Statewide Stream/River Probabilistic Monitoring Network for the State of Oklahoma from 2008-2011

Final Report
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FY-2011 WPCP-Monitoring Section 106 Supplemental, Project 2 (CA# I-00F432-01) –"The Statewide Stream/River Probabilistic Monitoring Network—Final Report"

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Full Report available at, including appendices, available at:
http://www.owrb.ok.gov/studies/reports/reports_pdf/StatewideStreamProbMonitoringNetwork2008-2011.pdf

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EXECUTIVE SUMMARY

Several agencies conduct water quality monitoring in the State of Oklahoma. These agencies meet complementary monitoring objectives that support the management of Oklahoma's surface waters. The two primary components of the statewide monitoring program include (a) the Beneficial Use Monitoring Program, a long-term, fixed-station water quality monitoring network of the Oklahoma Water Resources Board (OWRB), and (b) Oklahoma Conservation Commission's (OCC) Small-Watershed Rotating Basin Monitoring Program, targeting water quality and ecological conditions in waters flowing from 11-digit hydrologic units. The state recently completed a water quality monitoring strategy that describes their existing programs in detail and the monitoring objectives that cannot be met with existing resources (OWRB, 2012d). These objectives include the ability to make statistically valid inferences about environmental conditions throughout the state, based on a probabilistic selection of sites. Meeting this objective will improve the ability to make condition estimates required in section 305(b) of the Clean Water Act. This requirement includes a description of the quality of all lotic waters, and the extent that all waters provide for the protection and propagation of aquatic life. The Environmental Protection Agency (EPA) recently released guidance establishing the "10 Required Elements of a State Water Monitoring and Assessment Program" (USEPA, 2005). Among other things, the document states, "a State monitoring program will likely integrate several monitoring designs (e.g., fixed station, intensive and screening-level monitoring, rotating basin, judgmental and probability design) to meet the full range of decision needs. The State monitoring design should include probability-based networks (at the watershed or state-level) that support statistically valid inferences about the condition of all State water types, over time. EPA expects the State to use the most efficient combination of monitoring designs to meet its objectives."

From 2008-2011, Oklahoma completed its 2nd and 3rd statewide surveys of lotic waters. In SY 2008-2009, Oklahoma participated in the National Rivers and Streams Assessment (NRSA) and sampled fifty-two (52) stations equally proportioned across orders 1-4 and 5+, completing its second comprehensive survey. In SY 2010-2011, Oklahoma completed its third statewide probabilistic study with a sample size of 48 perennial streams and rivers. The new study population included perennial streams and rivers throughout Oklahoma, and continued through the NRSA draw into the remaining oversample sites. By combining the two studies, Oklahoma can report on several temporal scales, and on two (2) size classes—smaller and larger waterbodies. Temporal scales include:

- 52 sites in the 2008-2009 sampling period (NRSA study)
- 48 sites in the 2010-2011 sampling period (OWRB study)
- 100 sites over the 2008-2011 sampling period (combined study).

The probability-based survey was designed to assist Oklahoma's water quality managers in several ways. Furthermore, in keeping with the environmental goals of the state as outlined in the comprehensive water plan, an effective long-term management strategy based on sound science and defensible data can be developed using this data. The four over-arching goals were:

1. Estimate the condition of multi-assemblage biological indicators for Oklahoma's waters through a statistically-valid approach.
2. Estimate the extent of stressors that may be associated with biological condition.
3. Evaluate the relationship between stressors and condition for use in various long and short term environmental management strategies.
4. Assess waters for inclusion in Oklahoma's Integrated Water Quality Report.

To assess ecological and human health, one-time collections were made for a variety of biological, chemical, and physical parameters (Table 1). When sites were verified as target, a sampling schedule was implemented. All target sites were visited once (in rare instances twice) during a late spring to late summer index period (June 1 – August 30), under base flow conditions. The studies measured the condition of three biotic assemblages—fish, macroinvertebrates, and sestonic and benthic algae—and a variety of stressors, including nutrients, conductivity, turbidity, habitat and sedimentation, and toxics. Fish data were analyzed using two indices of biological integrity (IBI) commonly used in Oklahoma bioassessment studies, as well as the IBI developed by the NRSA. Macroinvertebrate data were analyzed using a Benthic-IBI (B-IBI) developed for Oklahoma benthic communities (OCC, 2005a) and commonly used by the OCC and OWRB Water Quality Divisions (OCC, 2008; OWRB, 2009 and 2010a; ODEQ, 2012), as well as the IBI developed by the NRSA. To estimate condition of algal biomass, chlorophyll-a concentrations were compared to several screening levels.

Data outputs include: 1) relative extent of indicator and stressor condition, 2) relative risk of stressors to indicators, and 3) attributable risk of stressors to indicator extent. Data will also combined with other sources and included in the 2014 303(d) assessment of the Oklahoma Integrated Water Quality Report.

Highlights of the relative extent include:

- For both fish and macroinvertebrates, nearly 35% of stream miles were classified in poor condition over the 4-year study period, and the poor category increased to greater than 40% from 2008-2009 and decreased to less than 25% from 2010-2011.
- When considering stream size, a greater percentage of large river stream miles are in poor condition than small streams.
- A relative small percentage of miles (10%) are classified in poor condition for benthic algae. a greater percentage of large rivers (22%) than small streams (6%) are in poor condition.
- For sestonic algae, the percentage of streams in poor condition across study years varies from nearly 20% (2008-2009) to nearly 30% from 2010-2011, while the percent in good condition is approximately 55% for all study periods, and approximately 60% of large river miles are in poor condition as compared less than 10% of small river miles.
- Phosphorus extent in poor condition is generally 30-40%, regardless of study period or source of screening limit, while the percent of total miles in good condition ranges from 40-50%.
- Total nitrogen poor condition is from 25-40%.
- For conductivity, poor condition ranges from 10-22%, and is 40-55% in larger rivers, as opposed to 5% in small streams.
- For turbidity, poor condition is nearly 25%, and is 37% in larger rivers as opposed to 9% in smaller streams.
- Excess sedimentation from greater than 25% in streams to 35% in rivers, with poor condition ranging from 15% in 2008-2009 to greater than 50% from 2010-2011.

The current study allows for unique analysis between both study periods and waterbody size.

- For indicators, both fish and macroinvertebrates demonstrate a downward trend in poor condition between study periods, with only the fish having a significant downward trend.
- Conversely, both algal indicators show an upward trend, with only the benthic algae trend having significance.
- All but one of the total phosphorus stressors shows an upward trend between the two study periods, with only turbidity and sediment having a significant trend.

Attributable risk analyses provided the following results:

- Notably, for fish, elimination of sediment in large rivers could create a significant reduction of poor condition in fish as could reduction in conductivity.
- For macroinvertebrates, elimination of both total phosphorus and total nitrogen could have a significant effect on poor condition
- The elimination of phosphorus in small streams results in a nearly 14% lowering of the percent of miles in poor condition.
- As with fish, the elimination of conductivity is significant in some scenarios.
- Sestonic algal condition shows significant reduction in poor condition when turbidity, conductivity, and nutrients are eliminated.

Future study plans include the 2013-2014 National Rivers and Streams Assessment and a subsequent two-year statewide study beginning in 2015 (OWRB, 2013b). Substantive changes to the program will include

- Use of the NRSA protocols for large Wadeable and non-wadeable waterbodies.
- Use of NRSA habitat protocols for wadeable streams in concert with the current RBP habitat protocol.
- Inclusion of a second winter macroinvertebrate index period.
- Development of a periphyton taxonomic assemblage.
- Assessments at aggregated ecoregion scales used in the 2005-2007 assessment (OWRB, 2009)
- Change/trend analyses through the use of revisit sites.

INTRODUCTION

Several agencies conduct water quality monitoring in the State of Oklahoma. These agencies meet complementary monitoring objectives that support the management of Oklahoma's surface waters. The two primary components of the statewide monitoring program include (a) the Beneficial Use Monitoring Program, a long-term, fixed-station water quality monitoring network of the Oklahoma Water Resources Board (OWRB), and (b) Oklahoma Conservation Commission's (OCC) Small-Watershed Rotating Basin Monitoring Program, targeting water quality and ecological conditions in waters flowing from 11-digit hydrologic units. The state recently completed a water quality monitoring strategy that describes their existing programs in detail and the monitoring objectives that cannot be met with existing resources (OWRB, 2012d). These objectives include the ability to make statistically valid inferences about environmental conditions throughout the state, based on a probabilistic selection of sites. Meeting this objective will improve the ability to make condition estimates required in section 305(b) of the Clean Water Act. This requirement includes a description of the quality of all lotic waters, and the extent that all waters provide for the protection and propagation of aquatic life.

The Environmental Protection Agency (EPA) recently released guidance establishing the "10 Required Elements of a State Water Monitoring and Assessment Program" (USEPA, 2005). Among other things, the document states, "a State monitoring program will likely integrate several monitoring designs (e.g., fixed station, intensive and screening-level monitoring, rotating basin, judgmental and probability design) to meet the full range of decision needs. The State monitoring design should include probability-based networks (at the watershed or state-level) that support statistically valid inferences about the condition of all State water types, over time. EPA expects the State to use the most efficient combination of monitoring designs to meet its objectives." Until 2005, Oklahoma had several monitoring programs that met these requirements including the Beneficial Use Monitoring Program (BUMP) and the Rotating Basin Monitoring Program (RBMP) (OWRB, 20012d). Furthermore, the state has developed several programs to intensively monitor areas that have been listed on Oklahoma's 303(d) list of impaired waters (ODEQ, 2010).

In 2001, the state requested assistance with the design of a probabilistic approach to stream and river site selection from the U.S. Environmental Protection Agency, Office of Research and Development (ORD), Western Ecology Division (OWRB, 2006a). The study design was completed, but Oklahoma agencies remained unable to initiate further planning and implementation because of a lack of resources and commitment. In 2004, the OWRB and OCC took part in the National Wadeable Streams Assessment (WSA) (USEPA, 2006), which was fortuitous to future planning efforts for several reasons. First, the timing of the study coincided with discussions in the state about implementing a probabilistic design. Although money was a question, staff and management were worried staff time could not be spent performing all of the necessary reconnaissance work or sampling that is required in a random based monitoring program. Participating in the WSA instilled confidence that this type of monitoring could be accomplished without impeding the success of other programs. In fact, this facet of Oklahoma's monitoring program has only enhanced other programs. Second, because the state showed interest in implementing a random design, USEPA Region 6 began working with staff to find appropriate funding. The initial funding came through a Clean Water Act (CWA) Section 104(b)(3) grant. This money funded not only the initial year of study (2005), but an outcome was to investigate the feasibility of full implementation (OWRB, 2006a). The study investigated feasibility on two fronts—logistic and funding—finding that the logistic portion could be overcome through proper planning and coordination of staff. The funding, however, was not easily dealt with because of program priorities. In 2005, another funding opportunity came open when the USEPA announced further funding of the Regional Environmental Monitoring and Assessment Program (REMAP) (OWRB, 2009). Funding from the REMAP grant allowed the state to continue implementation of probabilistic monitoring for an additional two years through 2007. In that study, the OWRB completed a large-scale statewide assessment of perennial rivers and streams, as well as assessments for three large ecoregion groupings including the Western and High Plains, the Forested Plains and Flint Hills, and the Eastern Highlands. A significant limitation during that study was the inability to determine biological condition in large rivers.

In SY 2008-2009, Oklahoma participated in the National Rivers and Streams Assessment (NRSA) and sampled fifty-two (52) stations equally proportioned across orders 1-4 and 5+, completing its second comprehensive survey. In SY 2010-2011, Oklahoma completed its third statewide probabilistic study with a sample size of 48 perennial streams and rivers. The new study population included perennial streams and rivers throughout Oklahoma, and continued through the NRSA draw into the remaining oversample sites. By combining the two studies, Oklahoma can report on several temporal scales, and on two (2) size classes—smaller and larger waterbodies. Temporal scales include:

- 52 sites in the 2008-2009 sampling period (NRSA study)
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The probability-based survey was designed to assist Oklahoma's water quality managers in several ways. Furthermore, in keeping with the environmental goals of the state as outlined in the Oklahoma Comprehensive Water Plan, an effective long-term management strategy based on sound science and defensible data can be developed using this data. The four over-arching goals were:

5. Estimate the condition of multi-assemblage biological indicators for Oklahoma's waters through a statistically-valid approach.
6. Estimate the extent of stressors that may be associated with biological condition.
7. Evaluate the relationship between stressors and condition for use in various long and short term environmental management strategies.
8. Assess waters for inclusion in Oklahoma's Integrated Water Quality Report.

The current assessment allows the state to make a statistically valid assessment of the condition of all of Oklahoma's streams/rivers, as required under Section 305(b) of the Clean Water Act (CWA) (ODEQ, 2012). The sample size allows for a statewide estimate of fish, macroinvertebrate, and algal condition on 3 temporal scales, as well as two size classes. Additionally, stressor extent is evaluated for a number of potential environmental stressors. Under the guidelines of the Integrated Listing Methodology (ODEQ, 2012), data allow for the assessment of the Fish & Wildlife Propagation beneficial use on more waters of the state. Although currently limited to certain beneficial uses and associated criteria, the support status of more waters can be determined. Future work may allow for more comprehensive 303(d) assessments so that the support status of probabilistic sites may be fully vetted. Finally, the survey provides information that will allow for better long- and short-range planning and resource allocation. A benefit of probabilistic design is that data results can be applied in a much broader context. For example, the relationship of condition can be associated with stressor extent through methodologies like relative risk analysis. The current study yields a wealth of biological, chemical, and physical data across a broad gradient of environmental conditions, supporting evaluation of these indicator relationships. Data can be used to calibrate existing biocriteria ranges, establish reference condition, and assist in nutrient criteria development. When integrated with fixed-station networks, it can assist in identifying local areas of concern. Also, although not accomplished by this report, landscape metrics can be associated with stressors and condition to develop predictive models. Probabilistic data can assist in efforts to regionalize environmental concerns. A bottom up approach to management identifies not only statewide issues but allows managers to identify local and regional concerns first, which often lead to issues farther down the watershed, and put resources where they are needed. The probabilistic methodology adds a valuable layer to that management approach.

METHODS

Study Design

An unequal probability random tessellation stratified (RTS) survey design (Stevens 1997, Stevens and Olsen 2004) was used to select stream sample sites across the state (USEPA, 2012 and Appendix D-1). The original design for the 4-year study emanated from Oklahoma's site file for the 2008-2009 NRSA. Unequal probability categories were defined separately for wadeable streams (1st to 4th order) and non-wadeable rivers (5th to 10th order). The terms wadeable and non-wadeable were used to designate Strahler order classes and did not imply that the streams were actually wadeable or non-wadeable, as defined by protocol. For the wadeable stream category, unequal selection probabilities were defined for 1st, 2nd, 3rd, and 4th order streams so that an equal number of sites would occur for each order. Then these unequal selection probabilities were adjusted by the Wadeable Streams Assessment (WSA) nine aggregated ecoregion categories so that an equal number of sites would occur in each WSA nine aggregated ecoregion category. For the non-wadeable river category, unequal selection probabilities were defined for 5th, 6th, 7th, and 8th + Strahler order Rivers so that the expected number of sites nationally would be 350, 275, 175, and 100 sites, respectively. Then these unequal selection probabilities were adjusted by WSA nine aggregated ecoregion categories so that an equal number of sites would occur in each WSA nine aggregated ecoregion category. Additionally, certain sites were selected as revisit sites from the 2004 Wadeable Streams, and included in the initial study design, weighted equally across the Strahler order categories mentioned above. In Oklahoma for the 4-year study period, the expected sample size was 51 for both wadeable streams and non-wadeable rivers. Oversample sites were provided for each Strahler order grouping. Site replacement was done within the two major Strahler order categories, 1st-4th and 5th+.

The study was spatially, temporally and hydrologically limited. Spatially, the study was limited to only streams defined as perennial in flow and excluded all sites within a reservoir flood pool. Temporal limitations were defined by biological index periods. The index period for the fish assemblage in Oklahoma was May 15th through September 15th with an optional extension to October 1st if the stream had not risen above summer seasonal base flow (OWRB, 2010b). The index habitat period for the macroinvertebrate assemblage in Oklahoma was June 1st through August 30th with collections completed in as short a time period as possible (OWRB, 2010c). Hydrologically, the study was limited by both an extended drought in SY-2011 as well as excessive rains and flooding in SY-2008. This impeded study progress in several ways. Sites originally verified as target sites were removed and an oversample site visited because of site changes between the period of reconnaissance and sampling. Additionally, several sites had partial collections because conditions changed between the period of macroinvertebrate/water sampling and fish sampling, or vice-versa. Furthermore, all of the smaller Strahler order category sites were ultimately evaluated. Because of accessibility issues related to drought in SY-11, only 48 sites were available for inclusion in the 2010-2011 study.

The study and subsequent site selection were designed to allow for three reporting periods and sub-categorization of "small" and "large" sites. The reporting periods include 2008-2011 (n = 100), 2008-2009 (n = 52), and 2010-2011 (n = 48). The 2008-2011 was sub-categorized to evaluate small (1st-4th Strahler Order) and large (5th+ Strahler Order) waterbodies. For each subcategory, an "n" of 50 was achieved. The oversample sites from the original NRSA sample design were used to provide sites for the 2010-2011 study.

Site Reconnaissance

Limited accessibility is the most serious problem with any probabilistic study. Unlike a fixed station design, study sites are typically not accessible by public roads and may only be accessed by foot. Compounding the problem is private ownership of land and the need to respect a landowner's choice of who may or may not access the property. Finally, probabilistic sites are selected from data frames that are not 100% accurate and may include non-candidate sites. Fortunately, proper planning and having an excess of available oversample sites can alleviate these issues. During the EPA's Wadeable Streams Assessment (USEPA, 2006) and Oklahoma's 1st Statewide Probabilistic Study (REMAP) (OWRB, 2009), the OWRB developed (with assistance from EPA documentation) and implemented a three-stage reconnaissance plan.

The first stage of planning was a "desk top" reconnaissance to determine if the proposed site was a candidate site. Candidate sites must meet certain criteria, including: 1) perennial flow, 2) not within normal pool elevation of a lake (oxbows or reservoirs), 3) not a wetland/swamp dominated river, 4) accessible by foot, and 5) landowner permission granted. Initially, each site was located using a variety of resources including topographic maps (OWRB, 2011), and other GIS mapping tools (NACEC, 1997). For each site, a site reconnaissance and tracking form (Figure 3) was created with the ultimate determination made to "accept" or "reject". At the outset, required hydrological characteristics were verified, and if not met, the site was rejected without further consideration. Then, a series of site maps containing at least two geographic scales were included with the site tracking form, and the necessary information to determine landowner was collected, including legal description of site and county. County assessor offices were the main source of landowner information. However, for some problem sites, staff used a variety of other resources including development of relationships with local realtors/developers or personal visits to nearby residences. Finally, a landowner permission packet was sent to each landowner, including a standardized permission letter (Figure 4), maps, a study brochure, and self addressed/stamped envelope for them to review and mail back to the OWRB either approving or disallowing access to their property. Based on landowner response, the site was accepted, accepted with restrictions/further instructions, or rejected. However, even when good landowner information was available, response to permission requests was occasionally slow for a variety of reasons, and therefore, a two stage process was developed to deal with slow responses. After two to three weeks, staff attempted contact by phone, and if unsuccessful, would send a reminder postcard. If still unsuccessful, in-person contact was attempted. If each of these attempts failed, the site was rejected.

Once site accessibility was verified (i.e., accepted) and a site was labeled as a study target site, a second planning stage was initiated. The planning objective was simply to collect thorough, well-documented information to assist field crews in locating and accessing the sampling reach. Because of color aerial satellite imagery, much of this information was gathered from the desktop. Notes were made and included in the tracking form of special considerations including hazards, best route of entry, time of travel, etc. Unfortunately, some sites required an on-site initial visit to complete the planning phase. Concerns did arise about the cost versus benefit of an extra site visit. However, over the course of three years, crews discovered that much of the information collected during the initial on-site planning visit was of great benefit on the actual day of sampling. Furthermore, because sites could be visited in batches and only one staff member was required, little expense was incurred.

The final planning stage involved all activities up to the first sampling visit, and involved compiling a complete site packet. The packet incorporated all information gathered in stages one and two, including a completed tracking form, landowner permission letter, and pertinent pictures and maps. In addition, all necessary field forms and labels were compiled and a checklist of equipment needed was completed.

Probabilistic Monitoring – Site Reconnaissance & Tracking Form

Stream Name: **Little Creek**

Site ID: **OKPB01-*027***

Lat/Long: **34^{0} 46’ 50.8” / 99^{0} 23’ 33.5”**

Site Type: [✓ **target**] or oversample

Sample Status: [✓ **Accepted**] or Rejected

If rejected, what is the reason:
[ ] Landowner Denied Permission
[ ] Site is Dry
[ ] Site is Impounded (part of a lake)
[ ] Site is Not Riverine Habitat (i.e., wetland, swamp, etc.)
[ ] Site is Not Physically Accessible
[ ] Other, Please Explain:

If rejected, what site replaces this one?:

Landowner Contact Information:

John Doe (Doe Land & Cattle Co.)
P.O. Box A
Your Town, OK 11111
(580)555-2222

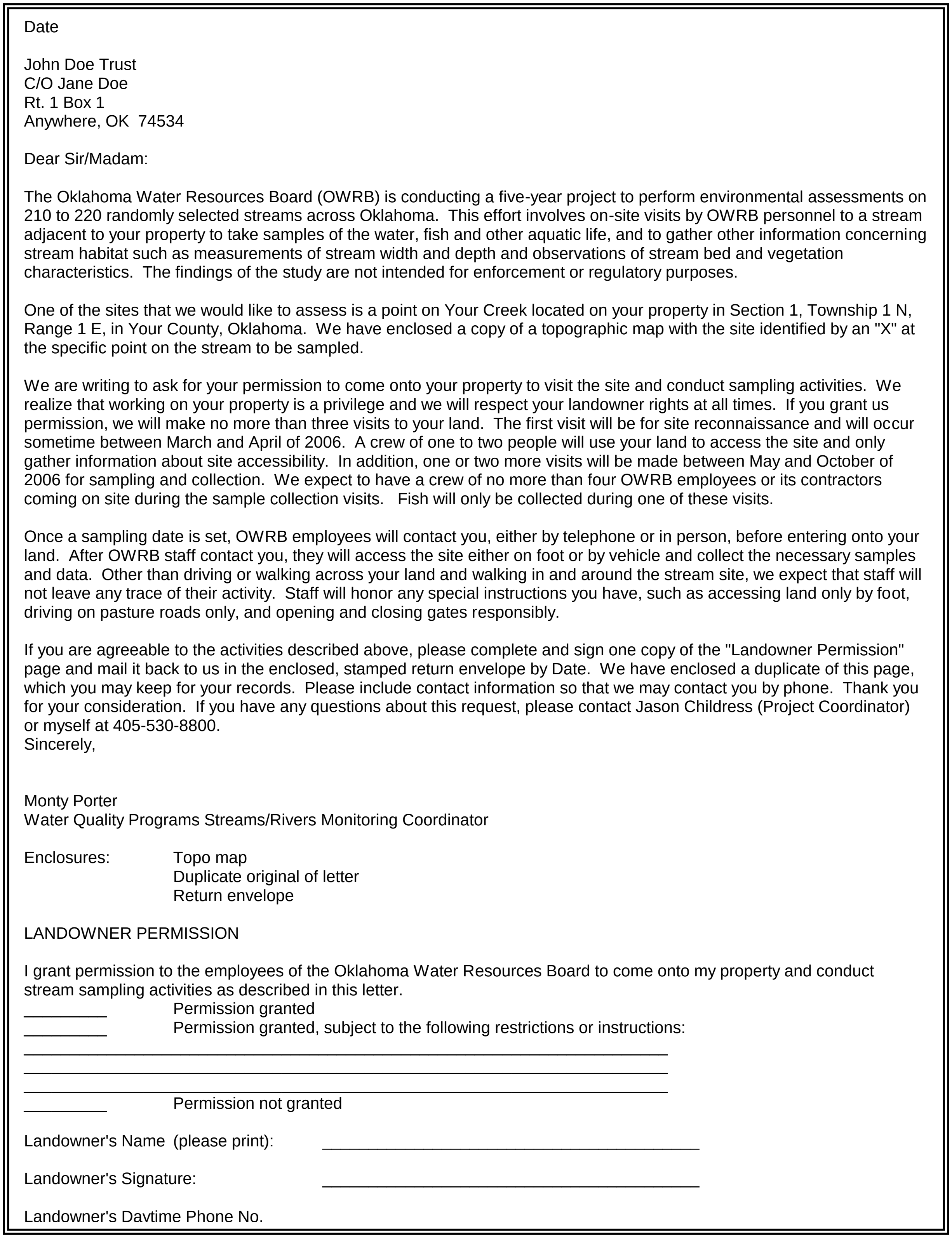
Landowner Requests:

None. You can drive down to the site if you need to.   (see attached permission letter)

Directions/Access to Site:

From Your Town, go west on SH 1 for 3.25 miles. The property is South of this point. Walk or drive across pasture to get to the X-site. (see attached maps)

Figure 1. Template site reconnaissance and tracking form used during study.



Date

John Doe Trust
C/O Jane Doe
Rt. 1 Box 1
Anywhere, OK 74534

Dear Sir/Madam:

The Oklahoma Water Resources Board (OWRB) is conducting a five-year project to perform environmental assessments on 210 to 220 randomly selected streams across Oklahoma. This effort involves on-site visits by OWRB personnel to a stream adjacent to your property to take samples of the water, fish and other aquatic life, and to gather other information concerning stream habitat such as measurements of stream width and depth and observations of stream bed and vegetation characteristics. The findings of the study are not intended for enforcement or regulatory purposes.

One of the sites that we would like to assess is a point on Your Creek located on your property in Section 1, Township 1 N, Range 1 E, in Your County, Oklahoma. We have enclosed a copy of a topographic map with the site identified by an "X" at the specific point on the stream to be sampled.

We are writing to ask for your permission to come onto your property to visit the site and conduct sampling activities. We realize that working on your property is a privilege and we will respect your landowner rights at all times. If you grant us permission, we will make no more than three visits to your land. The first visit will be for site reconnaissance and will occur sometime between March and April of 2006. A crew of one to two people will use your land to access the site and only gather information about site accessibility. In addition, one or two more visits will be made between May and October of 2006 for sampling and collection. We expect to have a crew of no more than four OWRB employees or its contractors coming on site during the sample collection visits. Fish will only be collected during one of these visits.

Once a sampling date is set, OWRB employees will contact you, either by telephone or in person, before entering onto your land. After OWRB staff contact you, they will access the site either on foot or by vehicle and collect the necessary samples and data. Other than driving or walking across your land and walking in and around the stream site, we expect that staff will not leave any trace of their activity. Staff will honor any special instructions you have, such as accessing land only by foot, driving on pasture roads only, and opening and closing gates responsibly.

If you are agreeable to the activities described above, please complete and sign one copy of the "Landowner Permission" page and mail it back to us in the enclosed, stamped return envelope by Date. We have enclosed a duplicate of this page, which you may keep for your records. Please include contact information so that we may contact you by phone. Thank you for your consideration. If you have any questions about this request, please contact Jason Childress (Project Coordinator) or myself at 405-530-8800.
Sincerely,

Monty Porter
Water Quality Programs Streams/Rivers Monitoring Coordinator

Enclosures: Topo map
Duplicate original of letter
Return envelope

LANDOWNER PERMISSION

I grant permission to the employees of the Oklahoma Water Resources Board to come onto my property and conduct stream sampling activities as described in this letter.
_________ Permission granted
_________ Permission granted, subject to the following restrictions or instructions:
____
____
____
_________ Permission not granted

Landowner's Name (please print): ____

Landowner's Signature: ____

Landowner's Daytime Phone No.

Figure 2. Template landowner permission letter used during study.

Data Collection

To assess ecological and human health, one-time collections were made for a variety of biological, chemical, and physical parameters (Table 1). When sites were verified as target, a sampling schedule was implemented. All target sites were visited once (in rare instances twice) during a late spring to late summer index period (June 1 – August 30), under base flow conditions. Collections included a comprehensive water chemistry sample and measurement of *in situ* water quality parameters, including water temperature, dissolved oxygen, pH, specific conductance, and turbidity. Additionally, biological assemblages were collected, including fish, macroinvertebrates, phytoplankton, and benthic periphyton. A comprehensive suite of physical habitat, riparian and human health influence measurements were made, as well as a variety of site observational information. In the event that a full collection could not be completed during the index period, an additional collection may have occurred for fish after May 10 or before October 15. Depending on circumstances, information was collected during the same site visit. Additionally, a winter index period was added for macroinvertebrates and water chemistry during the 2010 and 2011 sample years.

Table 1. Water quality variables included in study.

SAMPLE VARIABLES		
***In situ* Variables**		
Dissolved Oxygen (D. O.)	% D. O. Saturation	pH
Water Temperature	Specific Conductance	
Field Variables		
Nephelometric Turbidity	Total Alkalinity	Total Hardness
Instantaneous Flow	Stage	
Laboratory Variables--General Chemistry		
Total Kjeldahl Nitrogen	Ortho-Phosphorus	Total Phosphorus
*Nitrate Nitrogen	*Nitrite Nitrogen	Ammonia Nitrogen
Total Dissolved Solids—gravimetric	Chlorides	Sulfates
Total Settleable Solids	Total Suspended Solids	
Laboratory Variables—Metals		
Arsenic	Cadmium	Chromium
Copper	Lead	Mercury
Nickel	Selenium	Silver
Zinc	Thallium	Calcium
Barium	Iron	Magnesium
Potassium	Sodium	
Biological Variables		
Fish	Macroinvertebrates	Sestonic Chlorophyll-a
Habitat--Long Form	Habitat--Short Form	Benthic Chlorophyll-a

From 2008-2009, all collections strictly followed the NRSA field operations manual (USEPA, 2009a) and Quality Assurance Project Plan (USEPA, 2009b). Sample analyses for these years were provided by the NRSA contract laboratories and data/assessments for all samples and assemblages were provided by the USEPA through either their National Aquatic Resource Survey (NARS) sharefile portal (https://nars.sharefile.com/) (USEPA, 2012) or personal communication from EPA staff (Mitchell, 2013).

For study years 2010-2011, data for water quality variables was collected in one of two ways (OWRB, 2010e). Several variables (pH, dissolved oxygen, water temperature, and specific conductance) were monitored *in-situ* utilizing a Hydrolab® Minisonde or YSI® multi-probe instrument or with single parameter probes. Regardless of instrumentation and in accordance with manufacturer's specifications and/or published SOP's, all instruments (except water temperature) were calibrated at least weekly and verified daily with appropriate standards. The measurement was taken at the deepest point of the channel at a depth of at least 0.1 meters and no greater than one-half of the total depth. The data were uploaded from the instrument and saved to a data recorder, transferred manually to a field log sheet, and manually entered into the OWRB Water Quality database. Data for all other variables were amassed from water quality samples collected at the station. Grab samples were collected by one of two methods—a grab or a composite grab. The most common method employed was a grab sample, which was used in streams with a single, well-mixed channel. The sample was collected at the deepest, fastest flowing portion of the horizontal transect by completely submerging the bottle, allowing it to fill to the top, and capping the bottle underwater. Composite grabs were collected in rivers with multiple channels and were aliquotted into sample bottles using a clean splitter-churn. Each sample included three bottles for general chemistry analyses (two ice preserved and one sulfuric acid preserved), one bottle for metals analysis (nitric acid preserved), and one bottle each for field chemistry analysis and sestonic chlorophyll-a (ice preserved and kept dark). For benthic chlorophyll-a, a sample was composited, placed on ice to be preserved, and kept dark. The Oklahoma Department of Environmental Quality-State Environmental Laboratory (ODEQ-SEL) in accordance with the ODEQ's Quality Management Plan (QTRACK No. 00-182) (ODEQ, 2007) analyzed samples for most parameters listed in Table 4. OWRB personnel measured nitrogen and ortho-phosphorus using Hach® colorimeter protocols, hardness and alkalinity using Hach® titration protocols, and nephelometric turbidity using a Hach® Portable turbidometer.

Samples for algal biomass were collected in both the sestonic and benthic zones of each waterbody and processed in accordance with standard procedures outlined (OWRB, 2006b). Sestonic, or water column, samples were processed from water collected during the general water quality collection. A benthic sample was processed from a reach-wide composite. Benthic filters were extracted using an alternate method, whereby filters are placed in a standard aliquot of ethanol (25 mL) and extracted at room temperature for at least 72 hours. All chlorophyll-a samples were analyzed by the ODEQ-SEL under the previously mentioned QMP (ODEQ, 2007). Additionally, a 50-mL sample was collected from both the water column and the benthic composites for subsequent sestonic and benthic algal ID analysis. Samples were preserved with 10% formalin, wrapped with foil, and placed at 4°C.

Biological assemblages included aquatic macroinvertebrates and fish that were collected in accordance with Oklahoma's Rapid Bioassessment Protocols (RBP) (OWRB, 1999) and the OWRB's biological collection protocols (OWRB, 2010b and 2010d). Collections were completed over a 150-4000 meter reach depending on wetted width. Fish were collected during the summer index period using a pram or boat electrofishing unit depending on wadeability. The pram unit consisted of a Smith-Root 2.5 generator powered pulsator (GPP) attached to a 3000W Honda generator, and were operated with AC output current at 2-6 amps. The boat was equipped with a 9.0 GPP powered by a 9,000 Kohler generator, and operated at an AC output range of 7-20 amps. A battery powered Smith-Root backpack generator was used on rare occasions in sites with less than 1-meter average wetted width. Using two netters with ¼ inch mesh dipnets, collections were made in an upstream direction with target effort depending on reach length, site conditions, and protocol. When existing habitats existed could not be effectively electrofished, supplemental or stand-alone collections were made using 6' X 10-20' seines of ¼ inch mesh equipped with 8' brailles. Fish were processed at several intervals during each collection. The majority of fish were processed in the field, including enumeration and identification to species. Representative site voucher collections were made with a combination of appropriate photodocumentation and representative species vouchers. Fish that were not readily identifiable were fixed in 10% formalin and returned to the OWRB laboratory for identification and enumeration. Additionally, all representative voucher fish were fixed in a 10% formalin solution, subsequently preserved in 80% ethanol, and, along with photodocumentation, permanently housed in the OWRB fish collection library.

Aquatic macroinvertebrate collections were made during the summer and winter index period of each study year (OWRB, 2010d). Each sampling event included a variety of samples as defined in the OWRB's macroinvertebrate collection protocols. At wadeable sites, staff collected samples from available targeted habitats, including streamside vegetation, woody debris, and rocky riffles. The streamside vegetation and woody debris collections were semi-qualitative samples collected over flowing portions of the reach for total collection times of three and five minutes, respectively. The streamside sample was collected using a 500-micron D-frame net to agitate various types of fine structure sample including fine roots, algae, and emergent and overhanging vegetation. Likewise, the wood sample was collected using a 500-micron D-frame net to agitate, scrape, and brush wood of any size in various states of decay. Additionally, wood that could be removed from the stream was scanned for additional organisms outside the 5-minute sampling time. The riffle collection was a quantitative sample compositing three kicks representing slow, medium and fast velocity rocky riffles within the reach. Each sub-sample was collected by fully kicking one square meter into a 500-micron Zo seine. At non-wadeable sites, a large river collection protocol was used, with the sub-protocol determined by the dominant reach substrate, either fine or coarse substrate. In each protocol, the dominant substrate is sampled at each transect, and within each sub-reach, the dominant targeted habitat is sampled. The primary difference between the sub-protocols was the treatment of samples. The coarse protocol requires that all samples are processed and composited in a final collection type called large coarse-composite (LRC-Comp). While at the large river fine (LRF) sites, collections were kept separate and processed as LRF-THab (targeted habitat) and LRF-Sub (substrate) samples. At all LR sites, a riffle composite is collected, if available. All samples were field post-processed in a 500-micron sieve bucket to remove large material and silt in an effort to reduce sample size to fill no more than ¾ of a quart sample jar. Additionally, all nets and buckets were thoroughly scanned to ensure that no organisms were lost. After processing, each sample type was preserved independently in quart wide mouth polypropylene jars with ethanol and interior and exterior labels were added. Prior to taxonomic analysis, all samples were laboratory processed by study personnel to obtain a representative 100 and 300-count subsample, with a large/rare scan (OWRB, 2010d). After sorting, the subsamples were sent to the contract laboratory of record for identification and enumeration. Taxonomic data for each sample were grouped and metrics calculated by the contract laboratory. In general, most organisms were identified to genera with midges identified to tribe. The two contract laboratories used in the study were Environmental Services and Consulting (Lynchburg, VA) and Rhithron Associates (Missoula, MT).

Additionally, a detailed habitat assessment was made targeting in-stream substrate, habitat, width and depth, bank and riparian measurements, and human disturbance characteristics. The collections included both Oklahoma's semi-qualitative RBP habitat protocols (OWRB, 2010c), and the NRSA semi-quantitative habitat protocols (USEPA, 2009a). To date, the USEPA assessments have not been processed.

Discharge and/or stage data were also collected at each station (OWRB, 2005). Flow was determined through several methods including direct measurement of instantaneous discharge using a flow meter, interpolation of flow from a stage/discharge rating curve developed by the United States Geological Survey (USGS) or the OWRB, or through estimation of discharge using a float test (OWRB, 2004).

For a more detailed discussion of sampling procedures, please contact the OWRB/Water Quality Programs Division at (405) 530-8800 for copy of the BUMP Standard Operating Procedures (SOP) or visit the OWRB website at http://www.owrb.state.ok.us/quality/monitoring/monitoring.php#SOPs.

Analytical Methods

Condition classes for biotic assemblages and stressors were assigned by either the USEPA or OWRB, depending on study year. All data collected from 2008-2009 were processed and assessed by USEPA staff, excluding wadeable fish and chlorophyll-a data. All data collected from 2010-2011, as well as chlorophyll-a data from 2008-2009, were processed and assessed by OWRB staff.

Analysis of Fish Biological Condition.

Fish data were analyzed using two indices of biological integrity (IBI) commonly used in Oklahoma bioassessment studies, as well as the IBI developed by the NRSA. State biocriteria methods are outlined in Oklahoma's Use Support Assessment Protocols (OWRB, 20012b). In addition, an IBI commonly used by the OCC's Water Quality Division was used to provide an alternative bioassessment (OCC, 2005a and 2008; ODEQ, 2012). All metrics and IBI calculations were made using the OWRB's "Fish Assessment Workbook", an automated calculator OWRB staff built in Microsoft Excel (OWRB, 2012a). The NRSA condition assessments were taken from the tabular fish condition file on the USEPA's NARS sharefile site (USEPA, 2012). The multi-metric index (MMI) developed by the NRSA is described in Appendix D-3.

Oklahoma's biocriteria methodology (OKFIBI) uses a common set of metrics throughout the state (Table 2). Each metric is scored a 5, 3, or 1 depending on the calculated value, and scores are summed to reach two subcategory totals for sample composition and fish condition (OWRB, 2012b). The two subcategories are then summed for a final IBI score. The score is compared to ecoregion biocriteria to determine support status. For example, if the final IBI score is between 25-34, the status for sites in the Ouachita Mountain Ecoregion is deemed undetermined. Likewise, for scores greater than 34 and less than 25, the status is supported or not supported, respectively.

The OCCFIBI uses "a modified version of Karr's Index of Biotic Integrity (IBI) as adapted from Plafkin et al., 1989" (OCC, 2008; ODEQ, 2012). The metrics as well as the scoring system are in Table 3. Metric scores are calculated in two ways for both the test site and composite reference metric values of high-quality streams in the ecoregion (OCC 2005). Species richness values (total, sensitive benthic, sunfish, and intolerant) are compared to composite reference value to obtain a "percent of reference". A score of 5, 3, or 1 is then given the site depending on the percentages outlined in Table 6, while the reference composite is given a default score of 5. Proportional metrics (% individuals as tolerant, insectivorous cyprinids, and lithophilic spawners) are scored by comparing the base metric score for both the test site and the reference composite to the percentile ranges given in Table 3. After all metrics are scored, total scores are calculated for the test and composite reference sites. Finally, the site final score is compared to the composite reference final score and a percent of reference is obtained. The percent of reference is compared to the percentages in Table 4 and an integrity classification is assigned with scores falling between assessment ranges classified in the closest scoring group.

Fish taxonomic results for each site were analyzed to produce a raw score for the OKFIBI and a percent of reference score for the OCCFIBI. Additionally, when available, the condition class determined from the NRSA analysis was included in the evaluation. A preponderance of these assessments were used to then assign a final condition class of good, fair, and poor for each of the 3 study periods, as well as large and small streams.

Table 2. Index of biological integrity used to calculate scores for Oklahoma's biocriteria. Referenced figures may be found in OAC 785:15: Appendix C (OWRB, 2012b).

Metric	Value	Scoring 5	Scoring 3	Scoring 1	Score
Total # of species		fig 1	fig 1	fig 1	
Shannon's Diversity based upon numbers		>2.50	2.49-1.50	<1.50	
# of sunfish species		>3	2 to 3	<2	
# of species comprising 75% of sample		>5	3 to 4	<3	
Number of intolerant species		fig 2	fig 2	fig 2	
Percentage of tolerant species		fig 3	fig 3	fig 3	
TOTAL SCORE FOR SAMPLE COMPOSITION					0
Percentage of lithophils		>36	18 to 36	<18	
Percentage of DELT anomalies		<0.1	0.1-1.3	>1.3	
Total individuals		>200	75 to 200	<75	
TOTAL SCORE FOR FISH CONDITION					0
TOTAL SCORE					0

Table 3. Metrics and scoring criteria used in the calculation of OCC's index of biological integrity (OCC, 2008; ODEQ, 2012).

Metrics	5	3	1
Number of species	>67%	33-67%	<33%
Number of sensitive benthic species	>67%	33-67%	<33%
Number of sunfish species	>67%	33-67%	<33%
Number of intolerant species	>67%	33-67%	<33%
Proportion tolerant individuals	<10%	10-25%	>25%
Proportion insectivorous cyprinid individuals	>45%	20-45%	<20%
Proportion individuals as lithophilic spawners	>36%	18-36%	<18%

Table 4. Integrity classification scores and descriptions used with OCC's index of biological integrity (OCC, 2008; ODEQ, 2012).

% Comparison to the Reference Score	Integrity Class	Characteristics
>97%	Excellent	Comparable to pristine conditions, exceptional species assemblage
80 - 87%	Good	Decreased species richness, especially intolerant species
67 - 73%	Fair	Intolerant and sensitive species rare or absent
47 - 57%	Poor	Top carnivores and many expected species absent or rare; omnivores and tolerant species dominant
26 - 37%	Very Poor	Few species and individuals present; tolerant species dominant; diseased fish frequent

Analysis of Macroinvertebrate Biological Condition

Macroinvertebrate data were analyzed using a Benthic-IBI (B-IBI) developed for Oklahoma benthic communities (OCC, 2005a) and commonly used by the OCC and OWRB Water Quality Division (OCC, 2008; OWRB, 2009 and 2010a; ODEQ, 2012), as well as the IBI developed by the NRSA. The metrics and scoring criteria (Table 5) are taken from the original “Rapid Bioassessment Protocols for Use in Streams and Rivers” (Plafkin et al., 1989) with slight modifications to the EPT/Total and Shannon-Weaver tolerance metrics (OCC, 2008). Metrics were calculated by OWRB contractors and IBI calculations were made using the OWRB’s “B-IBI Assessment Workbook v. 3.0”, an automated calculator built by OWRB Staff in Microsoft Excel (OWRB, 2012a). The NRSA condition assessments were taken from the tabular macroinvertebrate condition file on the USEPA’s NARS sharefile site (USEPA, 2012). The IBI developed by the NRSA is described in Appendix D-4.

Calculation of the B-IBI is similar to the fish OCC-IBI discussed previously. Metric scores are calculated in two ways for both the test site and the composite reference metric values of high-quality streams in each ecoregion (OCC, 2008). Species richness (total and EPT) and modified HBI values are compared to the composite reference value to obtain a “percent of reference”. A score of 6, 4, 2 or 0 is then given the site depending on the percentages outlined in Table 5, while the reference composite is given a default score of 6. Proportional metrics (% dominant 2 taxa and %EPT of total) as well as the Shannon-Weaver Diversity Index are scored by comparing the base metric score for both the test site and the reference composite to the percentile ranges given in Table 5. After all metrics are scored, total scores are calculated for the test and composite reference sites. The site final score is then compared to the composite reference final score and a percent of reference is obtained. The percent of reference is compared to the percentages in Table 6 and an integrity classification is assigned with scores falling between assessment ranges classified in the closest scoring group.

Macroinvertebrate taxonomic results for each site were analyzed to produce a percent of reference score for the OKBIBI. From these scores, biological integrity classifications were assigned. For NRSA sites, the condition classification assigned by the NRSA was used because the samples were processed as 500 individual sub-samples. Instead of rarifying samples to a 100 individual sub-sample to allow use in Oklahoma’s B-IBI, it was decided that using NRSA condition assignments was more defensible and efficacious for final data analyses. Furthermore, the NRSA IBI was used to assign condition classes for large rivers that were too large to be processed through Oklahoma B-IBI. These samples were compared to national reference metrics and screening limits developed for the NRSA.

Table 5. Metrics and scoring criteria used in the calculation of the B-IBI (OCC, 2008; ODEQ, 2012).

B-IBI Metrics	6	4	2	0
Taxa Richness	>80%	60-80%	40-60%	<40%
Modified HBI	>85%	70-85%	50-70%	<50%
EPT/Total	>30%	20-30%	10-20%	<10%
EPT Taxa	>90%	80-90%	70-80%	<70%
% Dominant 2 Taxa	<20%	20-30%	30-40%	>40%
Shannon-Weaver Diversity Index	>3.5	2.5-3.5	1.5-2.5	<1.5

Table 6. Integrity classification scores and descriptions used with the B-IBI (OCC, 2008; ODEQ 2012).

% Comparison to the Reference Score	Biological Condition	Characteristics
>83%	Non-impaired	Comparable to the best situation expected in that ecoregion; balanced trophic and community structure for stream size
54 - 79%	Slightly Impaired	Community structure and species richness less than expected; percent contribution of tolerant forms increased and loss of some intolerant species
21 - 50%	Moderately Impaired	Fewer species due to loss of most intolerant forms; reduction in EPT index
<17%	Severely Impaired	Few species present; may have high densities of 1 or 2 taxa

Analysis of Algal Biomass

Algae are important in aquatic ecology acting as an important primary producer in aquatic food webs providing a food source for a wide variety of fish and macroinvertebrates. Furthermore, algae are indispensable producers of oxygen for aquatic organisms. However, algal blooms are also an important indicator of water quality perturbance and nutrient productivity. Introduction of nutrients to waterbodies occurs through a number of sources including runoff from urban and agricultural areas, wastewater treatment discharges, and a variety of other sources. As nutrient concentrations increase, uptake by primary producers increases and leads to algal blooms, as well as an increased standing crop. As eutrophication happens, aquatic life and human health beneficial uses can become impaired, as well as the aesthetic and recreational appeal of waterbodies being drastically reduced.

In order to quantify eutrophication, algal biomass was measured in both the benthic (i.e., periphyton) and water column (i.e., sestonic) areas of all study streams. Various measures exist to determine algal biomass including chlorophyll-a and ash free dry mass. For this study, chlorophyll-a concentrations were calculated because the Oklahoma Water Quality Standards (OWQS) (OWRB, 2012c) provides screening levels for both periphyton and sestonic chlorophyll-a.

To estimate condition of algal biomass, chlorophyll-a concentrations were compared to several screening levels. For benthic chlorophyll-a, several screening levels were used. First, Oklahoma's Use Support Assessment Protocol (USAP) (OWRB, 2012b) provides a screening level for periphyton chlorophyll-a in the aesthetic beneficial use. A value of 100 mg/m^2 represents a nuisance level for periphyton algae, and was used as the cut-point for poor-fair condition. Second, the OWRB has collected periphyton chlorophyll-a across the state for several programs throughout the years. To provide an alternate screening level, the 25th percentile of all OWRB benthic data were calculated at 45.7 mg/m^2, which was used as the cut-point for fair-good condition. Similarly, several screening levels were established for sestonic chlorophyll-a. The OWQS- includes a standard for sensitive water supplies of 10 mg/m^3 (SesChl10) of chlorophyll-a (OWRB, 2012c), which was set as the fair-good cut-point for condition assessment. Additionally, to establish the cut-point for the poor-fair condition, the distribution of all OWRB sestonic chlorophyll-a data were considered as a screening level (OWRB, 2009). The mean of all concentrations calculates at 19 mg/m^3 and was set as the poor-fair cut-point for sestonic chlorophyll-a analyses.

Stressor Methodology

During each visit a number of physical and water quality parameters were collected. These included nutrients, *in situ* measurements, metals, and salinity. Each of these may have some effect on the conditions analyzed in the previous results section. This effect can lead to decreased biological integrity (e.g., the effect of nutrients on fish condition) or may be responsible for the increase in a negative condition (e.g., the effect of total phosphorus on algal biomass concentration). Quantifying stressor extent is important for a variety of reasons including development and refinement of water quality screening levels and criteria, location of hotspots, and understanding the cause and effect relationship between stressors and indicators of biological integrity and human health concerns. Stressor descriptions are given in Table 7. The final stressor methodology for chemistry is detailed in Appendix D-5.

Table 7. Descriptions of stressors affecting biological condition.

Stressor Description	Stressor (code)	Source
Total nitrogen SL from the National Rivers and Streams Assessment (NRSA)	TN_NRSA	USEPA
Total nitrogen SL from USEPA's regional nutrient criteria development	TN_ECO	USEPA
Total phosphorus SL from the NRSA	TP_NRSA	USEPA
Total phosphorus SL from USEPA's regional nutrient criteria development	TP_ECO	USEPA
Conductivity SL from the NRSA	Cond_NRSA	USEPA
Conductivity SL based on regional OWRB historical data	Cond_ECO	USEPA
Turbidity SL from USEPA's regional nutrient criteria development	Turb_ECO	USEPA
Sediment based on sediment metric from NRSA and combination of %loose bed material, % embeddedness, and % deep pools from Oklahoma’s Rapid Bioassessment	Excess_Sed	USEPA/ OWRB
Instream cover assessment from the NRSA	InstCov	USEPA
Riparian vegetation cover from the NRSA	RipVegCov	USEPA
Metals chronic criteria for fish/wildlife propagation beneficial use housed in App. G, Table 2 of OWQS	XxChronic	OWRB

Nutrient stressors include measures of total phosphorus and total nitrogen (nitrate + nitrite + total Kjeldahl nitrogen). For comparison, two sources were used to determine screening levels for each parameter giving a variety of nutrient levels based upon stream characteristics and/or regional variation (Table 7). First, regional nutrient criteria were developed based on Omernik Level III ecoregions. The lower ender thresholds represent the 25th percentile of data from a variety of sources (USEPA, 2000a, 2000b, 2001a, 2001b; OWRB, 2009), while the upper end thresholds were developed from OCC regional monitoring data (OCC, 2005b, 2006a, 2006b, 2007, 2008). Second, the NRSA developed nutrient thresholds at a Level II ecoregion scale as described in Appendix D-5. The nutrient cut-point thresholds are in Table 8.

Additionally, both salinity and turbidity were evaluated as water quality stressors and are described in Table 7. Conductivity was used as a surrogate for salinity and several sources including both the USEPA regional criteria development (USEPA, 2000a, 2000b, 2001a, 2001b) and regional screening limits developed for Oklahoma’s original statewide assessment (OWRB, 2009). Turbidity screening levels were only based on the USEPA regional criteria development reports. The cut-points for conductivity and turbidity are provided in Table 9.

Numerical criteria for metals are housed in Appendix G, Table 2 of the OWQS (OWRB, 2012c). The OWQS provides criteria for a number of metals but only cadmium, copper, lead, selenium, and zinc are considered in this study. These analytes have both ecological and human health significance and appear more regularly in Oklahoma's Integrated Report as causes of impairment (ODEQ, 2012c). No other metals showed any level of potential impairment in the study. To facilitate analysis, dissolved metals concentrations were compared to dissolved chronic criterion.

Sedimentation was analyzed as a potential stressor to biological condition by using a combination of the state rule and NRSA condition assessments. For sites monitored as part of the NRSA, the sedimentation assessments were taken from the tabular habitat condition file on the USEPA's NARS sharefile site (USEPA, 2012), and the NARS methodology is described in Appendix D-2. For sites monitored in 2010-2011, metrics were calculated based on results from Oklahoma's Rapid Bioassessment Protocol (OWRB, 1999, 2010c, 2012b). The assessment consists of a variety of measures including flow, stream width and depth, substrates, embeddedness, habitat classification (i.e., pool, run, and riffle), fish cover, presence of point bars, erosion, and riparian structure. Metrics are scored based on predetermined ranges and a total score is obtained. Oklahoma's USAP (OWRB, 2012b) contains a protocol for determining sedimentation based upon loose bottom substrates (%LBS), embeddedness (%Emb), and presence of deep pools (%DP). Screening levels for sedimentation metrics are determined by comparing final site scores to a percent of reference condition. The reference condition is derived from the habitat scores for ecoregion based high quality sites developed by the OCC (2005a). For the most part, all high quality sites in an Omernik Level III ecoregion were used to develop reference condition. However, in certain ecoregions, some Omernik Level IV ecoregions were broken out from the whole. Omernik Level IV ecoregions used are the Broken Red Plains and Cross Timbers Transition of the Central Great Plains and the Arbuckle Uplift of the Cross Timbers. Additionally, the reference condition used is separated by aquatic life tier, and sites used to determine reference condition are required to be within 2 Strahler orders of the test stream. Finally, the cut-points for poor-fair-good are based on pre-determined percent of reference for each metric, with 2 or 3 metrics deemed to be fair or poor, respectively. Additionally, both instream cover and riparian vegetative cover were also evaluated as part of the NRSA. These stressors are included in the analysis of NRSA sites.

Statistical Methods

The processing of data for relative extent, relative risk, and attributable risk values were accomplished with R-statistical Software (R Foundation, 2013) using R-scripts developed for the NARS program (Van Sickle, 2012). Adjusted site weights were calculated and provided by the USEPA (Kincaid, 2013). Other analyses were performed using Minitab statistical software (Minitab, 2013). References to ecoregions throughout this document refer to those published by USEPA (Omernik, 1987; Woods et al., 2005).

Table 8. Ecoregion screening levels used as good/fair/poor cut-points for nutrient stressor analyses (Appendix D-5) (OWRB, 2009).

Ecoregion	TN _NRSA Poor_Fair (mg/L)	TN _NRSA Fair_Good (mg/L)	TN _ECO Poor_Fair (mg/L)	TN _ECO Fair_Good (mg/L)	TP _NRSA Poor_Fair (mg/L)	TP _NRSA Fair_Good (mg/L)	TP _ECO Poor_Fair (mg/L)	TP _ECO Fair_Good (mg/L)
Southwest Tablelands	1.570	0.698	1.050	0.450	0.095	0.052	0.055	0.025
Central Great Plains	1.570	0.698	1.600	0.840	0.095	0.052	0.130	0.090
Cross Timbers	1.570	0.698	0.900	0.680	0.095	0.052	0.110	0.038
Arbuckle Uplift	1.570	0.698	1.500	0.680	0.095	0.052	0.050	0.038
South Central Plains	2.078	1.092	0.750	0.385	0.108	0.056	0.070	0.050
Ouachita Mountains	0.535	0.296	0.450	0.300	0.024	0.018	0.025	0.010
Arkansas Valley	0.535	0.296	0.683	0.270	0.024	0.018	0.060	0.043
Ozark Highlands	0.535	0.296	1.500	0.379	0.024	0.018	0.070	0.007
Central Irregular Plains	3.210	1.750	1.150	0.712	0.338	0.165	0.160	0.093

Table 9. Ecoregion screening levels used as good/fair/poor cut-points for conductivity and turbidity stressor analyses. (Appendix D-5) (OWRB, 2009)

Ecoregion	Cond _NRSA Poor_Fair (uS/cm2)	Cond _NRSA Fair_Good (uS/cm2)	Cond _ECO Poor_Fair (uS/cm2)	Cond _ECO Fair_Good (uS/cm2)	Turb _ECO Poor_Fair (NTU)	Turb _ECO Fair_Good (NTU)
Southwest Tablelands	2000	1000	2300	1000	20	12
Central Great Plains	2000	1000	2925	1000	45	22
Cross Timbers	2000	1000	1000	550	40	4
Arbuckle Uplift	2000	1000	1000	500	7	4
South Central Plains	1000	500	500	180	20	10
Ouachita Mountains	1000	500	500	65	10	5
Arkansas Valley	1000	500	500	160	20	7
Ozark Highlands	1000	500	500	285	5	2
Central Irregular Plains	2000	1000	1000	450	40	16

RESULTS—EXTENT AND CONDITION ESTIMATES

Site Evaluation

For the study, a total of 177 randomly chosen sites were evaluated as candidate target sites, representing a total of 36,003 stream miles. Stream miles determined to be target, or sampleable, varied per study period (Figures 3-5). The total sampleable stream miles assessed per study period breaks down as follows:

- 21,019 miles for study period 2008-2011
- 25,466 miles for study period 2008-2009
- 15,572 miles for study period 2010-2011

The dramatic variation between the initial and subsequent 2-year study periods is obviously the number of rejected sites during the evaluation process. Although access denials increased between the study periods, the percentage of dry stream miles evaluated increased by over 300% from 3,094 to 10,605 evaluated miles, accounting for the dramatic decrease in assessed stream miles from reporting period to reporting period. Inaccessible and impounded miles were nearly equivalent across study periods. Furthermore, Figures 6 and 7 show a breakdown between large and small streams. Notably, small stream miles outnumbered large stream miles nearly 3.5:1, the majority of accessibility issues occurred in small streams.

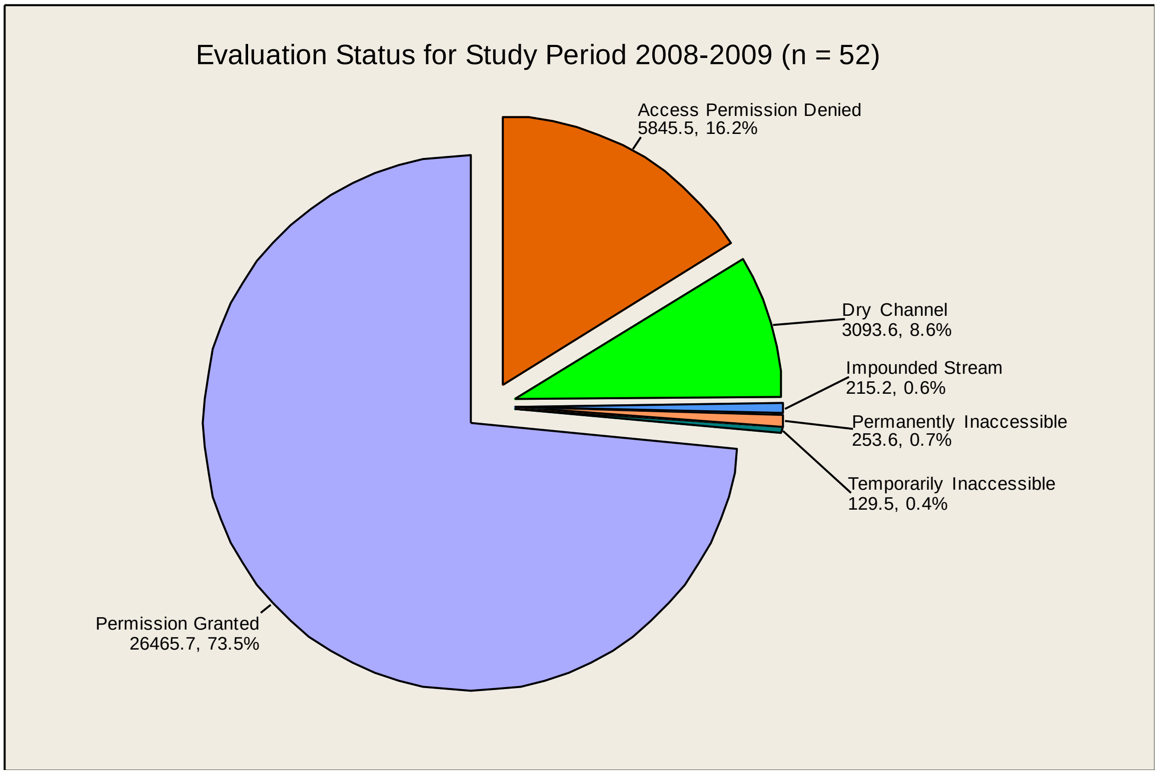


Figure 3. Site evaluation status for study period 2008-2009 (total miles = 36,003).

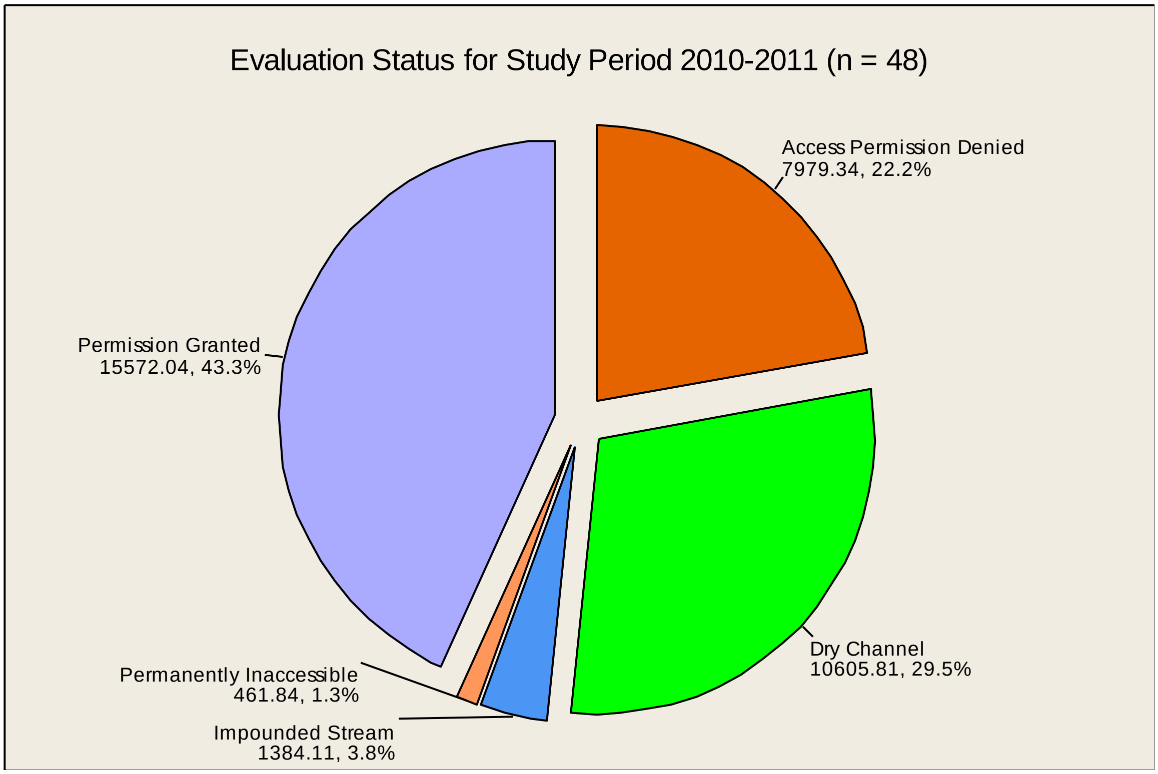


Figure 4. Site evaluation status for study period 2010-2011 (total miles = 36,003).

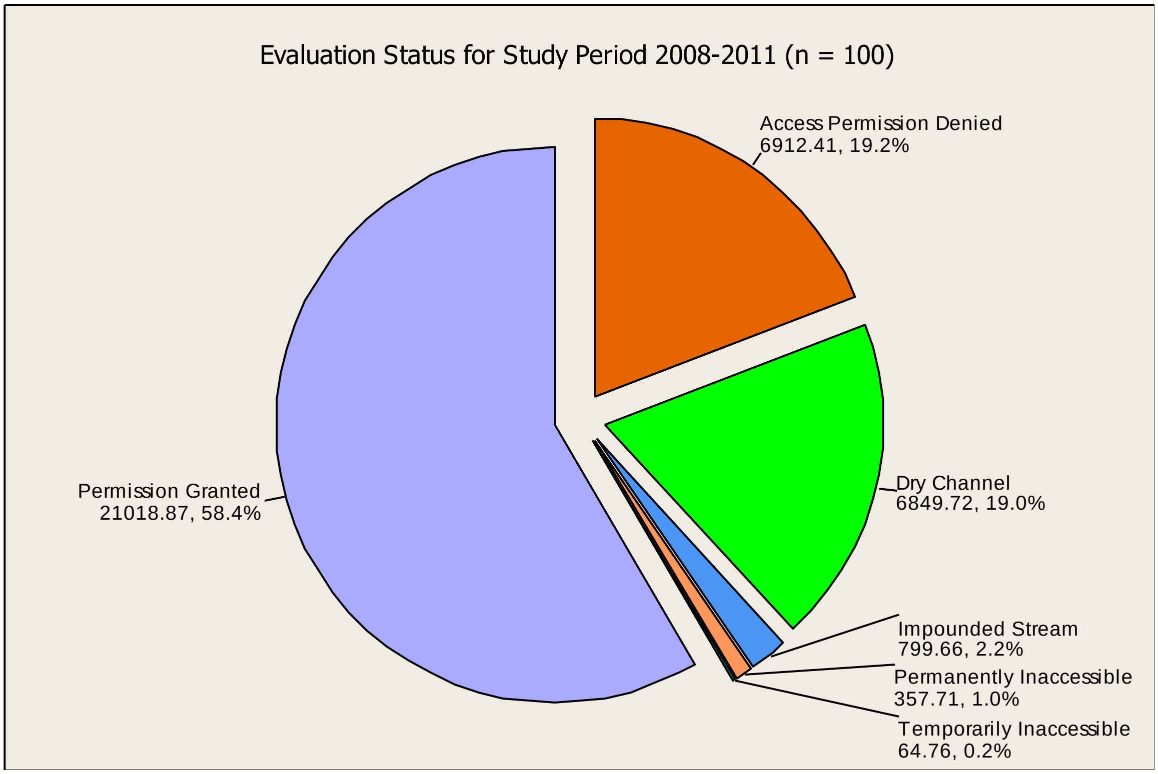


Figure 5. Site evaluation status for study period 2008-2011 (total miles = 36,003).

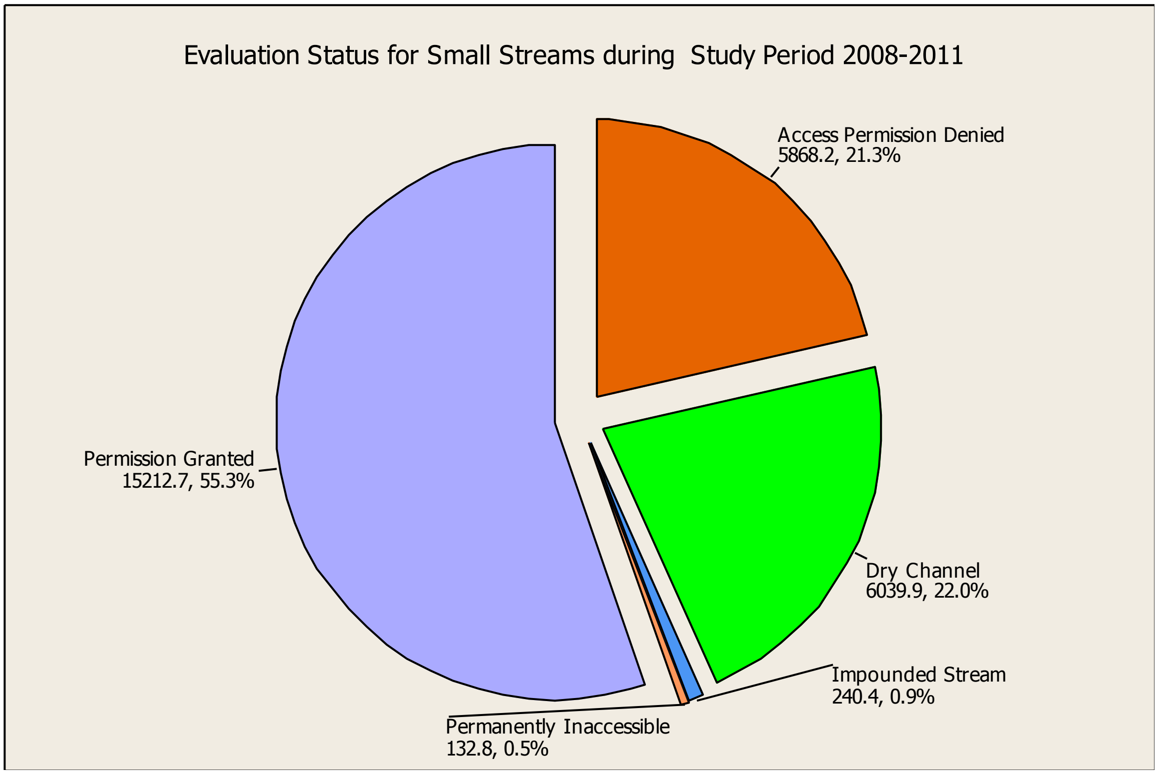


Figure 6. Site evaluation status for small streams from 2008-2011 (total miles = 27,494).

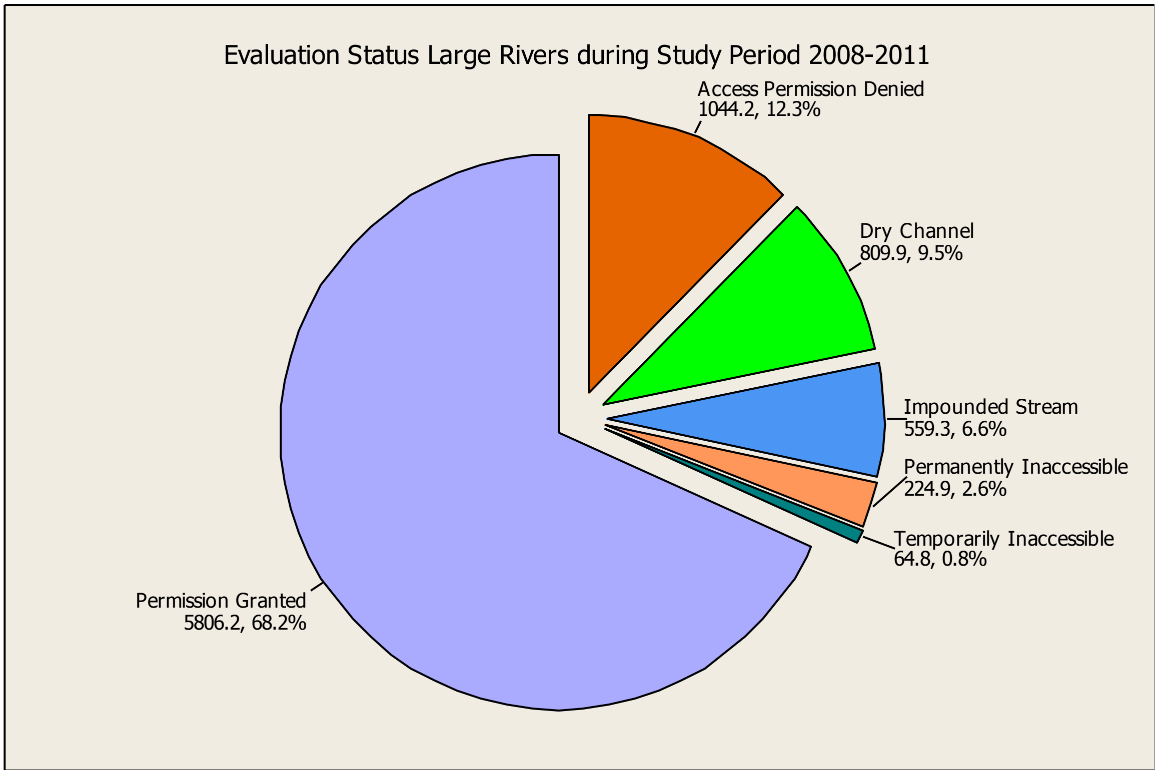


Figure 7. Site evaluation status for large streams from 2008-2011 (total miles = 8,509).

Biological Indicator Condition Extent

Statewide condition extent estimates were made for benthic macroinvertebrates, fish, phytoplankton (sestonic algae) at two levels, and periphyton. For each biotic assemblage, the indicator condition was categorized as good, fair, or poor based on methodology described in the "Methods" section, and percentages for each condition category are based on "percent of total miles". In Figures 8-9, good/fair/poor estimates are grouped for each indicator by both study periods and size. In Figures10-14, study periods and size classifications for each indicator are also depicted ungrouped with standard error for each classification.

For both fish and macroinvertebrates, nearly 35% of stream miles were classified in poor condition over the 4-year study period. Also, for both indicators, the poor category increased to greater than 40% from 2008-2009 and decreased to less than 25% from 2010-2011. A notable difference between the indicators is the higher percentage of stream miles in fair condition as opposed to good condition. For all study periods, the percentages of stream miles in fair condition are greater than 40% for macroinvertebrates and less than 10% for fish. When considering stream size, a greater percentage of large river stream miles are in poor condition than small streams. For benthic macroinvertebrates, nearly 65% of large river miles are in poor condition, with approximately 20% in fair or good condition. Conversely, in small streams, approximately 25% of stream miles are poor or good condition, while nearly 50% are in fair condition. Likewise, for fish, nearly 50% of large river miles are in poor condition and nearly 35% in good condition. In small streams, greater than 75% of miles are in good condition, while approximately 30% are in poor condition.

A relative small percentage of miles are classified in poor condition for benthic algae. For the 4-year study period, approximately 10% of miles are in poor condition, with greater than 75% of miles in good condition. In 2008-2009, the percentage in poor condition decreases to less than 5%, while the percentage in good condition increases to nearly 85%. However, in 2010-2011, the percentage in poor condition nearly doubles to greater than 20%, with greater than 65% in good condition. As with fish and macroinvertebrates, a greater percentage of large rivers (22%) than small streams (6%) are in poor condition.

For phytoplankton, or sestonic algae, the percentage of streams in poor condition across study years varies from nearly 20% (2008-2009) to nearly 30% from 2010-2011. The percent in good condition is approximately 55% for all study periods. Conversely, stream size varies significantly for poor and good condition. Approximately 60% of large river miles are in poor condition as compared less than 10% of small river miles. Conversely, less than 20% of large river miles are in good condition for sestonic algae, while nearly 70% of small river miles are considered in good condition.

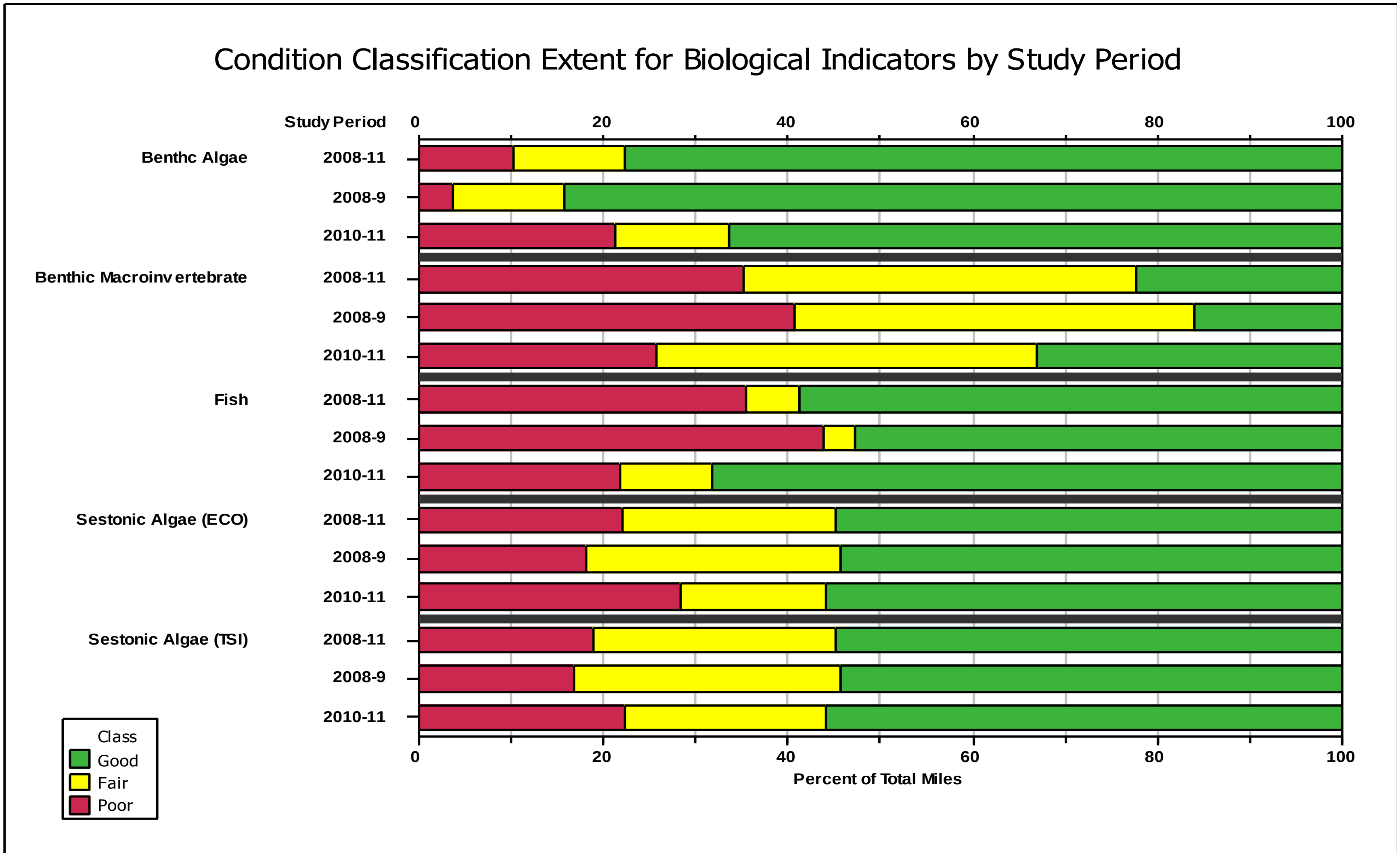


Figure 8. Stacked percentages of condition class estimates for study periods grouped by biological indicators.

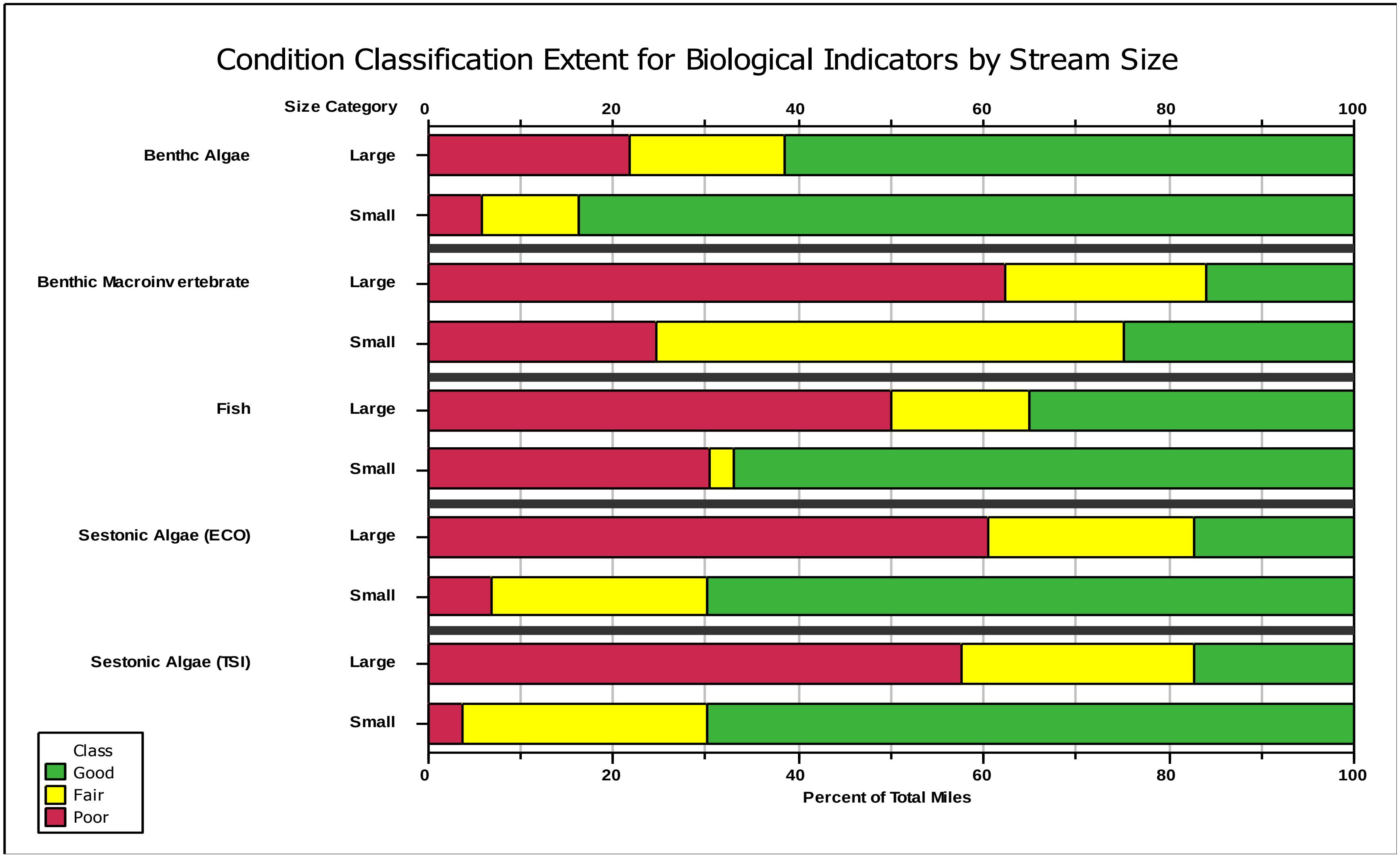


Figure 9. Stacked percentages of condition class estimates for stream size grouped by biological indicators.

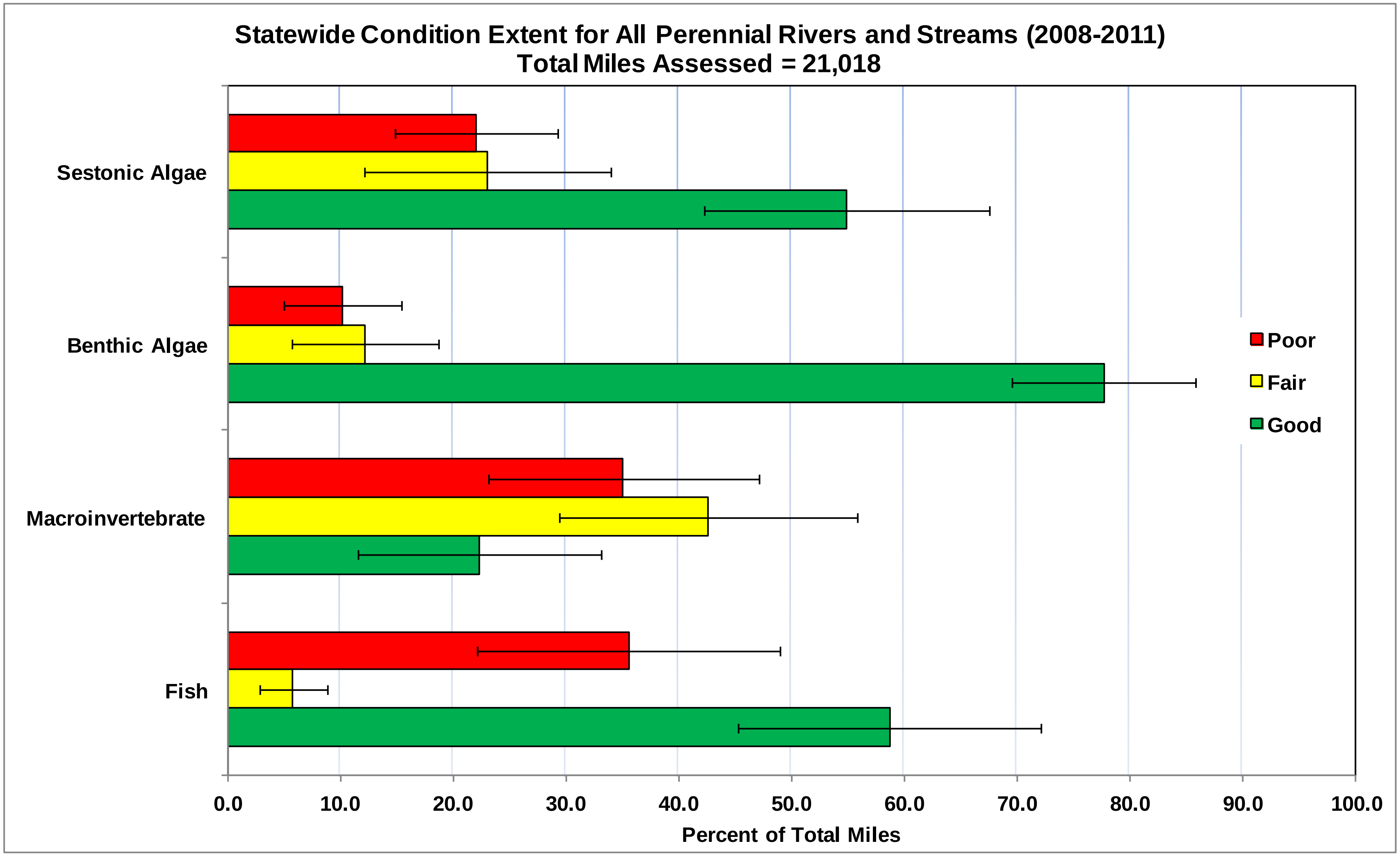


Figure 10. Biological indicator condition extent estimated statewide from 2008-2011. Upper and lower bounds represent a 95% confidence interval.

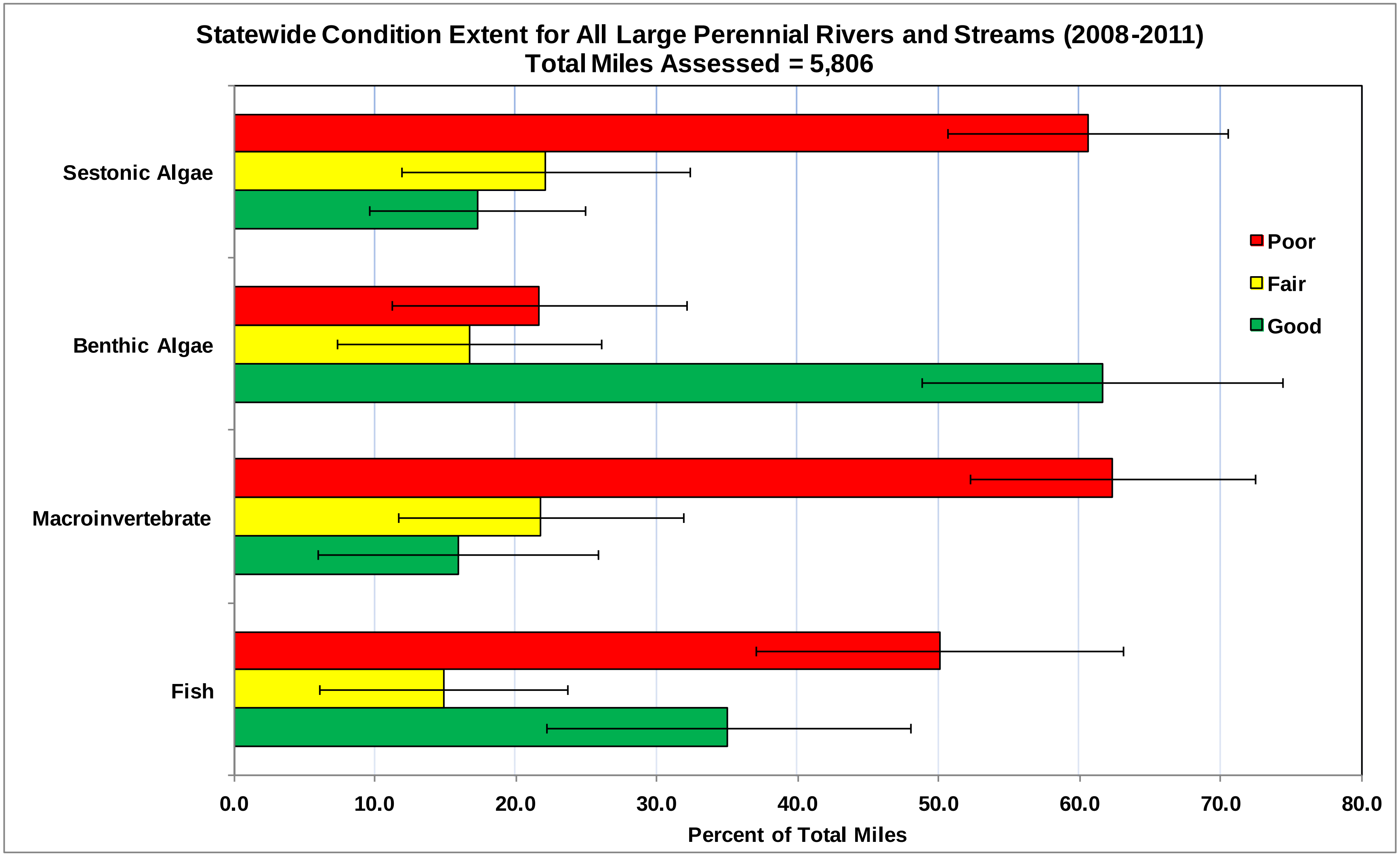


Figure 11. Biological indicator condition extent estimated statewide for larger streams and rivers (Strahler Order > 4) from 2008-2011. Upper and lower bounds represent a 95% confidence interval.

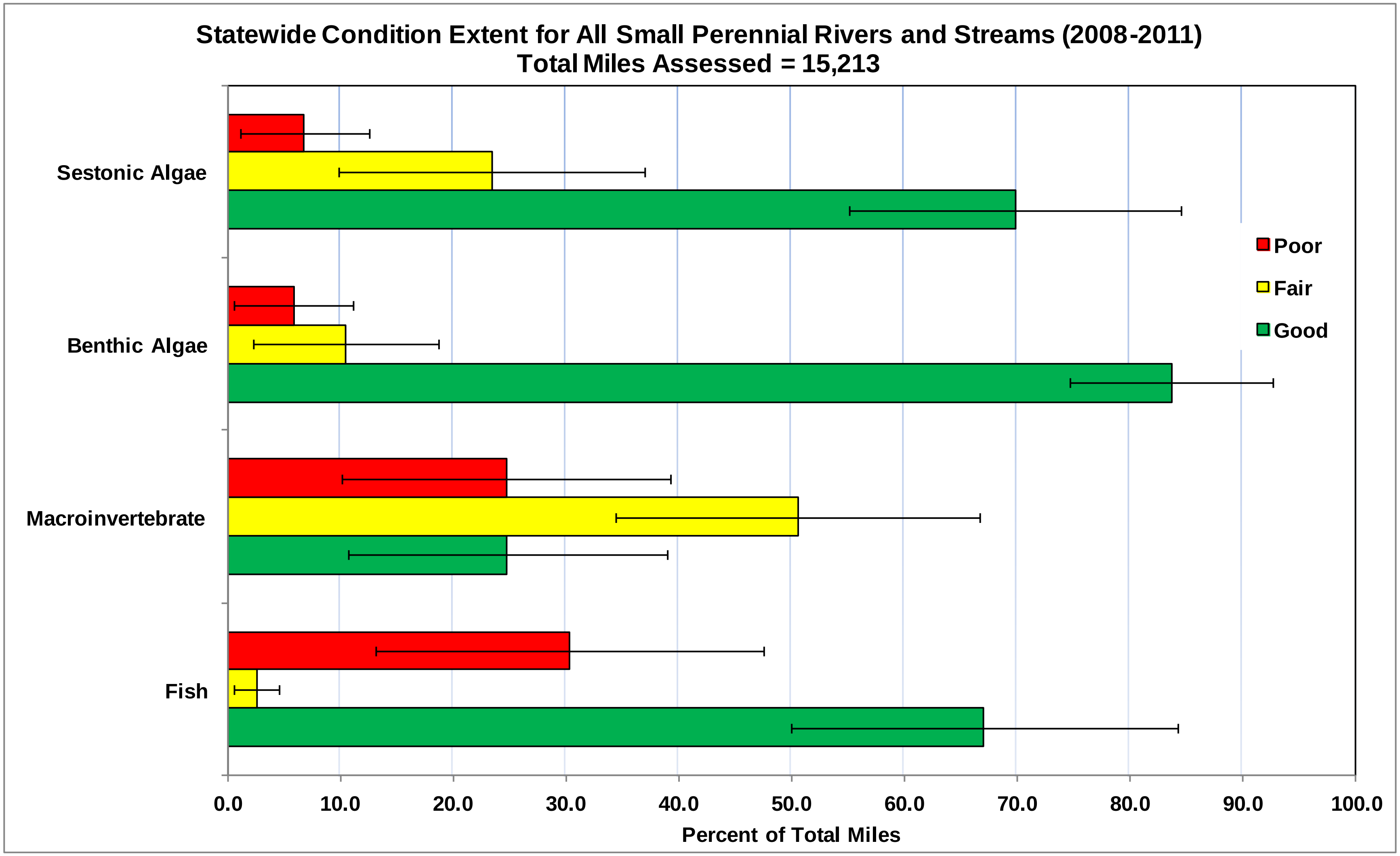


Figure 12. Biological indicator condition extent estimated statewide for smaller streams and rivers (Strahler Order < 5) from 2008-2011. Upper and lower bounds represent a 95% confidence interval.

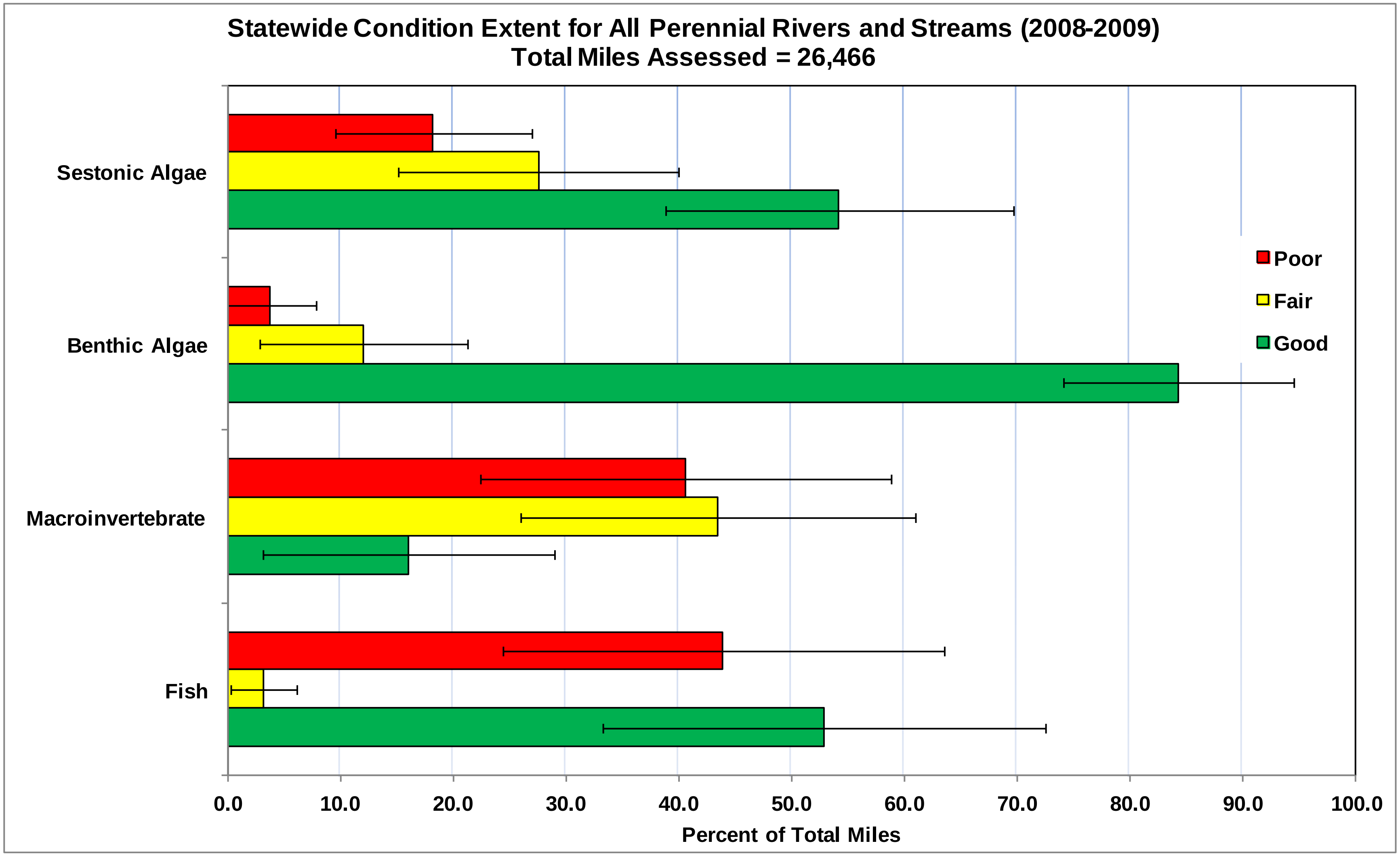


Figure 13. Biological indicator condition extent estimated statewide from 2008-2009. Upper and lower bounds represent a 95% confidence interval.

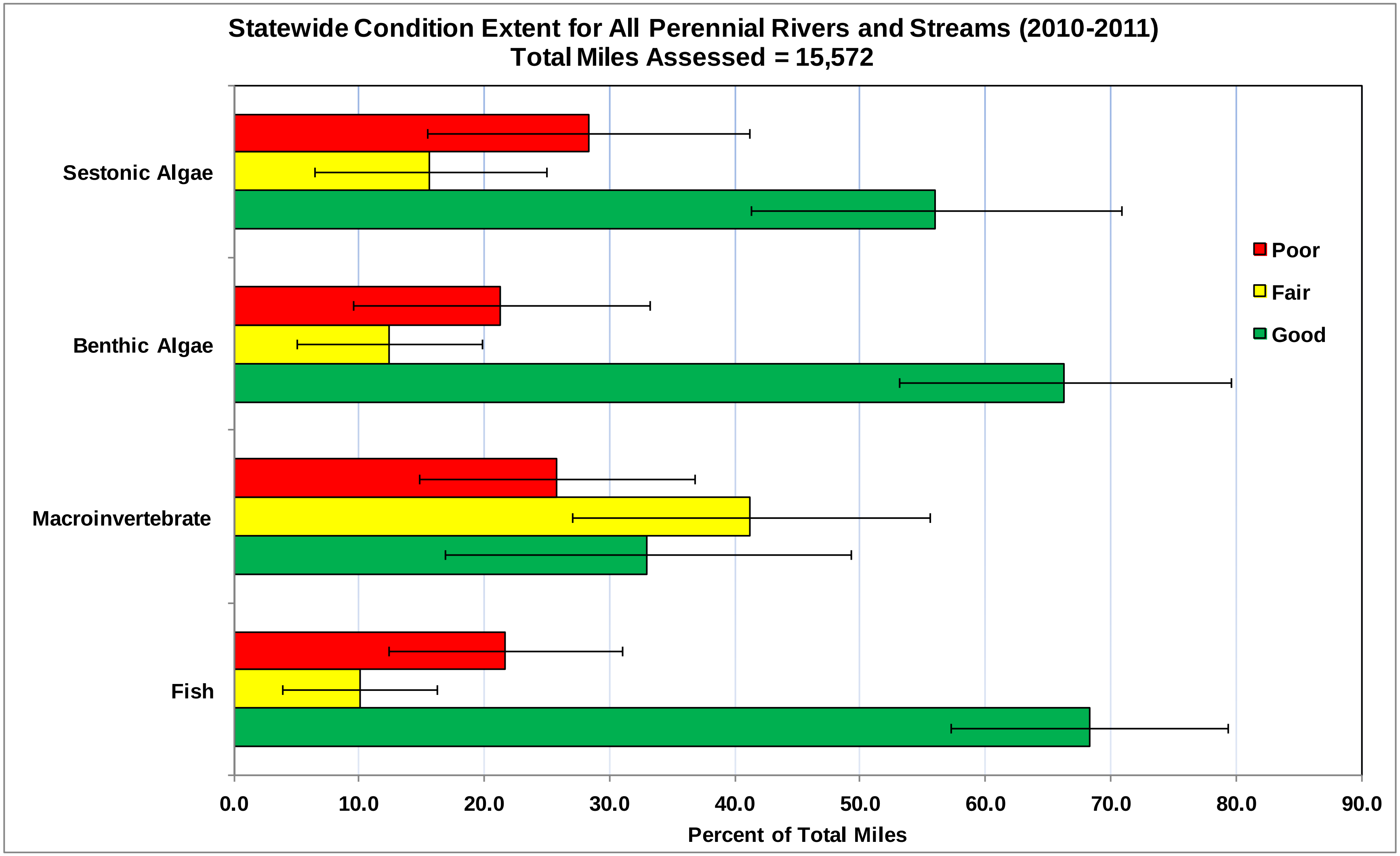


Figure 14. Biological indicator condition extent estimated statewide from 2010-2011. Upper and lower bounds represent a 95% confidence interval.

Stressor Extent

Statewide condition extent estimates were made for total nitrogen, conductivity, turbidity, metal toxicity, sedimentation, and instream and vegetative cover. Estimates employed a variety of NRSA and Omernick level III ecoregion screening levels. For each stressor except metals toxicity, the condition was categorized as good, fair, or poor based on methodology described in the “Methods” section, and percentages for each condition category are based on “percent of total miles”.

In Figures 15-16, good/fair/poor estimates for nutrients, conductivity and turbidity are grouped for each stressor by both study periods and size. In Figures 17-21, study periods and size classifications for each indicator are also depicted ungrouped with standard error for each classification. Phosphorus extent in poor condition is generally 30-40%, regardless of study period or source of screening limit, while the percent of total miles in good condition ranges from 40-50%. Generally, poor condition is lower for the NRSA screening limits, but is not significantly different. When considering stream size, large streams (approximately 75%) have a significantly higher percentage of miles in poor condition than small streams (10-25%). For total nitrogen, the difference between the sources of screening limits and study periods are more dramatic, but still not significantly different. For the NRSA screening limit, the percent of miles in poor condition ranges from less than 15% from 2008-2009, as opposed to nearly 25% from 2010-2011. For all study periods, good condition is greater than 50%. A similar pattern is evident with the ecoregion screening limit, with poor condition ranging from 25% (2008-2009) to nearly 40% from 2010-2011, and good condition ranging from nearly 50% to as low as approximately 25% during the same periods. Unlike total phosphorus, stream size is not significant when considering percent of miles in poor condition, with large ranging from 30-40% and small from 10-25%. However, the percent in good condition is significantly different with size. Large rivers range from 15-25%, with small streams ranging from 55-65% in good condition. Conductivity is generally not significantly different between study periods or sources of screening limits. Poor condition ranges from 10-20% from 2008-2009, and increases approximately 22% in the 2010-2011 study period. For the NRSA values, good condition is ranges from 60-65%, regardless of period. However, when using ecoregion screening limits, good condition during the 2010-2011 period shows a significant decrease to approximately 25%, while the 2008-2009 period is approximately 55%. As with nutrients, condition is significantly different when comparing streams to rivers. The percent of river miles in poor condition ranges from 40-55%, while streams are approximately 5% for both screening limits. Conversely, the percent of stream miles in good condition ranges from 55% to 80%, as opposed to 15-30% in large rivers. For turbidity, period is not significant, with poor condition ranging from 10-30%, and good at 30-35% for both periods. However, the percent of river miles (37%) in poor condition is significantly different from small streams (9%). The percentage in good condition is much closer with nearly 30% in large rivers and 35% in small streams.

The extent of various habitat stressors is depicted in Figure 22. Instream and riparian vegetative cover are considered for only the 2008-2009 period, with no delineation between waterbody sizes. Poor condition ranges from 5% for riparian to 15% for instream cover. Good condition is 65-70% for both. Excess sedimentation is not significantly different when considering waterbody size. Poor condition ranges from greater than 25% in streams to 35% in rivers, with the percent in good condition at nearly 35% in both. Study period is significantly different, with poor condition ranging from 15% (2008-2009) to greater than 50% from 2010-2011. Good condition is not significantly different, but does range from less than 20% (2010-2011) to greater than 50% in 2008-2009 study period. The percent of miles in fair condition is ranges from 30-40%, regardless of study period.

Finally, the extent of metals toxicity is represented in Figure 23. Miles in poor condition generally ranges from 10-15%. While no stressors are significantly different, more miles appear to be affected by selenium than any other metal.

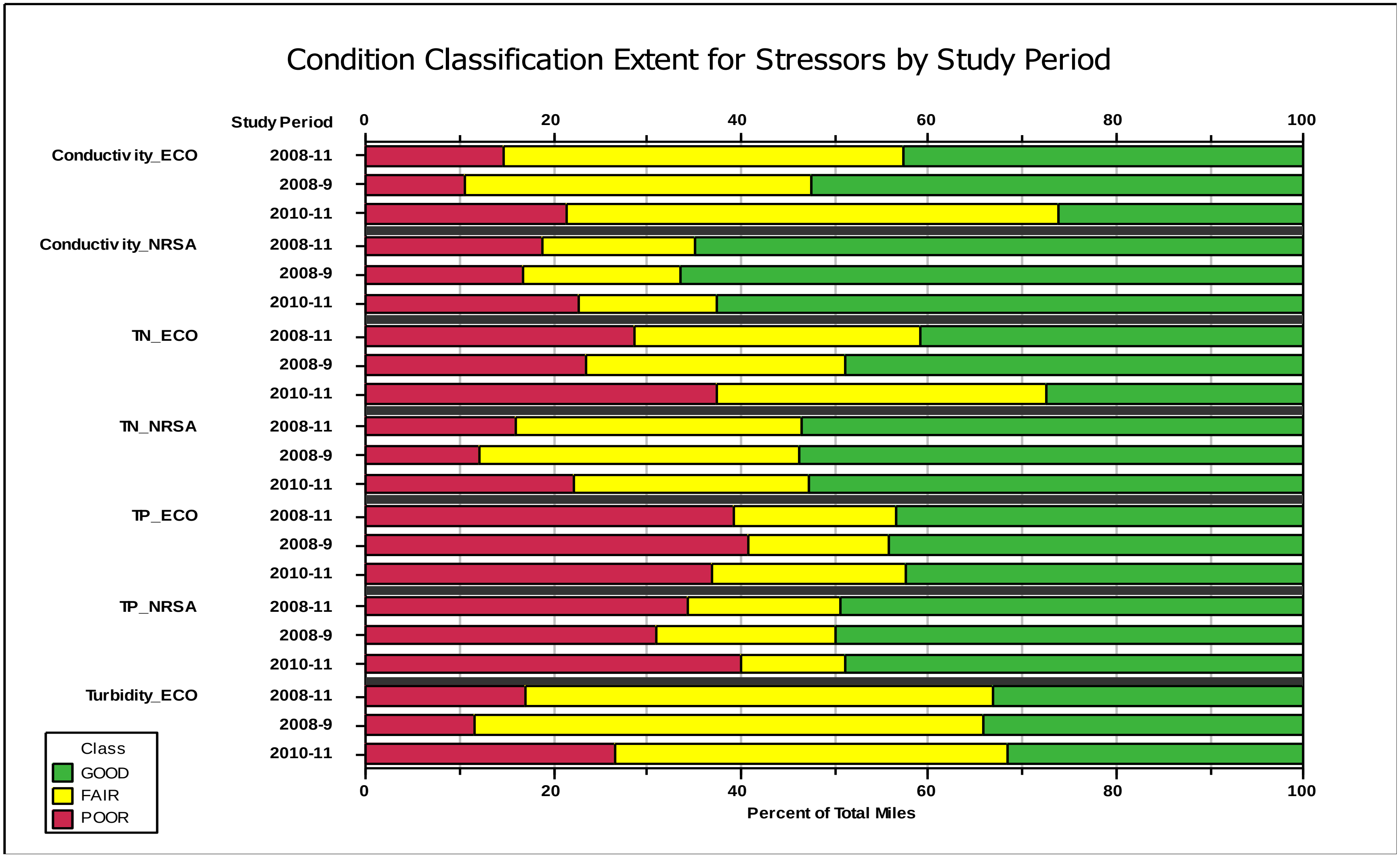


Figure 15. Stacked percentages of condition class estimates for study periods grouped by stressors. (Refer to Table 7 for stressor descriptions.)

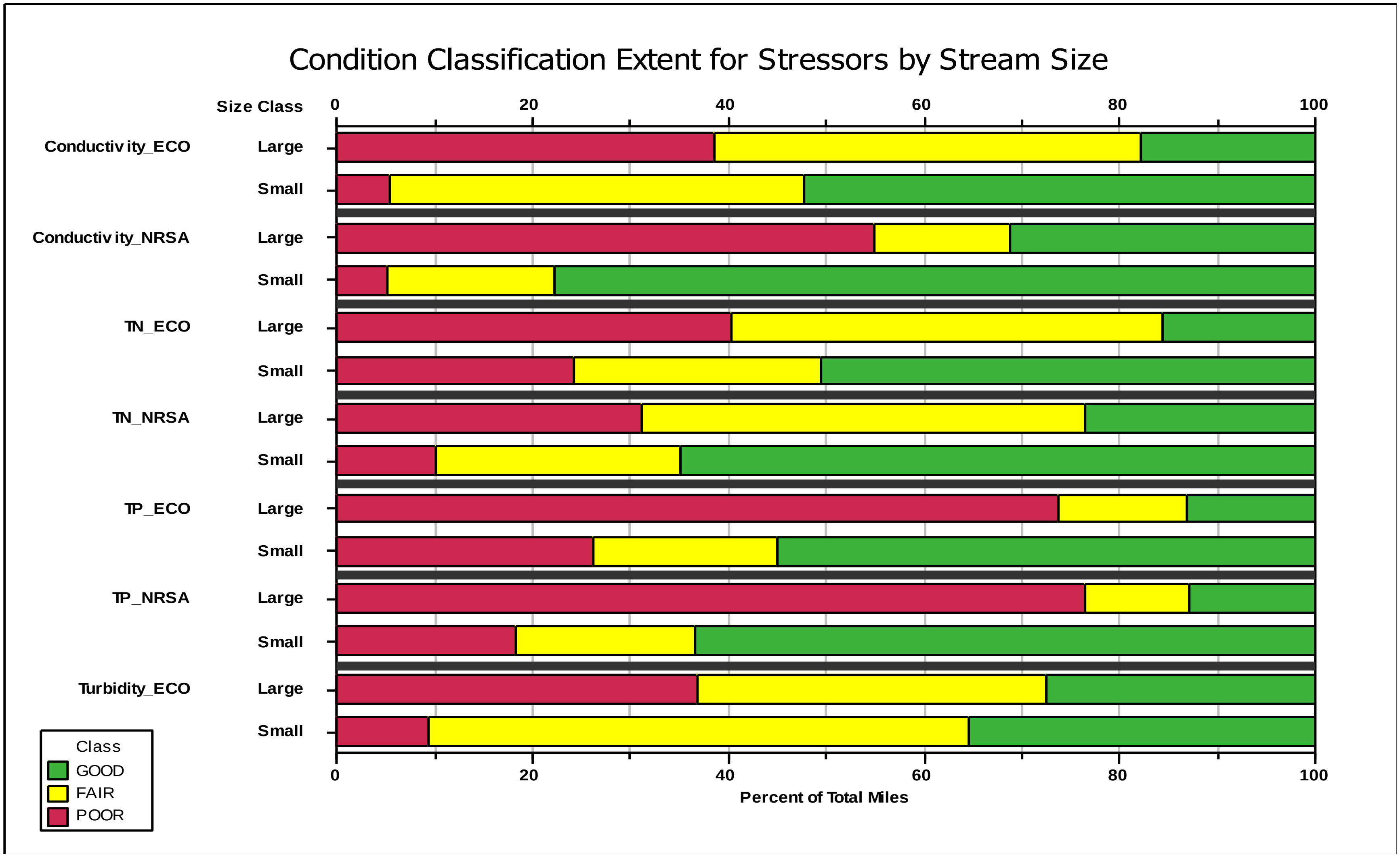


Figure 16. Stacked percentages of condition class estimates for stream size grouped by stressors. (Refer to Table 7 for stressor descriptions.)

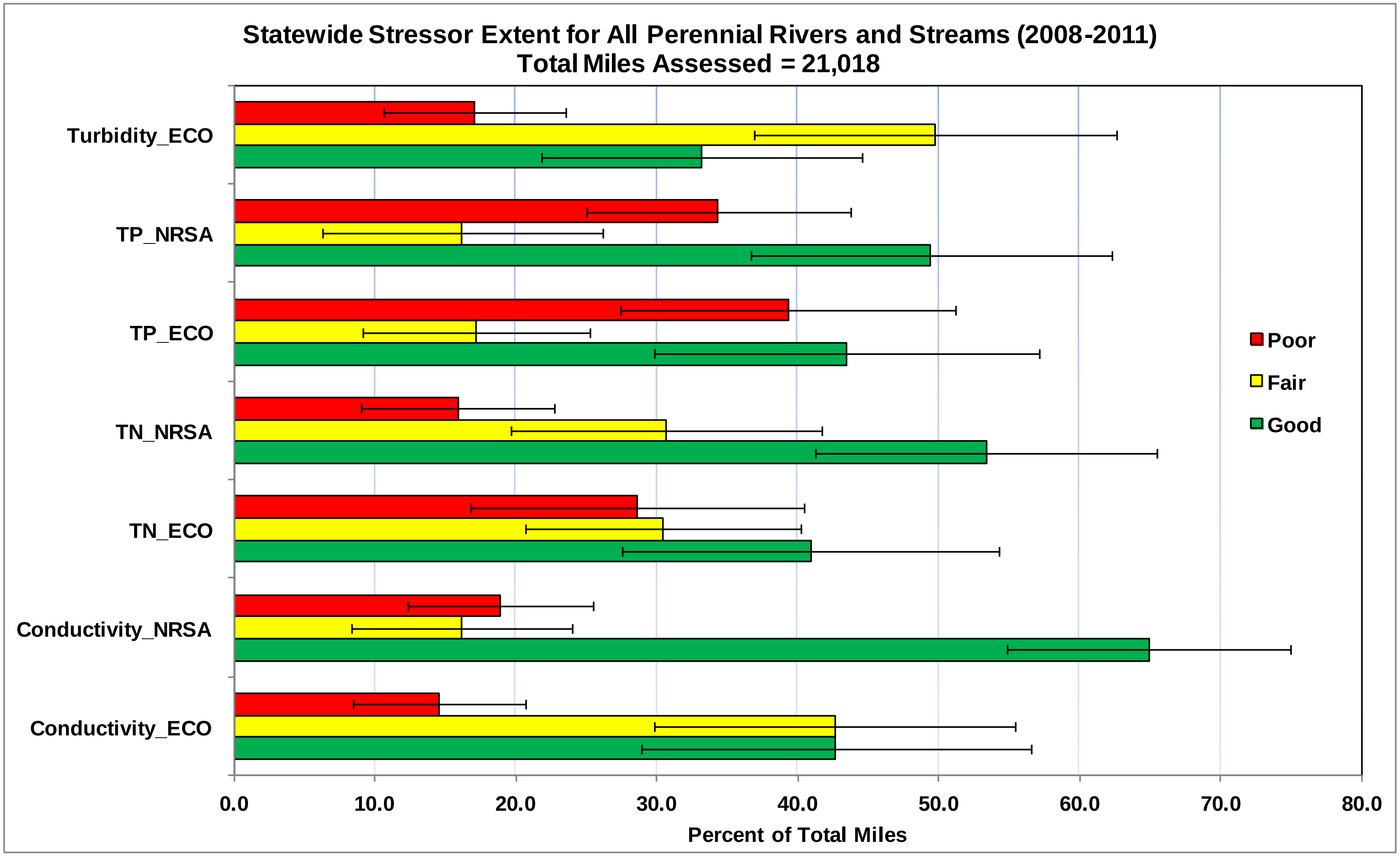


Figure 17. Stressor extent estimated statewide from 2008-2011. Upper and lower bounds represent a 95% confidence interval. (Refer to Table 7 for stressor descriptions.)

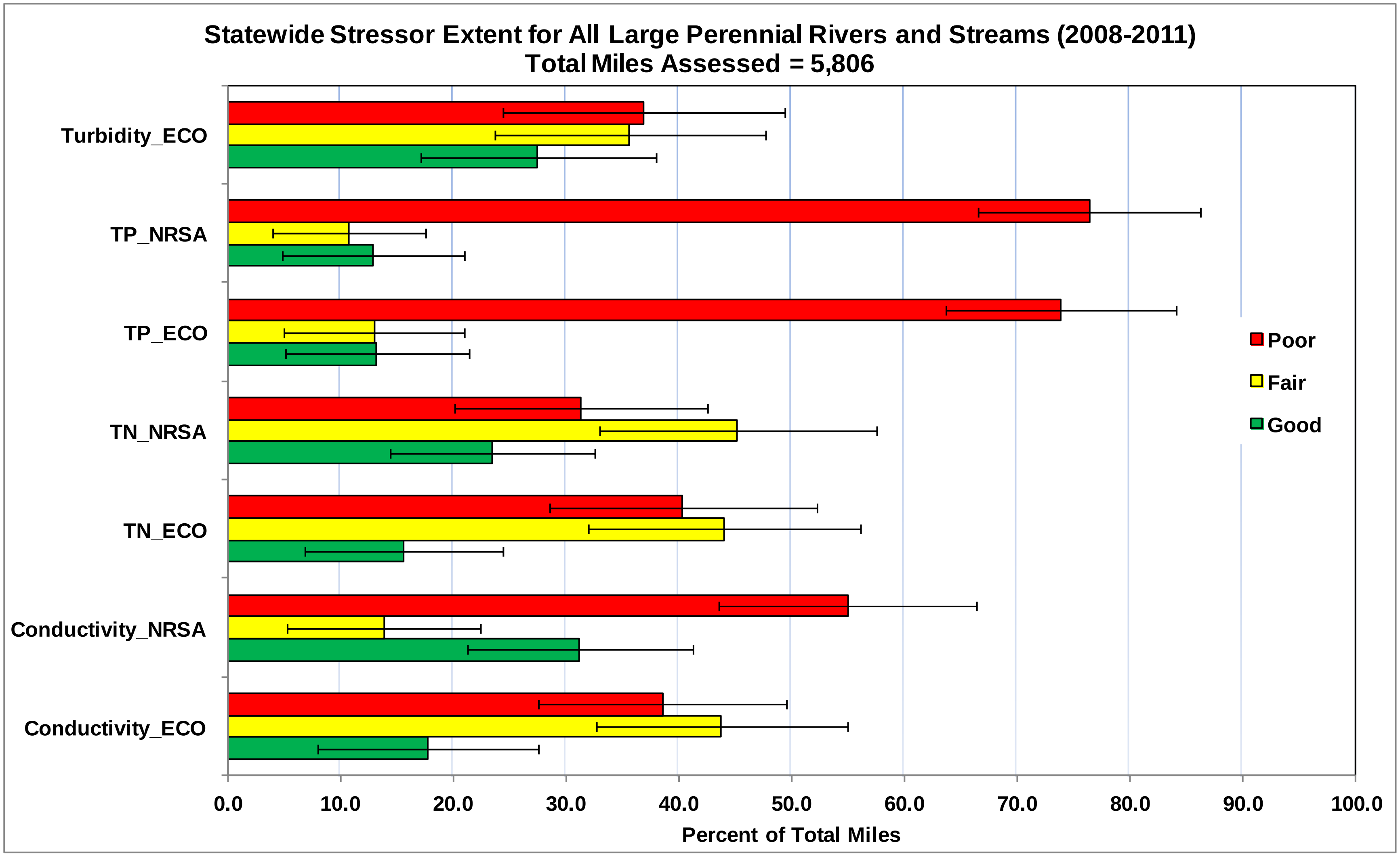


Figure 18. Stressor extent estimated statewide for larger streams and rivers (Strahler Order > 4) from 2008-2011. Upper and lower bounds represent a 95% confidence interval. (Refer to Table 7 for stressor descriptions.)

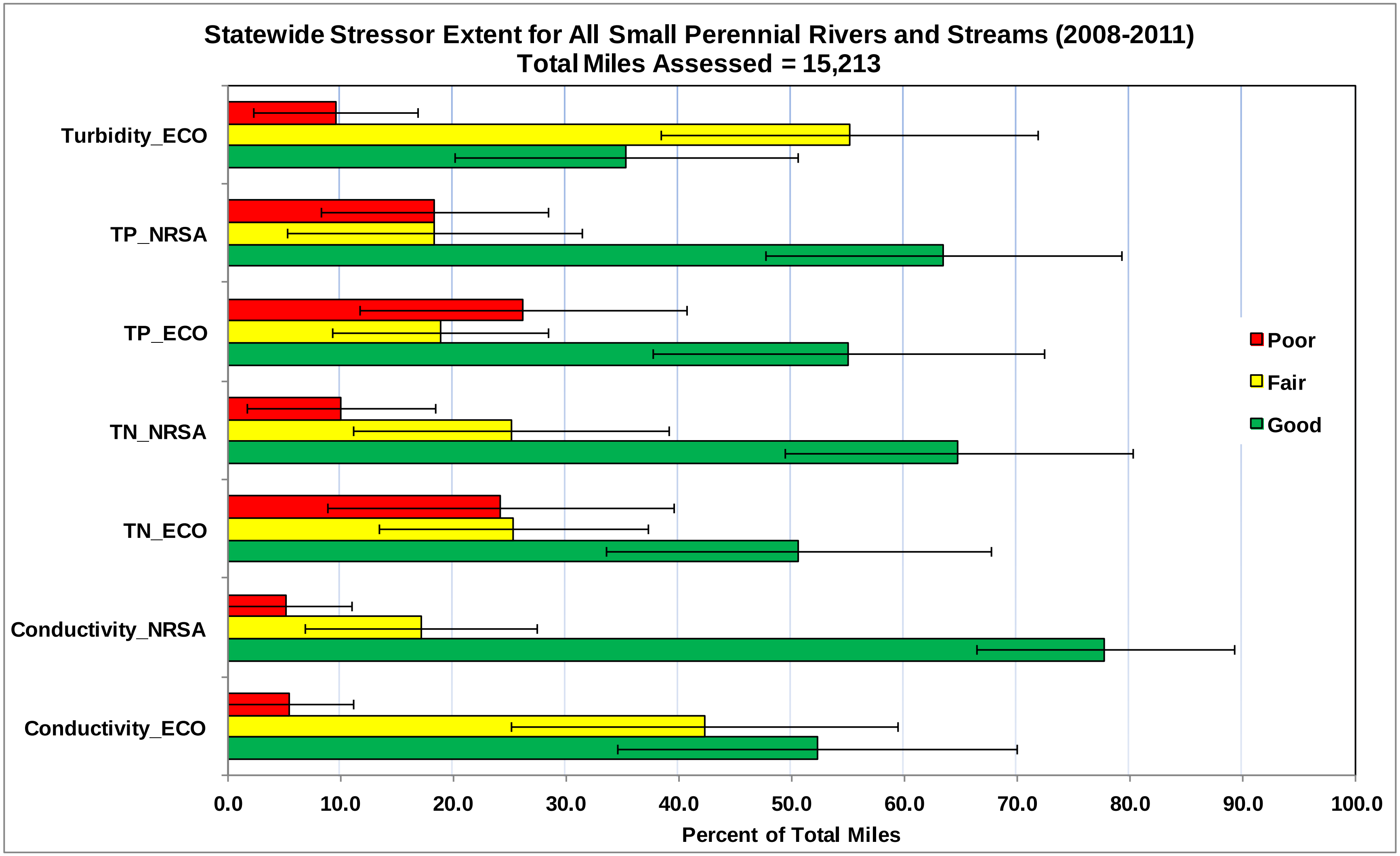


Figure 19. Stressor extent estimated statewide for smaller streams and rivers (Strahler Order < 5) from 2008-2011. Upper and lower bounds represent a 95% confidence interval. (Refer to Table 7 for stressor descriptions.)

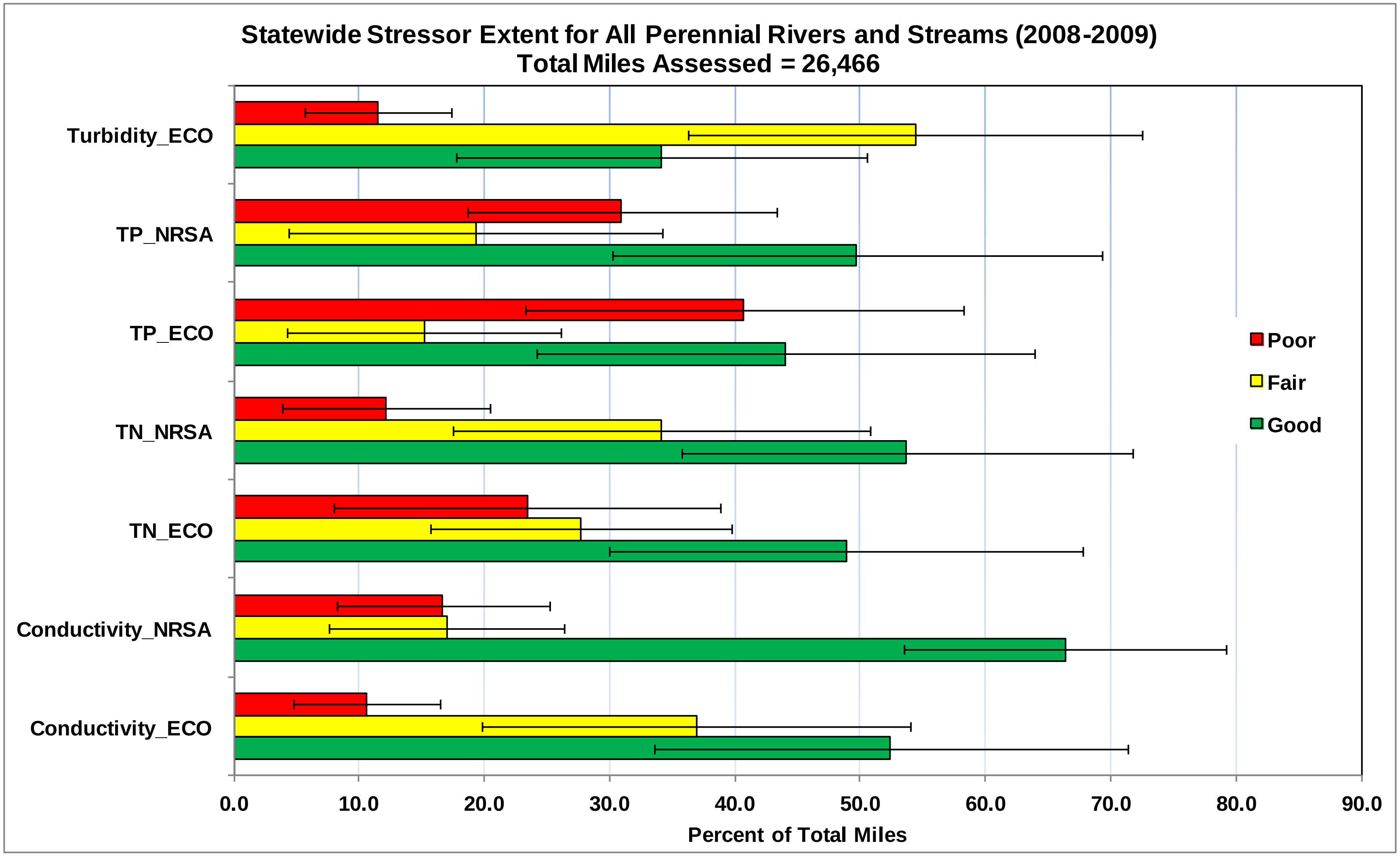


Figure 20. Stressor extent estimated statewide from 2008-2009. Upper and lower bounds represent a 95% confidence interval. (Refer to Table 7 for stressor descriptions.)

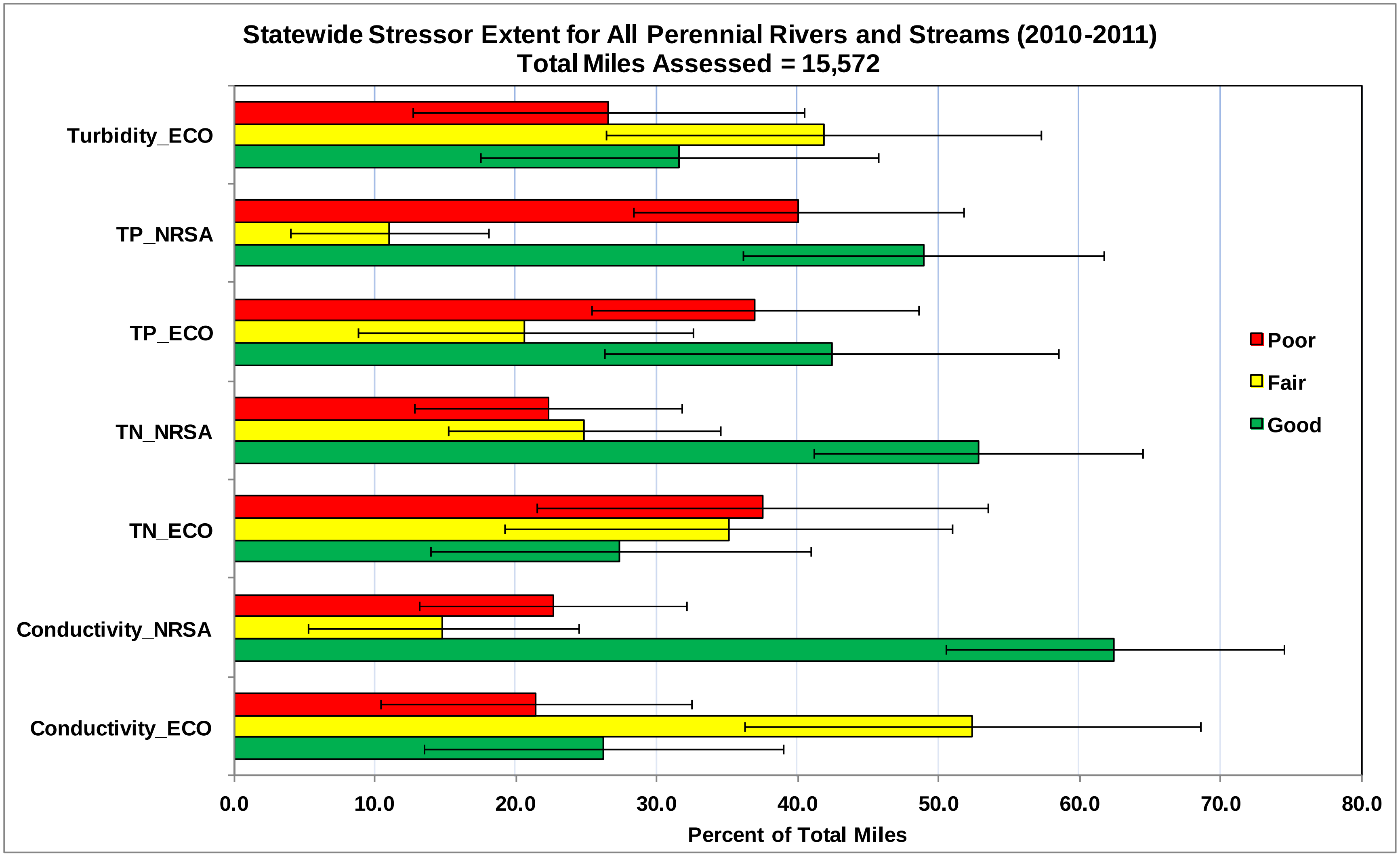


Figure 21. Stressor extent estimated statewide from 2010-2011. Upper and lower bounds represent a 95% confidence interval. (Refer to Table 7 for stressor descriptions.)

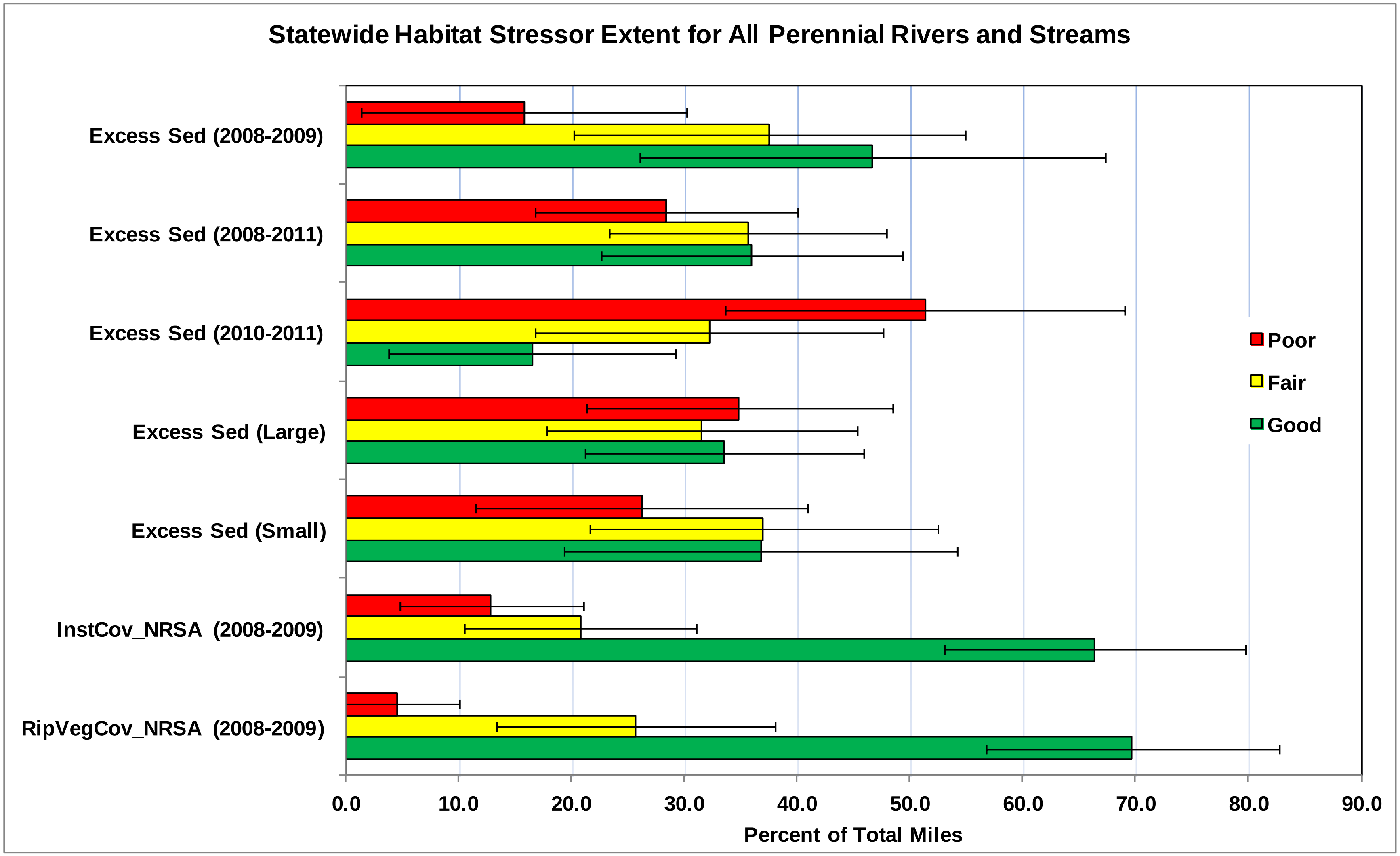


Figure 22. Sedimentation and other habitat stressors estimated statewide from 2008-2011. Upper and lower bounds represent a 95% confidence interval. (Refer to Table 7 for stressor descriptions.)

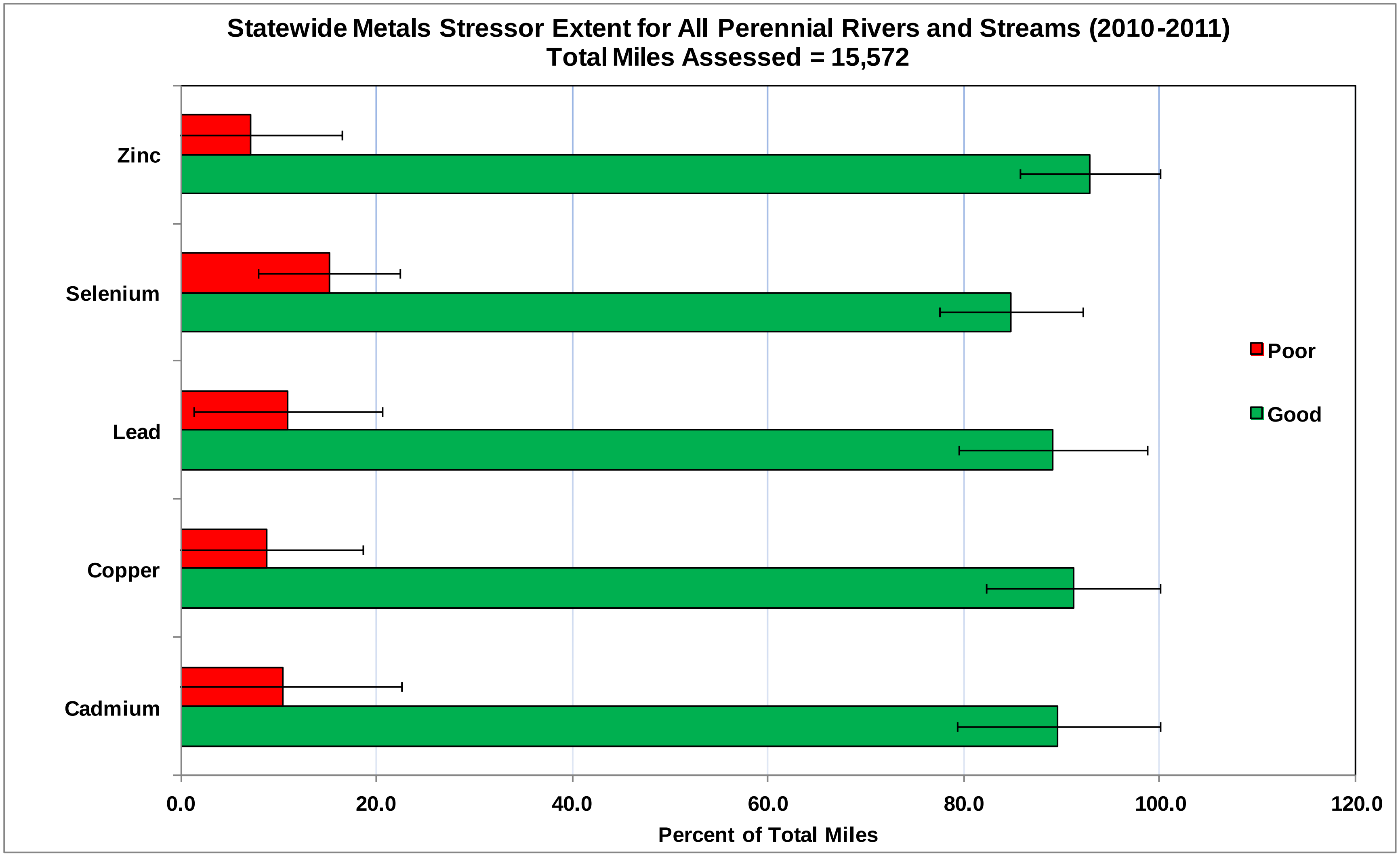


Figure 23. Metal toxicity extent estimated statewide from 2010-2011. Upper and lower bounds represent a 95% confidence interval. (Refer to Table 7 for stressor descriptions.)

Relative Risk Methodology

The concept of using relative risk to develop a relationship between biological condition and stressor extent was developed initially for the USEPA's National Wadeable Streams Assessment (USEPA, 2006). Van Sickle et al. (2006) drew upon a practice commonly used in medical sciences to determine the relationship of a stressor (e.g., high cholesterol) to a medical condition (e.g., heart disease). The method calculates a ratio between the number of streams with poor biological condition/high stressor concentration and those with poor biological condition/low stressor concentration. If the ratio is above 1, it indicates that biological condition is likely affected by high stressor concentrations (i.e., concentrations above a preset level). As the ratio increases beyond 1, the relative risk of the stressor increases (Van Sickle, 2004).

The following analyses include a comparison of a variety of stressors to biological conditions for fish, macroinvertebrates, and algal biomass. For each stressor, relative risk is determined for study period and/or waterbody size. The analysis uses a binomial designation of good/poor for condition and high/low for stressor concentration. These binomial designations are then placed in a two-way contingency table to determine relative risk. Two initial ratios are determined. The ratio for poor condition given high stressor concentration is compared to the total number of sites having high stressor concentration, regardless of condition. Likewise, the ratio for poor condition given low stressor concentration is compared to the total number of sites having low stressor concentrations, regardless of condition. These two ratios are then used to calculate relative risk. For each indicator and stressor, the good and fair conditions were collapsed into a good condition for purposes of calculating relative risk. Significant relative risk will be determined by applying a 95% confidence, which must remain above 1.0 for risk to be considered significant.

Relative Risk to Fish Condition

The relative risks of various stressors to fish condition are represented in Figures 24-29. The relative risk of poor fish condition is generally greater than 1 when most stressors are in poor condition. However, few are not significant, regardless of study period or size. For the 2008-2009 study period, the ecoregion total nitrogen screening limit shows a significant relative risk of nearly 2.5 to fish condition (Figure 24). Likewise, if the NRSA conductivity is in poor condition, the risk of poor fish condition is 4.7 times greater during 2010-2011 period (Figure 26) and 2.9 times greater in small streams (Figure 27). Additionally, the risk for poor fish condition is 1.7 times greater in large rivers when turbidity is in poor condition (Figure 27). When excess sediment leads to poor condition, poor fish condition is 2.1 times more likely in large rivers and 2.3 times during the 2008-2009 study period (Figure 28). Metals toxicity demonstrates no significant relative risk to fish condition (Figure 29).

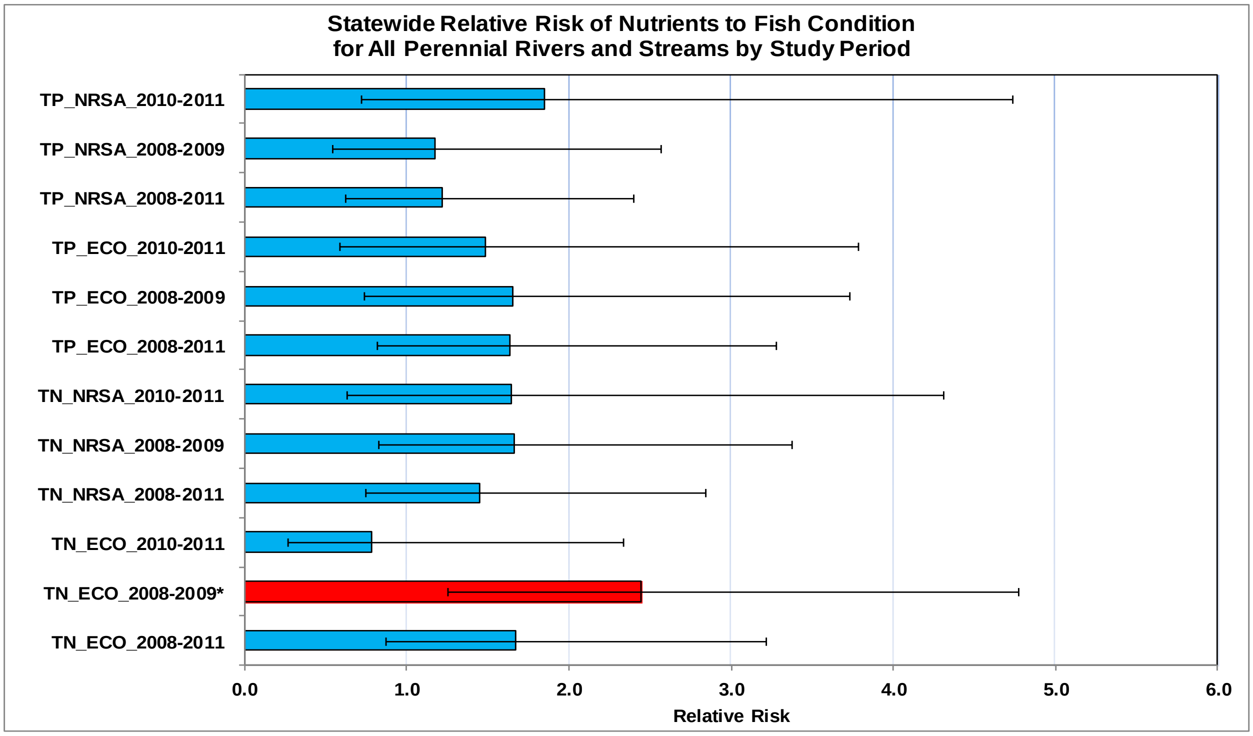


Figure 24. Relative risk of nutrient stressors affecting poor fish condition by study period. (upper/lower bounds represent a 95% confidence interval-CI) (* = significant relative risk-RR)

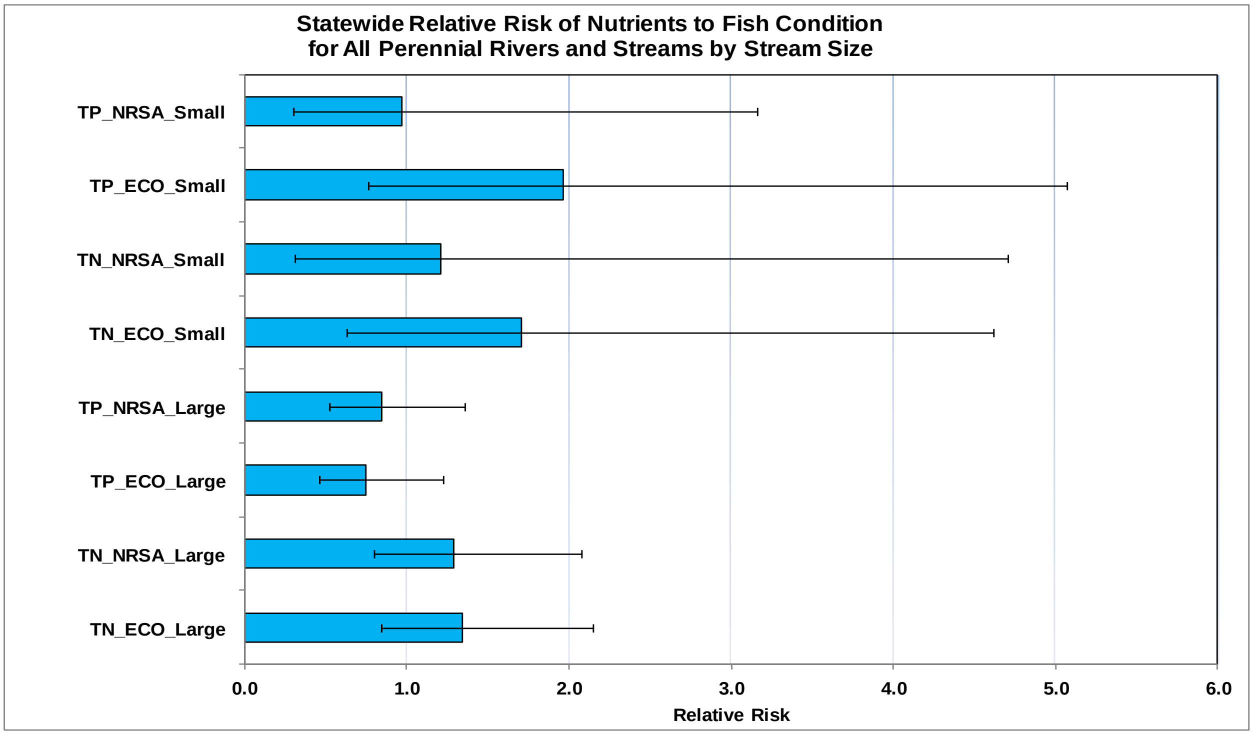


Figure 25. Relative risk of nutrient stressors affecting poor fish condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

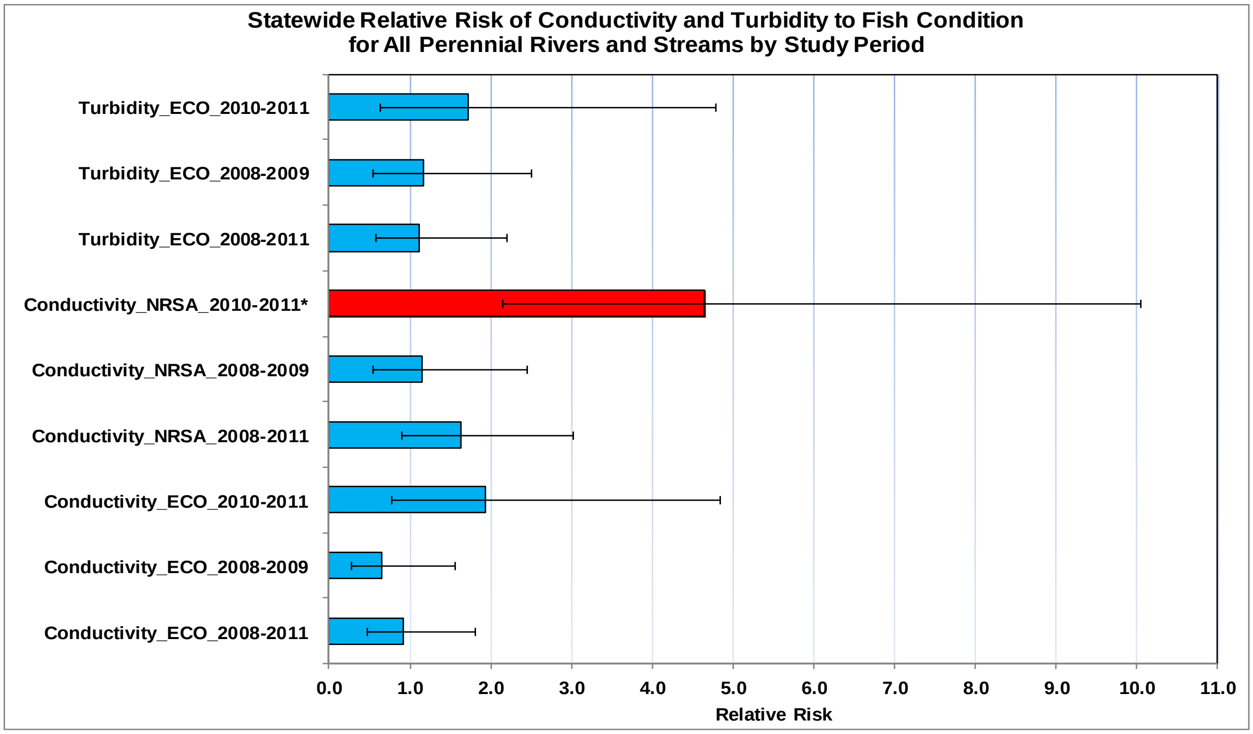


Figure 26. Relative risk of conductivity and turbidity stressors affecting poor fish condition by study period. (upper/lower bounds represent a 95% CI) (* = significant RR)

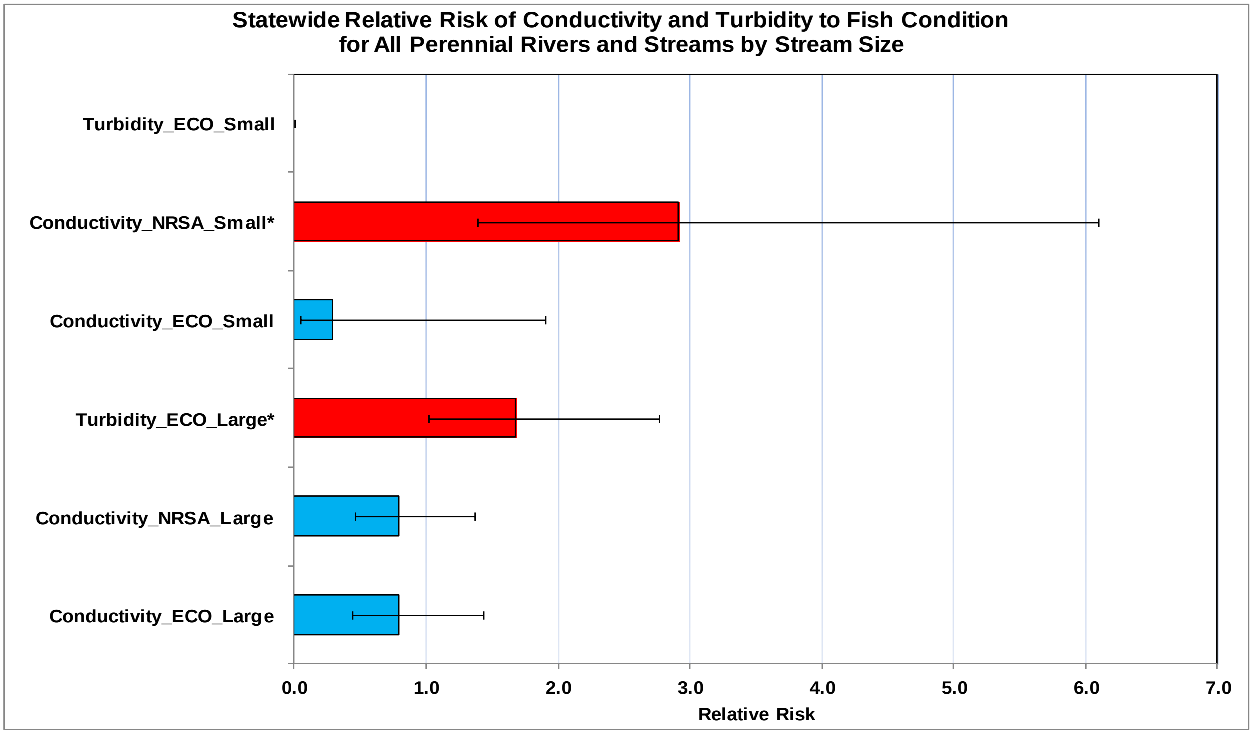


Figure 27. Relative risk of conductivity and turbidity stressors affecting poor fish condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

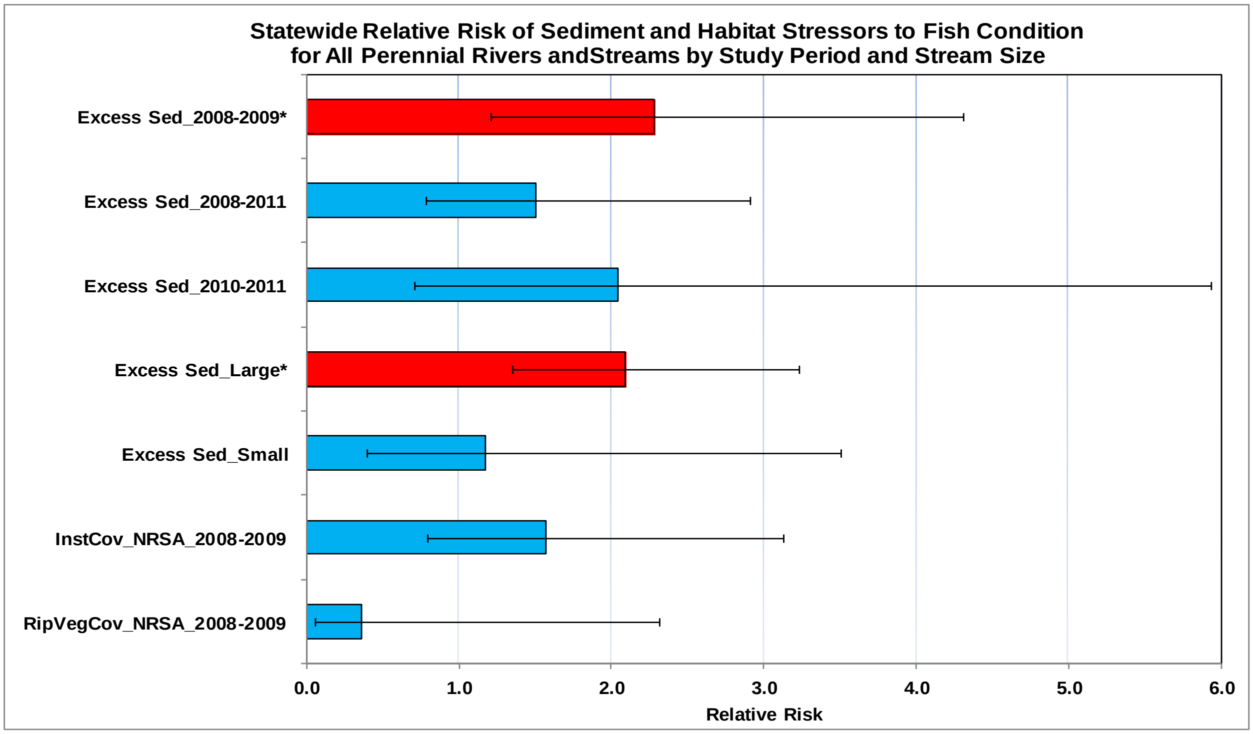


Figure 28. Relative risk of sediment and habitat stressors affecting poor fish condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

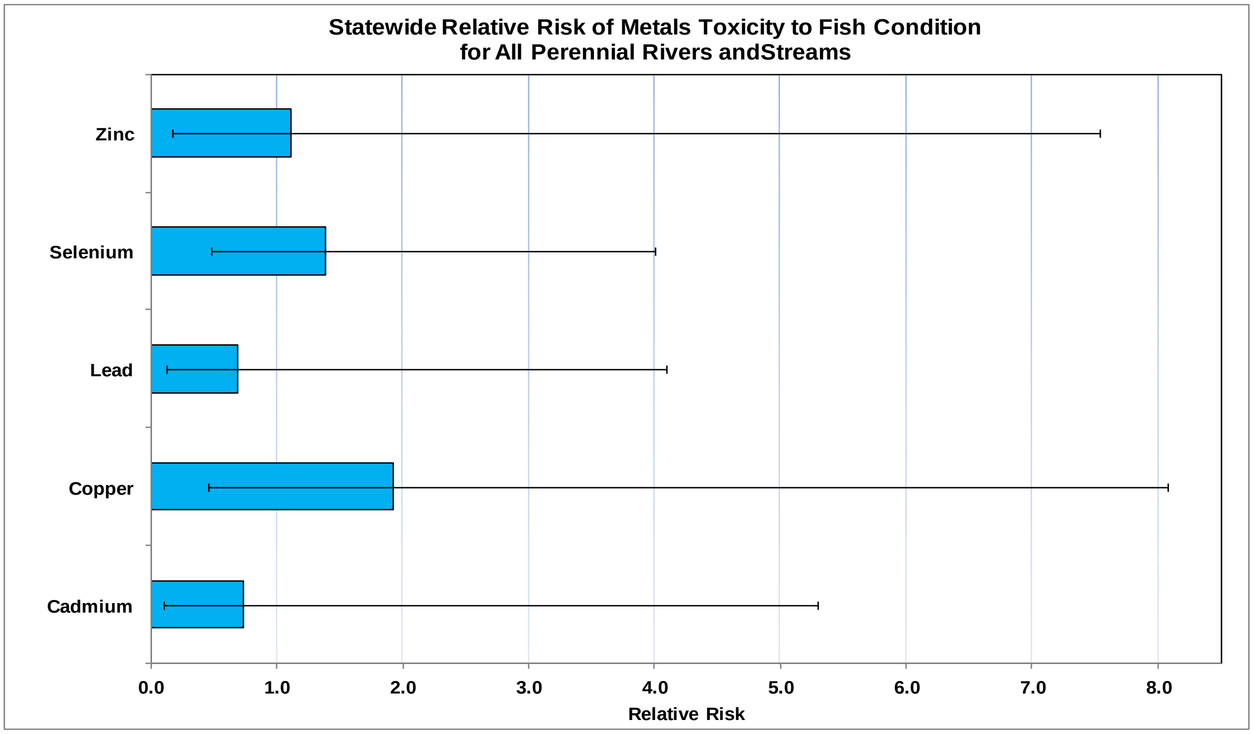


Figure 29. Relative risk of metal toxicity stressors affecting poor fish condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

Relative Risk to Macroinvertebrate Condition

The relative risks of various stressors to macroinvertebrate condition are shown in Figures 30-35. As with fish, the relative risk of poor macroinvertebrate condition is generally greater than 1 when most stressors are in poor condition, but unlike fish, many demonstrate significant risk. With the exception of the NRSA screening limit during study certain periods, the risk of poor macroinvertebrate condition is 2.3 to 3.5 times greater with poor total phosphorus condition and 1.9 to 4.3 times greater with poor total nitrogen condition (Figure 30). For stream size, small streams with poor total phosphorus condition are 3.4 to 5.8 times more likely to have poor macroinvertebrate condition (Figure 31). Poor total nitrogen condition, regardless of size, and total phosphorus in large rivers do not pose a significant relative risk to macroinvertebrate condition. When conductivity is in poor condition, all waterbodies are 2.4 to 3.2 times more likely to have poor macroinvertebrate condition, and from 2010-2011, poor condition was 2.9 times more likely when turbidity was in poor condition (Figure 32). Depending on the screening limit, risk of poor macroinvertebrate condition is 3.7 times greater in small streams and 1.7 times greater in large rivers when conductivity condition is poor (Figure 33). Turbidity demonstrates no significant relative risk to macroinvertebrate condition when considering waterbody size. The risk of poor macroinvertebrate condition is 2.3 times more likely when riparian vegetative cover is poor, and from 2008-2009, was 2.6 greater with excess sedimentation (Figure 34). Large rivers are also 1.5 times more likely to show poor condition with excess sedimentation. Finally, as with fish, metals toxicity demonstrates no significant relative risk to macroinvertebrate condition (Figure 29).

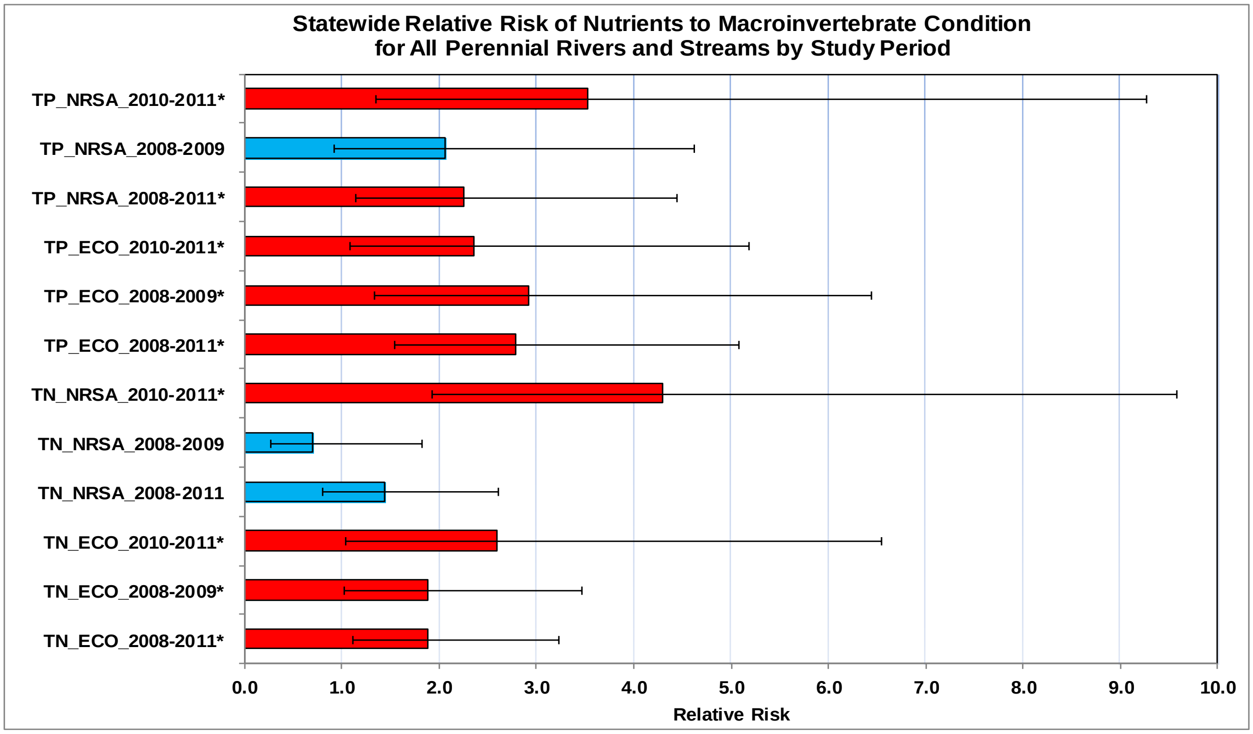


Figure 30. Relative risk of nutrient stressors affecting poor macroinvertebrate condition by study period. (upper/lower bounds represent a 95% CI) (* = significant RR)

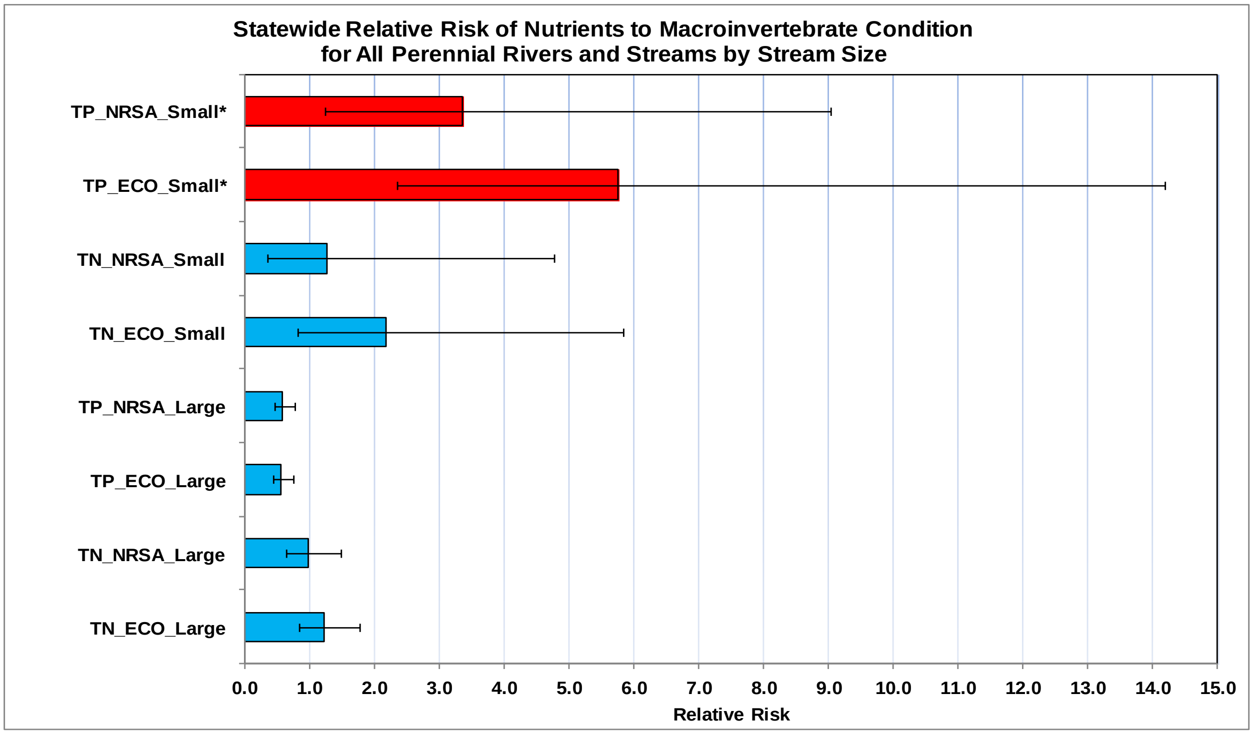


Figure 31. Relative risk of nutrient stressors affecting poor macroinvertebrate condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

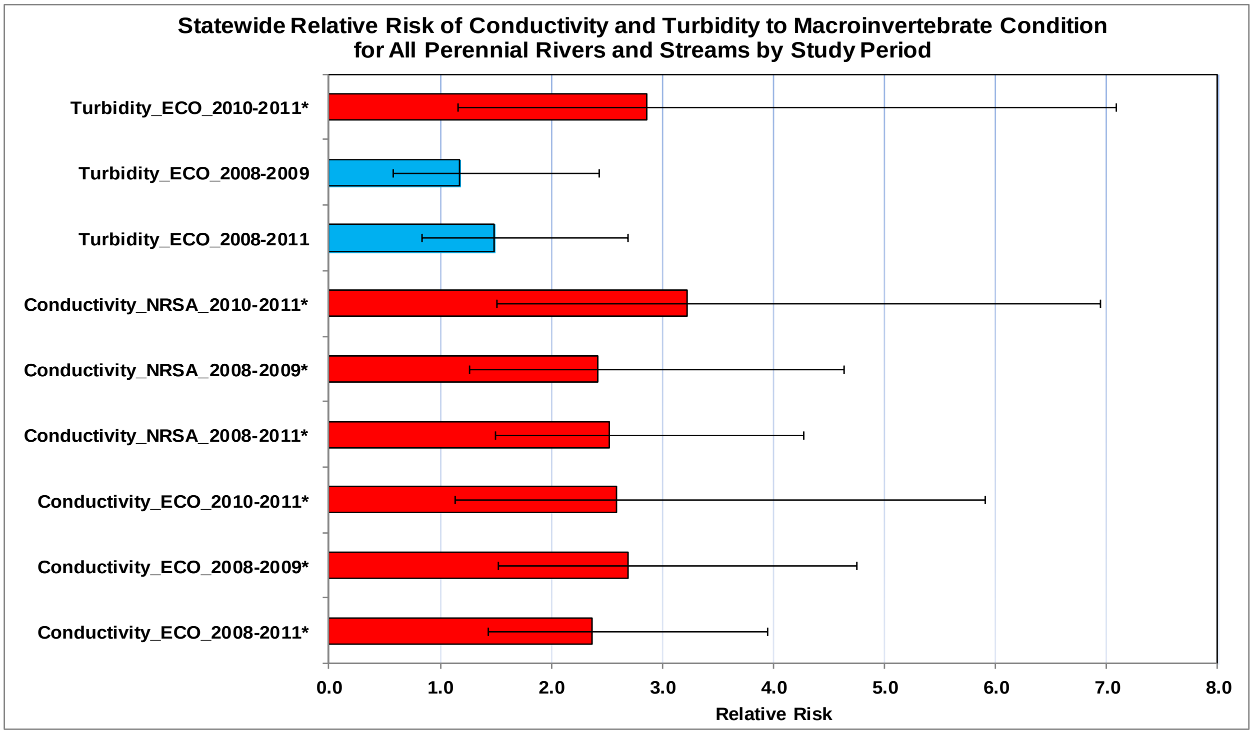


Figure 32. Relative risk of conductivity and turbidity stressors affecting poor macroinvertebrate condition by study period. (upper/lower bounds represent a 95% CI) (* = significant RR)

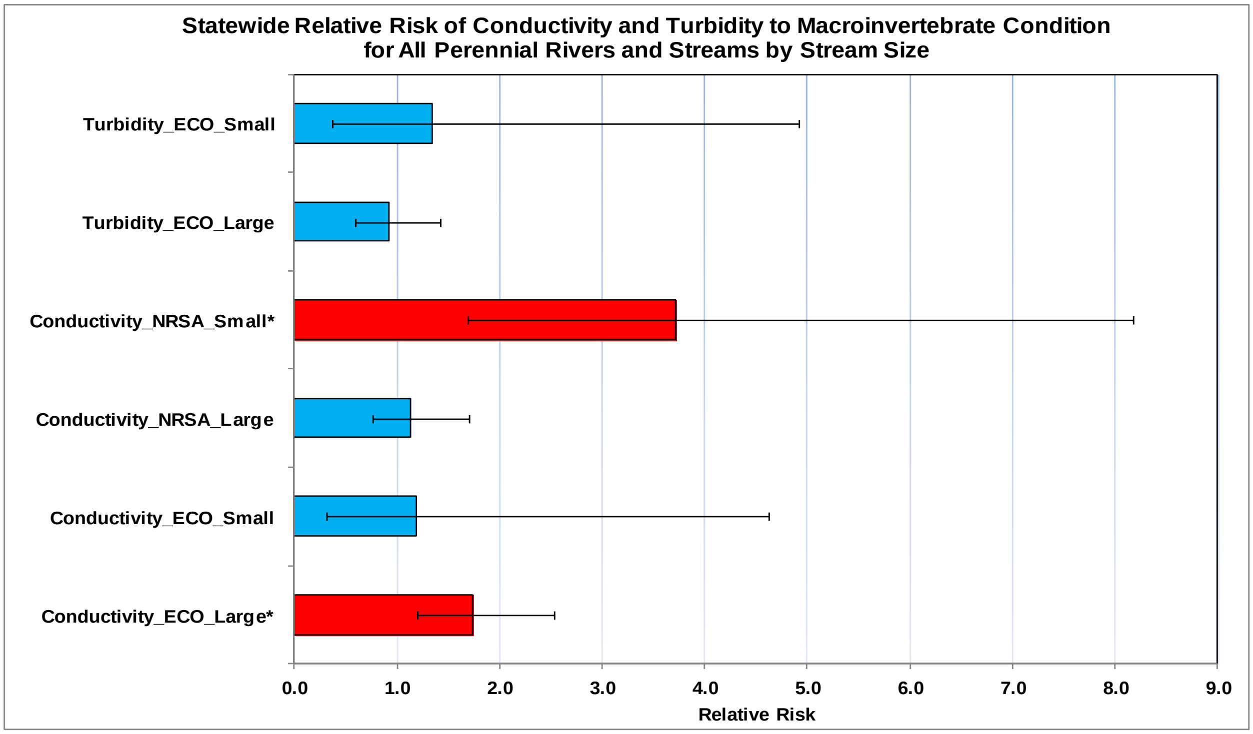


Figure 33. Relative risk of conductivity and turbidity stressors affecting poor macroinvertebrate condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

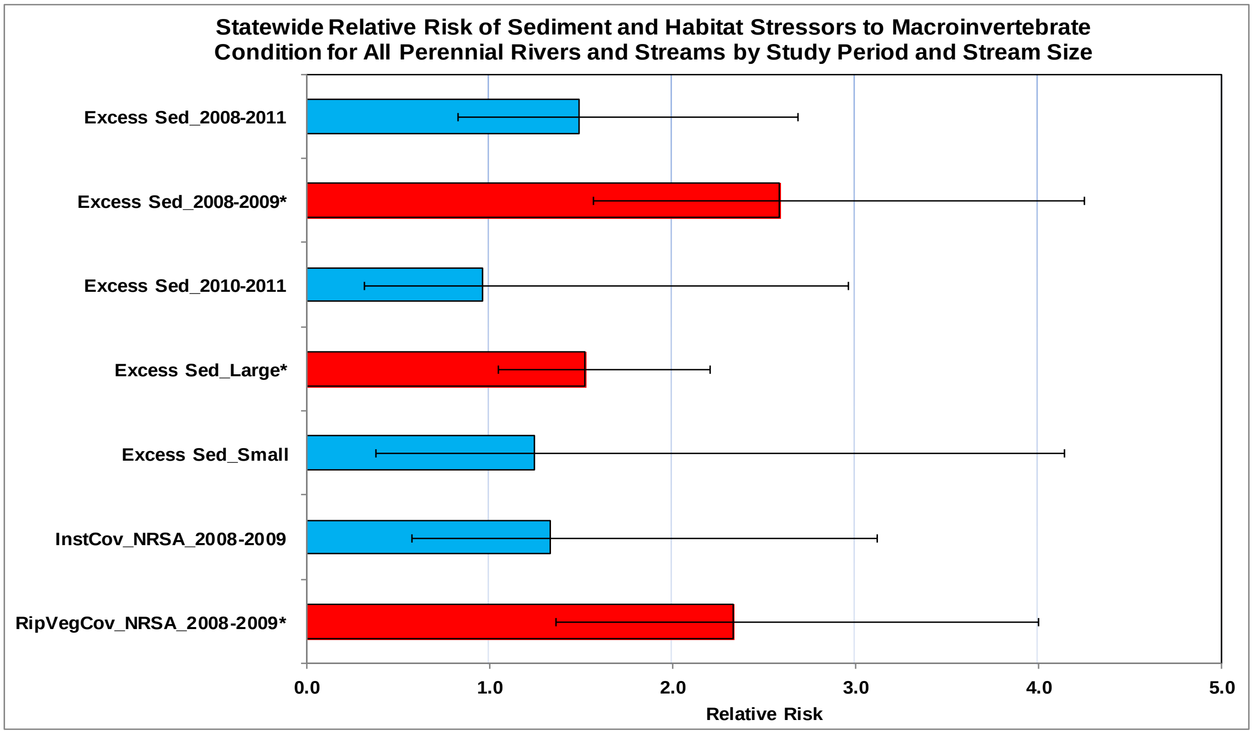


Figure 34. Relative risk of sediment and habitat stressors affecting poor macroinvertebrate condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

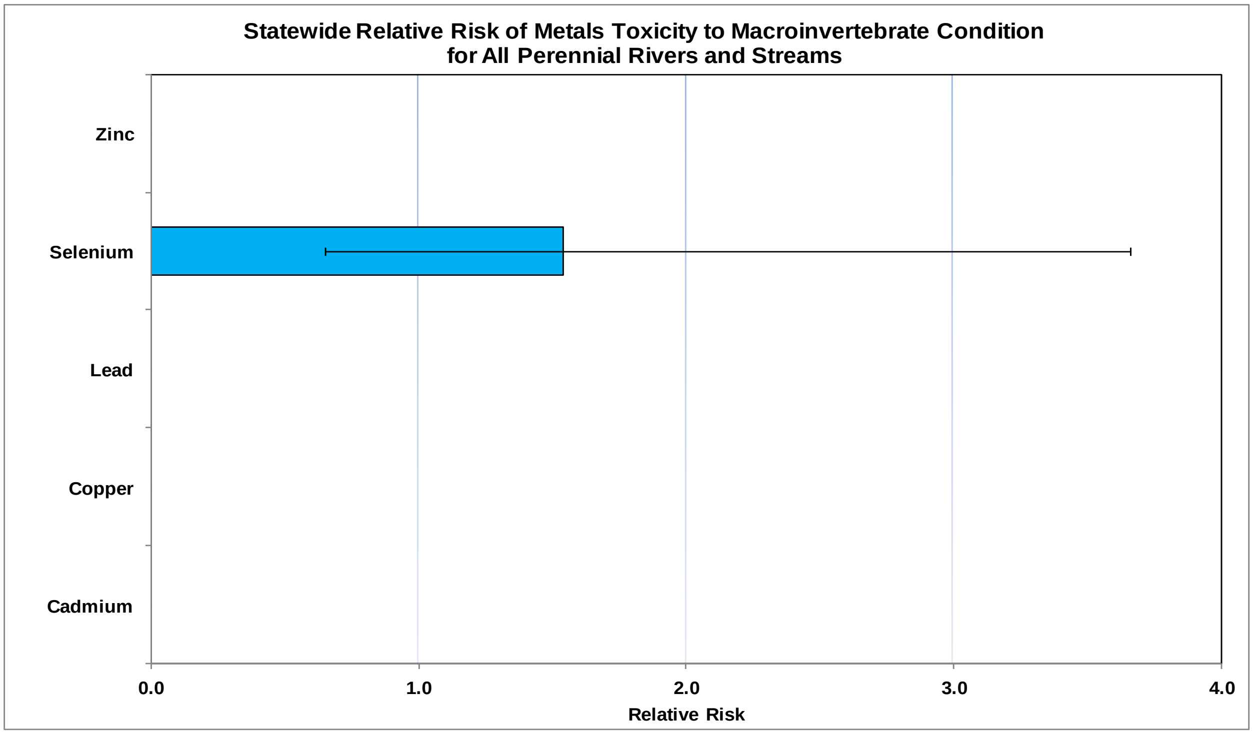


Figure 35. Relative risk of metal toxicity stressors affecting poor macroinvertebrate condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

Relative Risk to Benthic Algae Condition

The relative risks of various stressors to benthic algae condition are represented in Figures 36-41. Nutrients show very little significant relative risk, regardless of study period or waterbody size (Figures 36 and 37). For the 4-year study period, benthic algae condition was 3.3 times more likely to be poor when NRSA total nitrogen was in poor condition (Figure 36). Likewise, over the entire study period, poor conductivity condition was 3.0 to 4.5 times more likely to lead to excessive benthic algal growth (Figure 38). When the ecoregion conductivity was high, the likelihood of poor condition in the population increased by 10.2 times from 2008-2009 (Figure 38) and 9.6 times in small streams (Figure 39). Poor turbidity and habitat condition, as well as excess sedimentation, pose no significant relative risk to benthic algae condition (Figures 38-40). Interestingly, excess benthic algal growth is more likely when lead (3.9) and selenium (2.9) are above the applicable chronic toxicity criteria (Figure 41).

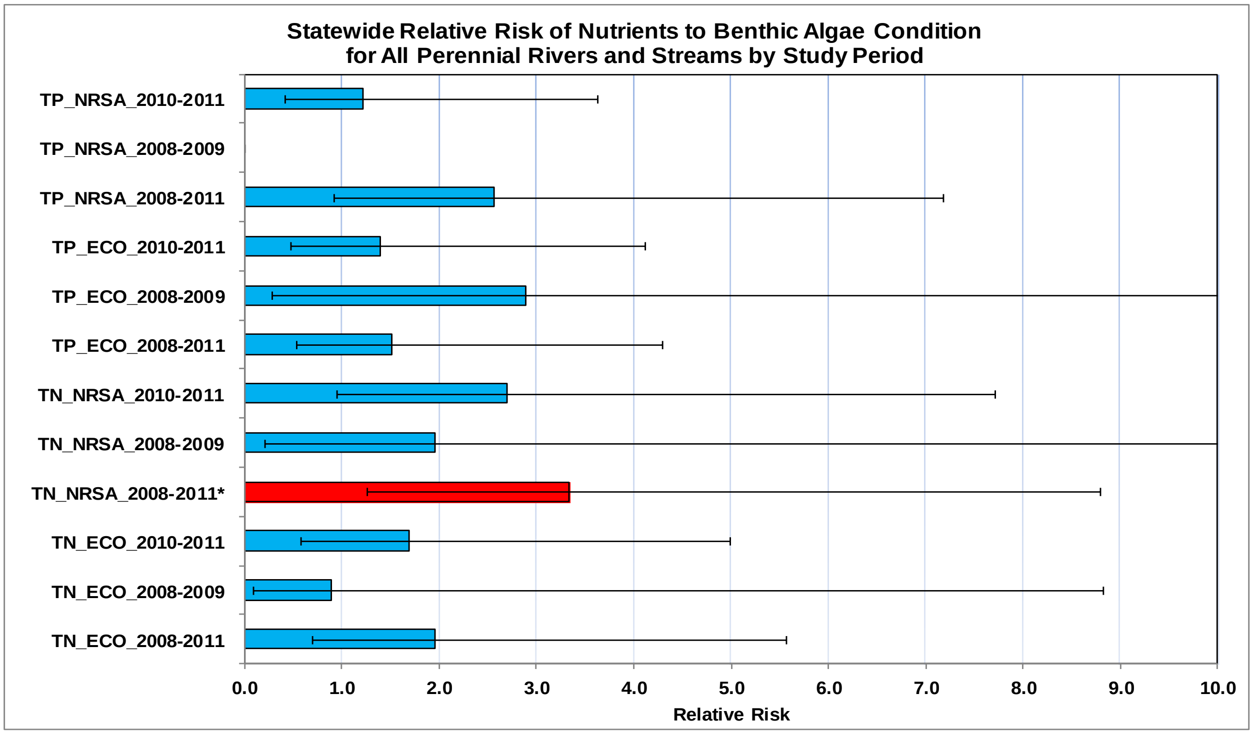


Figure 36. Relative risk of nutrient stressors affecting poor benthic algae condition by study period. (upper/lower bounds represent a 95% CI) (* = significant RR)

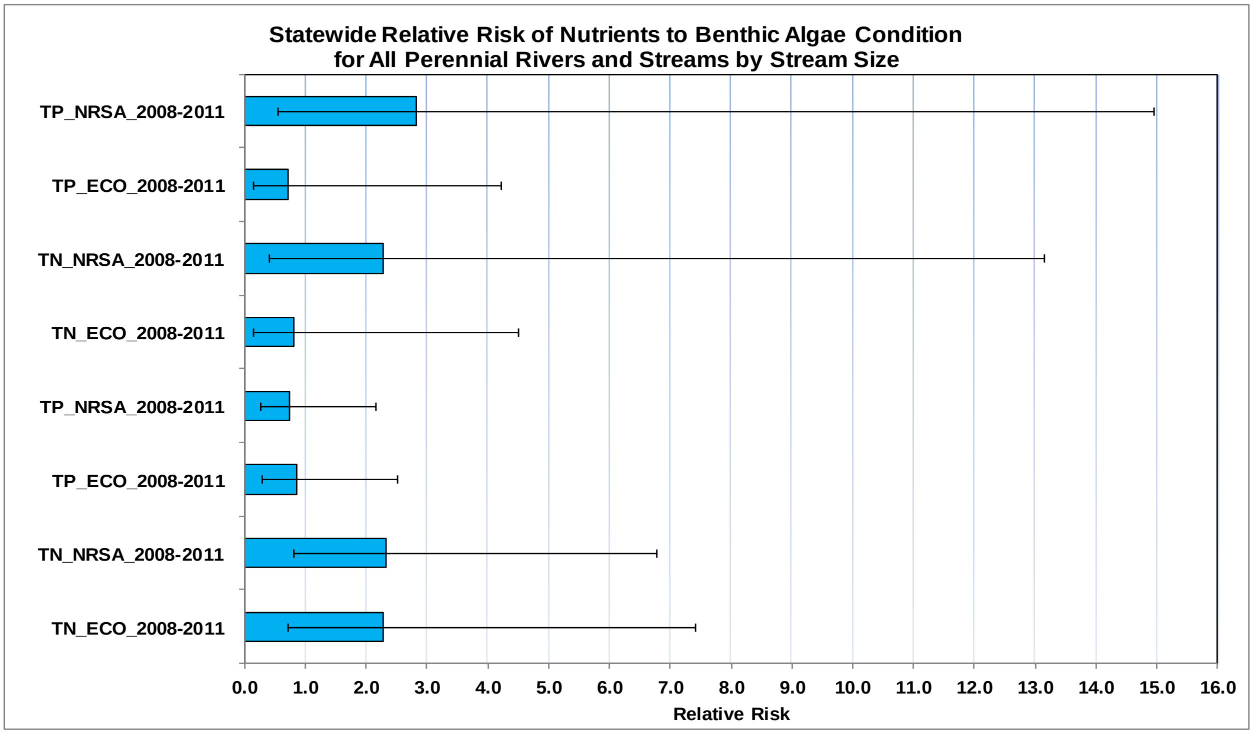


Figure 37. Relative risk of nutrient stressors affecting poor benthic algae condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

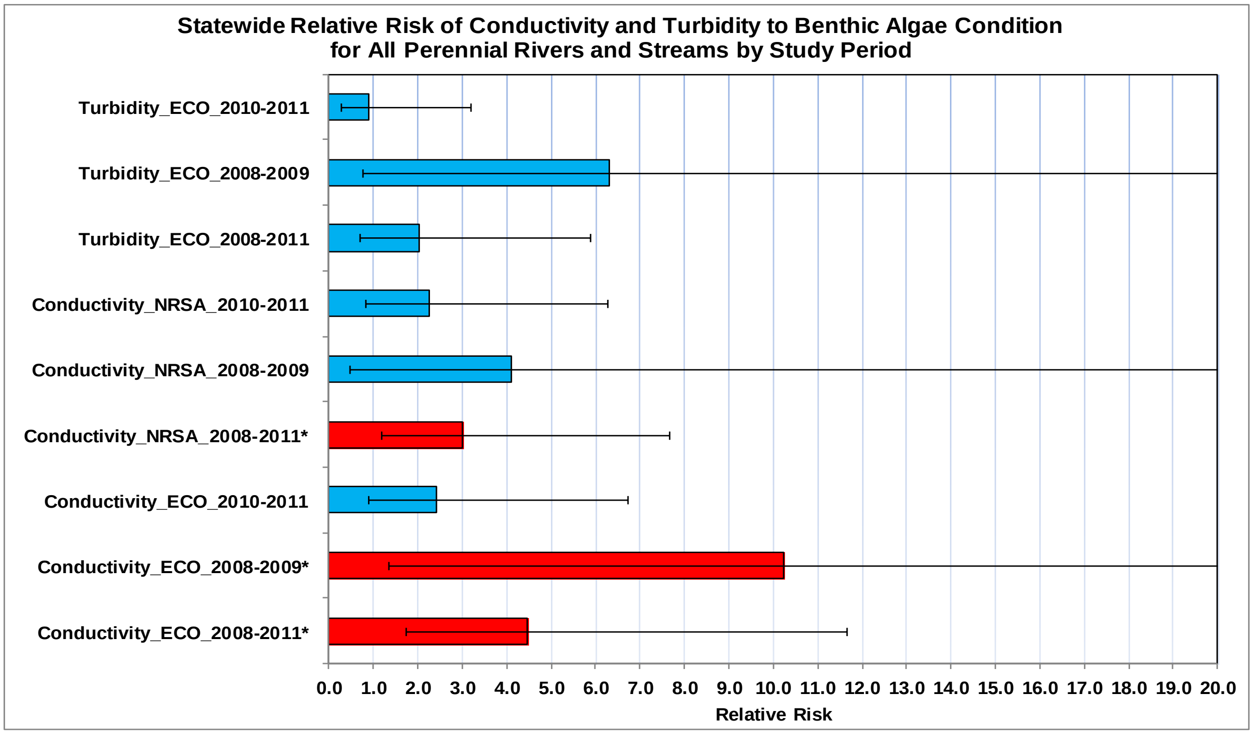


Figure 38. Relative risk of conductivity and turbidity stressors affecting poor benthic algae condition by study period. (upper/lower bounds represent a 95% CI) (* = significant RR)

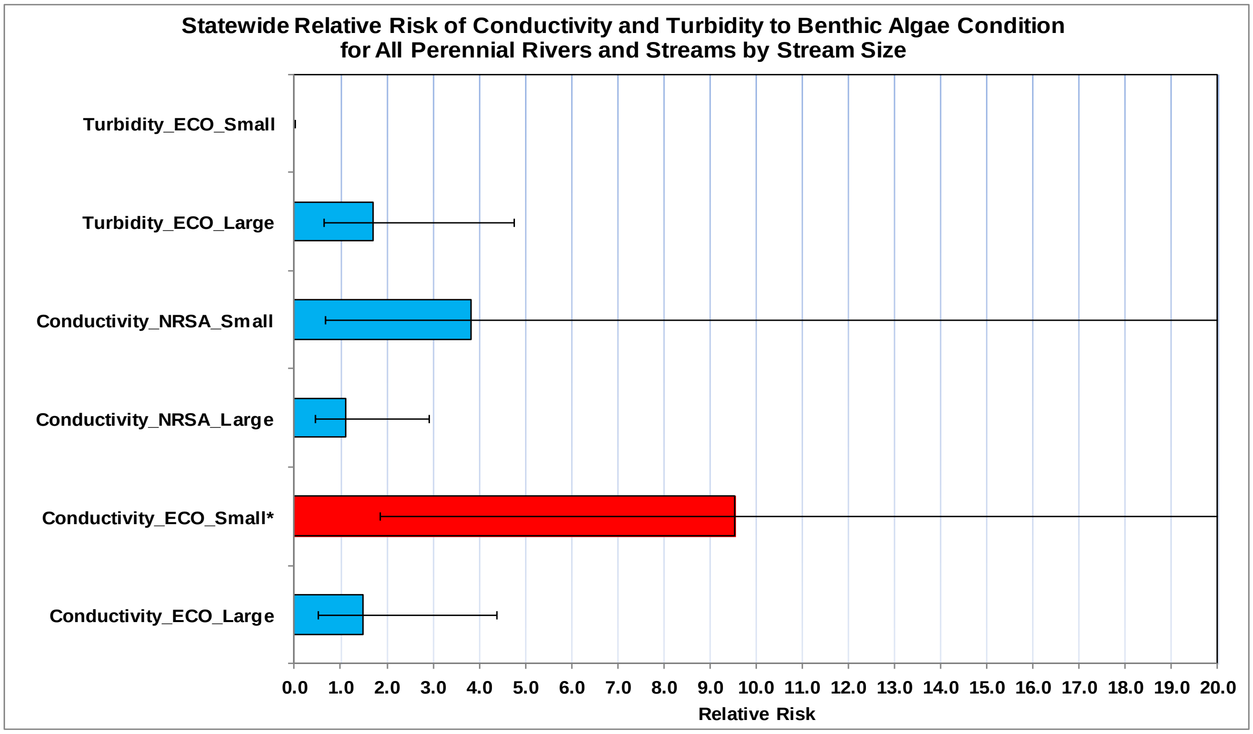


Figure 39. Relative risk of conductivity and turbidity stressors affecting poor benthic algae condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

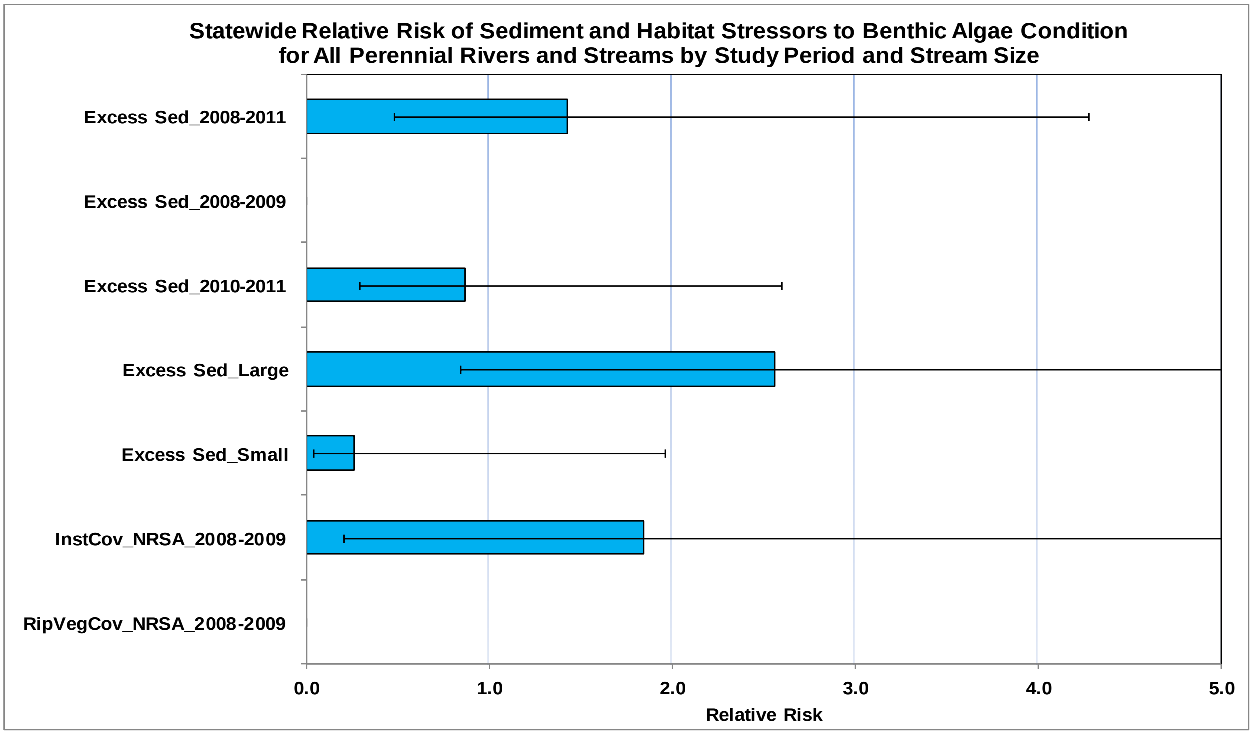


Figure 40. Relative risk of sediment and habitat stressors affecting poor benthic algae condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

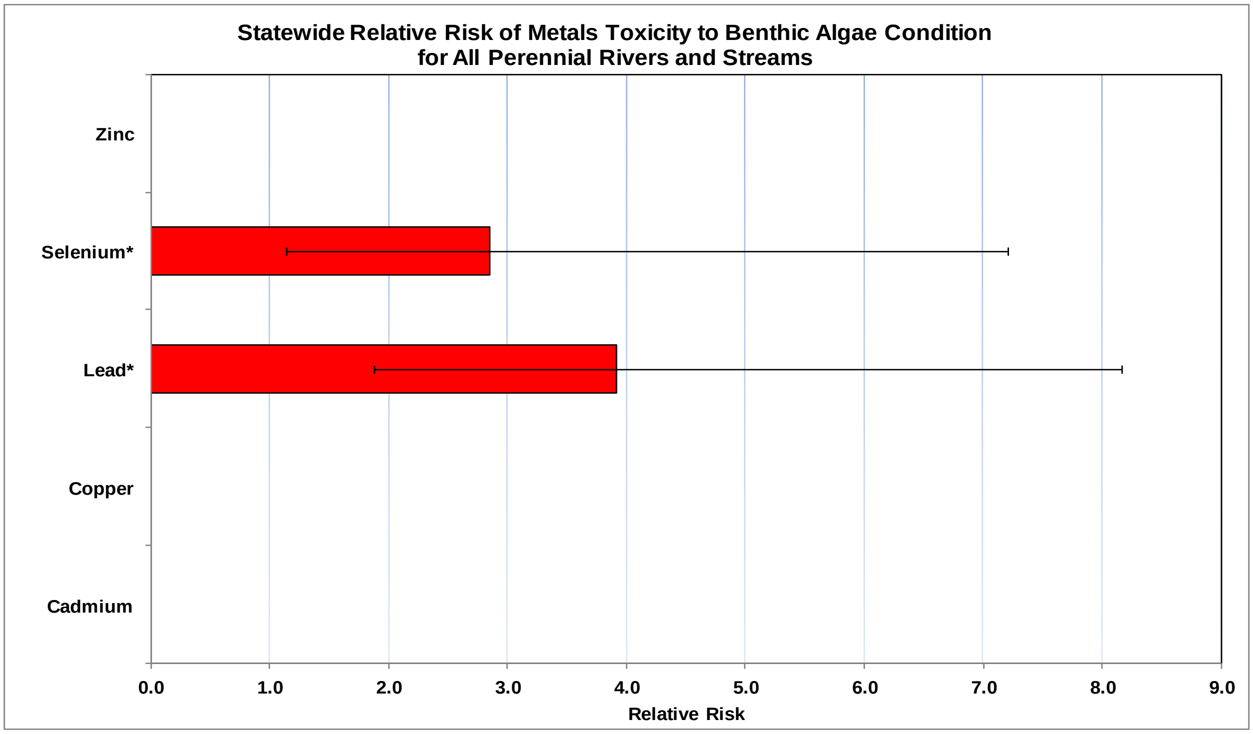


Figure 41. Relative risk of metal toxicity stressors affecting poor benthic algae condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

Relative Risk to Sestonic Algal Condition

The relative risks of various stressors to sestonic algae condition are represented in Figures 42-47. Regardless of study period, poor total phosphorus condition increases by 4.7-15.6 times the risk of poor sestonic algae condition (Figure 42). When the NRSA total nitrogen screening limit is in poor condition, the risk of poor condition increases by 2.8-3.4 times during the 4-year study period as well as the 2010-2011 period. In large rivers, the risk of poor sestonic algae condition increases by 2 to 3.7 times when total phosphorus is in poor condition and 1.4 times when total nitrogen is poor (Figure 43). Conversely, in small rivers, significant risk is confined to NRSA total phosphorus, with the risk of excess sestonic algal growth increased by 6.6 times. With poor conductivity condition, the risk of increased algal growth increased by 3 to 6.6 times, and poor turbidity condition increased risk by 2.7 to 4.5 times, during the 4-year and the 2008-2009 study periods (Figure 44). In small streams, high conductivity increased by 5.3 times the risk for excess sestonic algal growth (Figure 45), while large rivers showed no significant relative risk related to conductivity. There was not significant relative risk to poor turbidity condition in large or small waterbodies. Excess sediment and poor riparian vegetative cover did not significantly increase relative risk (Figure 46). However, poor instream cover increased the likelihood of excessive sestonic algal growth by 2.9 times. Finally, lead concentrations above the chronic criterion increased the likelihood of excessive algal growth by 3.2 times (Figure 47).

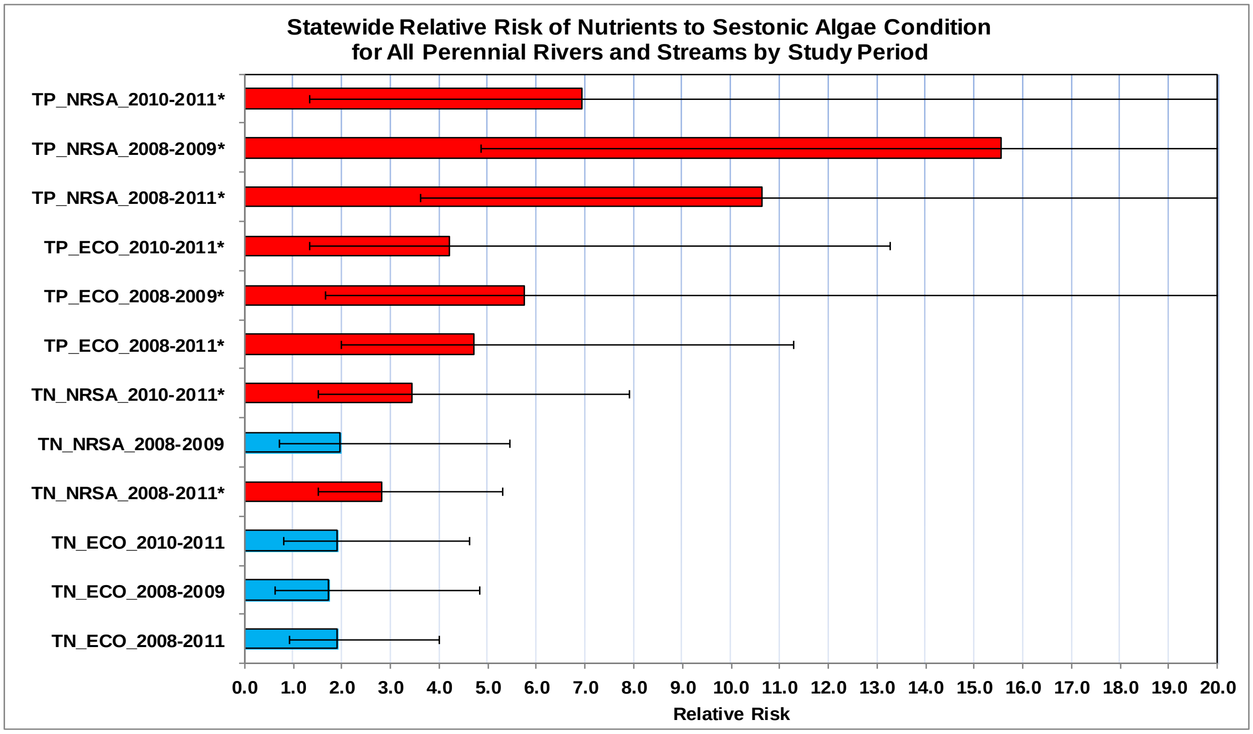


Figure 42. Relative risk of nutrient stressors affecting poor sestonic algae condition by study period. (upper/lower bounds represent a 95% CI) (* = significant RR)

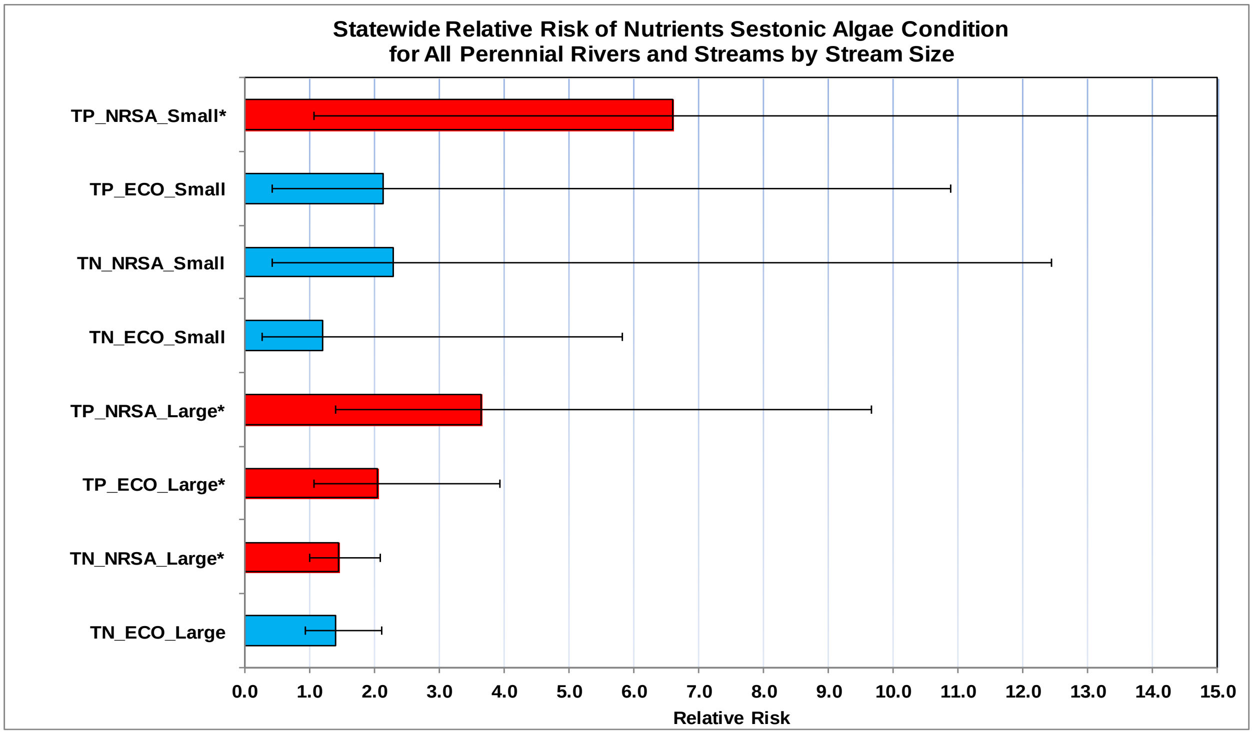


Figure 43. Relative risk of nutrient stressors affecting poor sestonic algae condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

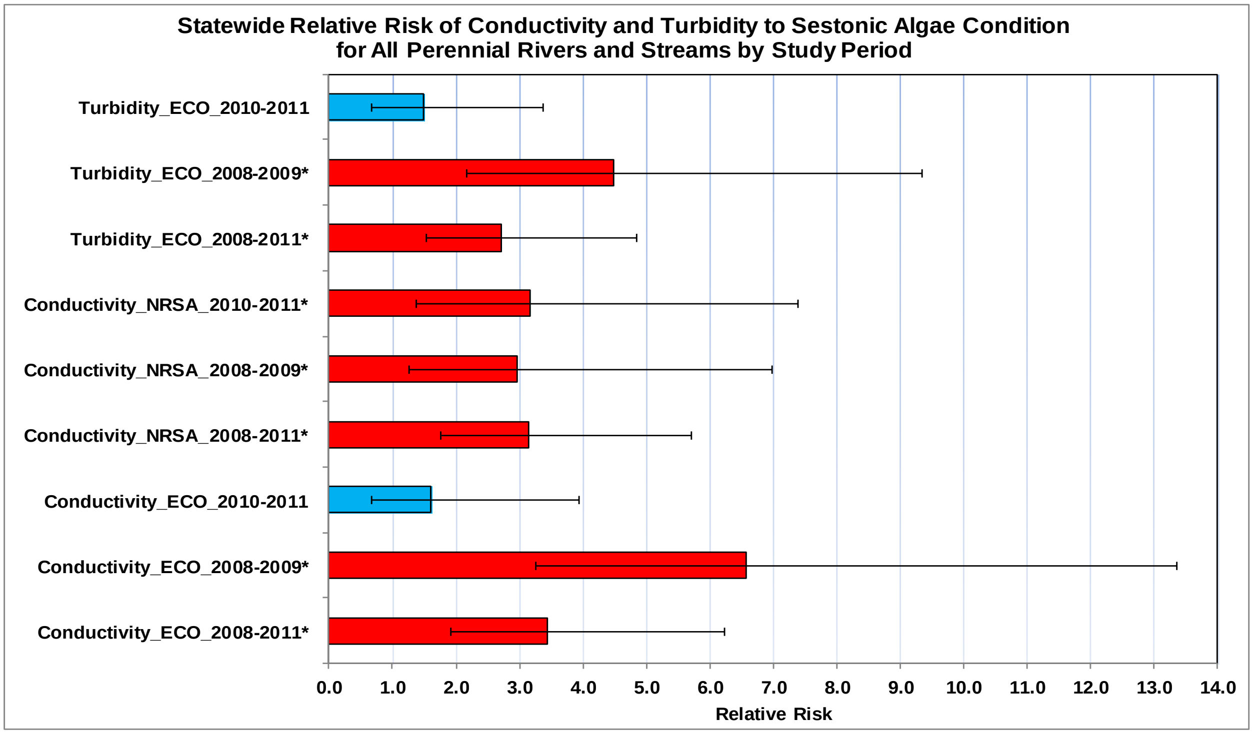


Figure 44. Relative risk of conductivity and turbidity stressors affecting poor sestonic algae condition by study period. (upper/lower bounds represent a 95% CI) (* = significant RR)

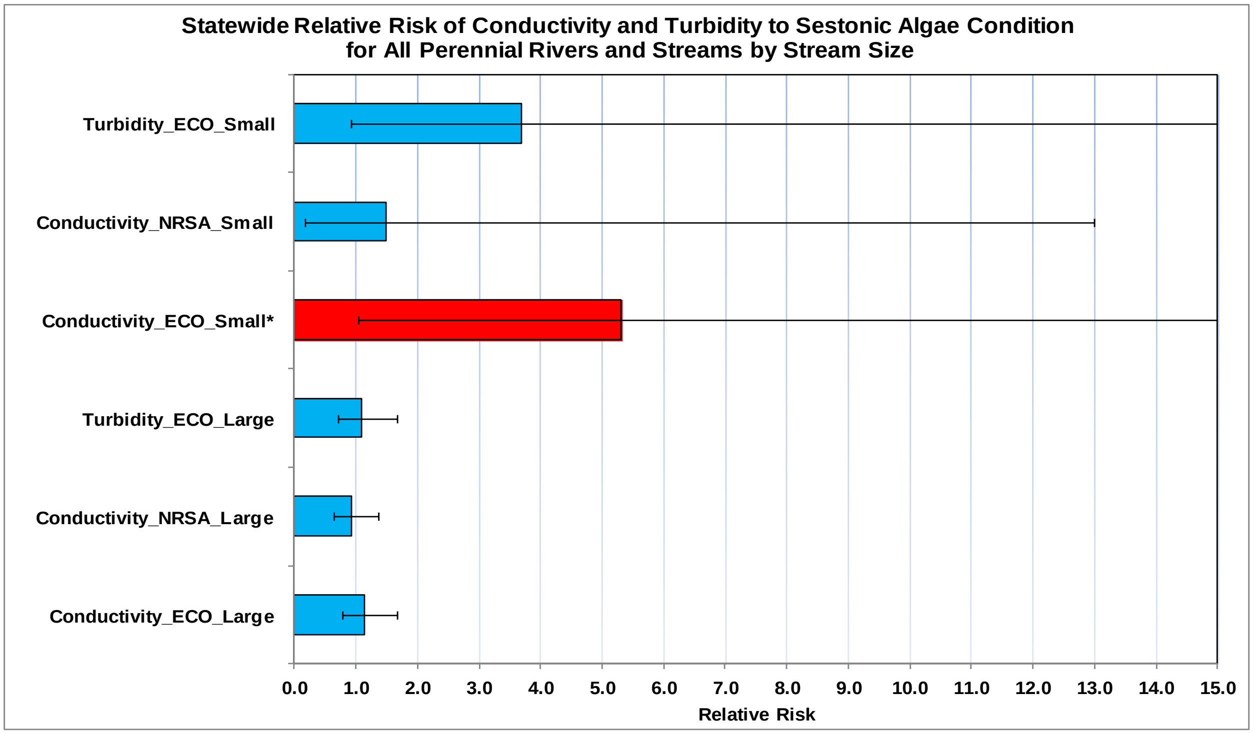


Figure 45. Relative risk of conductivity and turbidity stressors affecting poor sestonic algae condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

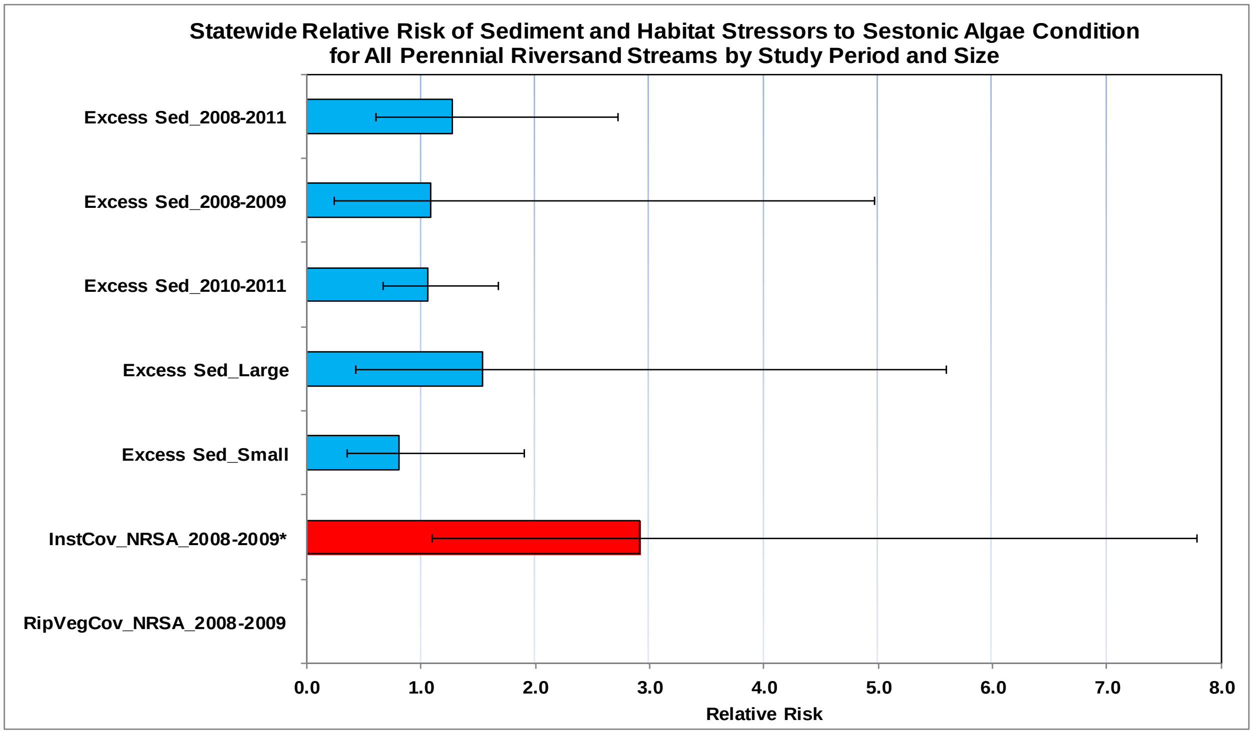


Figure 46. Relative risk of sediment and habitat stressors affecting poor sestonic algae condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

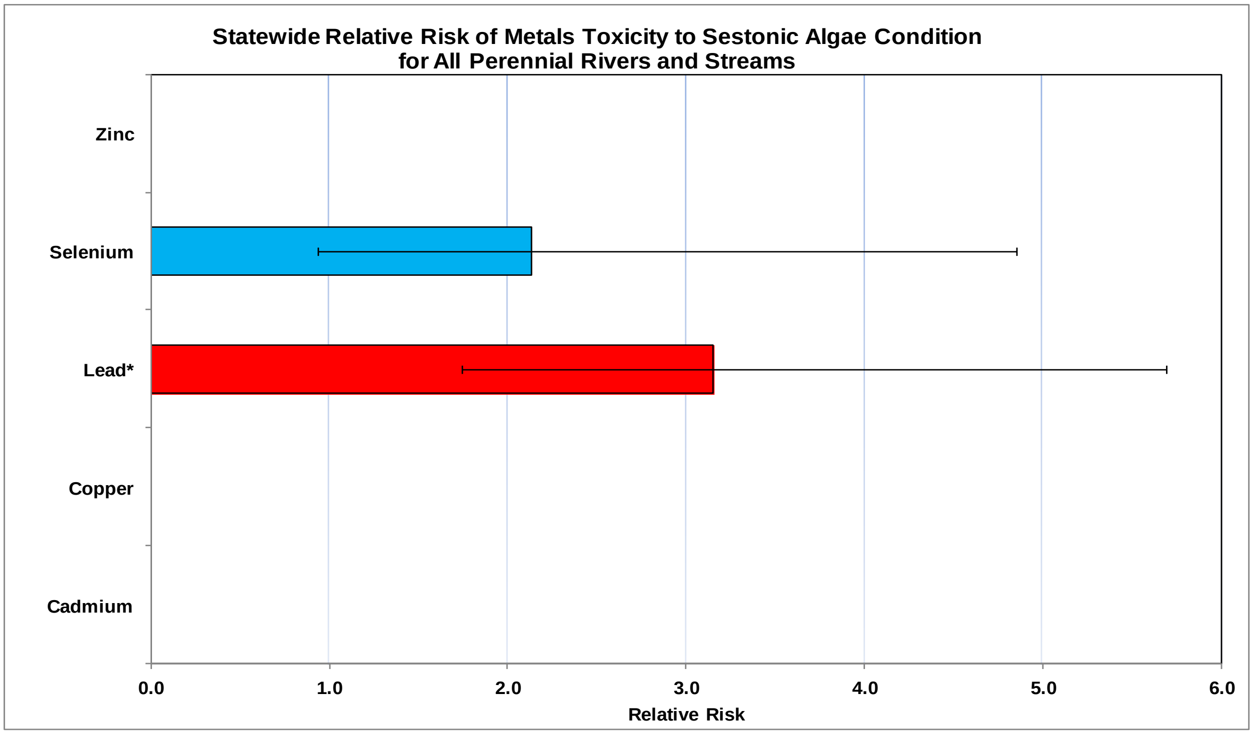


Figure 47. Relative risk of metal toxicity stressors affecting poor sestonic algae condition by waterbody size. (upper/lower bounds represent a 95% CI) (* = significant RR)

Oklahoma's Integrated Water Quality Report

Oklahoma's environmental agencies gather and assess data across the state for a wide variety of biological, chemical, and physical water quality indicators. One purpose of these data collections is to meet federal Clean Water Act requirements to compile a list of impaired waterbodies and determine the condition of all of these waters. These reports are compiled to the biannual Oklahoma Water Quality Assessment Integrated Report (ODEQ, 2010).

The current study benefits this report in several ways. First, this report marks Oklahoma's second and third statistically based assessments of the condition of Oklahoma's lotic waters. The OWRB recommends that this report be adopted into the 305(b) section of the 2012 or 2014 integrated report. Included graphics can be used to show overall statewide and regional condition. Second, individual lotic waterbodies not yet included in Oklahoma's Integrated Report (ODEQ, 2010) now have some level of assessment. The OWRB regularly submits waters for inclusion on Oklahoma's 303(d) list, and will do so again in October 2013. As a part of OWRB's submission, waterbodies assessed as part of this study will be included for consideration as not only category 5 (impaired), but as category 3 (not impaired for some uses). Because of assessment rules housed in Oklahoma's Continuing Planning Process (CPP) (ODEQ, 2012) and USAP (OWRB, 2012b), certain water quality parameters will not be included as part of the assessment. Most of Oklahoma's assessment protocols require that certain data requirements be met including the number of samples required to make an assessment determination. Protocols were developed to either assess short-term or long-term exposure. Short-term exposure protocols are written as percent exceedances, with typically a minimum of ten samples required. Long-term exposure protocols are based upon some measure of central tendency, but typically require a minimum number of samples to calculate the applicable descriptive statistic. Some exceptions to these rules include biological assessments, application of the sediment criteria, and a single sample maximum of 200 mg/m^3 for benthic chlorophyll-a. All other parameters included in this study will not be included in assessments for the impaired waters list but will be made publicly available in the event that another entity can include the data in their assessment. To ensure inclusion of relevant data, stations will be placed in the most current version of the OWRB Assessment Workbook (OWRB 2013c), which is not only used to assess waters for the Oklahoma Integrated Report but for the OWRB's Beneficial Use Monitoring Program (OWRB, 2013a)

Differences in Indicator/Stressor Levels

The current study allows for unique analysis between both study periods and waterbody size. Differences in poor condition of both indicators and stressors are presented in Table 10. The analysis simply compares the differences in percent of total miles in poor condition, and establishes significant difference between periods or size if the 95% confidence interval does not overlap the calculated percentage of the other subcategory. For example, for fish, the confidence intervals of period percentages overlap but do not overlap the calculated percentage. Additionally, the arrows in the trend column merely indicate the direction of a potential trend.

For indicators, both fish and macroinvertebrates demonstrate a downward trend in poor condition between study periods, with only the fish having a significant downward trend. Conversely, both algal indicators show an upward trend, with only the benthic algae trend having significance. Likewise, all but one of the total phosphorus stressors shows an upward trend between the two study periods, with only turbidity and sediment having a significant trend. Notably, environmental conditions, particularly drought, became more acute in 2010-2011, and high water was an issue during a portion of the 2009 index period. Otherwise, no other notable differences exist between the two periods, except the MMI used to analyze to macroinvertebrates, which could account for the difference in poor condition between the two periods. Lastly, when comparing large to small waterbodies, all indicators and stressors have a larger percentage of large river miles in poor condition that small river miles. And, with the exception of sediment, all differences are significant. Likely, this exists for several reasons. First, larger rivers and streams carry much heavier pollutant loads because they have a much larger area of input. Second, the development and refinement of reference condition, metrics, and stressor criteria/screening limits need continued development at both ecoregion and size scales. Data exists to perform these tasks and would eliminate much of the potential noise that is present in current assessments.

Table 10. The percentage of indicators and stressors in poor condition compared between study periods, as well as large and small waterbodies. Arrows show direction of potential trend (** = significant at alpha of 0.95)

Indicator/Stressor	2008-09 %Poor	2010-11 %Poor	Trend	Large %Poor	Small %Poor	Change
Fish	43.9%	21.7%	↓**	50.1%	30.4%	**
Macroinvertebrate	40.6%	25.7%	↓	62.3%	24.7%	**
Benthic Algae	3.7%	21.3%	↑**	21.7%	5.9%	**
Sestonic Algae	18.2%	28.3%	↑	60.6%	6.8%	**
Conductivity_ECO	10.6%	21.4%	↑	38.5%	5.5%	**
Conductivity_NRSA	16.7%	22.7%	↑	55.0%	5.1%	**
TN_ECO	23.4%	37.5%	↑	40.3%	24.1%	**
TN_NRSA	12.2%	22.3%	↑	31.3%	10.1%	**
TP_ECO	40.7%	36.9%	↓	73.8%	26.2%	**
TP_NRSA	31.0%	40.1%	↑	76.4%	18.3%	**
Turbidity_ECO	11.5%	26.6%	↑**	36.9%	9.5%	**
Sediment	15.8%	51.3%	↑**	34.9%	26.2%	NS

Attributable Risk

To determine the actual affect a stressor has on a particular biological indicator, relative risk analyses were made for each stressor-indicator pair and presented in the results section of this report. However, is there a way to determine how much affect a proportional reduction in a stressor would have on the incidence of poor condition in an indicator? Attributable risk provides an elimination scenario to investigate this relationship and potential beneficial outcomes of reduction (Sickle and Paulsen, 2008). Although assailable assumptions are made about causality and the analysis requires elimination of the stressor, it is still a useful extension of the stressor extent and risk models already used in probability assessments. As reported in the draft NRSA report:

> “Attributable risk represents the magnitude or importance of a potential stressor and can be used to help rank and set priorities for policymakers and managers. Attributable risk is derived by combining relative extent and relative risk into a single number for purposes of ranking. Conceptually, attributable risk provides an estimate of the proportion of poor biological conditions that could be reduced if high levels of a particular stressor were eliminated. This risk number is presented in terms of the percent of length that could be improved” (USEPA, 2013).

The results of attributable risk for the current Oklahoma studies are provided in Figures 49-52. In order to provide a meaningful analysis, an assumption was made that if relative risk was not significant, then calculating of an elimination scenario was not meaningful. Therefore, pollutant elimination analyses were only performed where stressor/indicator relative risk was significant. Confidence intervals were also calculated for each risk analysis, and significant potential reduction only exists where the upper confidence bound does not equal the original percent in poor condition. For example, in Figure 49, an elimination of turbidity could reduce poor condition for fish in large rivers by approximately 10%. However, upper confidence bound is not lower than the original percentage in poor condition, so the potential reduction is effectively not different from “0”.

Notably, for fish, elimination of sediment in large rivers could create a significant reduction of poor condition in fish as could reduction in conductivity (Figure 49). For macroinvertebrates, elimination of both total phosphorus and total nitrogen could have a significant effect on poor condition (Figure 50). The elimination of phosphorus in small streams results in a nearly 14% lowering of the percent of miles in poor condition. As with fish, the elimination of conductivity is significant in some scenarios. Sestonic algal condition shows potential promise with a variety of pollutant elimination scenarios (Figure 52). Turbidity, conductivity, and nutrients all show some significant results. Of particular interest, many of the total phosphorus measures show significant potential reduction in sestonic algal growth. For example, in large rivers, the elimination of phosphorus would reduce the percent of river miles in poor condition by greater than 25 to 40%. There is no significant pollutant elimination scenarios related to benthic algae condition (Figure (51).

Interestingly, the elimination of conductivity is consistently significant in reducing the prevalence of poor indicator condition. Because of Oklahoma’s significant conductivity gradient, this is to be expected. However, it is yet another indication of the need for refinement and further regionalization of reference condition and biological criteria, as well as the potential effect of dewatering and drought in alluvial systems. Likewise, the potential that the elimination of phosphorus would have on biological condition is prevalent throughout the analysis, regardless of study period, waterbody size, or screening limit source.

Future Plans

In terms of monitoring, probabilistic design has been completely integrated into both the OWRB and OCC monitoring programs (OWRB, 2012d). The OWRB is currently participating in the 2013-2014 National Rivers and Streams Assessment (NRSA) and will use data from it to provide an update to the current report. Also, the fourth two-year statewide study will begin in 2015 (OWRB, 2013b). Substantive changes to the program will include: 1) use of the NRSA protocols for large Wadeable and non-wadeable waterbodies, 2) use of NRSA habitat protocols for wadeable streams in concert with the current RBP habitat protocol, 3) inclusion of a second winter macroinvertebrate index period, 4) development of a periphyton taxonomic assemblage, 5) assessments at aggregated ecoregion scales used in the 2005-2007 assessment (OWRB, 2009), and 6) change/trend analyses through the use of revisit sites. Dependent upon future funding, additional plans are also in the works for future regionally based studies, similar to the Illinois River Basin Project (OWRB, 2010a).

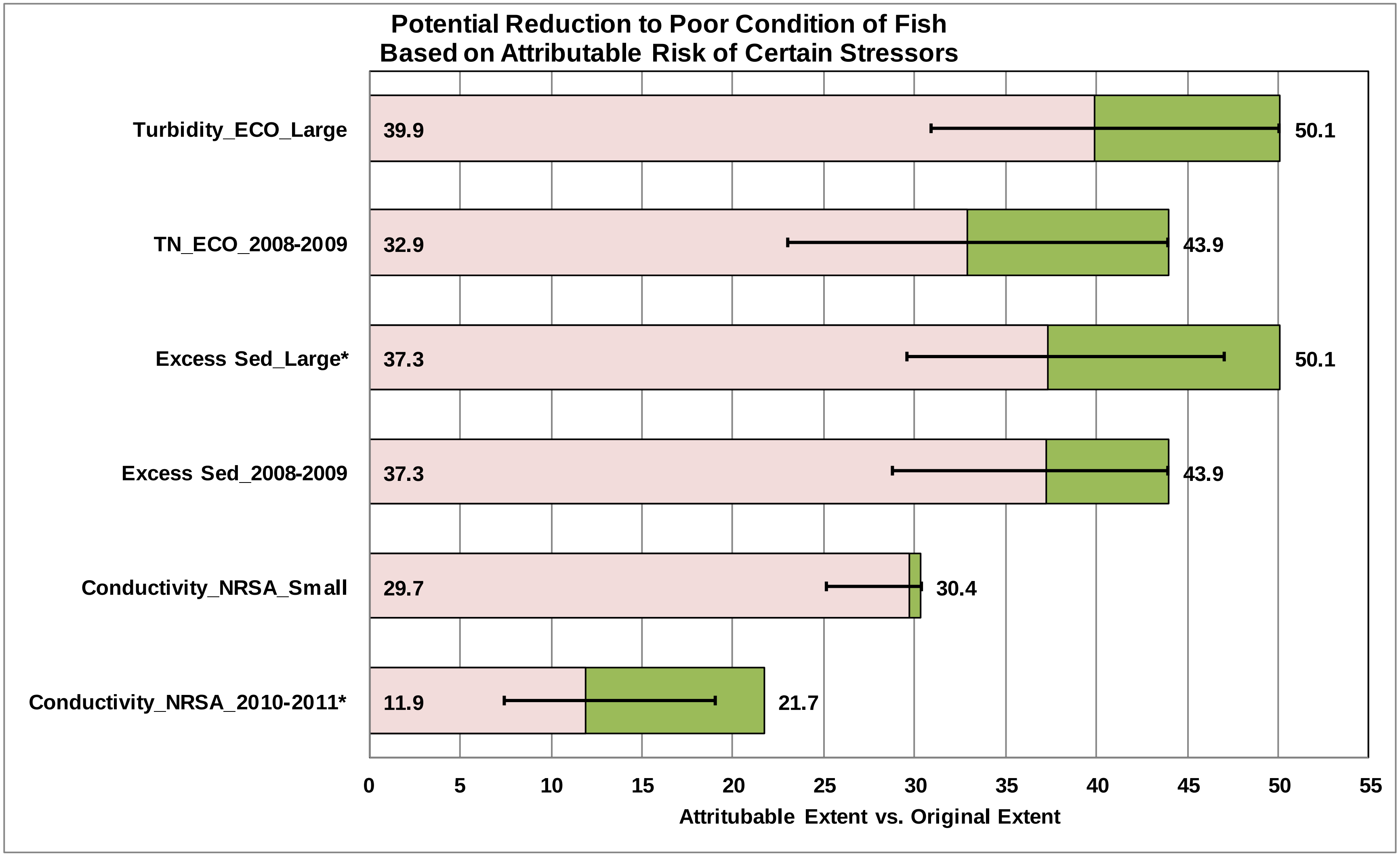


Figure 48. Potential reduction to poor condition of fish based on the attributable risk of stressors having significant relative risk. (upper/lower bounds represent a 95% confidence interval-CI)

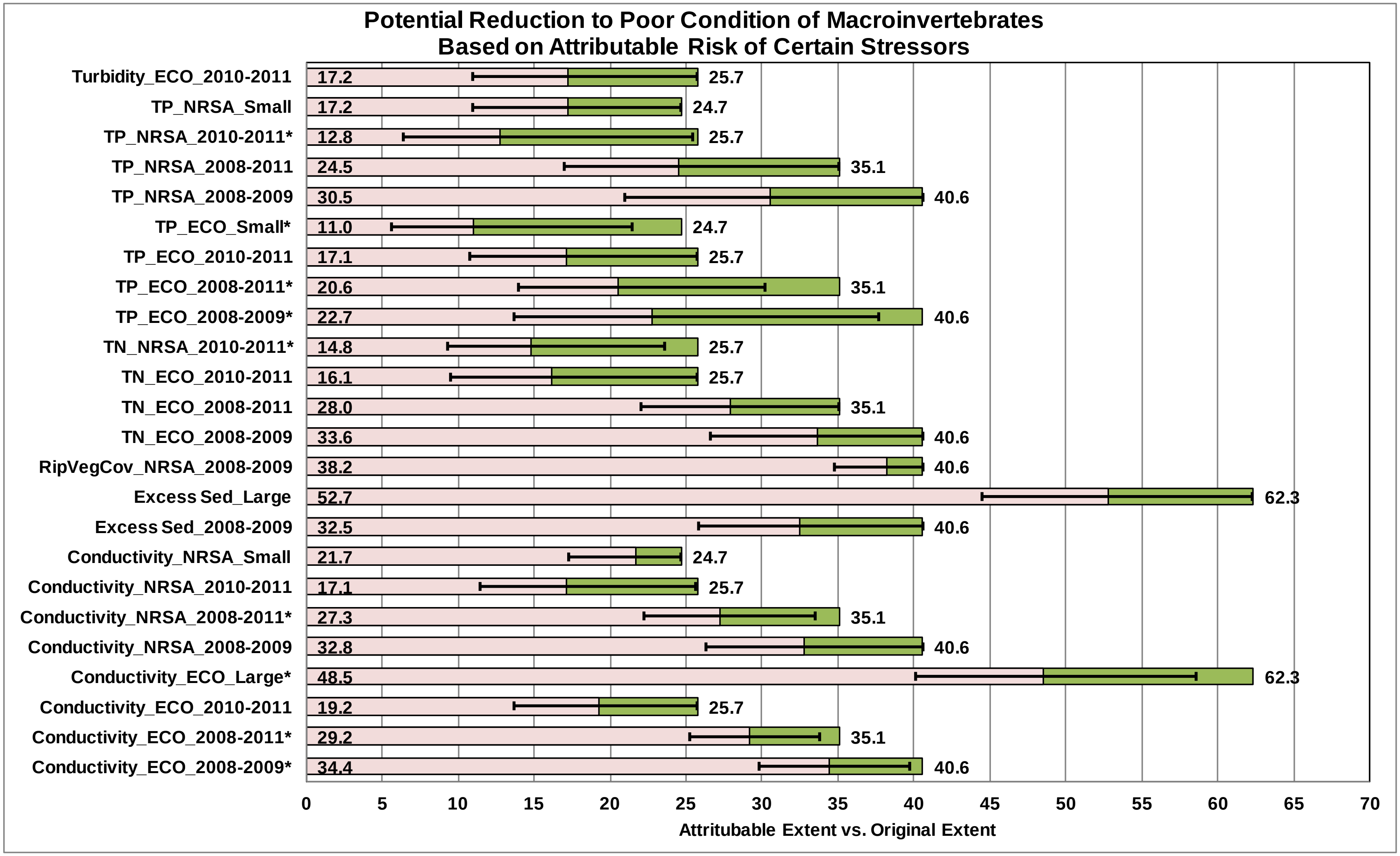


Figure 49. Potential reduction to poor condition of macroinvertebrates based on the attributable risk of stressors having significant relative risk. (upper/lower bounds represent a 95% confidence interval-CI)

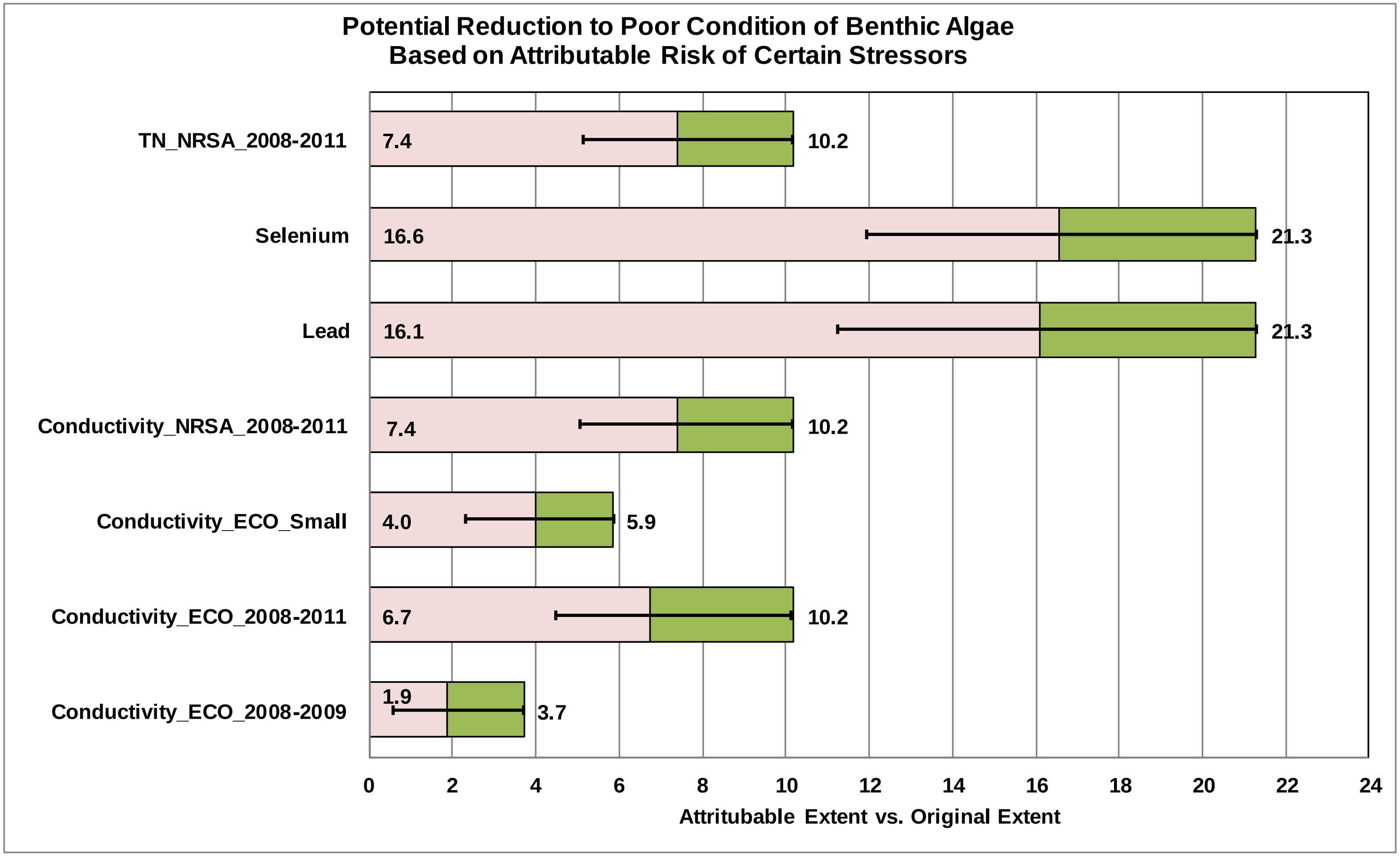


Figure 50. Potential reduction to poor condition of benthic algae based on the attributable risk of stressors having significant relative risk. (upper/lower bounds represent a 95% confidence interval-CI)

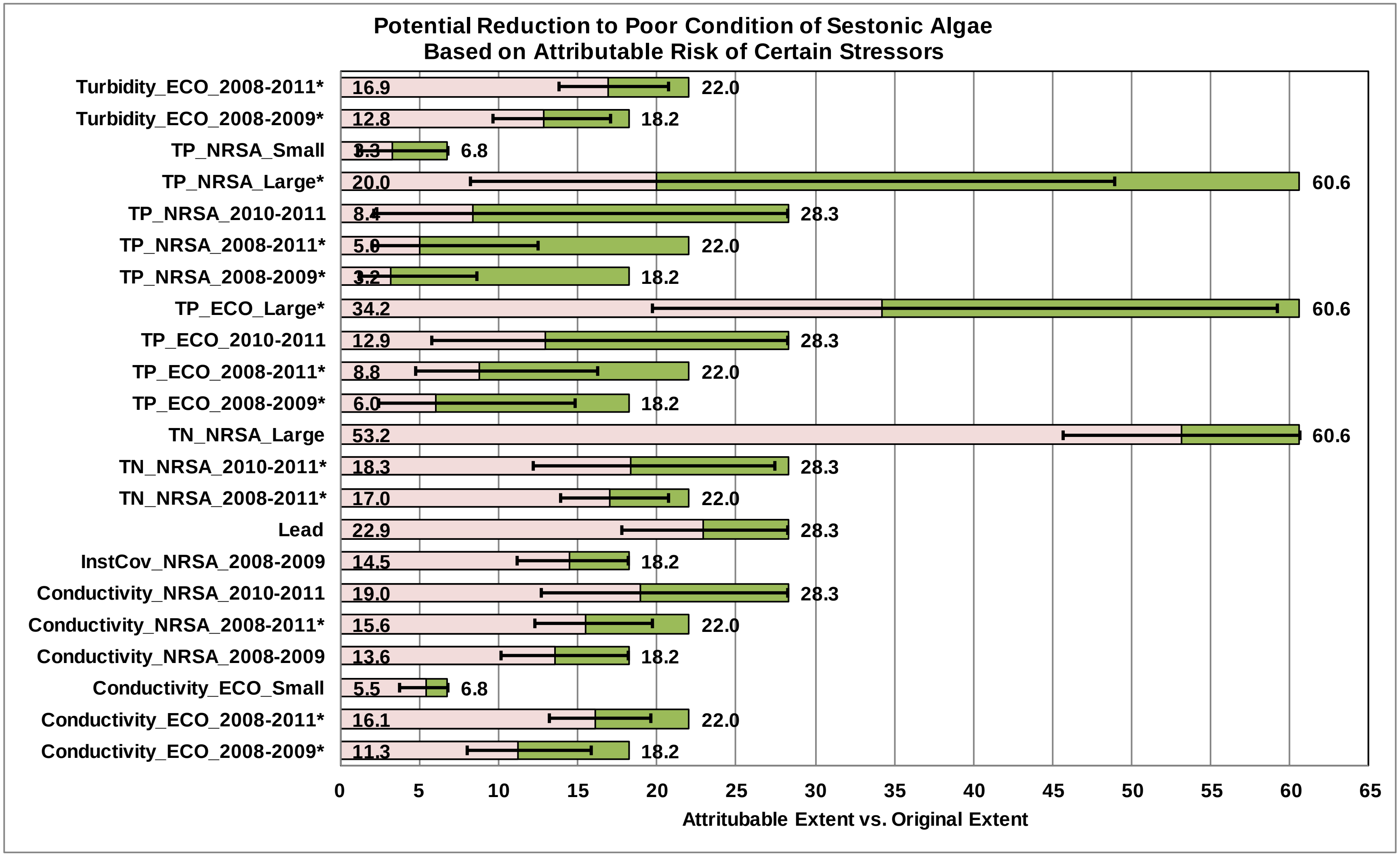


Figure 51. Potential reduction to poor condition of sestonic algae based on the attributable risk of stressors having significant relative risk. (upper/lower bounds represent a 95% confidence interval-CI)

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