A method for evaluating sediment-induced macroinvertebrate community composition changes in Idaho streams

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Abstract

This study developed stream surface fine sediment < 2 mm (SF) and macroinvertebrate fine sediment biotic index (FSBI) benchmarks and an application framework to test for sediment-induced macroinvertebrate community composition changes in 1st-4th order Idaho streams. FSBI reference benchmarks were calculated as the 25th percentile FSBI value among reference sites within three ecoregion-based site classes. Two approaches were used to develop SF benchmarks. Quantile regression was used to define reach-specific SF benchmarks representing an upper bound value expected under reference conditions. In addition, logistic regression was used to predict SF values with 50% and 75% probability that FSBI is worse than reference within each stream order and site class. The strength of association between SF benchmarks and macroinvertebrate community condition was evaluated by calculating relative risk using multiple datasets and examining responses of multiple macroinvertebrate indicators to SF benchmark status. SF reference benchmarks generally had stronger associations with poor macroinvertebrate condition than SF stressor-response benchmarks. Across datasets and macroinvertebrate indicators, poor macroinvertebrate condition was 1.8-3 times more likely when SF reference benchmarks were exceeded than when achieved. We propose rating the strength of evidence for a surface fine sediment-induced macroinvertebrate community composition change at the sample event scale as 'unlikely' if both SF and FSBI reference benchmarks are achieved, having 'mixed evidence' if only one reference benchmark is achieved, and 'likely' if both reference benchmarks

are not achieved. We recommend combining ratings with other relevant data in a weight-of-evidence approach to assess if sediment impairs aquatic life.

Introduction

Human activities can increase sediment delivery to streams, changing the composition, distribution, and abundance of stream aquatic life (Wood and Armitage 1997; EPA 2006). To manage undesirable ecological effects of anthropogenic sediment, resource managers in the United States often compare stream surface fine sediment levels to a benchmark representing desired conditions (Dodds et al. 2010, Hawkins et al. 2010). Surface fine sediment is commonly measured as the percentage of sand and smaller particles (< 2 mm diameter) using Wolman pebble count methods (Wolman 1954), though other fractions and methods are also used. At the state and regional scale, government agencies use surface fines benchmarks to estimate the percentage of stream length with elevated sediment levels and inform management decisions (Van Sickle et al. 2006, Larson et al. 2019, Miller et al. 2021). At the subwatershed or reach scale, managers use surface fines benchmarks to assess if sediment is a stressor impairing aquatic life (EPA 2006, Jessup et al. 2014). The Clean Water Act (CWA) requires states to identify stressor(s) impairing aquatic life and develop a restoration plan. Land management agencies also apply sediment benchmarks at the reach or subwatershed scale to identify stressors and evaluate the effectiveness of land management actions.

Few U.S. states have numeric surface fines water quality standards (WQS) under the CWA (EPA 2006), so managers often use literature benchmarks or local data to develop application-specific benchmarks. Surface fines benchmarks have been developed using reference and stressor-response approaches. Reference benchmarks are indicator values associated with limited human landscape disturbance (Stoddard et al. 2006; Hawkins et al. 2010). Surface fines reference benchmarks have typically been defined as the 70th or 75th percentile surface fine sediment value for groupings of reference sites, with groupings selected to reduce fines variability (EPA 2006; Jessup et al. 2014, Larson et al. 2019, EPA 2020, Miller et al. 2021). A few studies have developed empirical models predicting site-specific surface fine sediment reference benchmarks based on continuous environmental gradients, but such models often have low r^2 and large site prediction errors (Hawkins et al. 2010, Grangeon et al. 2023). Stressor-response benchmarks define stressor thresholds for a specific biological response of interest. They have been developed for surface fines levels associated with the initial onset of macroinvertebrate indicator changes (Burdon et al. 2013, Bryce et al. 2010, Relyea et al. 2012) and for levels associated with certain departure of macroinvertebrate indicators from reference condition (Jessup et al. 2014). Stressor-response benchmarks can be inferred from stressor-response plots (Relyea et al. 2012), based on quantile regression or changepoint analysis (Bryce et al. 2010, Burdon et al. 2013, Jessup et al. 2014), and based on logistic regression predicting the probability of a response across increasing substrate sediment levels (EPA 2006). Some studies have developed several

candidate benchmarks using multiple approaches to confirm stressor-response relationships and then have selected a benchmark that meets management goals (Bryce et al. 2010; Jessup et al. 2014).

In Idaho, state WQS do not include numeric criteria for stream bed sediment. Idaho WQS include a narrative sediment criterion requiring that sediment does not "impair designated beneficial uses" of water (IDAPA 58.01.02.200.08). Idaho WQS define full support of aquatic life beneficial uses as "where no biological group such as fish, macroinvertebrates, or algae has been modified significantly beyond the natural range of the reference streams or conditions approved by the Director in consultation with the appropriate basin advisory group" (IDAPA 58.01.02.010.42). Based on these requirements, the Idaho Department of Environmental Quality (IDEQ) established guidance for applying the narrative criterion (IDEQ 2016). Identifying narrative sediment criterion violations requires multiple lines of evidence, including i) evidence of at least one human sediment source in the watershed, ii) a potential transport pathway delivering anthropogenic sediment to a water body, and iii) at least two lines of evidence for a measurable adverse effect of sediment on a beneficial use (IDEQ 2016).

The objective of this study was to develop a method for assessing if excess stream surface fine sediment likely alters macroinvertebrate community composition relative to reference conditions in Idaho wadable (1st-4th order) streams at the sample event scale. Our approach was designed to meet the desire for two lines of evidence for a measurable sediment-induced effect established in IDEQ guidance (IDEQ 2016). We developed reference benchmarks for percent surface fine sediment < 2 mm and the macroinvertebrate fine sediment biotic index (FSBI) (Relyea et al. (2012), and stressor-response benchmarks indicating fines levels associated with 50% and 75% probability that FSBI is worse than reference. We then applied benchmarks in a simple framework rating a sediment-induced macroinvertebrate community composition change as 'likely' when both surface fines and FSBI benchmarks are not achieved. We confirmed framework ecological relevance by examining associations between framework predictions and macroinvertebrate condition using data from multiple macroinvertebrate indicators and datasets.

Materials & Methods

BURP Data. Benchmarks were developed using IDEQ Beneficial Use Reconnaissance Program (BURP) data. BURP is a bioassessment program that measures multiple stream physical, macroinvertebrate, and fish indicators in wadable 1st-4th order streams. IDEQ has collected BURP data in ~200 Idaho stream reaches during July-August each year in most years since 1993. BURP monitoring generally excludes federally designated wilderness areas, non-perennial streams, lake outlets, and reaches recently impacted by beaver activity or wildfire. Generally, BURP uses a targeted non-random sample design where crews select reaches representative of the associated stream assessment unit, the spatial scale used by IDEQ for CWA beneficial use

support assessments. However, in several years an additional population of sites was also selected using a probability survey design for statewide data summaries. Data from both targeted and probability sampling were included in analyses, as described further below. BURP does not include repeat sampling of the same reach across years, but in some cases, sampling is spatially clustered across years and a single stream segment (National Hydrography Dataset Plus version 2 comid) was sampled multiple times.

All BURP data used in analyses were collected following protocols described in the Beneficial Use Reconnaissance Program Field Manual for Streams (IDEQ 2017). During each sample event field crews delineated a reach with length 30 times bankfull width or a minimum of 100 m. Macroinvertebrate samples were a composite of three samples, one from each of three separate riffle habitats within the reach. If three riffle habitats were not present, one or more samples were collected in a run. Samples were collected with a 500 μm mesh Hess sampler and composited and preserved with ≥70% ethanol in the field. Samples were identified to the lowest practical taxonomic level (typically to genus or species) and enumerated by EcoAnalysts Inc. following methods described in Richards et al. (2018). The same laboratory and methods were used across years. Substrate particle size was measured using modified Wolman pebble count methods (Wolman 1954). Crews established three bankfull width transects, with each transect located one meter upstream of a macroinvertebrate sample location. Pebble counts were always conducted after macroinvertebrate samples to avoid disturbing macroinvertebrates during pebble counts. Within each transect at least 50 particles were selected at approximately equidistant intervals (heel to toe or one pace distance, etc.) and particle intermediate axis was measured and assigned to one of 11 size classes. Particles within both the wetted and non-wetted portion of the bankfull channel were included in counts. All particles within bankfull collected across the three transects were used to calculate percent surface fine sediment within the < 2.5 mm size class. We assumed this size class represents sand and smaller particles and is functionally equivalent to surface fines measured as < 2 mm. Hereafter we refer to percent surface fine sediment < 2.5 mm as 'SF', shorthand for 'sand and fines'.

Macroinvertebrate data were used to calculate fine sediment biotic index (FSBI) (Relyea et al. 2012) scores. FSBI is an index for assessing surface fine sediment impacts on macroinvertebrate community composition in northwest US streams. Relyea et al. (2012) used macroinvertebrate data from multiple monitoring programs in the Pacific Northwest, including BURP data, to identify 206 taxa that are common in the Pacific Northwest (occurring in ≥ 2% of streams in their database). They assigned each taxa a sediment sensitivity score based on the percent fines < 2 mm associated with the taxa's 75th percentile occurrence. FSBI scores for a sample are then calculated as the sum of taxa-level scores (Relyea et al. 2012). FSBI is thus based on taxa occurrence only. FSBI scores generally range from 0-350; high scores indicate many sediment-sensitive taxa are present and therefore elevated surface fine sediment levels likely have not impacted macroinvertebrate community composition. Low FSBI scores indicate few sediment-

sensitive taxa are present. FSBI has been applied in state-wide stream condition assessments in Washington State (Larson et al. 2019) and for assessing effects of streambed instability on macroinvertebrates (Kusnierz et al. 2015). FSBI was used rather than other macroinvertebrate indicators because FSBI is sediment-specific and is correlated with more generalized macroinvertebrate indicators such as ephemeroptera, plecoptera, and tricoptera (EPT) taxa richness (Larson et al. 2019). In preliminary analyses there also was a stronger stressor-response relationship between SF and FSBI than with EPT taxa richness.

The 'reference' and 'stress' site definitions and datasets used by IDEQ to develop BURP bioassessment metrics were used for analyses (Jessup 2011, Jessup and Pappani 2015, IDEQ 2016). These reference and stress site definitions are routinely applied by IDEQ for CWA applications in Idaho (IDEQ 2016). BURP reference and stress sites were defined as the 10% least and 10% most-disturbed 1998-2007 BURP sites within each of three site classes, based on 9 landscape indicators of upstream human landscape disturbance (Jessup and Pappani 2015). Site classes are ecoregion groupings that help explain macroinvertebrate community structure variability within reference sites (Figure 1). They were defined by applying non-metric multidimensional scaling and principal components analysis to Idaho macroinvertebrate data within BURP reference sites (Jessup 2011, Jessup and Pappani 2015). Site classes are described further in supplemental information. In cases where there were multiple BURP reference or stress sites within a stream segment (comid) across years, one reference or stress site per comid was randomly selected for use in analyses. Summary statistics for BURP reference and stress datasets used for analyses are in Table 1 and Table 2.

Reference Benchmarks. Reach-specific SF reference benchmarks (SF_{ref}) were developed based on relationships between SF and bankfull width within each stream order using data from BURP reference sites (Figure 2). Bankfull width and order both had strong correlations with SF (see supplemental information). SF decreased with order within 1st-4th order streams, and order appeared to be a reasonable categorical proxy for stream power and several other physical variables correlated with SF. Relyea et al. (2012) observed surface fines decreased with stream order using a larger Northwest U.S. dataset. Miller et al (2021) also observed strong relationships between bankfull width and SF in Idaho streams, and divided streams into groupings based on bankfull width to calculate SF reference benchmarks. Quantile regression was used to define SF_{ref}, the 75th percentile value expected among reference streams based on reach order and bankfull width (Figure 2). All BURP sites that met reference criteria, including sites sampled using a targeted (N = 277) and probability survey design (N = 17) were used in regressions. We used quantile regression because previous studies indicated trying to predict site-specific reference fines condition exactly can result in order of magnitude or larger site-specific prediction errors (Hawkins et al. 2010, Grangeon et al. 2023). Local geomorphic features, within-reach processes, and local hill slope processes can have significant impacts on reach bed sediment conditions but can be challenging to capture in models (Hawkins et al. 2010, Snyder et

al. 2013, Keesstra et al. 2018). Using quantile regression allowed us to acknowledge this local variability. The 75th percentile was selected to represent an upper bound SF value expected under reference conditions. This approach is conservative (protective) because 25% of reference sites have SF values exceeding this threshold. The 'quantreg' R package (version 5.97) was used for regressions (Koeneker 2023). FSBI reference benchmarks (FSBI$_{ref}$) were calculated as the 25th percentile FSBI value within each BURP site class described above.

Stressor-response benchmarks. Logistic regression was used to predict SF benchmarks with a 50% (SR50) and 75% (SR75) probability that FSBI would be worse (less) than FSBI$_{ref}$. Unlike reference benchmarks, stressor response benchmarks were not reach-specific. Separate logistic regressions and benchmarks were developed for each stream order/site class combination. Regressions used all BURP data collected 1998-2021 (reference, non-reference, stress collected using either targeted or probability survey design) with SF as the predictor variable and a binary value (1 or 0) indicating if FSBI was less than FSBI$_{ref}$ as the response variable. Logistic regressions were implemented using the 'glm' function in base R. Regression model fit was documented using the model chi square statistic, odds ratio confidence intervals, and Hosmer-Lemeshow (HL) goodness-of-fit test (Hosmer et al. 1997; Hosmer et al. 2013). The chi square statistic quantifies the difference between deviance associated with a null model with an intercept only and model deviance. A large and statistically significant (< 0.05) chi square statistic provides evidence to reject the null hypothesis that the model does not perform better than random chance. The model odds ratio indicates how the odds of classifying a reach as having FSBI worse than reference increases for a 1% increase in SF. When lower (2.5%) and upper (97.5%) confidence intervals for model odds ratio values both exceed one, this provides evidence that increasing SF reduces FSBI. The HL goodness-of-fit test describes the level of agreement between observed and predicted outcomes by decile of predicted probability. The HL null hypothesis is that the model provides a good fit. Low HL test p values provide evidence for rejecting the null hypothesis and concluding model fit is poor. Statistics and logistic regression curve plots were used in a weight of evidence approach to evaluate whether developed regression models were adequate for purposes of defining stressor-response benchmarks.

Relative Risk. Relative risk (RR) (Van Sickle et al. 2006) was calculated to describe the strength of association between poor SF condition and poor macroinvertebrate condition. RR was the ratio of two conditional probabilities: the probability that a macroinvertebrate indicator benchmark was exceeded when a SF benchmark was exceeded, divided by the probability that a macroinvertebrate indicator benchmark was exceeded when a SF benchmark was not exceeded. RR was calculated for SF$_{ref}$ and each stressor-response benchmark using data from two probability survey datasets. First, RR was calculating using data from 85 1st-4th order stream reaches sampled across Idaho 2013-2016 using BURP methods and a spatially balanced probability survey design (IDEQ 2018). Site inclusion probabilities were based on stream order and total state stream length within each order. These BURP probability survey data were not

used in reference benchmark development but were used for stressor-response benchmarks. Second, RR was calculated using 43 stream reaches sampled across Idaho Bureau of Land Management (BLM) lands 2013-2016 using a probability survey design and BLM Aquatic Inventory and Monitoring (AIM) program protocols (BLM 2021, Miller et al. 2021). Site inclusion probabilities were based on stream order categories (1st and 2nd order, 3rd and 4th order, and 5th + order) and stream linear extent within each category (Miller et al. 2021). AIM collects paired Wolman pebble and macroinvertebrate data within each reach but uses a different sample design and field methods from BURP. Compared to BURP, more transects are used per reach, more macroinvertebrate subsamples are collected, and different macroinvertebrate collection methods are used, among other differences. A table comparing monitoring programs is included in supplemental information. Calculating RR using AIM data tests if associations between SF benchmark exceedance and macroinvertebrate effects persist across different monitoring approaches.

RR was calculated using SF as the stressor indicator and FSBI as the response variable. SF and FSBI benchmark status was used to rate SF and FSBI as either 'good' or 'poor' for each sampled reach. In addition, RR was calculated using SF as the stressor indicator and other macroinvertebrate indicators as the response variable. For BURP data, IDEQ's multi-metric macroinvertebrate index (SMI2) was used. For AIM data, an index describing the reach-specific ratio of observed to expected (O/E) macroinvertebrate taxa (Miller et al. 2021) was used. FSBI is an index based on taxa sediment tolerances, whereas SMI2 and O/E are generalized indicators of macroinvertebrate community condition that are not specific to any pollutant. O/E describes the proportion of macroinvertebrate taxa expected under reach-specific reference conditions that were observed in samples. SMI2 reflects the macroinvertebrate community expected under BURP reference condition based on multiple individual macroinvertebrate metrics (IDEQ 2016). Program-specific SMI2 ($\geq$ 52-54 depending on site class) and O/E ($\geq$ 0.63) benchmarks were used to identify good and poor macroinvertebrate condition. For each dataset, RR values and an associated 95% confidence interval were calculated using the 'spsurvey' R package (Dumell et al. 2023). Calculations used site weights (i.e. inverse of site inclusion probability) to generate unbiased RR estimates. RR values with a 95% confidence interval > 1 indicate a risk of poor macroinvertebrate indicator condition when the SF benchmark is exceeded. Higher RR values suggest a stronger association between stressor and response indicators.

Application Framework. We developed a simple framework for applying SF and FSBI benchmarks to rate the strength of evidence for a sediment-induced change in macroinvertebrate community composition for each sample event with paired data. The framework rates a sediment effect as 'unlikely' if both SF_{ref} and $FSBI_{ref}$ benchmarks are achieved, as having 'mixed evidence' where only one reference benchmark is achieved, and as 'likely' if both reference benchmarks are not achieved. The framework was designed to be consistent with the desire for at

least two lines of evidence for a sediment effect when evaluating compliance with Idaho's narrative sediment criterion (IDEQ 2016).

We evaluated the framework by applying it to BURP, AIM, and PacFish/InFish Biological Opinion (PIBO) monitoring program (Kershner et al. 2004, Roper et al. 2019, Saunders 2022) data collected throughout Idaho. PIBO data were not included in RR calculations because the PIBO sample design was not suitable for RR calculations. BURP, AIM, and PIBO sample events where paired Wolman pebble and macroinvertebrate samples were collected were included in analyses. Because some AIM and PIBO sites were sampled multiple times across years, we randomly selected one sample event per AIM and PIBO site to reduce spatial sampling bias among data used for analyses. Datasets used for evaluation included 1998-2021 BURP data (N = 5,215 sites/events), 2013-2022 BLM AIM data (N = 299 sites/events), and 2004-2019 PIBO data (N = 665 sites/events). Notched boxplots were used to examine how macroinvertebrate indicator (FSBI, SMI2, O/E) distributions varied with benchmark status and framework prediction classes. Statistically significant differences in median macroinvertebrate indicator values between condition categories were inferred by examining overlap (or lack thereof) between boxplot notches representing median 95% confidence intervals. All data and R code used for analyses are available online (https://osf.io/3czrp/?view_only=d9ebc6430078439d98e387e9cd0961f0).

Results

Quantile regression equations used to develop reach-specific SF reference benchmarks are shown in Table 3 and benchmark distributions are shown in Figure 3. SF_{ref} benchmark distributions overlapped across stream orders, but SF_{ref} values and distribution peaks decreased as order increased (Figure 3). FSBI reference benchmarks were 76 for the Foothills site class, 140 for the mountains site class, and 20 for the PPBV site class. All SF stressor-response logistic regressions models and associated intercept and slope values were statistically significant ($p < 0.05$) and showed good model fit based on chi square and odds ratios (Table 4). All except two regression models (3rd and 4th order in the mountains site class) also showed good fit based on HL statistics. These two models had a significant HL p-value ($p = 0.02-0.04$) suggesting poor model fit but were retained because chi square values and odds ratios indicated good fit. Logistic regression curve plots are included in supplemental information. Order-specific stressor response SF benchmarks for 50% (SR50) and 75% (SR75) probability that FSBI is worse than reference ranged from 28-63% and 47-89% percent sand and fines respectively (Table 4). SR50 and SR75 benchmarks were similar between Mountains and Foothills site classes (Table 4). SR50 and SR75 benchmarks were consistently higher in the PPBV site class than in Mountains and Foothills classes (Table 4). For several stream order-site class combinations, SR50 benchmarks exceeded SF_{ref} distributions in Figure 3, indicating there was < 50% probability of FSBI worse than reference at SF_{ref} surface fines levels. SR50 benchmarks exceeded SF_{ref} distributions for 3rd-4th order streams in the mountains and foothills site classes, and for all orders in the PPBV site

classes. In contrast, for 1st and 2nd order streams in the mountains and foothills site classes, SR50 overlapped with SF_{ref} distributions.

Relative risk results are shown in Table 5. RR lower 95% confidence intervals (CI) calculated using SF_{ref} and $FSBI_{ref}$ were > 1 for both BURP and AIM data, indicating surface fines > SF_{ref} was associated with FSBI worse than reference condition. When SF_{ref} was exceeded, FSBI was 1.8-2.5 times more likely to be worse than $FSBI_{ref}$ than when SF_{ref} was achieved (Table 5). Poor SMI2 condition was 3.0 times more likely when SF_{ref} was exceeded than achieved. When using AIM O/E as the response variable, lower CI was 1 and poor O/E condition was 1.8 times more likely when SF_{ref} was exceeded than when achieved. SF50 and SF75 generally had weaker associations with macroinvertebrate condition than SF_{ref}. Lower CIs were < 1 for 4 of 8 cases examined (Table 5).

Boxplots indicated better (higher) FSBI scores were associated with fines < SF_{ref} across BURP, AIM, and PIBO data (Figure 4). Notches on boxplots representing median FSBI 95% confidence intervals did not overlap between good (< SF_{ref}) and poor (> SF_{ref}) SF condition, indicating median FSBI values were significantly greater when SF_{ref} was achieved. When SF_{ref} was achieved, the 25th percentile FSBI score was better than or very close to $FSBI_{ref}$ across all program/site class combinations, except in the mountains site class for BLM data (Figure 4). Median O/E values were also significantly higher when SF_{ref} was achieved for AIM and PIBO data (Figure 5). O/E values increased with FSBI (Figure 5).

Assessment framework predictions also showed strong associations with generalized macroinvertebrate indicators (Figure 5, Figure 6). For PIBO and AIM data, reaches where the framework rated a sediment effect as 'likely' had significantly lower median O/E values than those where an effect was rated as having 'mixed evidence' or 'unlikely' (Figure 5). Median O/E values did not achieve program O/E benchmarks in reaches with a 'likely' sediment effect and were better than program O/E benchmarks in 'mixed evidence' and 'effect unlikely' reaches (Figure 5). Similar patterns were observed for BURP SMI2 data (Figure 6).

Discussion

This study developed benchmarks and a simple framework for evaluating if excess surface fine sediment < 2 mm may alter macroinvertebrate community composition changes at the reach sample event scale in Idaho 1st-4th order streams. Relative risk calculations and box plots indicated exceeding SF_{ref} was strongly associated with altered macroinvertebrate community condition measured using both the sediment specific FSBI and two generalized macroinvertebrate indicators (SMI2, O/E). Associations persisted across multiple datasets using differing sample design and field methods. This indicates our benchmarks and framework are

ecologically relevant and potentially useful when applied to multiple monitoring programs in Idaho.

To our knowledge, only one previous study estimated surface fines benchmarks specifically for Idaho streams. Miller et al. (2021) defined reference benchmarks for surface percent fines < 2 mm for Idaho using data from 226 Western U.S. reference reaches sampled 2000-2009 across multiple EPA regional bioassessment monitoring programs. They defined benchmarks for small (≤ 10 m bankfull width) and large (> 10 m) streams within each of Northern Rockies and Northern Xeric Basins ecoregions and used the 70th percentile of reference sites. Their reference benchmarks ranged from 15-45% and overlapped with ours. Their benchmarks were lower for large streams than small streams, consistent with the pattern here (Figure 2). EPA defined surface fines < 2 mm reference benchmarks of 15% in the Northern Rockies and Pacific Mountains region for the National River and Streams Assessment (EPA 2020), and 16.19%-22.52% for wadable streams in the interior Columbia River Basin (EPA 2007). For New Mexico streams, Jessup et al. (2014) calculated 75th percentile fines < 2 mm benchmarks as 20.6-74.3% for various ecoregional groupings. A table summarizing literature-reported surface fines benchmarks is included in supplemental information. To our knowledge, this is the first study to develop FSBI reference and stressor-response benchmarks.

In relative risk analyses, we observed stronger associations between SF_{ref} and macroinvertebrate indicators than for stressor-response benchmarks using BURP data. RR values were similar for reference and stressor-response benchmarks using BLM AIM data (Table 5). Considering there was < 50% probability of FSBI worse than reference when SF_{ref} was exceeded for several site class/order combinations (Figure 3, Table 4), similar or higher RR values for reference benchmarks than stressor-response benchmarks may at first seem surprising. However, reference benchmarks likely had higher RR values than stressor-response benchmarks because of the wedge-shaped relationship between fines and FSBI (Figure 7). In our study and in others using different macroinvertebrate indicators, macroinvertebrates typically show a nonlinear wedge-shaped response to increasing surface fines, with large macroinvertebrate indicator variability at low sediment levels and lower indicator variability and values as sediment levels increase (Bryce et al. 2010, Relyea et al. 2012, Jessup et al. 2014). This suggests surface fines are only one factor affecting macroinvertebrate indicators at low levels and their relative importance increases as surface fines levels increase. When using higher SF benchmarks such as SF50 and SF75, false negative macroinvertebrate responses increase, reducing RR values.

With a wedge-shaped response pattern, there is also potential for false positive macroinvertebrate responses at low sediment levels due to high macroinvertebrate response variability (Figure 7). When applied to sites that meet PIBO reference criteria (in wilderness or having no mining and minimal grazing, timber harvest and road density, see supplemental information) (N = 123), false positive rates were 17% for SF_{ref} and 41% for $FSBI_{ref}$, but 14% for framework predictions. When

applied to BURP reference sites (N = 309), false positive rates were 27% for SF_{ref} and 21% for $FSBI_{ref}$, but 8% for framework predictions. By combining two lines of evidence, the framework reduces false positive rates. These patterns highlight that understanding the form of the stressor-response relationship for an indicator and benchmark performance is critical when selecting assessment protocols intended to manage a biological outcome.

Most studies calculating RR define three sediment condition categories – 'good' (sediment < reference benchmark), 'poor' (sediment > poor condition benchmark) and 'fair' (in between) (Van Sickle et al. 2006, Larson et al. 2019, Kaufmann et al. 2022). Those studies calculated RR based on macroinvertebrate responses at 'good' and 'poor' sites, ignoring 'fair' reaches where stressor status was not clear. RR calculated this way tests for macroinvertebrate responses that occur when there is a relatively large magnitude increase in stressor levels from 'good' to 'poor'. In contrast, we did not use 'fair' stressor and response condition categories. Our RR calculations test for the conditional probability that any SF increase above reference yields FSBI worse than reference. This approach is more protective but may reduce RR values relative to a 3-category approach. However, our RR values were comparable to those in other studies. Kaufmann et al. (2022) calculated evaluated macroinvertebrate multimetric index responses to relative bed stability (RBS) for Western U.S. streams sampled through the EPA National River and Streams Assessment and reported RR = 2.64. Van Sickle et al. (2006) reported RR = 1.75 for macroinvertebrate index of biotic integrity (IBI) response to RBS in dataset from the Mid-Atlantic U.S. However, Larson et al. (2019) reported RR = 4 for a macroinvertebrate IBI response to % fines < 2 mm for a Washington State probability survey dataset. Larson et al. (2019) used SF values > 25.5 to indicate poor condition, and < 15.5 to indicate good condition.

Our results demonstrate associations between SF and macroinvertebrate condition but cannot definitively confirm causation within a sampled reach. Degraded macroinvertebrate community condition clearly co-occurs with elevated SF levels. Relationships between SF and FSBI (Figure 7) demonstrate that the number of sediment-sensitive macroinvertebrate taxa decreases as SF levels increase. This relationship was the basis for FSBI construction (Relyea et al. 2012). Boxplots also demonstrate associations between increasing SF and other macroinvertebrate condition measures (Figure 5, Figure 6). Relationships in Figure 7 are also consistent with laboratory and mesocosm experiments documenting reduced density and richness of EPT taxa and other sediment-sensitive taxa in response to increasing sediment surface cover and fine sediment (Malinos and Donohue 2009, Wagenhoff et al. 2012, Conroy et al. 2016, Conroy et al. 2018). Definitively confirming causation in any individual sample reach would likely require dose-response experiments representative of reach conditions. Other approaches to rule out other potential causes, such as applying causal analysis decision frameworks (Seuter 2007), structural equation modeling (Fergus et al. 2023), or Bayesian path analysis (Irvine et al. 2015) could also be used. Our framework predictions describe the strength of evidence for a sediment-induced

macroinvertebrate community composition change. As discussed below, we recommend using framework predictions as only one line of evidence for stressor identification.

Application Considerations. The benchmarks and framework developed here could be used to assist stressor identification. The CWA requires states to identify stressor(s) impairing aquatic life and develop a restoration plan to reduce stressor levels. When macroinvertebrate samples suggest the community is not within the "natural range of reference streams or conditions" and thus does not meet the definition of full support of aquatic life use in Idaho WQS (IDAPA 58.01.02.010.42), methods to diagnose the specific stressor(s) causing impairment are needed. Our benchmarks and framework could be used to assist stressor identification but should not be used as the only evidence diagnosing sediment impairment. BURP, AIM, and PIBO bioassessment programs all collect paired Wolman pebble and macroinvertebrate data, but also measure many other parameters relevant to assessing sediment-induced macroinvertebrate effects. The parameters measured differ across programs but include various stream physical habitat integrity parameters and generalized macroinvertebrate metrics. These other data should also be considered when diagnosing sediment impairments. Our framework also does not provide information on potential human sources or transport pathways, which are needed to assess compliance with Idaho's narrative sediment criterion (IDEQ 2016). We recommend assessors combine benchmark and framework predictions with other lines of evidence in a weight of evidence approach, and explicitly articulate the lines of evidence and rationale for sediment assessment decisions.

When sediment has been confirmed as a stressor, the CWA requires states to define sediment targets to restore support of aquatic life use. Our benchmarks could be used as sediment restoration targets in streams where macroinvertebrate effects through substrate exposure pathways are the primary concern. Our approach does not address other sediment exposure pathways or ecological effects. Idaho WQS include numeric turbidity criteria to protect aquatic life from water column suspended sediment exposure pathways (IDAPA 58.01.02.250.02.3.e, IDAPA 58.01.02.401.02a). IDEQ guidance for selecting sediment targets also includes suggestions for suspended sediment concentration targets and substrate (surface plus subsurface) sediment targets based on streambed core samples for protecting salmonid spawning habitat (IDEQ 2003). IDEQ sediment target guidance did not include suggestions for surface fine sediment targets. This study represents one potential approach for selecting surface fine sediment targets.

Our benchmarks and framework predictions are specific to a single sample event within a single stream reach. Assessors conducting stressor identification analyses will likely face data from multiple sampled reaches within an area of interest or sample reaches with multiple sample events across years. Appropriate methods for addressing temporal variability or reconciling conflicting outcome predictions within or across reaches are application-specific and beyond the

scope of this study. As described above, we recommend considering framework predictions along with other relevant lines of evidence relevant to a sampled reach. What lines of evidence are available will vary geographically, so appropriate decision rules will also. Management goals, such as the biological endpoint (macroinvertebrates, fish, endangered species, etc.) targeted often varies geographically, affecting decision rules needed.

Our SF reference benchmarks are based on channel bankfull width and implicitly assume reach bankfull width is within reference condition. In cases where human activities have increased bankfull width, we still expect the benchmark and framework to identify sediment-induced macroinvertebrate community changes. SF reference benchmarks decrease as bankfull width increases (Figure 2) because in reference streams SF decreases with stream power. Generally, when human activities increase channel width stream power decreases and substrate fine sediment increases. In such cases, measured SF would likely exceed our SF reference benchmarks. Patterns in Figures 4-6 suggest relationships between reference benchmark exceedance and macroinvertebrate responses are robust. The benchmarks and framework are not a tool for identifying stream channel geomorphic changes from reference condition but may complement other tools for evaluating anthropogenic channel alterations.

Conclusions

This study developed SF and FSBI benchmarks and a framework for applying them that can be used to evaluate the strength of evidence for sediment-induced macroinvertebrate community composition change in Idaho streams. We confirmed framework ecological relevance by examining associations between framework predictions and macroinvertebrate condition using data from multiple macroinvertebrate indicators and datasets. We propose rating the strength of evidence for a surface fine sediment-induced macroinvertebrate community composition change at the sample event scale as 'unlikely' if both SF and FSBI reference benchmarks are achieved, having 'mixed evidence' if only one reference benchmark is achieved, and 'likely' if both reference benchmarks are not achieved. Ratings should be combined with other relevant data in a weight-of-evidence approach to assess if sediment impairs aquatic life.

Acknowledgements

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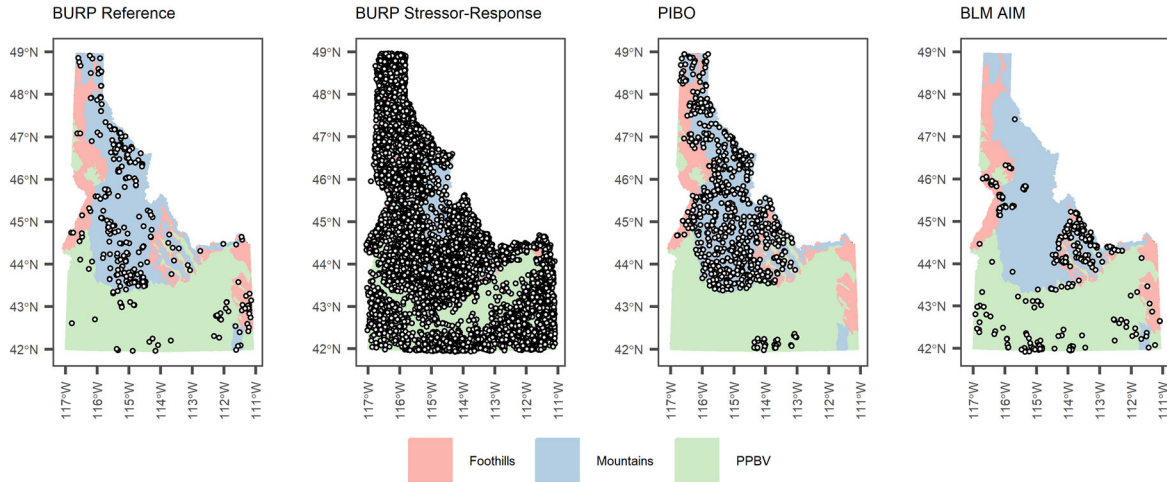
Figure 1. Locations of BURP site classes and stream reaches included in analyses. PPBV = plains, plateaus, and broad valleys.

Table 1. SF summary statistics for BURP reference and stress datasets used to develop benchmarks.

Order	Type	N	Min	Max	Mean	Median
1	Reference	74	3.7	77.5	30.8	28.8
	Stress	38	2.5	100	48.6	48.3
2	Reference	137	0.34	88.1	21.7	18.3
	Stress	43	2.55	100	44.4	39.4
3	Reference	65	2.53	72.8	19.5	16.3
	Stress	34	0.58	100	46.0	35.1
4	Reference	18	2.58	31.4	13.5	11.5
	Stress	17	0.47	99.0	36.7	13.0

Table 2. FSBI summary statistics for BURP reference and stress datasets used to develop benchmarks.

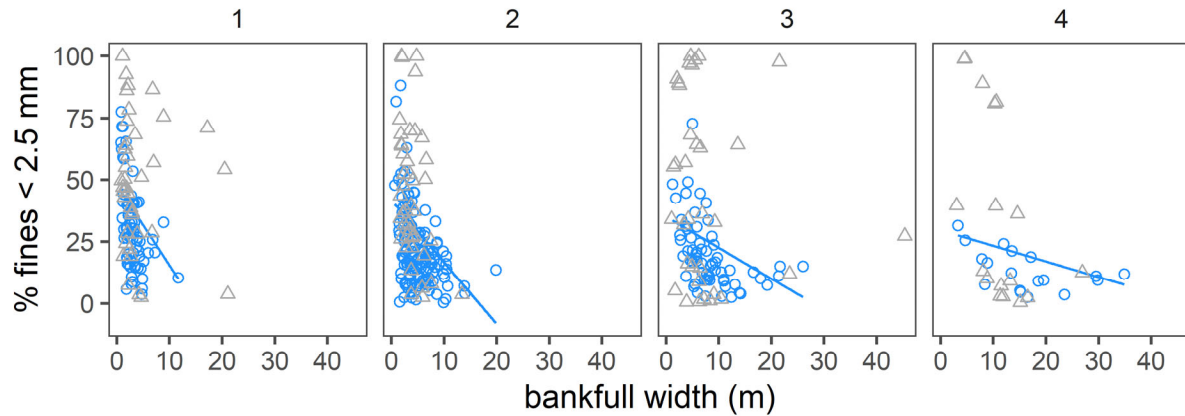| Site class	Type	N	Min	Max	Mean	Median
Foothills	Reference	26	20	195	108	102
	Stress	16	10	145	50.9	40.0
Mountains	Reference	184	35	310	175	178
	Stress	40	0	250	115	120
PPBV	Reference	31	0	180	58.9	50
	Stress	55	0	95	17.2	5

Figure 2. Relationship between bankfull width and % fines < 2.5 mm by stream order. The line is the 75th percentile quantile regression line for reference sites (blue circles). Grey triangles show BURP stress site data for comparison.

Table 3. Quantile regressions used to predict reference 75th percentile % fines < 2.5 mm (SF_{ref}). BW = bankfull width (m).

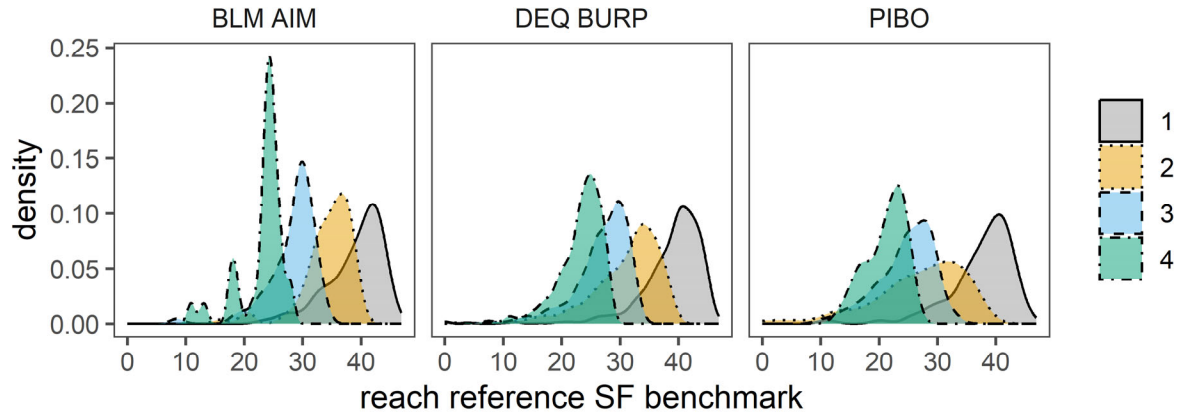| Order	Equation
1	$SF_{ref} = -3.22255*BW + 47.73073$
2	$SF_{ref} = -2.49803*BW + 41.62932$
3	$SF_{ref} = -1.24737* BW + 34.97105$
4	$SF_{ref} = -0.62823*BW + 29.54360$

Figure 3. Distribution of reach-specific SF reference benchmarks by stream order predicted using quantile regressions. For AIM and PIBO data, density distributions used one randomly selected sample event per site. N = 299 for BLM AIM, N = 5215 for DEQ BURP, and N = 665 for PIBO.

Table 4. SF stressor-response benchmarks and logistic regression model statistics.

Site Class	Order	N	SR50	SR75	Intercept (SE)	% fines B (SE)	Model X^2	Odds Ratio CI	HL p-value
Mountains	1	175	34	58	-1.45 (0.2)	0.04 (0.006)	64.7	1.03-1.05	0.09
	2	392	37	55	2.18 (0.13)	0.06 (0.005)	209	1.05-1.07	0.12
	3	315	42	71	-1.54 (0.13)	0.04 (0.006)	39.4	1.02-1.05	0.04
	4	122	31	53	-1.07 (0.29)	0.04 (0.02)	4.03	1.04-1.08	0.02
Foothills	1	503	35	52	-2.1 (0.43)	0.06 (0.01)	48.6	1.04-1.07	0.20
	2	1320	41	61	-1.98 (0.25)	0.05 (0.006)	83.8	1.04-1.07	0.16
	3	803	34	56	-1.6 (0.22)	0.05 (0.007)	62.0	1.03-1.06	0.14
	4	158	28	47	-1.5 (0.32)	0.05 (0.01)	19.9	1.03-1.09	0.12
PPBV	1	202	57	73	-3.75 (0.5)	0.07 (0.01)	73.3	1.05-1.09	0.3
	2	483	63	89	-2.5 (0.24)	0.04 (0.005)	73.3	1.03-1.05	0.13
	3	452	51	69	-2.9 (0.27)	0.06 (0.006)	143	1.05-1.07	0.24
	4	205	40	53	-3.05 (0.41)	0.08 (0.01)	76.5	1.06-1.1	0.29

Table 5. Relative risk estimates and 95% confidence intervals for benchmarks.

Benchmark	RR (SMI2)		RR (O/E)	RR (FSBI$_{ref}$)
	BURP	BLM AIM	BURP	BLM AIM
SF$_{ref}$	3.0 (1.3-6.7)	1.8 (1.0-3.2)	2.5 (1.5-4.2)	1.8 (1.1-2.9)
SR50	2.2 (0.9-5.3)	1.6 (0.9-3.1)	2.2 (1.3-3.9)	2.3 (1.5-3.4)
SR75	1.7 (0.4-7.1)	2.2 (1.8.2.8)	0.8 (0.2-3.2)	2.0 (1.4-2.7)
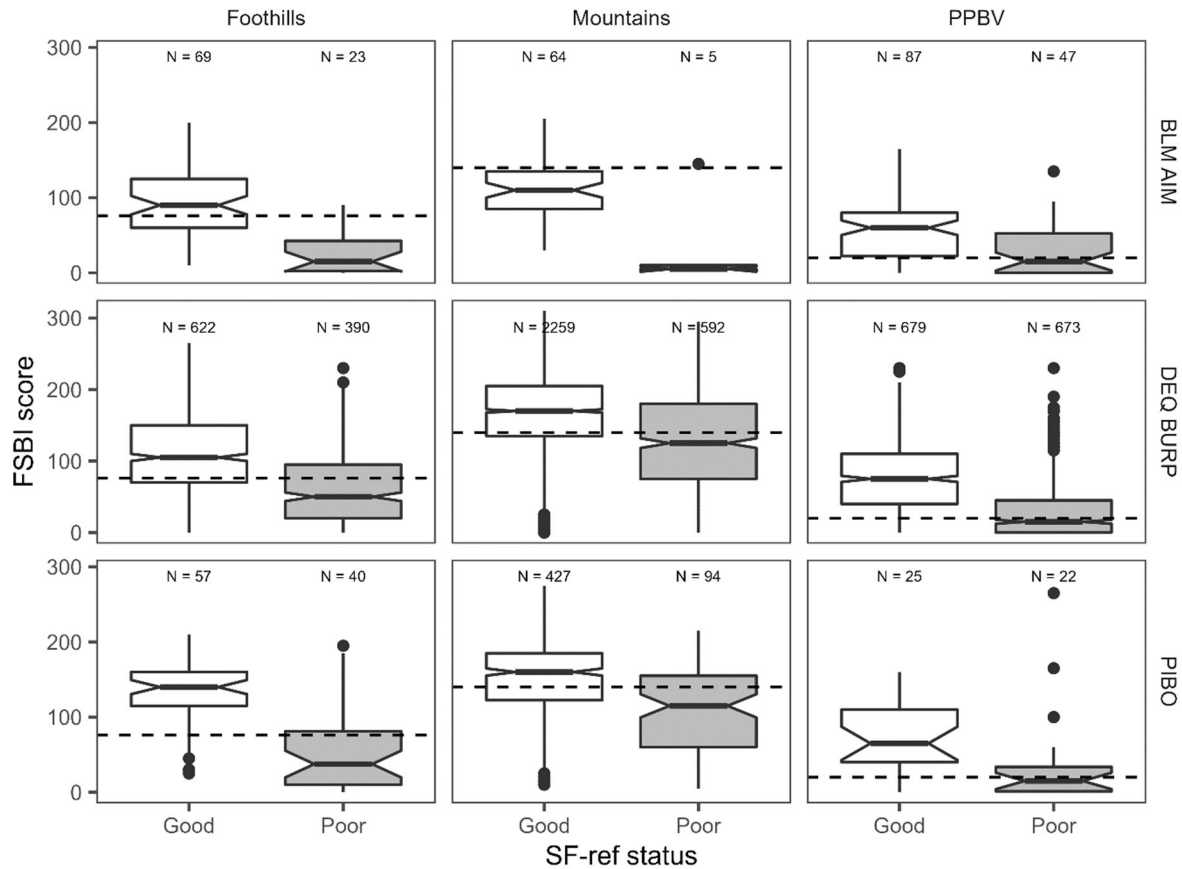
Figure 4. Relationship between SF benchmark achievement status and FSBI for BLM AIM, DEQ BURP, and PIBO data. The dashed horizontal line is the FSBI reference benchmark. Box lower and upper ends are 25th and 75th percentile, the horizontal line is the median, notches indicate median 95% confidence intervals, whiskers extend to 1.5 times the interquartile range (IQR), and circles are data points 1.5 times the IQR.
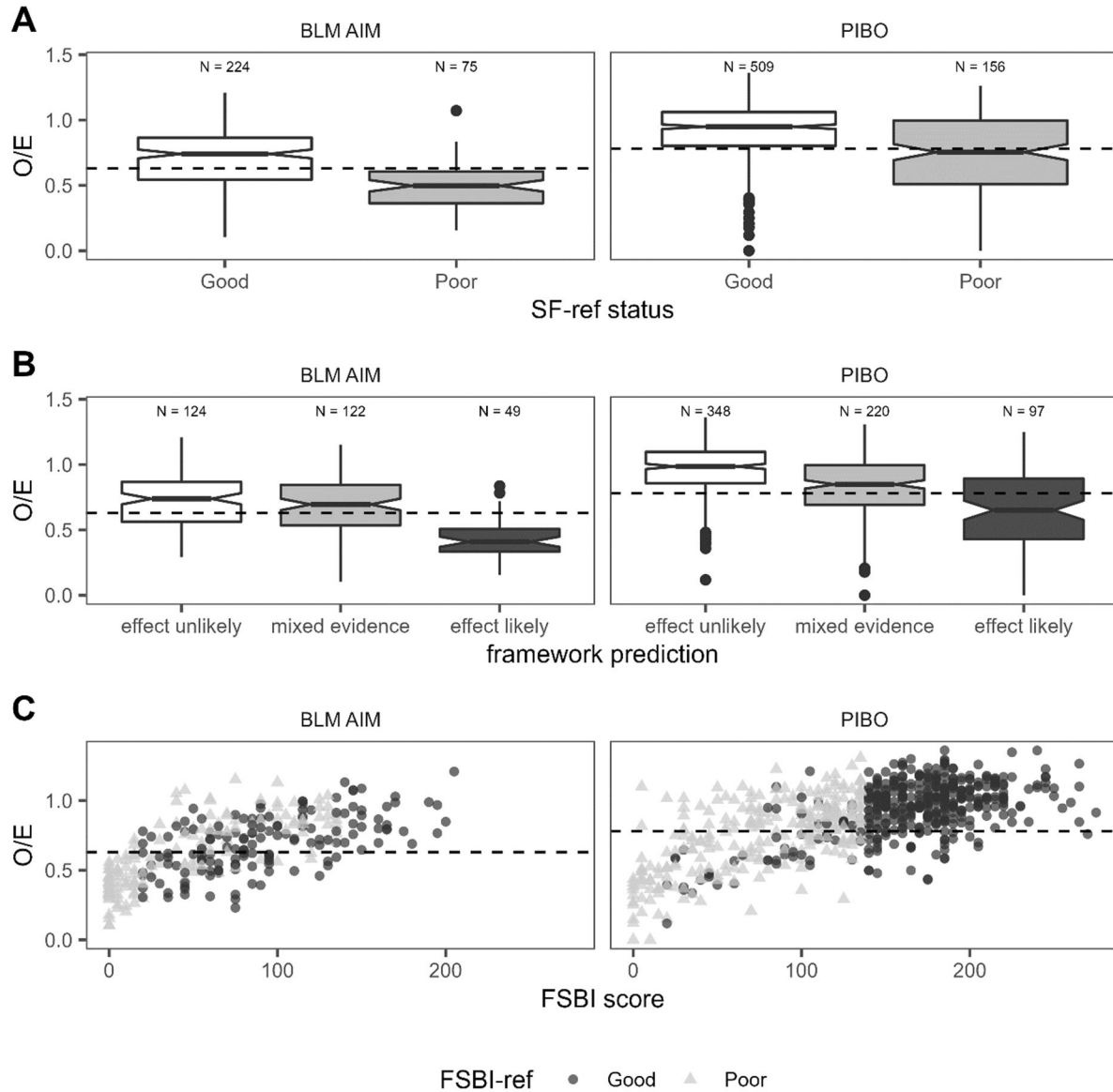
Figure 5. Relationship between SF benchmark achievement status and O/E for BLM AIM and PIBO data (A), relationship between framework prediction and O/E for BLM AIM and PIBO data (B), and relationship between O/E and FSBI score and $FSBI_{ref}$ status for PIBO and BLM data (C). The dashed horizontal lines are the program-specific O/E benchmarks.
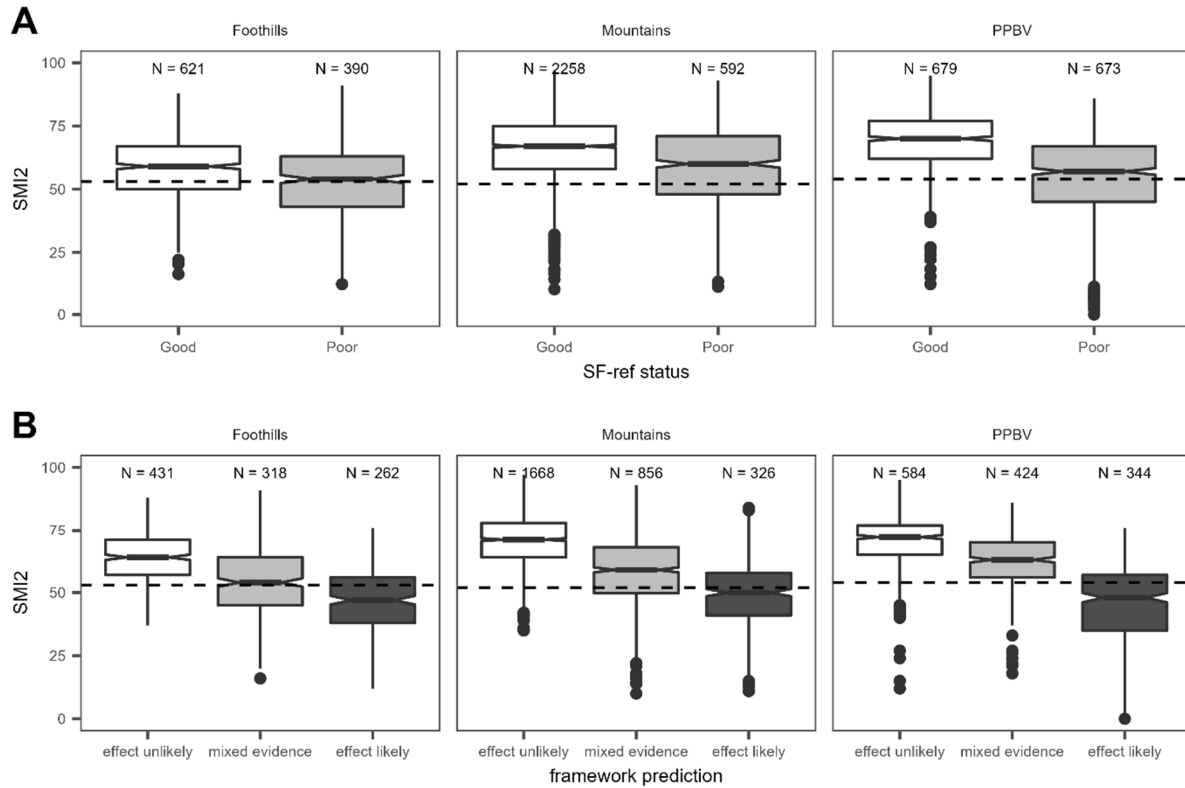
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Figure 6. Relationship between SF benchmark achievement status and SMI2 for DEQ BURP data. The dashed horizontal line is the SMI2 benchmark. See Figure 4 caption for boxplot descriptions.
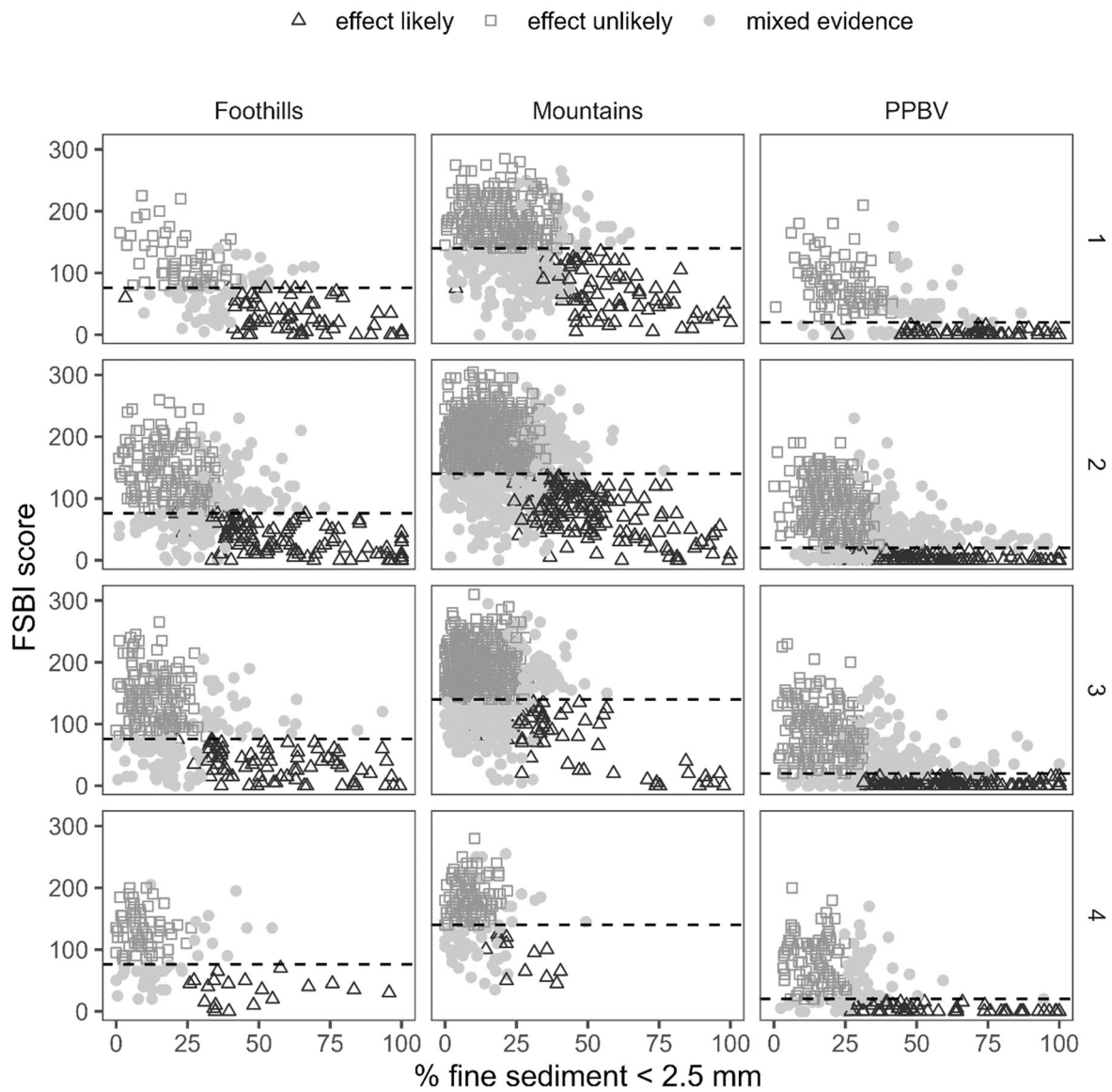
Figure 7. Surface fine sediment, FSBI, and framework predictions for BURP data by BURP siteclass and Strahler stream order. The dashed horizontal line is the FSBI reference benchmark.

Supplemental Information

Site Class Descriptions

Table S1. Site class descriptions.

Site Class	Level 4 Ecoregions
Mountains	The Wasatch-Unita mountains and selected sub-ecoregions of the Northern Rockies, Idaho Batholith, and the Middle Rockies (15i, 15o, 15p, 15y, 16 (except 16f), 17ad, 173, 19)
Foothills	The Blue mountains and selected sub-ecoregions of the Northern Rockies and Middle Rockies (11, 15j, 15f, 15m, 15n, 15s, 15u, 15v, 15w, 170, 17ab, 17j)
Plains Plateaus and Broad Valleys (PPBV)	The Columbia Plateau, Northern Basin and Range, Central Basin and Range, Snake River Plain, Wyoming Basin and selected sub-ecoregions of the Middle Rockies and Idaho Batholith (10, 12, 13, 17aa, 17n, 18, 80).

Site classes development is described in detail in Jessup (2011) and also in Jessup and Pappani (2015) and DEQ (2016).

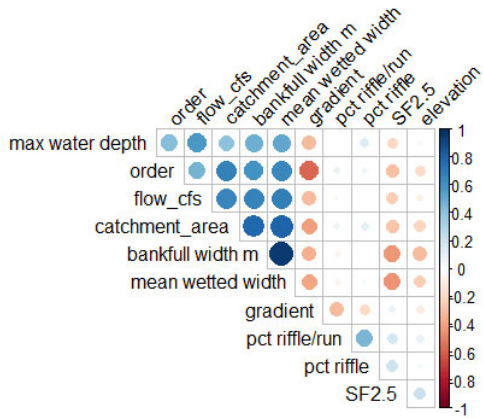**Physical Variable Relationships to % fines < 2.5 mm (BURP data)**

Figure S1. BURP reference site correlations. Size and color indicate coefficient magnitude.
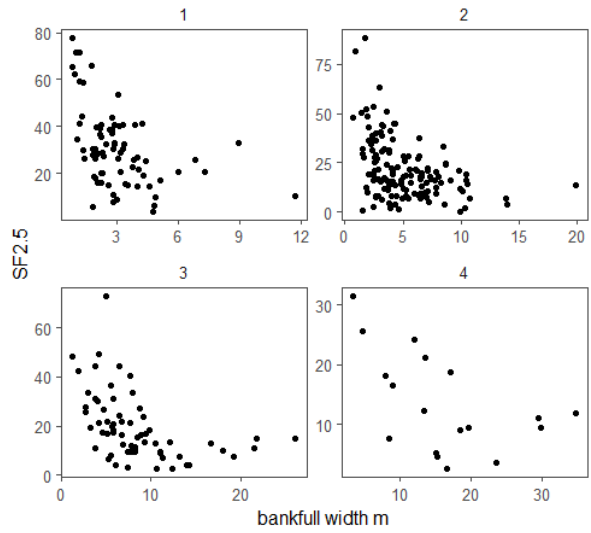
Figure S2. Relationship between bankfull width and % fines < 2.5 mm among BURP reference sites by stream order.
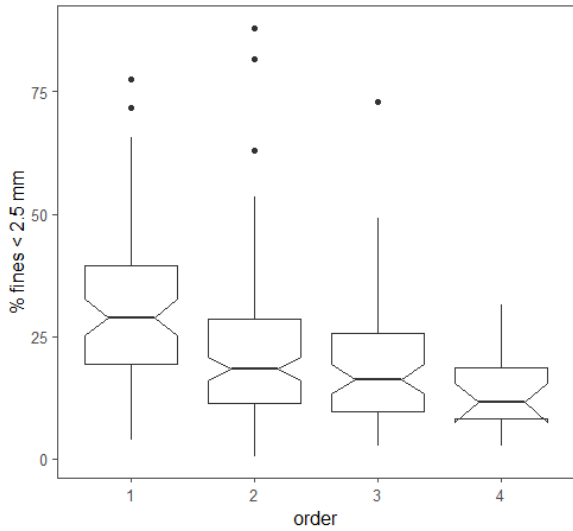

Figure S3. Relationship between stream order and % fines < 2.5 mm among BURP reference sites.

Table S2. Comparison of BURP, PIBO, and AIM monitoring programs.

|	BURP	PIBO	AIM
Agency	DEQ	USFS	BLM
Stream types sampled	wadable 1st-4th order	wadable 1st-4th order streams with < 4% gradient with and ≥ 50% federal ownership	Wadable 1st-4th order streams, and some large rivers using a boat-based protocol
Coverage	Idaho streams outside wilderness, including private and public lands	USFS and BLM lands	BLM lands
Sample design	Targeted nonrandom	Rotating panel survey design, plus some targeted nonrandom sites	Probability survey design, plus some targeted nonrandom sites
Sample timing	Summer baseflow	Summer baseflow	Summer baseflow
Repeat sampling of same reach across years	No	Yes - most sites sampled every 5 years, a subset sampled annually or biennially	Yes - most sites sampled every 5 years
Reference sites definition	Among 1998-2007 BURP sites, 10% least-disturbed sites based on 9 different land use criteria (Jessup and Pappani 2015).	Sites within Wilderness or meet all of: no obvious mining, no grazing within 30 years, < 5% timber harvest, road density < 0.5 km/km^2	No program-specific reference sites
Reach delineation	30 x bankfull width, 100 m minimum	20 x bankfull width, 160 m min and 500 m max length.	20 x bankfull width, 150 m min, 4 km max
Pebble count	Modified Wolman method, % < 2.5 mm, based on at least 50 particles from each of 3 riffle transects	Modified Wolman method, % < 2mm, based on 5 particles from each of 20 transects within reach	Modified Wolman method, % < 2 mm, based on 10 particles from each of 21 transects within reach
Macroinvertebrate sample collection	Composite of 3 500 µm mesh Hess samples from 3 riffle habitats	Composite of 8 500 µm mesh Surber net samples from riffle habitats	Composite of 8 500 µm mesh Surber net samples from riffle habitats or of 11 Surber samples spanning multiple habitat types
Taxonomic laboratory	EcoAnalysts	Utah State University / National Aquatic Monitoring Center	Utah State University / National Aquatic Monitoring Center
Macroinvertebrate condition assessment approach	MMI (SMI2 ≥ 2)	PIBO RIVPACS O/E model; target O/E > 0.78	PIBO RIVPACS O/E model; target O/E > 0.63
FSBI calculation	Yes. Calculated for each BURP sample 1998-present. See methods in supporting materials.	Not calculated. Calculated for this study.	Not calculated. Calculated for this study.
Data used in this study	1998-2007 for reference benchmarks; 1998-2021 for stressor-response benchmarks and framework performance analysis.	1st-4th order reaches sampled by PIBO in Idaho 2004-2019	1st-4th order reaches sampled by AIM in Idaho 2013-2022.

Logistic Regression Curves
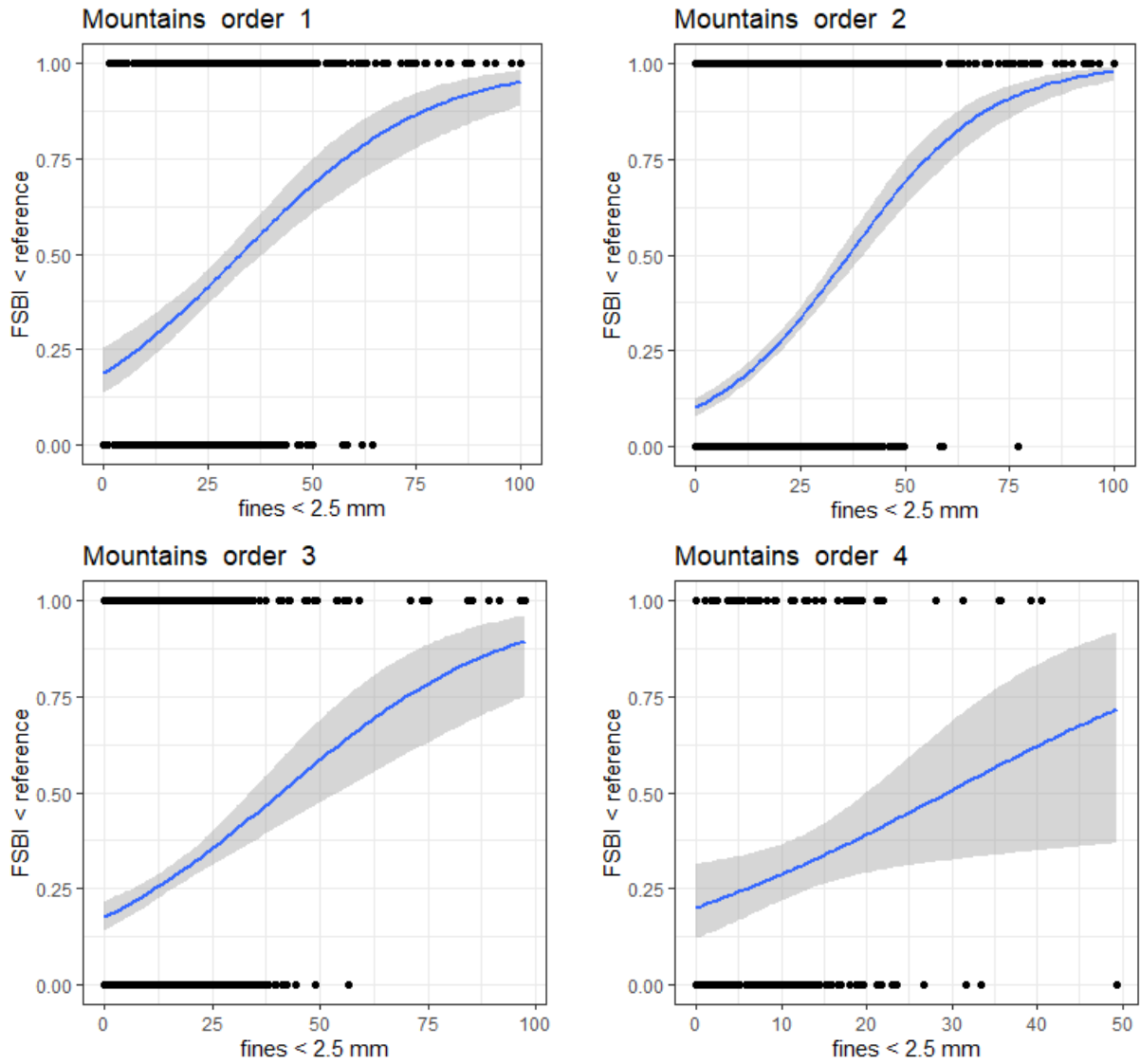
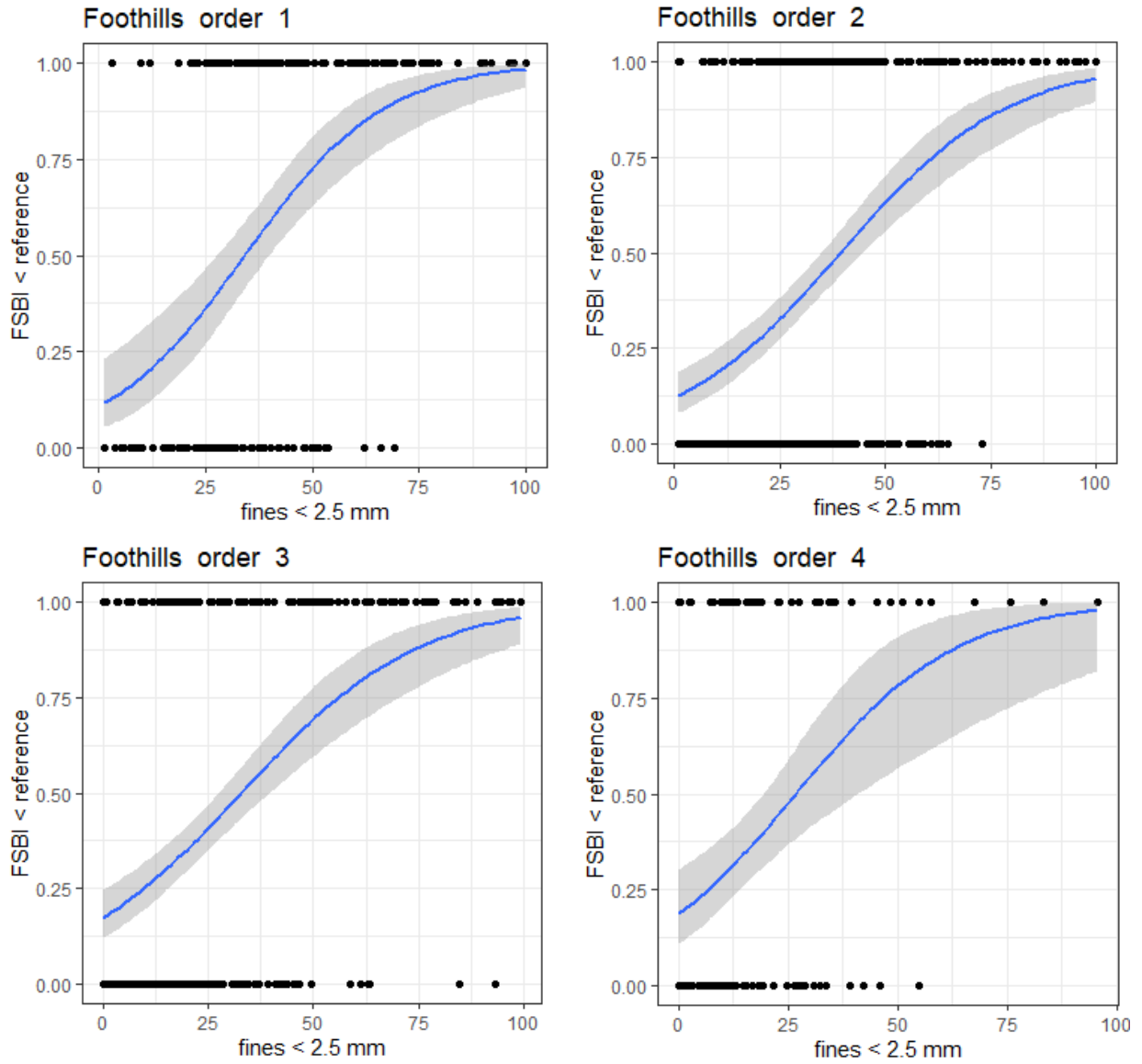**Figure S1**. Stressor-response logistic regressions for the Mountains site class.

Figure S2. Stressor-response logistic regressions for the Foothills site class.
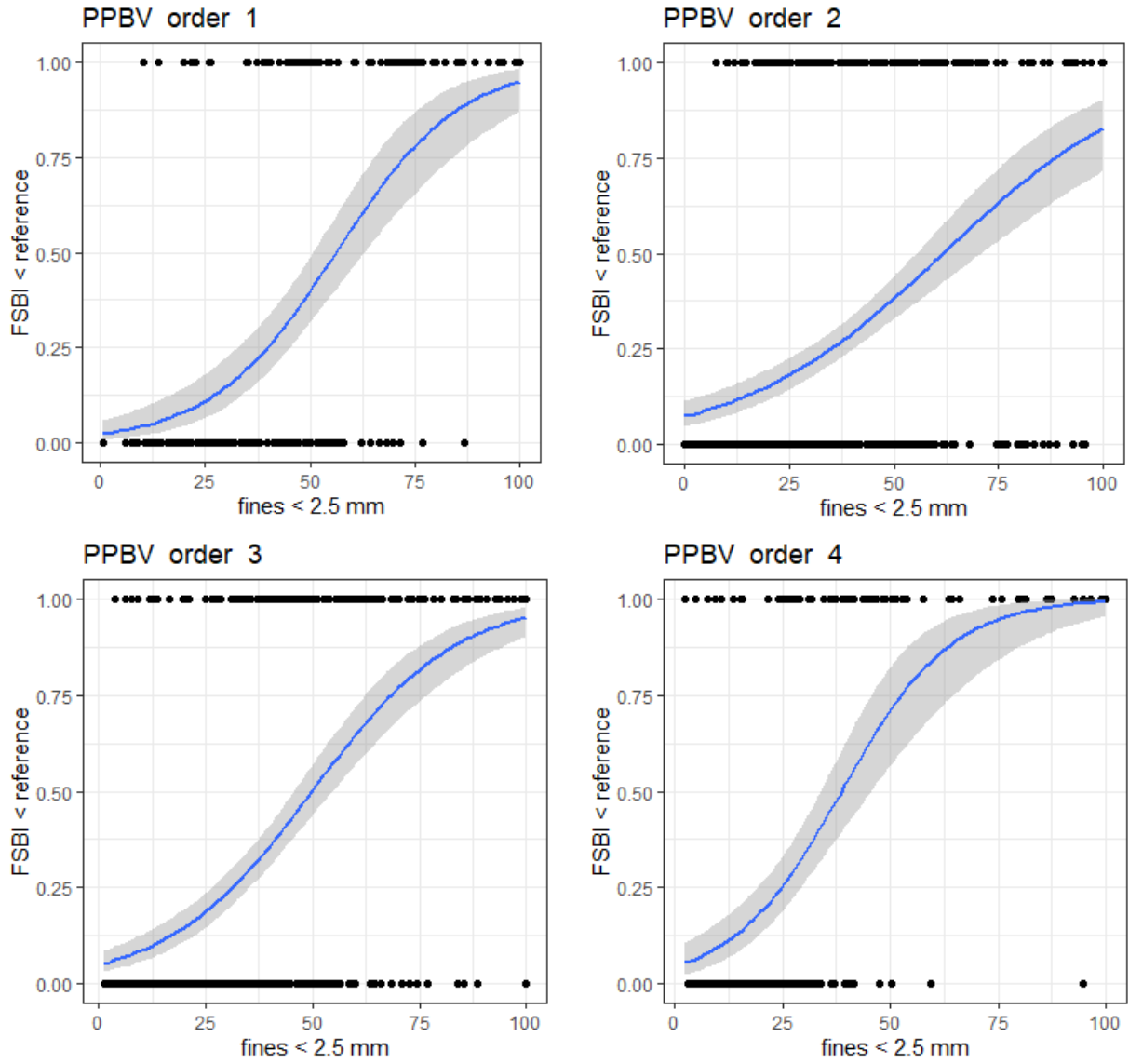
Figure S3. Stressor-response logistic regressions for the Plains Plateaus and Broad Valleys (PPBV) site class.

FSBI Calculation Methods

BURP data

The taxonomic laboratory (EcoAnalysts) identified and counted all individuals within each macroinvertebrate sample to the lowest possible taxonomic resolution, usually to genus or species. DEQ then assigned each taxa reported by the laboratory to an operational taxonomic unit (called a 'validated taxa' by DEQ) prior to importing macroinvertebrate data in to DEQ's database. Validated taxa are those for which have taxa attributes (including a FSBI-level taxa score) in DEQ's database and were used for development of BURP MMIs. In cases where a taxa identified by the laboratory is not in DEQ's validated taxa table, DEQ staff either add the taxa and its attributes to the database, or assign the taxa to a higher level validated taxa if reasonable. For example, the laboratory reports *Example species* in results, but this species is not in the database but a record for the associated genus is, in some cases the taxonomic result was imported as *Example sp.* if DEQ staff determined attributes were similar. Sample FSBI was calculated as the sum of all taxa-level FSBI scores associated with validated taxa within a sample.

PIBO and AIM data

For the PIBO and AIM programs, the taxonomic laboratory (National Aquatic Monitoring Center at Utah State University) identified up to 600 individual specimens from each sample to the lowest possible taxonomic resolution, usually to genus or species. Raw laboratory taxonomic identifications were then assigned to an operational taxonomic unit used for purposes of O/E calculations. USFS and BLM then randomly subsampled identified taxa to create a list of 300 identified individuals for each sample.

At the time of this study, the PIBO and AIM programs did not calculate sample FSBI from their macroinvertebrate data. USFS and BLM provided harmonized subsampled macroinvertebrate data to DEQ for FSBI calculations. Based on Relyea et al. 2012, DEQ assigned a taxa-level FSBI score to each unique taxa name reported by the laboratory (ScientificName values) included in subsampled data. Sample FSBI scores were then calculated using an R tool developed for this project (https://github.com/jjwill2/FSBI_calculator). Sample FSBI scores were calculated as the sum of assigned taxa-level FSBI scores within a sample. Assigned taxa-level FSBI scores and R inputs and outputs are available through the github link.

Table S4. Fine sediment benchmarks reported in the literature and used for comparison to calculated benchmarks. All thresholds are for surface fine sediment, except where noted otherwise.

Source	Benchmark Description	Biological Receptor	Sediment Size Fraction	Stream Size	Threshold Value
Bryce et al. 2010	Minimum effects threshold for Index of Biotic Integrity (IBI) value decreases in wadable Western U.S. mountain streams	aquatic vertebrates	≤ 0.06 mm	wadable	5%
		aquatic vertebrates	≤ 2 mm	wadable	13%
		aquatic macroinvertebrates	≤ 0.06 mm	wadable	3%
		aquatic macroinvertebrates	≤ 2 mm	wadable	10%
Jessup et al. 2014	Recommended reference benchmark for New Mexico streams in mountains site class, based on statistical distribution within reference sites and changepoint analysis for multiple biological indicators.	aquatic macroinvertebrates	≤ 2 mm	wadable	20%
Reylea et al. 2012	Percent fines levels at which sediment-sensitive macroinvertebrate taxa start disappearing from northwest US streams.	aquatic macroinvertebrates	< 2 mm	1-6th order	10-20%
Jensen et al. 2009	Surface plus subsurface fine sediment threshold for rapid decreases of egg-to-fry survival, based on a meta-analysis of lab and field studies in peer-reviewed literature	Chinook, Coho, and Chum salmon, and steelhead trout	< 0.85 mm	NA (lab & field experiments)	10%
Jensen et al. 2009	Surface plus subsurface fine sediment threshold for rapid decreases of egg-to-fry survival, based on a meta-analysis of lab and field studies in peer-reviewed literature	Chinook, Coho, and Chum salmon, and steelhead trout	< 3.4 mm, < 4.8 mm, < 6.4 mm	NA (lab & field experiments	25-30%
Burdon et al. 2013	Threshold above which rapid changes in pollution-sensitive invertebrates (% Ephemeroptera, Plecoptera, and Trichiptera) were observed across 20 New Zealand agricultural streams.	Aquatic macroinvertebrates	< 2 mm	1-3rd order	20%
EPA 2020 (Table 4.2)	Threshold used to identify reference sites within the Northern Rockies and Pacific Mountains region for the National River and Streams Assessment (NRSA)	NA (reference statistical distribution)	unclear	wadable & non-wadable	15%
EPA 2020 (Table 4.2)	Threshold used to identify most-disturbed sites within the Northern Rockies and Pacific Mountains region for the National River and Streams Assessment (NRSA)	NA (reference statistical distribution)	unclear	wadable & non-wadable	50%
EPA 2007	'Good' condition threshold used by EPA for assessing stream conditions in EMAP Report 'Ecological Condition of Wadable Streams of the Interior Columbia River Basin'. 'Good' percent fines condition was calculated as 75th percentile value among least-disturbed reference sites within Northern Rockies, Idaho Batholith, Middle Rockies, and Canadian Rockies ecoregions.	NA (reference statistical distribution)	< 2 mm	wadable	16.19%
EPA 2007	'Good' condition threshold used by EPA for assessing stream conditions in EMAP Report 'Ecological Condition of Wadable Streams of the Interior Columbia River Basin'. 'Good' percent fines condition was calculated as 75th percentile value among least-disturbed reference sites within Columbia Plateau and Northern Basin & Range ecoregions.	NA (reference statistical distribution)	< 2 mm	wadable	29.52%
Miller et al., 2021	70th percentile value among Northwest U.S. stream reference sites within Northern Rockies level III ecoregion	NA (reference statistical distribution)	< 2 mm	≤10 m bankfull width	29%
Miller et al., 2021	70th percentile value among Northwest U.S. stream reference sites within Northern Rockies level III ecoregion	NA (reference statistical distribution)	< 2 mm	> 10 m bankfull width	15%
Miller et al., 2021	70th percentile value among Northwest U.S. stream reference sites within Xeric Basins level III ecoregion	NA (reference statistical distribution)	< 2 mm	≤10 m bankfull width	45%
Miller et al., 2021	70th percentile value among Northwest U.S. stream reference sites within Xeric Basins level III ecoregion	NA (reference statistical distribution)	< 2 mm	> 10 m bankfull width	44%

Source	Benchmark Description	Biological Receptor	Sediment Size Fraction	Stream Size	Threshold Value
USFS et al. 1997	Surface fine sediment levels recommended by USFS and BLM in their draft EIS for Upper Columbia River Basin developed. Recommended values vary based on Rosgen channel type (A-C) and geology (plutonic, volcanic, or metamorphic rock). See also DEQ 2003.	Anadromous salmonids	< 6 mm	unclear	14-37%
USFS 1995	PacFish/InFish Environmental Assessment Alternative E ('which was not ultimately selected) stated "A Riparian Management Objective for sediment substrate would be established to be less than 20 percent fine sediment in spawning habitat" (USDA 1995, pA-16)	Anadromous salmonids	unclear	unclear	20%
CRITFC 1995.	Recommended surface fine sediment levels for an in-channel habitat condition coarse screening process. In cases where the benchmark is exceeded, land management actions to reduce sediment were recommended.	Anadromous salmonids	< 6 mm	unclear	20%
USFS et al. 1998	Recommended surface fines benchmark for use in making Endangered Species Act determinations of effect for individual or group actions at the watershed scale for the Clearwater Basin and Lower Salmon, applies to Rosgen channel type A & B	Chinook, Steelhead, and Bull Trout	< 6 mm	Not specified	≤10%
USFS et al. 1998	Recommended surface fines benchmark for use in making Endangered Species Act determinations of effect for individual or group actions at the watershed scale for the Clearwater Basin and Lower Salmon, applies to Rosgen channel type C & E	Chinook, Steelhead, and Bull Trout	< 6 mm	Not specified	≤20%
NMFS 1996	Recommended percent fines in gravel for streams classified as 'properly' functioning for purposes of making Endangered Species Act determinations of effect	Anadramous salmonids	< 0.85	Not specified	< 12%

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