Memo

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To	Stephen Fragaszy
Date	21 February 2020
Subject	Contract 23184: Task 8 – Estimation of deposited fine sediment band thresholds using SoE data

Background

Franklin et al. (2019) presented deposited fine sediment reference states for streams throughout New Zealand's river network. These reference states were estimates of the average levels of deposited fine sediment within a stream that we can expect, assuming minimal upstream urban, agricultural and forestry development. Reference states for deposited fine sediment were estimated using a model-based approach, following Dodds and Oakes (2004).

Deposited fine sediment reference states were estimated for streams within different 'sediment classes' of the New Zealand river network. The 'sediment classes' group streams that have similar sediment supply and retention characteristics. The rationale and method underpinning the assignment of New Zealand's streams to sediment classes—the Sediment State Classification (SSC)—is presented in Appendix D of Franklin et al. (2019). The deposited SSC groups streams according to four hierarchical levels of spatial aggregation (Aggregation Levels 1-4). Aggregation Level 1 is the coarsest level of aggregation, comprising only two classes, while Aggregation Levels 2, 3 and 4 comprise 4, 8 and 12 classes respectively. Deposited fine sediment reference states were estimated for each class at each level of aggregation. These reference states were required to derive fine sediment attribute band thresholds proposed within the National Objectives Framework (NOF).

The data used to estimate the reference states within Franklin et al. (2019) came from the New Zealand Freshwater Fish Database (NZFFD). These data are streamside visual estimates of the proportion of stream bed comprised of deposited fine sediment (< 2 mm grain size). These visual estimates are a subjective metric and are not made using a standard protocol or apparatus. As such, the NZFFD sediment data are not highly precise or accurate. The NZFFD contains few sites where observations have been made at different times. These data therefore represent many one-off observations rather than a set of at-site median values. However, an advantage of the NZFFD sediment data is its high spatial coverage of the New Zealand river network; a large quantity of data was available within all classes at all levels of spatial aggregation.

An alternative source of data for estimation of deposited fine sediment reference states comes from the Sediment Assessment Methods 1 and 2 (SAM1 and SAM2) (Clapcott et al. 2011), which have been utilised by some regional councils for State of the Environment (SoE) monitoring since ca. 2012. Estimates of deposited fine sediment areal cover made using SAM1 and SAM2 are less subjective than those within the NZFFD, and are made using standard protocols – these estimates are therefore more accurate and are more precise than estimates derived from the NZFFD. The current SAM data contains replicate observations through time for multiple sites. These data can therefore be used to calculate a set of site medians. A disadvantage of the SAM data is that it is monitored at few stations nationwide, so has poor coverage of the New Zealand river network. Importantly, SAM2 is currently proposed as the method for regional councils to assess instream deposited fine sediment against the proposed NOF attribute bands and bottom-line.

The brief from the Ministry for Environment (MfE) to NIWA was to develop reference states—and resultant management band thresholds—for the entire river network of New Zealand. Accordingly, Franklin et al. (2019) chose to use the NZFFD data, whose spatial coverage was far more extensive than that of the SoE data. Further, Franklin et al. (2019) anticipated that, despite the low precision of individual measurements within the NZFFD, precise estimates of reference state may still be made given the very large number of measurements within the NZFFD (following the Law of Large Numbers), under a critical assumption:

- *that the NZFFD estimates of deposited fine sediment are not biased relative to the chosen method of assessment by regional councils against the NOF*.

The method used by some regional councils for assessment of instream deposited fine sediment is the SAM2. In a recent memo to MfE (Task 4 memo), Stoffels et al. (2020) used a recent compilation of SAM2 data—much of which was not available prior to publication of Franklin et al. (2019)—to test the critical assumption of Franklin et al. (2019). They showed that the assumption was false, and concluded:

- The NZFFD estimates of deposited fine sediment are biased relative to the SAM1 and SAM2 methods of assessment.
- The proposed deposited fine sediment reference states in Franklin et al. (2019) are higher than deposited fine sediment observations made using SAM1 and SAM2 protocols, irrespective of where those SAM1 and SAM2 observations are made (i.e., whether they were made at reference sites or not).
- The biases in the proposed reference states are present in all classes at all levels of aggregation.
- In most cases, the differences between the proposed reference states and the SAM1 and SAM2 estimates are great, indicating the proposed reference states are not sufficiently protective of the life supporting capacity of New Zealand's streams.

Objectives

In light of the conclusions of Stoffels et al. (2020), and noting that SAM2 is currently the recommended method of assessing deposited sediment against the NOF, MfE contracted NIWA to re-estimate deposited fine sediment reference states and management band thresholds using SAM2 data, much more of which has been made available since the publication of Franklin et al. (2019). The specific objectives of the current analysis were:

- Compile the most recent SAM2 data and, taking a similar model-based approach to reference state estimation to the one utilised by Franklin et al. (2019), estimate new reference states for deposited fine sediment throughout New Zealand.

- Estimate reference states at spatial Aggregation Level 2 (four SSC classes), or lower, if the data permits.

- Using the new reference estimates, estimate thresholds between management bands A/B, B/C and C/D, by implementing the community deviation method already developed and described in Franklin et al. (2019). This should be done at Spatial Aggregation Level 2 (four SSC classes) or lower, if the data permits.

Method

Data preparation

SAM1 and SAM2 data for this analysis were collected by regional councils and provided by MfE. SAM2 is a 'semi-quantitative' method that applies visual assessment of the proportionate cover of deposited fine sediment from 20 randomly positioned quadrats on the streambed, within run habitats (Clapcott et al. 2011). SAM1 involves a rapid, qualitative, bankside visual assessment of the proportionate cover of the streambed by fine sediment (<2 mm) (Clapcott et al. 2011). SAM1 bankside assessments are made within either of three habitat types: pools, riffles and runs. Given SAM1_run (SAM1 method applied to the run habitat type) is an assessment of deposited sediment taken from the same habitat as SAM2, we retained SAM1_run data in the hope that it could be coupled with the SAM2 data to strengthen the estimation of reference states. Specifically, we retained SAM1_run data with the aims of:

- Determining whether there were regional biases in the method used by councils to assess deposited sediment coverage. Ideally, comparable data (e.g. all SAM2) from sites across all regions and river settings would be available to estimate reference conditions. If it was demonstrated that councils show a clear tendency to apply only one of the SAM methods, then use of SAM2 data alone will yield reference states whose estimation would have been influenced by conditions observed in some regions but not in other regions.
- Determining whether SAM2 and SAM1_run data have been collected from the same sites or reaches and, if so, whether there is a relationship between the two data sets that can be used to predict SAM2 from SAM1_run, thereby increasing the amount—and possibly spatial coverage— of data used to estimate reference state with respect to the SAM2 data collection method.

Table 1 presents the number of sites at which the two methods have been deployed within regions. Data are available for nine regions. Each council shows a clear tendency to apply either SAM1_run or SAM2 (Table 1). Indeed, no council has deployed both methods for assessment of deposited fine sediment, let alone at the same sites or reaches within regions. As a consequence, conversion from SAM1_run to SAM2 was not possible from these data.

Table 1. The number of sites at which deposited sediment is assessed by regional councils, grouped by sampling method (either SAM1_run or SAM2). Also presented are statistics concerning the number of individual observations taken within sites. Q1 and Q3 refer to the first and third quartiles of the distribution of the number of observations taken within sites.

Council	Method	N_sites	Within-site statistics (proportion of deposited fine sediment cover, %)					
			mean	min	max	Q1	median	Q3
Canterbury	SAM2	496	27.4	1	47	13	34	41
Hawke's Bay	SAM2	164	6.6	1	12	5	7	8
Horizons	SAM2	380	134.1	20	160	120	160	160
Nelson	SAM2	100	48.6	37	52	48	49	50
Northland	SAM1_run	296	1.4	1	2	1	1	2
Otago	SAM1_run	128	4.4	2	5	4	5	5
Southland	SAM2	132	34.6	3	51	31	37	44
Tasman	SAM1_run	100	43.3	32	74	39	41	44
Wellington	SAM2	104	14.6	9	21	12	14	17

Estimating reference state with only SAM2 data would exclude observations of deposited fine sediment from Northland, Otago and Tasman (Table 1), which in turn would mean our reference state estimates are not as representative of New Zealand's regional management units as they could be. Accordingly, we decided to include the SAM1_run data in our models for estimating reference state (see Modelling (below) for a description of how this was done).

Modelling

The model-based approach used to estimate reference state involves two key steps: (1) estimating the parameters of a regression model that represents the relationship between the state variable of interest—deposited fine sediment in our case—and anthropogenic stressor variables; then (2) using that model to predict the reference state when the anthropogenic stressor variables are set to a 'minimally-disturbed' state (e.g. zero agricultural development).

Generalised Linear Models (GLMs) were used to model deposited fine sediment (S) as a function of three anthropogenic stressors: the proportion of catchment upstream comprised of (1) heavy pasture (P); (2) forestry (F); and (3) urban development (U). Response data were assumed to conform to a binomial distribution as is appropriate for data describing proportions. Within each level of aggregation of the SSC we fit the following candidate set of models to the SAM data, noting C is a factor accounting for the effect of SSC 'class':

$$S = \beta_0 + \beta_1 P + \beta_2 PC + \epsilon \qquad \text{(M1)}$$

$$S = \beta_0 + \beta_1 P + \beta_2 PC + \beta_3 F + \beta_4 FC + \epsilon \qquad \text{(M2)}$$

$$S = \beta_0 + \beta_1 P + \beta_2 PC + \beta_3 U + \beta_4 UC + \epsilon \qquad \text{(M3)}$$

$$S = \beta_0 + \beta_1 P + \beta_2 PC + \beta_3 F + \beta_4 FC + \beta_5 U + \beta_6 UC + \epsilon \qquad \text{(M4)}$$

$$S = \beta_0 + \beta_1 P + \beta_2 PC + \beta_3 M + \epsilon \qquad \text{(M5)}$$

$$S = \beta_0 + \beta_1 P + \beta_2 PC + \beta_3 F + \beta_4 FC + \beta_5 M + \epsilon \qquad \text{(M6)}$$

$$S = \beta_0 + \beta_1 P + \beta_2 PC + \beta_3 U + \beta_4 UC + \beta_5 M + \epsilon \quad \text{(M7)}$$

$$S = \beta_0 + \beta_1 P + \beta_2 PC + \beta_3 F + \beta_4 FC + \beta_5 U + \beta_6 UC + \beta_7 M + \epsilon \quad \text{(M8)}$$

The number of levels of factor *C* was dependent on the level of aggregation; *C* had 2, 4, 8 and 12 levels at Aggregation Level 1, 2, 3 and 4, respectively. Models 5-8 include a parameter that accounts for the categorical effect of SAM method, *M* (thus *M* is a factor that has two levels: 'SAM1_run' and 'SAM2'). The individual data points for our regression analyses were site medians. There was no minimum number of individual observations from which our site medians were calculated, but the number of observations within each site was used as a weighting vector for our regressions (the weight for site *i*, was $w_i = n_i/\max(n)$). For a class to be included in the regression analysis, within each level of aggregation, it had to contain at least 10 sites; classes with less than 10 sites—hence 10 data points—were deemed unlikely to yield sensible class-specific parameters.

The Akaike Information Criterion (AIC) was used to select which of the eight candidate models was the most parsimonious ('best') model, given the data and candidate model set (Burnham and Anderson 2002). This AIC-based model selection procedure was implemented within each level of aggregation. Consequently, our algorithm allowed variation in the best models' covariates across aggregation levels.

To estimate reference state within each level of aggregation and class, the most parsimonious model was used to predict *S* when all stressor variables were set to 0 (no anthropogenic disturbance). Given SAM2 is currently the method of assessment most likely to be implemented following development of the fine sediment NOF, we set *M* = 'SAM2' for estimation of reference state. Taking this approach, we used as much data as possible to estimate reference state, while also yielding values that are quantitatively comparable with the proposed assessment method.

Within the algorithm we encoded a check for slopes that were counter-intuitive; that is, the situation when the model fitted to an individual class indicated deposited fine sediment declines as anthropogenic stressors increase. Exploratory analyses showed that this occasionally happened in classes with particularly small sample sizes and/or poor coverage of the stressor domain. When this occurred, the reference state assigned to that class was the median value of the model fit (restricted to the domain of the stressor data).

Our SSC was hierarchical, meaning that a class at a lower level of aggregation (e.g. Aggregation Level 4) is always nested within a 'parent class' at a higher level of aggregation (e.g. Aggregation Level 2). Classes with insufficient data for regression were assigned the reference state of the first parent class for which a reference was estimable.

Following estimation of reference states for each class, we passed the reference estimates to the community deviation algorithm described in Franklin et al. (2019) to estimate management band thresholds.

Results

For convenience we hereafter refer to the percentage cover of deposited fine sediment measured using SAM1_run and SAM2 as, % cover SAM1 and % cover SAM2 respectively. Both % cover SAM1 and % cover SAM2 showed a weak relationship with any of the three stressor variables. Exploratory analyses (not presented) showed that the proportion of catchment upstream comprised of heavy pasture ('heavy pasture', henceforth) was best correlated with % cover, but the correlation was weak (Figure 1).

At all levels of spatial aggregation the most parsimonious model was M8, which included the effects of method. Indeed, the probability that M8 was the most likely model in the candidate set, given the data, was 1 at all levels of aggregation (as indicated by the Akaike weights; Burnham and Anderson 2002). Given the candidate models and data available, there was little uncertainty about which models provided the most parsimonious fit to the data. The coefficients for *M* indicated that estimates of % cover SAM1 are generally higher than % cover SAM2. The tendency for assessors to estimate higher concentrations of deposited sediment using SAM1 is greater at higher levels of heavy pasture, as seen in Figure 2.

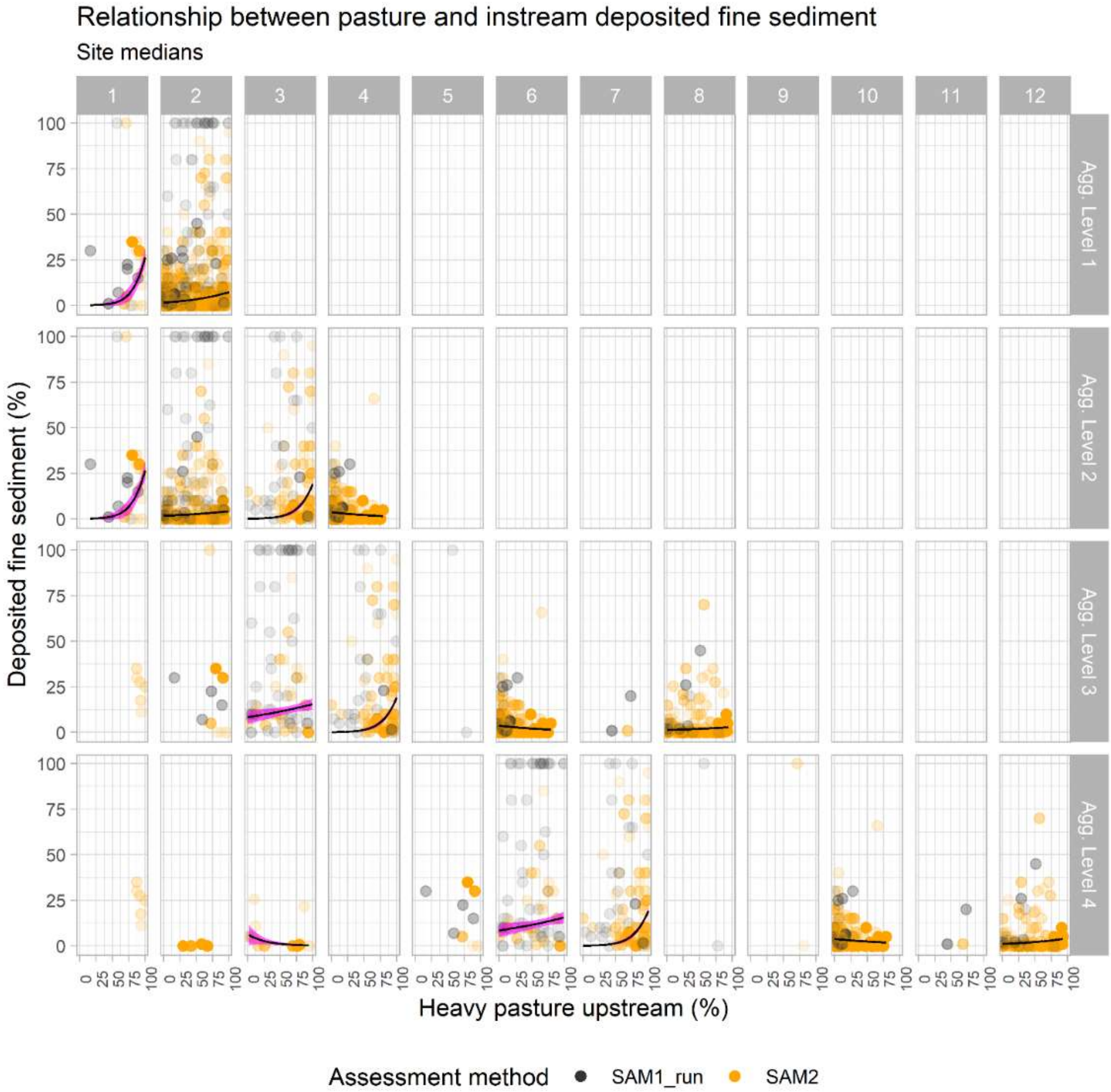

Figure 1. Median percentage deposited sediment at a site as a function of heavy pasture. Both site medians and best model fits (SAM2 fit only; fit +/- 95% CI) are presented. Shading of the points is positively related to the number of observations within sites, hence the regression weights. The darker the shading, the greater the number of observations. Classes containing no model fit contain too few sites (N < 10) to be included in the analysis.

The percentage improvement in deviance obtained by fitting M8 to the data, when compared with the Null model (a model containing just the intercept; McFadden's R^2) was 18%, 29%, 32% and 33% for Aggregation Levels 1 through to 4, respectively. It follows that (a) once we go beyond Aggregation Level 2 the improvement in model fit levels out and reaches an asymptote; and (b) the explanatory power of the models is generally quite low. A detailed plot of the relationship between % cover and heavy pasture at Aggregation Level 2 is presented in Figure 2.

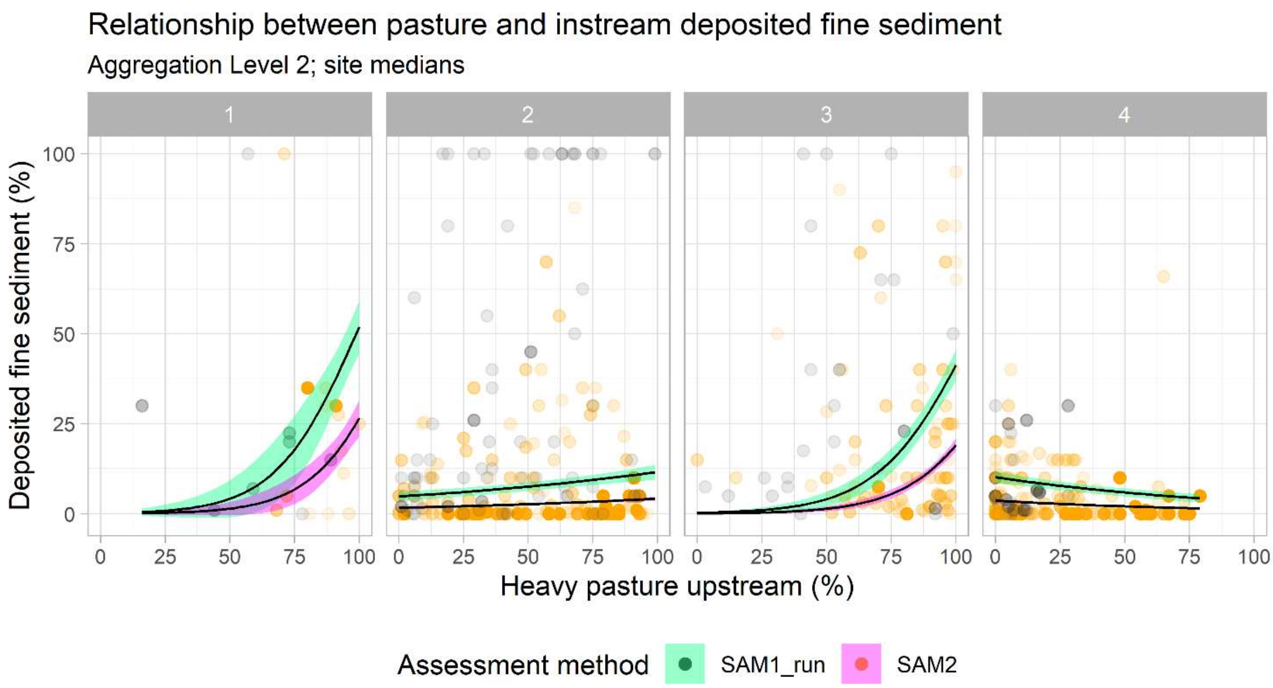

Figure 2. Median percentage deposited sediment at a site as a function of heavy pasture, within the four classes at Aggregation Level 2. Both site medians and best model fits (fit +/- 95% CI) are presented. Shading of the points is positively related to the number of observations within sites, hence the regression weights.

There were insufficient data to estimate reference states in Classes 3.1, 3.2, 3.5 and 3.7 (4 of 8 classes at Aggregation Level 3; Figure 1) and Classes 4.1-4.5, 4.8-4.9 and 4.11 (8 of 12 classes at Aggregation Level 4; Figure 1). These classes were all assigned the reference state of their parent classes (Table 2). At Aggregation Levels 2 and 3 nonsensical slopes were returned within Classes 2.4 and 3.6, respectively, while at Aggregation Level 4 nonsensical slopes were returned in Classes 4.3 and 4.10 (Figure 1); in these instances the median fitted value was assigned as the reference state (Table 2).

Reference states for % cover SAM2 were always below 8%, irrespective of aggregation level (Table 2). At Aggregation Level 2—the primary focus of this analysis—reference state varied between 0% and 7% (Table 2). When the reference states at Aggregation Level 2 were passed to the community deviation method (following Franklin et al. 2019), we obtained the management band thresholds in Table 3.

Table 2. Reference states for deposited fine sediment (Ref; % coverage) within the deposited SSC hierarchy. REC refers to the % of New Zealand Reaches within each class. CTG Classes are the Climate-Topography-Geology classes that formed the basis for further aggregation. Classes denoted with an * contained insufficient data for regression and were assigned the reference state of a parent class. Classes denoted by ** returned a nonsense slope and were assigned the median fitted value as the reference state.

Aggregation Level 1			Aggregation Level 2			Aggregation Level 3			Aggregation Level 4			CTG Classes
Class	Ref	REC	**Class**	Ref	REC	**Class**	Ref	REC	**Class**	Ref	REC	
1	*0*	5.9	**1**	*0*	5.9	**1***	*0*	1.9	**1***	*0*	1.9	WD_Low_VA; WD_Low_Al
						2*	*0*	3.4	**5***	*0*	3.1	WD_Low_SS
									9*	*0*	0.4	WD_Low_HS
						5*	*0*	0.1	**8***	*0*	0.1	WW_Lake_Any
						7*	*0*	0.4	**11***	*0*	0.4	WW_Low_Al
2	*2*	93.1	**2**	*2*	37.7	**3**	*8*	13.3	**6**	*8*	13.3	WW_Low_VA; WW_Low_HS; CD_Low_VA; CD_Hill_Al; CD_Low_HS
						8	*1*	24.4	**12**	*1*	19.7	CW_Hill_VA; CW_Low_VA; CW_Low_SS; CD_Hill_HS
									3**	*4*	4.7	CW_Lake_Any; CW_Low_Al; CD_Hill_SS
			3	*0*	15.5	**4**	*0*	15.5	**7**	*0*	15.5	WW_Low_SS; CD_Low_SS; CD_Low_Al
			4**	*7*	39.8	**6****	*7*	39.8	**10****	*7*	36.4	WW_Hill_VA; CW_Hill_HS; CW_Low_HS; CW_Mount_HS; CW_Hill_SS; CW_Hill_Al; CD_Mount_HS; CW_Mount_Al
									2*	*7*	1.5	WW_Hill_HS; CW_Mount_VA
									4*	*7*	2.0	CW_Mount_SS

Table 3. Reference state estimates and band thresholds for deposited sediment (% cover) based on the SAM2 assessment at Aggregation Level 2 of the SSC.

SSC Level	SSC class	Reference state	Band threshold		
			A/B	B/C	C/D
2	1	0	7	14	21
	2	2	10	19	29
	3	0	9	18	27
	4	7	13	19	27

Conclusions, Discussion and Recommendations

Stoffels et al. (2020) showed that estimates of reference states of % cover deposited fine sediment derived from the NZFFD were consistently greater than assessments made with any of the SAM methods. It is desirable that the NOF thresholds (Table 3) are derived using data generated by the same methods as those that will be used for monitoring and assessment against those thresholds. In the present analysis we collated the most recent data to estimate reference states for deposited fine sediment, as assessed using the SAM2 method, which is the method currently proposed for use by regional councils for monitoring and assessment of the deposited fine sediment attribute. From our analysis we conclude:

1. It was possible to use SAM2 data to estimate deposited sediment reference state using a model-based approach.
2. There were insufficient data to reliably estimate reference state lower than Aggregation Level 2 (4 classes nationwide) of the SSC.
3. Lower levels of deposited fine sediment were associated with lower anthropogenic stressors in three out of four classes at Aggregation Level 2.
4. The explanatory power of the models we used to define the relationship between deposited fine sediment and anthropogenic stressors was generally very low. This indicates that % areal cover of fine sediment observed using the SAM2 protocol exhibits a relatively weak relationship with the proportion of the catchment developed as pasture, forestry and/or urban settlements.
5. Once the new reference states were passed to the community deviation models, A/B band thresholds varied between 7% and 13%; B/C thresholds between 14% and 19%; and C/D (bottom line) thresholds between 21% and 29%, nationwide.
6. The reference state estimates provided using the model-based approach applied to SAM1_run and SAM2 data, were not concordant with our expectations based on the sediment supply and retention characteristics of the classes. Reference state estimates varied little among classes at Aggregation Level 2, varying between 0% and 7% cover. Further, the limited variation observed among classes was counterintuitive; for example, Class 2.4 is characterised by an environment of low sediment supply and retention, but returned the highest reference state (7%), while Class 2.1 (characterised by an environment of high sediment supply and retention) returned the equal lowest reference state (0%).

Why was the relationship between % cover SAM2 and REC land use variables poor?

One possible explanation for the poor relationship between our stressor variables and % cover SAM2 is that the variables ‘heavy pasture’, ‘forestry’ and ‘urban development’ do not adequately capture the effects of human development and primary industry on deposited sediment supply and retention in New Zealand’s streams. These three stressor variables provide a coarse description of the proportion of catchment upstream that is comprised of these land use types. Within these land use types, the variation in human influence on sediment supply and retention is likely to be large. For example, within catchments defined as heavy pasture, variation in riparian vegetation composition, density and maturity, stock access to streams, stock density, and localised topography—to name a few influences—will all affect the supply to and retention of sediment in streams. Variation in these localised drivers within land use types likely contributes noise to the relationships presented in Figure 1 and Figure 2.

A second possible explanation for the poor relationship between stressor variables and % cover SAM2 is that % cover SAM2 is not highly sensitive to the effects that human development and primary industry have on deposited sediment supply and retention in streams. SAM2 involves assessment of fine sediment cover in runs, which are habitats experiencing moderately fast water velocities and are therefore not highly depositional environments. Following this reasoning it is possible that anthropogenic impacts on deposited sediment in streams may first manifest in depositional environments (e.g. pools), and are only manifest in runs—where SAM2 is implemented— thereafter, and at higher levels of anthropogenic sediment supply.

Arguably, visual assessments of deposited fine sediment may be most sensitive to changes in fine to coarse sands (ca. ¼ mm – 2 mm). Suspendable inorganic sediments (SIS; ca. < ¼ mm; fine silts and clays) can form a fine layer over coarser substrates (> 2 mm diameter), without obscuring the discernibility of those substrates, meaning SIS may be under-estimated in visual assessments of deposited sediment. Indeed, Niyogi et al. (2007) showed that SIS values are more sensitive to increases in pastoral land cover than visual estimates of % cover. Further, macroinvertebrates themselves—key to the life supporting capacity of streams—show a greater sensitivity to SIS than % cover (Wagenhoff et al. 2011).

Why were reference states of % cover SAM2 across classes not concordant with our expectations?

One possible explanation for the low level of spatial variation in reference states of % cover SAM2 is that it may be a real feature of deposited sediment in New Zealand streams. That is, irrespective of which method is used to assess deposited sediment or where the assessment occurs nationally, the reference state of deposited sediment *in runs* is < 8% cover. Data have not been collected using either a sufficiently broad suite of methods, or across a sufficiently broad spectrum of landscape settings, to allow this explanation to be validated. It should be noted that this possible explanation does not infer that the reference state for % cover in other (non-run) habitats would vary little among SSC classes.

A second possible explanation for the low level of spatial variation in % cover SAM2, as well as the counterintuitive pattern of reference state variation among classes, is that we had too few data from SSC classes that should theoretically yield higher reference states. For example, Classes 2.1 and 2.3 are characterised by climates, topographies and geologies associated with higher levels of fine sediment supply and retention. However, the majority of the SAM2 data for those classes was collected from catchments covered by a high proportion of heavy pasture (Figure 2). The clustering of data in these classes at the high end of the heavy pasture domain, coupled with very little data at the low end of the domain and the use of a binomial GLM, may have contributed towards estimates of reference states biased towards low values. In Class 2.4, which is characterised by an environment of low sediment supply and retention, the data were collected from catchments with little pastoral development (Figure 2). The clustering of data at the low end of the heavy pasture domain, coupled with very few data at the upper end of the heavy pasture domain likely contributed to the counterintuitive reference estimate in Class 2.4 (7%). Again, without further data collected from these classes we are unable to comment further on the likelihood of this explanation being true.

Recommendations: adaptive policy and monitoring

Four key sources of uncertainty in the management of deposited fine sediment in New Zealand are phrased as questions below:

Q1. *Which size fractions of deposited inorganic sediment are being exported to streams by poor land management (e.g. SIS or sand grains > ¼ mm diameter)?*

Q2. *How sensitive is our chosen method of assessment (e.g. SAM2) to the size fractions of deposited fine sediment most influenced by poor land management practices?*

Q3. *How sensitive are our model-based estimates of reference state within classes to a) the quantity of data within classes, and b) the span of that data over the domain of anthropogenic stressors?*

Q4. *How variable are natural regimes of supply and retention of deposited fine sediment throughout New Zealand's river network?*

Later in this section we very briefly outline activities that could reduce these uncertainties in the long-term. In the short-term, the band thresholds of Table 3 are offered as a basis for the deposited fine sediment NOF, noting:

- the model-based method used for estimating reference states is a well-established, robust technique (Dodds and Oakes 2004);
- the models used for estimation of reference state provided a statistically significant fit to the SAM2 and SAM1_run data;
- the models yielded environmentally-protective estimates of % cover SAM2 reference state (max of 7% cover in one class at Aggregation Level 2; ≤ 2% cover for ca. 60% of New Zealand's river network);
- inclusion of deposited fine sediment in the NOF will encourage collection of more data, which will in turn provide better estimates of reference conditions and bottom lines.

Nevertheless, due to the uncertainties stated above (Q1-Q4), risks are associated with implementation of % cover SAM2 band thresholds of Table 3, which are worth explicating:

Risks to Effective Monitoring and Evaluation

- Difficulty of assessment and compliance. Following Conclusions 4 and 6, councils are likely to argue that numerous streams within Classes 2.1 and 2.3 have deposited sediment states that are naturally higher than indicated by estimates of reference state.
- The counterintuitive pattern in reference state variation across classes relative to their sediment supply and retention regimes could lead to a lack of stakeholder buy-in.

Risks to Ecological Values of Streams

- Given there are very few classes (four) nationwide, councils may observe large variation in % cover SAM2 within classes—variation that may not have an anthropogenic cause. This in turn may result in situations where:
    - deterioration is allowed in some streams (those streams whose natural state of % cover SAM2 is 'below the average' for the class);

- while in other streams managers try to reduce % cover SAM2 to levels that may be very hard to reach (those streams whose natural state of % cover SAM2 is 'above the average' for the class).
- Overall, there is likely to be little risk to the ecological values of streams resulting from the reference state estimates themselves, given they are all very low, hence very 'protective' of the ecological health of streams.

It is reasonable to ask: Given the low level of spatial variability in reference states and band thresholds, why retain four classes of band thresholds (at Aggregation Level 2) - why not just have a single set of band thresholds nationwide? We suggest retaining four deposited fine sediment band thresholds (Aggregation Level 2), for the following reasons:

- The differences between band thresholds among classes may seem small from a purely numerical point of view (ca. 10%), but these differences can equate to a substantial effect on the macroinvertebrate community, hence ecosystem health. Consider, for example, the % cover values of 10% and 20% - these % cover values may equate to SIS values of 6 and 7 g m^{-2} respectively. An increase in SIS from 6 to 7 g m^{-2} can substantially change MCI scores (Wagenhoff et al. 2011).
- Even though two classes may have the same threshold for certain bands, those classes may have different reference states, hence progressions through the band thresholds will occur as the deposited sediment state worsens (e.g. Classes 2.3 and 2.4). Consequently, by retaining such classes as separate management units, we retain information about how change in % cover is likely to affect the magnitudes of biotic community change.
- Given these reference states—hence resultant band thresholds—represent long-term site medians, we expect monitoring should yield sufficient precision to differentiate states that vary by ca. 5-10%.

Given the uncertainties that are identified in Q1-Q4, we encourage an adaptive approach to establishing fine sediment policy, based on appropriate monitoring/assessment (Walters 2007, Lindenmayer and Likens 2009, 2010). We suggest:

R1. Implementing deposited sediment monitoring programs at a subset of monitoring sites within regions utilising SAM4 (Quorer method, which is more indicative of SIS; Clapcott et al. 2011), as well as the SAM2. This would allow:
  - comparing and contrasting the link between land use practices and the size fraction of deposited fine sediment exported to streams;
  - reducing the risk of ineffective fine sediment policy and management caused by targeting a size fraction of inorganic sediment (sand loads detected with SAM2) that is either less sensitive to poor land use practices than, say, SIS (Niyogi et al. 2007), or is less detrimental to the life supporting capacity of streams than SIS (Wagenhoff et al. 2011);

R2. Implement 'multi-method' (as R1) deposited sediment monitoring across a broader range of SSC classes, and a broader domain of land-use gradients within classes, to better define spatial variation in reference state.

R3. Develop better indices of land use pressures that lead to spatial and temporal variation in the load of deposited fine sediment, and use these to improve monitoring. Using more accurate indices of anthropogenic sediment load, further test how well different SAM methods track variation in land use practices.

- We require an improvement on REC variables so that the proportion of land use in a catchment (i.e., indicators of how land management) may be used to understand how land use and management affects the load and composition of deposited fine sediment exported to streams.
- For example, within the land use type 'heavy pasture' we need to improve spatial representation of the intensity of grazing (e.g. stock density; grass cover), the geomorphological context (soil type), as well as the vegetative buffers (e.g. riparian vegetation composition), so that these may be used to better represent sediment export.
- Experts in sediment generation and transport processes should be consulted concerning this recommendation, or to identify alternate approaches that provide similar information.

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