NIWA
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Memo

From	**Paul Franklin, Doug Booker, Rick Stoffels**
To	Stephen Fragaszy
Date	13 March 2020
Subject	Contract 23184: Task 2 - Turbidity and visual clarity threshold conversion

Background

Although turbidity and visual clarity are strongly correlated, the predicted reference states and proposed attribute thresholds for turbidity were derived independently from those for visual clarity by Franklin et al. (2019). Differences in the spatial coverage and overall availability of turbidity data relative to visual clarity data have the potential to create non-uniform differences in the precision and statistical uncertainty of estimated reference conditions, and therefore in the proposed band thresholds for the two environmental state variables (ESV).

The Ministry for the Environment (MfE) requested that we characterise the consistency in the predicted reference states and derived attribute thresholds for turbidity relative to those for visual clarity at Level 4 of the Sediment State Classification (SSC) as proposed in Franklin et al. (2019). MfE requested that this be achieved by converting between the two environmental state variables using a national scale regression relationship between site-median turbidity and site-median visual clarity, and by comparing the estimated reference states and band thresholds presented in Tables 4-5 and 4-6 of Franklin et al. (2019).

Method

We used the latest version of the national State of the Environment monitoring dataset collated by Whitehead (2019) to derive the national regression relationship between site-median visual clarity and site-median turbidity. This incorporated minor corrections to improve the accuracy of site locations used in the original dataset by Franklin et al. (2019).

Site-medians for the period 2013-2017 inclusive were used for the regression analysis. The median number of observations at a site for visual clarity was 56 (range 18-113) and for turbidity was 60 (range 20-153). Only sites where at least 18 observations of both visual clarity and turbidity were available were included in the analysis (n=582). For each site, median visual clarity and median turbidity were independently calculated.

Both variables were natural log transformed and a simple linear regression was fitted to the entire national dataset using the lm function in R, with visual clarity as the dependent variable and turbidity as the independent variable.

The relationship between predicted references states for turbidity and visual clarity for each SSC class were then compared to the national regression relationship. The reference states used here are the updated values presented in Table 1 of the Task 7 memo following application of improved quality assurance procedures to the input data (see Task 7 memo for details).

We expressed differences in both percentage and absolute terms after back-transformation of each variable into its original units. It should be remembered that for relatively small values, small differences in absolute terms will be expressed as large percentage differences (e.g. the difference between 0.1 and 0.2 m is only 0.1 m, but represents a 50% proportional difference). Alternatively, at relatively high values a large difference in absolute terms will be expressed as only a small percentage difference (e.g. the difference between 9 and 10 m is 1 m, but also 10%).

Results

National regression relationship

Turbidity and visual clarity were strongly negatively correlated as expected ($r^2 = 0.88$; Figure 1) and the resulting regression relationship is described by the equation:

$$\ln(CLAR) = 1.21 - 0.72 \ln(TURB)$$

where CLAR is site-median visual clarity (m) and TURB is site-median turbidity (NTU). Visual inspection of Figure 1 indicated no evidence of curvature in the log-log relationship, and residuals were not heteroscedastic indicating an appropriate model structure. We chose to use turbidity as the predictor variable in the linear model because more turbidity data were available to predict turbidity reference state within classes of the SSC. Greater data availability typically improves statistical confidence in the predictions of reference state, which will also improve confidence in proposed band thresholds.

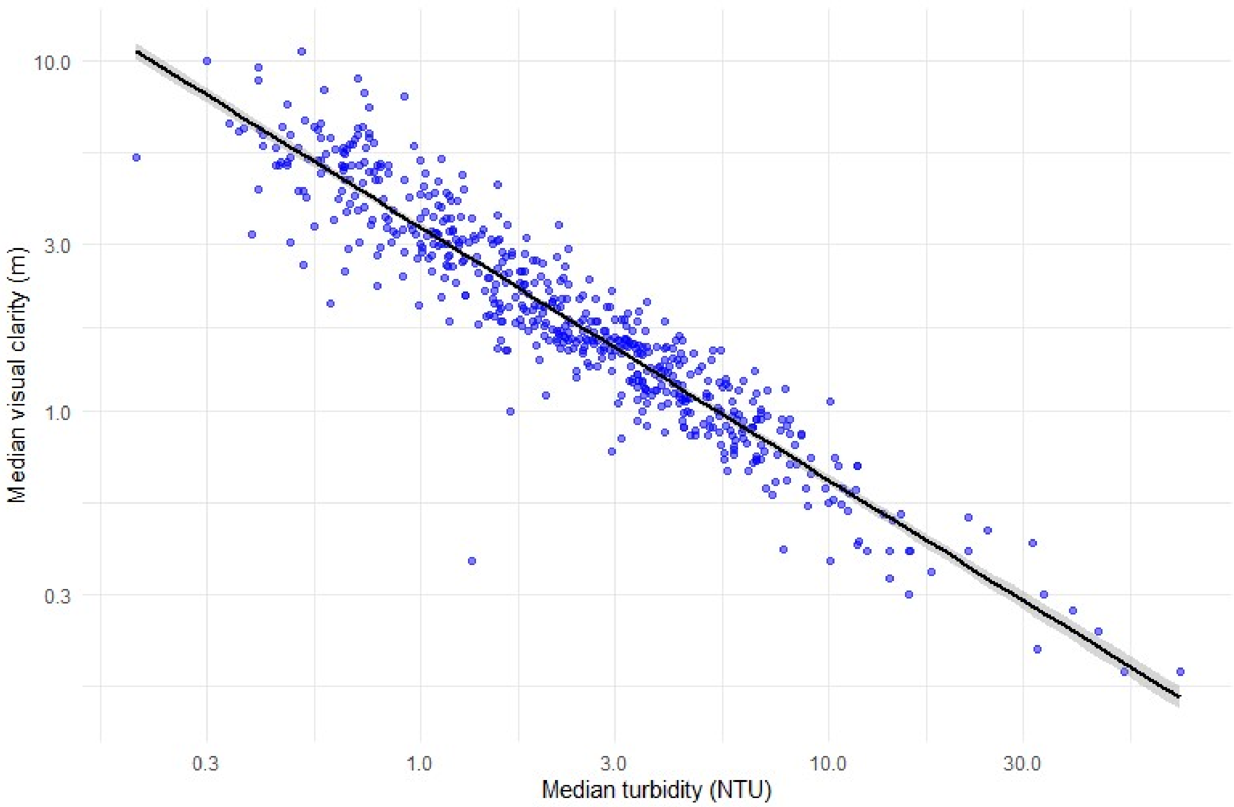

Figure 1: Scatter plot of site median visual clarity and turbidity for the national state of the environment monitoring dataset (n=582). Note that scales are logarithmic. The black line indicates the regression relationship with the standard error shown by the grey shading.

Comparison of predicted ESV reference states

We compared the predicted reference states for visual clarity and turbidity for each SSC class at all four levels of the SSC against the national regression relationship (Figure 2).

The correlations between predicted reference states for turbidity and visual clarity were consistent with the national regression relationship for most of the SSC classes at all four levels of aggregation (i.e. they plot close to the regression line). The number of classes where the correspondence between predicted reference states for turbidity and visual clarity departs from the national regression relationship is greatest at lower levels of aggregation (Figure 2 & 3). This is consistent with increased statistical uncertainty associated with smaller sample sizes within some classes at lower levels of aggregation (e.g. Level 4 Class 2).

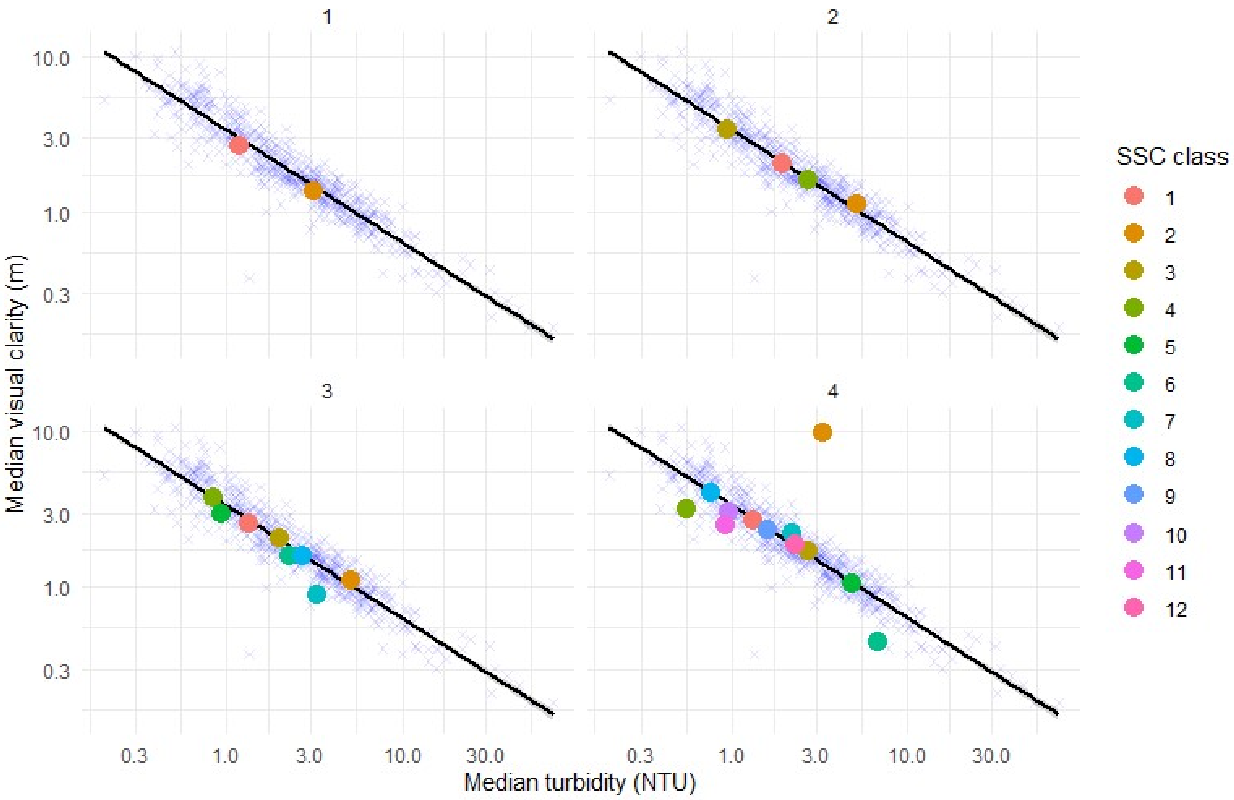

Figure 2: Scatter plot between the predicted reference states for turbidity and visual clarity for all classes at each level of the sediment state classification (SSC) overlaid on the national regression relationship (black line) and underlying data (blue crosses). Points for the predicted reference states are coloured by SSC class.

For each class within each level of the SSC, Figure 3 shows the percentage difference between the predicted reference state for visual clarity and the predicted reference state for turbidity converted to visual clarity using the national regression relationship. The predicted reference states for visual clarity and turbidity (converted to visual clarity) show the greatest concordance at Level 2 of the classification. The median deviation across all four classes at Level 2 is 4.0% (0.07 m in absolute terms), with a maximum difference in class 2 of 6.7% or 0.17 m from a 3.35 m visual clarity reference state. The median deviation at Level 4 of the SSC (i.e. 12-class level) was 9.9% or 0.21 m, although there were three classes (2, 4 and 6) where the difference between the visual clarity and converted turbidity estimates were greater than 50% (Figure 3).

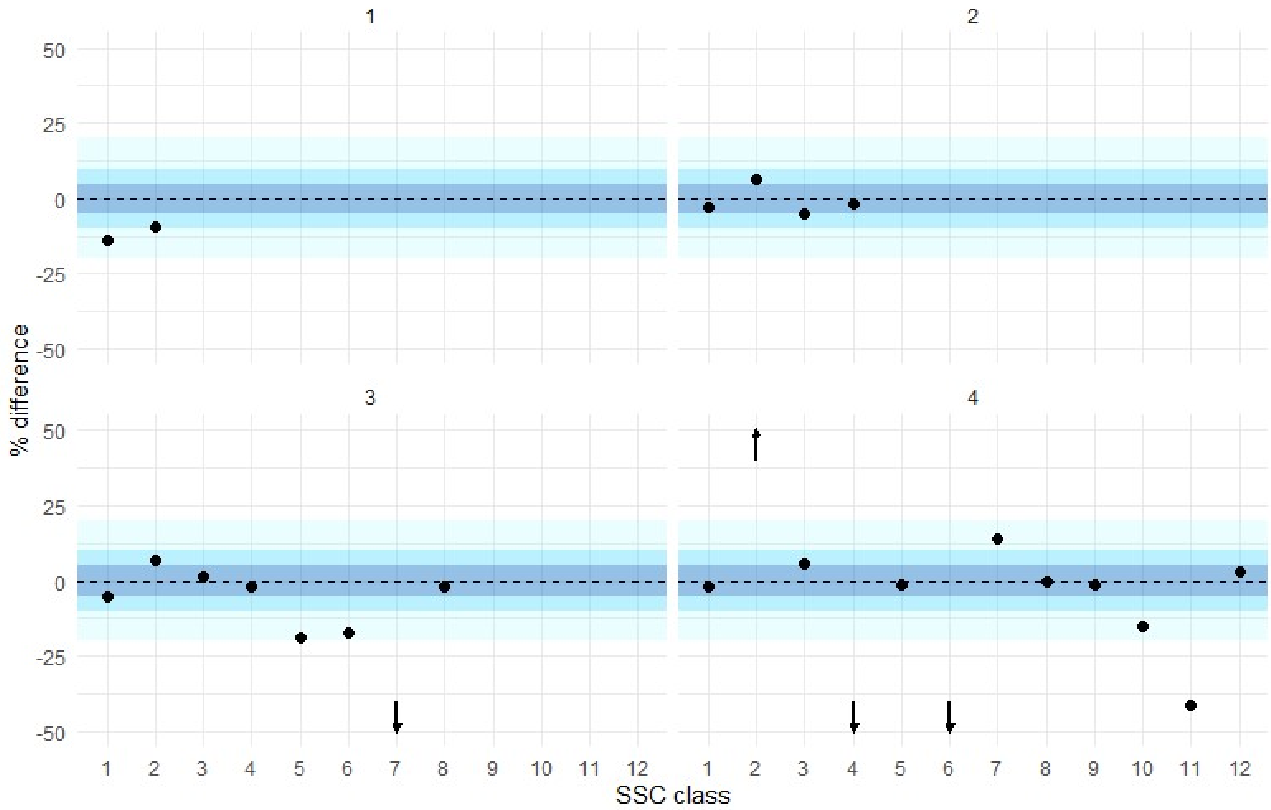

Figure 3: Plot showing the percentage difference between the predicted reference state for visual clarity and the conversion of the predicted reference state for turbidity to visual clarity using the national regression relationship. The black dashed line indicates zero difference. The dark blue, mid-blue and light blue bands indicate the range where predicted reference states are within ±5%, ±10% or ±20% of each other respectively. Black arrows indicate classes where the predictions differ by >50% and are not shown.

Infilling reference state estimates at SSC Level 4

Generally fewer data were available for predicting reference state for visual clarity compared to turbidity, creating a perception that predictions of reference state using turbidity may provide more certain estimates of reference condition. This led to a suggestion that a national scale regression relationship could be used to infill the visual clarity reference states from turbidity data where limited visual clarity data resulted in high statistical uncertainty.

In the original analyses presented in Franklin et al. (2019), insufficient visual clarity data (less than 20 points) were available at Level 4 of the SSC to directly estimate reference state in classes 2 and 3. Consequently, Franklin et al. (2019) used estimated reference states from higher levels of the SSC (Level 2 and Level 3 for classes 2 and 3 respectively) to populate reference states for classes 2 and 3 at Level 4 of the SSC. Franklin et al. (2019) demonstrated that with greater aggregation of SSC classes, bias in reference state estimates increased. Consequently, it was suggested that the reference state estimates for visual clarity presented in Table 4-6 of Franklin et al. (2019) could be updated with new estimates following conversion of estimated turbidity reference states for classes 2 and 3 at Level 4 of the SSC to visual clarity using the national regression relationship. The updated reference state analyses (i.e. Figure 2; Task 7 memo) supersede those presented in Franklin et al. (2019), making the recommendation to update the reference states for classes 2 and 3 redundant. However, the updated reference state predictions remain subject to data limitations in some classes; this is partly represented in the size of confidence intervals associated with each estimated reference condition (see Figure 6 & 7). Consequently, disparities between the predicted reference states for turbidity and visual clarity remain for some classes.

Figure 3 shows that at Level 4 of SSC classes 2, 4 and 6 (L4.2, L4.4 & L4.6), differences between the visual clarity and turbidity reference states exceed 50%. These are candidates for substitution of a revised reference state, estimated by converting the turbidity reference state to visual clarity. Such disparities can be a result of interaction between several factors, including the relative quality and quantity of available turbidity and visual clarity data, the relative spatial coverage of those datasets, varying coverage of the heavy pasture gradient within those datasets, and spatial differences in the regression relationship between visual clarity and turbidity.

In Task 7 we undertook exploratory analyses to better understand the primary cause(s) of the poor correspondence between the visual clarity and turbidity thresholds in some classes. After correction of errors in the input data, we concluded that the primary reasons for the observed disparities were lack of data (Figure 4), and poor representation of the heavy pasture gradient within the available data (Figure 5). These factors result in high uncertainty when characterising the regression relationship between the ESVs and heavy pasture, causing poor accuracy and large confidence intervals when delineating the intercept. The latter corresponds to the estimated reference state (Figure 6 and 7).

For all classes at Level 4 of the SSC where a large difference in the predicted reference states for visual clarity and turbidity exists (after conversion to visual clarity using the national regression relationship), relatively few sites were available for characterising the ESV versus heavy pasture regression relationship (Figure 4). Furthermore, the sites available for those classes with the biggest disparities (L4.2, L4.4 & L4.6) also had the highest median cover of heavy pasture (Figure 5). This results in very wide confidence intervals around the regression relationship at the intercept (Figure 6 & 7), decreasing the reliability of the estimated reference state. In all cases for L4.2, L4.4 and L4.6, a similarly low number of sites for estimating both visual clarity and turbidity reference states exist. As a consequence, no clear-cut, transparent or defensible basis exists for using either the visual clarity or turbidity reference state estimate for deriving attribute band thresholds or bottom-lines in these classes. Effectively, there is similar risk that both the visual clarity and turbidity reference state estimates are imprecise. We note that while class 12 also had a low number of sites contributing to the regression relationship, the correspondence between the turbidity and visual clarity reference states was still high (Figure 4). However, a key difference is that those sites were biased towards having low cover of heavy pasture (i.e. closer to reference condition), resulting in narrower confidence intervals at the intercept of the regression relationship.

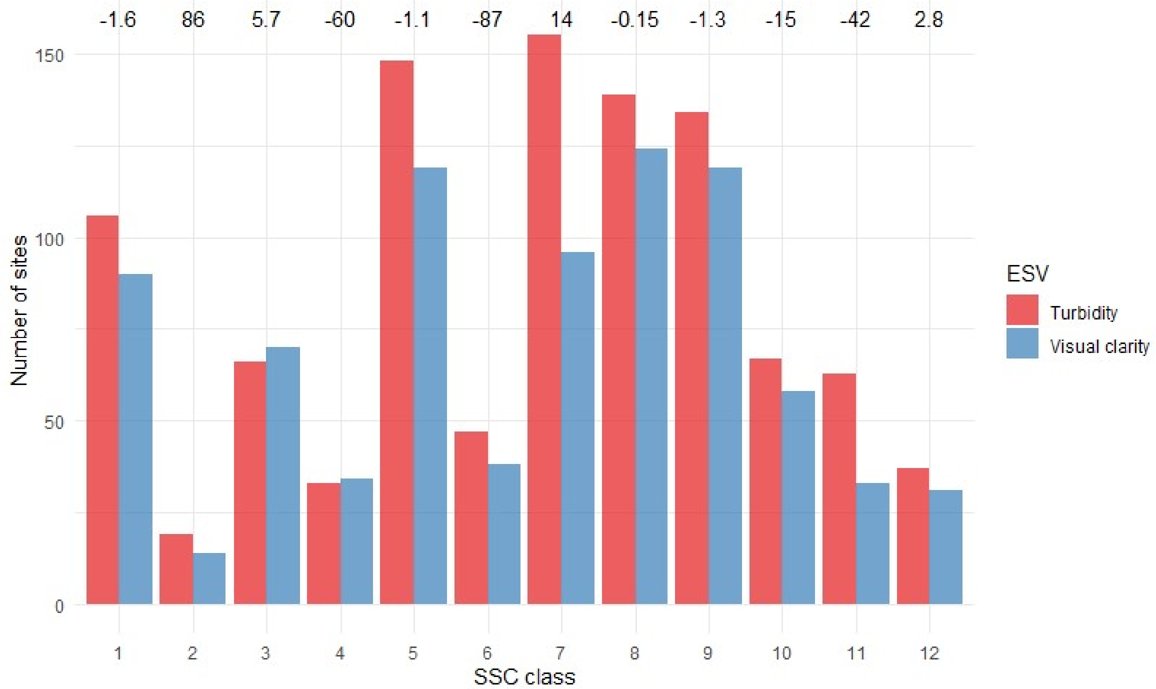

Figure 4: Bar plot showing the number of sites contributing to the regression relationship with heavy pasture for each ESV within each class at Level 4 of the SSC. The numbers above each set of bars are the percent difference between the visual clarity and turbidity (converted to visual clarity) predicted reference states as shown in Figure 3.

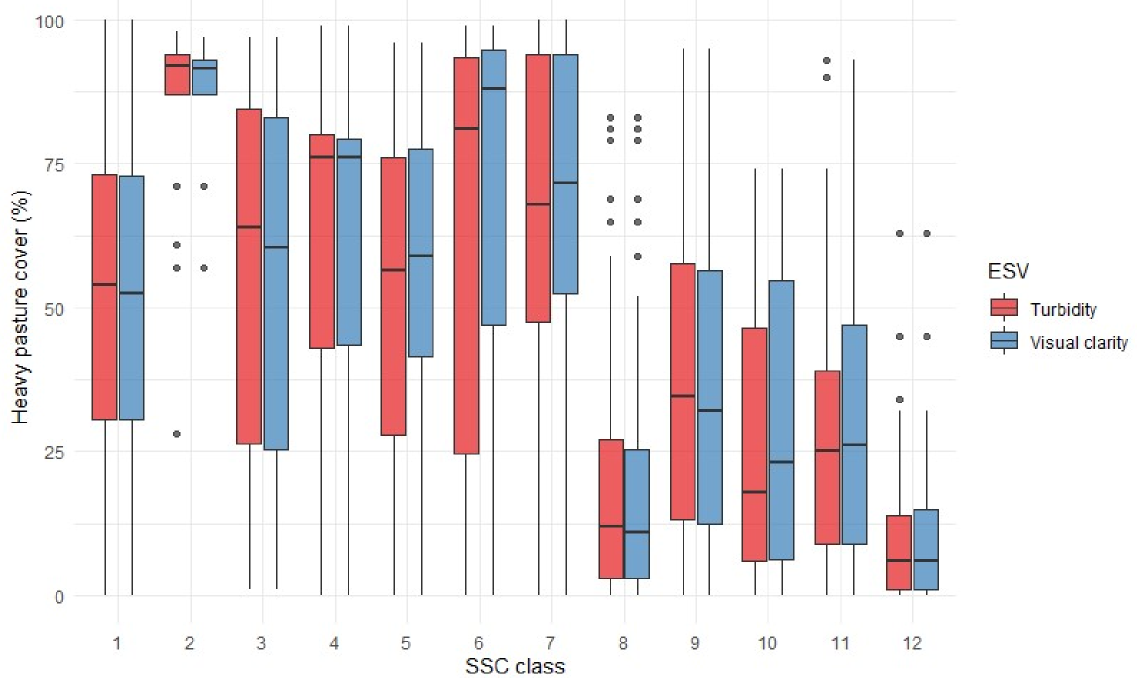

Figure 5: Box plots showing the distribution of sites across the heavy pasture gradient for the two ESVs within each of the 12 classes at Level 4 of the SSC. Boxes show the interquartile range and the black line within each box represents the median cover of heavy pasture. The upper whiskers extend from the hinge (75th percentile) to the largest value no further than 1.5 * IQR from the hinge (where IQR is the inter-quartile range, or distance between the first and third quartiles). The lower whiskers extend from the hinge to the smallest value at most 1.5 * IQR of the hinge. Data beyond the end of the whiskers (black dots) are "outlying" points.

Figure 6: Regression relationships between heavy pasture and visual clarity. The black circles represent site median visual clarity observations. The black line shows the fitted regression line with 95% confidence interval shown in orange.

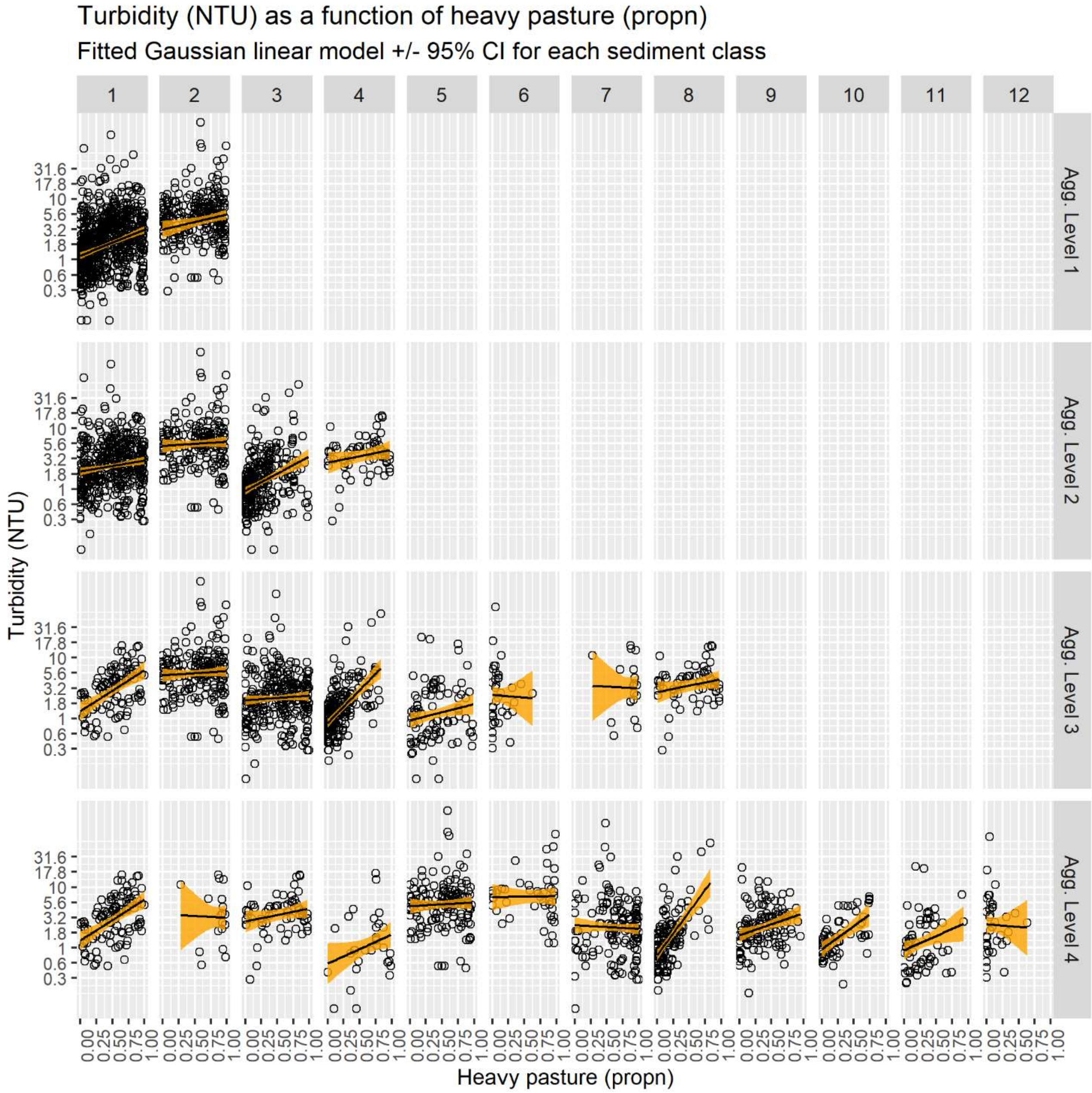

Figure 7: Regression relationships between heavy pasture and turbidity. The black circles represent site median visual clarity observations. The black line shows the fitted regression line with 95% confidence interval shown in orange.

Discussion & recommendations

Elevated fine sediment content in the water column is widely documented to impact on ecosystem health. However, there are multiple effects pathways with different mechanistic links to ecological responses. Visual clarity is a direct measure of visibility in the water column and reflects differences in both the concentration of suspended fine sediments, as well as water colour (e.g. because of tannin staining). There are direct mechanistic relationships between visibility in the water column and feeding efficiency of aquatic organisms. Turbidity is a surrogate measure for the total suspended solids content of the water column. It is affected by the concentration, composition and characteristics (e.g. angularity) of suspended fine sediments. At high concentrations, direct mechanistic relationships between elevated suspended solids concentration and lethal effects on aquatic organisms exist, and there is an indirect effect on visibility.

There is a strong correlation between site-median visual clarity and turbidity at the national scale. However, visual clarity and turbidity characterise different modes of impact, so we can also expect differences in the shape of the ecological response relationships with each ESV. This means it is not ecologically appropriate to directly convert attribute band thresholds derived for one suspended fine sediment ESV (e.g. turbidity) to form the basis of setting band thresholds for the other ESV (e.g. visual clarity). However, because the estimate of reference state is independent of the ecological response there is a sound basis for estimating reference states for one ESV from the other. This is particularly relevant where the limited data for one ESV results in greater statistical uncertainty in the reference state estimate. Once band thresholds have been set using the direct ecological response to that ESV, however, it is defensible to use calibrated correlations between ESVs derived from local site measurements for monitoring and evaluation purposes.

The scope of this analysis was limited to considering use of a single national scale regression relationship for converting between site-medians of visual clarity and turbidity. However, we found that the primary causes of poor correspondence between the visual clarity and turbidity reference state predictions at Level 4 of the SSC were the limited number of sites in those classes, and that those sites were biased towards high heavy pasture cover. We also found that for those classes with the greatest disparity between the ESV reference state estimates there were similarly few sites for estimating both visual clarity and turbidity. Consequently, there was no transparent and defensible basis for adopting either ESV measure as the basis for deriving attribute band thresholds or bottom-lines in those classes. The uncertainty arising from limited data availability in some classes at Level 4 of the SSC can be overcome by going to a higher level of the SSC with fewer groups (see Task 7 memo for further discussion of this).

The resulting band thresholds and bottom-lines for visual clarity derived from the updated reference state estimates are presented in Table 1 for completeness. However, based on the outcomes of the most recent analyses, we do not recommend the adoption of these thresholds as the basis of the new suspended sediment attribute because of the high uncertainty regarding the estimates of reference state in some classes.

Table 1: Visual clarity (m) band thresholds and bottom-lines for each class at Level 4 of the SSC. Thresholds derived using the community deviation method described in Franklin et al. (2019). * denotes classes that depart notably from the national regression relationship and should be treated with caution.

SSC	Predicted reference state	Visual clarity (m)		
		A/B threshold	B/C threshold	C/D threshold
L4.1	2.69	2.28	1.90	1.56
L4.2*	9.84	8.56	7.38	6.28
L4.3	1.73	1.49	1.27	1.07
L4.4*	3.22	2.80	2.41	2.05
L4.5	1.07	0.89	0.73	0.59
L4.6*	0.45	0.37	0.29	0.23
L4.7	2.21	1.95	1.69	1.46
L4.8	4.10	3.63	3.17	2.75
L4.9	2.35	2.07	1.81	1.57
L4.10	3.03	2.62	2.25	1.91
L4.11*	2.52	2.23	1.95	1.69
L4.12	1.90	1.73	1.57	1.41

References

Franklin, P., Stoffels, R., Clapcott, J., Booker, D., Wagenhoff, A., Hickey, C. (2019) Deriving potential fine sediment attribute thresholds for the National Objectives Framework. Client report to the Ministry for the Environment, 2019039HN. 290pp.