

Aquatic Life Water Quality Standards Draft Technical Support Document for Total Suspended Solids (Turbidity)

2011 Triennial Water Quality Standard Amendments to Minn. R. chs. 7050 and 7052



Minnesota Pollution Control Agency

Revised Draft, May 2011

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Note: This document incorporates minor revisions from the first draft published in November 2010 and serves as the final basis for the proposed TSS water quality standards. Changes were made in the Lower Mississippi River pool criteria as shown in Table 1 and discussed in Section V.K.

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Cover: The St. Croix River joins the Mississippi River at Prescott WI.

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Acronyms, abbreviations & commonly used terms

BOD ₅	5-day biochemical oxygen demand
CHF	North Central Hardwood Forests ecoregion
Chl-a	chlorophyll-a
Chl-T	total chlorophyll-a, which implies chlorophyll-a +pheophytin
CI	confidence interval
DA	Driftless Area ecoregion
DO	dissolved oxygen
HUC	hydrologic unit code
IBI	Index of biotic Integrity
max	maximum
MDH	Minnesota Department of Health
metric	used to refer to a biological measurement or class of organisms
mg/L	milligrams per liter; equivalent to parts per million
mg/m ²	milligram per meter squared; an areal-based measure commonly used to express periphyton biomass or chlorophyll-a
min	minimum
MPCA	Minnesota Pollution Control Agency
NGP	Northern Glaciated Plains ecoregion
NLF	Northern Lakes and Forests ecoregion
NMW	Northern Minnesota Wetlands ecoregion
NTU	Nephelometric turbidity units
quantile	a distribution that subdivides population into four equal portions, whereby first quartile represents lowest 25% of population...fourth quartile represents upper 25%
R	a statistical package
r ²	r squared, correlation coefficient
RRV	Red River Valley ecoregion
sestonic algae	algae suspended in the water; also referred to as phytoplankton
STORET	USEPA's data system - STOrage and RETrieval
TKN	total Kjeldahl nitrogen
TP	total phosphorus
TSS	Total suspended solids
ug/L	micrograms per liter, equivalent to parts per billion
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WCP	Western Corn Belt Plains ecoregion

Total Suspended Solids (Turbidity) Water Quality Standards Technical Report

I. Executive Summary

The existing turbidity water quality standard (WQS) has been in use since the late 1960's. The standard has several weaknesses, including being a statewide standard and, having Nephelometric Turbidity Units, is not concentration-based and not amenable to load-based studies. In addition, issues include having too much variation in measurements because of particle composition in water, variation among meters, and poor quantitative documentation of what a turbidity unit is.

Although recognized earlier, these weaknesses became a significant problem when EPA's and the Agency's Total Maximum Daily Load (TMDL) program became fully realized in the early 2000's. Once the TMDL studies began, it became clear that the existing standard was only indirectly related to biotic community health. In addition, TMDL development was challenging because the studies needed to be developed using Total Suspended Solids (TSS), which has concentration-based units (mg/L).

As a result, a committee of Agency staff across several Divisions met for over a year to develop TSS criteria. These draft TSS criteria are regional in scope and based on a combination of both biotic sensitivity to TSS concentrations and reference streams/least impacted streams as data allow. The Criteria table contains the recommended TSS criteria, utilizing multiple lines of evidence when available. TMDL development is also challenging due to the lack of frequency and duration in the current turbidity standard. Without frequency and duration, it is very difficult to determine critical conditions and to develop a load and wasteload allocation for the critical conditions, both of which are required elements of a TMDL.

Table 1. Criteria table

Substance, Characteristic, or Pollutant (Class 2A)	Units	CS	Basis for CS	MS	FAV	Basis for MS, FAV
Turbidity value	NTU	10	NA	-	-	NA
Total Suspended Solids [TSS]	mg/L	10	NA	-	-	NA
(TSS standards, for Class 2A, must not be exceeded more than 10% of the time over a multiyear data window; the assessment season is April through September)						
Substance, Characteristic, or Pollutant (Class 2Bd)	Units	CS	Basis for CS	MS	FAV	Basis for MS, FAV
Turbidity value	NTU	25	NA	-	-	NA
Northern River Nutrient Region (see 7050.XXX)						
Total Suspended Solids [TSS]	mg/L	15	NA	-	-	NA
Central River Nutrient Region (see 7050.XXX)						
Total Suspended Solids [TSS]	mg/L	30	NA	-	-	NA
Southern River Nutrient Region (see 7050.XXX)						
Total Suspended Solids [TSS]	mg/L	65	NA	-	-	NA
Red River mainstem – Headwaters to border						
Total Suspended Solids [TSS]	mg/L	100	NA	-	-	NA
(TSS standards, for the Class 2Bd Northern, Central, Southern River Nutrient Regions, above, and the Red River mainstem, above, must not be exceeded more than 10% of the time over a multiyear data window; the assessment season is April through September)						
Lower Mississippi River mainstem – Pools 2 through 4						
Total Suspended Solids [TSS], summer average	mg/L	32	NA	-	-	NA
Lower Mississippi River mainstem below Lake Pepin						
Total Suspended Solids [TSS], summer average	mg/L	30	NA	-	-	NA
(TSS standards for the Class 2Bd Lower Mississippi River must not be exceeded more than 50% of the summers over a multiyear data window; the assessment season is defined as June through September)						
Substance, Characteristic, or Pollutant (Class 2B)	Units	CS	Basis for CS	MS	FAV	Basis for MS, FAV
Turbidity value	NTU	25	NA	-	-	NA
Northern River Nutrient Region (see 7050.XXX)						
Total Suspended Solids [TSS]	mg/L	15	NA	-	-	NA
Central River Nutrient Region (see 7050.XXX)						
Total Suspended Solids [TSS]	mg/L	30	NA	-	-	NA
Southern River Nutrient Region (see 7050.XXX)						
Total Suspended Solids [TSS]	mg/L	65	NA	-	-	NA
Red River mainstem – Headwaters to border						
Total Suspended Solids [TSS]	mg/L	100	NA	-	-	NA
(TSS standards, for the Class 2B Northern, Central, Southern River Nutrient Regions, above, and the Red River mainstem, above, must not be exceeded more than 10% of the time over a multiyear data window; the assessment season is April through September)						
Lower Mississippi River mainstem – Pools 2 through 4						
Total Suspended Solids [TSS], summer average	mg/L	32	NA	-	-	NA
Lower Mississippi River mainstem below Lake Pepin						
Total Suspended Solids [TSS], summer average	mg/L	30	NA	-	-	NA
(TSS standards for the Class 2B Lower Mississippi River must not be exceeded more than 50% of the summers over a multiyear data window; the assessment season is defined as June through September)						

II. Background/Introduction of the pollutant/stressor

Excess turbidity and total suspended solids [TSS] have been recognized as water quality problems for many decades and a number of reviews have been written through the years [USEPA, 1977; Davies-Colley & Smith, 2001; USEPA, 2003;]. These reviews consistently discuss {1} the physical-chemical effects [reservoir filling, toxic substance transport, nutrient transport, aesthetic effects, and effects on water supply] and {2} their effects on aquatic biota, such as reductions of algal and macrophyte growth from reduced light (USEPA, 2003), and on zooplankton, macroinvertebrates, salmonids [cold water fishery], and other fishes from gill abrasion, gill clogging, and burial of fish eggs and macroinvertebrates (USEPA, 1977; USEPA, 2010). The most visually obvious stressor is reduced light penetration, but other impacts can include increased water temperatures [Davies-Colley & Smith, 2001].

Turbidity in water is caused by suspended soil particles, algae, etc., that scatter light in the water column making the water appear cloudy. Excess turbidity can significantly degrade the aesthetic qualities of waterbodies. People are less likely to recreate in waters degraded by excess turbidity. Also, turbidity can make the water more expensive to treat for drinking or food processing uses. Turbidity values that exceed the standard can harm aquatic life. Aquatic organisms may have trouble finding food, gill function may be affected, and spawning beds may be buried.

EPA has related nutrient reductions to increased water clarity as their long-term goal (USEPA Office of Inspector General, 2009). The term 'turbidity' is not defined in state statute or rule, but the U.S. Environmental Protection Agency [EPA] describes turbidity as follows:

"Turbidity is a principal physical characteristic of water and is an expression of the optical property that causes light to be scattered and absorbed by particles and molecules rather than transmitted in straight lines through a water sample. It is caused by suspended matter or impurities that interfere with the clarity of water. These impurities may include clay, silt, finely divided inorganic and organic matter, soluble colored organic compounds, and plankton and other microscopic organisms. Typical sources of turbidity ... include the following ...:

- Waste discharges,
- Runoff from watersheds, especially those that are disturbed or eroding,
- Algae or aquatic weeds and products of their breakdown in water reservoirs, rivers, or lakes, and
- Humic acids and other organic compounds resulting from decay of plants .

Simply stated, turbidity is the measure of relative clarity of a liquid." (USEPA, 1999)

III. Summary of the presence of turbidity in Minnesota's surface waters

III.A. River Data summary

Total suspended solids (TSS) river data in Minnesota has been collected since at least the 1950's. Christopherson (2000) analyzed those data (and other major pollutants) by decade, focusing on overall trends. He found that in 42% of the sampling stations showed decreasing TSS, 4% of the sampling stations showed increasing TSS, and 54% of the sampling stations showed no trend for decadal data from the 1950's through the 1990's.

An MPCA (2002) study of Minnesota River data, including TSS, for the period of 1992 through 2001 showed decreases at the mouth of the Blue Earth River and in two lower Minnesota River mainstem stations. The study noted that TSS decreased 1.5 to 2.0 percent per year on average at all three stations. They attributed the decrease to an increased use of conservation tillage and wastewater treatment plant upgrades.

A more recent MPCA Environmental Information Report (2009a) assessed all the known stressors affecting Minnesota's environment, including transported sediment. In terms of aquatic organisms, it is almost entirely from nonpoint sources and is a widespread problem throughout the state. Levels of TSS have decreased by almost 50% over the last 30 years, mostly as a result of point source controls, but also where improved cultivation practices have been put into place. The largest sources of transported sediment include agricultural runoff and construction, followed by urban runoff and streambank erosion.

In terms of aesthetics, transported sediment reduced clarity and increased nutrients tied to sediment. Clarity levels were generally low in southern and western Minnesota rivers, especially following rainfall. A 2010 Biennial Assessment of Water Quality showed a 41% decreasing TSS trend (MPCA and MDA, 2010).

III.B. TMDL List history:

Total Maximum Daily Load (TMDL) lists are required by Section 303(d) of the federal Clean Water Act. Minnesota has been developing draft Lists since 1992. Below is a table with the most current list totals for turbidity impairments based on the long-standing WQS of 10 and 25 NTU (as described below). The increases in the number of turbidity impairments can be attributed to increasing monitoring coverage of the state.

TMDL List	draft 2010	2008	2006	2004	2002	1998
Turbidity	324	283	218	118	93	43

III.C. List of USEPA approved TMDLs [as of 7/2/2010]:

Lower Otter Tail River TMDL: Turbidity
Lower Cannon River TMDL: Turbidity
Rock River TMDL: Fecal and Turbidity
Pipestone Creek TMDL: Fecal Coliform Bacteria and Turbidity
Lower Wild Rice River TMDL: Turbidity
Vermillion River TMDL: Turbidity
Mustinka River: Turbidity
Knife River: Turbidity

IV. Current Water Quality Standard (WQS)

IV.A. Current WQS

Turbidity is measured in nephelometric turbidity units (NTU). The standards are shown below:

- 10 NTU, Class 2A waters
- 25 NTU, Class 2Bd, 2B, 2C, 2D waters

The turbidity water quality standard (WQS) has existed, unchanged, in Minn. R. 7050.0222 (or its earlier versions) since the late 1960's. Gervino (2005) briefly discusses the evolution of the turbidity WQS, from a measure with no units to Jackson Turbidity Units (JTU) to concentrations of SiO_2 as mg/L, to Nephelometric Turbidity Units (NTU), which is the units of the current state turbidity WQS. He also discusses various meters with their resulting differing NTU units.

The link between a water quality standard and an impairment determination is the assessment protocol, which is found in the Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment (MPCA, 2009b). Turbidity is a highly variable water quality measure. For the 2010 assessment cycle, because of this variability, and the use of TSS and transparency as surrogates, a total of 20 independent observations are required for a turbidity assessment. If sufficient turbidity measurements exist, only turbidity measurements will be used to determine impairment. If there are insufficient turbidity measurements, any combination of independent turbidity, transparency, and total suspended solids observations may be combined to meet assessment criteria. If there are multiple observations of a single parameter in one day, the mean of the values will be used in the assessment process. For a water body to be listed as impaired for turbidity, at least three observations, and 10 percent of observations must be in violation of the turbidity standard (MPCA, 2009b).

IV.B. Use of TSS as a surrogate for NTU as a numeric translator

Transparency and total suspended solids (TSS) values reliably predict turbidity and have been used as surrogates at sites where there are an inadequate number of turbidity observations (Guidance Manual, 2009b). Large sets of monitoring data have been used to develop transparency and TSS thresholds which will identify the large majority of waters with turbidity impairments while minimizing the number of waterbodies falsely identified. For transparency, a transparency tube measurement of less than 20 centimeters indicates a violation of the 25 NTU turbidity standard. For TSS, a measurement of more than 60 mg/L in the Western Corn Belt Plains (WCBP) and Northern Glaciated Plains (NGP) ecoregions or more than 100 mg/L in the North Central Hardwood Forest (NCHF) ecoregion indicates a violation.

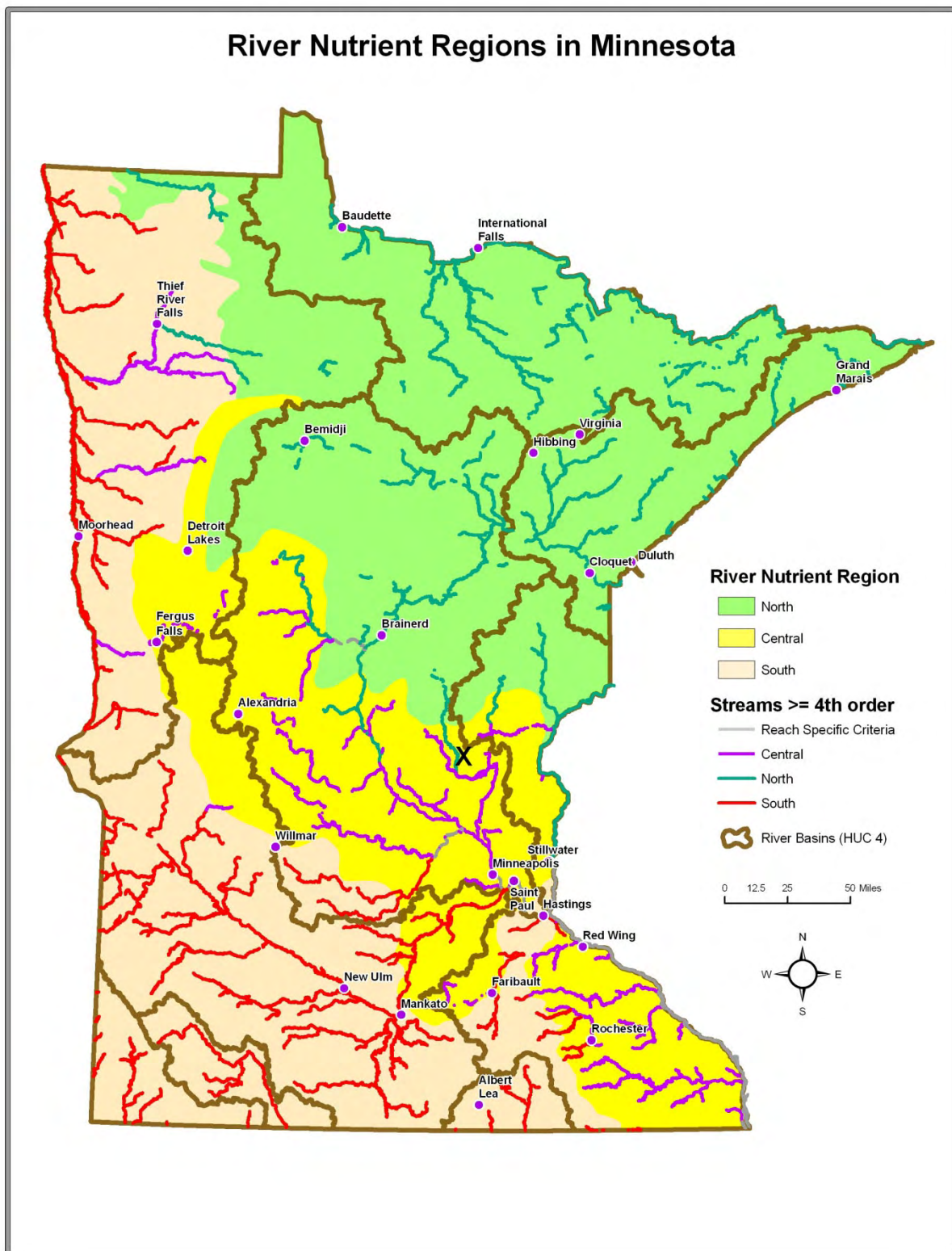
V. Draft Water Quality Standards

V.A. Use of River Nutrient Regions:

We are measuring a different dimension of suspended solids as we transition from an NTU WQS to a TSS WQS, but the intent has not changed – the protection of aquatic life. Concurrently with the development of the revised turbidity WQS is the development of river nutrient WQS [Heiskary *et al*, 2010]. One important component of that effort is the development of River Nutrient Regions [Heiskary & Parson, 2009]. Many of the watershed dynamics that contribute to excess nutrients in rivers are very similar to the watershed dynamics that contribute to excess turbidity. As a result, the same statewide mapping schema used for the river nutrient WQS will be used for the draft TSS WQS (Figure 1).

River Nutrient Regions are mainly ecoregion-based, but the borders between regions were studied extensively and some area-specific changes have been made [Heiskary & Parson, 2009]. Using similar maps will minimize confusion as to what standards apply where.

Figure 1. River Nutrient Regions in Minnesota



V.B. Technical Summary from the Literature of Adverse Effects to Aquatic Biota:

There is a vast array of literature describing the impacts of excess suspended sediment on biota. Berkman and Rabeni (1987) studied fish in NE Missouri. As the percentage of fine substrate increased, the distinction among riffle, run, and pool communities decreased. The loss of distinction indicates a diminution of diversity. The guild analysis indicated that species with similar ecological requirements had a common response to habitat degradation by siltation. Guilds are groups of highly interconnected plants or animals, with similar function. An example of a guild is decomposers. This guild of organisms resides in or on the soil surface where it processes organic matter (i.e., plants).

Principal components analysis indicated that the distinction between tolerant and intolerant classifications was determined largely by tolerance to suspended sediment, specific conductance, chloride, and total phosphorus (Meador et al. 2007).

Severity of ill effect is ranked on a 15-step scale that ranges from 0 to 14, where zero represents nil effect and 14 represents 100 percent mortality (Newcombe 2003). This model, based on peer consultation and limited meta analysis of peer reviewed reports, accomplishes the following: (a) identifies the threshold of the onset of ill effects among clear water fishes; (b) postulates the rate at which serious ill effects are likely to escalate as a function of reduced visual clarity and persistence; (c) provides a context (the “visual clarity” matrix, with its cell coordinates) to share and compare information about impacts as a function of visual clarity “climate” (d) demonstrates changes in predator prey interactions at exposures greater than and less than the threshold of direct ill effects; (e) calibrates trout reactive distance as function of water; (f) identifies black disk sighting range, in meters, and its reciprocal, beam attenuation, as preferred monitoring variables; and (g) provides two additional optical quality variables (Secchi disk extinction distance and turbidity) which, suitably calibrated as they have been in this study, expand the range of monitoring options in situations in which the preferred technology—beam attenuation equipment or black disk sighting equipment—is unavailable or impractical to use. This new model demonstrates the efficacy of peer collaboration and defines new research horizons for its refinement (Newcombe 2003).

Siltation and subsequent biological impairment is a national problem prompting state regulatory agencies to develop sediment total maximum daily loads (TMDL) for many streams. To support TMDL targets for reduced sediment yield in disturbed watersheds, a critical need exists for stream assessments to identify threshold concentrations of suspended sediment that impact aquatic biota. Because of the episodic nature of stream sediment transport, thresholds should not only be a function of sediment concentration, but also of duration and dose frequency Schwartz et al. 2008. To characterize turbidity data in an ecologically relevant manner, a methodology for concentration-duration-frequency (CDF) curves was developed using turbidity doses that relate to different levels of biological impairment. Our findings showed that the CDF curves derived by an exponential function performed reasonable well, with most curves significant at a 95% confidence level. These CDF curves were then used to demonstrate how they could be used to assess biological impairment, and identify future research needs for improved development of sediment TMDLs Schwartz et al. 2008.

Total abundance of benthic invertebrate and family richness declined as sediment pulse duration increased. Path analysis suggests that the direct effects of fine sediment on trout (impaired vision leading to reduced prey capture and (or) increased metabolic costs from physiological stress) are more important to trout growth than indirect effects (decreased drift and benthic invertebrate richness and drift abundance) (Shaw & Richardson 2001).

Adding frequency and duration allows for the development of relations between suspended sediments and biology (Simon & Klimetz 2008). Brook trout in turbid water became more active and switched foraging strategies from drift feeding to active searching. This switch was energetically costly and resulted in lower specific growth rates in turbid water as compared with clean water (Sweka & Hartman

2001). Vondracek et al. (2003) studied effects of suspended solids on fish in Minnesota with a focus on doing effective TMDL [Total Maximum Daily Load] planning. They found sediment to be a greater stress to coldwater fish than warmwater fish and the episodic nature of sediment delivery to rivers make TMDL development very challenging.

Wood and Armitage (1997) provide a holistic approach to studying the fine sediment problem and recommending solutions for identifying sources and understanding transport and depositional processes.

Zimmerman et al (2003) found a 98% decrease in 'lethal' [define] concentrations of suspended sediment on fish in Wells Creek with an increase in conservation tillage, riparian buffers, and permanent vegetative cover. Lethal" effects were described as reduced growth rate, delayed hatching, reduced fish density, increased predation, severe habitat degradation, and mortality.

V.C. Identification of TSS Threshold Concentrations: Assessing the Relationships between Biology and Water Quality Using Field-Collected River Data

The use of field-collected biological data is a relatively new approach that is gaining increased attention and has some additional benefits beyond simple lab dose response methodology. This approach has many advantages (e.g., avoids artifacts caused by lab experiments) and there are a number of new statistical tools which make the use of field data an expanding area of water quality standard development. Some disadvantages of using field-collected data include the lack of control of environmental and process variables.

A relatively new analysis method, called quantile regression, has been used as a tool to identify threshold concentrations and to develop criteria to protect aquatic life. Quantile regression is well suited for the wedge-shaped plots (caused by heterogeneous variances; *i.e.*, heteroscedasticity) that are common with biological monitoring data (Terrell *et al.* 1996, Koenker & Hallock 2001, Cade & Noon 2003, Bryce *et al.* 2008; see Figure 2). These wedge-shaped plots are the result of the limitation of biological attributes (*e.g.*, taxa richness) by the variable of interest on the outer or upper edge of the wedge (Bryce *et al.* 2008; see Figure 2).

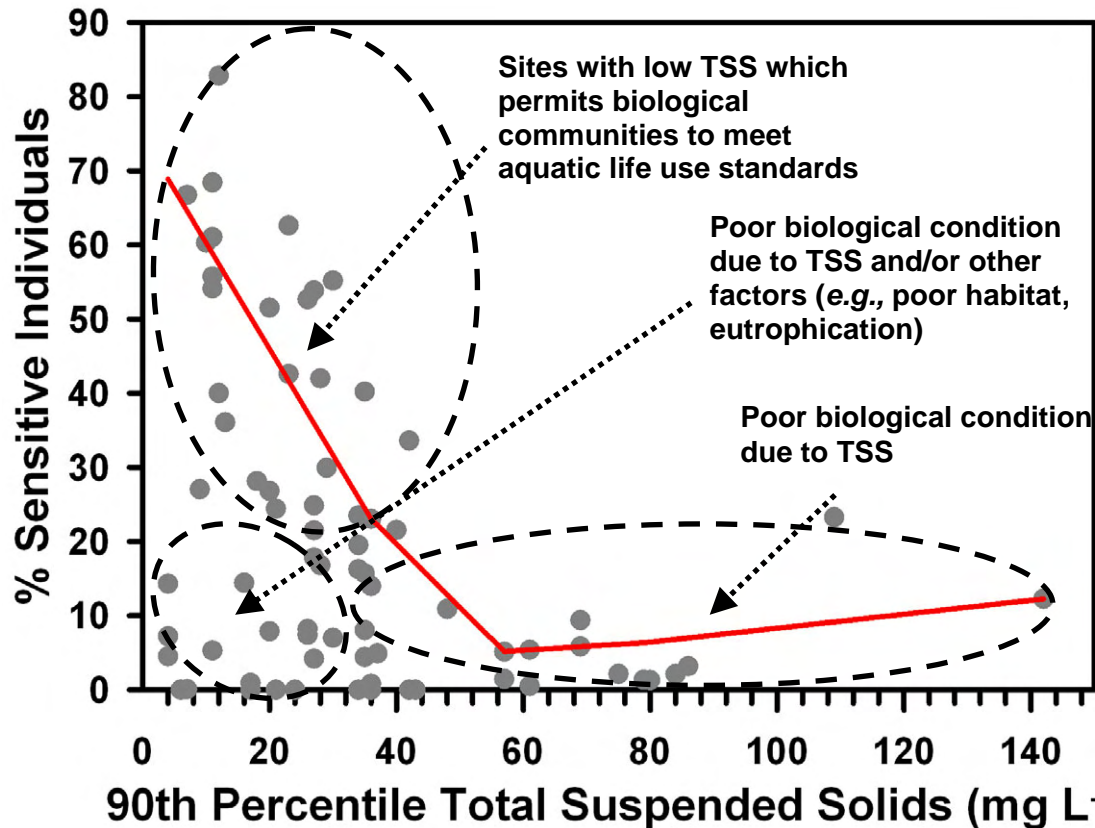


Figure 2. Relationship between the 90th percentile of TSS and the percent of centrarchid individuals for central streams with additive quantile regression smoothing line (red line). This is an example of the typical wedge-shaped data to which quantile regression is suited.

Limitations to biological measures inside the wedge are caused by other unmeasured variables (Figure 2). In combination with sediment or alone there are a number of other factors (*e.g.*, nutrients, habitat) that can limit biological condition in Minnesota streams and rivers. As a result of these different factors reducing biological measures, there is unequal variation of the response variable at different levels of the predictor variable. This unequal variation often makes field-derived data (*e.g.*, biomonitoring data) less suitable for the more traditional least squares regression. Quantile regression differs from least squares regression in that it estimates the median (*i.e.*, 50th quantile) or other quantiles whereas least squares regression estimates the mean. Another advantage of quantile regression is that extreme outliers do not impact regression quantile estimates (Terrell *et al.* 1996).

Regression tree or changepoint analysis is another technique that can be used to identify thresholds where biological condition declines in heteroscedastic (having different variances) data. This analysis splits that data into groups where the sites within that group are more homogeneous (De'ath & Fabricius 2000). For example, groups may have different mean values of the response variable. The location of the splits or nodes indicates a change between groups which may suggest that a threshold has been crossed.

V.D. Quantile Regression and Changepoint Datasets

Several different datasets were used to develop TSS criteria in conjunction with biological information (Table 2). The purpose of these multiple datasets was to examine different patterns between regions in the state and stream type. Patterns among northern, central, and southern regions were assessed to

determine if different criteria should be proposed for these areas of the state. Differences between coldwater and warmwater streams were also assessed to determine if different criteria were justified for these stream classes.

The data used to identify threshold concentrations from fish and invertebrate data was derived from STORET (EPA's environmental data system (STORage and RETrieval)). The STORET data comes from a variety of sources including agencies and individuals. TSS data from STORET were downloaded from EPA's STORET site (<http://www.epa.gov/storet/>) and linked to AUIDs.

Water quality data was only used if:

- Measurements were collected from April to September
- Appropriate sampling and lab techniques were used
- Sampling was not event based (e.g., not focused on rain events but rather performed on a regular interval)
- Sampling was made within 5 years of biomonitoring sampling
- At least 10 records were present

Assessment for non-impairment of TSS will require a showing that more than 90% of the TSS measurements are below the criterion (i.e., cannot exceed the criterion more than 10% of the time). Additional details were discussed in section IV.A. To reflect this assessment requirement the 90th percentile was calculated for the TSS measurements from each AUID.

The biological data used in analyses came from data collected as part of the MPCA biomonitoring program. Some additional screening was performed to reduce the effects of habitat modification. Sites identified as channelized (*i.e.*, >50% of reach channelized) during biological sampling were excluded from analyses.

The regional classification for the biomonitoring dataset was based on level III ecoregions (**Northern Region:** Northern Minnesota Wetlands, Northern Lakes and Forests; **Central Region:** North Central Hardwoods; **Driftless Area:** Driftless Area; **Southern Region:** Northern Glaciated Plains; Western Corn Belt Plains, Lake Agassiz Plain). The Driftless Area was separated from the other Central Region because initial analyses indicated that the biological communities in this region were responding differently to TSS. To identify TSS threshold concentrations specific to the Minnesota River mainstem, paired TSS and biological data from rivers with watersheds greater than 500 mi² within the Minnesota River basin were selected.

Table 2. Numbers of collections in each dataset used assess relationships between TSS and biological measures.

Region	Fish	Invertebrates
North	44	23
Central	72	41
South	88	61
Coldwater	47	11

V.E. Metric Selection

Before quantile regression and changepoint analyses were performed, it was necessary to select appropriate response measures or biological metrics. The selection of metrics was made by identifying biological metrics that indicated a response to TSS through examination of scatter plots. Metrics that were not relevant to sediment stress were not used in the final analyses. Ten metrics were selected for warmwater fish communities; 14 for coldwater communities (Table 3). Six metrics were selected for

invertebrates (Table 4). At the time of this work, the MPCA was still in the process of developing new IBIs so this index was not included in the development of concentration thresholds.

Table 3. Description of fish metrics used in changepoint and quantile regression analyses.

Metric	Description
%Benthic Feeders	Benthic feeders rely on undisturbed benthic habitats to feed. Degradation of benthic habitat will cause benthic invertivore species to decline.
%Carnivore	As adults, carnivorous fish species feed largely on fish, other vertebrates, and large invertebrates (e.g., crayfish). These species include many sport fish (e.g., bass, pike, walleye, and trout) (Barbour et al. 1999).
%Centrarchid-Tolerant	Fish species in the family Centrarchidae. These species are sight feeders which can be negatively impacted by increased turbidity. Species classified as tolerant are not included in this metric.
%Herbivore	Fish species that utilize vegetation. These species are negatively impacted by the loss of vegetation which can be caused by sedimentation and hydromodification.
%Intolerant	Intolerant species are those that are known to be sensitive to environmental degradation. They are often the first species to disappear following a disturbance. Their presence in a stream is an indication of a high quality resource.
%Long Lived	Long lived species typically have long life histories and as a result require more time to recover from disturbance.
%Perciformes-Tolerant	Fish species in the family Percidae which includes walleye, perch, and darters. Species classified as tolerant are not included in this metric.
%Riffle	Riffle species are those that require riffle habitat as part of their life history either for feeding, reproduction, or both. Sedimentation can decrease this type of habitat thereby negatively impacting these species.
%Sensitive	Sensitive species are susceptible to environmental degradation and often decline in abundance and richness following disturbance. They are not as susceptible as intolerant taxa but their presence in a stream is an indication of a high quality resource.
%Simple Lithophils	Simple lithophilic spawners broadcast their eggs over clean gravel substrates. The metric is inversely correlated with habitat degradation due to siltation.

Table 4. Description of invertebrate metrics used in changepoint and quantile regression analyses.

Metric	Description
%Collector-Filterers	The number of collector-filterer taxa represents the number of different taxa that collect their food by filtering it out of the water column. The filtering is typically done one of two ways: 1) by using physical adaptation such as antennal structures or 2) by constructing a net which filters the water, gathering filtered material from the net (Chirhart 2003).
%Intolerant	Taxa with tolerance values less than or equal to 2 (Hilsenhoff 1987). Intolerant species are those that are known to be sensitive to environmental degradation and often decline in abundance and richness following disturbance. Their presence in a stream is an indication of a high quality resource.
%Long Lived	Long lived species typically have long life histories and as a result require more time to recover from disturbance.
%Odonata	Odonata, or dragon and damselflies, are a diverse group of organisms that display a wide array of sensitivities and life histories. They exploit most aquatic microhabitats, and their diversity is considered a good indicator of aquatic health (Chirhart 2003).
%Plecoptera	Plecoptera, or stoneflies, are among the most sensitive indicator organisms. They occupy the interstitial spaces between rocks, woody debris, and vegetation, and require a relatively high amount of dissolved oxygen in order to survive.
%Scraper	Scrapers are species that graze algae and other microorganisms from hard substrates such as rocks and wood. Excess sedimentation can smother this food source and negatively impact scraper species.
%Shredder	Shredders are species that feed upon leaves and other coarse organic material. This habitat or food resource can be negatively impacted by sedimentation (Kreutzweiser et al. 2005).
%Trichoptera	Trichoptera, or caddisflies, are a diverse group of benthic insects that are considered good indicators of environmental disturbance. As a group, they are somewhat more tolerant to pollution than mayflies, but in the presence of significant impairment they do not persist as a diverse community. Because of their ability to exploit a variety of habitats, their diversity is a good indicator of habitat quality. Their ability to thrive in lentic conditions makes them excellent indicators for use in slow moving streams as well (Chirhart 2003).

V.F. Biological Threshold Analyses

A number of patterns can be observed between TSS and the biological metrics (Brenden *et al.* 2008) although the relationship between biology and TSS is often wedge shaped (Wang *et al.* 2007). In the Minnesota datasets used for this study, a distinct wedge with breakpoint(s) (Figure 3a, b, c) was most commonly observed. This dataset shape was associated with a sufficient disturbance gradient. The “upper plateau” occurred at generally low levels of sediment or stressors and was characterized by high variability in the biological metric. The steep portion of the wedge occurred at moderate levels of sediment and indicated that a threshold had been crossed and that biological condition was declining. At higher levels of sediment or stressors there were generally low biological metric scores indicating that the response variable had largely reached bottom and was not declining or declining at a much slower rate. Additive quantile regression smoothing and changepoint analyses were both effective with this type of dataset. The fit of the quantile regression and the ability of the changepoint analysis to identify thresholds were assessed and analyses with a poor fit or those not identifying relevant thresholds were omitted. For some datasets, no analysis was appropriate as a gradient sufficient for these analyses was not present (see Figure 3d). This pattern suggests that most streams in such as class have already exceeded the biological threshold or that the metric is not effective in the class.

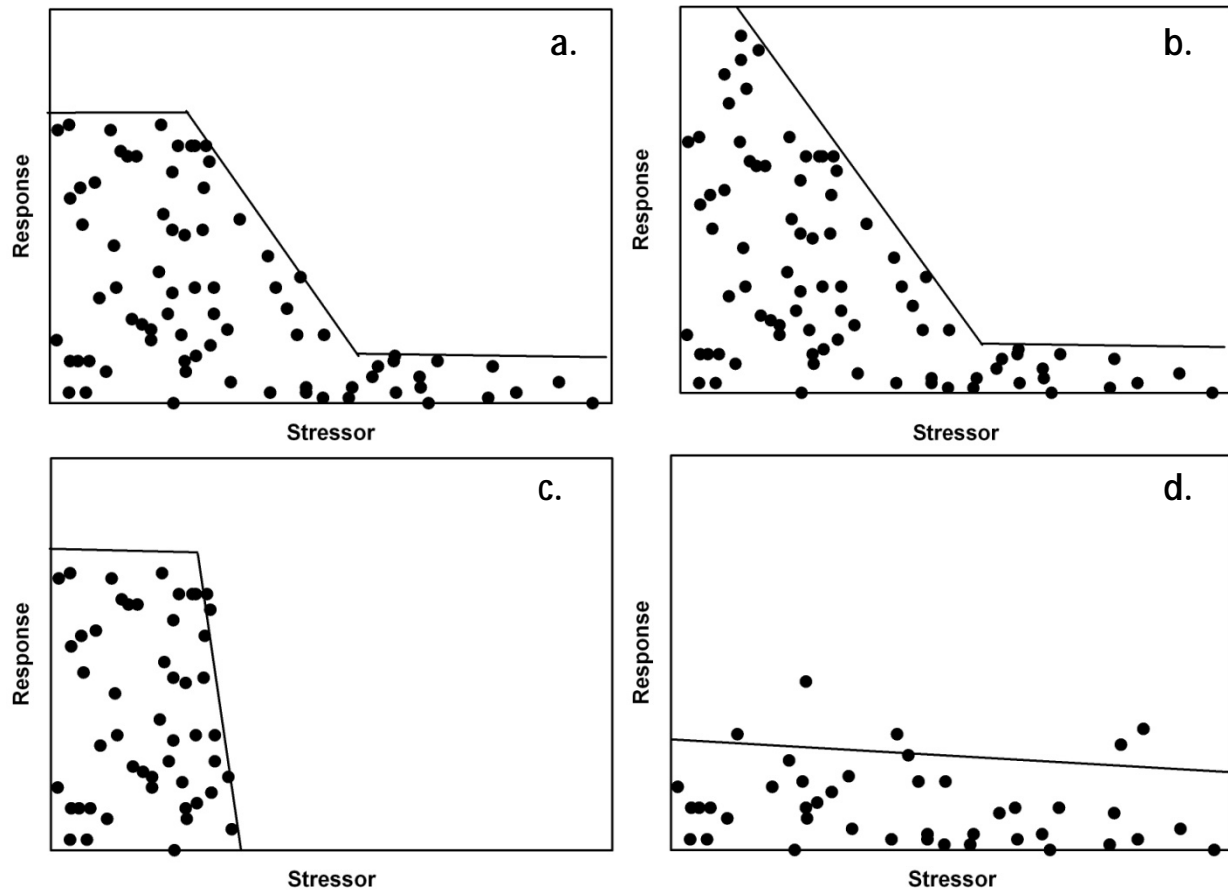


Figure 3. Illustration of response patterns to stress resulting from sediment and other stressors observed in field-collected data.

V.G. Statistical Methods - Additive Quantile Regression Smoothing

Additive quantile regression smoothing (“rqss” in “quantreg” package; Koenker 2009) was performed in the program R ver. 2.10.0 (R Development Core Team 2009). This method is similar to linear quantile regression, but instead of fitting a single line to the data, this approach fits a regression line to subsets of the data (see Figure 4). As a result, additive quantile regression smoothing (AQRS) can also be used to identify changepoints in addition to fitting the outside of the data wedge. The 75th percentile ($\tau = 0.75$) was used with additive quantile regression smoothing to minimize the effect of outliers. This was important because there is a tendency for increasing variation in the estimates as τ approaches 1 in some datasets (Cade & Noon 2003). Once the 75th percentile quantile regression was fitted, threshold concentrations were interpolated as the midpoint between breakpoints (see Figure 3a). If no upper breakpoint was present then the midpoint between the lower breakpoint and the lowest TSS value was used (see Figure 3b). If no lower breakpoint was present (see Figure 3c, d) then no threshold concentration could be determined. The additive quantile regression smoothing approach required the selection of a lambda (λ) value which determines the amount of smoothing. Values of λ were selected by eye on how well the line fit the outside of the curve and was not affected by single values. 90% confidence bands were also determined to examine regression fits and the strength of the breakpoints.

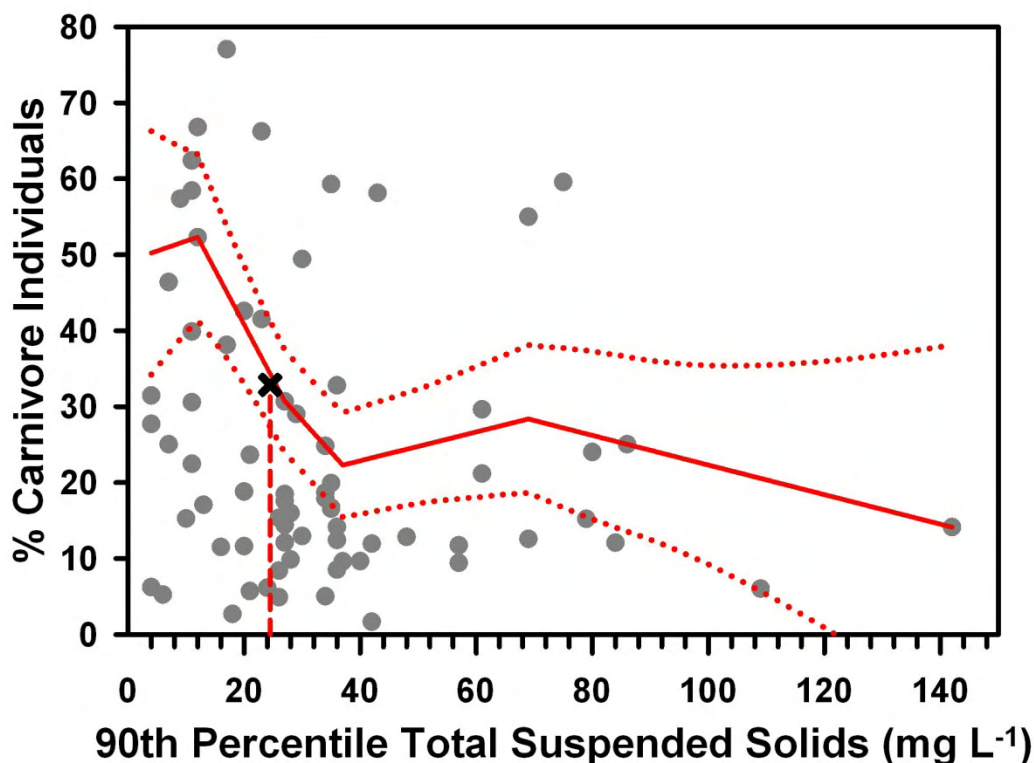


Figure 4. Example of 75th percentile additive quantile regression smoothing for the central region (solid line = AQRs fit; dotted lines = 90% confidence bands; dashed line = interpolation of TSS concentration).

V.H. Statistical Methods - Changepoint Analysis

Changepoint analysis was performed in the program R ver. 2.10.0 (R Development Core Team 2009) using the regression tree analysis ("rpart" in the "rpart" package; Therneau & Atkinson 2008). This method identifies thresholds by dividing sites into two groups based on differences in both their mean and variance (Qian *et al.* 2003). Trees were constrained to a single split with a bucket size of 5 sites or 10% of the sample depending on which was larger (*e.g.*, Figure 5). 90% confidence bands were determined using a bootstrap analysis which resampled 1000 times. Bootstrap analysis was performed in the program R ver. 2.10.0 (R Development Core Team 2009) using the bootstrap function ("boot" in the "boot" package; Canty & Ripley 2009). In some datasets the sample size was too small and a confidence band could not be determined. Since regression tree analysis will identify a change point in any dataset, a significance test was applied to determine if the change point was significant at the $\alpha = 0.05$ level. A Mann-Whitney Rank-Sum test was performed in SigmaPlot ver. 11 (Systat Software 2008) to determine if there is a significant difference in the biological metric scores above and below the threshold concentration determined by regression tree analysis. Threshold concentrations identified from non-significant change points were not used in further analyses.

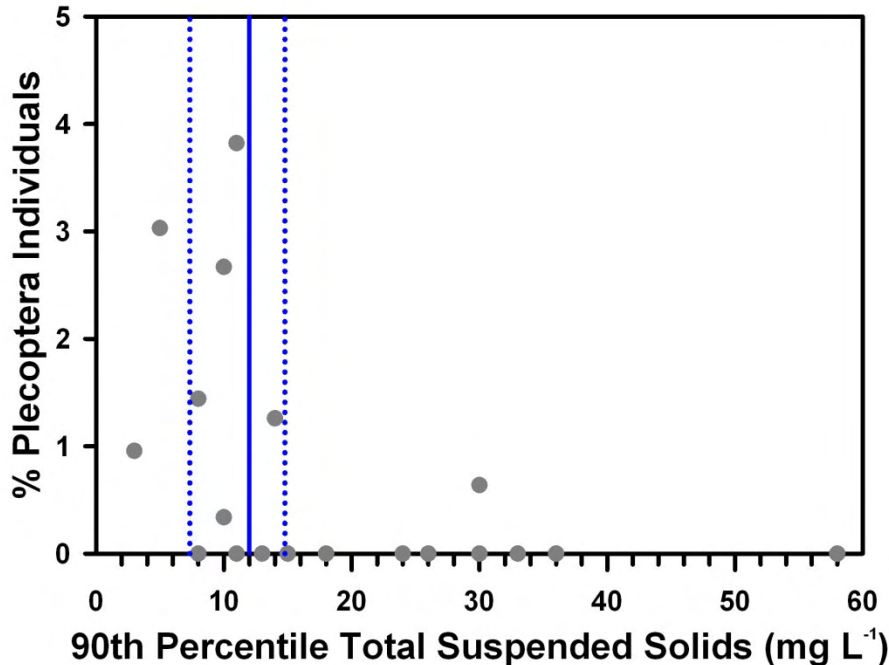


Figure 5. Example of changepoint analyses using % Plecoptera Individuals from the North Class.

V.I. Results

A total of 16, 14, and 17 threshold concentration values could be determined for warmwater streams in the North, Central, and South regions using quantile regression and changepoint analysis on 10 fish and 8 invertebrate metrics (see Tables 8-11). Threshold concentrations could not be determined for all metrics due to a limited response in some regions. Table 5 provides a summary of these values for the three regions. The most relevant values are the 25th percentile of threshold concentrations for each class. This is because these statistics in Table 5 represent many different metrics and not all of which may be very sensitive to TSS. Therefore by using the 25th percentile we can focus on the response of the more sensitive metrics. The advantage of examining many relevant metrics rather selecting what we think is the most sensitive metric (*e.g.*, % Sensitive Species) is that it allows us to empirically identify the metrics that are most sensitive to TSS. In addition the most sensitive metric may not be the same for different regions so the examination of multiple metrics gives us more flexibility and increases the likelihood that we will be able to identify protective thresholds. Many fewer threshold concentrations could be developed for invertebrates. It is not clear whether this is the result of a weaker relationship between invertebrates and TSS or a reflection of limitations with the invertebrate data (*e.g.*, fewer sites, genus-level resolution). Due to the small sample size, no statistics are available for the coldwater streams.

Table 5. Threshold criteria (T.C.) statistics for the 90th percentile of TSS (mg/L) for fish and invertebrates calculated using changepoint and additive quantile regression analyses. TSS data from STORET.

Region	Mean	Median	25th	75th	#T.C.	Range
Coldwater (Statewide)	10	10	7	13	10	5-21
North	19	20	14	24	17	11-28
Central	27	27	24	32	14	18-36
South	89	80	66	100	19	44-165

There was an increase in threshold concentrations from the north to south regions with some overlap between the interquartile ranges of the north and central regions (Figure 6). Southern T.C.s were considerably higher than the northern and central classes. There was some difference between the fish and the invertebrates, with fish appearing less sensitive. However this pattern is an artifact of the small number of T.C.s that could be determined for invertebrates in the central and southern regions. In general the fish were more useful as many more T.C.s could be identified using this taxonomic group. Several T.C.s could be determined for coldwater streams using fish (the invertebrate dataset was too small for analysis). However, caution should be exercised with these numbers because the patterns were largely driven by two AUIDS.

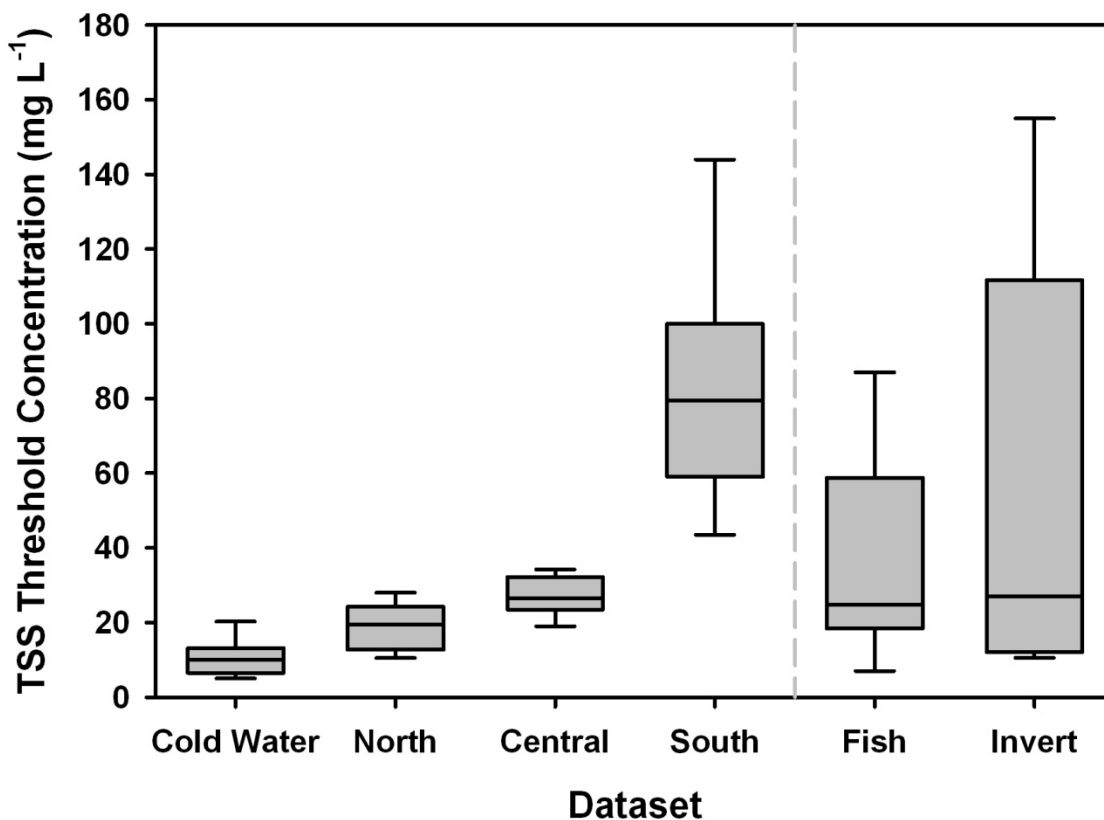


Figure 6. Box plots of TSS threshold concentrations for region and biological group (description of box plots: solid line = median, upper and lower bounds = 75th and 25th percentiles, whisker caps = 10th and 90th percentiles; n values: North = 16, Central = 14, South = 17, Fish = 38, Invertebrates (Invert) = 8). See Appendix for raw threshold concentration values used to generate box plots.

V.J. Identification of TSS Threshold Concentrations: Use of chemistry data for 'least impacted' & reference streams

The overall approach for this portion of the evaluation is to consider a standard based on TSS levels in "reference" or "least-impacted" Minnesota streams. Because TSS levels vary across the state, even for "least-impacted" streams, depending on factors such as topography, soils, climate, etc., the draft TSS standard likewise varies across the state according to River Nutrient Regions.

Monitoring data from streams across the state was examined, and various measures were used to filter out non-representative (mostly storm-biased) data. One hundred sixty eight non-mainstem stream reaches of at least five miles in length were found to have good, sizeable data sets. (The larger mainstem reaches are unique in character and not suitable for a least-impacted reference stream approach; stream reaches less than five miles in length are often very small and sometimes intermittent headwaters or are for other reasons not representative of the more general range of streams.) These 168 reaches were then ranked within the three River Nutrient Regions according to mean TSS levels. Stream reaches ranking from the 10th to the 40th percentiles in terms of mean TSS water quality in the South River Nutrient Region and the 30th to the 50th percentiles in the Central and North River Nutrient Regions were considered to be reference streams. Because streams in the latter two River Nutrient Regions are generally less impacted than streams in the South River Nutrient Region, a reference level was used that is closer to average existing conditions.

Under this approach, these reference streams would essentially be the draft standard. They would form the basis of comparison for the assessment of other streams within each ecoregion.

The specific numeric standard under this approach is determined by choosing the TSS concentration at some specific point on the reference stream TSS frequency curve. (This reference stream TSS frequency curve is calculated by combining the various reference streams in each region into a single "average" reference stream.)

The specific point on the curve could come from any number of choices, with the most likely candidates being 1) the average TSS concentration, 2) the maximum TSS concentration, or 3) the 90th percentile TSS concentration.

Average stream conditions, though, are not necessarily fully indicative of watershed problems that can result in high TSS levels. Especially for smaller, "flashier" streams, impairment is generally more evident under storm-influenced, high-TSS conditions than it is under average conditions. Maximum TSS levels, however, are difficult, if not impossible, to determine. If the weather is sufficiently extreme, TSS concentrations will almost certainly be higher than any reasonable and meaningful maximum TSS standard.

The 10th percentile TSS level, on the other hand, can be easily calculated and is a good indication of the health of a stream in terms of TSS. The use of the 10th percentile TSS level has the additional advantage that it matches with the current MPCA assessment criterion, which essentially states that a stream has to meet the state water quality standard for turbidity at least 90% of the time (no more than 10% of measurements can exceed the standard).

As for the time period over which the 10th percentile TSS level is measured and is used as a basis of comparison for the reference streams and the streams to be assessed, the period April through September has been chosen, rather than the full year. This period is used because TSS monitoring is generally done during this period, and because the data used to determine reference-stream TSS levels is much better for this period than it is for the year as a whole and because TSS problems generally occur during this period.

V.K. Use of extensive TMDL deliberations for lower Mississippi from Pool 2 to below L Pepin on to the Iowa State Line:

The mainstem Mississippi River has been extensively studied for many decades, by our Agency [<http://www.pca.state.mn.us/water/tmdl/tmdl-development.html>], the Metropolitan Council, the Long-Term Resource Monitoring Program [e.g. http://www.umesc.usgs.gov/reports_publications/ltrmp_rep_list.html], and the Upper Mississippi River Conservation Committee [URMCC] [<http://mississippi-river.com/umrcc/>].

The submersed aquatic vegetation (SAV) in the lower Mississippi River has been studied for decades and is considered the keystone community for ensuring a healthy aquatic community (UMRCC, 2003). SAV are sources of food for waterfowl, serve as substrate for invertebrates and periphyton, and as habitat for larval and adult fish. SAV also helps stabilize sediments by creating quiescent areas around their stems and leaves. SAV are used by the UMRCC as a measure of ecosystem health.

A key document used in setting the TSS WQS for the lower Mississippi River from Pool 2 to the mouth of Lake Pepin is by Sullivan *et al* (2009). For details on the MPCA South Metro Mississippi TMDL Turbidity Impairment, link to the following Agency web site: <http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/tmdl-projects/lower-mississippi-river-basin-tmdl-projects/project-south-metro-mississippi-turbidity.html>. Because there is a site-specific WQS for this stretch of river, it will be used as the criterion instead of the regional criteria recommended for the remainder of the Central Region.

Relying on an extensive data set and historical information, the URMCC recommended a TSS criterion of 32 mg TSS/L as a summer average. This criterion will allow adequate transparency to allow submersed aquatic vegetation (SAV) to reach their target community densities. This site-specific water quality standard was approved by US EPA on November 8, 2010.

Another recent document relates light penetration to turbidity (Giblin *et al*, 2010). Giblin *et al*, 2010 recommended a TSS goal of 30 mg TSS/L to maintain SAV densities below Lake Pepin. That recommendation forms the basis for the TSS WQS of 30 mg TSS/L as a summer average below Lake Pepin.

V.L. Use of least impacted reach data for Red River mainstem:

In establishing a TSS water quality criterion for the main stem of the Red River, there are some additional factors to consider. For most areas of the state we were able to utilize a “filter” and reference sites to find the appropriate AUIDs for calculating the TSS criteria. For the main stem of the Red River, there were only eight (8) AUIDs that had sufficient data for this procedure. It has also been a challenge to find a “least impacted” and/or reference reach for the Red River. The Red River is known for its high concentration of suspended solids. The fine clay and silt lake plain sediments are easily suspended, and tend to stay in suspension even during relatively low-flow conditions. Red River median concentrations of TSS for the eight AUIDs ranged from 58 mg/L to 342 mg/L for 2003-2004 (State of the Red River of the North, 2006).

Despite the elevated TSS concentrations that exist within the Red River, fish IBI scores in the Red River ranged from fair to good (EPA 905-R-96-005, 1998). In spite of the input from a multitude of potential pollution sources, IBI scores did not decrease with increasing distance downstream. Rather, some of the highest scoring sites were located nearest the Canadian border.

With these factors in mind, it was decided that a TSS criterion would be established using the AUID that begins at the headwaters of the Red River in Breckenridge, MN. This reach of the Red River typically exhibits the lowest TSS concentrations and for our purposes will be considered the “least impacted”. The 90th percentile TSS concentration for this AUID was calculated as 106 mg/L (Christopherson, 2009). The TSS criteria are written to partially encompass the variable nature of suspended sediment in streams due to snowmelt and rainfall storm events. TSS concentrations in streams are not to exceed regional or mainstem criteria more than 10% of the time. For the Red River, this means that no more than 10 percent of the TSS values were greater than 106 mg/L. Building in an additional 5% margin of safety, 100 mg/L of TSS will be recommended as the criteria for the Red River. The 100 mg/L will be the TSS criteria for the Red River from the headwaters to the Canadian border.

The draft 2010 TMDL List of impaired waters contained 49 new listings for turbidity, using the current NTU water quality standard. An informal review was conducted using the same turbidity data but using the draft TSS criteria. Our assessment process has two steps: a pre-assessment computer determination followed by a final determination using expert best professional judgment. The pre-assessment data found 58 impairment candidates for impairment by the draft TSS criteria. Because of data quantity and quality considerations, only a portion of pre-assessment candidates are found to be worthy of including in the TMDL List. As a result, for future listing cycles, the draft TSS criteria will result in about the same number of listings.

V.M. Combining biological and chemical data

The recommendations from the section above were combined with those from the bio-statistical sections above, using best professional judgment regarding the multiple lines of information. The resulting draft criteria are shown in Table 6. When developing TSS WQS that will be used to protect the aquatic life designated use, the preferred approach is to use biological data to develop the TSS criteria. When this is not possible, the use of reference streams provides a reasonable alternative. Because biological datasets with comparable TSS were sparse and TSS reach datasets were comparatively more robust, the results were combined. Because of the differences in the types of data and the types of statistical tests used, the approach used to combine the two approaches was a narrative-type Best Professional Judgment [BPJ] & Weight of Evidence [WOE] approach.

It is recognized that modifications to the draft standards may be necessary on a stream-by-stream basis, depending on the specific conditions – topography, soils, climate, stream size, land-use, etc. – involved. Such site specific determinations are permissible by existing rule conditions (see Mn Rule Ch. 7050.0222 Subp. 7).

Table 6. Criteria table

Substance, Characteristic, or Pollutant (Class 2A)	Units	CS	Basis for CS	MS	FAV	Basis for MS, FAV
Turbidity value	NTU	10	NA	-	-	NA
Total Suspended Solids [TSS]	mg/L	10	NA	-	-	NA
(TSS standards, for Class 2A, must not be exceeded more than 10% of the time over a multiyear data window; the assessment season is April through September)						
Substance, Characteristic, or Pollutant (Class 2Bd)	Units	CS	Basis for CS	MS	FAV	Basis for MS, FAV
Turbidity value	NTU	25	NA	-	-	NA
Northern River Nutrient Region (see 7050.XXX)						
Total Suspended Solids [TSS]	mg/L	15	NA	-	-	NA
Central River Nutrient Region (see 7050.XXX)						
Total Suspended Solids [TSS]	mg/L	30	NA	-	-	NA
Southern River Nutrient Region (see 7050.XXX)						
Total Suspended Solids [TSS]	mg/L	65	NA	-	-	NA
Red River mainstem – Headwaters to border						
Total Suspended Solids [TSS]	mg/L	100	NA	-	-	NA
(TSS standards, for the Class 2Bd Northern, Central, Southern River Nutrient Regions, above, and the Red River mainstem, above, must not be exceeded more than 10% of the time over a multiyear data window; the assessment season is April through September)						
Lower Mississippi River mainstem – Pools 2 through 4						
Total Suspended Solids [TSS], summer average	mg/L	32	NA	-	-	NA
Lower Mississippi River mainstem below Lake Pepin						
Total Suspended Solids [TSS], summer average	mg/L	30	NA	-	-	NA
(TSS standards for the Class 2Bd Lower Mississippi River must not be exceeded more than 50% of the summers over a multiyear data window; the assessment season is defined as June through September)						
Substance, Characteristic, or Pollutant (Class 2B)	Units	CS	Basis for CS	MS	FAV	Basis for MS, FAV
Turbidity value	NTU	25	NA	-	-	NA
Northern River Nutrient Region (see 7050.XXX)						
Total Suspended Solids [TSS]	mg/L	15	NA	-	-	NA
Central River Nutrient Region (see 7050.XXX)						
Total Suspended Solids [TSS]	mg/L	30	NA	-	-	NA
Southern River Nutrient Region (see 7050.XXX)						
Total Suspended Solids [TSS]	mg/L	65	NA	-	-	NA
Red River mainstem – Headwaters to border						
Total Suspended Solids [TSS]	mg/L	100	NA	-	-	NA
(TSS standards, for the Class 2B Northern, Central, Southern River Nutrient Regions, above, and the Red River mainstem, above, must not be exceeded more than 10% of the time over a multiyear data window; the assessment season is April through September)						
Lower Mississippi River mainstem – Pools 2 through 4						
Total Suspended Solids [TSS], summer average	mg/L	32	NA	-	-	NA
Lower Mississippi River mainstem below Lake Pepin						
Total Suspended Solids [TSS], summer average	mg/L	30	NA	-	-	NA
(TSS standards for the Class 2B Lower Mississippi River must not be exceeded more than 50% of the summers over a multiyear data window; the assessment season is defined as June through September)						

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VII. Appendix

The tables and figures below contain the background material for Table 5. **below**

Table 7 through Table 10 below assess both fish and invertebrates using both quantile regression and changepoint analysis. The figures that follow assess regional differences in the influence of TSS on fish and invertebrates.

Table 7. Raw total TSS threshold concentration values (mg L⁻¹) for fish using additive quantile regression smoothing analysis. Abbreviations: T.C. = Threshold Concentration.

Region	Group	Metric	T.C.	Test	Notes
North	Fish	%Benthic Feeders	28	<0.0001	
North	Fish	%Carnivore			weak breakpoint
North	Fish	%Centrarchid-Tolerant			weak breakpoint
North	Fish	%Herbivore	20	<0.0001	
North	Fish	%Intolerant	18	<0.0001	
North	Fish	%Long Lived	21	<0.0001	
North	Fish	%Perciformes-Tolerant			weak breakpoint
North	Fish	%Riffle	26	<0.0001	
North	Fish	%Sensitive			weak breakpoint
North	Fish	%Simple Lithophils			weak breakpoint
Central	Fish	%Benthic Feeders			no lower breakpoint
Central	Fish	%Carnivore	25	<0.0001	
Central	Fish	%Centrarchid-Tolerant	24	<0.0001	
Central	Fish	%Herbivore			weak relationship
Central	Fish	%Intolerant	33	<0.0001	
Central	Fish	%Long Lived	21	<0.0001	
Central	Fish	%Perciformes-Tolerant	26	<0.0001	
Central	Fish	%Riffle			no lower breakpoint
Central	Fish	%Sensitive	29	<0.0001	
Central	Fish	%Simple Lithophils			weak relationship
South	Fish	%Benthic Feeders	58	<0.0001	
South	Fish	%Carnivore	59	<0.0001	
South	Fish	%Centrarchid-Tolerant			weak relationship
South	Fish	%Herbivore	100	<0.0001	
South	Fish	%Intolerant			weak relationship
South	Fish	%Long Lived			weak relationship
South	Fish	%Perciformes-Tolerant	80	<0.0001	
South	Fish	%Riffle	100	<0.0001	
South	Fish	%Sensitive	87	<0.0001	
South	Fish	%Simple Lithophils	59	<0.0001	
Coldwater	Fish	%Benthic Feeders			no lower breakpoint
Coldwater	Fish	%Carnivore			positive relationship
Coldwater	Fish	%Centrarchid-Tolerant			weak relationship
Coldwater	Fish	%Herbivore			weak relationship
Coldwater	Fish	%Intolerant	21	<0.0001	
Coldwater	Fish	%Long Lived			weak relationship
Coldwater	Fish	%Perciformes-Tolerant	13	<0.0001	
Coldwater	Fish	%Riffle			no lower breakpoint
Coldwater	Fish	%Sensitive	14	<0.0001	
Coldwater	Fish	%Simple Lithophils			no lower breakpoint
Coldwater	Fish	%Darters+Sculpins	13	<0.0001	
Coldwater	Fish	%Detritivores			no lower breakpoint
Coldwater	Fish	%NativeCold+Cool			weak relationship
Coldwater	Fish	%Mature≥4Years	13	<0.0001	

Table 8. Raw total TSS threshold concentration values (mg L⁻¹) for invertebrates using additive quantile regression smoothing analysis. Abbreviations: T.C. = Threshold Concentration.

Region	Group	Metric	T.C.	Test	Notes
North	Invertebrates	%Collector-Filterers	11	<0.0001	
North	Invertebrates	%Intolerant			weak relationship
North	Invertebrates	%Long Lived			weak relationship
North	Invertebrates	%Odonata			weak relationship
North	Invertebrates	%Plecoptera	11	<0.0001	
North	Invertebrates	%Scraper			weak relationship
North	Invertebrates	%Shredder			weak relationship
North	Invertebrates	%Trichoptera	18	<0.0001	
Central	Invertebrates	%Collector-Filterers			weak relationship
Central	Invertebrates	%Intolerant	33	<0.0001	
Central	Invertebrates	%Long Lived			weak breakpoints
Central	Invertebrates	%Odonata	27	<0.0001	
Central	Invertebrates	%Plecoptera			weak relationship
Central	Invertebrates	%Scraper			weak relationship
Central	Invertebrates	%Shredder			weak relationship
Central	Invertebrates	%Trichoptera			weak relationship
South	Invertebrates	%Collector-Filterers	165	<0.0001	
South	Invertebrates	%Intolerant			weak relationship
South	Invertebrates	%Long Lived	99	<0.0001	
South	Invertebrates	%Odonata			weak relationship
South	Invertebrates	%Plecoptera			weak relationship
South	Invertebrates	%Scraper			weak relationship
South	Invertebrates	%Shredder			weak relationship
South	Invertebrates	%Trichoptera	140	<0.0001	
Coldwater	Invertebrates	%Collector-Filterers			n too small for analysis
Coldwater	Invertebrates	%Intolerant			n too small for analysis
Coldwater	Invertebrates	%Long Lived			n too small for analysis
Coldwater	Invertebrates	%Odonata			n too small for analysis
Coldwater	Invertebrates	%Plecoptera			n too small for analysis
Coldwater	Invertebrates	%Scraper			n too small for analysis
Coldwater	Invertebrates	%Shredder			n too small for analysis
Coldwater	Invertebrates	%Trichoptera			n too small for analysis

Table 9. Raw Total Suspended Solids (TSS) threshold concentration values (mg L⁻¹) for fish using regression tree (changepoint) analysis. Abbreviations: T.C. = Threshold Concentration L = 90% Lower Bound, U = 90% Upper Bound.

Region	Group	Metric	T.C.	L	U	Test	Bucket	Notes
North	Fish	%Benthic Feeders	24	15	38	0.0020	5	
North	Fish	%Carnivore				0.1474	5	not significant
North	Fish	%Centrarchid-Tolerant				0.0871	5	not significant
North	Fish	%Herbivore	25	15	44	0.0032	5	
North	Fish	%Intolerant	14	0	21	0.0059	5	
North	Fish	%Long Lived	24			0.1398	5	not significant
North	Fish	%Perciformes-Tolerant						weak relationship
North	Fish	%Riffle	28	21	47	<0.0001	5	
North	Fish	%Sensitive		21	52	0.0293	5	
North	Fish	%Simple Lithophils	22	6	37	0.0099	5	
Central	Fish	%Benthic Feeders				0.0629	7	not significant
Central	Fish	%Carnivore	18	5	24	0.0044	7	
Central	Fish	%Centrarchid-Tolerant	24	16	33	<0.0001	7	
Central	Fish	%Herbivore				0.0874	7	not significant
Central	Fish	%Intolerant	32	29	49	0.0042	7	
Central	Fish	%Long Lived		-3	23	0.0245	7	
Central	Fish	%Perciformes-Tolerant	24	12	30	<0.0001	7	
Central	Fish	%Riffle				0.0932	7	not significant
Central	Fish	%Sensitive	32	23	50	<0.0001	7	
Central	Fish	%Simple Lithophils				0.0658	7	not significant
South	Fish	%Benthic Feeders	73	52	97	<0.0001	9	
South	Fish	%Carnivore	92	14	147	0.0019	9	
South	Fish	%Centrarchid-Tolerant	144	123	223	0.0162	9	
South	Fish	%Herbivore	73	43	92	<0.0001	9	
South	Fish	%Intolerant				0.9387	9	not significant
South	Fish	%Long Lived						weak relationship
South	Fish	%Perciformes-Tolerant	44	-55	86	0.0033	9	
South	Fish	%Riffle	73	34	101	<0.0001	9	
South	Fish	%Sensitive	44	11	55	<0.0001	9	
South	Fish	%Simple Lithophils	73	35	117	0.0014	9	
Coldwater	Fish	%Benthic Feeders				0.0055	5	positive relationship
Coldwater	Fish	%Carnivore				0.3002	5	not significant
Coldwater	Fish	%Centrarchid-Tolerant				0.8324	5	not significant
Coldwater	Fish	%Herbivore				0.4429	5	not significant
Coldwater	Fish	%Intolerant	7			0.1577	5	not significant
Coldwater	Fish	%Long Lived				0.7851	5	not significant
Coldwater	Fish	%Perciformes-Tolerant	7			0.0067	5	
Coldwater	Fish	%Riffle				0.0755	5	not significant
Coldwater	Fish	%Sensitive	5			0.0309	5	
Coldwater	Fish	%Simple Lithophils				0.3163	5	not significant
Coldwater	Fish	%Darters+Sculpins	7			<0.0001	5	
Coldwater	Fish	%Detritivores				0.1015	5	not significant
Coldwater	Fish	%NativeCold+Cool				0.8327	5	not significant
Coldwater	Fish	%Mature≥4Years	5			<0.0001	5	

Table 10. Raw Total Suspended Solids (TSS) threshold concentration values (mg L⁻¹) for invertebrates using regression tree (changepoint) analysis. Abbreviations: T.C. = Threshold Concentration L = 90% Lower Bound, U = 90% Upper Bound.

Region	Group	Metric	T.C.	L	U	Test	Bucket	Notes
North	Inverts	%Collector-Filterers	12	2	18	0.0050	5	
North	Inverts	%Intolerant				0.1966	5	not significant
North	Inverts	%Long Lived				0.0586	5	not significant
North	Inverts	%Odonata						weak relationship
North	Inverts	%Plecoptera	12	7	15	0.0027	5	
North	Inverts	%Scraper				0.2324	5	not significant
North	Inverts	%Shredder				0.1679	5	not significant
North	Inverts	%Trichoptera	15	6	22	0.0438	5	
Central	Inverts	%Collector-Filterers						weak relationship
Central	Inverts	%Intolerant				0.6836	5	not significant
Central	Inverts	%Long Lived	36	27	65	0.0438	5	
Central	Inverts	%Odonata				0.1514	5	not significant
Central	Inverts	%Plecoptera				0.1942	5	not significant
Central	Inverts	%Scraper				0.0736	5	not significant
Central	Inverts	%Shredder						weak relationship
Central	Inverts	%Trichoptera				0.1477	5	not significant
South	Inverts	%Collector-Filterers	125	87	153	0.0094	6	
South	Inverts	%Intolerant				0.0552	6	not significant
South	Inverts	%Long Lived				0.2806	6	not significant
South	Inverts	%Odonata				0.9533	6	not significant
South	Inverts	%Plecoptera				0.0716	6	not significant
South	Inverts	%Scraper						weak relationship
South	Inverts	%Shredder				0.2556	6	not significant
South	Inverts	%Trichoptera				0.0590	6	not significant
Coldwater	Inverts	%Collector-Filterers						n too small for analysis
Coldwater	Inverts	%Intolerant						n too small for analysis
Coldwater	Inverts	%Long Lived						n too small for analysis
Coldwater	Inverts	%Odonata						n too small for analysis
Coldwater	Inverts	%Plecoptera						n too small for analysis
Coldwater	Inverts	%Scraper						n too small for analysis
Coldwater	Inverts	%Shredder						n too small for analysis
Coldwater	Inverts	%Trichoptera						n too small for analysis

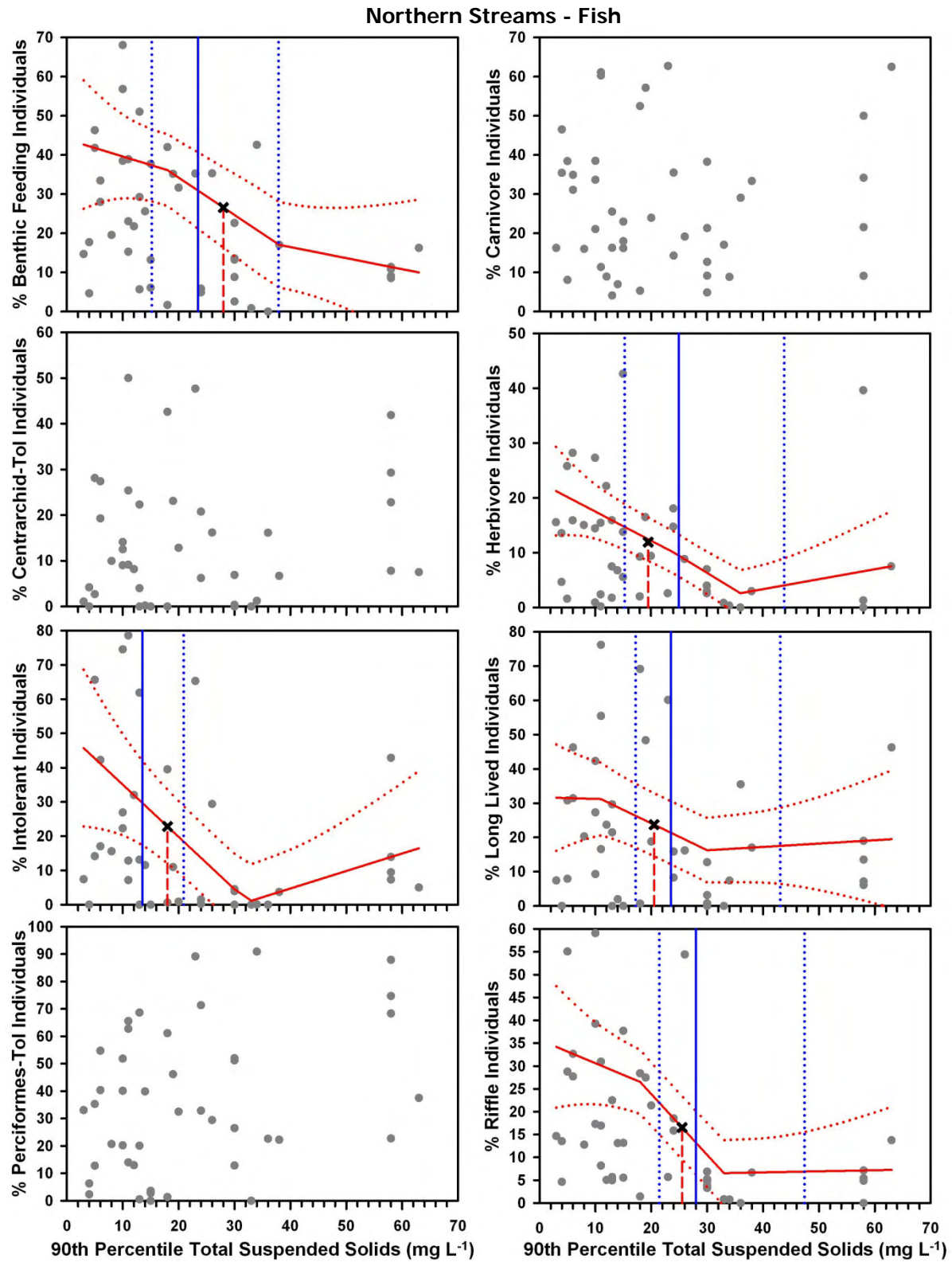


Figure 7. Relationships between Total Suspended Solids (TSS) mg L^{-1} and fish metrics for the North Region (red line = additive quantile regression with 90% confidence bands, blue line = changepoint with 90% confidence bands).

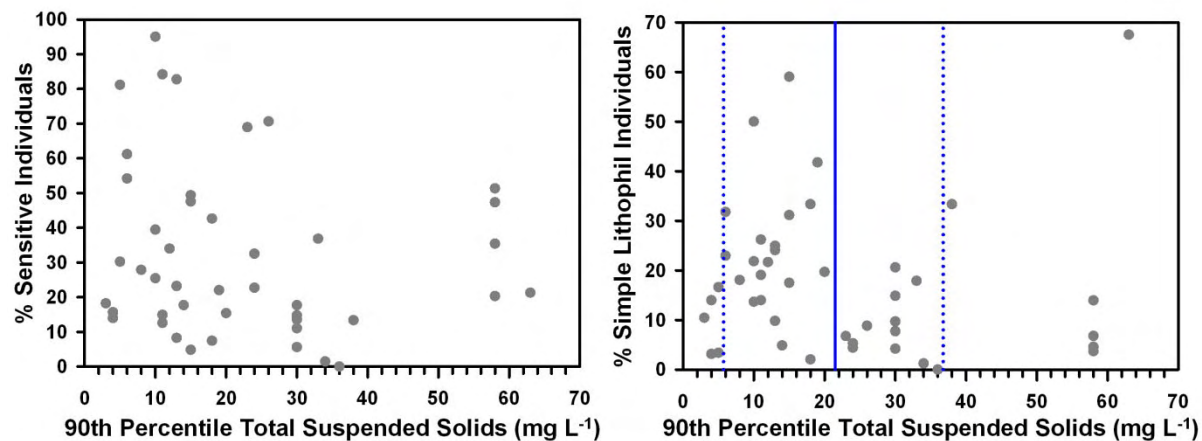


Figure 7 (continued). Relationships between Total Suspended Solids (TSS) mg L⁻¹ and fish metrics for the North Region (red line = additive quantile regression with 90% confidence bands, blue line = changepoint with 90% confidence bands).

Northern Streams - Invertebrates

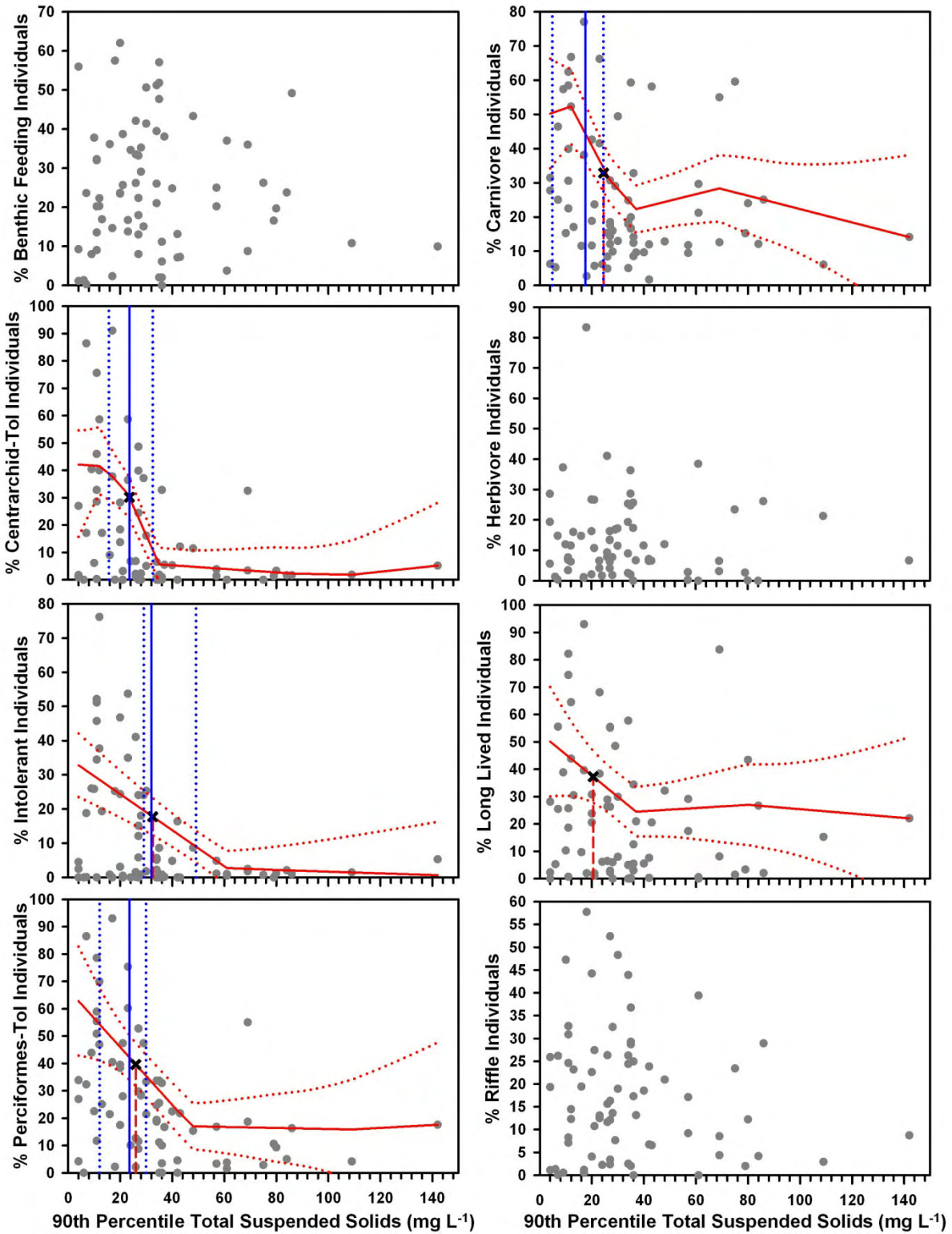


Figure 8. Relationships between Total Suspended Solids (TSS) mg L^{-1} and invertebrate metrics for the North Region (red line = additive quantile regression with 90% confidence bands, blue line = changepoint with 90% confidence bands).

Central Streams - Fish

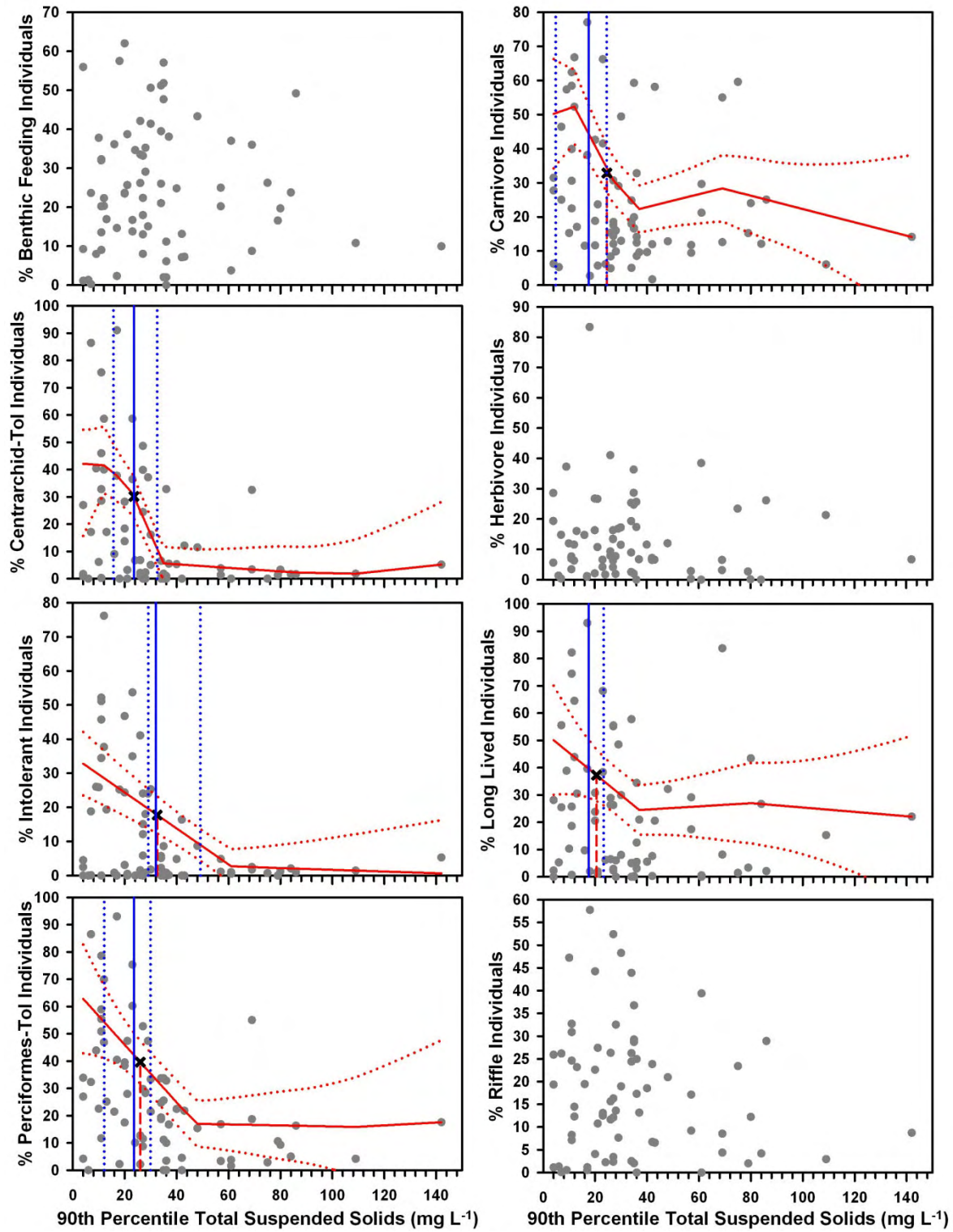


Figure 9. Relationships between Total Suspended Solids (TSS) mg L^{-1} and fish metrics for the Central Region (red line = additive quantile regression with 90% confidence bands, blue line = changepoint with 90% confidence bands).

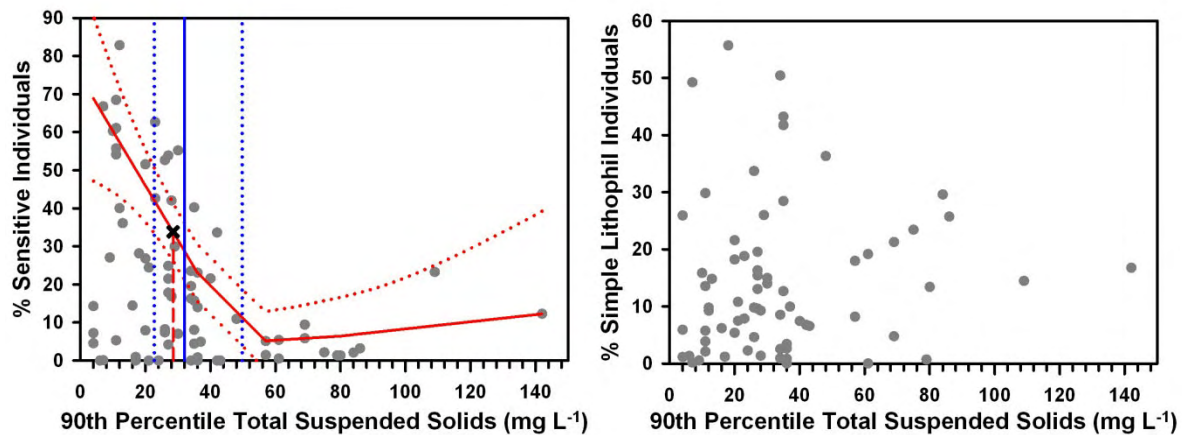


Figure 9 (continued). Relationships between Total Suspended Solids (TSS) mg L⁻¹ and fish metrics for the Central Region (red line = additive quantile regression with 90% confidence bands, blue line = changepoint with 90% confidence bands).

Central Streams - Invertebrates

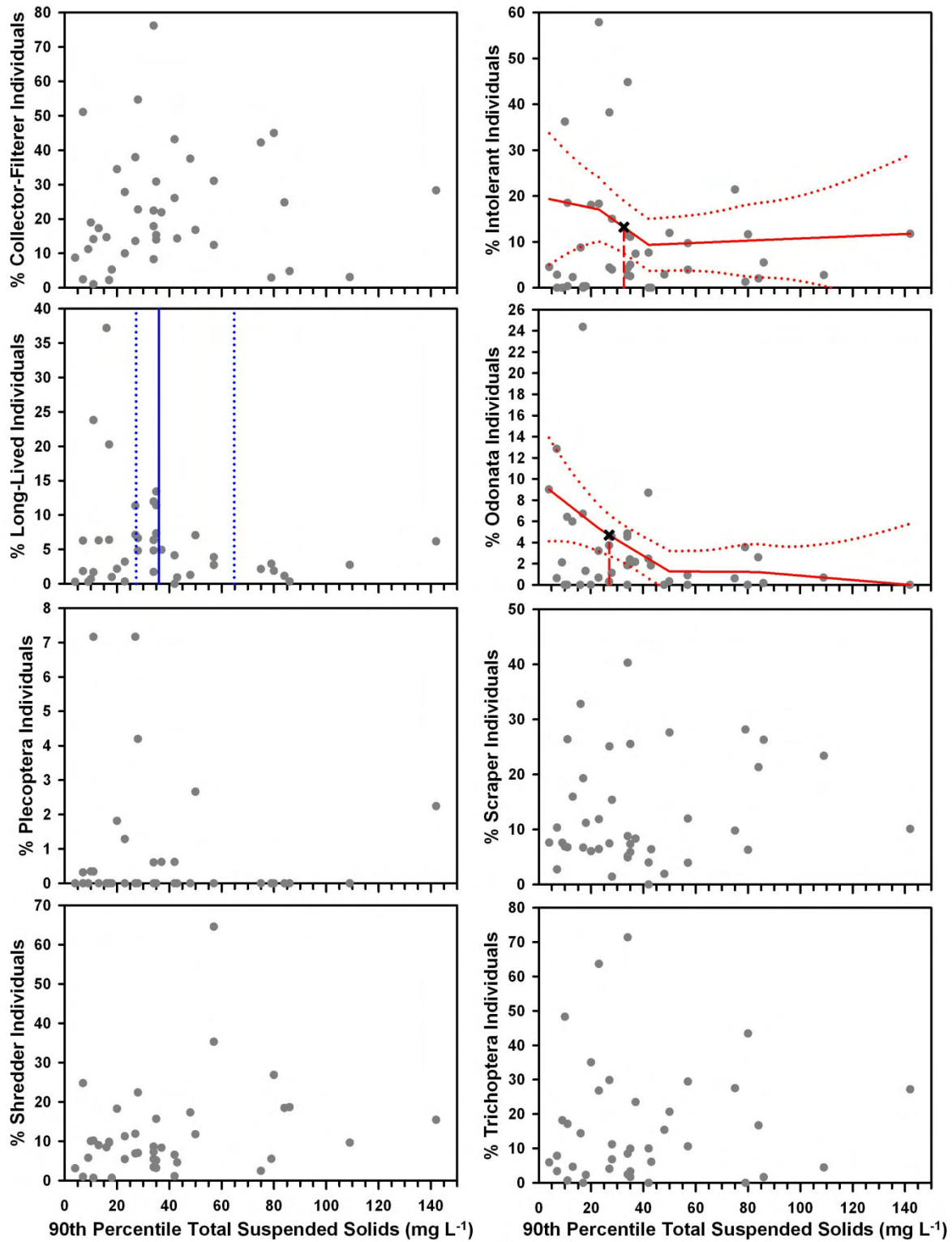


Figure 10. Relationships between Total Suspended Solids (TSS) mg L^{-1} and invertebrate metrics for the Central Region (red line = additive quantile regression with 90% confidence bands, blue line = changepoint with 90% confidence bands).

Southern Streams - Fish

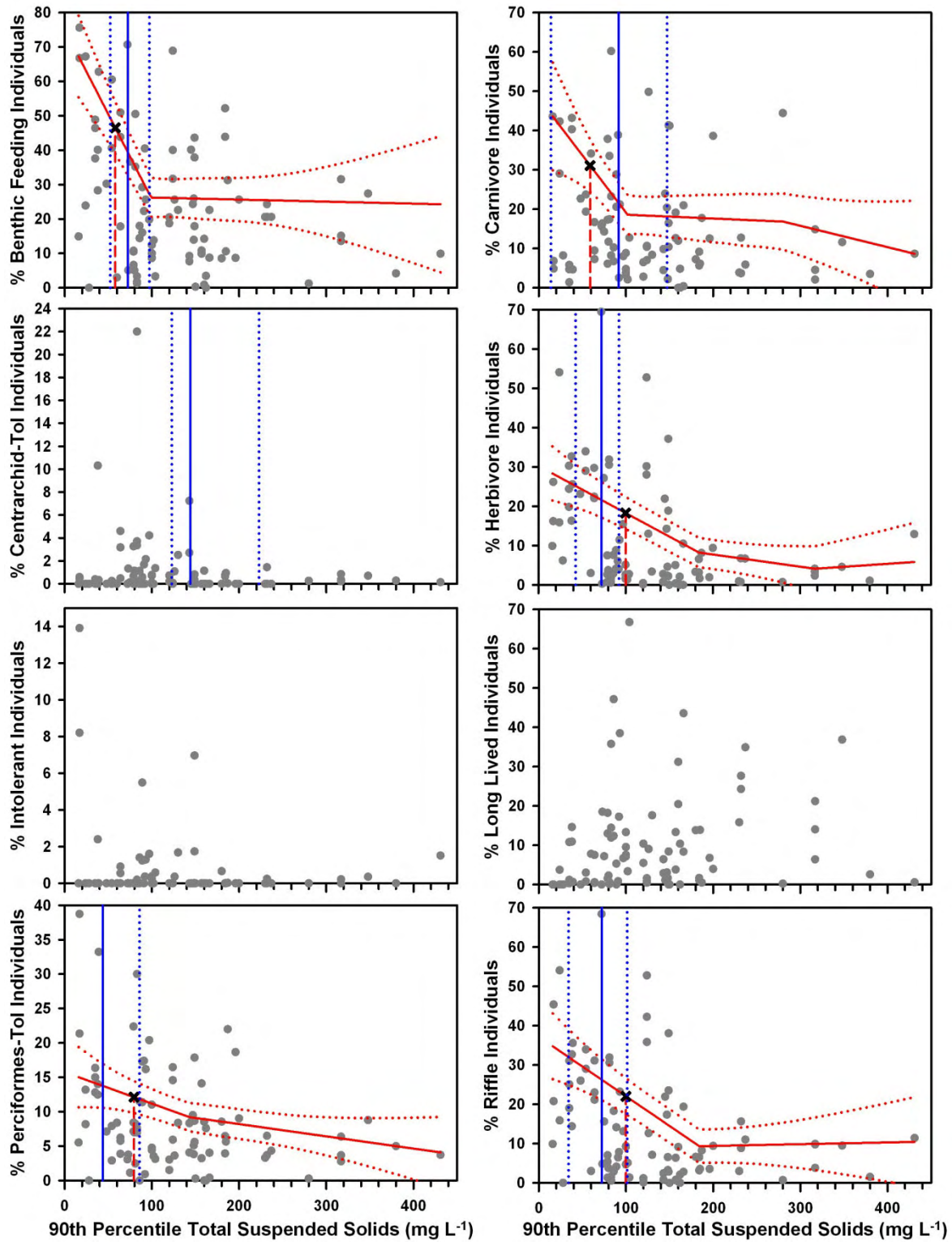


Figure 11. Relationships between Total Suspended Solids (TSS) mg L^{-1} and fish metrics for the South Region (red line = additive quantile regression with 90% confidence bands, blue line = changepoint with 90% confidence bands).

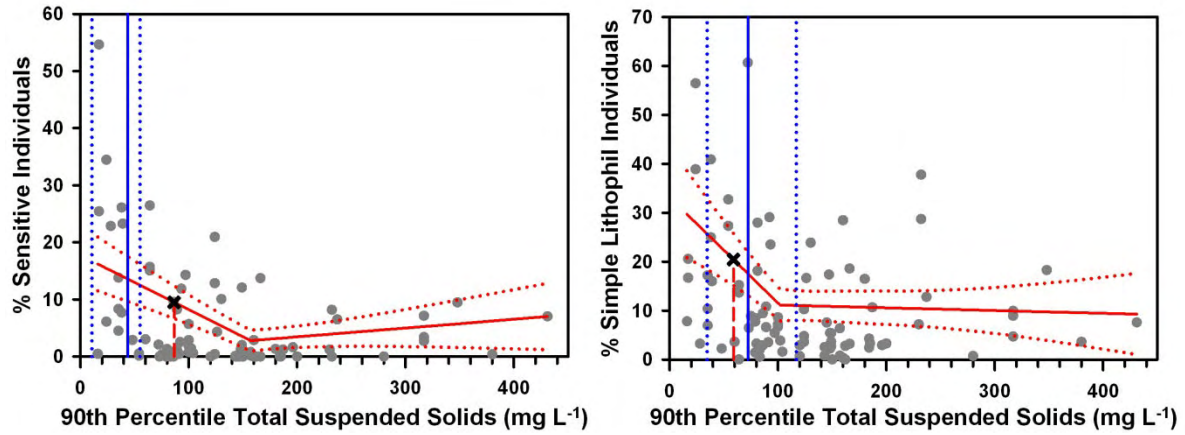


Figure 11 (continued). Relationships between Total Suspended Solids (TSS) mg L⁻¹ and fish metrics for the South Region (red line = additive quantile regression with 90% confidence bands, blue line = changepoint with 90% confidence bands).

Southern Streams - Invertebrates

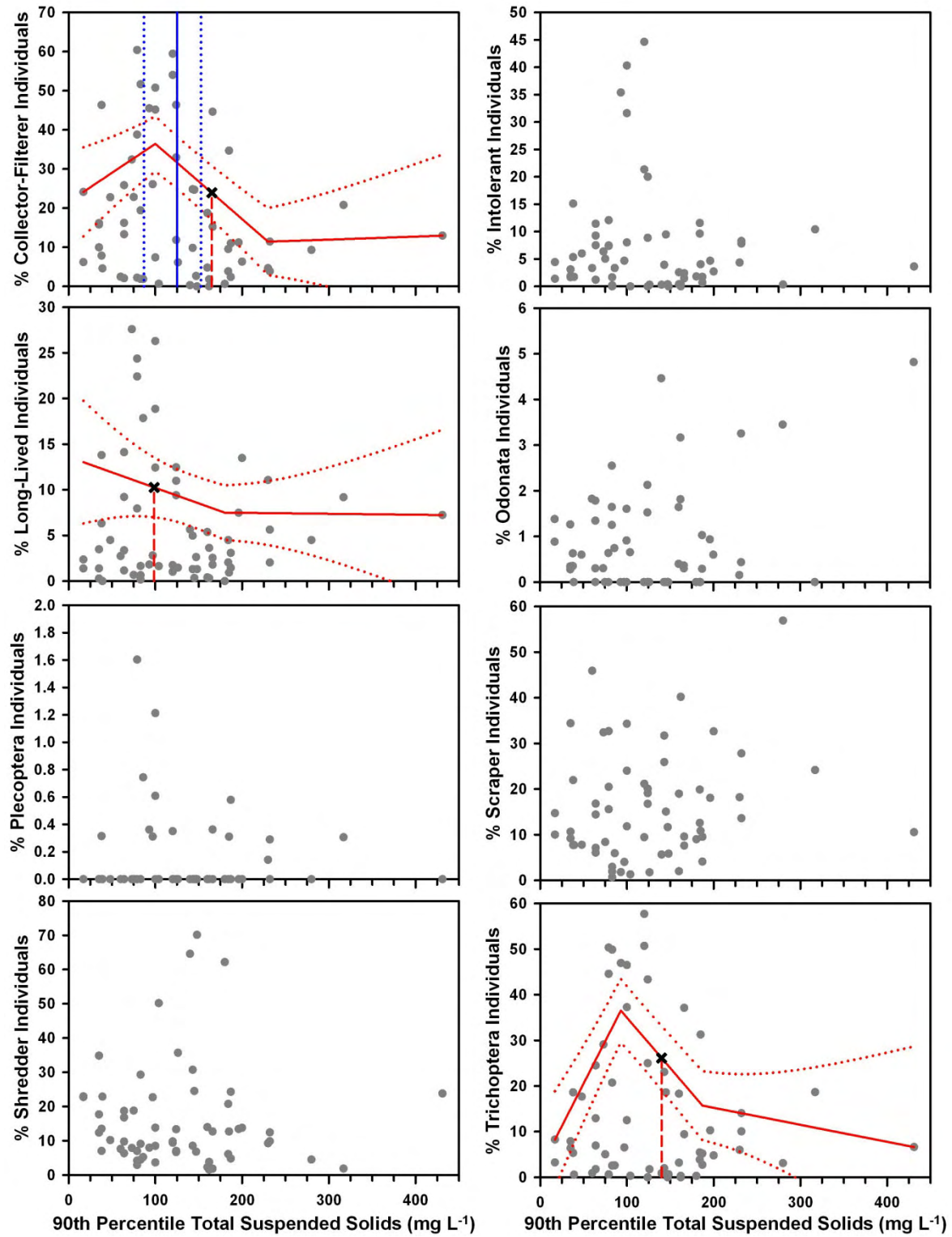


Figure 12. Relationships between Total Suspended Solids (TSS) mg L^{-1} and invertebrate metrics for the South Region (red line = additive quantile regression with 90% confidence bands, blue line = changepoint with 90% confidence bands).

Coldwater Streams - Fish

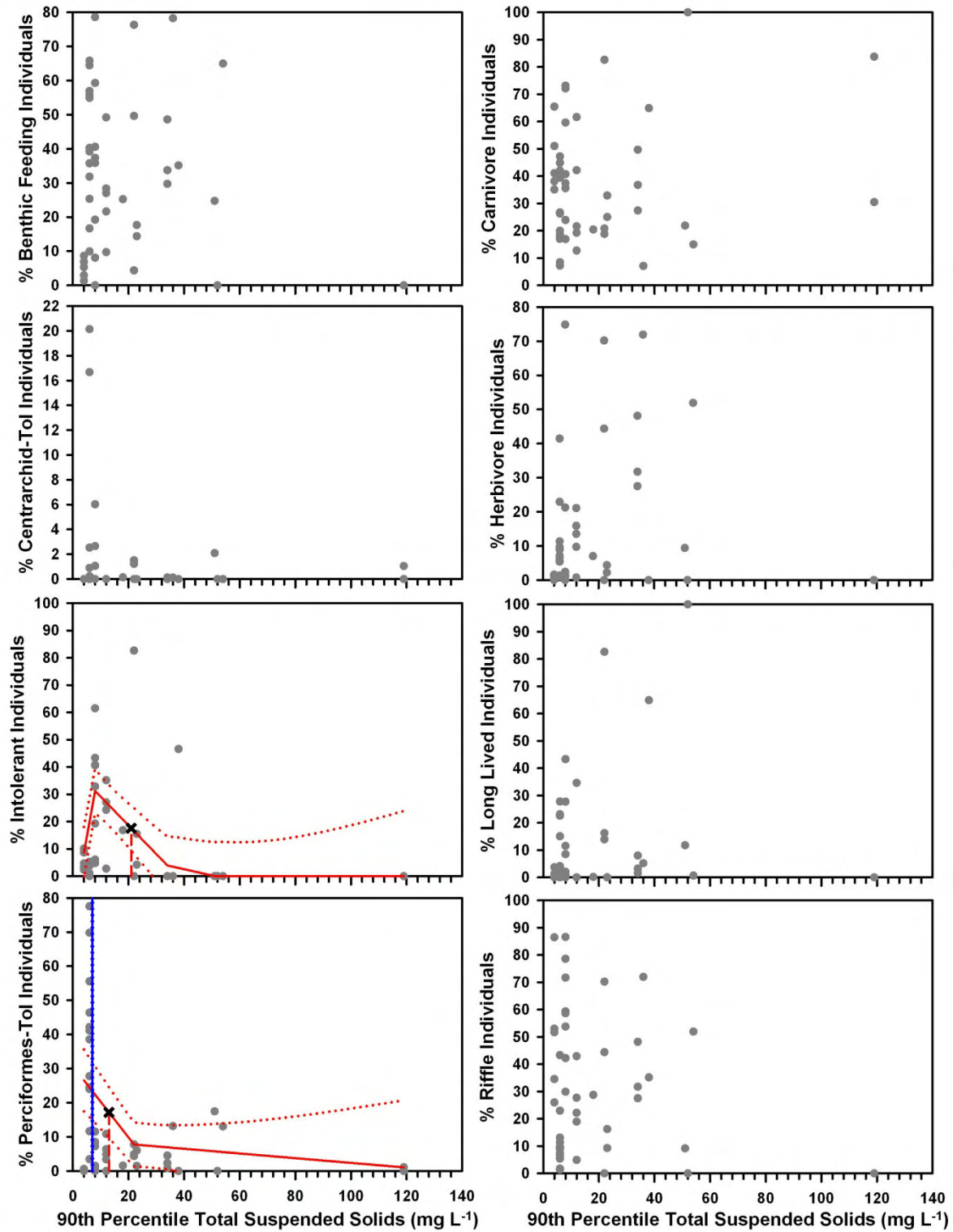


Figure 13. Relationships between Total Suspended Solids (TSS) mg L^{-1} and fish metrics for the Coldwater Streams (red line = additive quantile regression with 90% confidence bands, blue line = change point with 90% confidence bands).

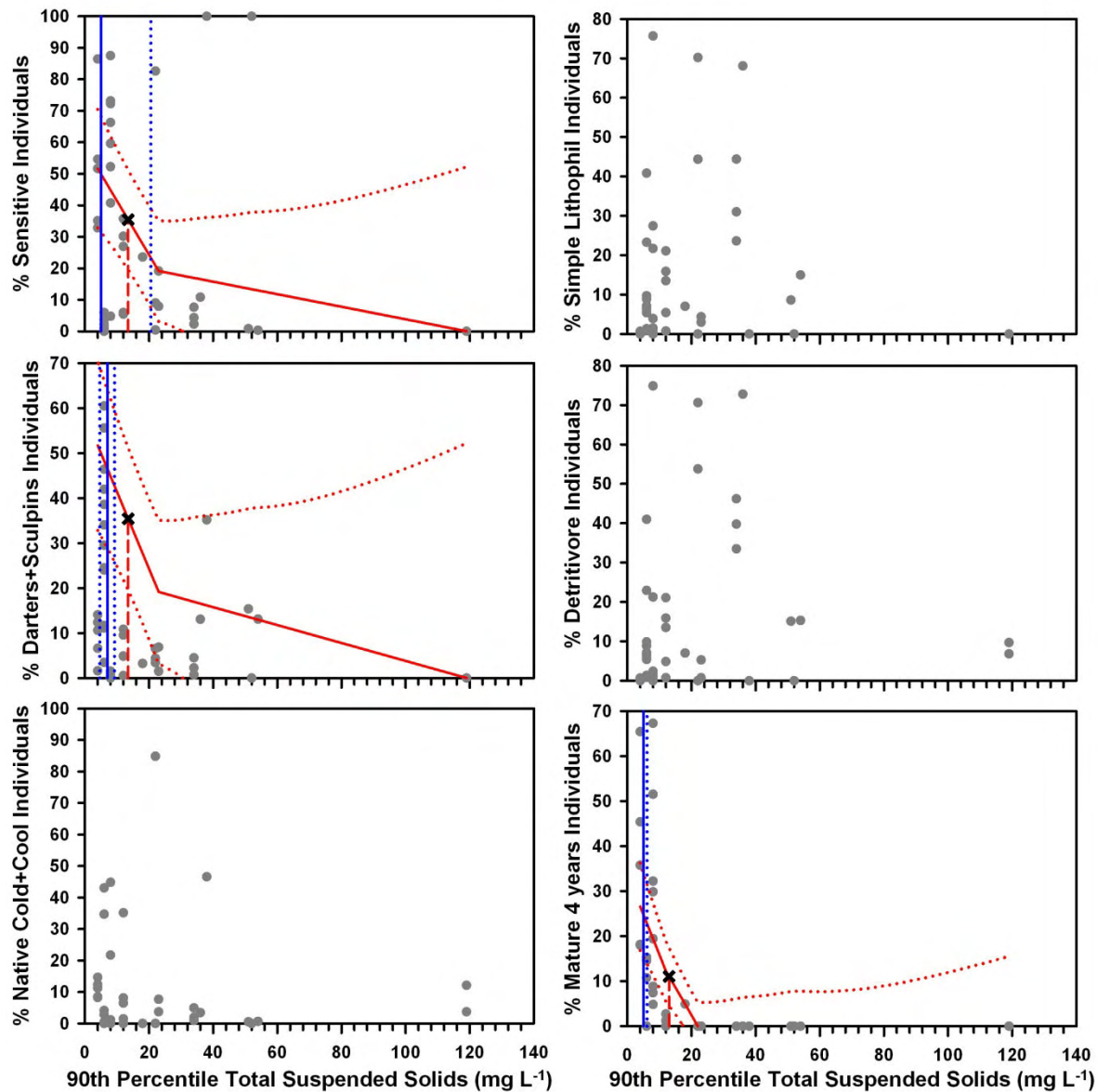


Figure 13 (continued). Relationships between Total Suspended Solids (TSS) mg L⁻¹ and fish metrics for the Coldwater Streams (red line = additive quantile regression with 90% confidence bands, blue line = changepoint with 90% confidence bands).

Coldwater Streams - Invertebrates

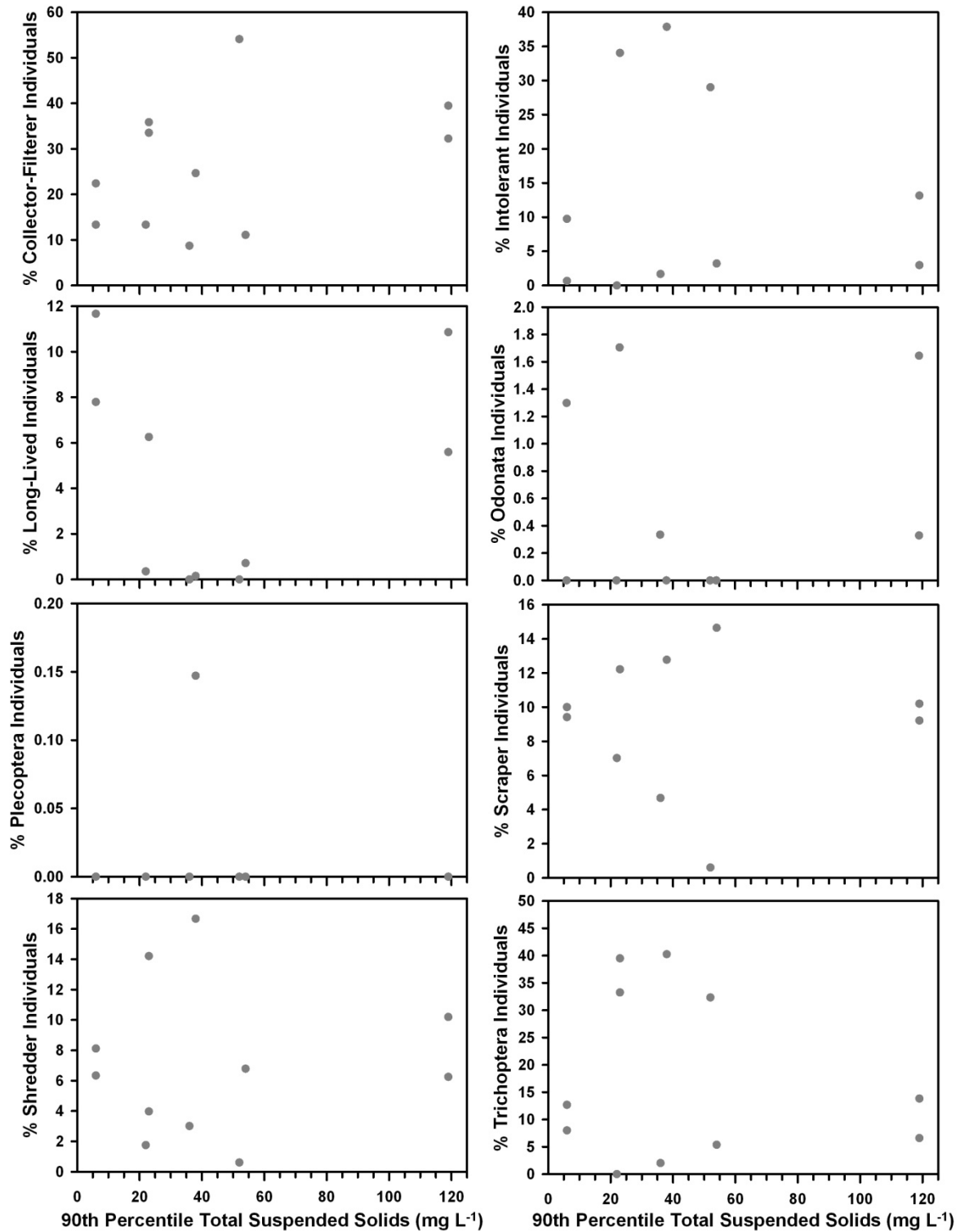


Figure 14. Relationships between Total Suspended Solids (TSS) mg L^{-1} and invertebrate metrics for the Coldwater Streams (red line = additive quantile regression with 90% confidence bands, blue line = changepoint with 90% confidence bands).