Using Multiple Fine-sediment Size Classes to Evaluate the Condition of Trout Spawning Habitat

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Trout biomass and substrate samples from potential spawning areas were analyzed from 36 streams throughout the Monongahela National Forest, West Virginia to determine if trout biomass and sediment relationships on the forest were consistent with what is reported in scientific literature, and whether the data could provide additional insights into those relationships. Graphs of trout biomass plotted against various size fractions of substrate sediment show fairly large variability in the data, suggesting that fine sediment is only one of many factors that controls trout populations. Trout biomass did not change significantly as the percent of fine sediment < 4 mm diameter increased, showing that this more traditional metric is not applicable for the small sized trout found in this forest's streams. By contrast, trout biomass decreased significantly as the percentage of sediment < 1 mm diameter increased. The most important size class for predicting trout biomass was the < 1 mm fraction. Once sediment < 1 mm diameter comprised 45 percent of the < 4 mm fraction, trout biomass was almost always less than 20 kg/ha. Analyses of other individual particle sizes indicate that "good" spawning materials contain a mix of particle size classes. Consequently, we propose that the traditional single-size classification approach be replaced by an evaluation of multiple particle sizes. This approach, particularly when combined with data about other factors that could affect trout productivity, would provide a more thorough understanding of how management activities could affect trout or whether mitigations could improve stream conditions for trout.

Keywords: *sedimentation, stream substrate, trout, monitoring*

Introduction

A wealth of literature supports the effects of sediment on salmonids in the North America. Unfortunately, much of that research has been performed in the laboratory or in controlled environments, such as flume experiments. There is a need to examine sediment relationships using field data, to determine how well results under controlled conditions compare with those in the field.

The Monongahela National Forest in West Virginia has conducted aquatic monitoring for more than two decades, including the routine collection of substrate sediment and fish data. The forest traditionally has evaluated stream conditions by classifying fine sediment as those < 4 mm diameter (Chapman 1988), as this size class is widely accepted as the critical one for salmonids. However, the < 4 mm diameter class was established primarily based on studies of western salmonids larger than those typically found in the eastern U.S., especially the salmonids of the inland East. Regional and local studies in the East have suggested that smaller particles are more important in affecting smaller fishes and their habitats. For example, Hausle and Coble (1976) and Argent and Flebbe (1999) reported a negative relationship between brook trout (*Salvelinus fontinalis*) egg and fry survival when fine sediments comprised 20-25 percent of the bed substrate. Hausle and Coble (1976) defined fine sediment as < 2 mm diameter, while Argent and Flebbe (1999) defined them as 0.43 to 0.85 mm. Peterson and Metcalfe (1981) showed that Atlantic salmon (*Salmo salar*) eggs had poorer survival in fine sediment defined as 0.06 to 0.5 mm diameter, when compared to fine sediment defined as 0.5 to 2.2 mm

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diameter. Hakala (2000) showed that sediment between 0.063 mm and 1 mm diameter had a negative effect on spawning substrate quality and brook trout populations in West Virginia.

Consequently, we wanted to examine data collected from the Monongahela National Forest's routine monitoring procedures to determine: 1) if they show relationships between trout biomass and sediment that are consistent with the literature; and 2) if the data already available from the monitoring program can provide additional useful insights. These questions are of more than just academic interest. For years the forest has used the literature to make statements about relationships between trout and sediment in a variety of documents, but it has not substantiated that those relationships apply to streams in the Monongahela National Forest. Being able to confirm some of the most basic relationships would strengthen the validity of statements in those documents. In terms of the second point, too often monitoring simply is done to fulfill a legal or institutional requirement without consideration of the long-term value for land management decisions. With the limited resources available for monitoring, it is critical to ensure that monitoring actually provides useful information.

Methods

Sites and Field Procedures

Forty-one streams across twelve land type associations on the Monongahela National Forest (Figure 1) were selected for fish sampling in 1999 because: 1) few data existed for these streams, 2) there was interest in examining the productivity of these streams, or 3) projects were planned in the watersheds in which they exist. While some data were available for several years since 1990, only the data from 1999 were used in this analysis; this data set was large enough for analysis without interjecting variability from multiple years of data collection with potentially greatly different streamflow conditions. In each stream, a 91.4-m representative reach was electrofished. Two passes were made moving upstream and two crewmembers netted shocked fish. Each fish was identified to species and weighed prior to returning them to the stream. Biomass was expressed as kg/ha of stream surface area.

Five streams (Beaver Creek of the Greenbrier River, Fox Run, Ken's Creek, Little Laurel Creek, and Mill Run, a tributary to Taylor Run) had either no fish in the sampled reaches or only non-game species of fish. The other 36 streams contained either native brook trout only or mixes of brook trout and non-native rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*) or both. In this paper we report only on the trout (both native and non-native) that were captured, though the relationships for all trout mirrored those of only brook trout. None of the sampled streams are stocked with fish, so the rainbow and brown trout originated from migrating individuals from off-site stocking.

During the same site visit, spawning gravel substrate were sampled from the same reach using shovel sampling (Grost et al. 1991). Shovel sampling entails pushing the blade into the desired location in the streambed to about half way up the length of the blade. The handle of the shovel then is pushed downward to lever the blade out of the bed. The shovel blade then is slowly lifted from the stream, and water is allowed to drain from the sample before storing it in a zipper-lock plastic bag. During extraction and transference to the bag, care is taken to avoid losing the smallest fraction of the sample.

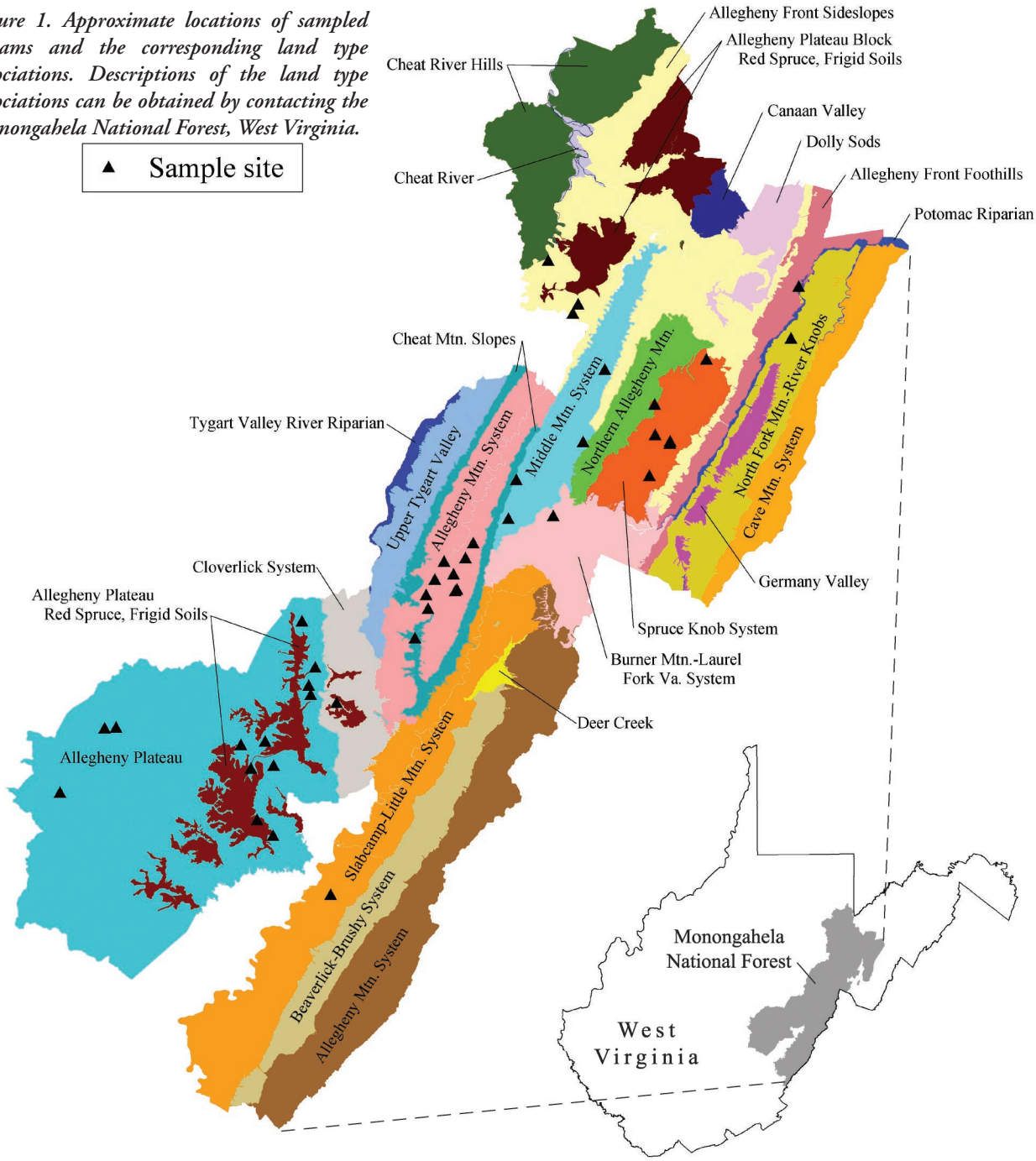
Six shovel samples were collected from six separate sites considered by the forest's fisheries biologist to have suitable characteristics for spawning. Suitable spawning materials were defined in terms of adequate substrate size (predominantly gravel to small gravel) and position in the channel (typically, but not exclusively, pool tails). Each shovel sample was placed in a separate zipper-lock plastic bag and processed individually. Samples were oven-dried at 100°C until they reached a constant weight. Each oven-dried sample was mechanically shaken through a nest of sieves [mesh sizes: 53.8 mm, 38.1 mm, 8 mm, 6.3 mm, 4 mm, 2 mm, 1 mm, and < 1 mm (i.e., pan)] for 7 minutes. The sample weight in each sieve was determined gravimetrically to the nearest gram.

Percent fine sediment of each sample was defined in two ways: < 4 mm diameter (cumulative weights of the materials in the pan, 1-mm, and 2-mm sieves), which is the procedure that the forest traditionally has used to define fine sediments, and < 1 mm diameter (the pan fraction). The latter was considered because a recent study by Hakala (2000) showed sediment between 0.063 mm and 1 mm diameter was most detrimental to brook trout in Monongahela National Forest streams. For the purposes of percentage computations, total sample weight was determined from the cumulative sample weights in only the 8-mm and smaller sieves, because the fisheries staff on the Monongahela has defined spawning materials as particles < 38.1 mm.

Data Analysis

Mean fine sediment weights were determined for each stream reach based on the six samples. Mean percentages then were determined and are used in the analyses in this paper.

Figure 1. Approximate locations of sampled streams and the corresponding land type associations. Descriptions of the land type associations can be obtained by contacting the Monongahela National Forest, West Virginia.



To describe the general relationships between trout biomass and mean fine sediment values for all the sampled sites, trend lines were developed using locally weighted regression with Locfit software (Loader 1998). Locally weighted regression was used because this approach does not assume an a priori defined form of the fitted equation, such as linear, quadratic, etc. Thus, it can be used to provide a trend line that better describes the overall pattern of the data than one that has a more stringent user-defined form, particularly for trends that are difficult to determine visually. The degree value of the local polynomial and smoothing parameter for the locally weighted regressions were selected using procedures outlined by Cleveland (1994), in which the residual pattern was examined to assure the values of both parameters were appropriate and not over-fitted.

Because locally-weighted trend lines do not have associated slope and intercept coefficients, tests of significance were performed on the data, not on the trend lines. Mann-Kendall tests (Mann 1945) were run to determine whether the increases or decreases in the data were statistically significant. Because the data were

relatively widely spread and there are other factors that can affect productivity, statistical significance was defined at $p \leq 0.10$. Where trend lines showed a change in direction in trout biomass from increasing to decreasing or from increasing to leveling off, the data set was separated into two data sets at the inflection point and both were analyzed for significance.

Stepwise regression was used to determine the size classes that were most important to controlling trout biomass levels (SAS Institute Inc. 1988). Nonparametric correlation analysis (Spearman correlation analysis) was performed (SAS Institute Inc. 1988) to verify if the size classes that were identified as important were directly or indirectly related to trout biomass.

RESULTS

Trout biomass from all the sampled streams except one, Strader Run, fell within a wide, but well-defined range of 4.48 kg/ha to 99.7 kg/ha (Figure 2). The broad range of trout biomass found across the forest suggests, not surprisingly, that fine sediment is only one factor controlling fish productivity. For unknown reasons, Strader Run appears to be an anomaly for streams on the Monongahela, with a biomass of 168.1 kg/ha. Because of its atypical, extraordinarily high biomass and the potential for that single stream to bias the trend and statistical results, Strader Run was removed from the data set for all subsequent analyses.

Trout biomass relationships for the < 1 mm and < 4 mm fine sediment fractions are similar (Figures 2a and 2b, respectively). Most data are clustered and bounded by the dashed lines we inserted to better illustrate the common range of the data. If these streams are representative of streams throughout the forest, the lower and upper boundaries in Figures 2a and 2b suggest that few streams in the Monongahela have less than 4 percent of spawning materials composed of < 1 mm diameter fractions or less than 12 percent composed of < 4 mm particles, and greater than 18 percent composed of < 1 mm diameter fractions or greater than 45 percent composed of < 4 mm particles.

The general relationships between trout biomass and the percentages of sediment < 1 mm and < 4 mm diameters are illustrated by the trend lines fitted to the data (Figure 3a

Figure 2. Relationships between trout biomass and fine sediment in potential spawning materials for fine sediment defined as (a) particles < 1 mm diameter and (b) particles < 4 mm diameter.

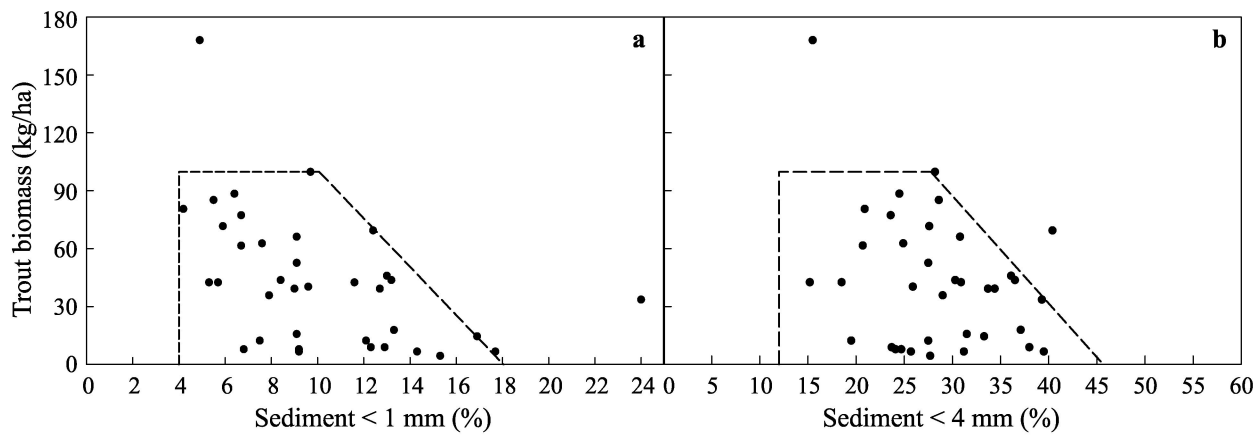
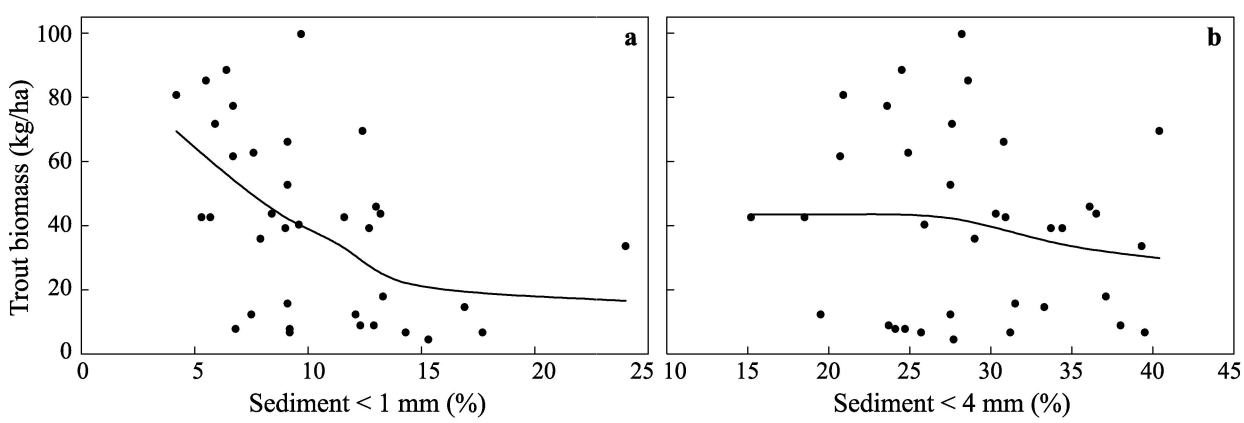
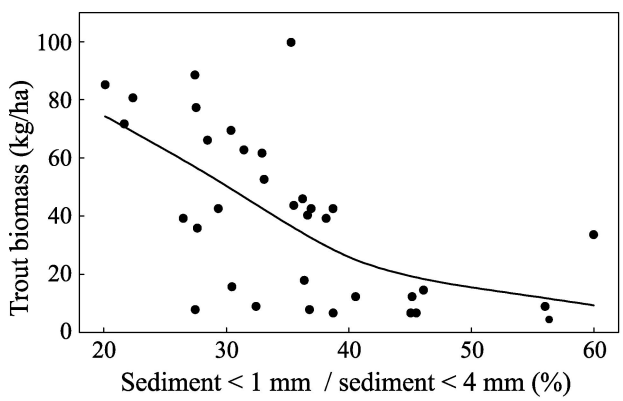


Figure 3. Locally-weighted regression lines show trout biomass responses to increasing fine sediment in potential spawning materials for fine sediment defined as (a) particles < 1 mm diameter and (b) particles < 4 mm diameter.



and 3b). Trout biomass decreased significantly (p = 0.002) as the percentage of < 1 mm sediment increased (Figure 3a). By contrast, trout biomass showed a much less distinct and not statistically significant response (p = 0.378) in relation to particles < 4 mm diameter (Figure 3b). Not surprisingly given the relationships in Figures 3a and 3b, as the percentage of < 1 mm particles increased relative to total fine sediment (i.e., < 4 mm) there was a corresponding significant (p = 0.000) reduction in trout biomass (Figure 4). When approximately 45 percent of total fine sediment was made up of < 1 mm materials, trout biomass was almost always less than 20 kg/ha.

Figure 4. Trout biomass responses as < 1 mm particles in potential spawning materials become an increasing larger percentage of the < 4 mm fraction. The trend line was determined using locally-weighted regression.



The distinct differences in trout biomass patterns between the individual < 1 mm size class compared to the cumulative < 4 mm size class illustrates the potential importance of considering size classes individually rather than cumulatively. Consequently, to obtain a clearer understanding of how individual sediment size classes are related to trout biomass, we examined trout biomass relative to the percentage of materials in each individual sieved particle size class (except for the < 1 mm size, which is presented in Figure 3a).

The trend line for the 1 to < 2 mm size fraction indicates that trout biomass increased and then decreased with increasing percentages of particles in that fraction (Figure 5a); however, the data are widely distributed and the probabilities of significance on both sides of the inflection point were not significant (p = 0.239 increasing trend line side; p = 0.779 decreasing trend line side). For the next two larger size fractions (2 to < 4 mm and 4 to < 6.3 mm), the trend lines for trout biomass increased with increasing percentages of these particles, and then reached a plateau (Figures 5b and 5c, respectively). The probabilities for the increasing portions of the 2 to < 4 mm and the 4 to < 6.3 mm fractions were significant (p = 0.008 and p = 0.092, respectively), but as the trend lines suggested, the data on the plateaus did not change significantly (p = 0.806 and p = 0.721, respectively). The point at which the trend lines leveled off occurred at a greater percentage than where the inflection point occurred for the 1 to < 2 mm fraction. This shift suggests these slightly larger particles are less deleterious to trout than the smaller ones. While the trend line for the 6.3 to < 8 mm fraction shows similar leveling off after increasing, it is difficult to say how trout are affected when the percentage of particles in the 6.3 to < 8 mm size class becomes large, because there was only one mean value that exceeded 12 percent. Consequently, the data were not separated into different sets for analysis of significance, and the data did not show any significant increase (p = 0.221). Trout biomass for the largest size spawning materials (8 to < 38.1 mm) returned to the same pattern as that exhibited by smaller sized particles, first increasing slightly then decreasing in response to increasing sediment (Figure 5e). The pattern of the trend line was not strong, and the analyses of the data indicate no significant changes in biomass on either side of the inflection point of the trend line, though the probability was approaching significance for the data on the increasing portion of the trend line (p = 0.127). Data on the decreasing portion had a significance of p = 0.272.

Obviously, these trend lines represent only the overall responses of the available data; they do not represent predictions of fish biomass for a specific sediment level in an individual stream. Indeed, one reason for using locally-weighted regression was to focus on the trends rather than inappropriately predicting biomass responses from sediment values based on a small data set. The shape of the trend lines is the important feature here, and the points of inflection should not be used as thresholds for defining the ideal allowable percentage of sediment in any size class. There simply is too much variation in biomass data because of the myriad limiting factors to use an inflection point derived from analysis of a single variable as a threshold.

The trend lines and statistical results do provide some useful preliminary information and insights, which should be validated further as more monitoring data become available. First, the < 1 mm particle size data are consistent with the general findings in the literature that fine sediment is detrimental to trout (Argent and Flebbe 1999; Hausle and Coble 1976; Phillips et al. 1975; Tappel and Bjornn 1983; van den Berghe and Gross 1989), and the more specific findings from a small set of streams in the Monongahela National Forest that particles of < 1 mm diameter have the most demonstrable negative effect on trout biomass (Hakala 2000). Second, defining fine

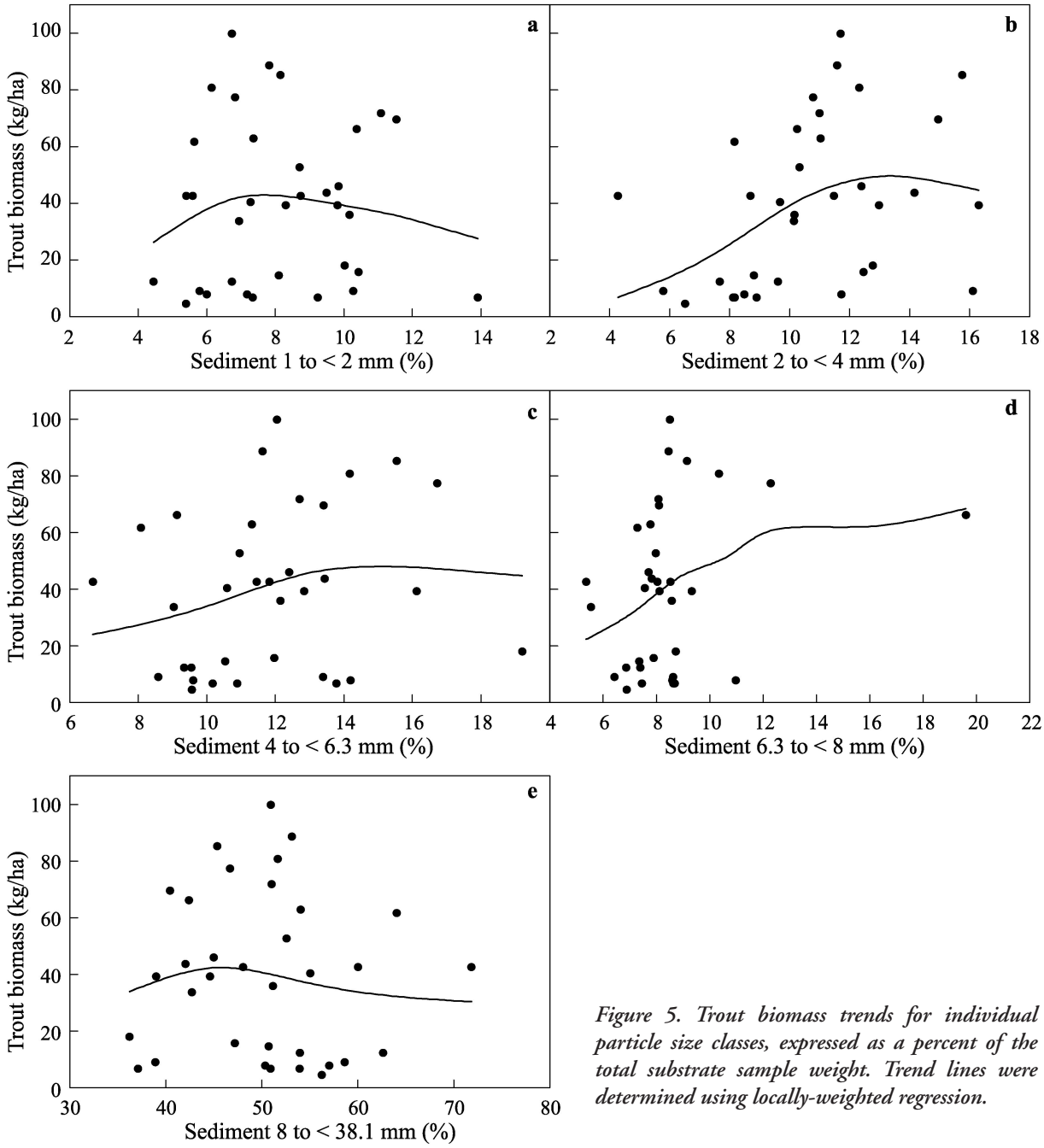


Figure 5. Trout biomass trends for individual particle size classes, expressed as a percent of the total substrate sample weight. Trend lines were determined using locally-weighted regression.

sediment as materials < 4 mm in diameter does not seem to be a useful metric for determining the suitability of spawning materials for the relatively small-sized trout found in the Monongahela National Forest. And third, the increasing and then decreasing or flattening patterns of the data and/or trend lines for particle sizes ≥ 1 mm suggest that the best spawning materials are ones that contain a mixture of particle sizes and are not dominated by a single size. Again, this is a general trend, and other conditions, such as water chemistry, habitat availability, and fishing pressure, will influence how well trout succeed in any individual stream.

As a result of these three findings, we propose that the traditional single-size classification approach be replaced with a multiple particle size analysis approach to evaluate the condition of spawning habitat or the extent to which sediment may be a limiting factor in a stream. Without knowing much else about a stream (which often is the case for many streams on public lands), simply determining the mix of particle sizes may indicate if sediment is a limiting factor for trout. A good mix of particle sizes seems to be one in which the intermediate class sizes (2 to < 4 mm, 4 to < 6 mm, 6 to < 8 mm) have percentages similar to each other and greater percentages than the smaller size classes,

the < 1 mm size class is only a small percentage of the total spawning material, and the 8 to 38 mm diameter particles make up about half of the spawning material by weight.

Results from stepwise regression support the idea that a mixture of substrate size classes is important for trout success. This procedure is parametric and assumes each of the individual sediment size classes is independent of the others, which is not wholly true, but the results are illustrative nonetheless. In the model, the most important size class for predicting trout biomass was the < 1 mm fraction ($p = 0.0039$); this is not surprising based on the fairly strong (i.e., less variability in the data around the trend line than for other size classes) inverse relationships in Figures 3a and 4. The only other variable that was statistically significant in the stepwise regression was the 2 to < 4 mm fraction ($p = 0.0396$). Nonparametric correlation analysis showed trout biomass to be positively and significantly correlated with this fraction ($r = 0.42$, $p = 0.0114$), meaning that trout biomass generally increases with increasing percentages of 2 to < 4 mm materials, consistent with Figure 5b. The other intermediate size fractions (4 to < 6.3 mm and 6.3 to < 8 mm) and the 1 to < 2 mm fraction each were positively and significantly correlated to the 2 to < 4 mm size fraction ($r = 0.76$, 0.49, and 0.52, respectively, and $p \leq 0.0001$, 0.0026, and 0.0011, respectively). The high degrees of correlation explain why these other fractions were not significant in the stepwise regression; i.e., the contributions of each fraction to predicting trout biomass would have been duplicative with the 2 to < 4 mm class. The high degrees of correlation also support the idea that balanced percentages of these size classes provide the mixes of particle sizes that are conducive to trout success.

Discussion

As stated earlier, our findings are only empirical, so we only can speculate about the mechanisms driving the responses. Since the samples were collected in potential spawning materials, it is perhaps most intuitive to make conclusions related directly to sediment effects on spawning, redd conditions, and egg development. Thus, the interpretation would be that very small particles hinder oxygen diffusion to eggs laid in redds and fry emergence (Chapman 1988). More-intermediate sized particles provide better conditions in terms of oxygen supply, better substrate for spawning use and success, or both.

However, the composition of spawning material in any reach is an index of the overall sediment composition throughout the reach, not just the spawning areas. Thus, one could reasonably assume that if very small sized sediment dominates spawning materials, other habitats in the reach also are affected by high percentages of very fine sediments. This parity simply could mean that poor physical conditions are ubiquitous in the stream reach and contribute to a lack of habitat variability, which would affect trout during all portions of their life cycle, as well food sources for the fish (Suttle et al. 2004).

The empirical relationships between trout biomass and the very smallest sized mineral materials also have implications relating to current on-the-ground activities-for example, selection of road-surfacing materials. Research by Kochenderfer and Helvey (1987) in the Monongahela National Forest found that 38.1-76.2 mm clean limestone gravel provided a stronger roadbed and less surface erosion than crusher run limestone gravel (0-76.2 mm). Finer materials, including crusher run types of gravel, are usually recommended on older, well-established roads because they create a smoother riding surface, but they are more apt to experience washing (Kochenderfer and Helvey 1987) and "kicking" off of the driving surface by vehicles. Consequently, the combination of our findings and this road research suggest that fine-sized road surfacing particles should be avoided on new road construction, particularly around stream crossings and their approaches, and around water diversion features, such as cross drain culverts and broad-based dips. In addition, on established roads, small-sized, angular stone (to improve packing) composed of stable material (e.g., limestone rather than friable sandstone) would be less detrimental to streams than stone that grades down to very fine-sized particles.

The deleterious effects of even low levels of the finest-sized sediment also may mean that sediment delivery to streams needs to be controlled much more vigorously than is often done. Implementation of sediment control practices that extend beyond those routinely recommended in forestry best management practices may be needed to control the introduction of very fine sediments, as these can be dislodged and transported by even small amounts of water, such as those encountered during small storm events. Installation of silt fences, straw bales, geotextiles, or other sediment retention methods immediately around stream crossings or other sensitive areas may be required in all cases, not just in some cases or at the equipment operator's discretion.

We believe the general relationships we observed between trout biomass and the very small sediment particle sizes, and between trout biomass and the mixture of more intermediate particle sizes probably apply to other streams in the Appalachians that hold similar communities of similarly sized fish. Of course, given the broad range of biomass occurring with the various sediment size classes, it is important to re-emphasize what may be obvious.

Sediment may not be, and probably is not, the only limiting factor in many stream systems, but sediment should be one of the variables that is evaluated when reviewing overall stream conditions. A thorough understanding of stream conditions and potential limiting factors is necessary to determine if a proposed project or a routine activity will significantly affect stream health, or if dollars spent on mitigation to improve conditions will target important factors or be wasted because other factors are equally or more important in controlling fisheries health.

Conclusion

Trout biomass and associated particle size data from likely spawning materials in reaches from streams across the Monongahela National Forest were examined. The results indicated that the traditional classification of fine sediment as materials < 4 mm in diameter is not a useful metric by which to evaluate spawning materials conditions for small-sized trout on the forest. Instead, we recommend a simultaneous analysis of all available size fractions, paying particular attention to the percentage of materials in the < 1 mm fraction and the percentages of more intermediate particle sizes. The best spawning materials likely are ones that contain a mixture of particle sizes and are not dominated by a single size. Of course, combining information about other stream conditions or limiting factors in the assessment of spawning conditions should further improve any conclusions made, help identify the need for and types of mitigation strategies used during forest management activities, or suggest how routine on-the-ground procedures can be modified to positively affect stream health.

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