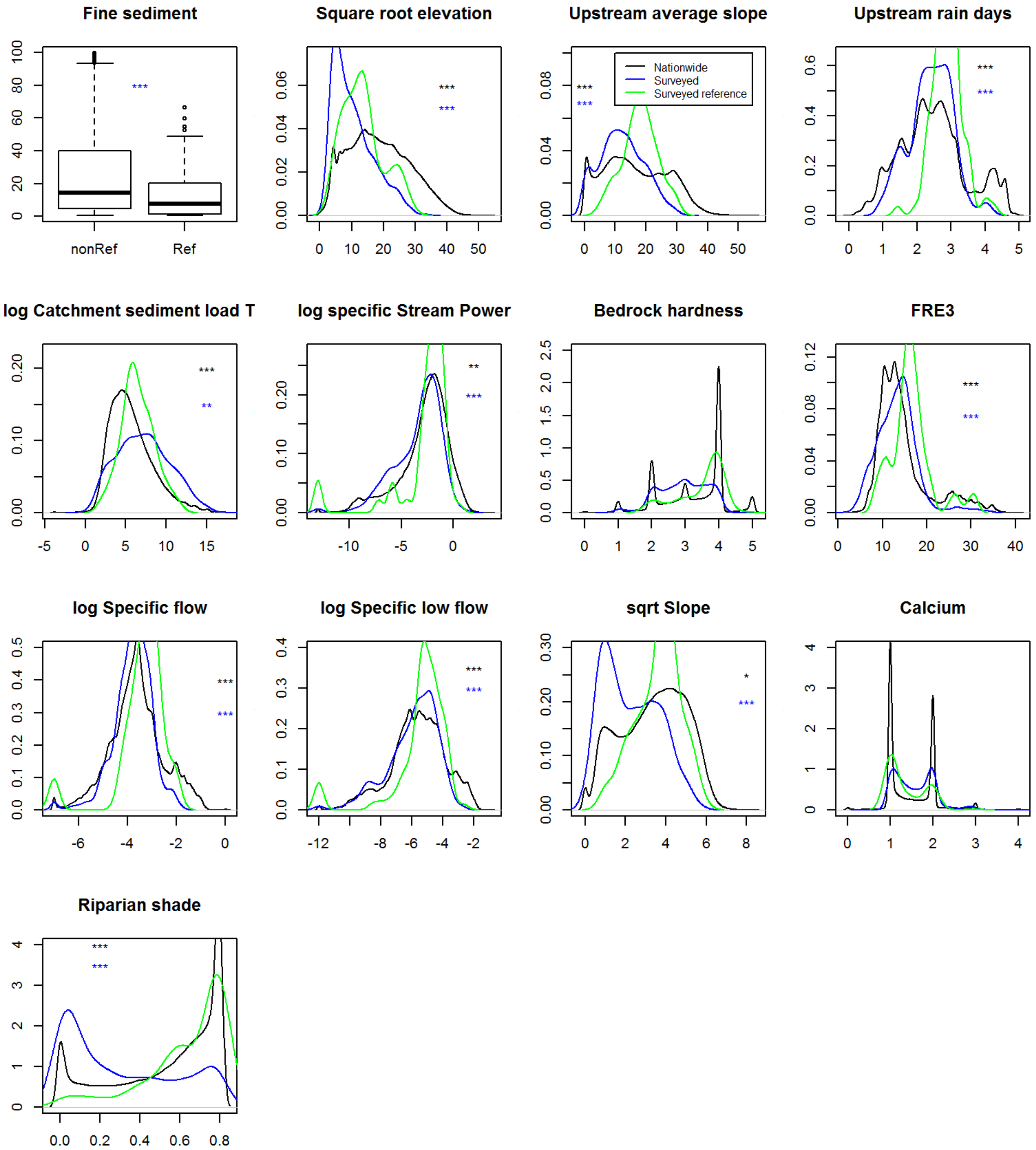

Figure A1.2. The distribution of reference sites and all sites in the *% cover A* dataset relative to all stream segments in New Zealand, across continuous gradients of environmental descriptors. Stars in the top right indicate significance of the difference between the distributions of the reference sites and nationwide (black) or non-reference (blue), according to a Kolmogorov Smirnov test: *** = 0.001 ** = 0.01 * = 0.05.

There was insufficient data (n = 94) to develop a classification based on reference site data in the *% cover A* dataset.

Predicting reference condition for all stream segments

Four land cover variables explained 7.3% of the variability in *% cover A* data, with sediment showing a logical response to each variable (Figure A1.3). *Pastoral heavy cover* was the most important land cover variable. Environmental variables explained 23.3% of the residual variation in sediment. Sediment cover showed a logical relationship with most environmental variables (Figure A1.4). For example, sediment increased in response to increasing *USDaysRain* and *Flow stability*, and decreased in response to increasing *Elevation* and *Stream power*.

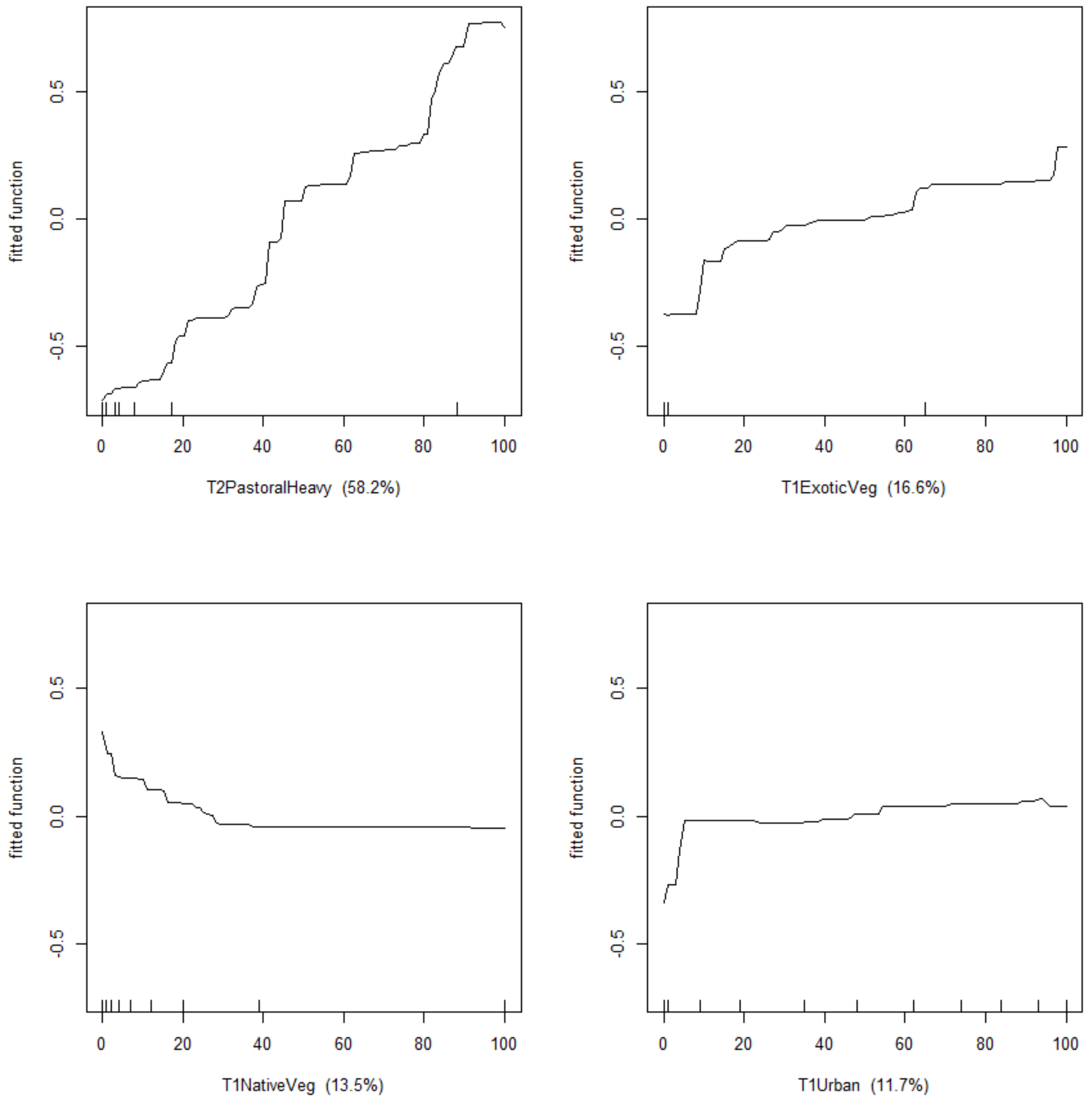

Figure A1.3. Shape of the relationship between land cover variables and logit transformed sediment cover *(% cover A*). The relative contribution of each predictor is given in parentheses.

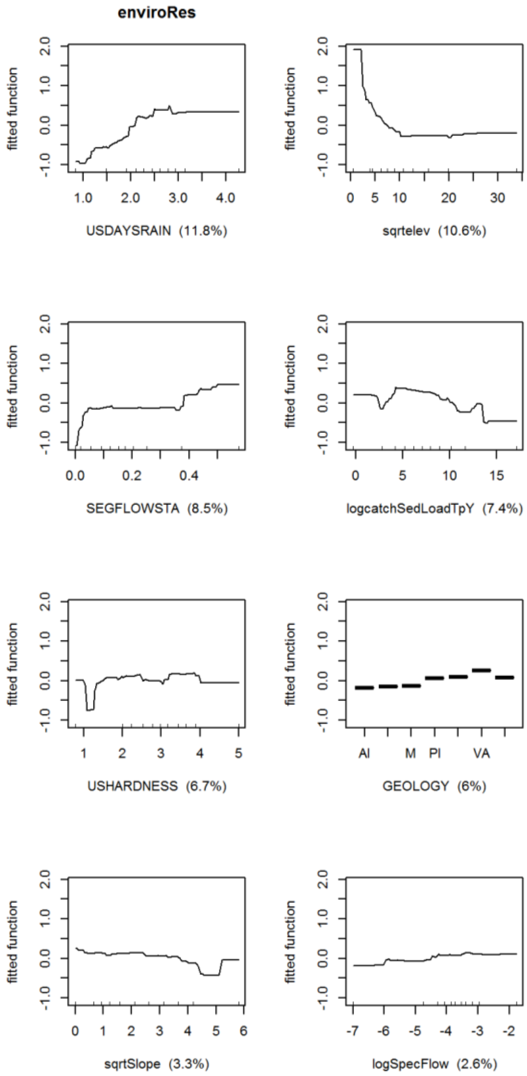

Figure A1.4. Shape of the relationship between environmental variables and variation in logit transformed sediment cover (*% cover A*) not explained by land cover. The relative contribution of each predictor is given in parentheses.

There was a good correlation (R = 0.6) between sediment cover observed at 1393 sites and values predicted by the two step BRT model of the *% cover A* dataset (Figure A1.5a). The NSE statistic suggested good model performance and there was effectively no model bias. There was also a good correlation (R = 0.59) between predicted reference state and observed sediment values at 94 reference sites defined by land cover rules (Figure A1.5b). Other model performance statistics showed a fair-good fit to the 1:1 line (NSE = 0.49) and effectively no bias.

We predicted contemporary and reference state for all stream segments in New Zealand and viewed the map to assess if predictions seemed reasonable

(Figure A1.6). There were no higher contemporary sediment values predicted for the South Island.

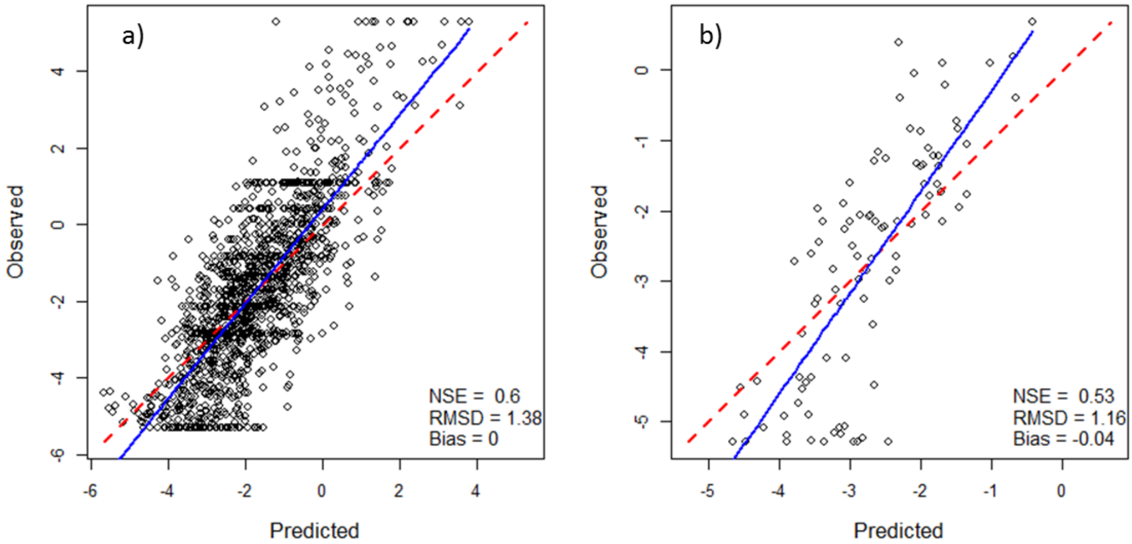

Figure A1.5. Scatterplots of the relationship between logit transformed observed and predicted values from a two-step BRT model for sediment cover (*% cover A*) at (a) all surveyed sites and (b) reference sites only. The dashed line is the 1:1 line and the blue line is the line of best fit. Model performance statistics are explained in text.

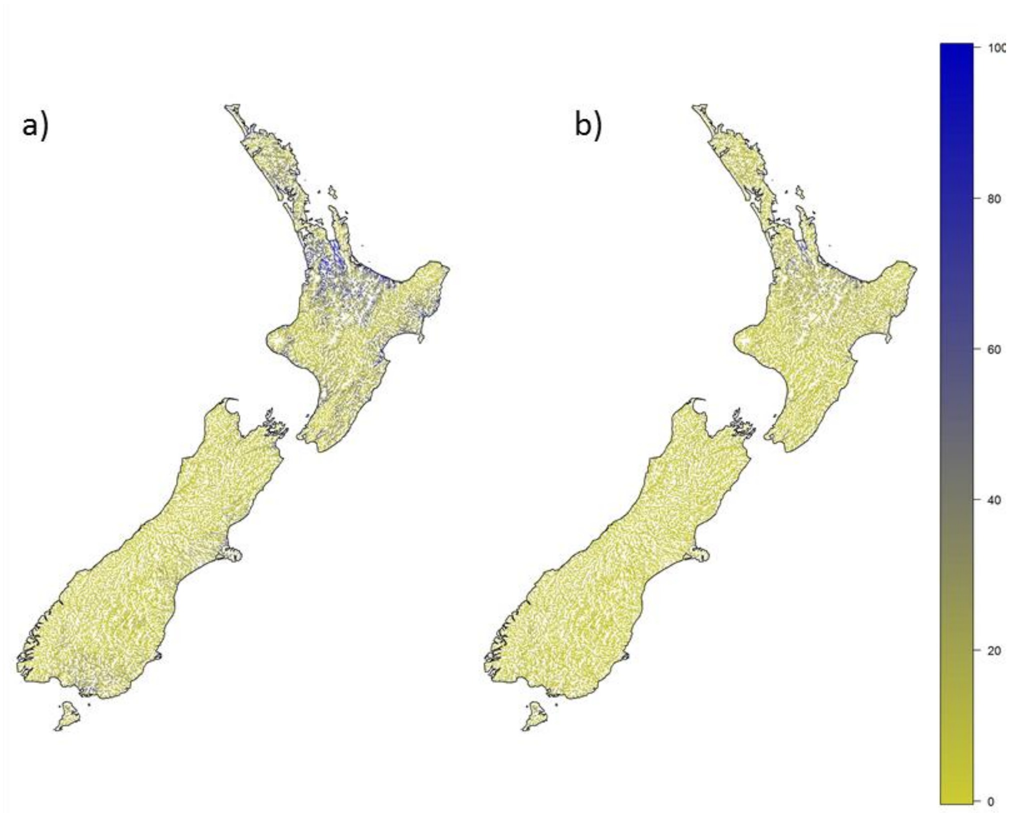

Figure A1.6. Map showing predicted sediment cover (%) from a two-step model of the *% cover A* dataset for (a) contemporary state and (b) reference state.

Exploring stream classifications for predicted reference condition

The PRESS statistic suggested good CART model performance (R^2 = 0.54). The initial split at the head of the tree was made based on *Geology*. Below that one group was split by *Elevation*, the other by *USSlope* (Figure A1.7).

The CART resulted in 18 categories with overlapping distributions (Figure A1.8). We manually lumped categories based on their similar distributions into three classes (Table A1.1). The largest class (90.2% of the stream network) had a median sediment cover value of 3.8%. The two categories above that had medians of 15.6% (9.5% of the stream network) and 60.9% (0.3% of the stream network). Mapped it appears most of the country should have less than 20% sediment cover in streams (Figure A1.9). Higher sediment cover values are predicted for parts of Waikato and Bay of Plenty.

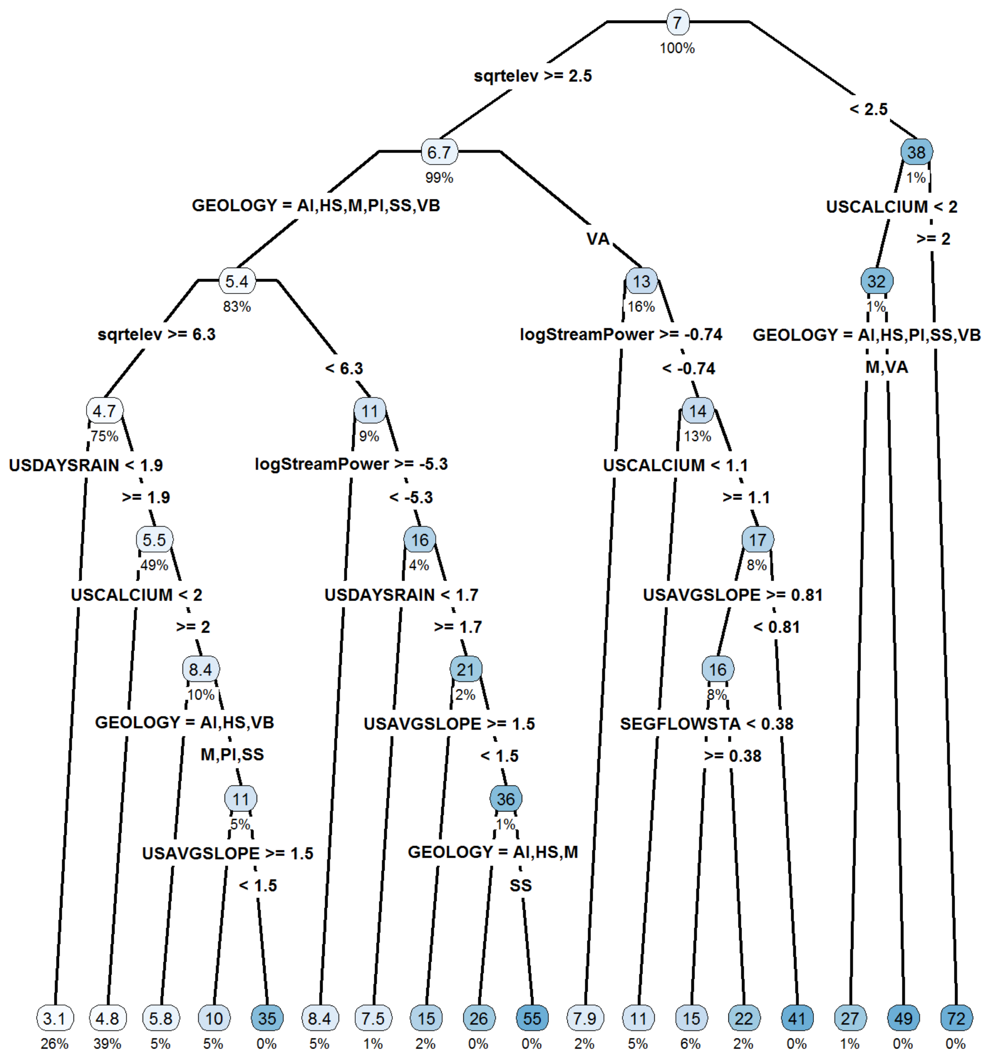

Figure A1.7. Decision tree structure for a classification tree model of reference sediment predictions from the *% cover A* dataset. Each node is labelled by the average sediment value for the group and beneath each node is the percentage of the training data. At each intermediate node is the condition that determines whether the case goes to the left or right child node.

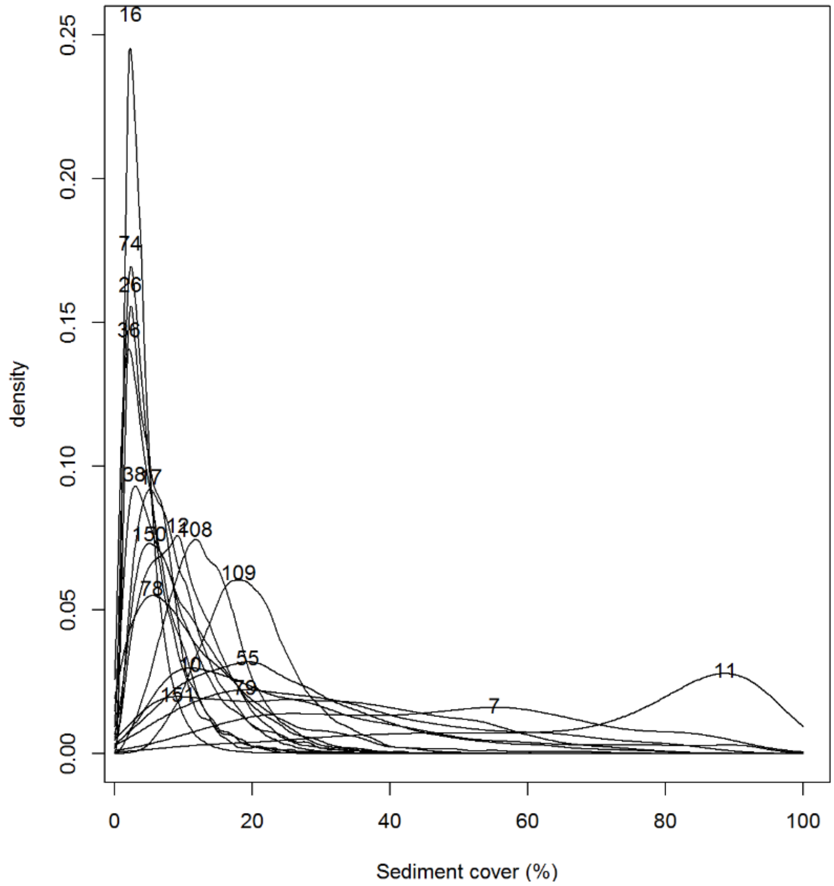

Figure A1.8. Distribution of sediment classes from a CART of reference sediment predictions based on the *% cover A* database.

Table A1.1. Summary of sediment cover values for each lumped group from a CART of reference sediment predictions based on the *% cover A* database.

Group	Group statistics	% network	Classes	Class medians
1	Min: 0.13	90.2%	16	3.4
	25%: 2.4		74	4.1
	Median: 3.8		36	4.4
	75%: 6.3		26	4.8
	Max: 83.3		38	6.7
	SD: 4.5		17	7.6
			150	8.9
			12	9.4
			78	10.1
2	Min: 0.74	9.5%	108	12.8
	25%:10.9		109	19.2
	Median: 15.6		10	21.9
	75%: 22.2		55	22.0
	Max: 96.4		151	28.1
	SD: 12.7		79	29.1
3	Min: 3.0	0.3%	7	47.1
	25%: 37.8		11	80.6
	Median: 60.9			
	75%: 83.8			
	Max: 97.5			
	SD: 25.9			

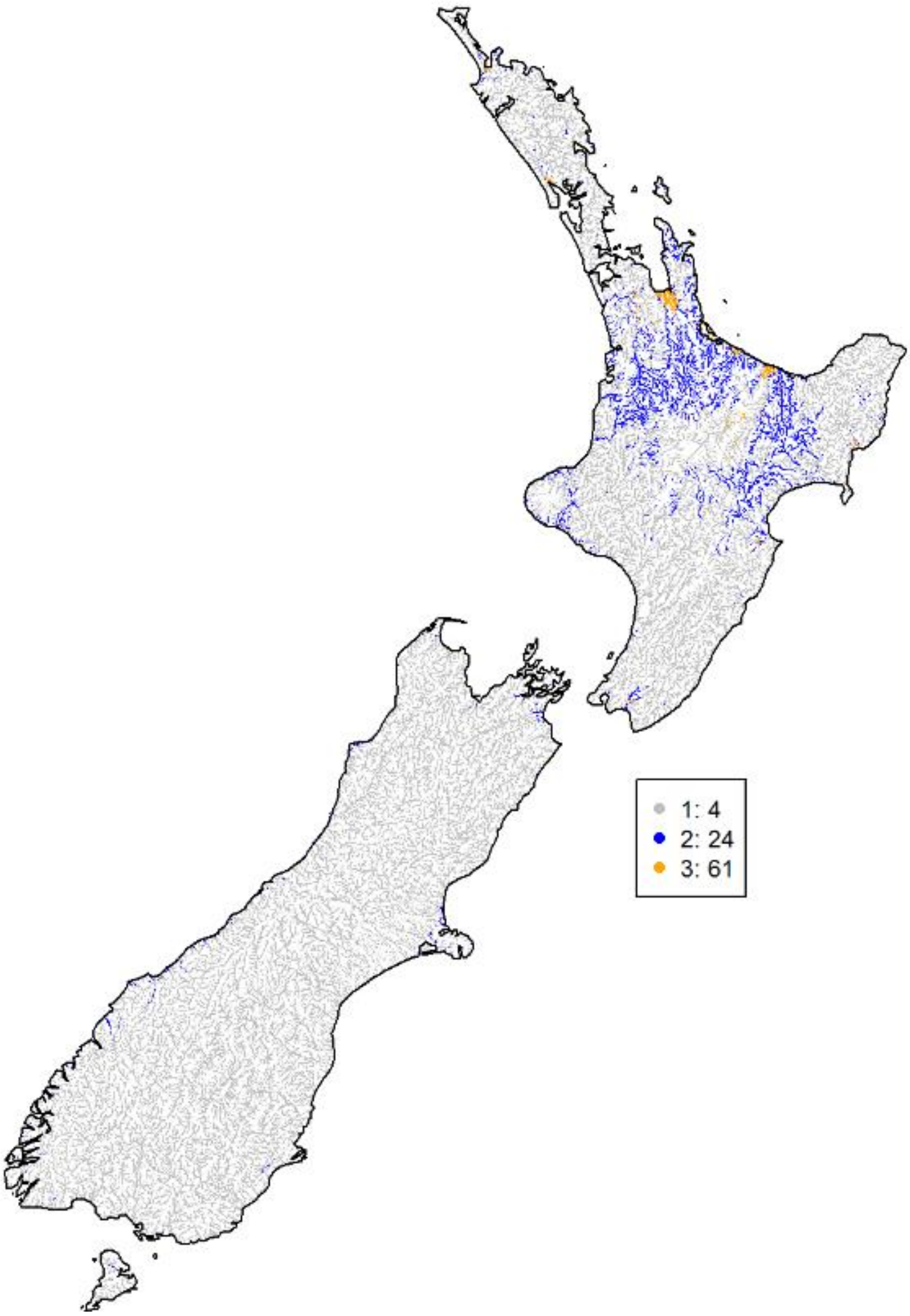

Figure A1.9. Map of Groups from a sediment classification based on predictions of reference condition from the *% cover A* dataset.

Summary of reference condition by REC

We grouped nationwide reference state predictions from the *% cover A* dataset by the various components of the REC classification: climate, source of flow, geology, and land cover. Testing for difference between pairs within these categories suggests that the bulk of them have distinct sediment values (Figure A1.10). All REC groupings have median values less than 10% sediment, except volcanic-acidic (VA = 11.1%). All

75%iles are less than 15%, except volcanic-acidic (VA = 17.2%) and urban and wetland land covers (U = 16.2%, W = 32.2%).

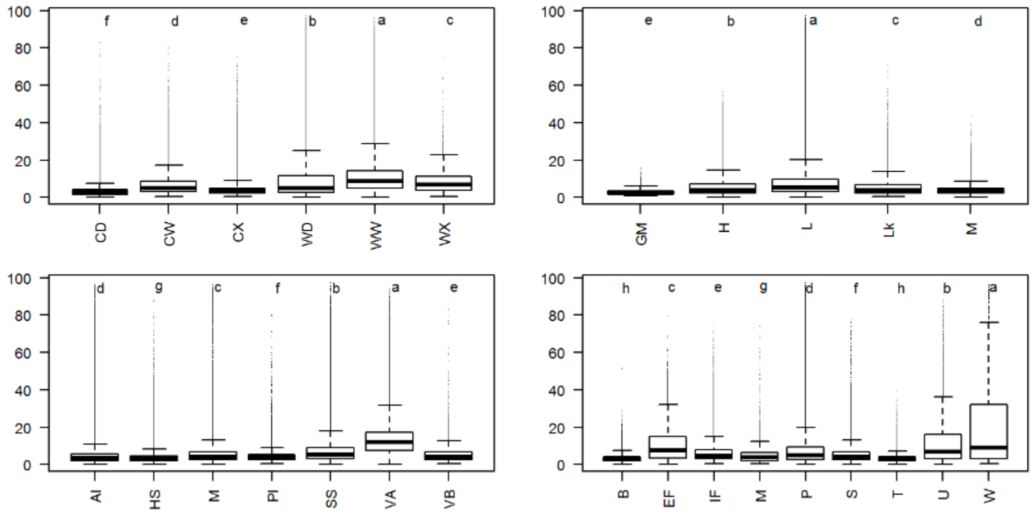

Figure A1.10. Box plots of sediment at reference sites predicted from the *% cover A* dataset grouped by REC groups Climate, Source of flow, Geology, and Land cover. Letters indicate a significant difference between groups (Tukey's $p < 0.05$).

Appendix 2. SIS

Exploring variation at reference sites

We explored the distribution of sites in the *SIS* dataset at a national spatial scale (Figure A1.11) and across continuous environmental gradients (Figure A1.12) to assess their representativeness. The national coverage of sites was limited regionally and there were only two reference sites in the South Island (Figure A1.11). Regardless, there was reasonably good alignment of surveyed sites to the national stream network in terms of distribution across environmental gradients (Figure A1.12). This exploration suggests that there may be a lack of reference data to develop a sediment classification, but there may be sufficient *SIS* data to predict reference condition for all stream segments, which could then be used to develop a stream classification.

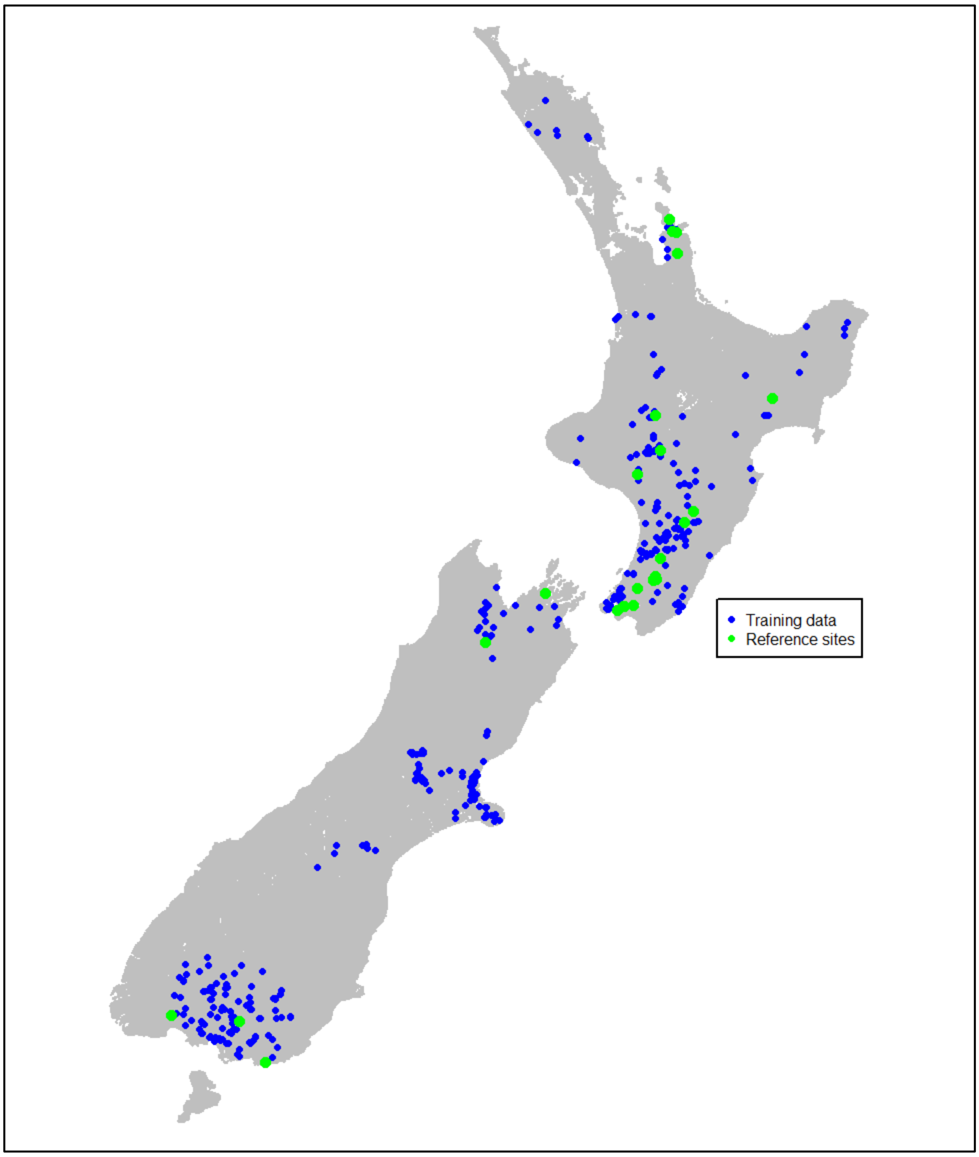

Figure A1.11. Distribution of reference sites and all surveyed (training) sites where *SIS* data was collected.

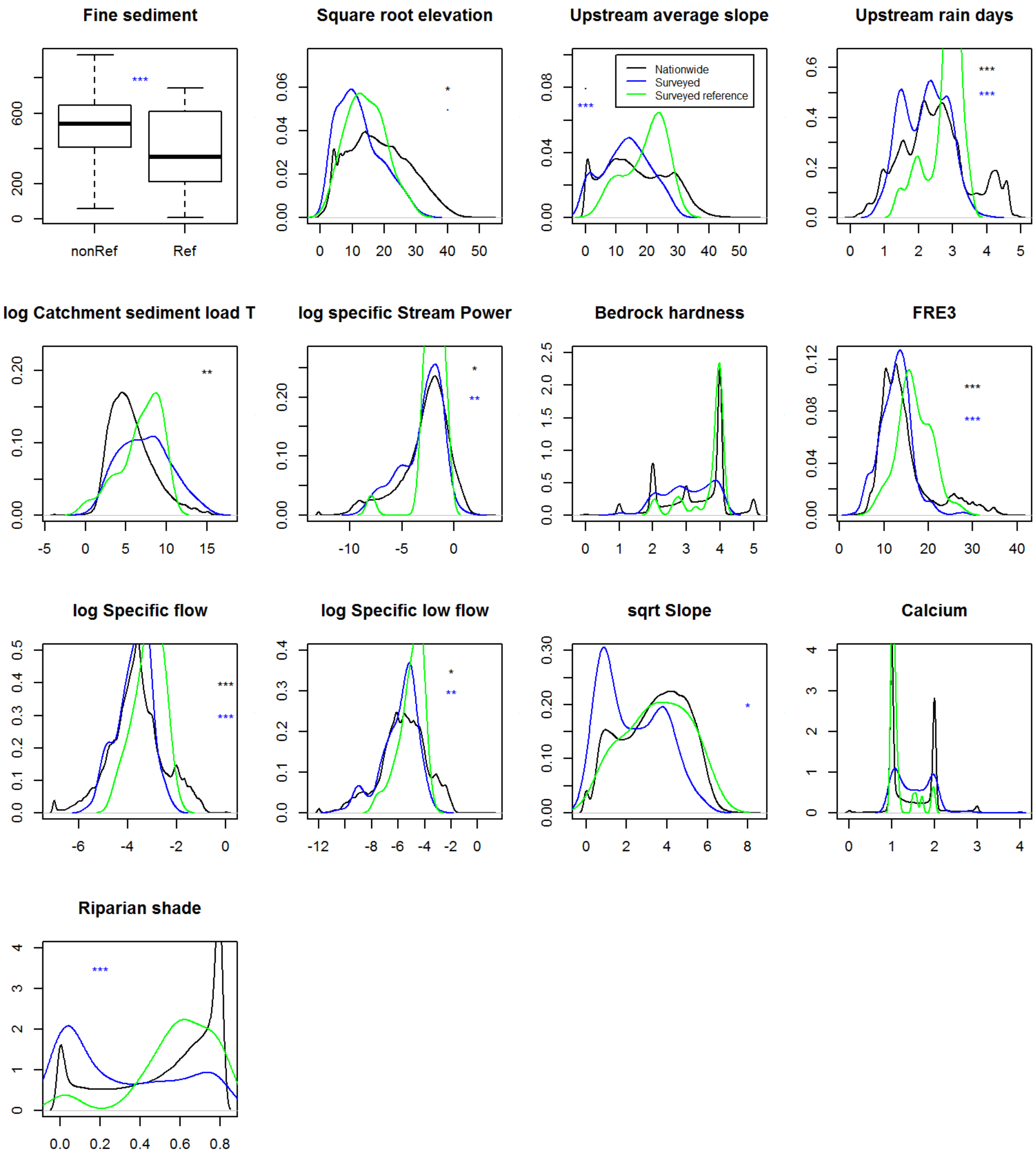

Figure A1.12. The distribution of reference sites and all sites in the *SIS* dataset, relative to all stream segments in New Zealand, across continuous gradients of environmental descriptors. Stars in the top right indicate significance of the difference between the distributions of the reference sites and nationwide (black) or non-reference (blue), according to a Kolmogorov Smirnov test: *** = 0.001 ** = 0.01 * = 0.05.

There was insufficient data (n = 27) to develop a classification based on reference site data in the *SIS* dataset.

Predicting reference condition for all stream segments

Five land cover variables explained 18.7% of the variability in *SIS* data (Figure A1.13), three times more variation compared to either of the % cover datasets. Sediment showed a logical response to each variable and *Native vegetation cover* was the most important land cover predictor of *SIS*. Environmental variables explained 16.8% of the residual variation in *SIS*. REC Geology was the most important environmental variable and there were generally logical relationships between *SIS* and environmental variables (Figure A1.14).

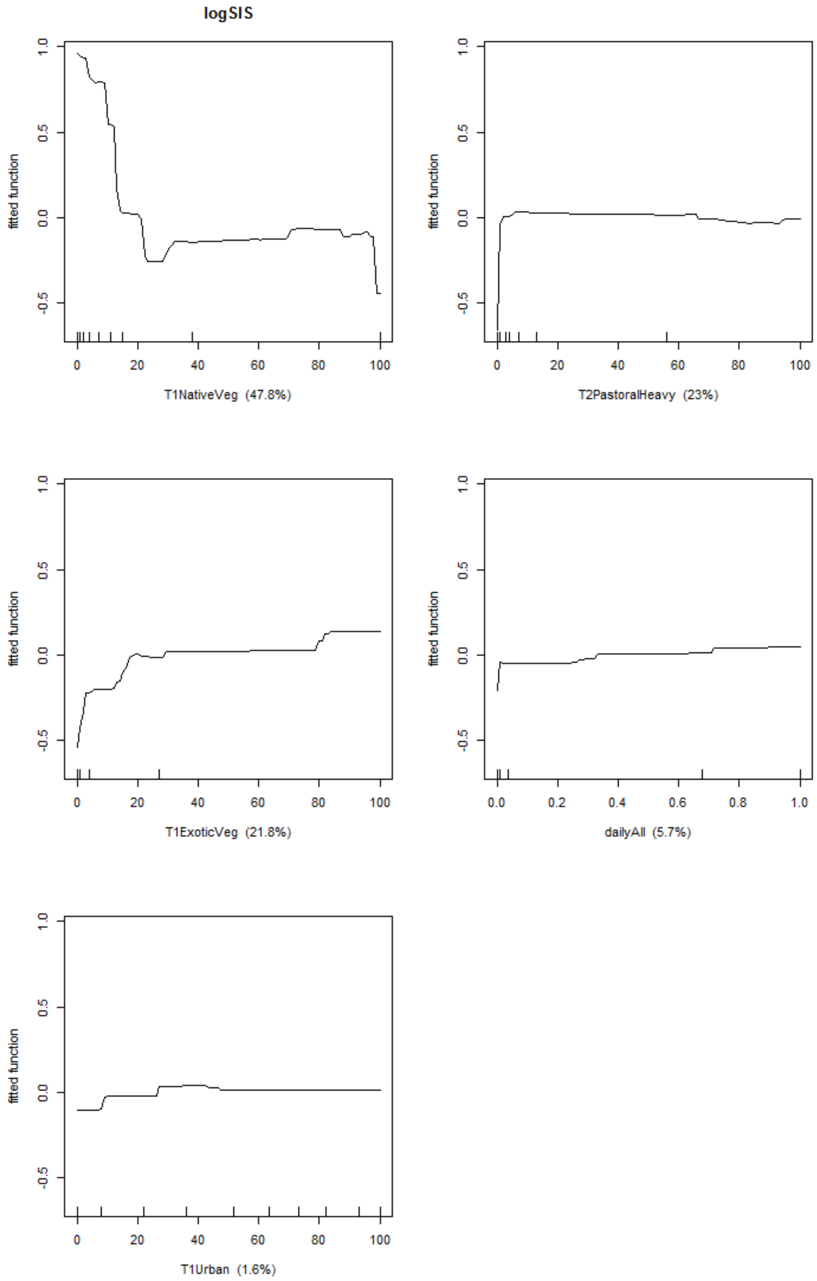

Figure A1.13. Shape of the relationship between land cover variables and log transformed suspended inorganic sediment (*SIS*). The relative contribution of each predictor is given in parentheses.

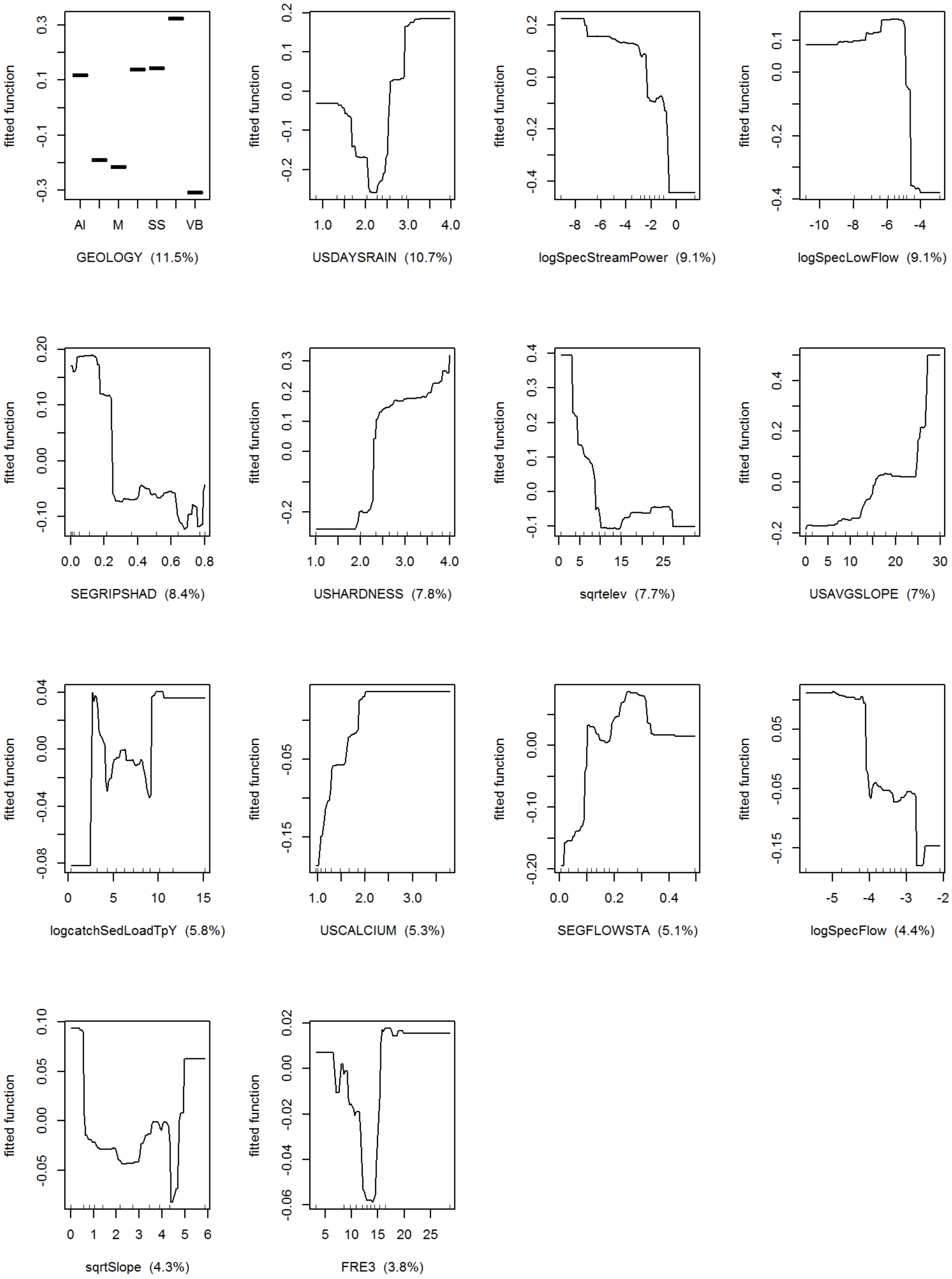

Figure A1.14. Shape of the relationship between environmental variables and variation in log transformed suspended inorganic sediment (*SIS*) not explained by land cover. The relative contribution of each predictor is given in parentheses.

There was a good correlation (R = 0.65) between suspendable inorganic sediment observed at 420 sites and values predicted by the two step BRT model of the *% cover B* dataset (Figure A1.15a). The NSE statistic suggested good model performance and effectively no model bias. There was also a very good correlation (0.71) between predicted reference state and *SIS* values observed at 27 reference sites defined by land cover rules (Figure A1.15b). The NSE statistic showed a good fit to the 1:1 line (NSE = 0.63), however, positive bias suggested an underestimation of *SIS* values.

We predicted contemporary and reference state for all stream segments in New Zealand and viewed the map to assess if predictions seemed reasonable (Figure A1.16).

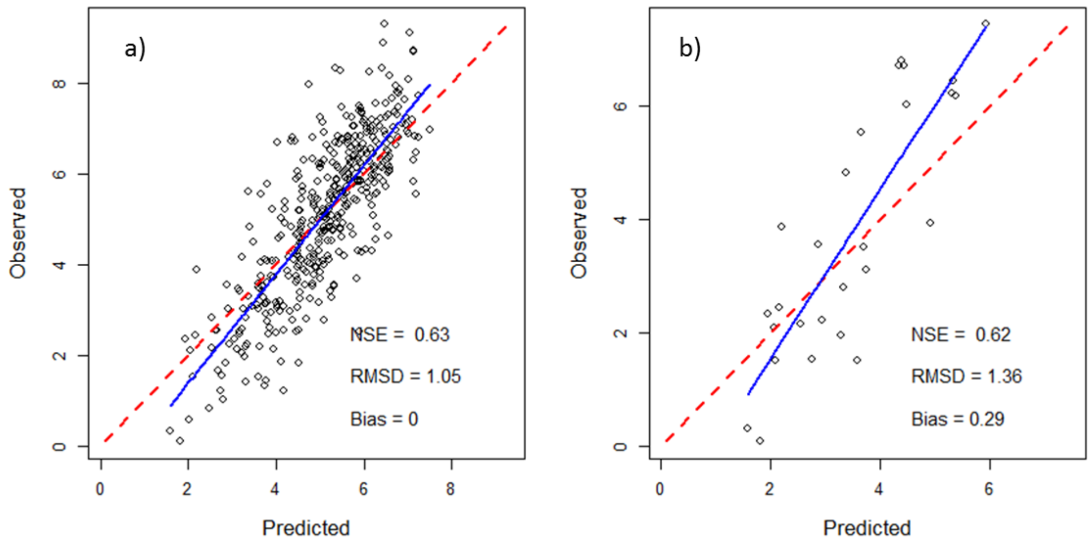

Figure A1.15. Scatterplots of the relationship between log-transformed observed and predicted values from a two-step BRT model for suspendable inorganic sediment (*SIS*). The dashed line is the 1:1 line and the blue line is the line of best fit. Model performance statistics are explained in text.

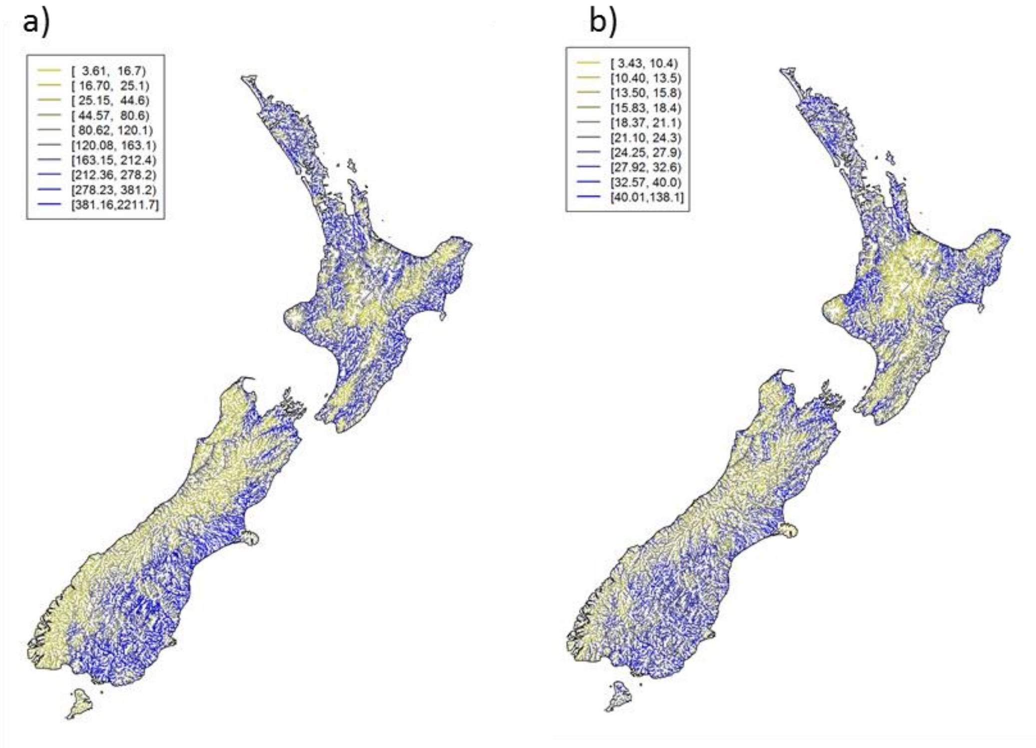

Figure A1.15. Map showing predicted suspendable inorganic sediment (SIS) cover from a two-step model of the *SIS* dataset for a) contemporary and b) reference state.

Exploring stream classifications for predicted reference condition

The PRESS statistic suggested good CART model performance (R^2 = 0.48). The initial split at the head of the tree was made based on *Specific low flow* (>=0.000025 m^3/m^2). Below that one group was split by *Specific stream power*, the other by *Riparian shade* (Figure A1.16).

The CART resulted in 15 classes with overlapping distributions (Figure A1.17). We manually lumped classes based on their similar distributions into three Groups (Table A1.2). The largest Group (39% of the stream network) had a median suspendable inorganic sediment value of 30.3 g/m^2. The other two categories had lower medium values. The national distribution of groups is shown in Figure A1.18.

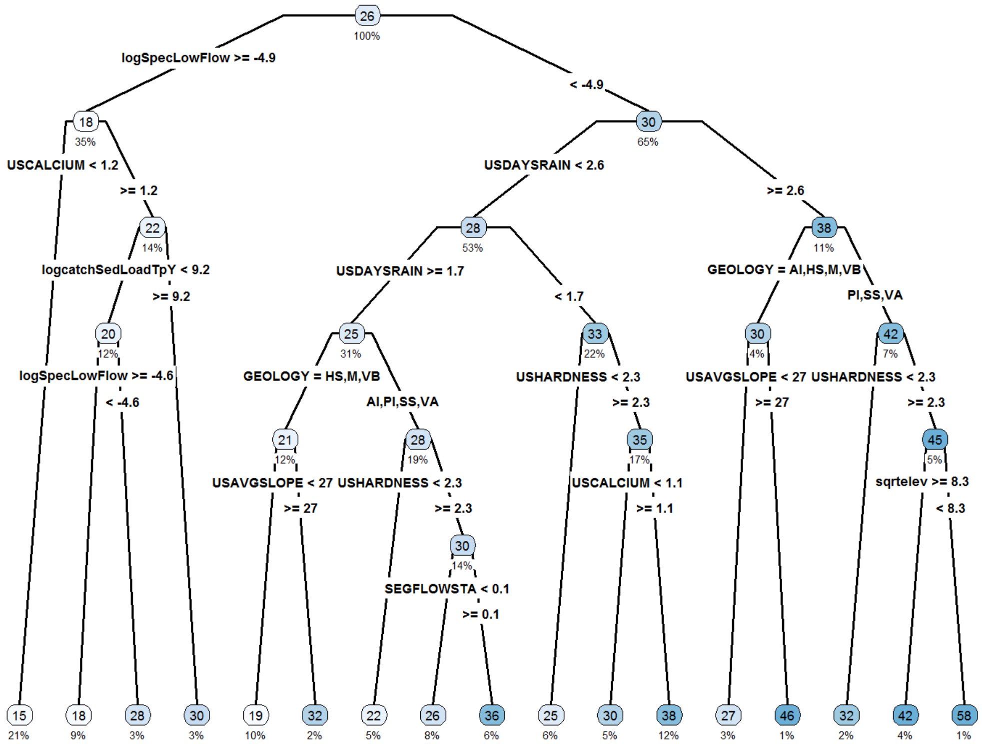

Figure A1.16. Decision tree structure for a classification tree model of reference sediment predictions from the *SIS* dataset. Each node is labelled by the average sediment value for the group and beneath each node is the percentage of the training data. At each intermediate node is the condition that determines whether the case goes to the left or right child node.

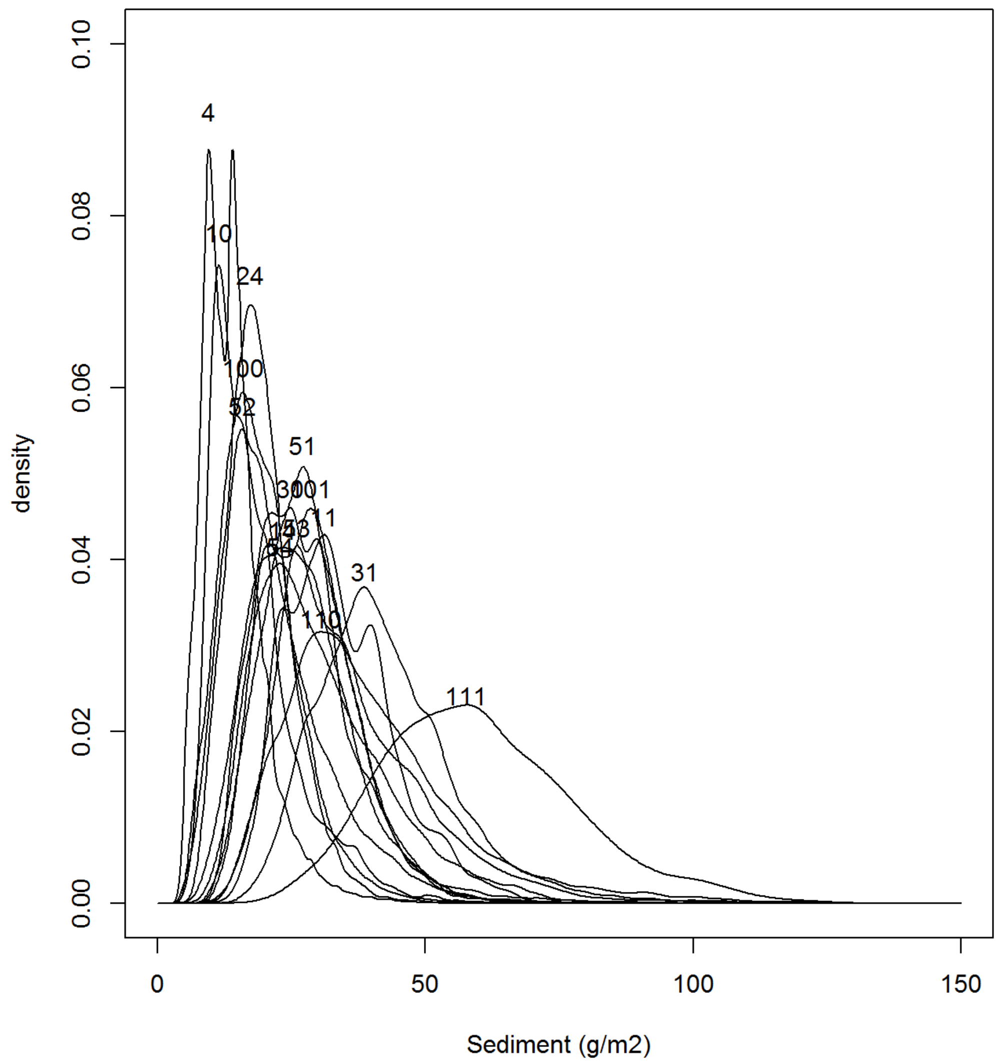

Figure A1.17. Distribution of sediment classes from a CART of reference sediment predictions based on the *SIS* database.

Table A1.2. Summary of suspendable inorganic sediment cover values (g/m^2) for each lumped group from a CART of reference sediment predictions based on the *SIS* database.

Group	Group statistics	% network	Classes	Class medians
1	Min: 3.4	27.3%	4	13.4
	25%: 9.9		10	16.0
	Median: 13.5			
	75%: 17.1			
	Max: 68.7			
	SD: 6.1			
2	Min: 4.2	33.7%	100	18.3
	25%: 15.0		24	18.3
	Median: 19.5		52	20.1
	75%: 25.2		14	25.8
	Max: 119.4		30	26.0
	SD: 8.7			
3	Min: 6.3	39%	51	27.6
	25%: 23.9		101	27.7
	Median: 30.3		54	27.8
	75%: 38.8		11	32.5
	Max: 138.100		53	32.9
	SD: 12.9		110	36.3
			31	40.7
			111	58.4

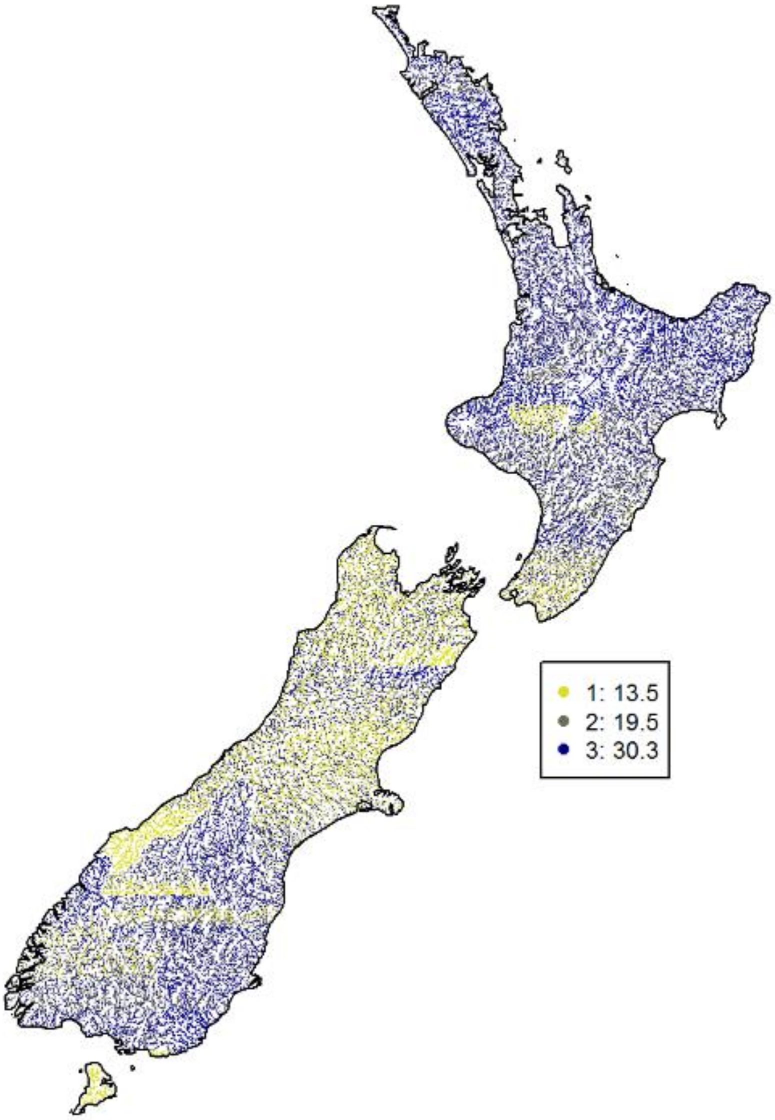

Figure A1.18. Map of Groups from a sediment classification based on predictions of reference condition from the *SIS* dataset.

Summary of reference condition by REC

We grouped nationwide reference state predictions from the *SIS* dataset by the various components of the REC classification: climate, source of flow, geology, and land cover. Testing for difference between pairs within these categories suggests that the bulk of them have distinct sediment values, but less so for land cover (Figure A1.19). All REC groupings have median values less than 30 g/m^2. The guideline value recommended by Clapcott et al (2011) is < 450 g/m^2.

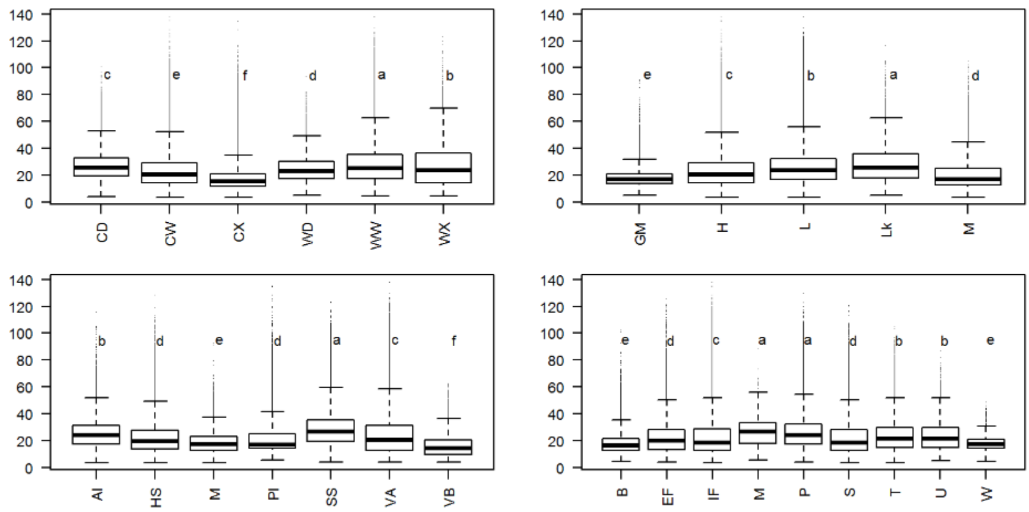

Figure A1.19. Box plots of sediment at reference sites predicted from the *SIS* dataset grouped by REC groups Climate, Source of flow, Geology, and Land cover. Letters indicate a significant difference between groups (Tukey's $p < 0.05$).