FINAL

USING MBSS DATA TO IDENTIFY STRESSORS FOR STREAMS THAT FAIL BIOCRITERIA IN MARYLAND

Prepared by:

Mark Southerland
Jon Vølstad
Edward Weber
Versar, Inc.
Columbia, MD

Ray Morgan
University of Maryland
Frostburg, MD

Lee Currey
John Holt
Charles Poukish
Matt Rowe
Maryland Department of the Environment
Baltimore, MD

DEPARTMENT OF THE ENVIRONMENT
1800 Washington Boulevard, Suite 540
Baltimore, Maryland 21230-1718

June 2007

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ANC	Acid Neutralizing Capacity
BIBI	Benthic Macroinvertebrate Index of Biotic Integrity
CADDIS	Causal Analysis Diagnosis Decision Information System
DNR	Maryland Department of Natural Resources
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
FIBI	Fish Index of Biotic Integrity
HBI	Hilsenhoff Biotic Index
IBI	Index of Biotic Integrity
MBSS	Maryland Biological Stream Survey
MDE	Maryland Department of the Environment
PSU	Primary Sampling Unit
SAV	Submerged Aquatic Vegetation
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus

1.0 BACKGROUND

Over the coming years the Maryland Department of the Environment (MDE) is required to prepare a number of Total Maximum Daily Load (TMDL) analyses for Maryland 8-digit watersheds listed as impaired under Category 5 of the State 303(d) list. MDE recognizes that the TMDLs will contain uncertainty, but at the same time, the Department plans to ensure that the TMDLs can be adapted to new information that may become available in the future.

For all waterbodies listed as impaired under Category 5 of the Integrated 303(d) List, the State is required to either establish a TMDL of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate that water quality standards are being met (CFR 2007). Examples of possible impairments include: pH, fecal coliform, nutrients, sediments, and metals. Additionally, a number of Maryland waterbodies are currently listed for impacts to biological communities, indicating that while the biology of a stream is impaired, the specific stressors to the waterbody are unknown (MDE 2007). MDE, with the support of the University of Maryland and Versar, Inc., has recently revised its approach to developing TMDLs for sediment-impaired waters. The new approach is based on the Maryland Biological Stream Survey (MBSS) data (DNR 2007).

The study described within this report applied an MBSS-based analytical approach similar to that used in the sediment study to identify additional stressors that are likely to affect biologically impaired watersheds on the Category 5 List. This study was a cooperative effort between the University of Maryland, Versar, and MDE. It compliments MDE's stressor identification framework by accumulating evidence for differentiating candidate causes of impairment.

2.0 OBJECTIVES

The primary goal of the cooperative study summarized in this document was to identify likely stressors affecting "biologically" impaired watersheds within Maryland by using a wide range of physical, chemical, and biological data made available by the statewide MBSS program (DNR 2007). In addition, to ensure valid ecological concepts and methodologies, Versar and the University of Maryland completed a peer review of the MDE framework. As a result, a systematic weight-of-evidence approach was developed that compares conditions for stressor surrogate variables in reference watersheds to values found at sites in other watersheds throughout Maryland. While the weight-of-evidence approach provides indicators of stressor likelihood that are based on the currently available information, it is also flexible enough to accommodate new information and an evolving MDE stressor identification framework.

3.0 STRESSOR IDENTIFICATION CONCEPTUAL FRAMEWORK

Versar and the University of Maryland reviewed MDE's conceptual stressor identification framework described in the draft document entitled *Development of a Decision Matrix for Biological Impairments* (Holt 2006). MDE's framework consists of candidate causes of degradation, conceptual cause and effect models, and specific predictions of variable response. The initial framework included 13 candidate causes (i.e., stressor categories), each with specific predictions. The framework was evaluated for:

(1) the validity and comprehensiveness of the thirteen candidate causes (and causal scenarios) proposed,
(2) the validity of the proposed stressors and mechanisms involved in each causal scenario (conceptual model),
(3) the validity and practicality of specific predictions, and
(4) the validity of a weight-of-evidence methodology.

The consensus of the study team (Versar, University of Maryland, and MDE scientists) was that the framework was valid and useful for accomplishing MDE objectives.

Development of the final conceptual framework was an iterative process. First, the number of candidate causes was reduced as many predictions did not have data to support them. Specifically, the 76 predictions with data (each with one or more variables) were combined into the following six general candidate causes (Appendix A):

- Flow regime,
- Terrestrial sediment,
- Energy source,
- Oxygen consuming and thermal waste,
- Inorganic pollutants,
- Organic pollutants.

Next, the team evaluated the merits of each variable (see Appendix A) as a surrogate under each candidate cause (i.e., stressor category). Of concern was the ability to differentiate among different candidate causes when about one-third of the variables were duplicated among causes. If a variable was deemed a significantly better predictor of one stressor, it was retained in that category only, while equally applicable variables were retained in more than one stressor category.

The team made additional revisions to the framework as analyses eliminated candidate variables and the ability to distinguish among candidate causes (stressor categories) diminished. In particular, the land use variables were eliminated so that they could be used for source identification in the future. The team also recognized that certain candidate causes could not be evaluated with the available data and that additional water chemistry sampling would be required. As a result, the final stressor identification conceptual framework (see Figures 1, 2, and 3) was simplified to include only the following three candidate causes:

- The Flow Regime (A) and Terrestrial Sediment (B) candidate causes were combined into one Flow/Sediment (AB) candidate cause.
- The Energy Source (C) and Oxygen-Depleting Thermal Waste (D) candidate causes were combined into a single candidate cause, Energy Source (CD). This was done because both causes shared the Dissolved Organic Carbon (DOC) and Dissolved Oxygen (DO) variables and were therefore hard to differentiate.
- The Hilsenhoff Biotic Index (HBI) variable was moved from the Organic Pollutants (F) candidate cause to the Energy (CD) candidate cause, leaving no variables in Organic Pollutants (F) and eliminating that category. Thus, the remaining third and final candidate cause was Inorganic Pollutants (E).

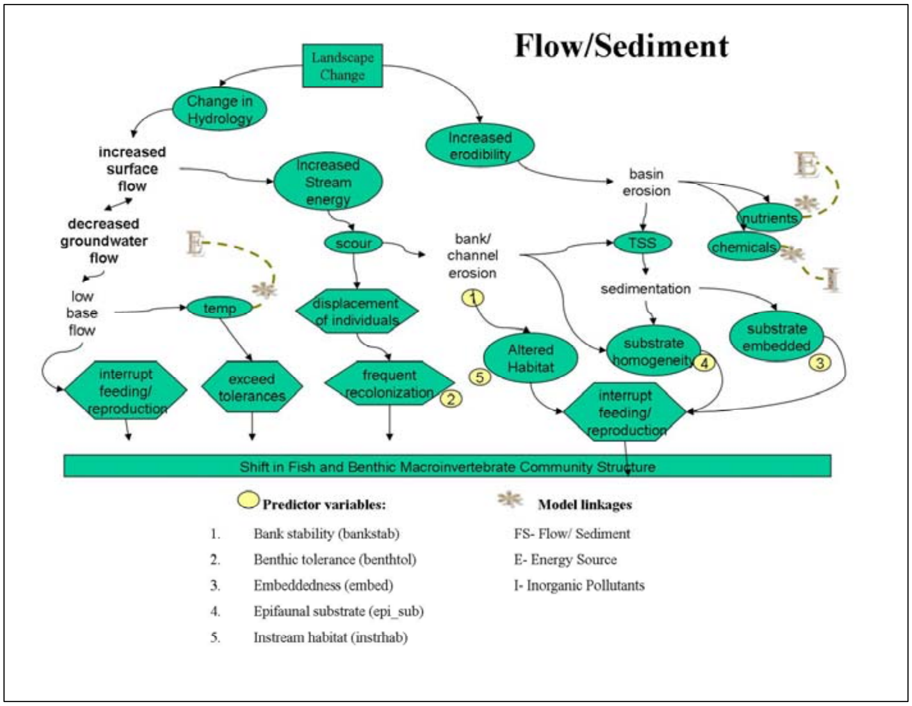
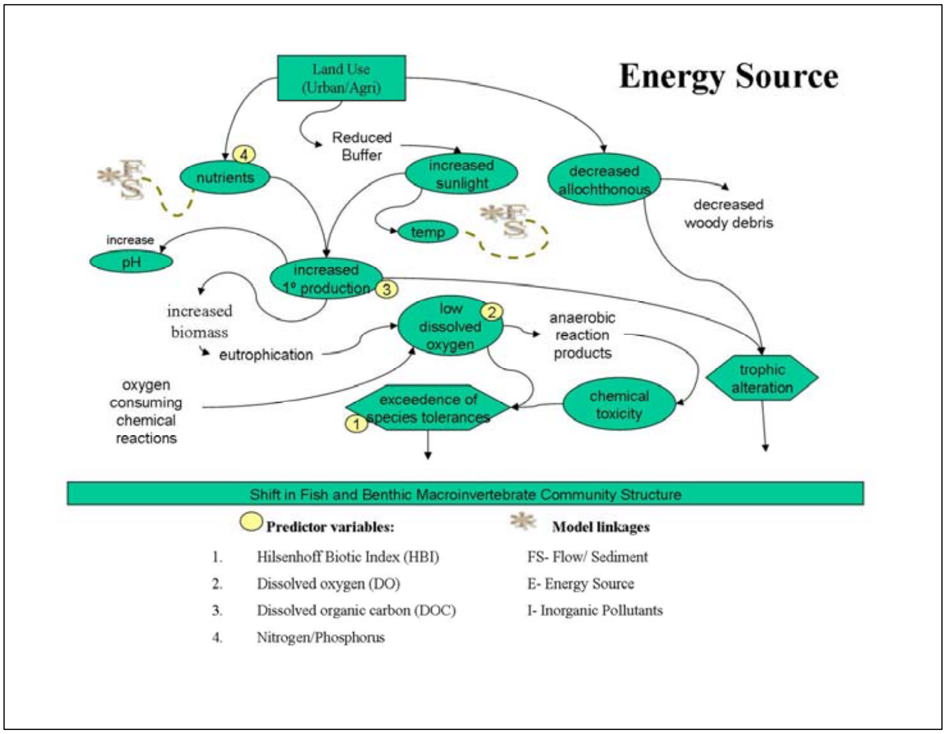


Figure 1: Flow/Sediment Stressor (AB) Identification Conceptual Framework



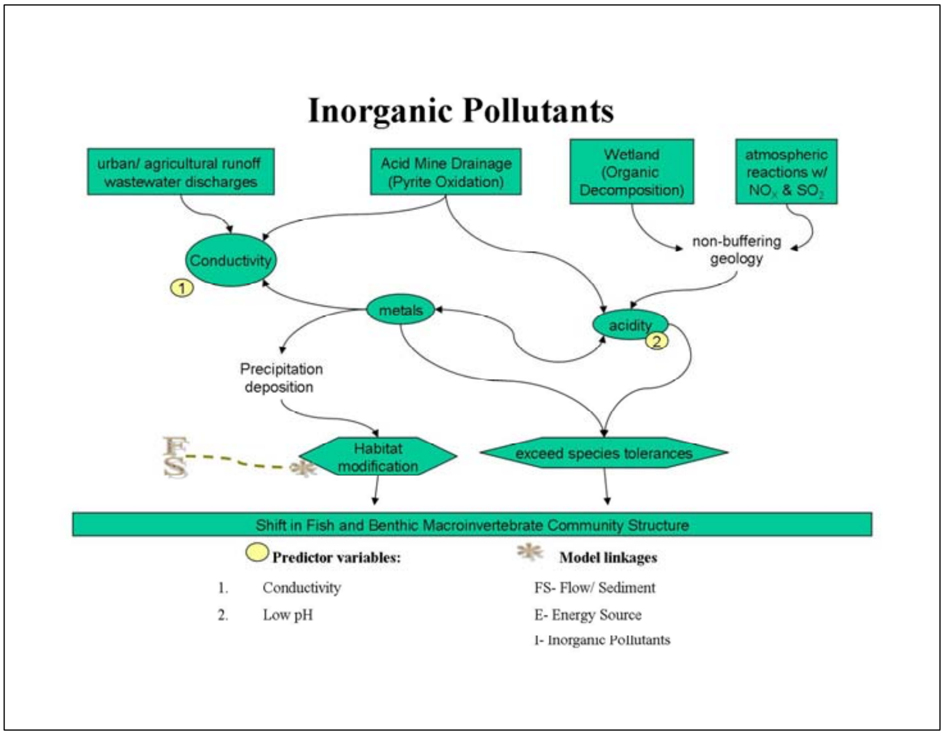
Predictor variables:

1. Hilsenhoff Biotic Index (HBI)
2. Dissolved oxygen (DO)
3. Dissolved organic carbon (DOC)
4. Nitrogen/Phosphorus

Model linkages

FS- Flow/ Sediment
E- Energy Source
I- Inorganic Pollutants

Figure 2: Energy Source (CD) Stressor Identification Conceptual Model



Predictor variables:

1. Conductivity
2. Low pH

Model linkages

FS- Flow/ Sediment
E- Energy Source
I- Inorganic Pollutants

Figure 3: Inorganic Pollutants (E) Stressor Identification Conceptual Framework

4.0 STRESSOR IDENTIFICATION METHODOLOGY

Beginning in March 2005, the cooperators from MDE, Versar, and the University of Maryland, with advice from the Maryland Department of Natural Resources (DNR) and the U. S. Environmental Protection Agency (EPA) developed and evaluated several candidate stressor identification approaches (see Appendix B), which related stressor surrogate information (e.g., instream measures of embeddedness) to degraded biological condition.

The study team considered several ways of relating degraded biological conditions to candidate stressor variables. In the end, the group decided to use both the fish and benthic macroinvertebrate Indices of Biotic Integrity (IBIs) to describe degraded biological conditions (Southerland et al. 2005), as this approach was already codified in the state's biocriteria. The team chose quantile regression as the most suitable method for identifying the threshold values indicative of biological degradation in a stressor variable-IBI relationship. The option of developing a multivariate approach was considered but was deemed statistically not tractable nor intuitive enough for implementation. The team decided to focus on analyzing individual MBSS variables to develop a metric for each variable based on a comparison with reference conditions in the appropriate geographic region: Coastal Plain, Eastern Piedmont, or Highlands. The goal of the analysis was to identify watersheds or Primary Sampling Units (PSUs) used in Round 2 of the Maryland Biological Stream Survey where the metric values of selected variables were outside of the normal range for unimpaired streams in the region. Finally, the team needed to decide how to combine the individual stressor variables into a weight of evidence at the scale of the biological impairments (i.e., Maryland 8-digit watersheds or combined watersheds within MBSS PSUs with at least 10 MBSS sites).

Ultimately, the team recommended using a "stream disturbance index" method to score stressor values on a 1-3-5 scale and subsequently combine them in a manner analogous to the multi-metric IBIs. Figure 4 summarizes the steps used to develop the stressor identification method.

4.1 Review Data and Screen Variables

Appendix A lists the MBSS stream site and upstream catchment variables associated with each of the predictions in the original stressor identification framework. This list includes one or more MBSS stream site and catchment variables for most of the 11 to 14 different predictions within each original candidate cause. The appendix also includes comments for variables that are limited in their utility or need further development.

When deciding on an appropriate reference benchmark, the team decided to use the IBI of 3.0 plus a confidence limit (approximately 3.1-3.2). This approach is consistent with Maryland's biocriteria. The stressor identification analyses used only the benthic macroinvertebrate IBI (BIBI) as it would be difficult to combine or reconcile the differing results of the BIBI and fish IBI (FIBI) values. While the team recognized that stressor-variable relationships may differ by environment, developing unique regions for each variable is intractable. Thus, the team decided to test all variables separately in each of the three geographic regions (consistent with IBI development) and use only those variables that performed well in each region. Finally, analysis of the biological variables (e.g., dominance of pioneer taxa) used the original MBSS reference sites (selected based on abiotic conditions) rather than the BIBI to avoid circularity.

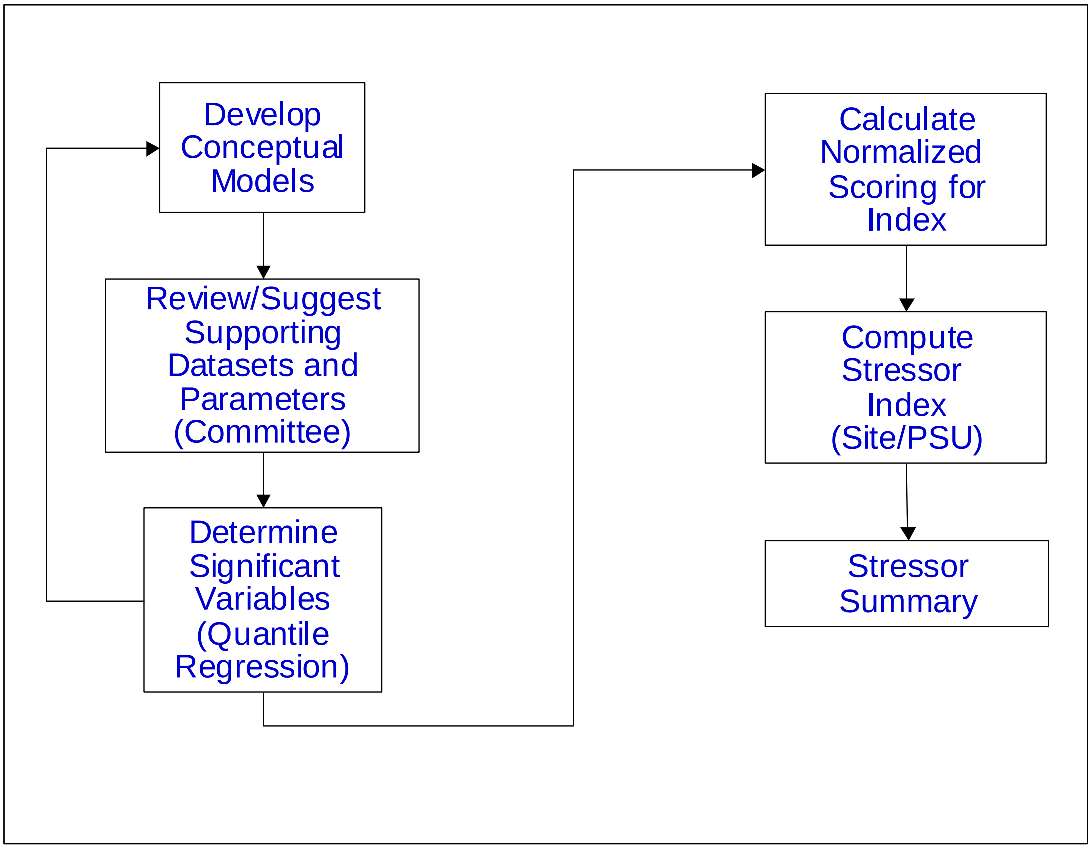


Figure 4: Steps Used to Develop the Stressor Identification Method

The team reviewed the complete list of candidate stressor variables by comparing the distribution of variable values within each watershed to the variable distribution at reference sites within the appropriate region: Highlands, Eastern Piedmont, and Coastal Plain. Only variables with a less than 0.2% chance of having the same distribution as the references sites (defined as having a BIBI score of 3.0 plus a confidence limit) were retained. In addition, for each of the MBSS variables, the 75th percentile of all values occurring at reference sites was also determined. The variable value for each site in the watershed was plotted and coded red if it exceeded the 75th reference percentile; sites not exceeding the 75th reference percentile were coded black (see Figure 5 for example). The team compared the relative number of red values vs. black values in each of the three watershed categories: watersheds passing biocriteria, watersheds indeterminate for biocriteria, and watersheds failing biocriteria. Only variables where at least 50% of the failing watersheds had relatively more red than black values were retained. Lastly, the team visually inspected the graphs to determine if the magnitude of the difference in red values between passing and failing watersheds was sufficient to retain the variable.

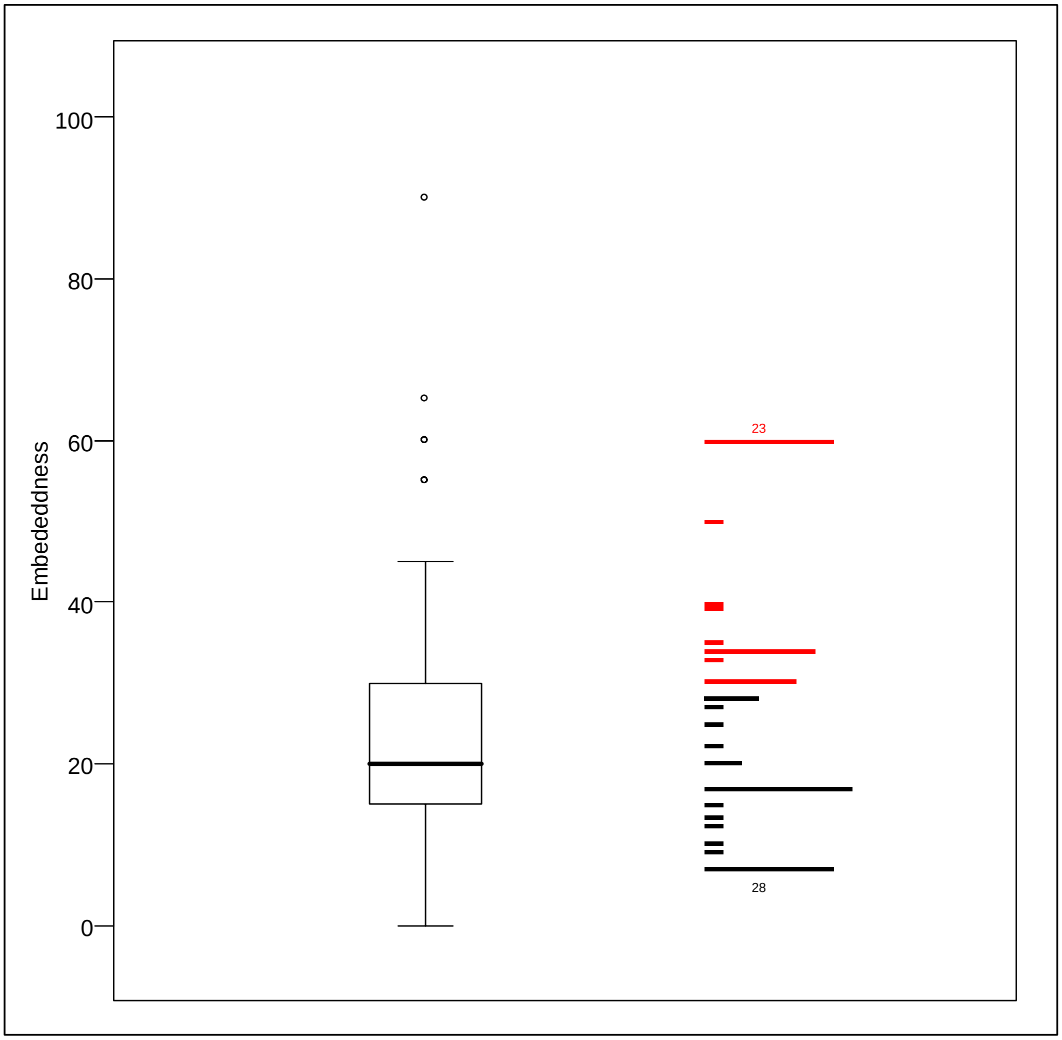


Figure 5: Embeddedness Variable Values Exceeding (Red) and Not Exceeding (Black) the 75th Percentile of Reference watersheds

Appendix C provides the graphs of all variable values for each watershed as described above. The box and whisker graph plot to the left of each bar graph shows the distribution of reference sites within the region. The bars at each PSU show the distribution of variable values within that PSU. The red and black numbers above and below the bar graphs indicate the total number of red or black sites, respectively. The dotted blue lines separate PSUs in each of three categories of watersheds: watersheds passing biocriteria, watersheds indeterminate for biocriteria, and watersheds failing biocriteria (appear in order from left to right in the graphs in Appendix C). If the variable is binary, the proportion of reference sites is marked with a symbol rather than a box plot, and PSUs are recorded using bar graphs that indicate the proportion of sites affected.

Additionally, the Stranko et al. (2005) fish model data (e.g., percent of fish species excluded by low DO) was included and treated the same as the other variables.

The variables meeting all three criteria were designated as the ultimate candidate variables for use in the subsequent analysis. Next, the team reviewed the results for additional candidate variables including a wide range of land use variables developed by Holt (2006) and a few additional biological variables. As a result of this analysis, a decision was made to replace any MBSS land use variables with comparable variables developed by Holt (2006). Appendix D provides the full list of candidate variables.

4.2 Test Variables for Significance Using Quantile Regression

The variables based on land use data were removed from the candidate variable list so that they could be used to identify sources of degradation in the future. In addition, minimum buffer width, SO_4, Submerged Aquatic Vegetation (SAV), and anomalies were removed after additional review of the data, while total nitrogen (TN) and total phosphorus (TP) were added to the list because of their importance to the TMDL process. The remaining 15 candidate variables were evaluated for inclusion in the final method using quantile regression, which is a robust technique for evaluating relationships to biological conditions where both natural variability and interacting stressors can influence the analysis (Cade and Noon 2003).

Variables to be retained as significant stressor surrogates were selected based on the 90th (or 10th) percentile quantile regression of all values within each ecological region: Highlands, Eastern Piedmont, and Coastal Plain. Quantile regressions were done separately for BIBI values and FIBI values (see Figure 6 for an example). A variable was selected if the p value for the quantile regression slope was less than 0.05. This criterion was consistent with visual inspection of the quantile regression plots, (i.e. those graphs showing a clear relationship between the variable values and IBI values from 1 to 5). Appendix E shows the quantile regression graphs for each variable separately for BIBI and FIBI scores grouped by ecological region.

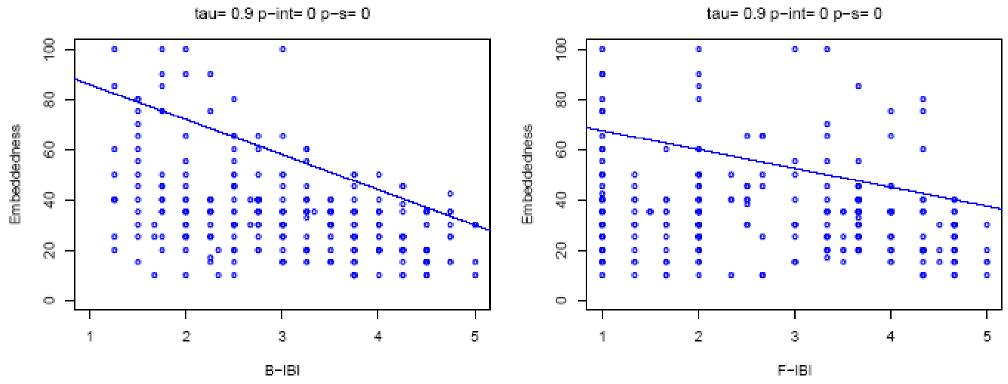


Figure 6: Quantile Regressions of Embeddedness Stressor Variables Against Benthic and Fish IBIs to Identify Significant Relationships

4.3 Calculate Normalized Scoring For Stream Disturbance Index

A stream disturbance index for normalizing variables with significant quantile regression slopes was developed by scoring them as 1-3-5 for each site. Variable vs. IBI relationships were developed separately for the BIBI and FIBI scores in each of the three IBI regions: Highlands, Eastern Piedmont, and Coastal Plain. For variables that increase with higher IBI scores, variable values less than the 10th percentile of sites with an IBI equal to or greater than 3 were scored a 1, values between the 10th and 50th percentiles were scored a 3, and values greater than the 50th percentile were scored a 5. For variables that decrease with higher IBI scores, the scoring was reversed (i.e., 1 greater than the 90th, 3 between the 90th and 50th, and 5 less than the 50th). The 10th percentile limit for pH was adjusted to 6.2 to match the established pH threshold. Also, The 10th percentile limit for DO was adjusted to 6 mg/l in the Highlands and Eastern Piedmont and 5 mg/l in the Coastal Plain to match the established threshold. The percentile thresholds used to score each variable value are shown in Tables 1, 2, and 3. This 1-3-5 scoring method is consistent with that used to develop the Maryland IBIs and is illustrated in Figure 7.

Table 1: Flow/Sediment Percentile Thresholds Used to Develop the Stream Disturbance Index Scores for Each Variable by Region

Stressor Category - Flow/Sediment (AB)		Highland				Eastern Piedmont				Coastal			
			Percent				Percent				Percent		
		n	10	50	90	n	10	50	90	n	10	50	90
Bank Stability Index	Site F&B IBI >=3	122	12	19									
Benthic Tolerant Species	Site F&B IBI >=3	122		4.2	5.3	139		4.7	5.6	172		5.6	6.5
Embeddedness	Site F&B IBI >=3	121		25	40	139		24	45				
Epifaunal Substrate Condition	Site F&B IBI >=3	122	10	15		139	11	16		172	7	13	
Instream Habitat Condition	Site F&B IBI >=3	122	10	16		139	11	16		172	8	14	

* Sites with fish and benthic IBIs were used to determine percentiles.

Table 2: Energy Source Percentile Thresholds Used to Develop the Stream Disturbance Index Scores for Each Variable by Region

Stressor Category - Energy Source (CD)		Highland				Eastern Piedmont				Coastal			
			Percent				Percent						
		n	10	50	90	n	10	50	90	n	10	50	90
Hilsenhoff Biotic Index	Site F&B IBI >=3	122		3.7	5.6	139		4.6	6.6	172		5.4	7.0
Percent Shading	Site F&B IBI >=3	122	40	83		139	55	85		172	30	87	
Dissolved Oxygen	Site F&B IBI >=3	122	7.3(a)	8.4		139	7.2(a)	8.3		171	4.8(b)	7.0	
Dissolved Organic Carbon	Site F&B IBI >=3	122		1.4	2.5	139		1.5	2.9	171		3.6	10.7
Total Nitrogen	Site F&B IBI >=3	122		0.8	2.8								
Ammonia - NH_3	Site F&B IBI >=3	122		0.004	0.018	139		0.011	0.036	171		0.028	0.099
Total Phosphorus	Site F&B IBI >=3	122		0.011	0.023	139		0.016	0.045	171		0.03	0.094

Notes: (a) Dissolved oxygen 10th percentile adjusted to 6.0 mg/l based on daily cold water use per COMAR
(b)Dissolved oxygen 10th percentile adjusted to 5.0 mg/l per COMAR

* Sites with fish and benthic IBIs were used to determine percentiles

Table 3: Inorganic Pollutants Percentile Thresholds Used to Develop the Stream Disturbance Index Scores for Each Variable by Region

Stressor Category - Inorganic Pollutants (E)		Highland				Eastern Piedmont				Eastern Piedmont			
			Percent				Percent				Percent		
		n	10	50	90	n	10	50	90	n	10	50	90
Conductivity	Site F&B IBI >=3	122		0.11	0.30	139		0.17	0.27	172		0.14	0.25
Low pH	Site F&B IBI >=3	122	6.9(a)	7.3		139	6.9*	7.3		172	6.1	6.7	
Acid Neutralizing Capacity	Site F&B IBI >=3	122	90(b)	271(c)		139	225(b)	439(c)		172	66(b)	225(c)	

Notes: (a)Value adjusted to 6.2 based on literature review
(b) Value adjusted to 50 based on literature review
(c) Value adjusted to 200 based on literature review

* Sites with fish and benthic IBIs were used to determine percentiles
* ANC = Acid Neutralizing Capacity

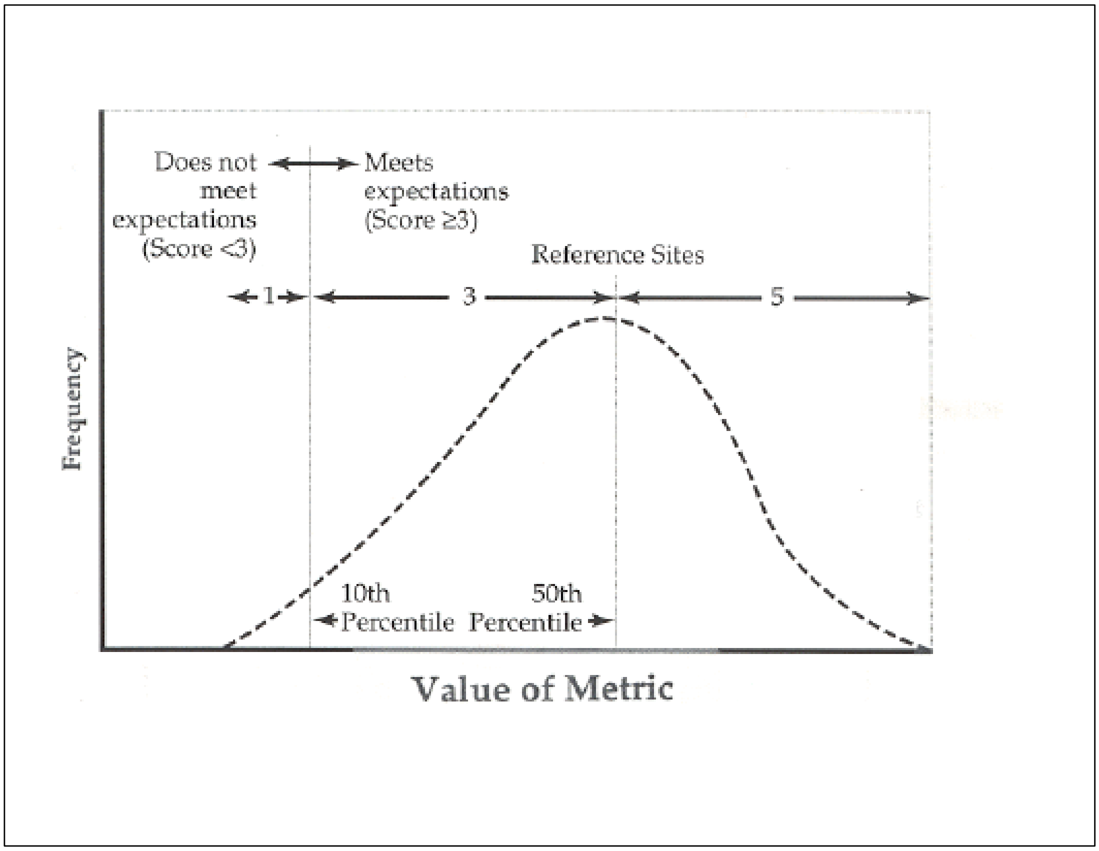


Figure 7: Scoring Method Used to Normalize Variable Values as Stream Disturbance Index Scores

4.4 Ecological Rationale for Variables Included in the Method

The final variables listed in Tables 1-3 were determined to be the best surrogates for stressors available in the MBSS data set. Unlike the land use variables, the selected variables are direct measures of degradation in the stream itself rather than hypothesized causes of degradation. They are also closely tied to specific predictions in the stressor identification framework. This section summarizes the ecological rationale for including each variable in the method.

Table 4: Final Variable Selection for Each IBI per Geographic Region

Stressor Category	Stressor	Highland		Eastern Piedmont		Coastal	
		BIBI	FIBI	BIBI	FIBI	BIBI	FIBI
AB	Bank Stability Index (10%)	S	NS	NS	NS	NS	NS
AB	Benthic Tolerant Species (90%)	S	NS	S	S	S	S
AB	Embeddedness (90%)	S	S	S	S	NS	NS
AB	Epifaunal Substrate Condition (10%)	S	S	S	S	S	S
AB	Instream Habitat Condition (10%)	NS	S	S	S	S	S
CD	Hilsenhoff Biotic Index (90%)	S	NS	S	S	S	NS
CD	Percent Shading (10%)	NS	NS	NS	NS	NS	NS
CD	Dissolved Oxygen (10%)	NS	S	S	S	S	S[a]
CD	Dissolved Organic Carbon (90%)	S	NS	S	S	S	NS
CD	Temperature [b] (90%)	S	NS	S	NS	NS	NS
CD	Total Nitrogen (90%)	S	S	NS	NS	NS	NS
CD	Amonnia-NH_3 (90%)	S	NS	S	S	S	NS
CD	Total Phosphorus (90%)	S	NS	S	NS	S	NS
E	Conductivity (90%)	S	S	S	S	S	S
E	Low pH (10%)	S	S	NS	S	S	S
E	Acid Neutralizing Capacity (10%)	NS	S	NS	S	S	S

Notes: [a] Regression analysis results indicated parameter was not significant, but it was retained since it is a regulatory water quality criterion.
[b] Temperature removed from future analysis.

* Final variables for each IBI and geographic region were selected based on results from stepwise logistic regression. S denotes 10th or 90th percentile QR slope significantly different than zero at $p < 0.05$. NS denotes QR slope NOT significantly different than zero at $p < 0.05$. Stressor categories are Flow/Sediment (AB), Energy Source (CD), and Inorganic Pollutants (E).

4.4.1 Flow and Sediment (AB)

Bank Stability Index

The bank stability index is a composite score combining a visual rating based on the presence or absence of riparian vegetation and other stabilizing bank materials, such as boulders and rootwads, with quantitative measures of erosional extent and severity. Bank stability is a measure of channel erosion, which is a major source of downstream sediment transport. Low bank stability values indicate that a substantial amount of stream bank soil is being eroded and deposited in the stream. Such erosion is the result of high stream flows, frequently caused by stormwater runoff. More than half of the sediment loading in Maryland may result from bank erosion rather than from terrestrial sources.

Benthic Tolerant Taxa

Benthic tolerant taxa is the percentage of the benthic macroinvertebrates in a stream sample considered tolerant of disturbance (i.e., individuals with tolerance values between 7 and 10). Tolerant species are the last to disappear following disturbance and the first to return as systems begin to recover. The percentage of tolerant individuals within a stream increases with increased physical and chemical habitat degradation. The most frequent causes of disturbance in many streams are high flows from increased stormwater runoff. High flows scour benthic habitats and increase sediment inputs to the system. Runoff and sediment particles can also carry pollutants into the stream, further increasing the percentage of tolerant taxa.

Embeddedness

Embeddedness is the percentage of gravel, cobble, and boulder particles in the streambed that are surrounded by fine sediment. High embeddedness is direct evidence of sediment deposition. Although embeddedness is confounded by natural variability (e.g., Coastal Plain streams will naturally have more embeddedness than Highlands streams), embeddedness values higher than reference streams are indicative of anthropogenic sediment inputs from overland flow or stream channel erosion. High embeddedness values indicate a reduction in the amount of habitat available to benthic macroinvertebrates, fish, and salamanders for shelter, foraging, and breeding.

Instream Habitat

Instream habitat is a visual rating based on the perceived value of habitat within the stream channel to the fish community. Multiple habitat types, varied particle sizes, and uneven stream bottoms provide valuable habitat for fish. High instream habitat scores are evidence of a lack of sediment deposition. Like embeddedness, instream habitat is confounded by natural variability. Low instream habitat values can be caused by both high flows that collapse undercut banks and sediment inputs that fill pools and other fish habitats.

4.4.2 Energy (CD)

Hilsenhoff Biotic Index

The Hilsenhoff Biotic Index is a numerical index originally developed to identify low dissolved oxygen conditions caused by organic loading. The HBI uses only arthropods that require dissolved oxygen for respiration to calculate a 0-10 tolerance value for each benthic macroinvertebrate sample. Organisms that are most sensitive to low concentrations of dissolved oxygen have low tolerance values and organisms that are least sensitive to low DO concentrations have high tolerance values. The HBI index is indicative of thermal pollution and nutrient enrichment that reduce dissolved oxygen, but it may also be sensitive to effects of impoundment, high sediment loads, and some types of chemical pollution.

Dissolved Oxygen

Dissolved Oxygen is the amount (usually measured in mg/L) of oxygen dissolved in the water as a function of physical parameters such as water temperature, atmospheric pressure, and flow. In unpolluted streams, DO levels are generally above 80% saturation; low DO levels may indicate organic pollution since heterotrophic organisms such as bacteria consume oxygen. DO levels within a stream typically exhibit diel and spatial variation, but unusually low DO levels may result from thermal inputs (via discharges or sunlight in unshaded streams) or nutrient enrichment (via bacterial consumption of organic matter).

Dissolved Organic Carbon

Dissolved Organic Carbon is the amount of organic carbon present in stream water, usually measured as mg/L. DOC is an important component of normally functioning stream ecosystems; however, elevated levels may indicate the presence of organic pollution sources (i.e., fertilizer, animal wastes, sewage, etc.). Naturally occurring elevated DOC concentrations are often associated with blackwater streams. In Maryland, blackwater streams occur in both the Coastal Plain and boreal bog ecosystems of western Maryland.

Total Phosphorus

Total Phosphorus is a measure of all phosphorus species (either as µg/L or mg/L) found in a stream, consisting of both inorganic and organic forms of phosphorus. The movement and cycling of phosphorus, a naturally occurring nutrient, within a stream system is vital to stream ecosystems. In freshwater ecosystems, phosphorus is often the limiting nutrient, and excess phosphorus may severely affect stream ecosystems. As with TN, excess TP may come from stormwater runoff carrying fertilizers and animal wastes. It may cause aesthetic impairment, interference with uses by the human population, severe effects on aquatic life, and excessive downstream nutrient loads, especially to coastal ecosystems.

4.4.3 Inorganic Pollution (E)

Conductivity

Conductivity, the ability of water to pass an electrical current, is one of the fundamental water quality parameters measured in streams (either as µS/cm or mS/cm). Stream conductivity is affected by inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (all carrying a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (carrying a positive charge). Stream conductivity is determined primarily by the geology of the area through which the stream flows. Streams supporting fish assemblages usually have a range between 150 and 500 µS/cm; conductivity outside this range may indicate that the water is unsuitable for certain species of fish or macroinvertebrates. In urban systems, high conductivity may be an indicator of road salt usage.

Low pH

Low pH may affect stream chemical and biological processes. Most stream organisms are tolerant of a pH range of 6.5 to 8.0; however, there are stream systems in Maryland that drain freestone geological formations with only low levels of cations to provide buffering. Normal pH levels in these streams may be from 6.1 to 6.2, with low alkalinities. In addition, there are blackwater streams with viable biotic assemblages that have pH levels from 4.4 to 4.8, where weakly dissociated organic acids drive pH levels. Unnaturally low stream pH may be caused by acidic deposition, acid mine drainage, and wastewater discharges. Low pH may allow toxic elements, such as aluminum, to be mobilized for uptake by aquatic plants and animals, producing conditions toxic to aquatic life.

Acid Neutralizing Capacity

Acid neutralizing capacity (ANC) is a measure of the ability of dissolved constituents in the water column to react with and neutralize acids and can be used as an index to assess the sensitivity of surface waters to acidification. The higher the ANC, the more acid a system can assimilate before experiencing a decrease in pH. Repeated additions of acidic materials may cause a decrease in ANC.

4.5 Assigning Likely Causes to Impaired Watersheds

The stream disturbance index scores were used to identify the candidate cause(s) of impairment within a particular watershed or PSU. Only watersheds or PSUs with 10 or more sites were evaluated. The stream indicator scores were averaged in two steps:

(1) average of all variables within a stressor category (candidate cause) at each site and
(2) average of these composite stream disturbance index site scores over the entire watershed (or PSU).

The likelihood of a candidate cause affecting the watershed (or PSU) was described as high, medium, low, or none based on the following average watershed indicator scores:

- High - upper confidence limit of score < 3,
- Medium - mean of score < 3 and upper confidence limit of score >3,
- Low - mean of score >3 and lower confidence limit of score < 3,
- None - lower confidence limit of score > 3.

The final evaluation of likely causes to impaired watersheds was based on the Round 2 MBSS data. This round is the first Maryland biocriteria assessment sampling conducted at the 8-digit watershed scale. All Round 2 MBSS sites were sampled between 2000 and 2004. The MBSS sites used in the final analysis were comprised of the core random sites (allocated to PSUs in a stratified random manner) and other randomly selected sites sampled within the Round 2 time period. These other random sites included those sampled within specific geographic areas for the National Park Service, US EPA Wadeable Stream Assessment, and other programs. Multiple sample results from the same site were not used; however, average IBIs were used for random sites that later became sentinel sites and were sampled annually. Any core or other random site sampled within a PSU during Round 2 was used regardless of which year it was sampled.

Table 5 lists the likely cause ratings (high, moderate, or low) derived from the average stream disturbance index scores in each watershed or PSU (listed in alphabetical order within the three ecological regions) for each of the three candidate causes. The left-hand columns list the ratings for the BIBI, and the right-hand columns list the ratings for the

FIBI. Appendix F provides the stream disturbance results for each watershed, and a summary graph shows the likelihood that the particular watershed is degraded (based on the IBI). Furthermore, separate graphs for each candidate cause (stressor category) show the average IBI and stream disturbance scores (and 90% confidence interval) for each constituent variable. Results for the benthic IBI and fish IBI are shown separately.

Table 5: Likely Stressors in Each Maryland PSU (single or combined 8-digit watersheds) Based on Both Benthic IBI and Fish IBI Components of Final Stressor Identification Approach

Region	PSU	Benthic	Flow/ Sediment	Energy Source	Inorganic Pollutants	Fish	Flow/ Sediment	Energy Source	Inorganic Pollutants
COASTAL	Aberdeen Proving Ground/Swan Creek	fail	moderate	low	----	indeterminate	moderate	moderate	----
COASTAL	Assawoman/Isle of Wight/Sinepuxent/Newport/Chincoteague Bays	fail	high	----	moderate	indeterminate	high	Low	moderate
COASTAL	Bodkin Creek/Baltimore Harbor	fail	high	----	high	Fail	high	moderate	high
COASTAL	Breton/St. Clements Bays	pass	----	----	----	indeterminate	----	High	----
COASTAL	Corsica River/Southeast Creek	pass	low	moderate	----	Pass	low	moderate	----
COASTAL	Dividing Creek/Nassawango Creek	indeterminate	----	----	low	Pass	----	moderate	low
COASTAL	Eastern Bay/Kent Narrows/Lower Chester River/Langford/Kent Island	indeterminate	moderate	moderate	----	indeterminate	moderate	moderate	----
COASTAL	Fishing Bay/Transquaking River	fail	high	moderate	low	indeterminate	high	moderate	low
COASTAL	Gilbert Swamp	pass	----	----	----	indeterminate	----	----	----
COASTAL	Honga River/Little Choptank/Lower Choptank	indeterminate	high	low	high	Fail	high	moderate	high

Region	PSU	Benthic	Flow/ Sediment	Energy Source	Inorganic Pollutants	Fish	Flow/ Sediment	Energy Source	Inorganic Pollutants
COASTAL	Lower Elk River/Bohemia River/Upper Elk River/Back Creek/Little Elk Cree	indeterminate	----	low	----	indeterminate	----	----	----
COASTAL	Lower Pocomoke River	fail	high	low	high	indeterminate	high	moderate	high
COASTAL	Lower Wicomico/Monie Bay/Wicomico Creek/Wicomico River Head	fail	moderate	high	----	indeterminate	moderate	High	----
COASTAL	Magothy/Severn River	indeterminate	moderate	----	high	Fail	moderate	----	high
COASTAL	Marshyhope Creek	indeterminate	moderate	----	moderate	indeterminate	moderate	moderate	moderate
COASTAL	Mattawoman Creek	pass	----	----	low	indeterminate	----	----	low
COASTAL	Middle Chester River	indeterminate	moderate	----	----	Pass	moderate	----	----
COASTAL	Miles River/Wye River	pass	moderate	moderate	----	indeterminate	moderate	Low	----
COASTAL	Nanjemoy Creek	indeterminate	low	----	low	indeterminate	low	moderate	low
COASTAL	Nanticoke River	indeterminate	low	----	----	indeterminate	low	Low	----
COASTAL	Patuxent River (Lower)	pass	low	----	----	Fail	low	----	----
COASTAL	Patuxent River (Middle)	pass	----	----	low	indeterminate	----	----	low
COASTAL	Patuxent River (Upper)	fail	moderate	----	----	Fail	moderate	----	----
COASTAL	Piscataway Creek	fail	low	----	low	indeterminate	low	----	low
COASTAL	Pocomoke Sound/Tangier Sound/Big Annemessex/Manokin River	fail	high	high	high	indeterminate	high	High	high
COASTAL	Port Tobacco River	indeterminate	low	----	----	fail	low	High	----
COASTAL	Potomac Lower Tidal/Potomac Middle Tidal	pass	----	----	----	indeterminate	----	moderate	----

Region	PSU	Benthic	Flow/ Sediment	Energy Source	Inorganic Pollutants	Fish	Flow/ Sediment	Energy Source	Inorganic Pollutants
COASTAL	Potomac Upper Tidal/Oxon Creek	fail	moderate	----	low	fail	moderate	----	low
COASTAL	Sassafras River/Stillpond-Fairlee	indeterminate	moderate	moderate	----	indeterminate	moderate	moderate	----
COASTAL	South River/West River	fail	high	----	moderate	fail	high	Low	moderate
COASTAL	St. Mary's River	pass	----	----	----	indeterminate	----	----	----
COASTAL	Tuckahoe Creek	pass	low	----	----	indeterminate	low	Low	----
COASTAL	Upper Chester River	indeterminate	moderate	----	----	pass	moderate	Low	----
COASTAL	Upper Choptank River	indeterminate	moderate	----	----	indeterminate	moderate	Low	----
COASTAL	Upper Pocomoke River	indeterminate	moderate	moderate	low	indeterminate	moderate	moderate	low
COASTAL	West Chesapeake Bay	pass	moderate	----	----	fail	moderate	High	----
COASTAL	Western Branch	indeterminate	moderate	----	----	pass	moderate	Low	----
COASTAL	Wicomico River	pass	low	----	----	indeterminate	low	----	----
COASTAL	Zekiah Swamp	pass	----	----	low	indeterminate	----	----	low
EPIEDMNT	Anacostia River	fail	high	moderate	high	indeterminate	high	moderate	high
EPIEDMNT	Back River	fail	high	moderate	high	fail	high	High	high
EPIEDMNT	Brighton Dam	pass	----	----	----	indeterminate	----	----	----
EPIEDMNT	Broad Creek	pass	----	----	----	indeterminate	----	----	----
EPIEDMNT	Bush River/Bynum Run	fail	high	moderate	moderate	indeterminate	high	moderate	moderate
EPIEDMNT	Deer Creek	pass	----	----	----	indeterminate	----	----	----
EPIEDMNT	Gunpowder River/Lower Gunpowder Falls/Bird River/Middle River-Browns	fail	moderate	low	high	indeterminate	moderate	moderate	low
EPIEDMNT	Gwynns Falls	fail	----	low	high	fail	low	Low	low

Region	PSU	Benthic	Flow/ Sediment	Energy Source	Inorganic Pollutants	Fish	Flow/ Sediment	Energy Source	Inorganic Pollutants
EPIEDMNT	Jones Falls	indeterminate	moderate	----	high	indeterminate	moderate	Low	----
EPIEDMNT	Liberty Reservoir	pass	----	----	----	pass	----	----	----
EPIEDMNT	Little Gunpowder Falls	pass	----	----	----	indeterminate	----	----	----
EPIEDMNT	Little Patuxent River	fail	low	low	high	pass	low	low	low
EPIEDMNT	Loch Raven Reservoir	indeterminate	moderate	low	moderate	indeterminate	moderate	low	----
EPIEDMNT	Lower Susquehanna River/Octoraro Creek/Conowingo Dam Susquehanna River	indeterminate	----	----	low	indeterminate	low	----	----
EPIEDMNT	Lower Winters Run/Atkisson Reservoir	fail	low	low	high	pass	low	low	low
EPIEDMNT	Middle Patuxent River	indeterminate	moderate	moderate	moderate	indeterminate	moderate	high	----
EPIEDMNT	Northeast River/Furnace Bay	pass	high	low	----	pass	high	high	----
EPIEDMNT	Patapsco River Lower North Branch	fail	low	----	high	indeterminate	low	----	moderate
EPIEDMNT	Prettyboy Reservoir	pass	----	----	low	indeterminate	----	----	----
EPIEDMNT	Rock Creek/Cabin John Creek	fail	low	low	low	indeterminate	moderate	low	----
EPIEDMNT	Rocky Gorge Dam	pass	low	moderate	high	pass	----	high	----
EPIEDMNT	S Branch Patapsco	pass	----	----	----	pass	----	----	----
HIGHLAND	Antietam Creek	fail	high	high	----	indeterminate	moderate	low	----
HIGHLAND	Casselman River	indeterminate	low	----	low	indeterminate	----	----	moderate
HIGHLAND	Catoctin Creek	indeterminate	moderate	high	high	fail	moderate	----	----
HIGHLAND	Conewago Creek/Double Pipe Creek	fail	high	high	----	indeterminate	moderate	moderate	----
HIGHLAND	Conococheague	fail	high	high	high	indeterminate	high	low	high
HIGHLAND	Evitts Creek	fail	moderate	moderate	----	indeterminate	moderate	low	----

Region	PSU	Benthic	Flow/ Sediment	Energy Source	Inorganic Pollutants	Fish	Flow/ Sediment	Energy Source	Inorganic Pollutants
HIGHLAND	Fifteen Mile Creek	pass	----	----	----	indeterminate	----	moderate	low
HIGHLAND	Georges Creek	indeterminate	----	----	----	fail	----	----	low
HIGHLAND	Little Conococheague/Licking Creek	pass	----	----	----	indeterminate	low	----	low
HIGHLAND	Little Youghiogheny/Deep Creek Lake	indeterminate	high	high	----	fail	high	high	----
HIGHLAND	Lower Monocacy River	fail	low	moderate	----	indeterminate	low	----	----
HIGHLAND	Potomac R WA Co/Marsh Run/Tonoloway/Little Tonoloway	fail	high	----	moderate	fail	high	----	----
HIGHLAND	Potomac River (Frederick County)	fail	high	high	----	indeterminate	high	low	----
HIGHLAND	Potomac River (Lower North Branch)	pass	----	----	----	fail	----	----	low
HIGHLAND	Potomac River AL Co/Sideling Hill Creek	indeterminate	----	----	high	indeterminate	----	----	low
HIGHLAND	Potomac River MO Co	indeterminate	moderate	high	----	pass	----	----	----
HIGHLAND	Potomac River Upper North Branch	indeterminate	----	----	high	fail	----	----	moderate
HIGHLAND	Savage River	pass	----	----	----	pass	----	----	----
HIGHLAND	Seneca Creek	fail	moderate	high	low	indeterminate	----	----	----
HIGHLAND	Town Creek	pass	----	----	----	indeterminate	----	moderate	----
HIGHLAND	Upper Monocacy River	fail	low	low	----	indeterminate	----	----	----
HIGHLAND	Wills Creek	indeterminate	low	----	----	fail	low	----	----
HIGHLAND	Youghiogheny River	indeterminate	----	----	----	indeterminate	----	----	high

*PSUs status as passing, indeterminate, or failing biocriteria is shown for benthic and fish separately.

5.0 DISCUSSION

The stressor identification method developed by the team and adopted by MDE is based on current scientific knowledge, the best available data, and Maryland's biocriteria methods. The study team drew from the current US EPA (2002) stressor identification guidance and scientific literature to develop the stressor identification conceptual framework and subsequent approach. The statewide MBSS provided a quality-assured data set of water quality and physical habitat information coincident with the state's biological condition information. The method was designed to use the same composite indicator approach for stressor information as is used for biological information in Maryland's biocriteria.

The MBSS benthic and fish IBIs are used in Maryland's biological criteria because they are effective integrators of biota affected by stressors over time (Southerland et al. 2005). The challenge in identifying the stressors affecting these biota is that the water quality and physical habitat data collected by the MBSS are not comprehensive (i.e., they do not include all possible stressors). Therefore, it is to be expected that the method will not identify stressors for all of Maryland's impaired watersheds, nor is it expected that the stressors identified will include all the stressors present. At the same time, the variables measured by the MBSS do address, at least in part, major common stressors to Maryland streams such as flow regime, sediments, nutrients, thermal impacts, and chemical pollution. Consistent with US EPA guidance, using stressor surrogate variables collected at the same sites that the IBIs were scored means that the stress and biological condition are coincident in space and time (though not necessarily that the cause preceded the impact). While this approach cannot eliminate stressors as being present, it can produce a rigorous weight of evidence.

The final conceptual framework for stressor identification developed for this method had to accommodate the lack of breadth of variables available from the MBSS and the lack of precision in these variables as surrogates of stressors. The strength of the method is that it rigorously evaluates the relationship of each surrogate variable with biological condition. Only those variables that made ecological and empirical sense were included in the method. In addition, the thresholds for each variable were selected to represent the amount of stress that is sufficient to produce the effect and the thresholds were validated or modified based on the scientific literature (consistent with US EPA guidance). The weakness of the method is that some variables overlap as surrogates for different stressors, and therefore stressor categories (candidate causes) that were originally separate had to be combined. For example, the method provides a likelihood that either flow regime or terrestrial sediment (or both) is affecting a watershed, but does not differentiate between the two.

Lastly, the variable values collected by the MBSS have an inherent variability just as the IBI scores do. Therefore, it is more reliable to identify likely stressors at the scale of 10 or more sites (i.e., the scale of Maryland watersheds or small watersheds combined in PSUs. The MBSS Round 2 design is based on 10 or more randomly selected sites within each of the 84 PSUs. IBI scores at the site level have a variability shown in repeat samples (R^2 of 0.80); the mean IBI in a watershed reaches a robust average with 10 random sites. In addition to the statistical and ecological appropriateness of the data, conducting the analysis at the watershed scale is consistent with MDE’s need to address watershed impairments on the 303(d) list. The watershed-based stressor identification approach described above is not limited to a particular scale; it only requires that enough representative information be available (e.g., random site results for the appropriate variables). The approach is also not limited to the current list of selected variables. As new information (e.g., from remote sensing or stream walks) becomes available and is shown to be an effective surrogate for stress on biota, it can be added to the appropriate stressor categories within the stream disturbance index method. In this way, the stressor identification approach adopted by MDE is an evolving method, one that provides a balanced weight of evidence given the best available information.

REFERENCES

Cade, B. S., and B. R. Noon. 2003. A Gentle Introduction to Quantile Regression for Ecologists. *Frontiers in Ecology and Environmental Science* 1: 412-420.

CFR (Code of Federal Regulations). 2007. *40 CFR 130.7.* http://a257.g.akamaitech.net/7/257/2422/22jul20061500/edocket.access.gpo.gov/cfr_2006/julqtr/40cfr130.7.htm (Accessed March, 2007).

COMAR (Code of Maryland Regulations). 2007. *26.08.02*. http://www.dsd.state.md.us/comar/26/26.08.02.02.htm (Accessed March, 2007).

DNR (Department of Natural Resources). 2007. *Maryland Biological Stream Survey*. http://www.dnr.state.md.us/streams/mbss/index.html (Accessed March 2007).

Holt, J. 2006. *Development of a Decision Matrix for Biological Impairments*. Baltimore, MD: Maryland Department of the Environment.

MDE (Maryland Department of the Environment). 2007. *Maryland's 2006 Integrated Report*. http://www.mde.state.md.us/Programs/WaterPrograms/TMDL/Maryland%20303%20dlist/2006_303d_list_final.asp (Accessed March, 2007).

Southerland, M. T., G. .M. Rogers, M. J. Kline, R. P. Morgan, D. .M. Boward, P. F. Kazyak, R. J. Klauda, and S. A. Stranko. 2005. *Maryland Biological Stream Survey 2000-2004 Volume 16: New Biological Indicators to Better Assess the Condition of Maryland Streams*. Annapolis, MD: Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment.

Stranko, S. A., M. K. Hurd, and R. J. Klauda. 2005. Applying a Large, Statewide Database to the Assessment, Stressor Diagnosis, and Restoration of Stream Fish Communities. *Environmental Monitoring and Assessment* 23: 99-121.

US EPA (U.S. Environmental Protection Agency). 2002. Stressor Identification Guidance Document. Washington, DC: U.S. Environmental Protection Agency, Office of Water and Office of Research and Development.

Appendix A

APPENDIX A
MBSS STREAM SITE AND CATCHMENT VARIABLES ASSOCIATED WITH EACH OF THE PREDICTIONS IN THE STRESSOR IDENTIFICATION FRAMEWORK

Table A-1: MBSS Stream Site and Catchment Variables for the Flow Regime Candidate Cause

A. Flow Regime				
Cause	**#**	**Prediction**	**Variables**	**Comments**
A	1	Dominance of pioneer taxa.	fibi pabdom bibi pabdom	
	2	Community composition temporally variable.	None	
	3	Community composition variable along stream length.	None	Because of the randomized site selection very few stream reaches has more than 1 sample, and thus the dissimilarity within reaches can not be estimated with adequate precision, if at all
	4	Stream banks unstable.	Erodsv	On either bank
	5	High bank erosion.	Erodex	Sum of both banks
	6	Low embeddedness.	Embed	
	7	Stream not at equilibrium.	Pending	Should use some ratio of wetwid and thalde. Average of 0, 25, 50, and 75 m measurements.
	8	Frequent high discharge.	None	
	9	Frequent low discharge.	None	
	10	High temperature.	temp_fld	
	11	High salinity near fall line.	cond_fld	
	12	Large proportion of watershed developed.	Impsurf	
	12	Low Density Urban	WB_LURB	MDE Whole Basin
	12	High Density Urban	WB_HURB	MDE Whole Basin
	12	Low intensity developed	WB_LOWI	MDE Whole Basin
	12	Transportation	WB_TRAN	MDE Whole Basin
	12	Transportation	60M_TRAN	MDE 60M Buffer
	13	Large groundwater/ surface water withdrawals.	None	
	14	Channelization present.	chan_yn	

*MBSS variable names are defined in Rogers et al. (2005). Land use variable abbreviations include WB for whole basin upstream of the site or 60M for the upstream riparian area. Further explanation and limitations of each variable are listed in the comments.

Table A-2: MBSS Stream Site and Catchment Variables for the Terrestrial Sediment Candidate Cause

B. Terrestrial Sediment				
Cause	**#**	**Prediction**	**Variables**	**Comments**
B	1	Biological impairment predicted by MDE sediment model.	None	
	2	Embeddedness identified as stressor using predicted fish tolerance thesholds.	Embed	
	3	Decreased proportion of taxa or feeding groups sensitive to fine sediment.	Pending	Need to identify specific taxa.
	4	High embeddedness.	Embed	
	5	High % fine substrate.	epi_sub	
	6	Homogeneous substrate.	Instrhab	
	7	High phosphorus due to sediments of terrestrial origin.	None	
	8	Limited vegetative buffer.	rv_wid_r riv_wid_l	Total of both banks
	8	natural grass	60M_GRAS	MDE 60M Buffer
	8	Forest	60M_FRST	MDE 60M Buffer
	8	Wetland	60M_WETL	MDE 60M Buffer
	8	Barren	60M_BARR	MDE 60M Buffer
	8	pasture/hay	60M_PHAY	MDE 60M Buffer
	8	Croplands	60M_CROP	MDE 60M Buffer
	9	High riparian agriculture.	adj_cv_L adj_cv_R	Where cover is crop
	9	Agriculture	60M_AGRI	MDE 60M Buffer
	9	pasture/hay	60M_PHAY	MDE 60M Buffer
	9	Croplands	60M_CROP	MDE 60M Buffer
	10	High riparian urban.	adj_cv_L adj_cv_R	Where cover is housing, parking lot, or paved road
	10	Low Density Urban	60M_LURB	MDE 60M Buffer
	10	High Density Urban	60M_HURB	MDE 60M Buffer
	10	Low intensity developed	60M_LOWI	MDE 60M Buffer
	11	Presence of high TSS NPDES dischargers.	None	

Table A-3: MBSS Stream Site and Catchment Variables for the Energy Source Candidate Cause

C. Energy source				
Cause	**#**	**Prediction**	**Variables**	**Comments**
C	1	Shift in feeding strategies.	Pending	Need to identify specific taxa.
	2	Increased prevalence of algae.	None	Data not available for this analysis.
	3	Increased SAV.	SAV	This is recorded as present, absent, or exotic. Entered as a binary variable for present or absent.
	4	Poor stream shading.	Shading	
	5	Increased primary production.	DOC_lab	
	6	Increased pH due to increased CO2 removal.	pH_lab	
	7	Low dissolved oxygen.	DO_fld	
	8	Decreased woody debris.	Woodinst	
	9	Poor stream shading.	adj_cv_L adj_cv_R	Entered as a binary variable for cover = 0 on either side (Y/N)
	10	High temperature.	temp_fld	
	11	Low proportion of wooded riparian.	adj_cv_L adj_cv_R rv_wid_r rv_wid_l	Where cover = FR, sum of width on both banks
	11	natural grass	60M_GRAS	MDE 60M Buffer
	11	Forest	60M_FRST	MDE 60M Buffer
	11	Barren	60M_BARR	MDE 60M Buffer
	11	pasture/hay	60M_PHAY	MDE 60M Buffer
	11	Croplands	60M_CROP	MDE 60M Buffer
	12	High whole basin agriculture.	Agri	
	12	Agriculture	WB_AGRI	MDE Whole Basin
	12	pasture/hay	WB_PHAY	MDE Whole Basin
	12	Croplands	WB_CROP	MDE Whole Basin
	13	High whole basin residential.	high_res	
	13	Low Density Urban	WB_LURB	MDE Whole Basin
	13	High Density Urban	WB_HURB	MDE Whole Basin
	13	Low intensity developed	WB_LOWI	MDE Whole Basin
	14	Presence of high nutrient NPDES dischargers.	None	

Table A-4: MBSS Stream Site and Catchment Variables for the Oxygen Consuming and Thermal Waste Candidate Cause

D. Oxygen Consuming and Thermal Waste				
Cause	**#**	**Prediction**	**Variables**	**Comments**
D	1	Oxygen identified as stressor using predicted fish tolerance thresholds.	Proportion of spp eliminated by DO min from model	
	2	Nutrients identified as stressor using predicted fish tolerance thresholds*.	Proportion of spp eliminated by NO3 max from model	
	3	Biotic index score low.	Hilsenhoff Index	
	4	Presence of nuisance tolerant algae.	None	Data not available for this analysis
	5	Gleying present from reduction of iron to ferrous form (Fe2+)	None	Data not available for this analysis
	6	High temperature.	temp_fld	
	7	Low dissolved oxygen.	DO_fld	
	8	High dissolved organic carbon (DOC)*.	DOC_lab	
	9	High ammonia.	NH3_lab	
	10	Low sulfate.	SO4_lab	
	11	High whole basin agriculture.	Agri	
	11	Agriculture	WB_AGRI	MDE Whole Basin
	11	pasture/hay	WB_PHAY	MDE Whole Basin
	11	Croplands	WB_CROP	MDE Whole Basin
	12	High whole basin urban.	Urban	
	12	Low Density Urban	WB_LURB	MDE Whole Basin
	12	High Density Urban	WB_HURB	MDE Whole Basin
	12	Low intensity developed	WB_LOWI	MDE Whole Basin
	13	Presence of high BOD NPDES dischargers.	None	

Table A-5: MBSS Stream Site and Catchment Variables for the Inorganic Pollutants Candidate Cause

E. Inorganic Pollutants				
Cause	**#**	**Prediction**	**Variables**	**Comments**
E	1	Acidity identified as stressor using predicted fish tolerance thresholds.	Proportion of species eliminated by pH min and ANC min from model	
	2	Decreased proportion of acid sensitive fish species.	Proportion of species eliminated by pH min and ANC min from model	
	3	Decrease proportion of Gastropoda*.	Pending	Data set needs updating
	4	Decrease proportion of Amphipoda*.	Pending	Data set needs updating
	5	Decrease proportion of Unionidae*. (bivalve)	un_pres	Compared live or recent shells present versus old shells present or none.
	6	Deposits on substrate.	None	
	7	High acidity.	pH_lab	
	8	Low acid neutralizing capacity (ANC).	ANC_lab	
	9	High conductance.	Cond_lab	
	10	Presence of high/low pH NPDES dischargers.	None	
	11	High whole basin agriculture.	Agri	
	11	Agriculture	WB_AGRI	MDE Whole Basin
	11	Croplands	WB_CROP	MDE Whole Basin
	12	High whole basin urban.	Urban	
	12	Low Density Urban	WB_LURB	MDE Whole Basin
	12	High Density Urban	WB_HURB	MDE Whole Basin
	13	High coal mining activity.	surfmine(Y/N)	
	13	Extractive	WB_EXTR	MDE Whole Basin

Table A-6: MBSS Stream Site and Catchment Variables for the Organic Pollutants Candidate Cause

Organic Pollutants				
Cause	**#**	**Prediction**	**Variables**	**Comments**
F	1	Dominance of pioneer taxa.	Pending	Need to identify specific taxa.
	2	Community composition temporally variable.	None	
	3	Absence of large fish individuals.	gfis length	This is problematic due to differences in species composition, stream size, and fishing pressure among streams
	4	Absence of macrophytes.	SAV	
	5	Increased anomalies.	Anomaly	In Round 2, it was just flagged (yes/no - of the 30 Species X we caught, were there any anomalies?)
	6	Fish kills related to water chemistry.	None	
	7	Exceedance of water quality criteria for one or more pollutants.	None	
	8	High industrial land use.	high_com	
	8	High Density Urban	WB_HURB	MDE Whole Basin
	9	High whole basin agriculture.	Agri	
	9	Agriculture	WB_AGRI	MDE Whole Basin
	10	High density of road crossings.	Culvpres	Road crossing variable pending
	10	Transportation	WB_TRAN	MDE Whole Basin
	10	Transportation	60M_TRAN	MDE 60M Buffer
	11	Presence of high toxic* NPDES dischargers.	None	

Reference

Rogers, G. and E. Franks. 2005. *Data Dictionary for Round 2 of the Maryland Biological Stream Survey, 2000-2004*. Annapolis, MD: Maryland Department of Natural Resources.

Appendix B

APPENDIX B
CANDIDATE STRESSOR IDENTIFICATION APPROACHES

1.0 CANDIDATE STRESSOR IDENTIFICATION APPROACHES

All cooperators from MDE, Versar, and the University of Maryland, plus Scott Stranko of Maryland DNR and Dr. Sue Norton of U. S. EPA attended an initial meeting held in March 2005 to begin the stressor identification development process. At the meeting, Dr. Norton presented U.S. EPA's Causal Analysis/Diagnosis Decision Information System (CADDIS) approach to stressor identification. Mr. Stranko presented his Prediction and Diagnosis Model that uses MBSS fish tolerance data (Stranko et al. 2005), and John Holt of MDE presented his Framework for Addressing Biological Impairments.

The team decided to develop an approach for identifying stressors in Maryland watersheds using MBSS data. MDE agreed to better define management objectives and establish guidelines for the data to be used. Versar agreed to try to merge the sediment TMDL model and Stranko et al. (2005) fish PDM into a strawman approach.

1.1 Identifying Stressors by Proportion of Fish Species Lost

Versar developed a preliminary approach that used the Stranko et al. (2005) fish tolerance model. Figure B-1 shows the minimum dissolved oxygen concentrations at which fish species are expected to be present in the Coastal Plain watersheds. Superimposed on the list of species are the 50th and 10th percentiles of fish species eliminated at the indicated DO levels. Figure B-2 shows the proportion of stream miles in each watershed that exceed the 50th and 10th percentiles of fish species eliminated by low dissolved oxygen. Comparable graphs were prepared for each of the variables predicted by the fish model.

The team felt that this approach was hard to interpret and decided to pursue other approaches. Determining a threshold for fish species lost was problematic, as it is not codified in the state biocriteria regulations. This approach is also somewhat limited by the variables for which fish tolerance models have been developed. Thirdly, the approach requires that the results for each variable be compiled within each watershed (this is an obstacle for other approaches as well).

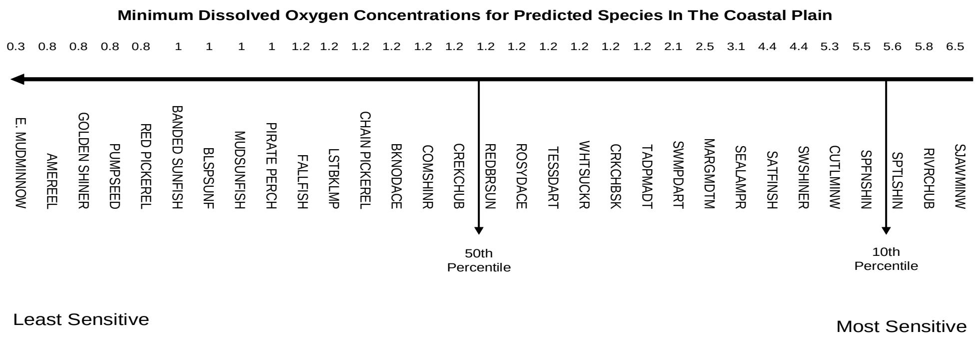


Figure B-1: Minimum dissolved oxygen (DO) concentrations for predicted species in the Coastal Plain (per Stranko et al. 2005)

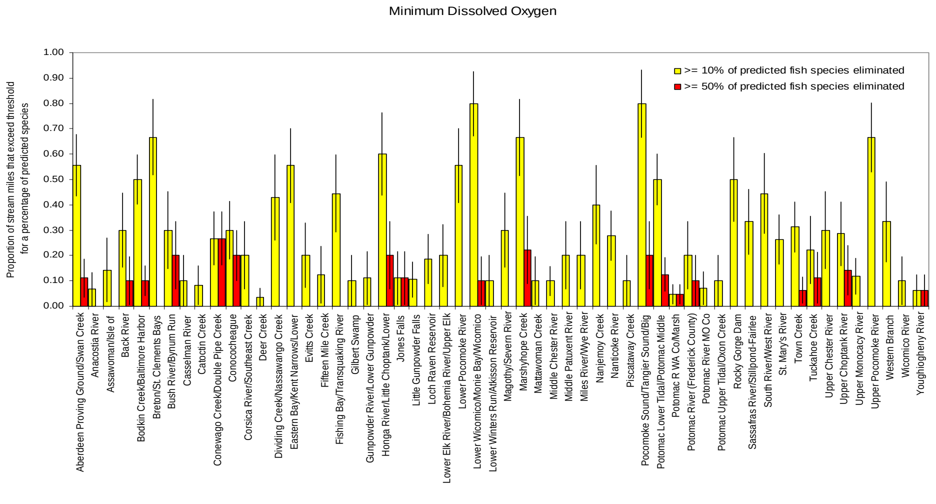


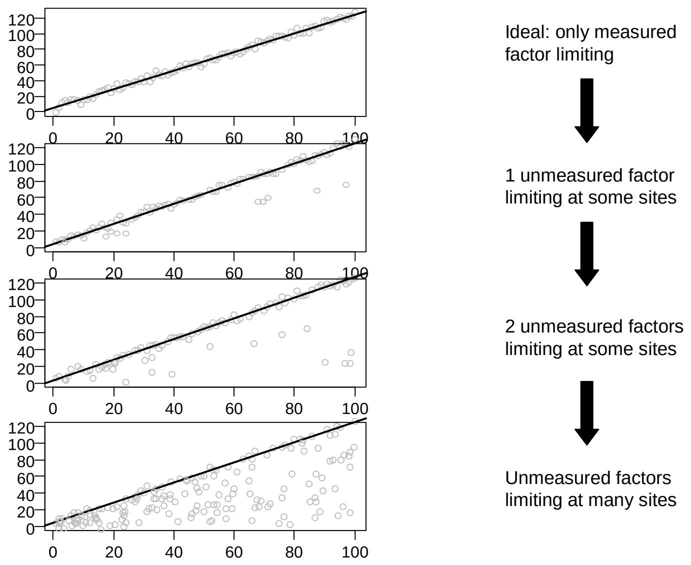
Figure B-2: Proportion of stream miles in each watershed that exceed 10th and 50th percentile of predicted fish species eliminated (per Stranko et al. 2005)

1.2 Setting Stressor Thresholds Using Quantile Regression

In July 2005, Versar presented an approach that used quantile regression to identify limiting factors for biota as represented by the benthic macroinvertebrate metric Ephemeroptera, Plecoptera, and Trichoptera (EPT). MBSS variables included in the MDE sediment impairment model ─ embeddedness, instream habitat, and riffle run ─ were analyzed within selected watersheds. Figure B-3 illustrates how quantile regression works (from Cade and Noon 2003). Quantile regression is performed at specific quantiles, such as the 90th, in order to better describe the slope and intercept of limiting factors. Figure B-4 shows the EPT vs. sediment variable results in the Middle Chester River watershed superimposed on the 10th, 25th, 50th, 75th, and 95th quartiles for the Coastal Plain. Figure B-5 shows how the relationship of EPT to embeddedness, instream habitat, and riffle run varies for the subset of sites with chloride concentrations > 50 mg/l.

These results led to an extensive discussion of how both natural variability (e.g., the relationship of embeddedness to slope and altitude) and interacting stressors can confound the analysis. While non-parametric quantile regression is fairly robust for these data, developing “better” metrics, such as embeddedness adjusted for slope, by looking at reference (forested) watersheds in different regions and stream types would be quite challenging. The option of developing a multivariate approach was deemed not statistically tractable nor intuitive enough for implementation. However, the team agreed that quantile regression was promising and ultimately used it to identify robust variables for inclusion in the final methodology.

Quantile Regression – the Idea



Adapted from:
Cade, B.S., and B.R. Noon. 2003. A gentle introduction to quantile regression for ecologists. Frontiers in Ecology and Environmental Science 1:412-420.

Figure B-3: How quantile regression works (adapted from Cade and Noon 2003)

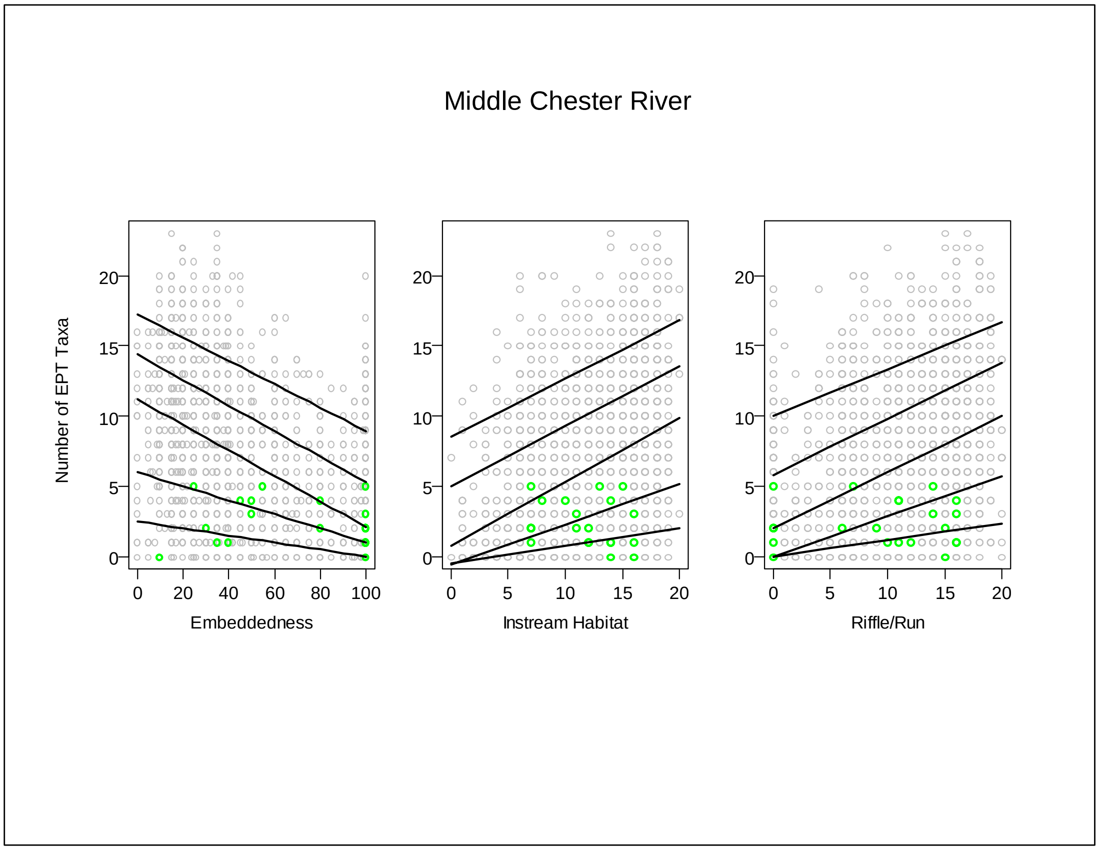


Figure B-4: EPT vs. sediment variable results in Middle Chester River over quantiles derived from all Coastal Plain sites

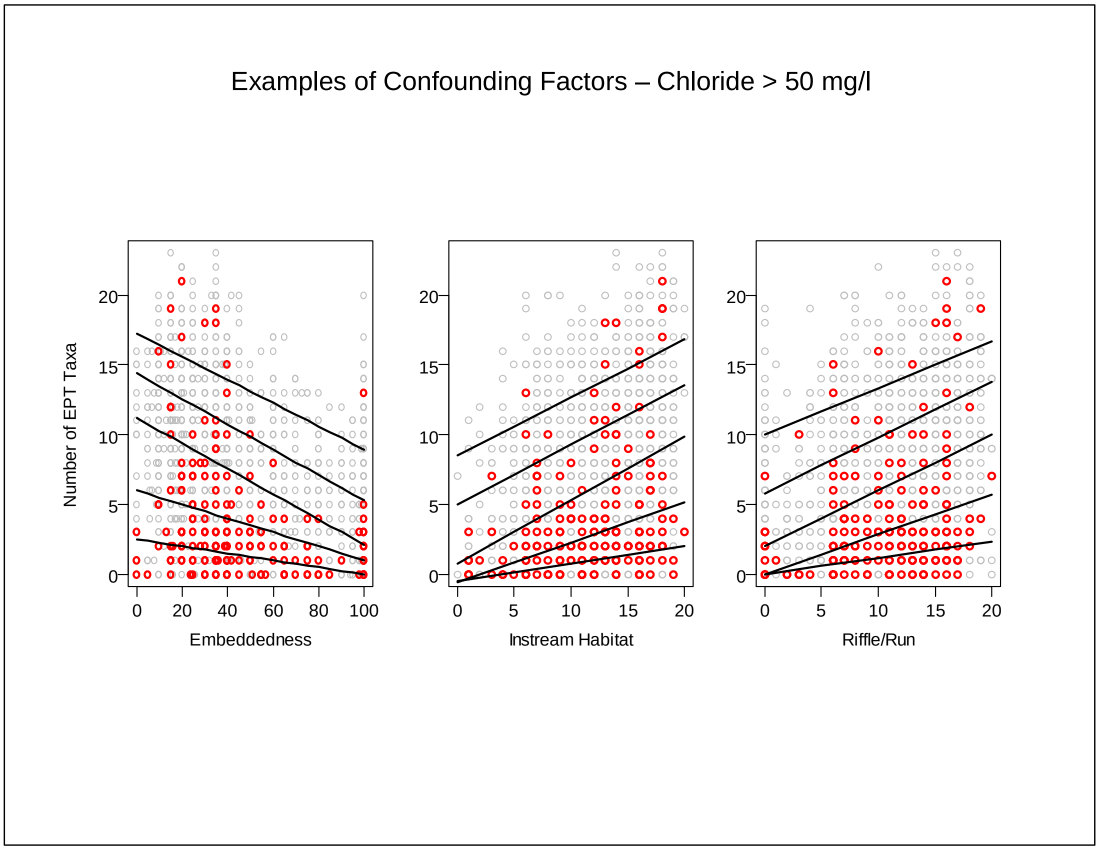


Figure B-5: EPT vs. sediment variable for subset of sites with chloride > 50 over quantiles derived from all Coastal Plain sites

1.3 Weight-of-Evidence Method for Identifying Stressors by Watershed

After lengthy discussions, the team decided to focus the study on analyzing individual MBSS variables in order to develop a threshold for each variable based on a comparison with reference conditions in the region. Sites with B-IBI scores meeting biocriteria (> 3 + confidence limit) were originally chosen to serve as the best available "reference condition" benchmark. Specifically, the cutoff was based on IBIs where the estimated lower bound of the 90% confidence interval was greater than 3.0. The resultant value was about 3.1-3.2. Versar presented the following approach:

- Identify variables from the MBSS (and other sources as available) that match predictions in MDE framework
- Graph the distribution of values for all MBSS sites passing biocriteria (i.e., those sites where the lower bound of the confidence interval is greater than 3) and identify the 75th percentile; do this separately for each ecoregion
- Plot all sites within each single or combined 8-digit watershed (PSU) against the benchmark distribution

- Estimate the proportion of scores outside the 75th percentile
- Identify the threshold proportion of bad sites that characterizes watersheds that have passed biocriteria vs. watersheds that failed biocriteria (e.g., more than 50% of sites outside the 75th percentile of benchmark sites)
- Score the prediction as “met” for the watersheds where the proportion of bad sites exceed the threshold (for variables showing good discrimination)
- Combine the predictions met within each stressor category to provide weight of evidence that the candidate cause represented by that category is likely resulting in impairment of the watershed

The general approach of the analysis was to identify watersheds or PSUs (the primary sampling unit for Round 2 of the Maryland Biological Stream Survey) where measures of selected variables were outside of the normal range for unimpaired streams in the geographic region (Coastal Plain, Eastern Piedmont, or Highlands). For each variable tested, we selected the set of values associated with sites where the benthic IBI was significantly greater than 3, which consequently reflected the natural variation in that variable for streams that were not impaired. The uncertainty in IBI values measured for each site was estimated based on a small set of sites that were resampled one or more times during the survey. The mean coefficient of variation for benthic IBIs from these replicated samples within sites was 8%. Therefore, we calculated an approximate one-way lower 90% confidence interval for each IBI score based on a single sample as $IBI - 1.28 * \sqrt{0.08 * IBI}$, to account for within-site variability, and selected sites where the lower confidence interval was greater than or equal to 3.0 (note that $z_{0.10} = 1.28$). Data from these sites were used as indicators of the normal range of scores within a region for each variable tested.

Variables sampled from individual watersheds were judged to be outside the normal range for unimpaired streams in a region if they were greater than the 75th percentile of the normal scores (where an increase in magnitude of the variable indicated impairment) or if they were lower than the 25th percentile (where a decrease in magnitude indicated impairment). The hypothesis that the distribution of sample values for the variable of interest in each watershed was shifted in a direction that would indicate impairment was tested using one of two analyses. For binary variables (i.e., variables such as channelization where the response was either yes or no), a one-way proportions test was performed (Agresti 1990). For other variables, a one-sided Wilcoxon exact test was performed, and exact probabilities were calculated (Hollander and Wolfe 1973). Watersheds where statistical tests were significant at the 0.05 level were identified as likely affected by the stressor associated with the variable tested. In addition, the extent to which watersheds had sample values that differed from the average condition for non-impaired sites in a region was tested by calculating the proportion of sites sampled that were outside the 25th or 75th percentile, as appropriate.

The most difficult challenge involved in developing an approach to identifying stressors likely affecting impaired watersheds was how to combine the lines of evidence into a weight of evidence (i.e., how to combine the results for each variable in a stressor category). The team debated this over several months and considered the following options:

- Case-by-case evaluation of results for each watershed to produce a unique narrative based on best professional judgment
- Simple two-step rule based on (1) flagging variables where the number of sites with variable values exceeding the reference site values is > 50% and the p measure (significance) of "exceeding" the reference distribution is < 0.05 and (2) more than half the variables in a stressor category are flagged
- Modification of the simple two-step rule that allows best professional judgment to review the flagged variables and determine if their combination warrants identifying the stressor category as likely affecting that watershed
- Complex two-step rule that applies weights to each flagged variable based on (1) a pre-determined importance of that variable (from ecological theory) or (2) importance of that variable as derived from the magnitude of its exceedences
- Composite rule that summarizes the p (significance) values for all variables in a stressor category using an established combined probability test (as in metanalysis)

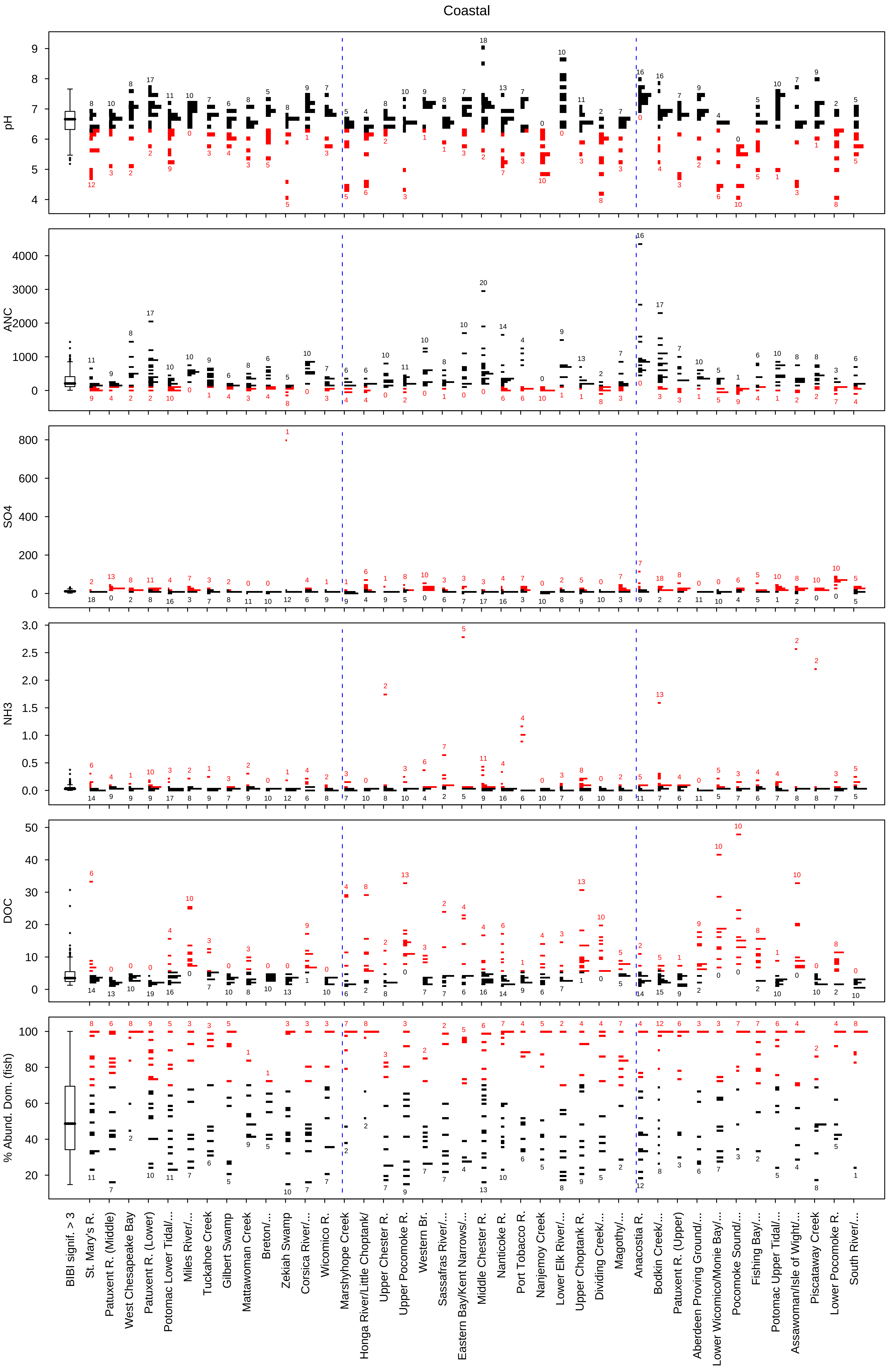
References

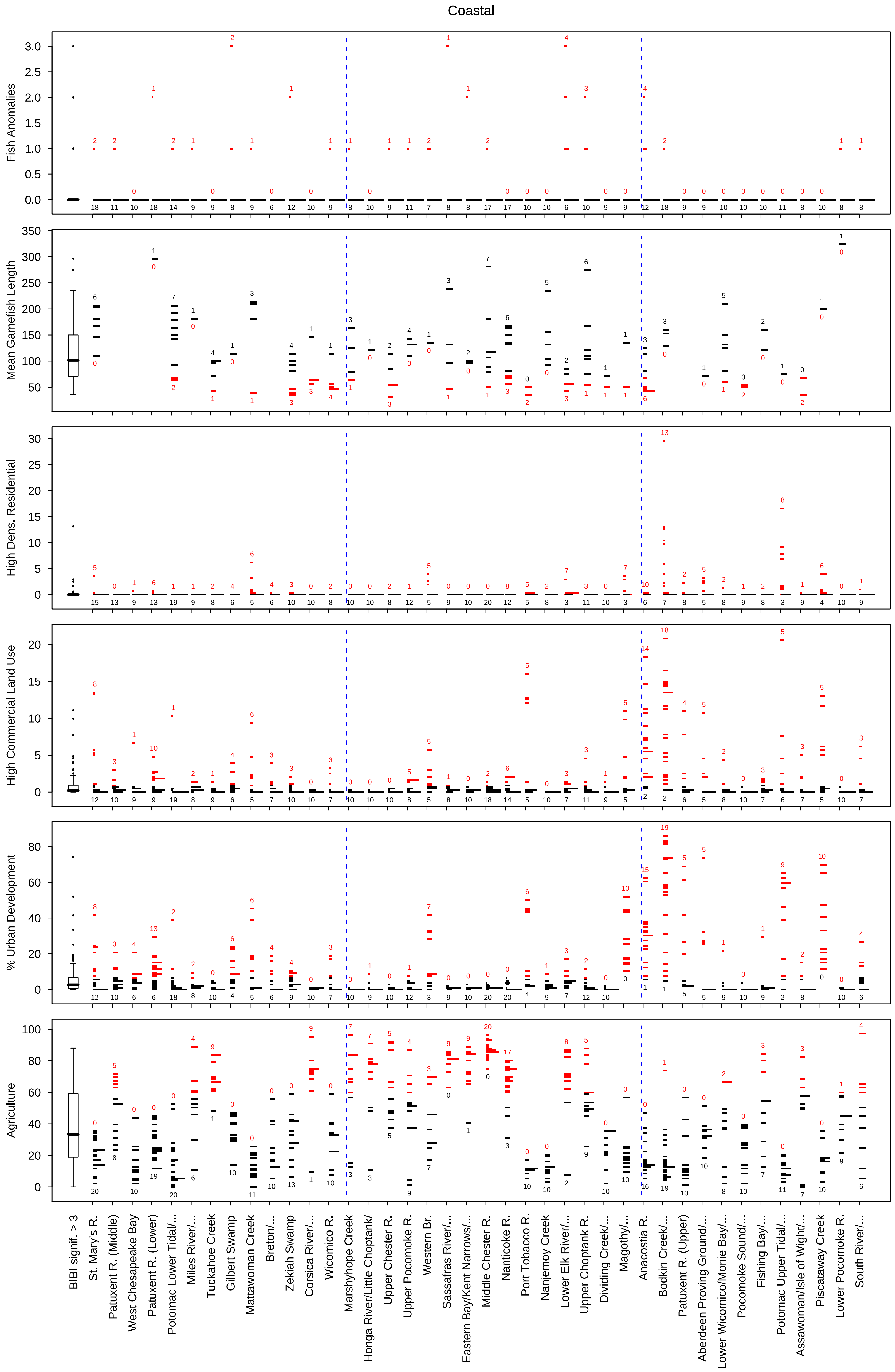
Agresti, A. 1990. *Categorical Data Analysis*. New York, NY: John Wiley and Sons.

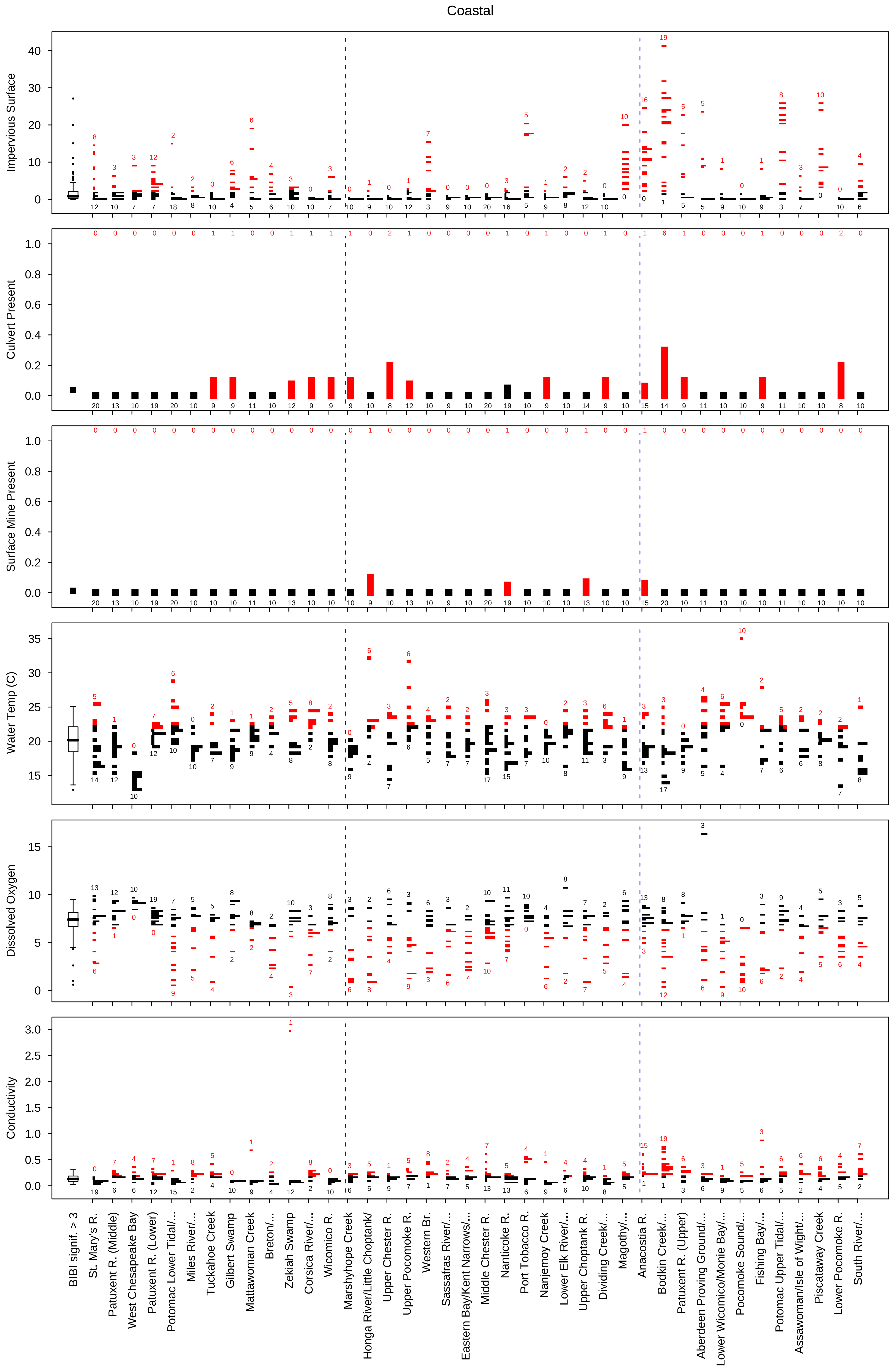
Hollander, M. and D. A. Wolfe. 1973. *Nonparametric Statistical Inference*. New York, NY: John Wiley and Sons.

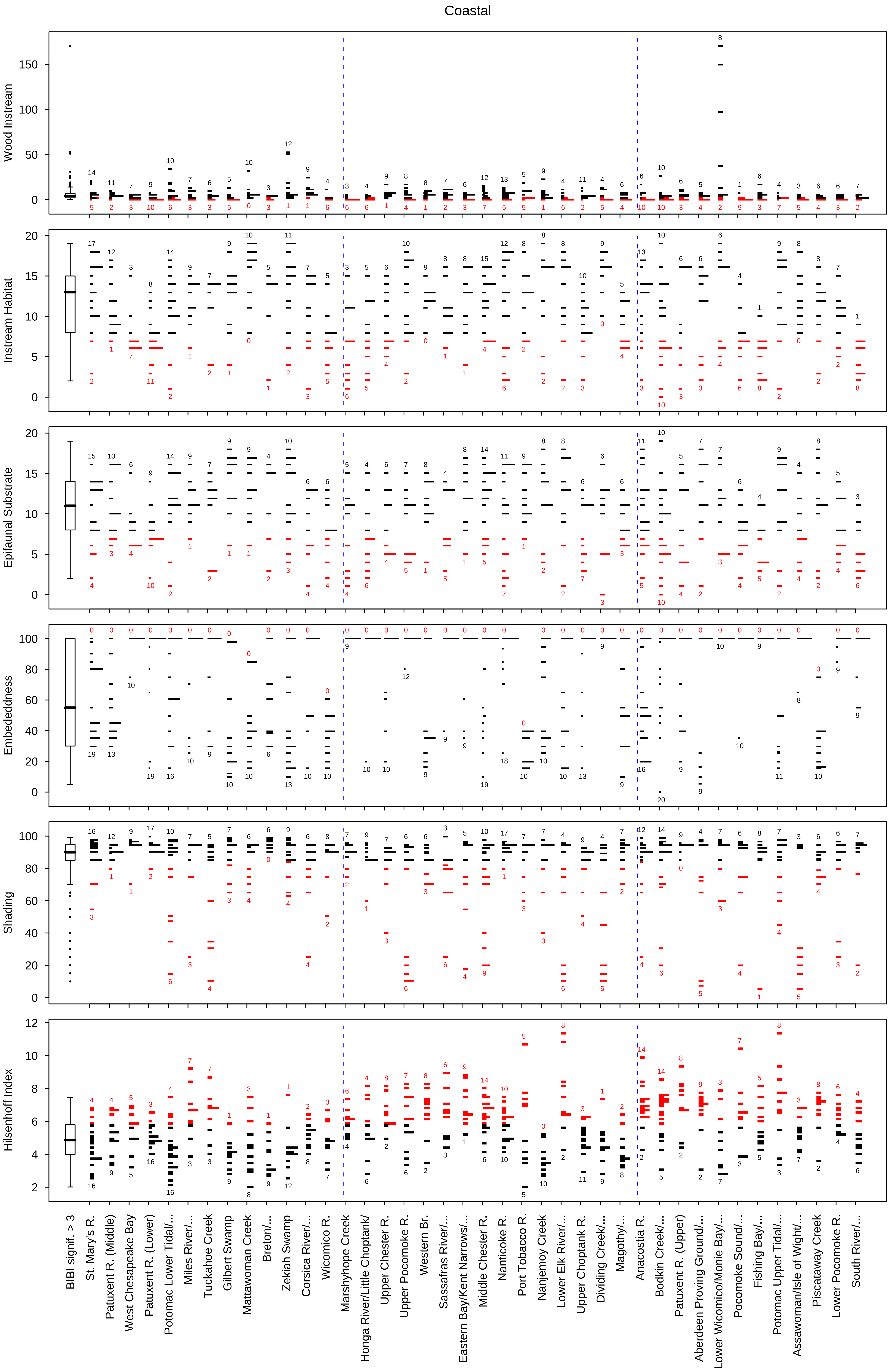
Appendix C

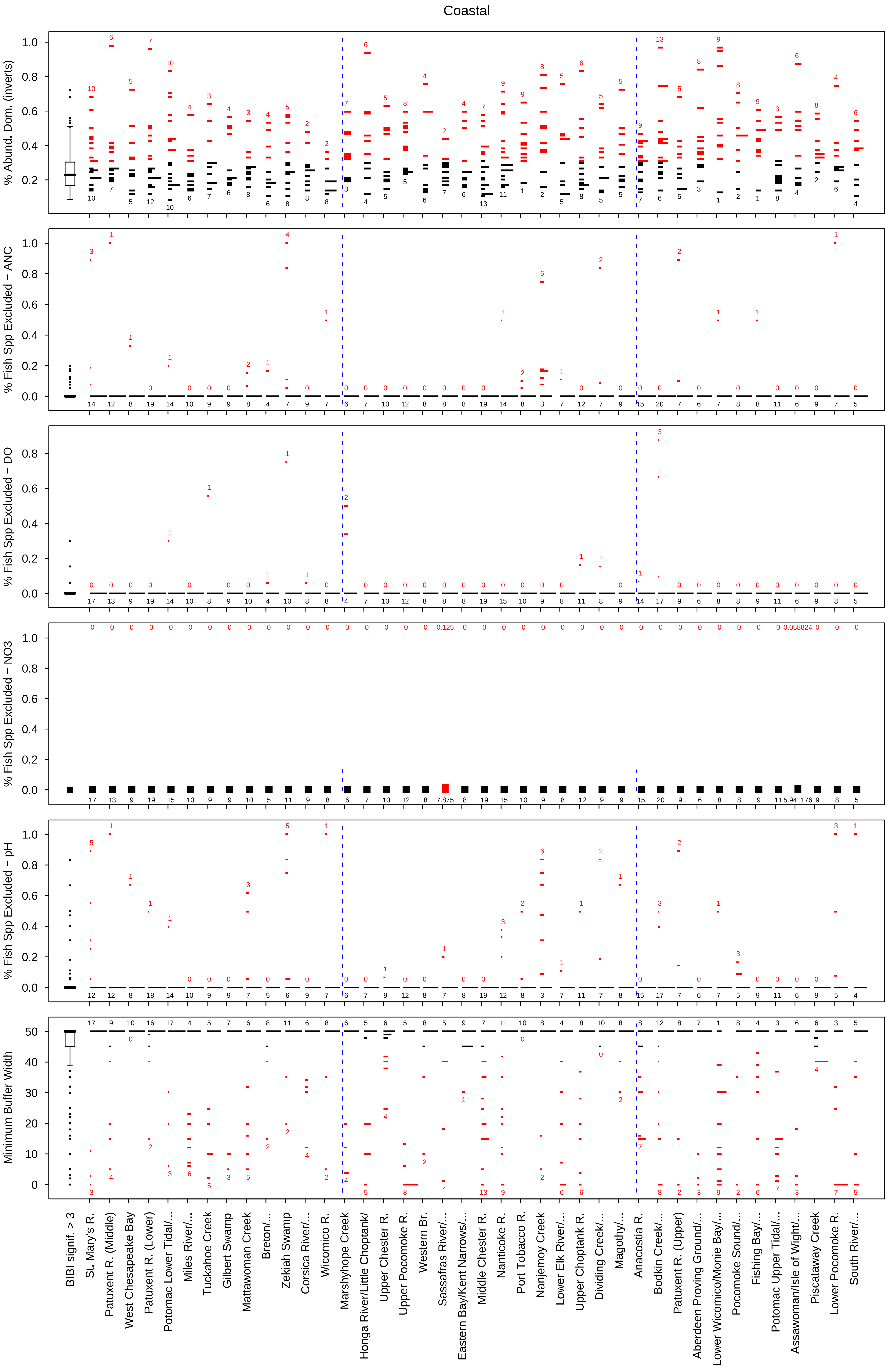
APPENDIX C
GRAPHS OF EACH CANDIDATE VARIABLE AS NUMBER OF EXCEEDANCES BEYOND THE 75TH REFERENCE PERCENTILE

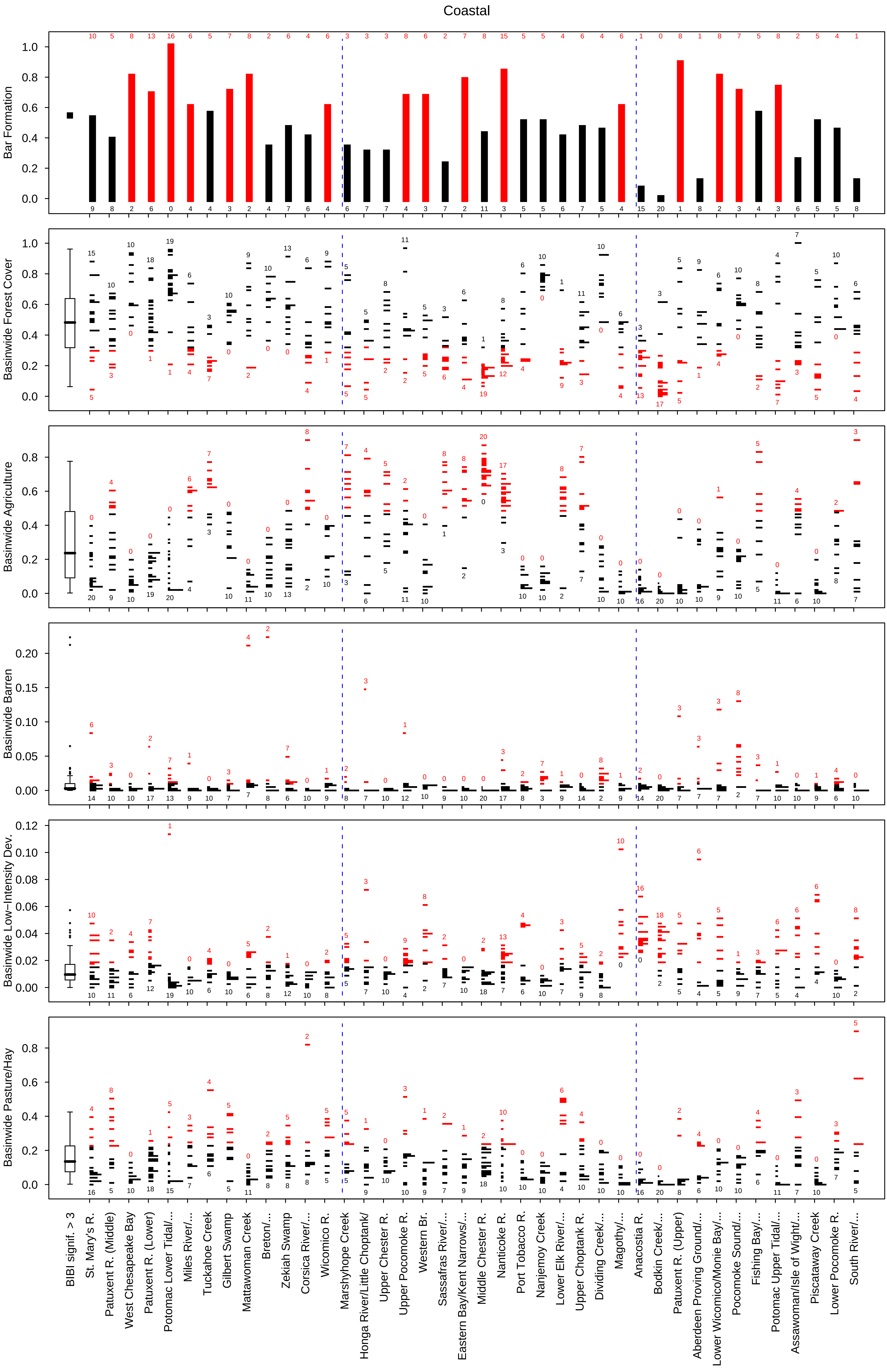

Coastal
pH
9
8
7
6
5
4
ANC
4000
3000
2000
1000
0
SO4
800
600
400
200
0
NH3
3.0
2.5
2.0
1.5
1.0
0.5
0.0
DOC
50
40
30
20
10
0
% Abund. Dom. (fish)
100
80
60
40
20
BIBI signif. > 3
St. Mary's R.
Patuxent R. (Middle)
West Chesapeake Bay
Patuxent R. (Lower)
Potomac Lower Tidal/...
Miles River/...
Tuckahoe Creek
Gilbert Swamp
Mattawoman Creek
Breton/...
Zekiah Swamp
Corsica River/...
Wicomico R.
Marshyhope Creek
Honga River/Little Choptank/
Upper Chester R.
Upper Pocomoke R.
Western Br.
Sassafras River/...
Eastern Bay/Kent Narrows/...
Middle Chester R.
Nanticoke R.
Port Tobacco R.
Nanjemoy Creek
Lower Elk River/...
Upper Choptank R.
Dividing Creek/...
Magothy/...
Anacostia R.
Bodkin Creek/...
Patuxent R. (Upper)
Aberdeen Proving Ground/...
Lower Wicomico/Monie Bay/...
Pocomoke Sound/...
Fishing Bay/...
Potomac Upper Tidal/...
Assawoman/Isle of Wight/...
Piscataway Creek
Lower Pocomoke R.
South River/...

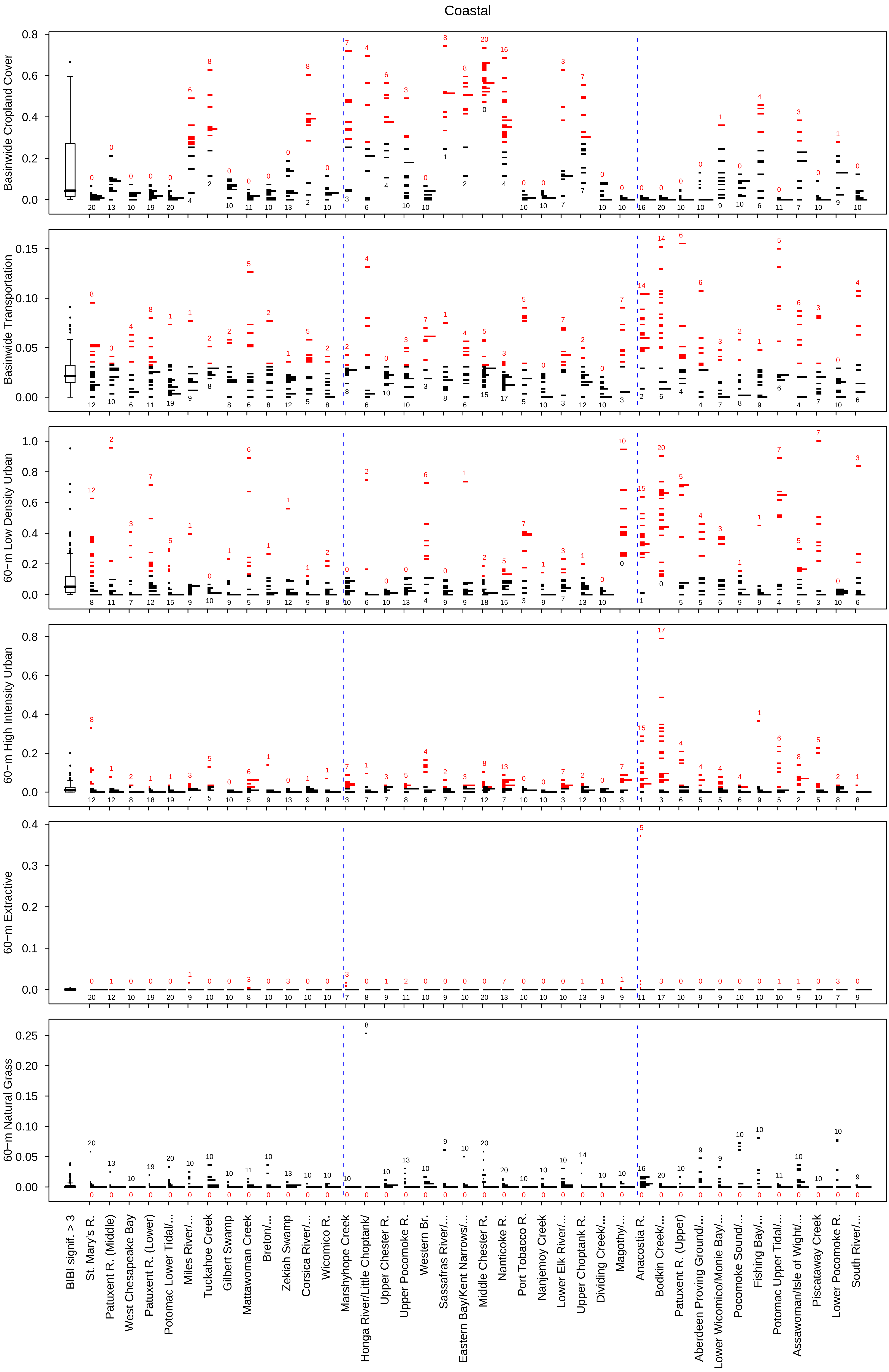

Coastal
Fish Anomalies
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Mean Gamefish Length
50
100
150
200
250
300
350
High Dens. Residential
0
5
10
15
20
25
30
High Commercial Land Use
0
5
10
15
20
% Urban Development
0
20
40
60
80
Agriculture
0
20
40
60
80
100
BIBI signif. > 3
St. Mary's R.
Patuxent R. (Middle)
West Chesapeake Bay
Patuxent R. (Lower)
Potomac Lower Tidal/...
Miles River/...
Tuckahoe Creek
Gilbert Swamp
Mattawoman Creek
Breton/...
Zekiah Swamp
Corsica River/...
Wicomico R.
Marshyhope Creek
Honga River/Little Choptank/
Upper Chester R.
Upper Pocomoke R.
Western Br.
Sassafras River/...
Eastern Bay/Kent Narrows/...
Middle Chester R.
Nanticoke R.
Port Tobacco R.
Nanjemoy Creek
Lower Elk River/...
Upper Choptank R.
Dividing Creek/...
Magothy/...
Anacostia R.
Bodkin Creek/...
Patuxent R. (Upper)
Aberdeen Proving Ground/...
Lower Wicomico/Monie Bay/...
Pocomoke Sound/...
Fishing Bay/...
Potomac Upper Tidal/...
Assawoman/Isle of Wight/...
Piscataway Creek
Lower Pocomoke R.
South River/...

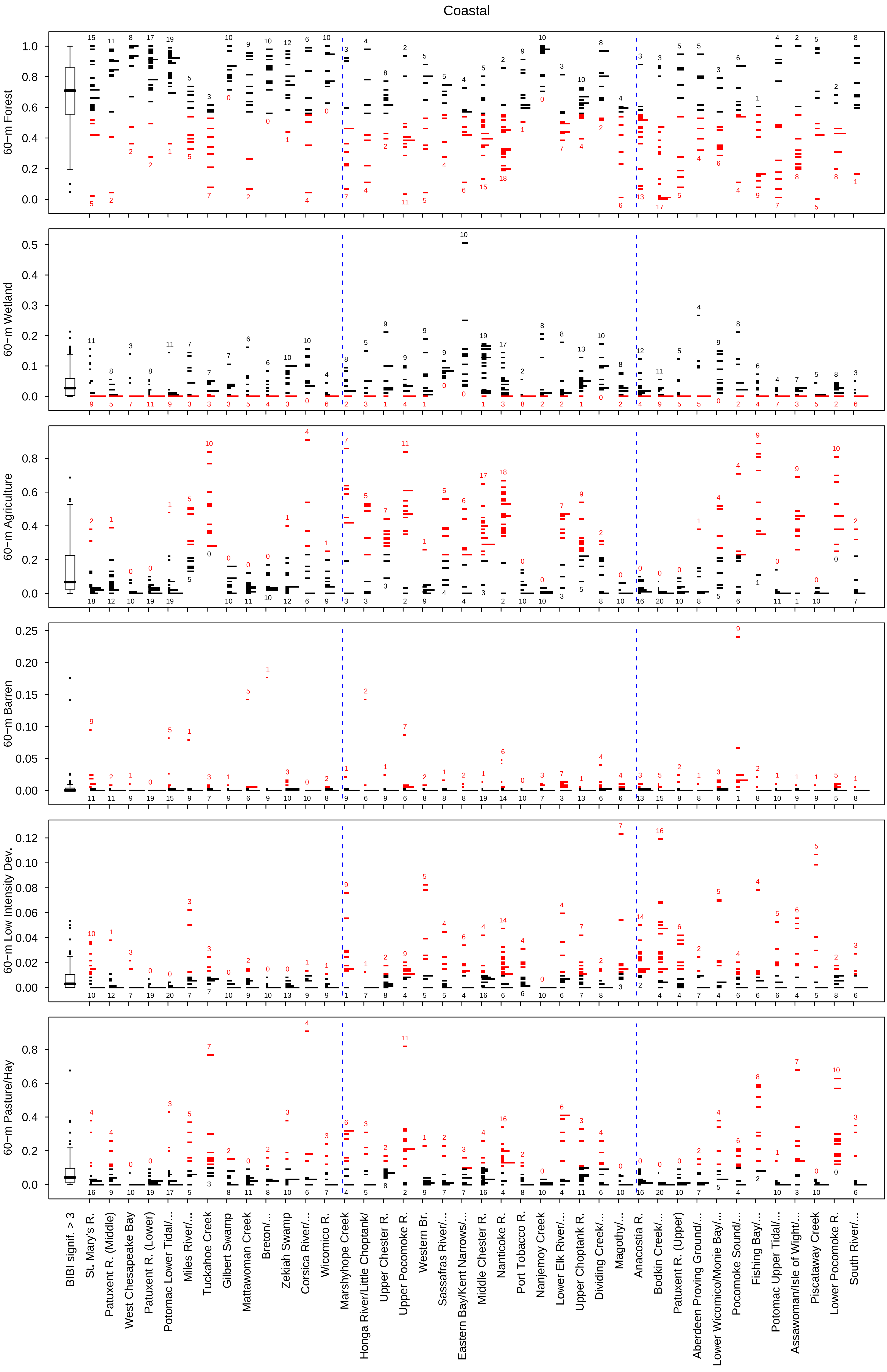

Coastal
Impervious Surface
0
10
20
30
40
Culvert Present
0.0
0.2
0.4
0.6
0.8
1.0
Surface Mine Present
0.0
0.2
0.4
0.6
0.8
1.0
Water Temp (C)
15
20
25
30
35
Dissolved Oxygen
0
5
10
15
Conductivity
0.0
0.5
1.0
1.5
2.0
2.5
3.0
BIBI signif. > 3
St. Mary's R.
Patuxent R. (Middle)
West Chesapeake Bay
Patuxent R. (Lower)
Potomac Lower Tidal/...
Miles River/...
Tuckahoe Creek
Gilbert Swamp
Mattawoman Creek
Breton/...
Zekiah Swamp
Corsica River/...
Wicomico R.
Marshyhope Creek
Honga River/Little Choptank/
Upper Chester R.
Upper Pocomoke R.
Western Br.
Sassafras River/...
Eastern Bay/Kent Narrows/...
Middle Chester R.
Nanticoke R.
Port Tobacco R.
Nanjemoy Creek
Lower Elk River/...
Upper Choptank R.
Dividing Creek/...
Magothy/...
Anacostia R.
Bodkin Creek/...
Patuxent R. (Upper)
Aberdeen Proving Ground/...
Lower Wicomico/Monie Bay/...
Pocomoke Sound/...
Fishing Bay/...
Potomac Upper Tidal/...
Assawoman/Isle of Wight/...
Piscataway Creek
Lower Pocomoke R.
South River/...

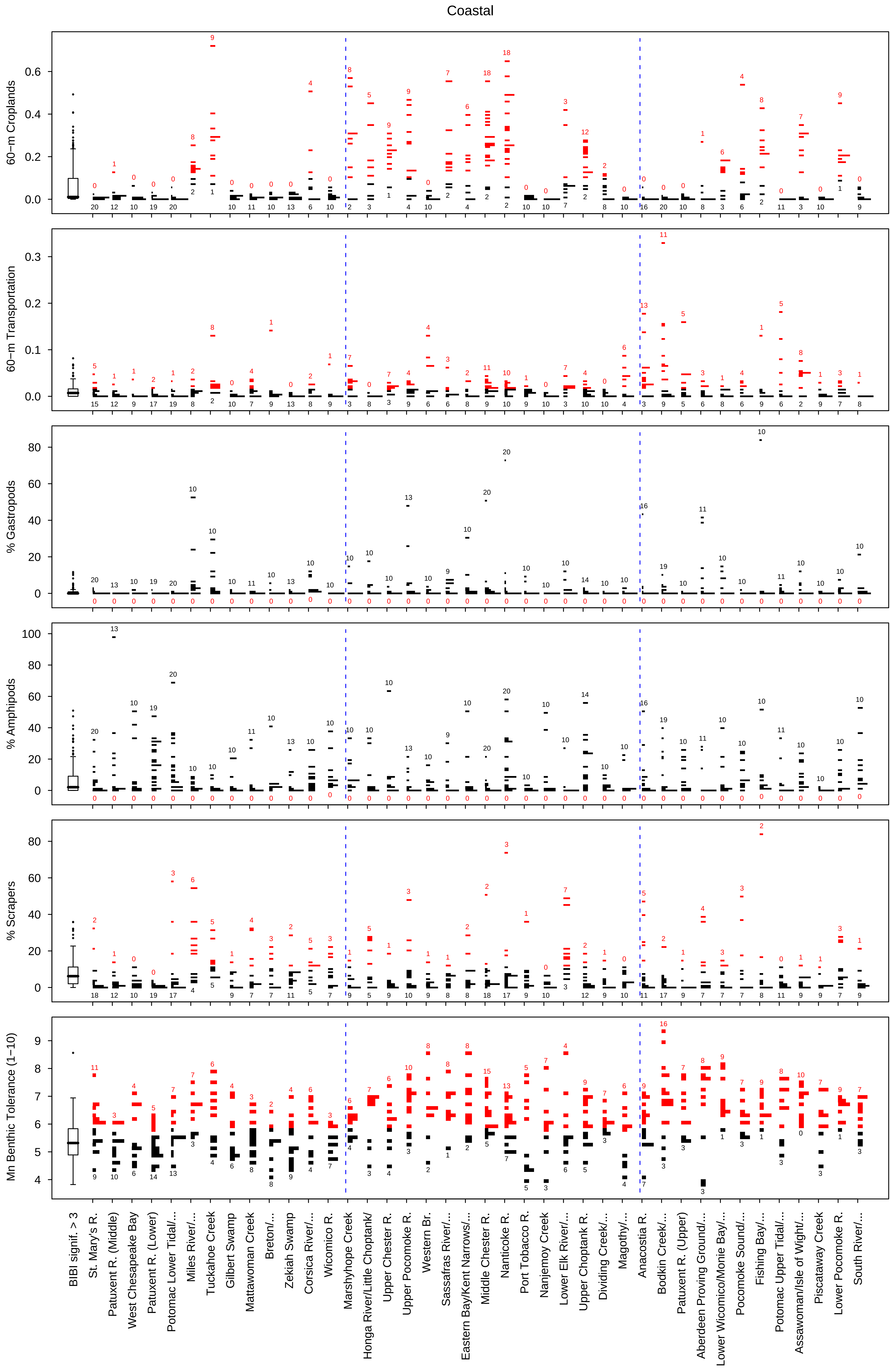

Coastal
Wood Instream
0
50
100
150
Instream Habitat
0
5
10
15
20
Epifaunal Substrate
0
5
10
15
20
Embeddedness
0
20
40
60
80
100
Shading
0
20
40
60
80
100
Hilsenhoff Index
2
4
6
8
10
12
BIBI signif. > 3
St. Mary's R.
Patuxent R. (Middle)
West Chesapeake Bay
Patuxent R. (Lower)
Potomac Lower Tidal/...
Miles River/...
Tuckahoe Creek
Gilbert Swamp
Mattawoman Creek
Breton/...
Zekiah Swamp
Corsica River/...
Wicomico R.
Marshyhope Creek
Honga River/Little Choptank/
Upper Chester R.
Upper Pocomoke R.
Western Br.
Sassafras River/...
Eastern Bay/Kent Narrows/...
Middle Chester R.
Nanticoke R.
Port Tobacco R.
Nanjemoy Creek
Lower Elk River/...
Upper Choptank R.
Dividing Creek/...
Magothy/...
Anacostia R.
Bodkin Creek/...
Patuxent R. (Upper)
Aberdeen Proving Ground/...
Lower Wicomico/Monie Bay/...
Pocomoke Sound/...
Fishing Bay/...
Potomac Upper Tidal/...
Assawoman/Isle of Wight/...
Piscataway Creek
Lower Pocomoke R.
South River/...

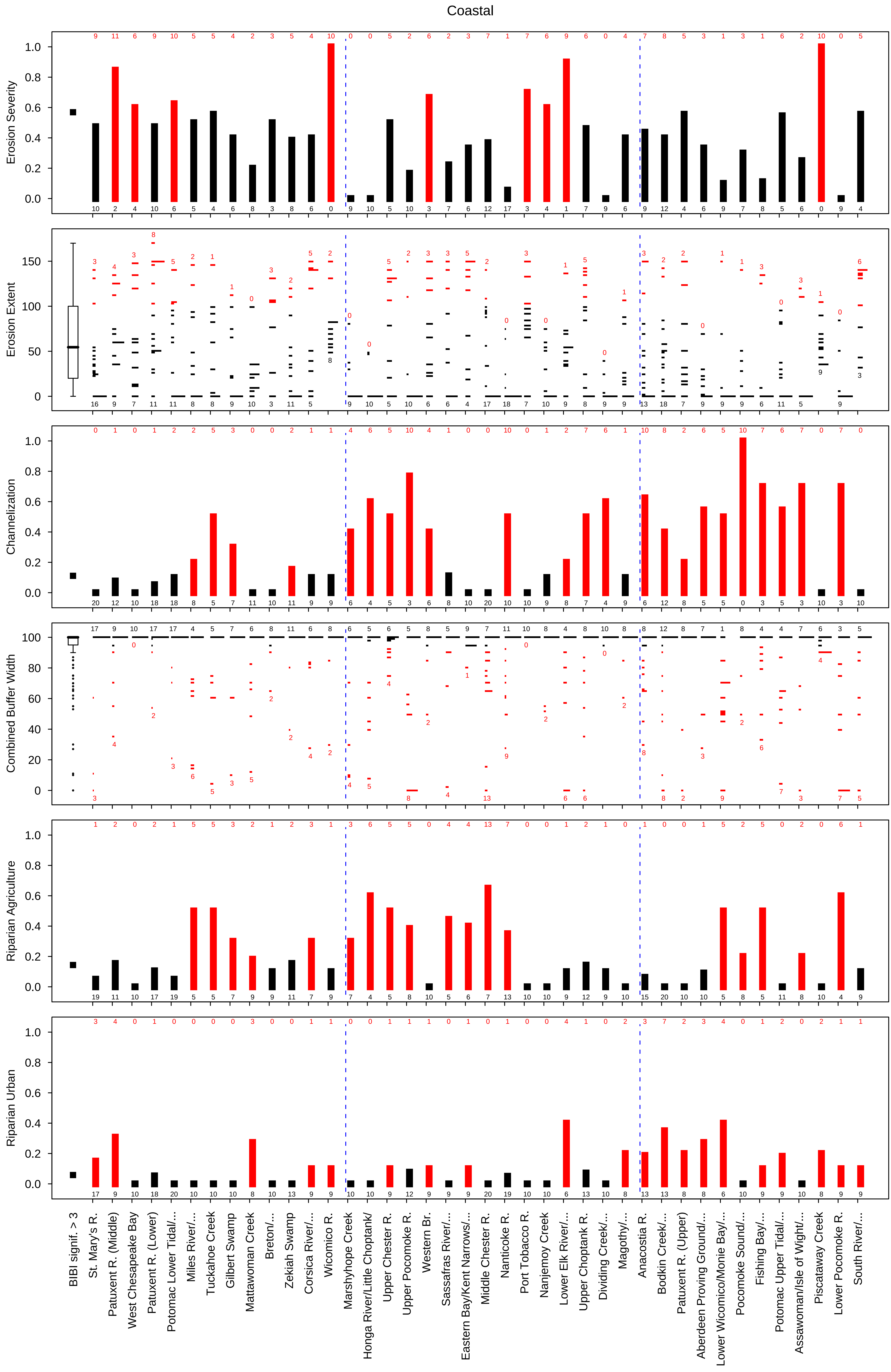

Coastal
% Abund. Dom. (inverts)
1.0
0.8
0.6
0.4
0.2
% Fish Spp Excluded – ANC
1.0
0.8
0.6
0.4
0.2
0.0
% Fish Spp Excluded – DO
0.8
0.6
0.4
0.2
0.0
% Fish Spp Excluded – NO3
1.0
0.8
0.6
0.4
0.2
0.0
0.125
7.875
0.058824
5.941176
% Fish Spp Excluded – pH
1.0
0.8
0.6
0.4
0.2
0.0
Minimum Buffer Width
50
40
30
20
10
0
BIBI signif. > 3
St. Mary's R.
Patuxent R. (Middle)
West Chesapeake Bay
Patuxent R. (Lower)
Potomac Lower Tidal/...
Miles River/...
Tuckahoe Creek
Gilbert Swamp
Mattawoman Creek
Breton/...
Zekiah Swamp
Corsica River/...
Wicomico R.
Marshyhope Creek
Honga River/Little Choptank/
Upper Chester R.
Upper Pocomoke R.
Western Br.
Sassafras River/...
Eastern Bay/Kent Narrows/...
Middle Chester R.
Nanticoke R.
Port Tobacco R.
Nanjemoy Creek
Lower Elk River/...
Upper Choptank R.
Dividing Creek/...
Magothy/...
Anacostia R.
Bodkin Creek/...
Patuxent R. (Upper)
Aberdeen Proving Ground/...
Lower Wicomico/Monie Bay/...
Pocomoke Sound/...
Fishing Bay/...
Potomac Upper Tidal/...
Assawoman/Isle of Wight/...
Piscataway Creek
Lower Pocomoke R.
South River/...

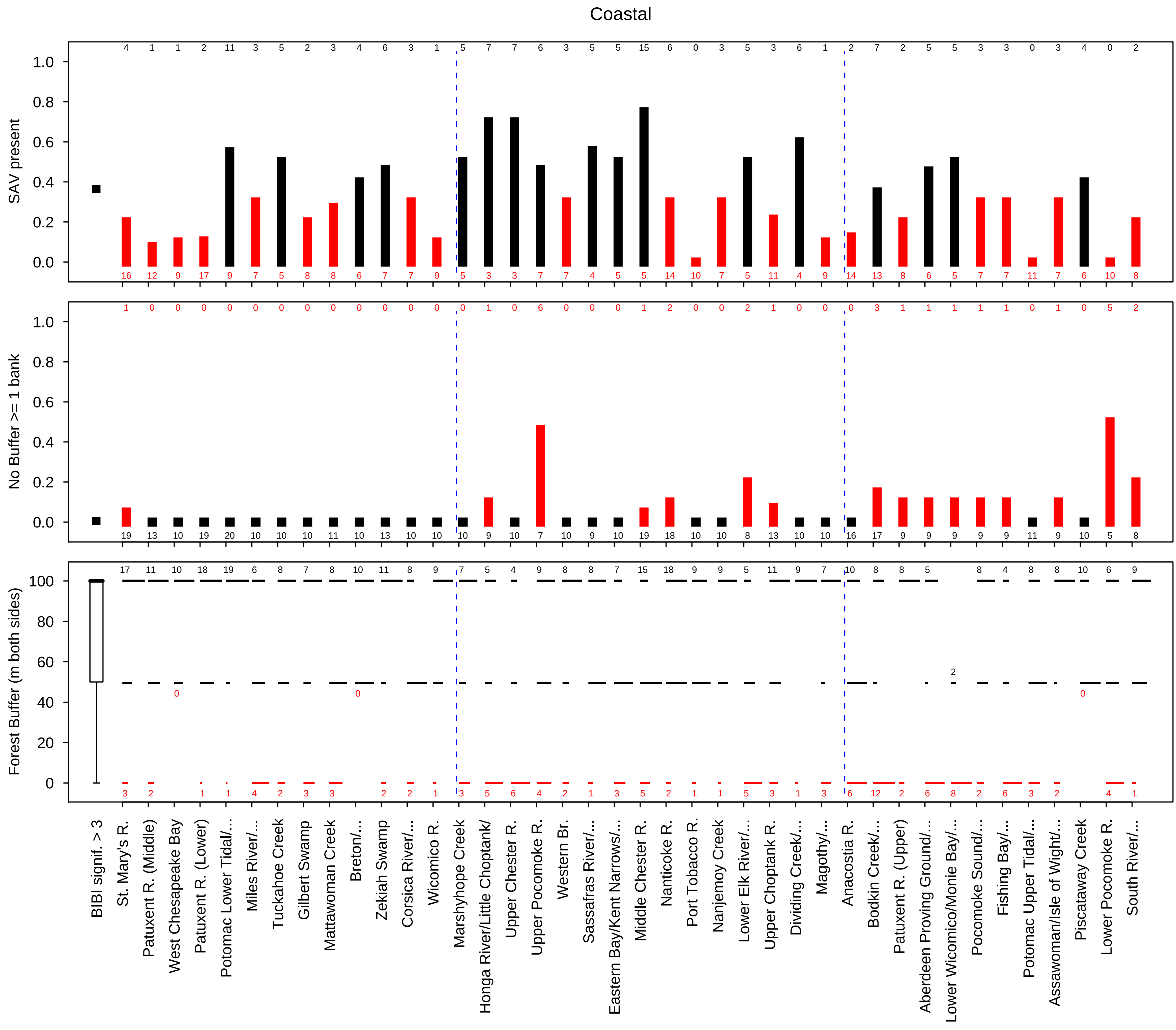

Coastal
Bar Formation
Basinwide Forest Cover
Basinwide Agriculture
Basinwide Barren
Basinwide Low−Intensity Dev.
Basinwide Pasture/Hay
0.0
0.2
0.4
0.6
0.8
1.0
0.00
0.05
0.10
0.15
0.20
0.02
0.04
0.06
0.08
0.12
BIBI signif. > 3
St. Mary's R.
Patuxent R. (Middle)
West Chesapeake Bay
Patuxent R. (Lower)
Potomac Lower Tidal/...
Miles River/...
Tuckahoe Creek
Gilbert Swamp
Mattawoman Creek
Breton/...
Zekiah Swamp
Corsica River/...
Wicomico R.
Marshyhope Creek
Honga River/Little Choptank/
Upper Chester R.
Upper Pocomoke R.
Western Br.
Sassafras River/...
Eastern Bay/Kent Narrows/...
Middle Chester R.
Nanticoke R.
Port Tobacco R.
Nanjemoy Creek
Lower Elk River/...
Upper Choptank R.
Dividing Creek/...
Magothy/...
Anacostia R.
Bodkin Creek/...
Patuxent R. (Upper)
Aberdeen Proving Ground/...
Lower Wicomico/Monie Bay/...
Pocomoke Sound/...
Fishing Bay/...
Potomac Upper Tidal/...
Assawoman/Isle of Wight/...
Piscataway Creek
Lower Pocomoke R.
South River/...

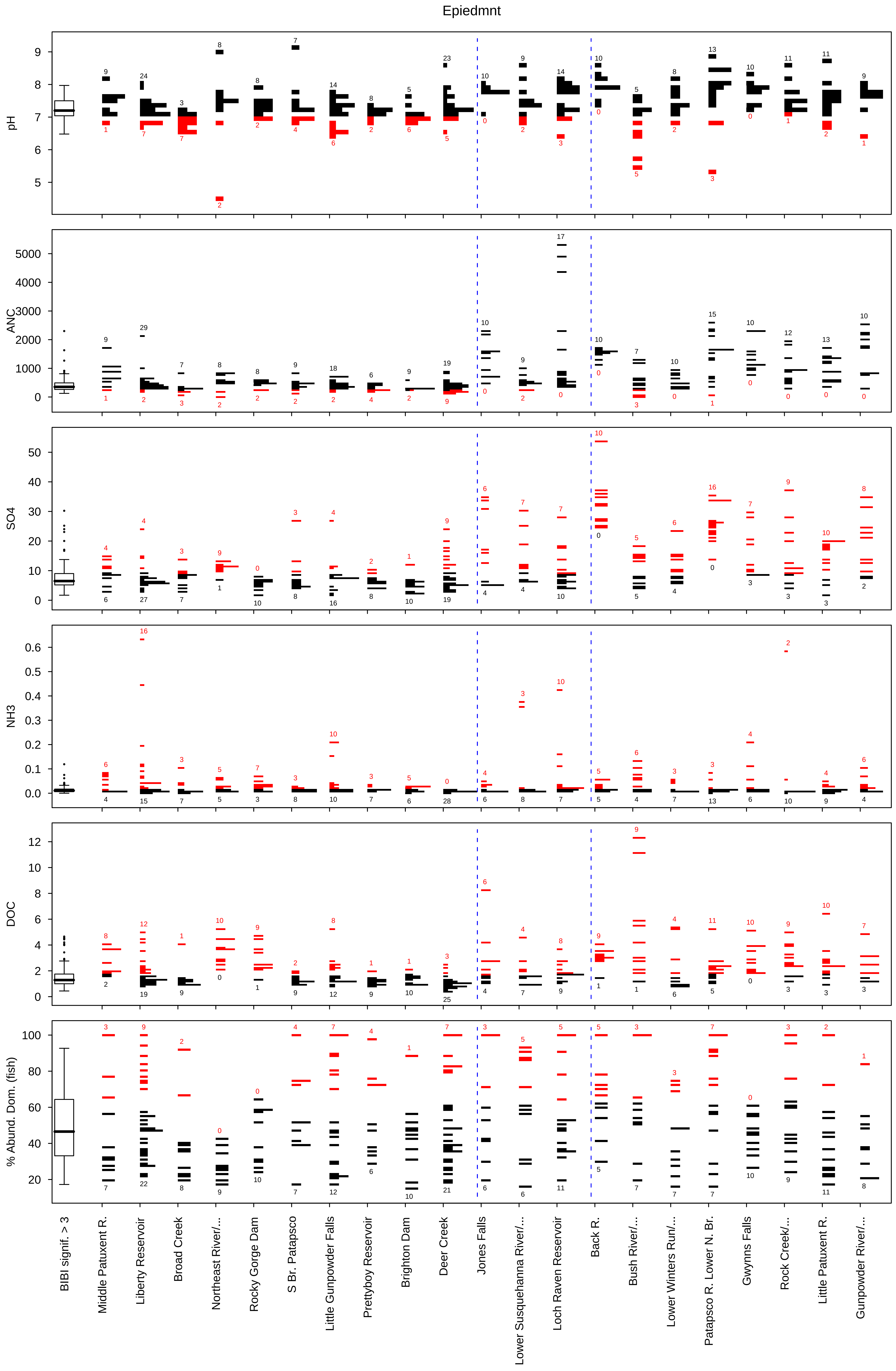

Coastal
Basinwide Cropland Cover
0.0
0.2
0.4
0.6
0.8
Basinwide Transportation
0.00
0.05
0.10
0.15
60−m Low Density Urban
0.0
0.2
0.4
0.6
0.8
1.0
60−m High Intensity Urban
0.0
0.2
0.4
0.6
0.8
60−m Extractive
0.0
0.1
0.2
0.3
0.4
60−m Natural Grass
0.00
0.05
0.10
0.15
0.20
0.25
BIBI signif. > 3
St. Mary's R.
Patuxent R. (Middle)
West Chesapeake Bay
Patuxent R. (Lower)
Potomac Lower Tidal/...
Miles River/...
Tuckahoe Creek
Gilbert Swamp
Mattawoman Creek
Breton/...
Zekiah Swamp
Corsica River/...
Wicomico R.
Marshyhope Creek
Honga River/Little Choptank/
Upper Chester R.
Upper Pocomoke R.
Western Br.
Sassafras River/...
Eastern Bay/Kent Narrows/...
Middle Chester R.
Nanticoke R.
Port Tobacco R.
Nanjemoy Creek
Lower Elk River/...
Upper Choptank R.
Dividing Creek/...
Magothy/...
Anacostia R.
Bodkin Creek/...
Patuxent R. (Upper)
Aberdeen Proving Ground/...
Lower Wicomico/Monie Bay/...
Pocomoke Sound/...
Fishing Bay/...
Potomac Upper Tidal/...
Assawoman/Isle of Wight/...
Piscataway Creek
Lower Pocomoke R.
South River/...

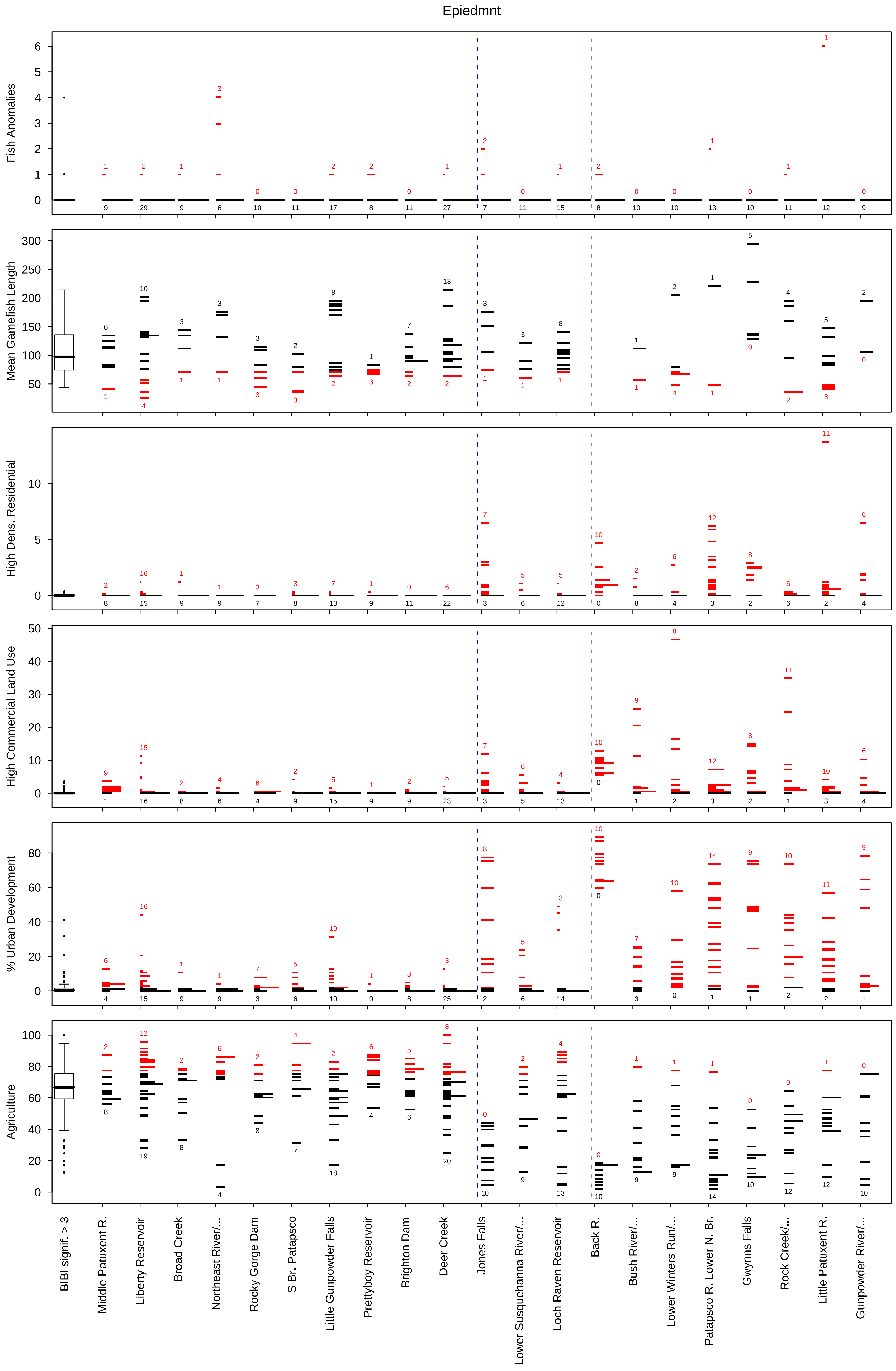

Coastal
60−m Forest
60−m Wetland
60−m Agriculture
60−m Barren
60−m Low Intensity Dev.
60−m Pasture/Hay
BIBI signif. > 3
St. Mary's R.
Patuxent R. (Middle)
West Chesapeake Bay
Patuxent R. (Lower)
Potomac Lower Tidal/...
Miles River/...
Tuckahoe Creek
Gilbert Swamp
Mattawoman Creek
Breton/...
Zekiah Swamp
Corsica River/...
Wicomico R.
Marshyhope Creek
Honga River/Little Choptank/
Upper Chester R.
Upper Pocomoke R.
Western Br.
Sassafras River/...
Eastern Bay/Kent Narrows/...
Middle Chester R.
Nanticoke R.
Port Tobacco R.
Nanjemoy Creek
Lower Elk River/...
Upper Choptank R.
Dividing Creek/...
Magothy/...
Anacostia R.
Bodkin Creek/...
Patuxent R. (Upper)
Aberdeen Proving Ground/...
Lower Wicomico/Monie Bay/...
Pocomoke Sound/...
Fishing Bay/...
Potomac Upper Tidal/...
Assawoman/Isle of Wight/...
Piscataway Creek
Lower Pocomoke R.
South River/...

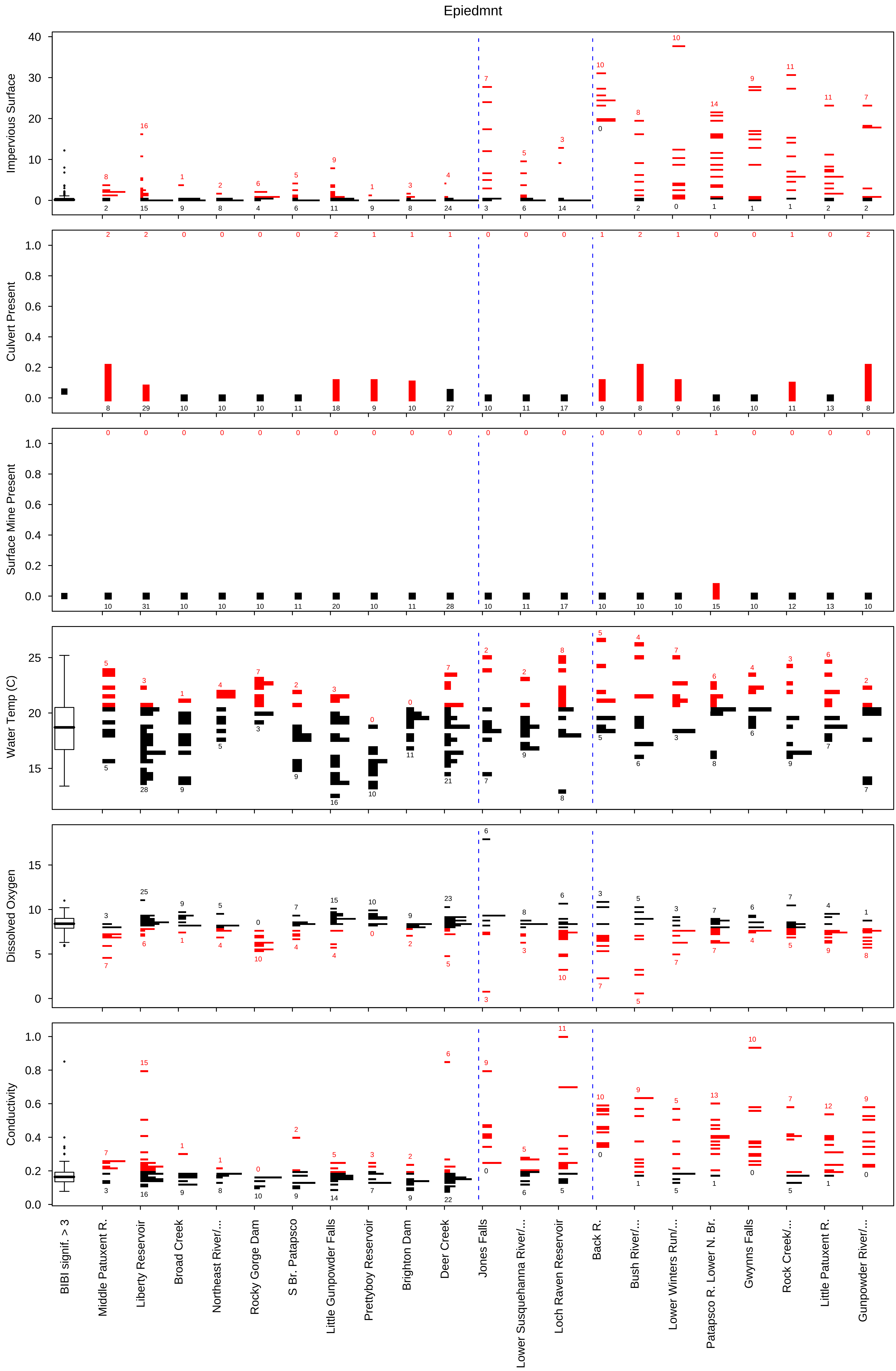

Coastal
60−m Croplands
0.0
0.2
0.4
0.6
60−m Transportation
0.0
0.1
0.2
0.3
% Gastropods
0
20
40
60
80
% Amphipods
0
20
40
60
80
100
% Scrapers
0
20
40
60
80
Mn Benthic Tolerance (1−10)
4
5
6
7
8
9
BIBI signif. > 3
St. Mary's R.
Patuxent R. (Middle)
West Chesapeake Bay
Patuxent R. (Lower)
Potomac Lower Tidal/...
Miles River/...
Tuckahoe Creek
Gilbert Swamp
Mattawoman Creek
Breton/...
Zekiah Swamp
Corsica River/...
Wicomico R.
Marshyhope Creek
Honga River/Little Choptank/
Upper Chester R.
Upper Pocomoke R.
Western Br.
Sassafras River/...
Eastern Bay/Kent Narrows/...
Middle Chester R.
Nanticoke R.
Port Tobacco R.
Nanjemoy Creek
Lower Elk River/...
Upper Choptank R.
Dividing Creek/...
Magothy/...
Anacostia R.
Bodkin Creek/...
Patuxent R. (Upper)
Aberdeen Proving Ground/...
Lower Wicomico/Monie Bay/...
Pocomoke Sound/...
Fishing Bay/...
Potomac Upper Tidal/...
Assawoman/Isle of Wight/...
Piscataway Creek
Lower Pocomoke R.
South River/...

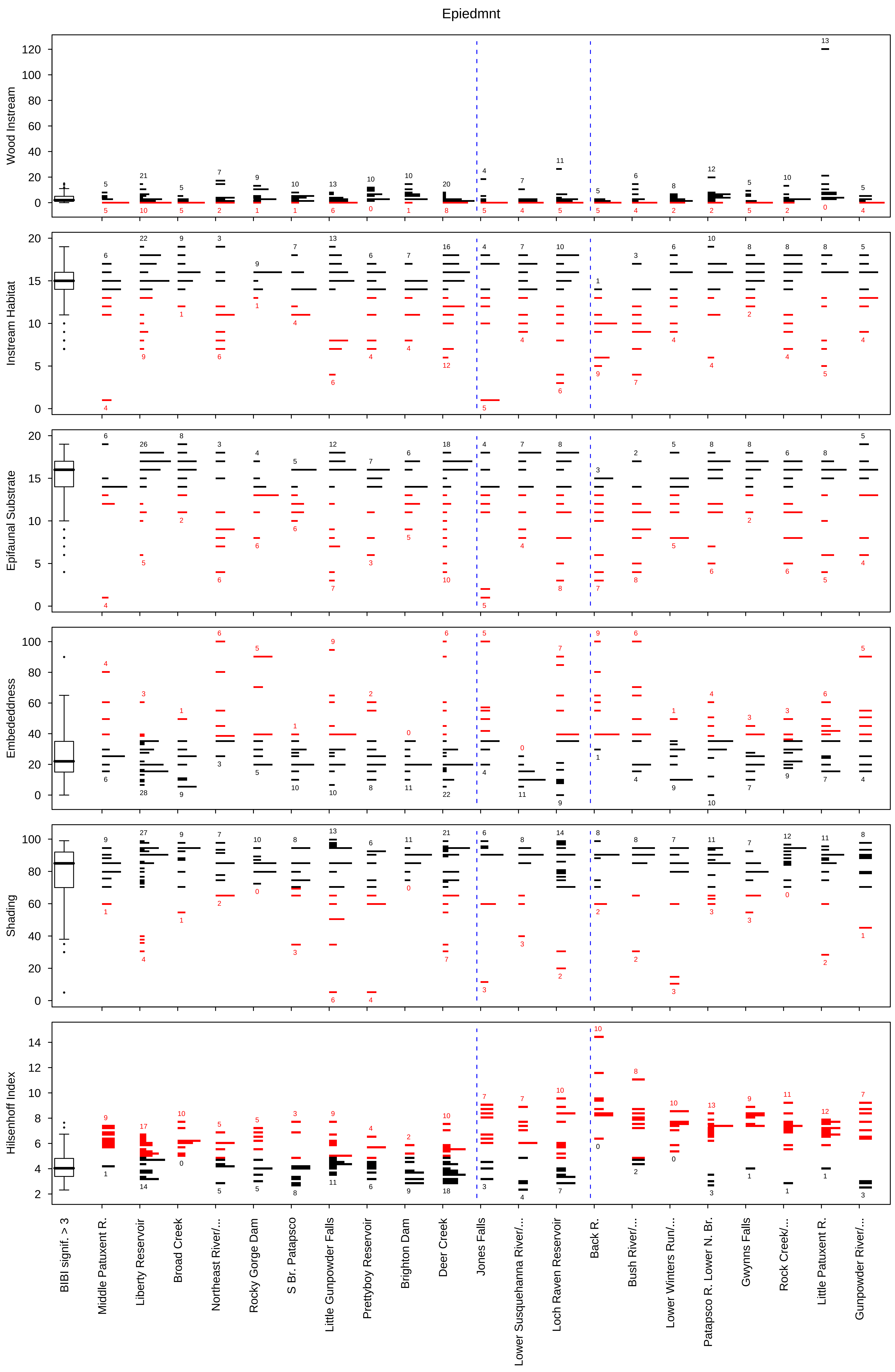

Coastal
Erosion Severity
Erosion Extent
Channelization
Combined Buffer Width
Riparian Agriculture
Riparian Urban
BIBI signif. > 3
St. Mary's R.
Patuxent R. (Middle)
West Chesapeake Bay
Patuxent R. (Lower)
Potomac Lower Tidal/...
Miles River/...
Tuckahoe Creek
Gilbert Swamp
Mattawoman Creek
Breton/...
Zekiah Swamp
Corsica River/...
Wicomico R.
Marshyhope Creek
Honga River/Little Choptank/
Upper Chester R.
Upper Pocomoke R.
Western Br.
Sassafras River/...
Eastern Bay/Kent Narrows/...
Middle Chester R.
Nanticoke R.
Port Tobacco R.
Nanjemoy Creek
Lower Elk River/...
Upper Choptank R.
Dividing Creek/...
Magothy/...
Anacostia R.
Bodkin Creek/...
Patuxent R. (Upper)
Aberdeen Proving Ground/...
Lower Wicomico/Monie Bay/...
Pocomoke Sound/...
Fishing Bay/...
Potomac Upper Tidal/...
Assawoman/Isle of Wight/...
Piscataway Creek
Lower Pocomoke R.
South River/...

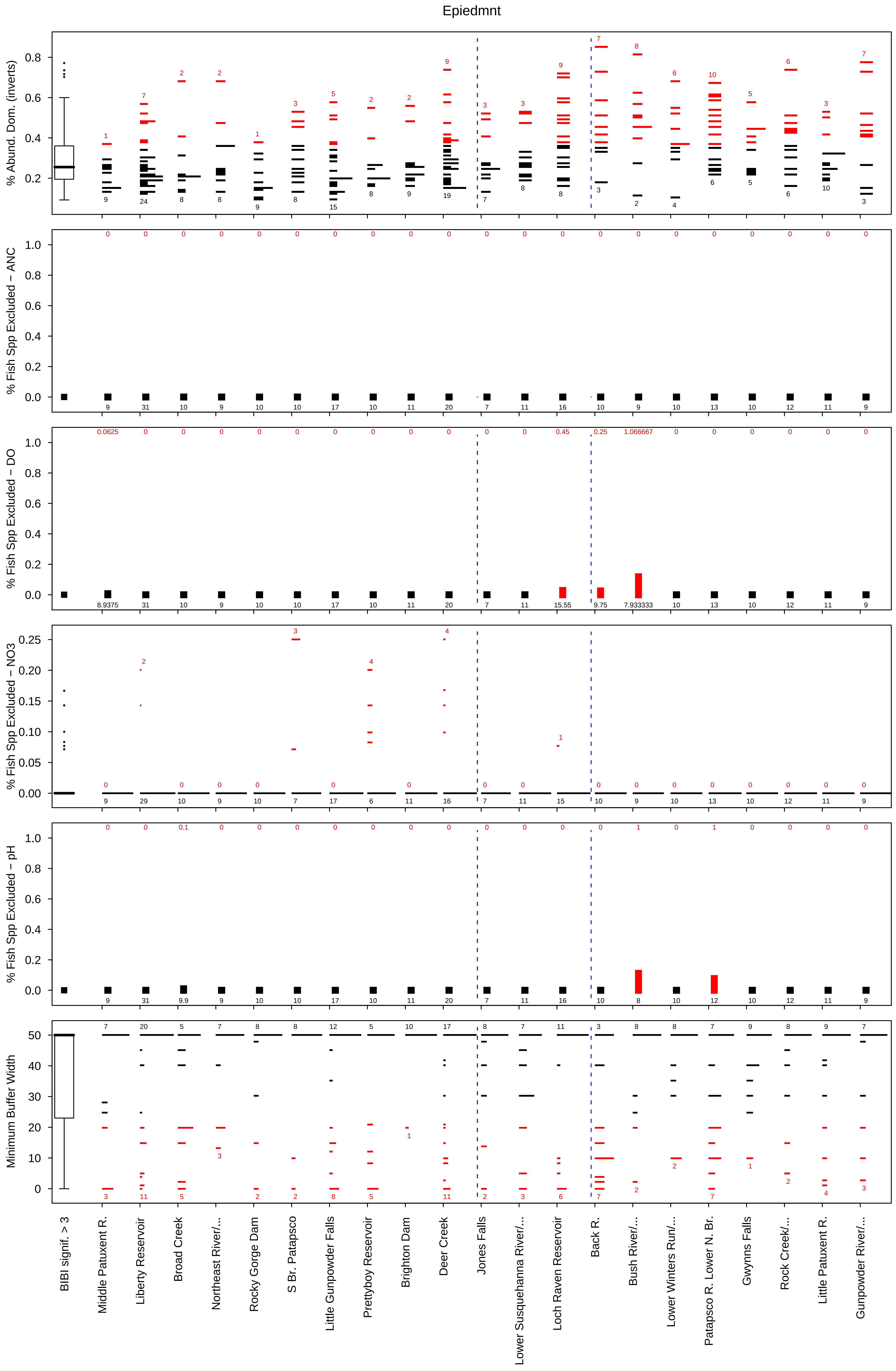

Coastal
SAV present
1.0
0.8
0.6
0.4
0.2
0.0
No Buffer >= 1 bank
1.0
0.8
0.6
0.4
0.2
0.0
Forest Buffer (m both sides)
100
80
60
40
20
0
BIBI signif. > 3
St. Mary's R.
Patuxent R. (Middle)
West Chesapeake Bay
Patuxent R. (Lower)
Potomac Lower Tidal/...
Miles River/...
Tuckahoe Creek
Gilbert Swamp
Mattawoman Creek
Breton/...
Zekiah Swamp
Corsica River/...
Wicomico R.
Marshyhope Creek
Honga River/Little Choptank/
Upper Chester R.
Upper Pocomoke R.
Western Br.
Sassafras River/...
Eastern Bay/Kent Narrows/...
Middle Chester R.
Nanticoke R.
Port Tobacco R.
Nanjemoy Creek
Lower Elk River/...
Upper Choptank R.
Dividing Creek/...
Magothy/...
Anacostia R.
Bodkin Creek/...
Patuxent R. (Upper)
Aberdeen Proving Ground/...
Lower Wicomico/Monie Bay/...
Pocomoke Sound/...
Fishing Bay/...
Potomac Upper Tidal/...
Assawoman/Isle of Wight/...
Piscataway Creek
Lower Pocomoke R.
South River/...

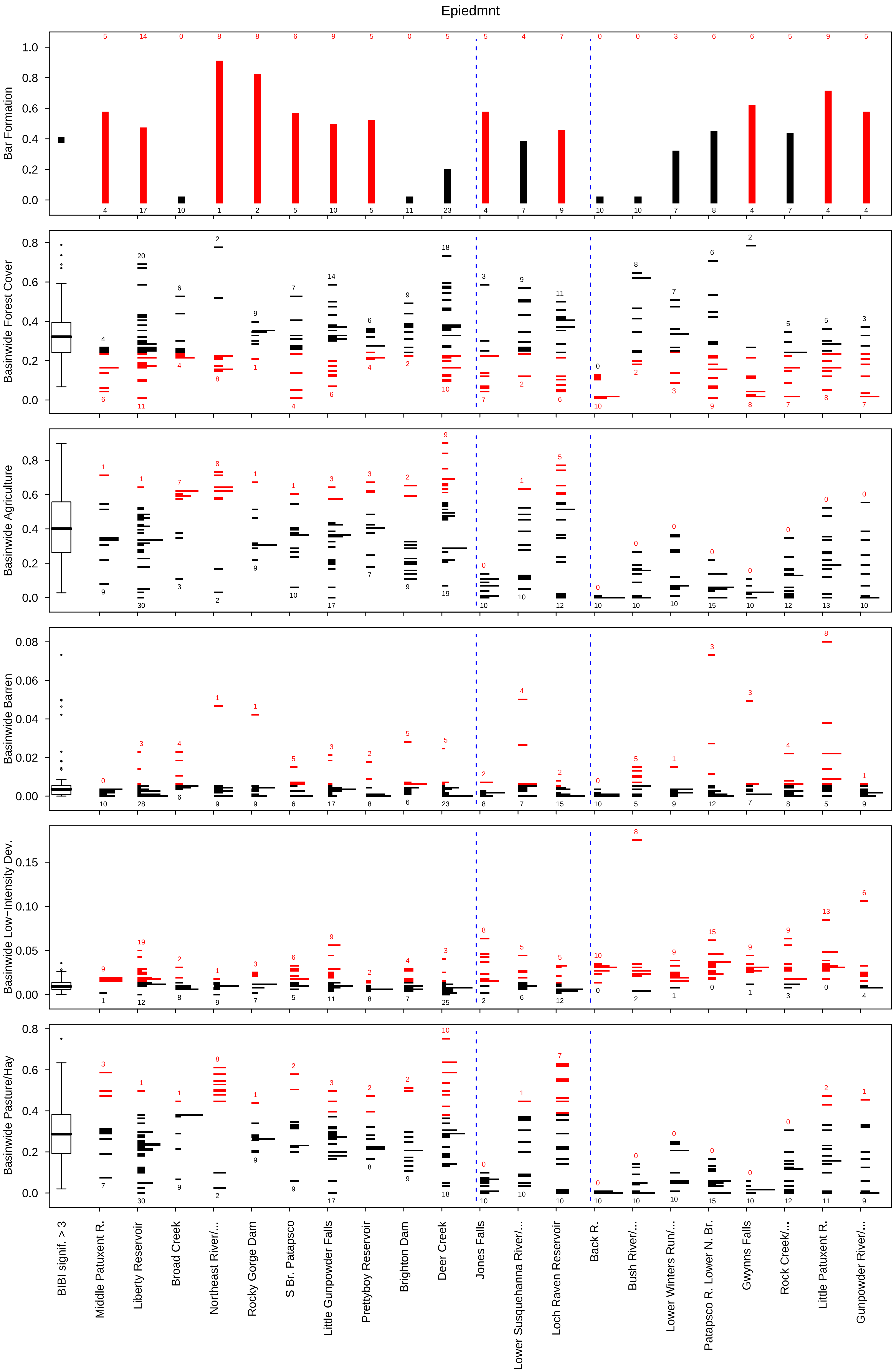

Epiedmnt
pH
9
8
7
6
5
9 24 3 8 8 7 14 8 5 23 10 9 14 10 5 8 13 10 11 11 9
1 7 7 2 2 4 6 2 6 5 0 2 3 0 5 2 3 0 1 2 1
ANC
5000
4000
3000
2000
1000
0
9 29 7 8 8 9 18 6 9 19 10 9 17 10 7 10 15 10 12 13 10
1 2 3 2 2 2 2 4 2 9 0 2 0 0 3 0 1 0 0 0 0
SO4
50
40
30
20
10
0
4 4 3 9 0 3 4 2 1 9 6 7 7 10 5 6 16 7 9 10 8
6 27 7 1 10 8 16 8 10 19 4 4 10 0 5 4 0 3 3 3 2
NH3
0.6
0.5
0.4
0.3
0.2
0.1
0.0
6 16 3 5 7 3 10 3 5 0 4 3 10 5 6 3 3 4 2 4 6
4 15 7 5 3 8 10 7 6 28 6 8 7 5 4 7 13 6 10 9 4
DOC
12
10
8
6
4
2
0
8 12 1 10 9 2 8 1 1 3 6 4 8 9 9 4 11 10 9 10 7
2 19 9 0 1 9 12 9 10 25 4 7 9 1 1 6 5 0 3 3 3
% Abund. Dom. (fish)
100
80
60
40
20
3 9 2 0 0 4 7 4 1 7 3 5 5 5 3 3 7 0 3 2 1
7 22 8 9 10 7 12 6 10 21 6 6 11 5 7 7 7 10 9 11 8
BIBI signif. > 3
Middle Patuxent R.
Liberty Reservoir
Broad Creek
Northeast River/...
Rocky Gorge Dam
S Br. Patapsco
Little Gunpowder Falls
Prettyboy Reservoir
Brighton Dam
Deer Creek
Jones Falls
Lower Susquehanna River/...
Loch Raven Reservoir
Back R.
Bush River/...
Lower Winters Run/...
Patapsco R. Lower N. Br.
Gwynns Falls
Rock Creek/...
Little Patuxent R.
Gunpowder River/...

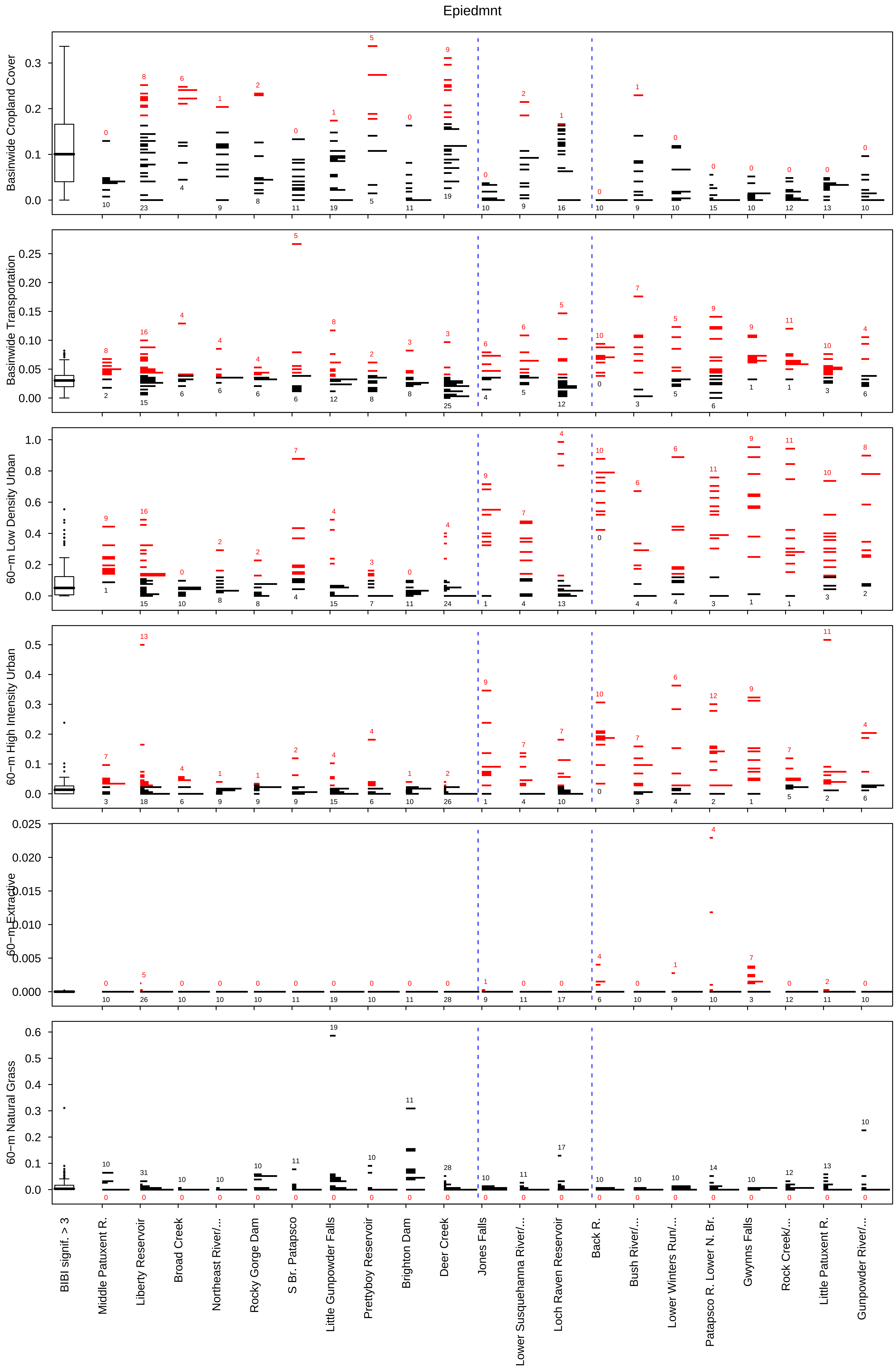
Epiedmnt
Fish Anomalies
0
1
2
3
4
5
6
1 2 1 3 0 0 2 2 0 1 2 0 1 2 0 0 1 0 1 1 0
9 29 9 6 10 11 17 8 11 27 7 11 15 8 10 10 13 10 11 12 9
Mean Gamefish Length
50
100
150
200
250
300
6 10 3 3 3 2 8 1 7 13 3 3 8 1 2 1 5 4 5 2
1 4 1 1 3 3 2 3 2 2 1 1 1 1 4 1 0 2 3 0
High Dens. Residential
0
5
10
2 16 1 1 3 3 7 1 0 6 7 5 5 10 2 6 12 8 6 11 6
8 15 9 9 7 8 13 9 11 22 3 6 12 0 8 4 3 2 6 2 4
High Commercial Land Use
0
10
20
30
40
50
9 15 2 4 6 2 5 1 2 5 7 6 4 10 9 8 12 8 11 10 6
1 16 8 6 4 9 15 9 9 23 3 5 13 0 1 2 3 2 1 3 4
% Urban Development
0
20
40
60
80
6 16 1 1 7 5 10 1 3 3 8 5 3 10 7 10 14 9 10 11 9
4 15 9 9 3 6 10 9 8 25 2 6 14 0 3 0 1 1 2 2 1
Agriculture
0
20
40
60
80
100
2 12 2 6 2 4 2 6 5 8 0 2 4 0 1 1 1 0 0 1 0
8 19 8 4 8 7 18 4 6 20 10 9 13 10 9 9 14 10 12 12 10
BIBI signif. > 3
Middle Patuxent R.
Liberty Reservoir
Broad Creek
Northeast River/...
Rocky Gorge Dam
S Br. Patapsco
Little Gunpowder Falls
Prettyboy Reservoir
Brighton Dam
Deer Creek
Jones Falls
Lower Susquehanna River/...
Loch Raven Reservoir
Back R.
Bush River/...
Lower Winters Run/...
Patapsco R. Lower N. Br.
Gwynns Falls
Rock Creek/...
Little Patuxent R.
Gunpowder River/...

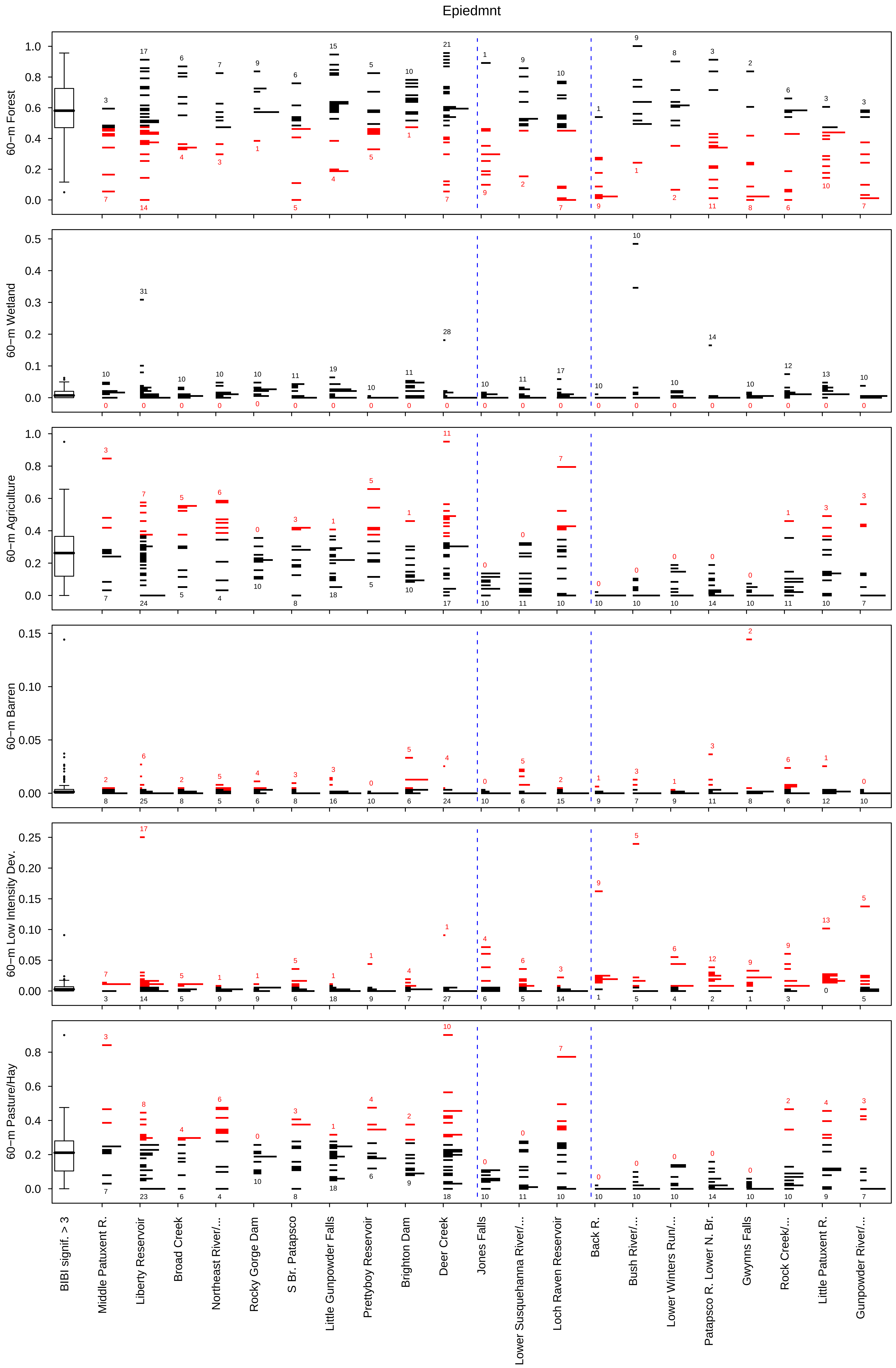

Epiedmnt
Impervious Surface
0
10
20
30
40
Culvert Present
0.0
0.2
0.4
0.6
0.8
1.0
Surface Mine Present
0.0
0.2
0.4
0.6
0.8
1.0
Water Temp (C)
15
20
25
Dissolved Oxygen
0
5
10
15
Conductivity
0.0
0.2
0.4
0.6
0.8
1.0
BIBI signif. > 3
Middle Patuxent R.
Liberty Reservoir
Broad Creek
Northeast River/...
Rocky Gorge Dam
S Br. Patapsco
Little Gunpowder Falls
Prettyboy Reservoir
Brighton Dam
Deer Creek
Jones Falls
Lower Susquehanna River/...
Loch Raven Reservoir
Back R.
Bush River/...
Lower Winters Run/...
Patapsco R. Lower N. Br.
Gwynns Falls
Rock Creek/...
Little Patuxent R.
Gunpowder River/...

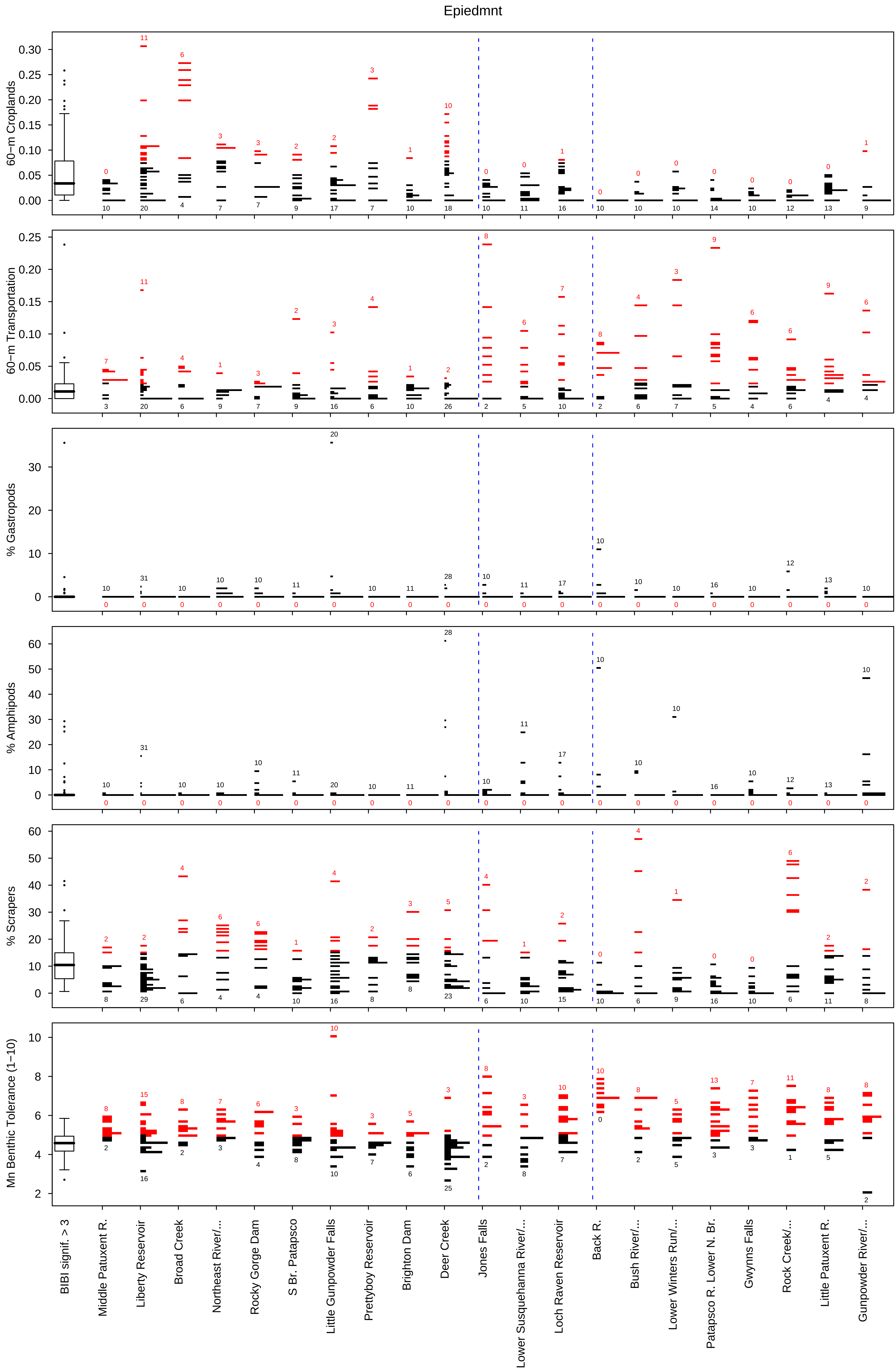

Epiedmnt
Wood Instream
0
20
40
60
80
100
120
Instream Habitat
0
5
10
15
20
Epifaunal Substrate
0
5
10
15
20
Embededdeness
0
20
40
60
80
100
Shading
0
20
40
60
80
100
Hilsenhoff Index
2
4
6
8
10
12
14
BIBI signif. > 3
Middle Patuxent R.
Liberty Reservoir
Broad Creek
Northeast River/...
Rocky Gorge Dam
S Br. Patapsco
Little Gunpowder Falls
Prettyboy Reservoir
Brighton Dam
Deer Creek
Jones Falls
Lower Susquehanna River/...
Loch Raven Reservoir
Back R.
Bush River/...
Lower Winters Run/...
Patapsco R. Lower N. Br.
Gwynns Falls
Rock Creek/...
Little Patuxent R.
Gunpowder River/...

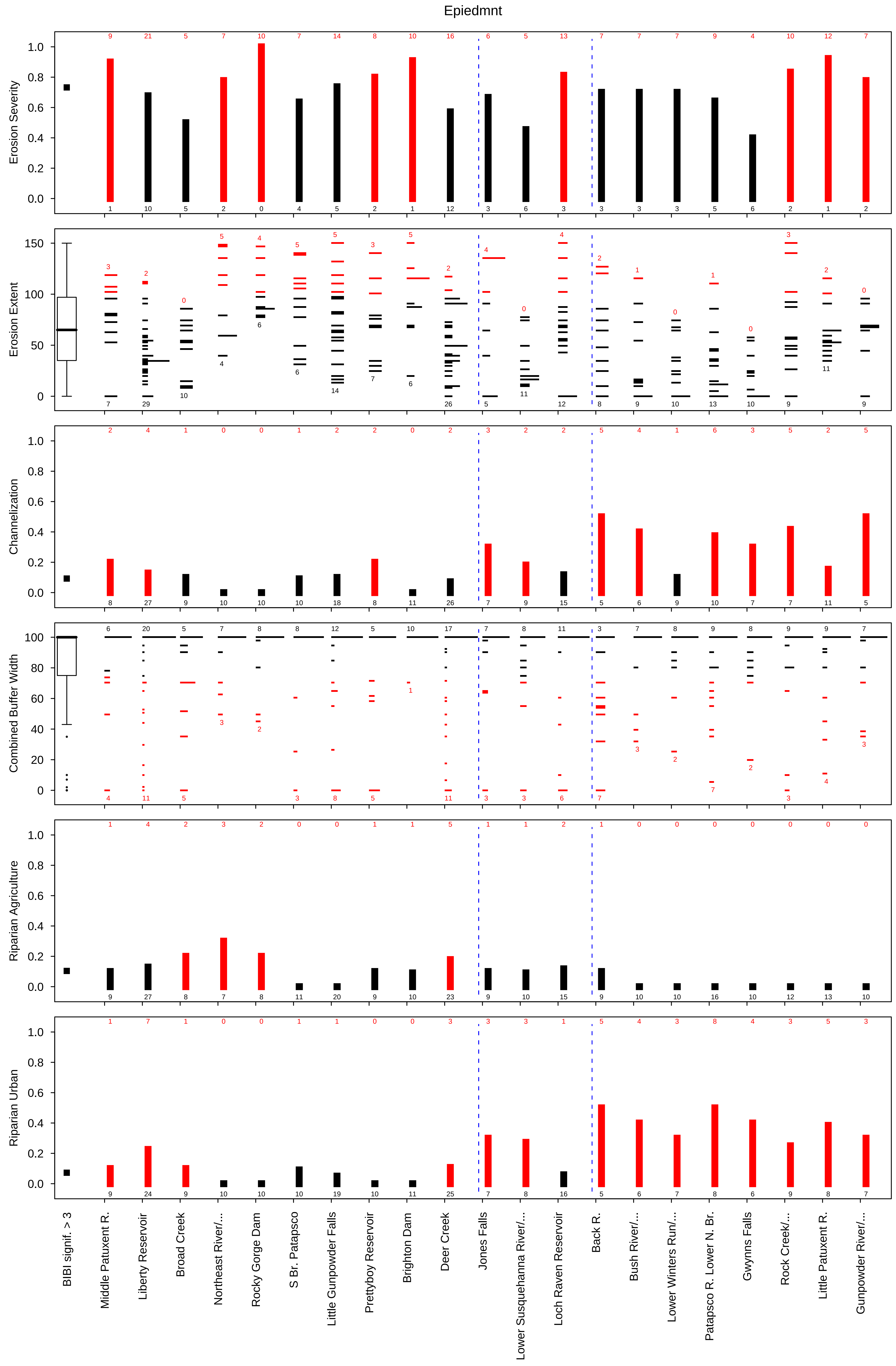

Epiedmnt
% Abund. Dom. (inverts)
0.2
0.4
0.6
0.8
% Fish Spp Excluded − ANC
0.0
0.2
0.4
0.6
0.8
1.0
% Fish Spp Excluded − DO
0.0
0.2
0.4
0.6
0.8
1.0
% Fish Spp Excluded − NO3
0.00
0.05
0.10
0.15
0.20
0.25
% Fish Spp Excluded − pH
0.0
0.2
0.4
0.6
0.8
1.0
Minimum Buffer Width
0
10
20
30
40
50
BIBI signif. > 3
Middle Patuxent R.
Liberty Reservoir
Broad Creek
Northeast River/...
Rocky Gorge Dam
S Br. Patapsco
Little Gunpowder Falls
Prettyboy Reservoir
Brighton Dam
Deer Creek
Jones Falls
Lower Susquehanna River/...
Loch Raven Reservoir
Back R.
Bush River/...
Lower Winters Run/...
Patapsco R. Lower N. Br.
Gwynns Falls
Rock Creek/...
Little Patuxent R.
Gunpowder River/...
0.0625
0.45
0.25
1.066667
8.9375
15.55
9.75
7.933333
9.9


Epiedmnt
Bar Formation
1.0
0.8
0.6
0.4
0.2
0.0
Basinwide Forest Cover
Basinwide Agriculture
Basinwide Barren
0.08
0.06
0.04
0.02
0.00
Basinwide Low−Intensity Dev.
0.15
0.10
0.05
Basinwide Pasture/Hay
BIBI signif. > 3
Middle Patuxent R.
Liberty Reservoir
Broad Creek
Northeast River/...
Rocky Gorge Dam
S Br. Patapsco
Little Gunpowder Falls
Prettyboy Reservoir
Brighton Dam
Deer Creek
Jones Falls
Lower Susquehanna River/...
Loch Raven Reservoir
Back R.
Bush River/...
Lower Winters Run/...
Patapsco R. Lower N. Br.
Gwynns Falls
Rock Creek/...
Little Patuxent R.
Gunpowder River/...

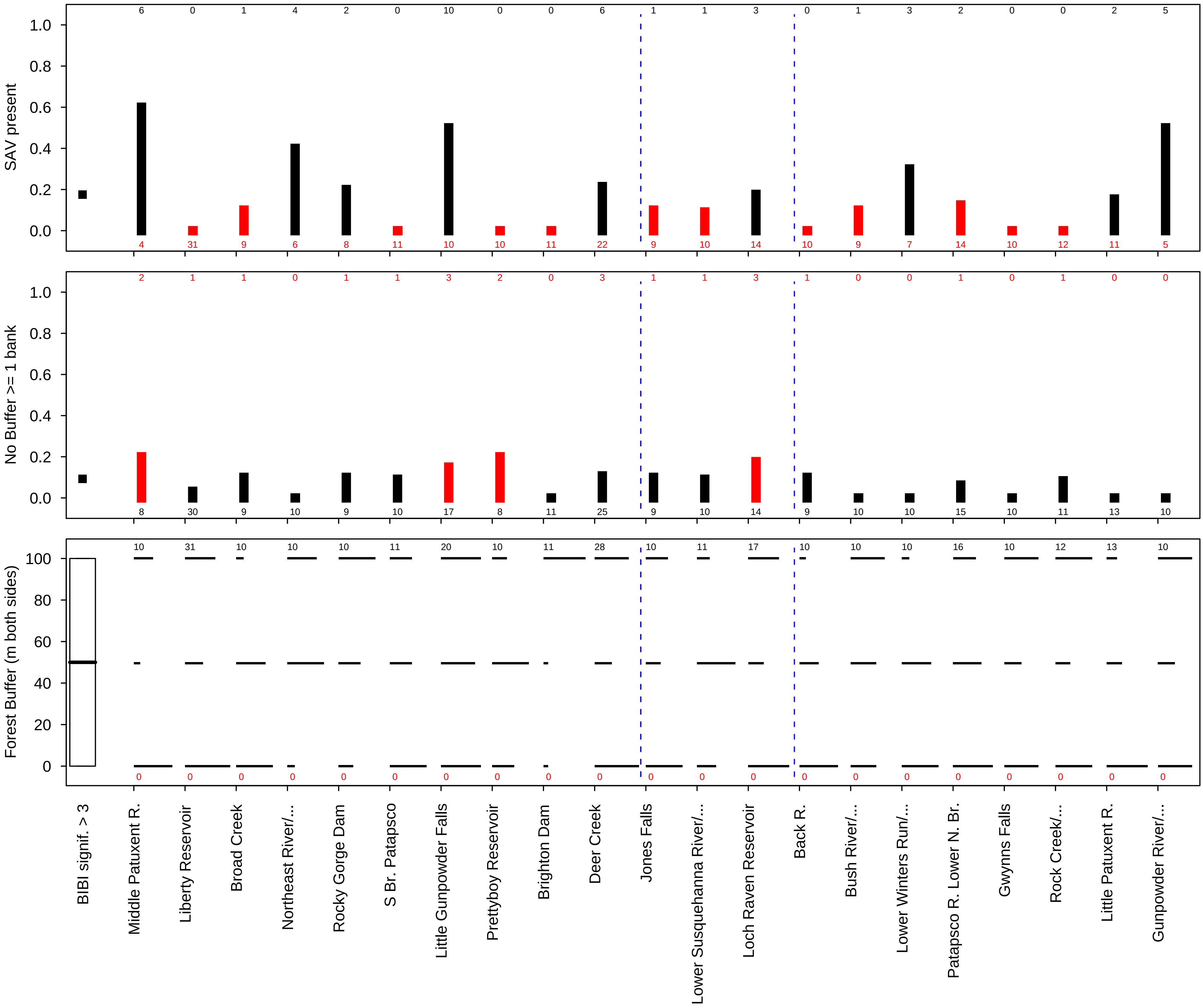

Epiedmnt
Basinwide Cropland Cover
Basinwide Transportation
60−m Low Density Urban
60−m High Intensity Urban
60−m Extractive
60−m Natural Grass
BIBI signif. > 3
Middle Patuxent R.
Liberty Reservoir
Broad Creek
Northeast River/...
Rocky Gorge Dam
S Br. Patapsco
Little Gunpowder Falls
Prettyboy Reservoir
Brighton Dam
Deer Creek
Jones Falls
Lower Susquehanna River/...
Loch Raven Reservoir
Back R.
Bush River/...
Lower Winters Run/...
Patapsco R. Lower N. Br.
Gwynns Falls
Rock Creek/...
Little Patuxent R.
Gunpowder River/...


Epiedmnt
60−m Forest
1.0
0.8
0.6
0.4
0.2
0.0
3 17 6 7 9 6 15 5 10 21 1 9 10 1 9 8 3 2 6 3 3
7 14 4 3 1 5 4 5 1 7 9 2 7 9 1 2 11 8 6 10 7
60−m Wetland
0.5
0.4
0.3
0.2
0.1
0.0
10 31 10 10 10 11 19 10 11 28 10 11 17 10 10 10 14 10 12 13 10
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
60−m Agriculture
1.0
0.8
0.6
0.4
0.2
0.0
3 7 5 6 0 3 1 5 1 11 0 0 7 0 0 0 0 0 1 3 3
7 24 5 4 10 8 18 5 10 17 10 11 10 10 10 10 14 10 11 10 7
60−m Barren
0.15
0.10
0.05
0.00
2 6 2 5 4 3 3 0 5 4 0 5 2 1 3 1 3 2 6 1 0
8 25 8 5 6 8 16 10 6 24 10 6 15 9 7 9 11 8 6 12 10
60−m Low Intensity Dev.
0.25
0.20
0.15
0.10
0.05
0.00
7 17 5 1 1 5 1 1 4 1 4 6 3 9 5 6 12 9 9 13 5
3 14 5 9 9 6 18 9 7 27 6 5 14 1 5 4 2 1 3 0 5
60−m Pasture/Hay
0.8
0.6
0.4
0.2
0.0
3 8 4 6 0 3 1 4 2 10 0 0 7 0 0 0 0 0 2 4 3
7 23 6 4 10 8 18 6 9 18 10 11 10 10 10 10 14 10 10 9 7
BIBI signif. > 3
Middle Patuxent R.
Liberty Reservoir
Broad Creek
Northeast River/...
Rocky Gorge Dam
S Br. Patapsco
Little Gunpowder Falls
Prettyboy Reservoir
Brighton Dam
Deer Creek
Jones Falls
Lower Susquehanna River/...
Loch Raven Reservoir
Back R.
Bush River/...
Lower Winters Run/...
Patapsco R. Lower N. Br.
Gwynns Falls
Rock Creek/...
Little Patuxent R.
Gunpowder River/...


Epiedmnt
60−m Croplands
0.00
0.05
0.10
0.15
0.20
0.25
0.30
60−m Transportation
0.00
0.05
0.10
0.15
0.20
0.25
% Gastropods
0
10
20
30
% Amphipods
0
10
20
30
40
50
60
% Scrapers
0
10
20
30
40
50
60
Mn Benthic Tolerance (1−10)
2
4
6
8
10
BIBI signif. > 3
Middle Patuxent R.
Liberty Reservoir
Broad Creek
Northeast River/...
Rocky Gorge Dam
S Br. Patapsco
Little Gunpowder Falls
Prettyboy Reservoir
Brighton Dam
Deer Creek
Jones Falls
Lower Susquehanna River/...
Loch Raven Reservoir
Back R.
Bush River/...
Lower Winters Run/...
Patapsco R. Lower N. Br.
Gwynns Falls
Rock Creek/...
Little Patuxent R.
Gunpowder River/...

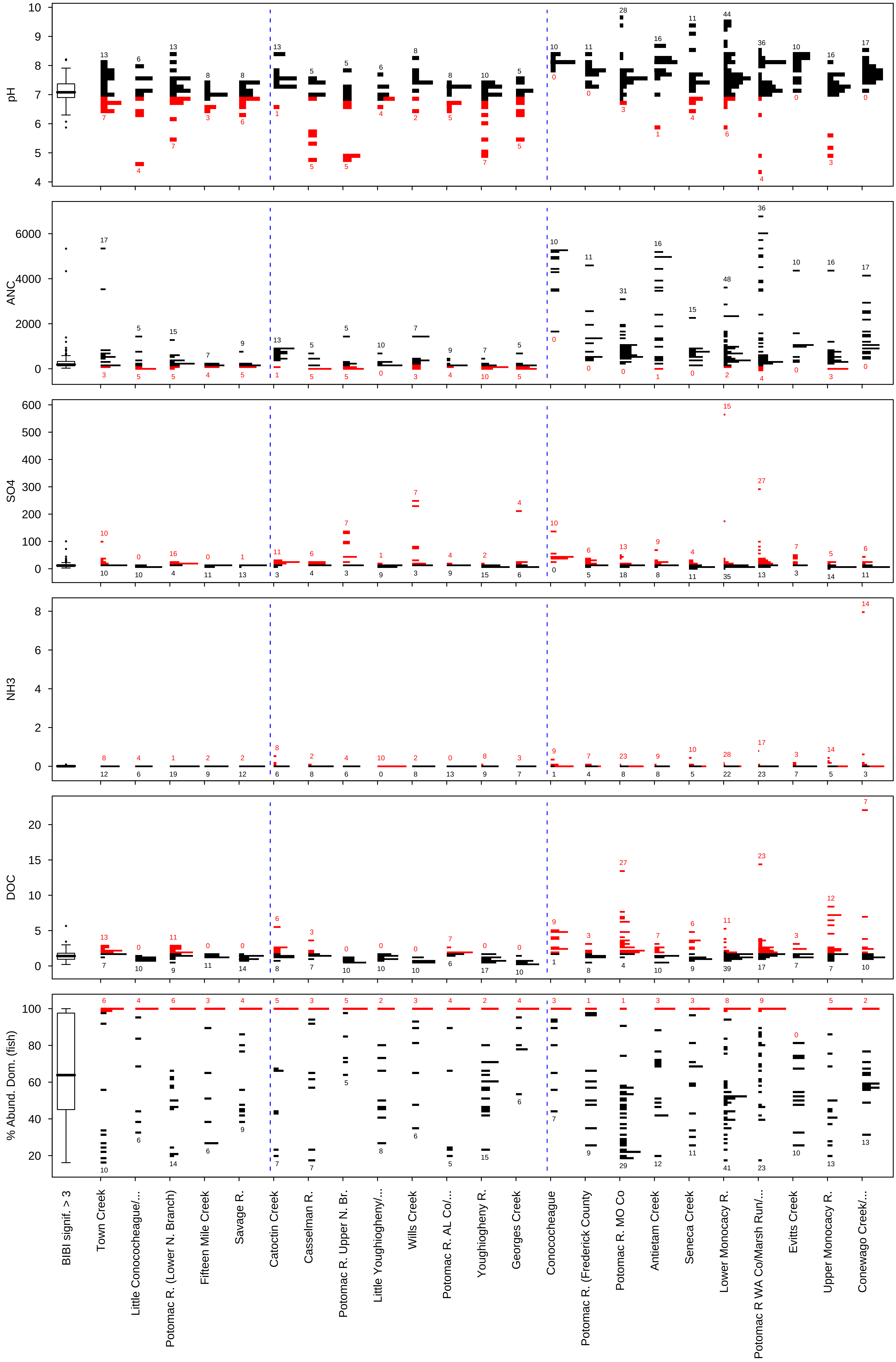

Epiedmnt
Erosion Severity
0.0
0.2
0.4
0.6
0.8
1.0
Erosion Extent
0
50
100
150
Channelization
0.0
0.2
0.4
0.6
0.8
1.0
Combined Buffer Width
0
20
40
60
80
100
Riparian Agriculture
0.0
0.2
0.4
0.6
0.8
1.0
Riparian Urban
0.0
0.2
0.4
0.6
0.8
1.0
BIBI signif. > 3
Middle Patuxent R.
Liberty Reservoir
Broad Creek
Northeast River/...
Rocky Gorge Dam
S Br. Patapsco
Little Gunpowder Falls
Prettyboy Reservoir
Brighton Dam
Deer Creek
Jones Falls
Lower Susquehanna River/...
Loch Raven Reservoir
Back R.
Bush River/...
Lower Winters Run/...
Patapsco R. Lower N. Br.
Gwynns Falls
Rock Creek/...
Little Patuxent R.
Gunpowder River/...

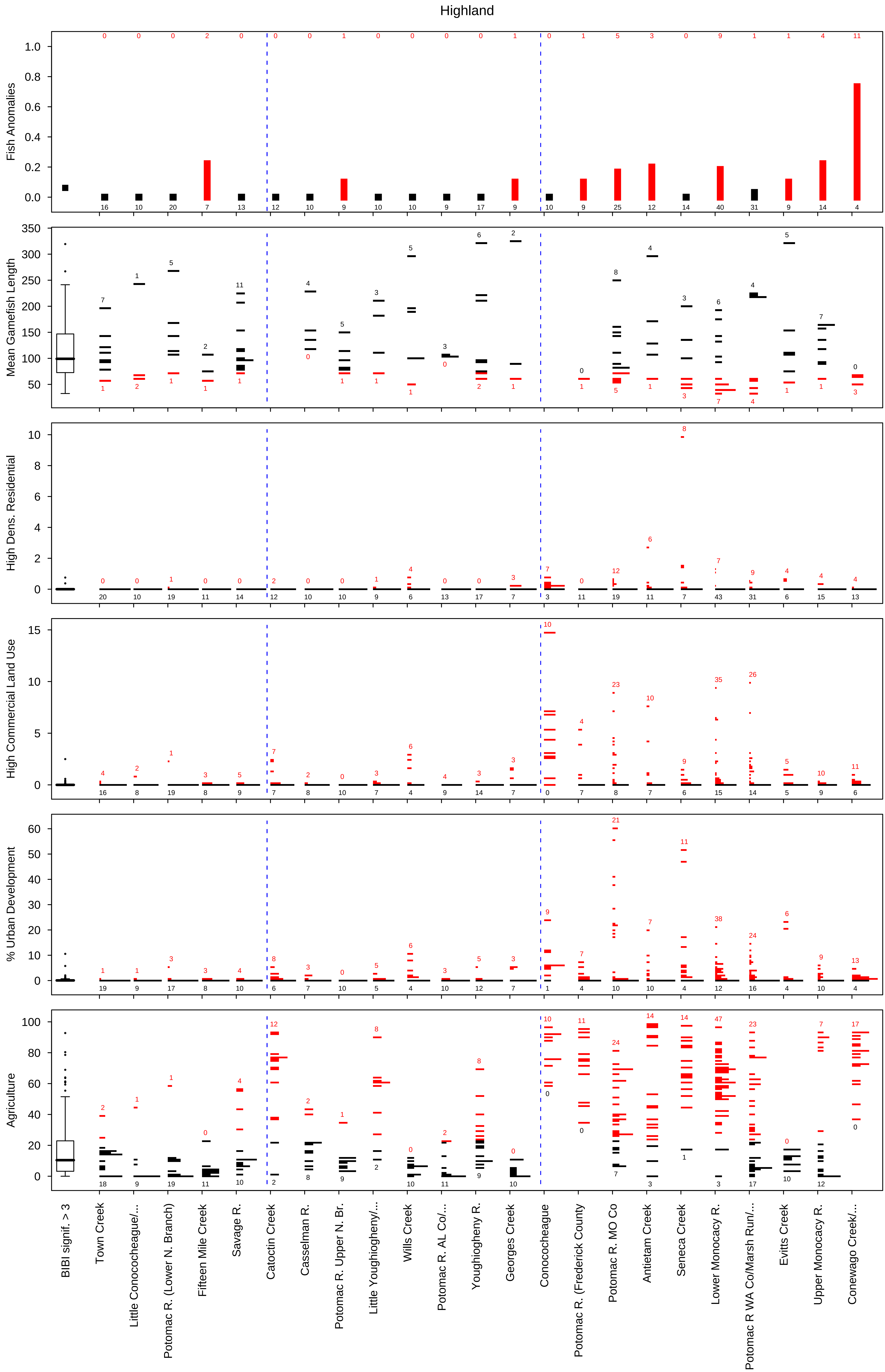
Epiedmnt

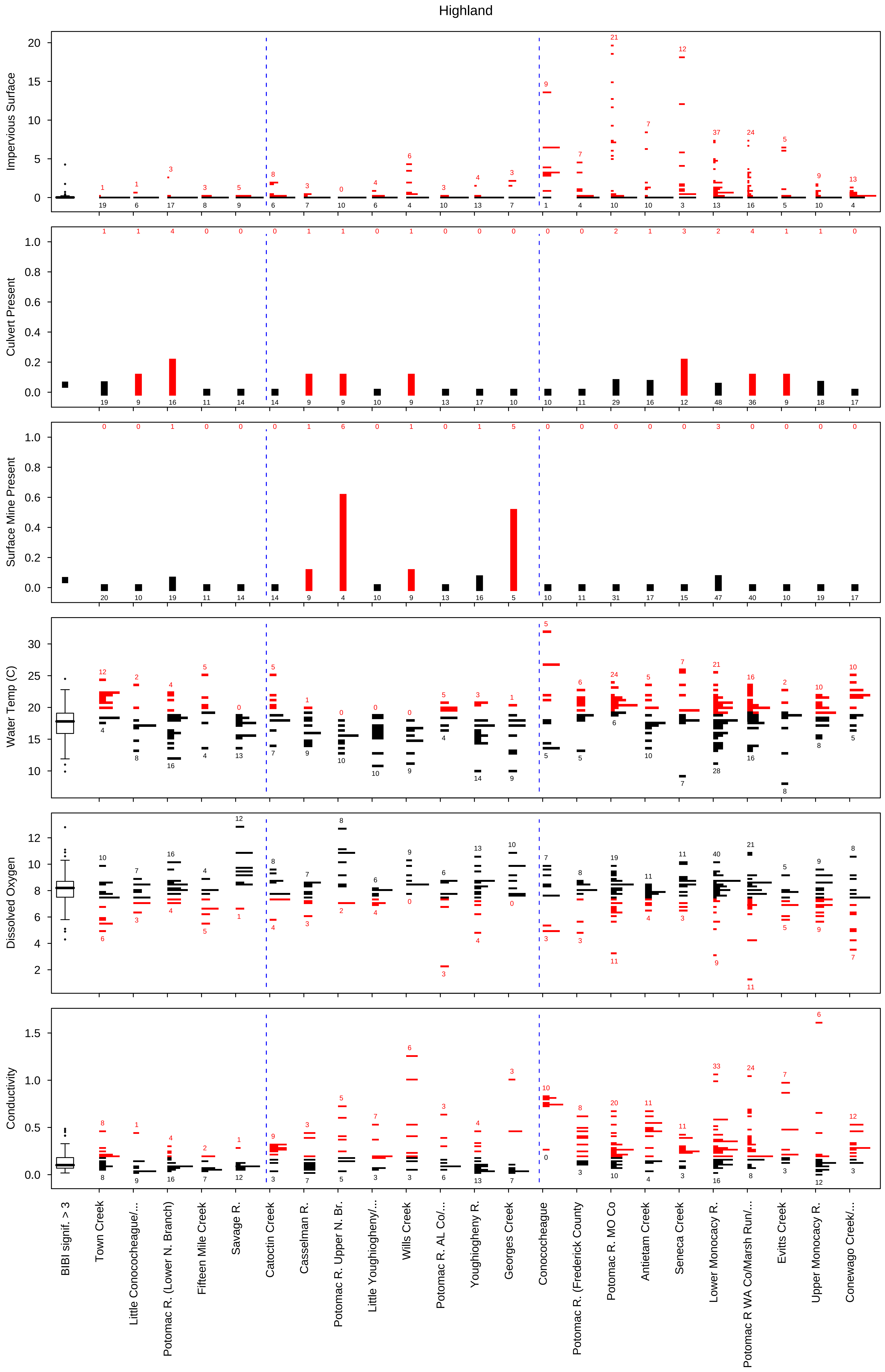


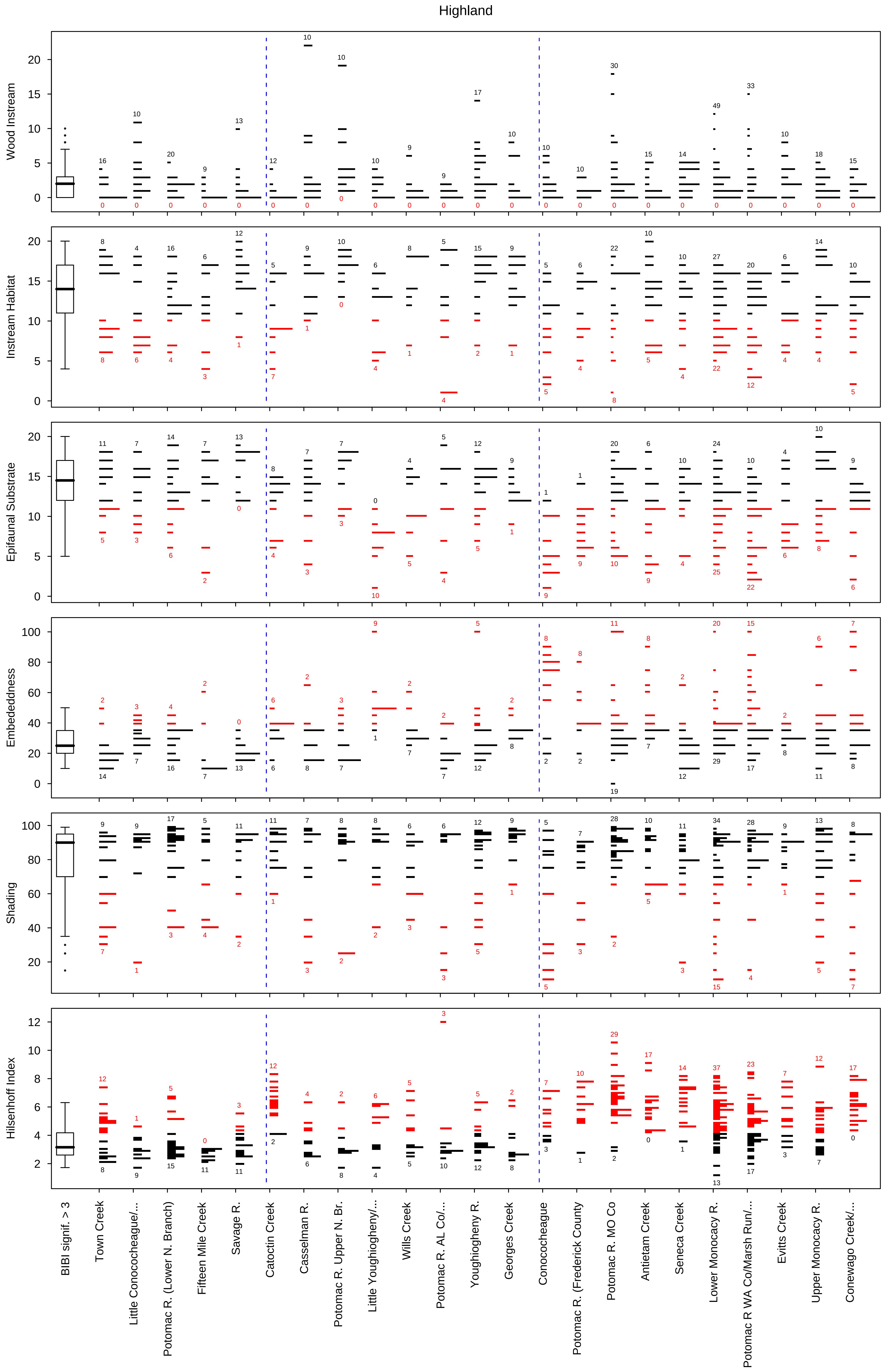
SAV present
1.0
0.8
0.6
0.4
0.2
0.0
6 0 1 4 2 0 10 0 0 6 1 1 3 0 1 3 2 0 0 2 5
4 31 9 6 8 11 10 10 11 22 9 10 14 10 9 7 14 10 12 11 5
No Buffer >= 1 bank
1.0
0.8
0.6
0.4
0.2
0.0
2 1 1 0 1 1 3 2 0 3 1 1 3 1 0 0 1 0 1 0 0
8 30 9 10 9 10 17 8 11 25 9 10 14 9 10 10 15 10 11 13 10
Forest Buffer (m both sides)
100
80
60
40
20
0
10 31 10 10 10 11 20 10 11 28 10 11 17 10 10 10 16 10 12 13 10
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
BIBI signif. > 3
Middle Patuxent R.
Liberty Reservoir
Broad Creek
Northeast River/...
Rocky Gorge Dam
S Br. Patapsco
Little Gunpowder Falls
Prettyboy Reservoir
Brighton Dam
Deer Creek
Jones Falls
Lower Susquehanna River/...
Loch Raven Reservoir
Back R.
Bush River/...
Lower Winters Run/...
Patapsco R. Lower N. Br.
Gwynns Falls
Rock Creek/...
Little Patuxent R.
Gunpowder River/...

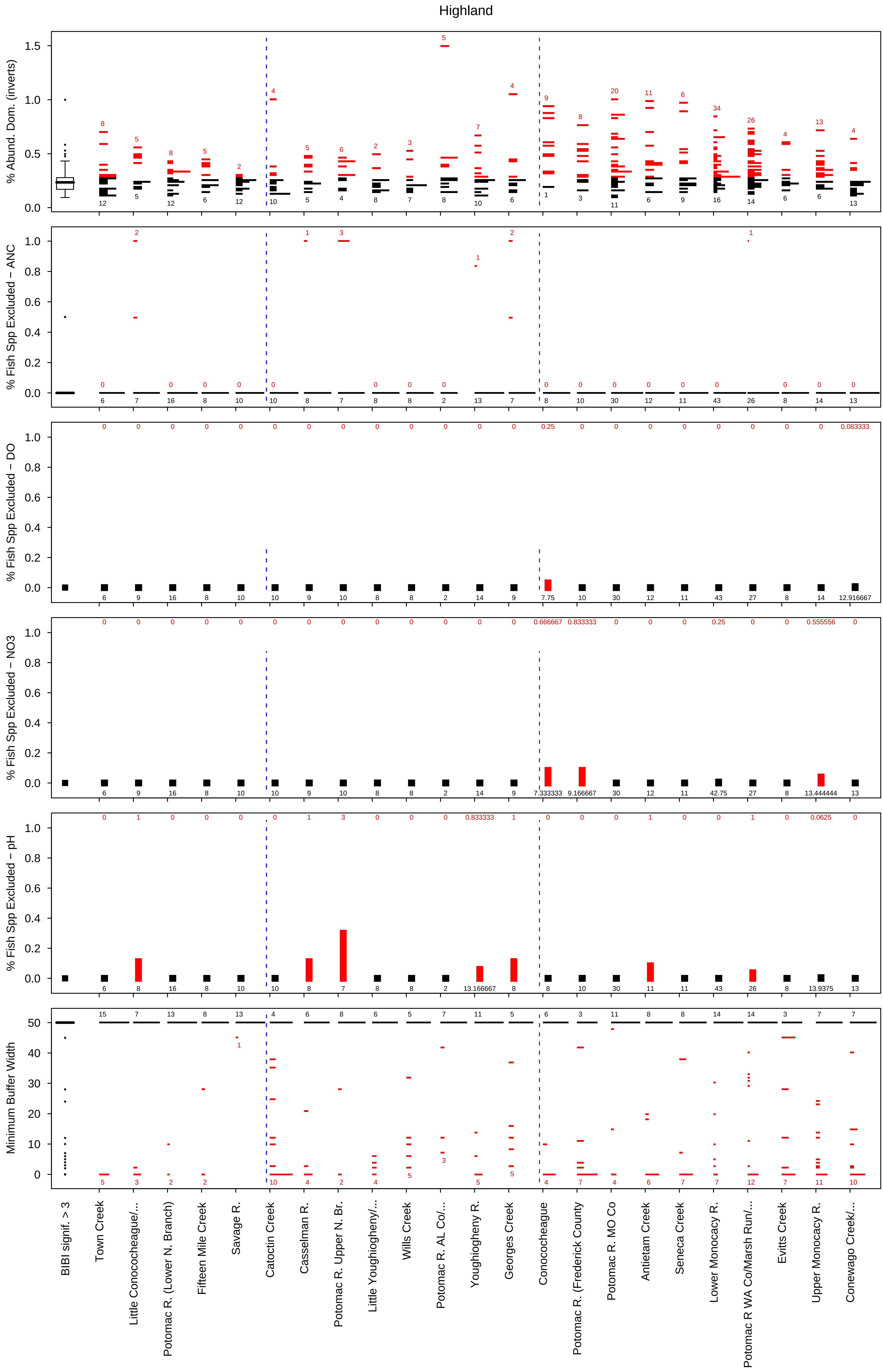
Highland

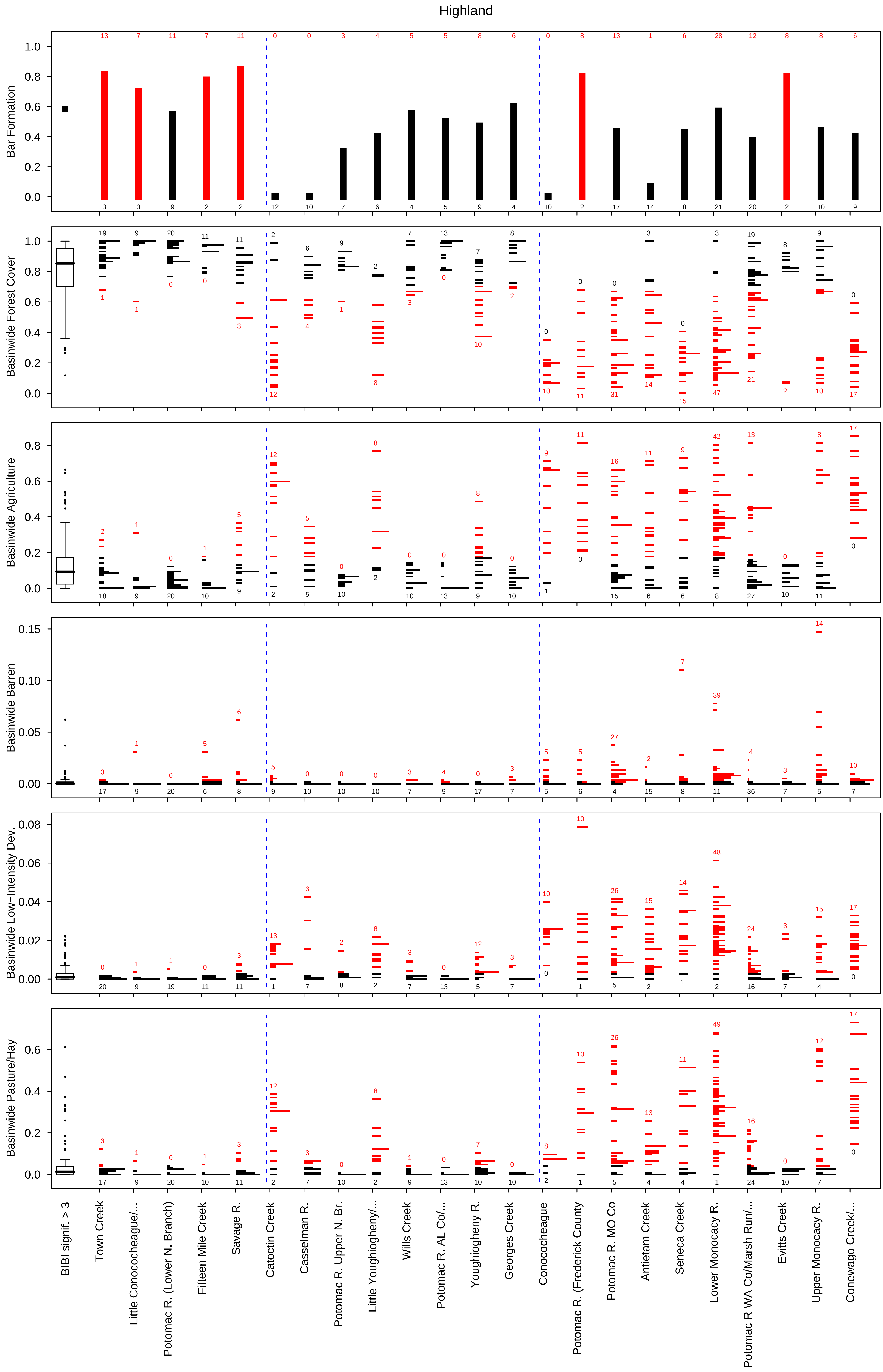

pH
10
9
8
7
6
5
4
ANC
6000
4000
2000
0
SO4
600
500
400
300
200
100
0
NH3
8
6
4
2
0
DOC
20
15
10
5
0
% Abund. Dom. (fish)
100
80
60
40
20
BIBI signif. > 3
Town Creek
Little Conococheague/...
Potomac R. (Lower N. Branch)
Fifteen Mile Creek
Savage R.
Catoctin Creek
Casselman R.
Potomac R. Upper N. Br.
Little Youghiogheny/...
Wills Creek
Potomac R. AL Co/...
Youghiogheny R.
Georges Creek
Conococheague
Potomac R. (Frederick County
Potomac R. MO Co
Antietam Creek
Seneca Creek
Lower Monocacy R.
Potomac R WA Co/Marsh Run/...
Evitts Creek
Upper Monocacy R.
Conewago Creek/...

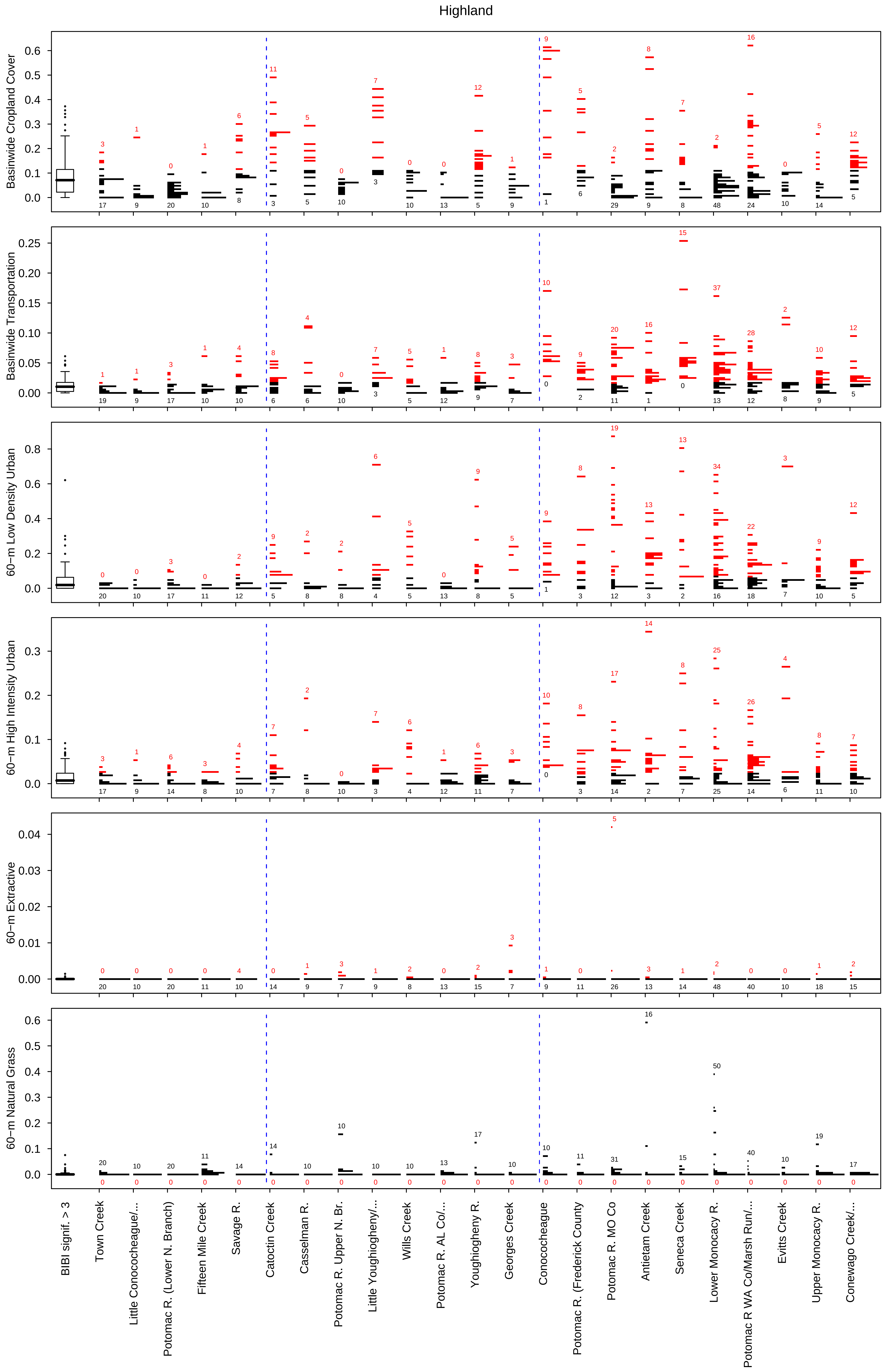

Highland
Fish Anomalies
0.0
0.2
0.4
0.6
0.8
1.0
Mean Gamefish Length
50
100
150
200
250
300
350
High Dens. Residential
0
2
4
6
8
10
High Commercial Land Use
0
5
10
15
% Urban Development
0
10
20
30
40
50
60
Agriculture
0
20
40
60
80
100
BIBI signif. > 3
Town Creek
Little Conococheague/...
Potomac R. (Lower N. Branch)
Fifteen Mile Creek
Savage R.
Catoctin Creek
Casselman R.
Potomac R. Upper N. Br.
Little Youghiogheny/...
Wills Creek
Potomac R. AL Co/...
Youghiogheny R.
Georges Creek
Conococheague
Potomac R. (Frederick County
Potomac R. MO Co
Antietam Creek
Seneca Creek
Lower Monocacy R.
Potomac R WA Co/Marsh Run/...
Evitts Creek
Upper Monocacy R.
Conewago Creek/...

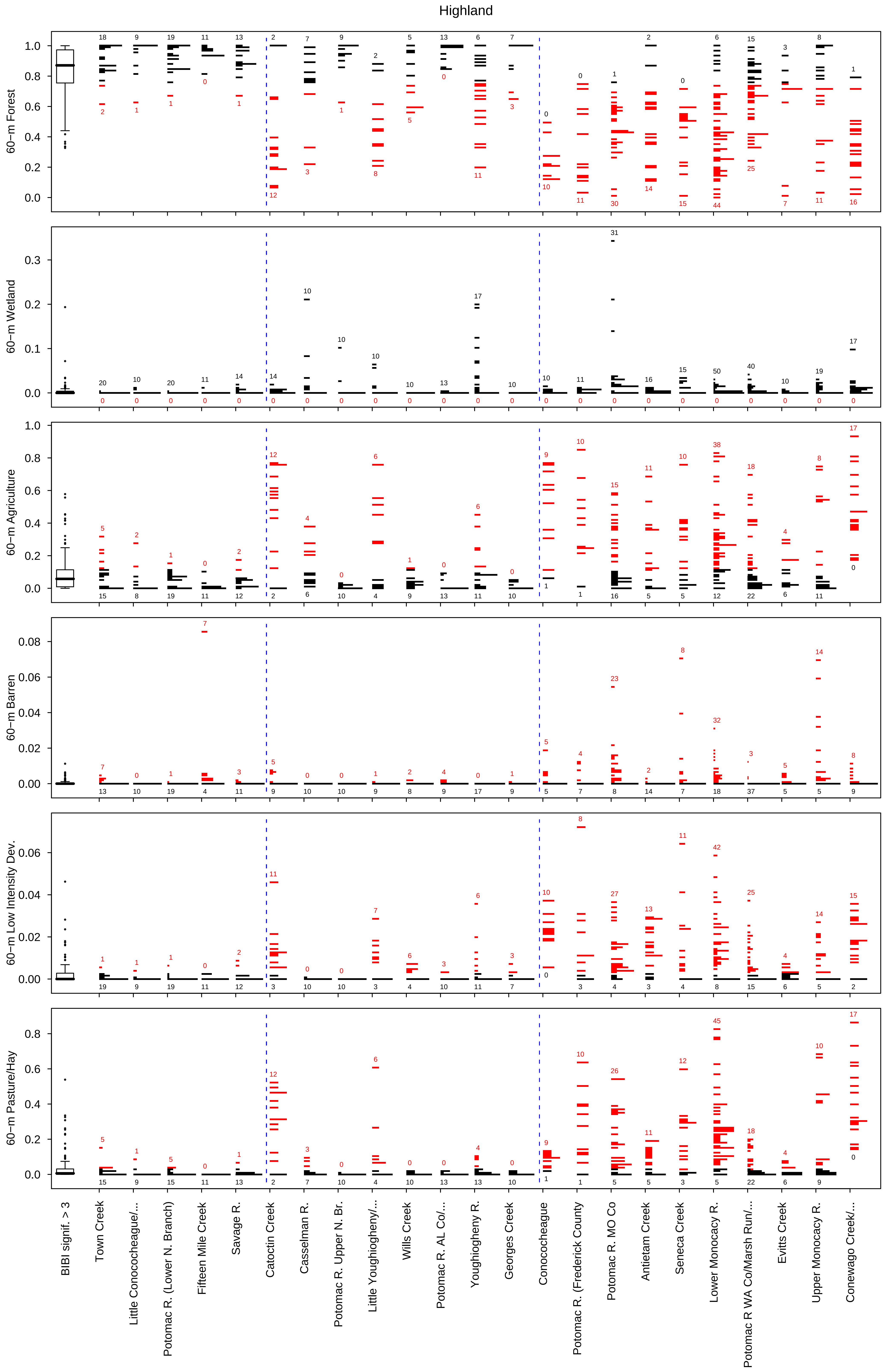

Highland
Impervious Surface
0
5
10
15
20
1 1 3 3 5 8 3 0 4 6 3 4 3 9 7 21 7 12 37 24 5 9 13
19 6 17 8 9 6 7 10 6 4 10 13 7 1 4 10 10 3 13 16 5 10 4
Culvert Present
0.0
0.2
0.4
0.6
0.8
1.0
1 1 4 0 0 0 1 1 0 1 0 0 0 0 0 2 1 3 2 4 1 1 0
19 9 16 11 14 14 9 9 10 9 13 17 10 10 11 29 16 12 48 36 9 18 17
Surface Mine Present
0.0
0.2
0.4
0.6
0.8
1.0
0 0 1 0 0 0 1 6 0 1 0 1 5 0 0 0 0 0 3 0 0 0 0
20 10 19 11 14 14 9 4 10 9 13 16 5 10 11 31 17 15 47 40 10 19 17
Water Temp (C)
10
15
20
25
30
12 2 4 5 0 5 1 0 0 0 5 3 1 5 6 24 5 7 21 16 2 10 10
4 8 16 4 13 7 9 10 10 9 4 14 9 5 5 6 10 7 28 16 8 8 5
Dissolved Oxygen
2
4
6
8
10
12
10 7 16 4 12 8 7 8 6 9 6 13 10 7 8 19 11 11 40 21 5 9 8
6 3 4 5 1 4 3 2 4 0 3 4 0 3 3 11 4 3 9 11 5 9 7
Conductivity
0.0
0.5
1.0
1.5
8 1 4 2 1 9 3 5 7 6 3 4 3 10 8 20 11 11 33 24 7 6 12
8 9 16 7 12 3 7 5 3 3 6 13 7 0 3 10 4 3 16 8 3 12 3
BIBI signif. > 3
Town Creek
Little Conococheague/...
Potomac R. (Lower N. Branch)
Fifteen Mile Creek
Savage R.
Catoctin Creek
Casselman R.
Potomac R. Upper N. Br.
Little Youghiogheny/...
Wills Creek
Potomac R. AL Co/...
Youghiogheny R.
Georges Creek
Conococheague
Potomac R. (Frederick County
Potomac R. MO Co
Antietam Creek
Seneca Creek
Lower Monocacy R.
Potomac R WA Co/Marsh Run/...
Evitts Creek
Upper Monocacy R.
Conewago Creek/...

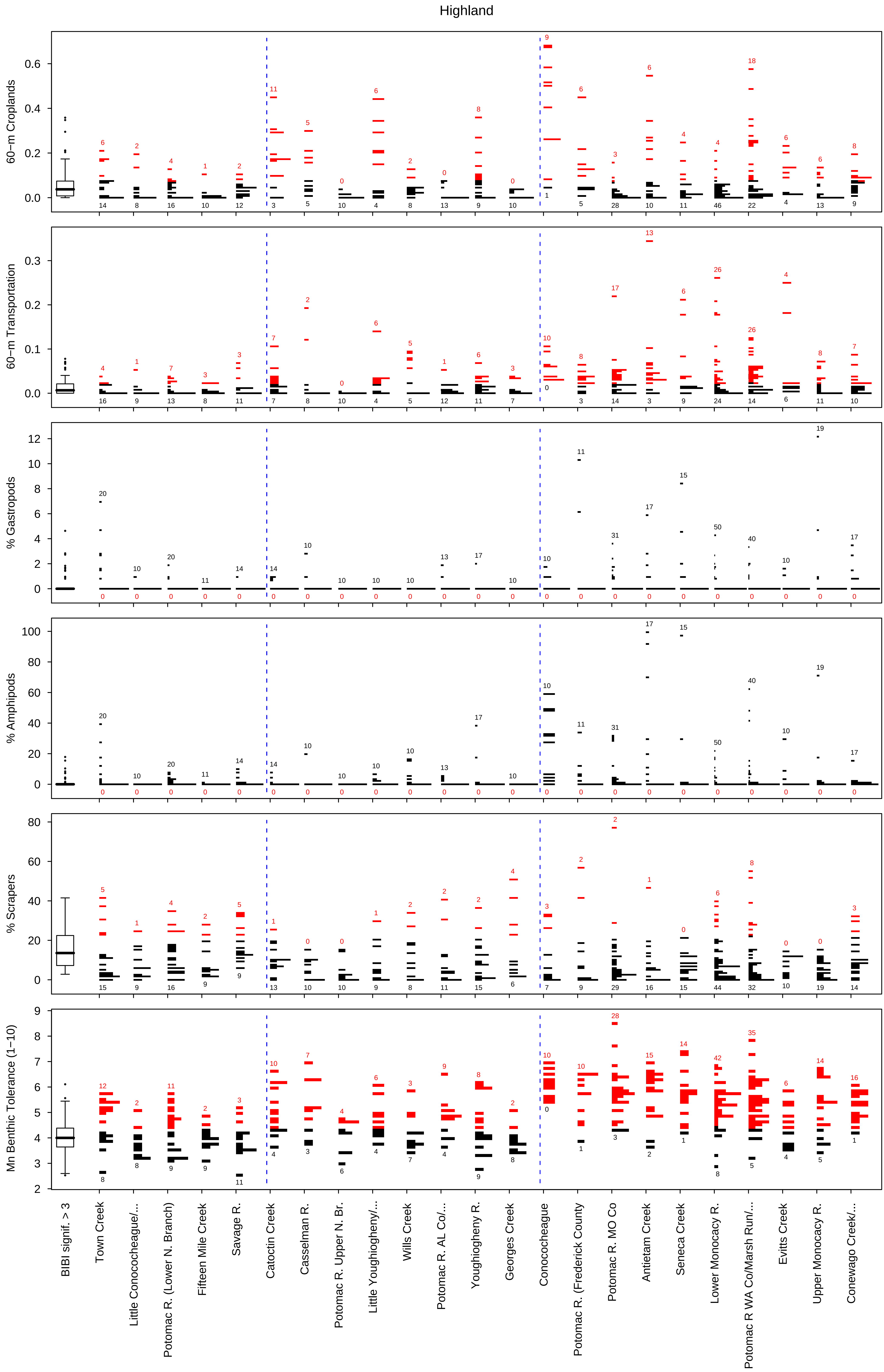
Highland
Wood Instream
Instream Habitat
Epifaunal Substrate
Embededdness
Shading
Hilsenhoff Index
BIBI signif. > 3
Town Creek
Little Conococheague/...
Potomac R. (Lower N. Branch)
Fifteen Mile Creek
Savage R.
Catoctin Creek
Casselman R.
Potomac R. Upper N. Br.
Little Youghiogheny/...
Wills Creek
Potomac R. AL Co/...
Youghiogheny R.
Georges Creek
Conococheague
Potomac R. (Frederick County
Potomac R. MO Co
Antietam Creek
Seneca Creek
Lower Monocacy R.
Potomac R WA Co/Marsh Run/...
Evitts Creek
Upper Monocacy R.
Conewago Creek/...

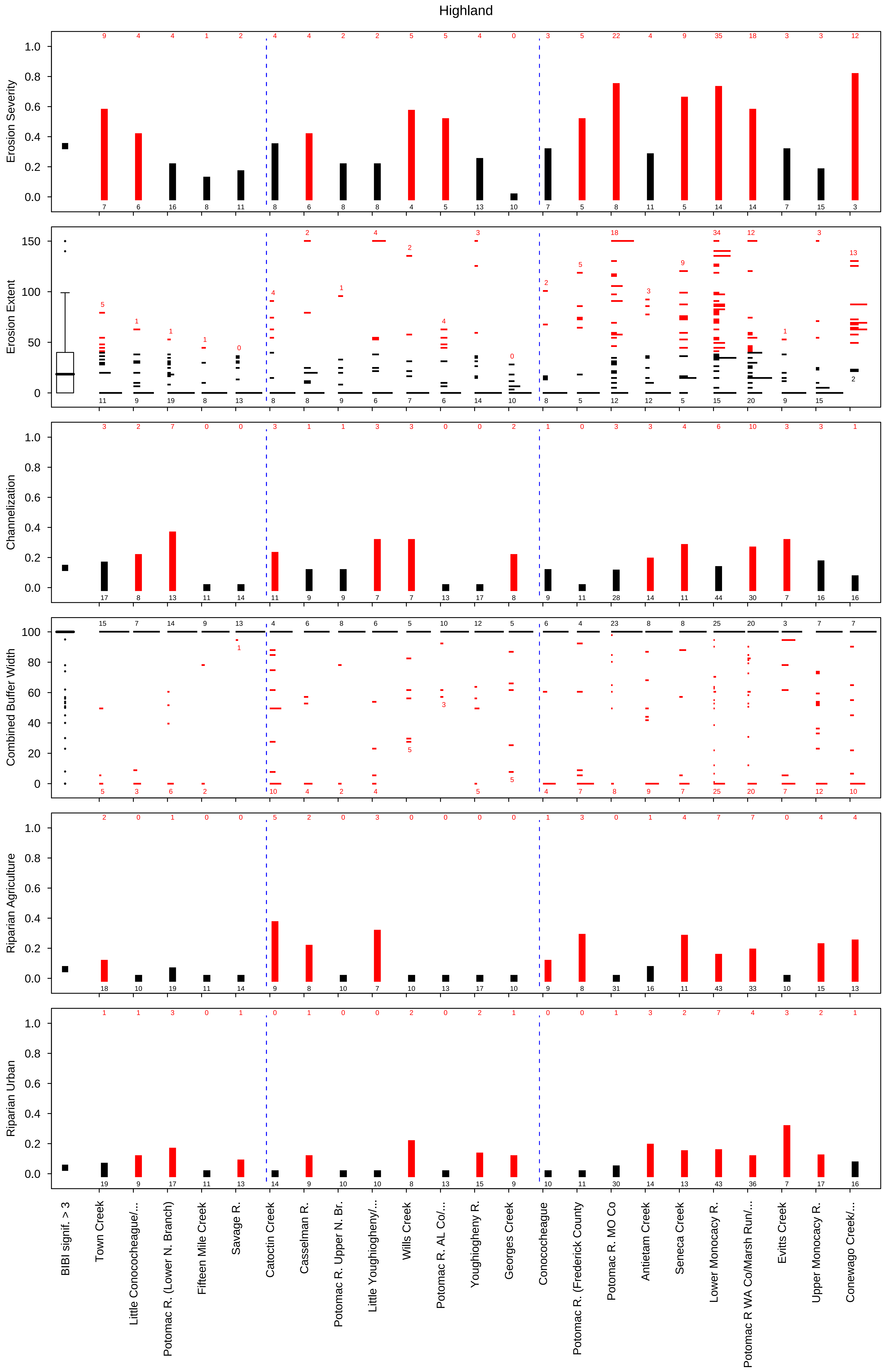

Highland
% Abund. Dom. (inverts)
% Fish Spp Excluded – ANC
% Fish Spp Excluded – DO
% Fish Spp Excluded – NO3
% Fish Spp Excluded – pH
Minimum Buffer Width
BIBI signif. > 3
Town Creek
Little Conococheague/...
Potomac R. (Lower N. Branch)
Fifteen Mile Creek
Savage R.
Catoctin Creek
Casselman R.
Potomac R. Upper N. Br.
Little Youghiogheny/...
Wills Creek
Potomac R. AL Co/...
Youghiogheny R.
Georges Creek
Conococheague
Potomac R. (Frederick County
Potomac R. MO Co
Antietam Creek
Seneca Creek
Lower Monocacy R.
Potomac R WA Co/Marsh Run/...
Evitts Creek
Upper Monocacy R.
Conewago Creek/...

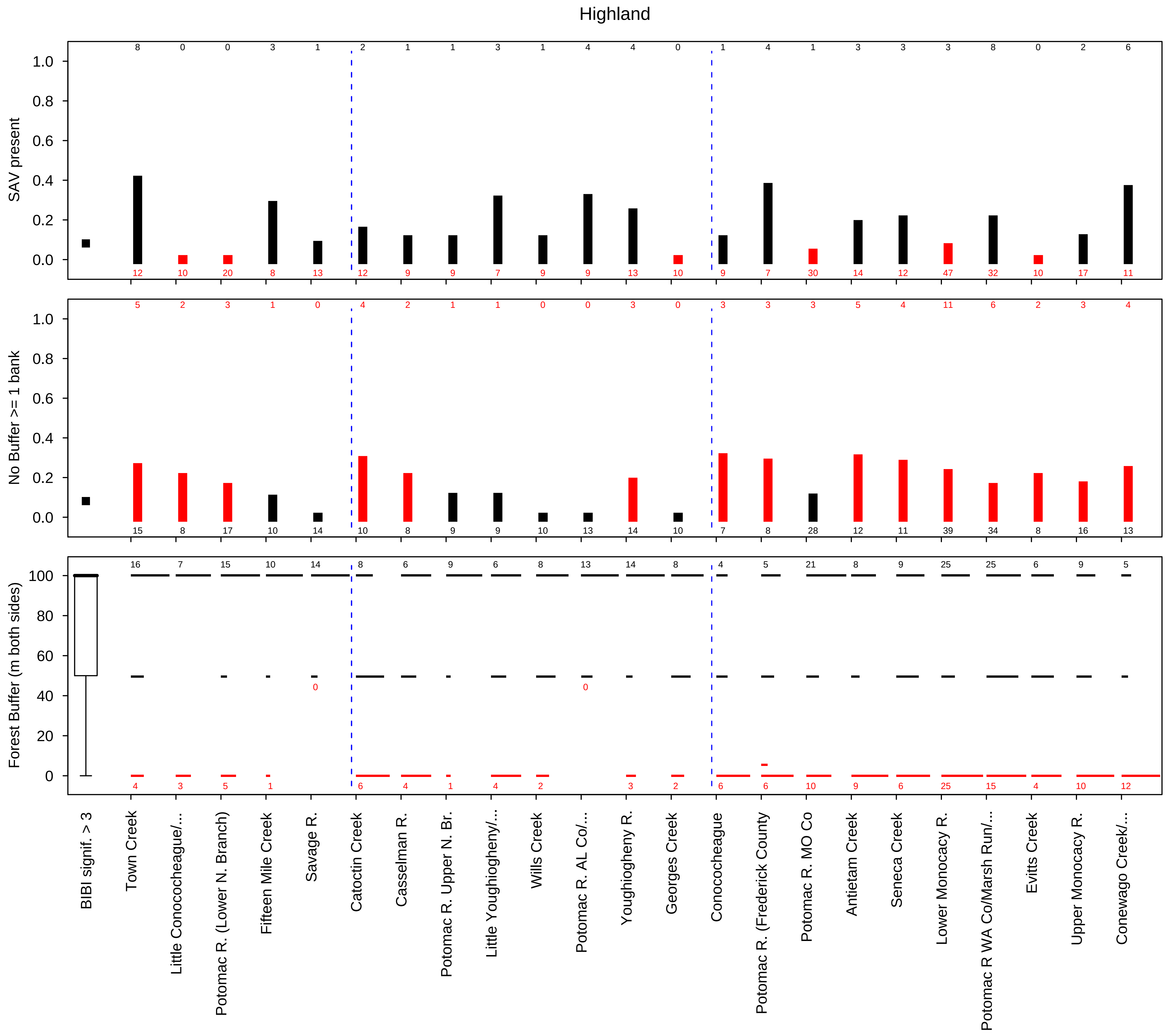

Highland
Bar Formation
1.0
0.8
0.6
0.4
0.2
0.0
13 7 11 7 11 0 0 3 4 5 5 8 6 0 8 13 1 6 28 12 8 8 6
3 3 9 2 2 12 10 7 6 4 5 9 4 10 2 17 14 8 21 20 2 10 9
Basinwide Forest Cover
1.0
0.8
0.6
0.4
0.2
0.0
19 9 20 11 11 2 6 9 2 7 13 7 8 3 3 19 8 9
1 1 0 0 3 12 4 1 8 3 0 10 2 0 11 0 31 14 0 15 47 21 2 10 0 17 10
Basinwide Agriculture
0.8
0.6
0.4
0.2
0.0
2 1 0 1 5 12 5 0 8 0 0 8 0 9 11 16 11 9 42 13 0 8 17 0
18 9 20 10 9 2 5 10 2 10 13 9 10 1 0 15 6 6 8 27 10 11
Basinwide Barren
0.15
0.10
0.05
0.00
3 1 0 5 6 5 0 0 0 3 4 0 3 5 5 27 2 7 39 4 3 14 10
17 9 20 6 8 9 10 10 10 7 9 17 7 5 6 4 15 8 11 36 7 5 7
Basinwide Low−Intensity Dev.
0.08
0.06
0.04
0.02
0.00
0 1 1 0 3 13 3 2 8 3 0 12 3 10 10 26 15 14 48 24 3 15 17
20 9 19 11 11 1 7 8 2 7 13 5 7 0 1 5 2 1 2 16 7 4 0
Basinwide Pasture/Hay
0.6
0.4
0.2
0.0
3 1 0 1 3 12 3 0 8 1 0 7 0 8 10 26 13 11 49 16 0 12 17
17 9 20 10 11 2 7 10 2 9 13 10 10 2 1 5 4 4 1 24 10 7 0
BIBI signif. > 3
Town Creek
Little Conococheague/...
Potomac R. (Lower N. Branch)
Fifteen Mile Creek
Savage R.
Catoctin Creek
Casselman R.
Potomac R. Upper N. Br.
Little Youghiogheny/...
Wills Creek
Potomac R. AL Co/...
Youghiogheny R.
Georges Creek
Conococheague
Potomac R. (Frederick County
Potomac R. MO Co
Antietam Creek
Seneca Creek
Lower Monocacy R.
Potomac R WA Co/Marsh Run/...
Evitts Creek
Upper Monocacy R.
Conewago Creek/...


Highland
Basinwide Cropland Cover
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Basinwide Transportation
0.00
0.05
0.10
0.15
0.20
0.25
60−m Low Density Urban
0.0
0.2
0.4
0.6
0.8
60−m High Intensity Urban
0.0
0.1
0.2
0.3
60−m Extractive
0.00
0.01
0.02
0.03
0.04
60−m Natural Grass
0.0
0.1
0.2
0.3
0.4
0.5
0.6
BIBI signif. > 3
Town Creek
Little Conococheague/...
Potomac R. (Lower N. Branch)
Fifteen Mile Creek
Savage R.
Catoctin Creek
Casselman R.
Potomac R. Upper N. Br.
Little Youghiogheny/...
Wills Creek
Potomac R. AL Co/...
Youghiogheny R.
Georges Creek
Conococheague
Potomac R. (Frederick County
Potomac R. MO Co
Antietam Creek
Seneca Creek
Lower Monocacy R.
Potomac R WA Co/Marsh Run/...
Evitts Creek
Upper Monocacy R.
Conewago Creek/...


Highland
60−m Forest
0.0
0.2
0.4
0.6
0.8
1.0
60−m Wetland
0.0
0.1
0.2
0.3
60−m Agriculture
0.0
0.2
0.4
0.6
0.8
1.0
60−m Barren
0.00
0.02
0.04
0.06
0.08
60−m Low Intensity Dev.
0.00
0.02
0.04
0.06
60−m Pasture/Hay
0.0
0.2
0.4
0.6
0.8
BIBI signif. > 3
Town Creek
Little Conococheague/...
Potomac R. (Lower N. Branch)
Fifteen Mile Creek
Savage R.
Catoctin Creek
Casselman R.
Potomac R. Upper N. Br.
Little Youghiogheny/...
Wills Creek
Potomac R. AL Co/...
Youghiogheny R.
Georges Creek
Conococheague
Potomac R. (Frederick County
Potomac R. MO Co
Antietam Creek
Seneca Creek
Lower Monocacy R.
Potomac R WA Co/Marsh Run/...
Evitts Creek
Upper Monocacy R.
Conewago Creek/...


Highland
60−m Croplands
0.0
0.2
0.4
0.6
6 2 4 1 2 11 5 0 6 2 0 8 0 9 6 3 6 4 4 18 6 6 8
14 8 16 10 12 3 5 10 4 8 13 9 10 1 5 28 10 11 46 22 4 13 9
60−m Transportation
0.0
0.1
0.2
0.3
4 1 7 3 3 7 2 0 6 5 1 6 3 10 8 17 13 6 26 26 4 8 7
16 9 13 8 11 7 8 10 4 5 12 11 7 0 3 14 3 9 24 14 6 11 10
% Gastropods
0
2
4
6
8
10
12
20 10 20 11 14 14 10 10 10 10 13 17 10 10 11 31 17 15 50 40 10 19 17
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
% Amphipods
0
20
40
60
80
100
20 10 20 11 14 14 10 10 10 10 13 17 10 10 11 31 17 15 50 40 10 19 17
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
% Scrapers
0
20
40
60
80
5 1 4 2 5 1 0 0 1 2 2 2 4 3 2 2 1 0 6 8 0 0 3
15 9 16 9 9 13 10 10 9 8 11 15 6 7 9 29 16 15 44 32 10 19 14
Mn Benthic Tolerance (1−10)
2
3
4
5
6
7
8
9
12 2 11 2 3 10 7 4 6 3 9 8 2 10 10 28 15 14 42 35 6 14 16
8 8 9 9 11 4 3 6 4 7 4 9 8 0 1 3 2 1 8 5 4 5 1
BIBI signif. > 3
Town Creek
Little Conococheague/...
Potomac R. (Lower N. Branch)
Fifteen Mile Creek
Savage R.
Catoctin Creek
Casselman R.
Potomac R. Upper N. Br.
Little Youghiogheny/...
Wills Creek
Potomac R. AL Co/...
Youghiogheny R.
Georges Creek
Conococheague
Potomac R. (Frederick County
Potomac R. MO Co
Antietam Creek
Seneca Creek
Lower Monocacy R.
Potomac R WA Co/Marsh Run/...
Evitts Creek
Upper Monocacy R.
Conewago Creek/...


Highland
Erosion Severity
Erosion Extent
Channelization
Combined Buffer Width
Riparian Agriculture
Riparian Urban
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
0
20
40
60
80
100
BIBI signif. > 3
Town Creek
Little Conococheague/...
Potomac R. (Lower N. Branch)
Fifteen Mile Creek
Savage R.
Catoctin Creek
Casselman R.
Potomac R. Upper N. Br.
Little Youghiogheny/...
Wills Creek
Potomac R. AL Co/...
Youghiogheny R.
Georges Creek
Conococheague
Potomac R. (Frederick County
Potomac R. MO Co
Antietam Creek
Seneca Creek
Lower Monocacy R.
Potomac R WA Co/Marsh Run/...
Evitts Creek
Upper Monocacy R.
Conewago Creek/...


Highland
SAV present
1.0
0.8
0.6
0.4
0.2
0.0
8 0 0 3 1 2 1 1 3 1 4 4 0 1 4 1 3 3 3 8 0 2 6
12 10 20 8 13 12 9 9 7 9 9 13 10 9 7 30 14 12 47 32 10 17 11
No Buffer >= 1 bank
1.0
0.8
0.6
0.4
0.2
0.0
5 2 3 1 0 4 2 1 1 0 0 3 0 3 3 3 5 4 11 6 2 3 4
15 8 17 10 14 10 8 9 9 10 13 14 10 7 8 28 12 11 39 34 8 16 13
Forest Buffer (m both sides)
100
80
60
40
20
0
16 7 15 10 14 8 6 9 6 8 13 14 8 4 5 21 8 9 25 25 6 9 5
0
0
4 3 5 1 6 4 1 4 2 3 2 6 6 10 9 6 25 15 4 10 12
BIBI signif. > 3
Town Creek
Little Conococheague/...
Potomac R. (Lower N. Branch)
Fifteen Mile Creek
Savage R.
Catoctin Creek
Casselman R.
Potomac R. Upper N. Br.
Little Youghiogheny/...
Wills Creek
Potomac R. AL Co/...
Youghiogheny R.
Georges Creek
Conococheague
Potomac R. (Frederick County
Potomac R. MO Co
Antietam Creek
Seneca Creek
Lower Monocacy R.
Potomac R WA Co/Marsh Run/...
Evitts Creek
Upper Monocacy R.
Conewago Creek/...

Appendix D

APPENDIX D
CANDIDATE VARIABLES SELECTED FOR FURTHER ANALYSIS

Table D-1: Candidate Variables Selected for Further Analysis

	COASTAL	EPIDEDMONT	HIGHLANDS
A: Flow Regime	Impervious Surface	Impervious Surface	Impervious Surface
	Catchment High Urban	Benthic Dominants	Benthic Dominants
	Catchment Low Urban	Catchment Forest	Catchment Forest
		Catchment Transportation	Catchment Transportation
		Riparian Transportation	Riparian Transportation
		Channelization	Erosion Severity
			Erosion Extent
B: Terrestrial Sediment	Epifaunal Substrate	Epifaunal Substrate	Epifaunal Substrate
	Riparian High Urban	Riparian High Urban	Riparian High Urban
	Riparian Low Urban	Riparian Low Urban	Riparian Low Urban
	Riparian Forest	Riparian Forest	Riparian Forest
	Riparian Crop		Riparian Crop
	Minimum Buffer Width		Minimum Buffer Width
			Embeddedness
			Instream Habitat
			Riparian Pasture/Hay
C and D: Energy Source and Oxygen Consumption/Thermal Waste	DOC	DOC	DOC
	DO	DO	Shading
	SO4	SO4	SO4
	Riparian Forest	Riparian Forest	Riparian Forest
	Catchment High Urban	Catchment High Urban	Catchment High Urban
	Catchment Low Urban	Catchment Low Urban	Catchment Low Urban
	No Buffer	Temperature	Temperature
	NH3	HBI	HBI
	Riparian Crop		Riparian Crop
			NH3
			SAV
			Riparian Pasture/Hay
			Catchment Pasture/Hay
E: Inorganic Pollutants	Conductivity	Conductivity	Conductivity
	pH	Riparian Extractive	Riparian Extractive
F: Organic Pollutants	HBI	Catchment High Urban	Catchment High Urban
		Catchment Transportation	Catchment Transportation
		Riparian Transportation	Riparian Transportation
			Anomalies

* Candidate variables selected for further analysis showed the best relationships between divergence from variable values at reference sites and degradation of watersheds

Appendix E

APPENDIX E
QUANTILE REGRESSIONS (90TH OR 10TH) OF CANDIDATE STRESSOR IDENTIFICATION VARIABLES

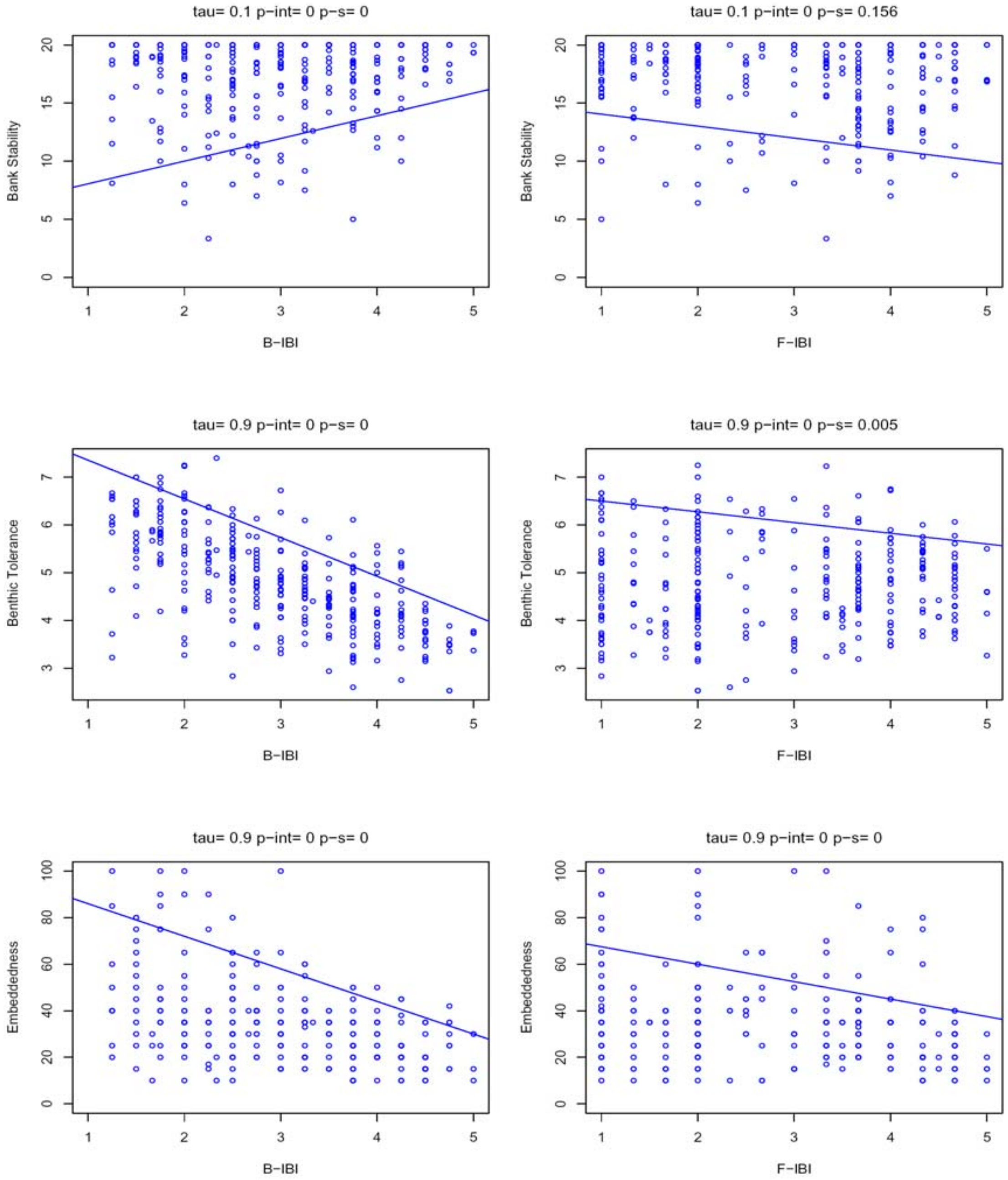


Figure E-1: Highland Bank Stability, Benthic Tolerance, and Embeddedness Values vs. IBI Score Regressions

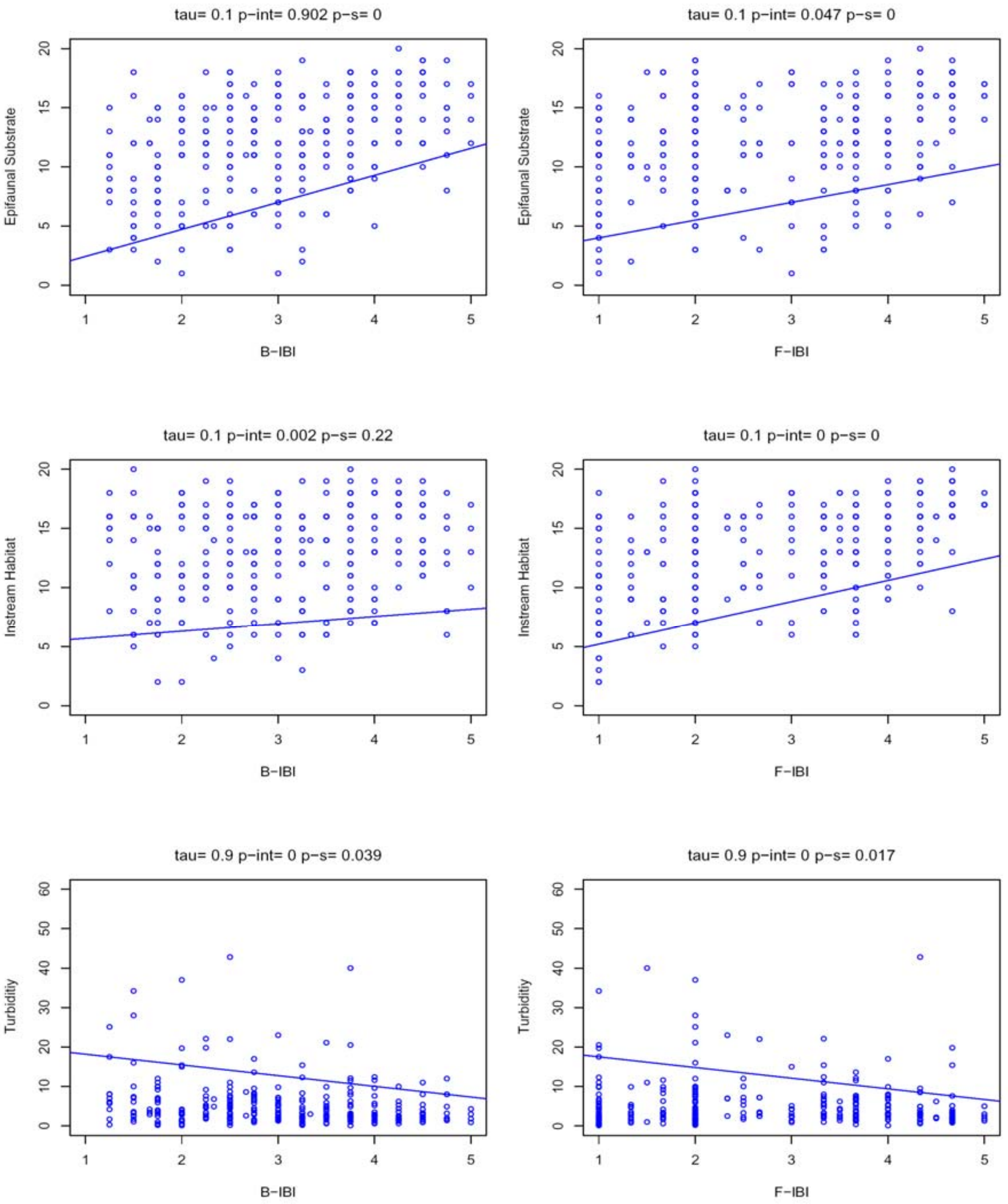


Figure E-2: Highland Epifaunal Substrate, Instream Habitat, and Turbidity Values vs. IBI Score Regressions

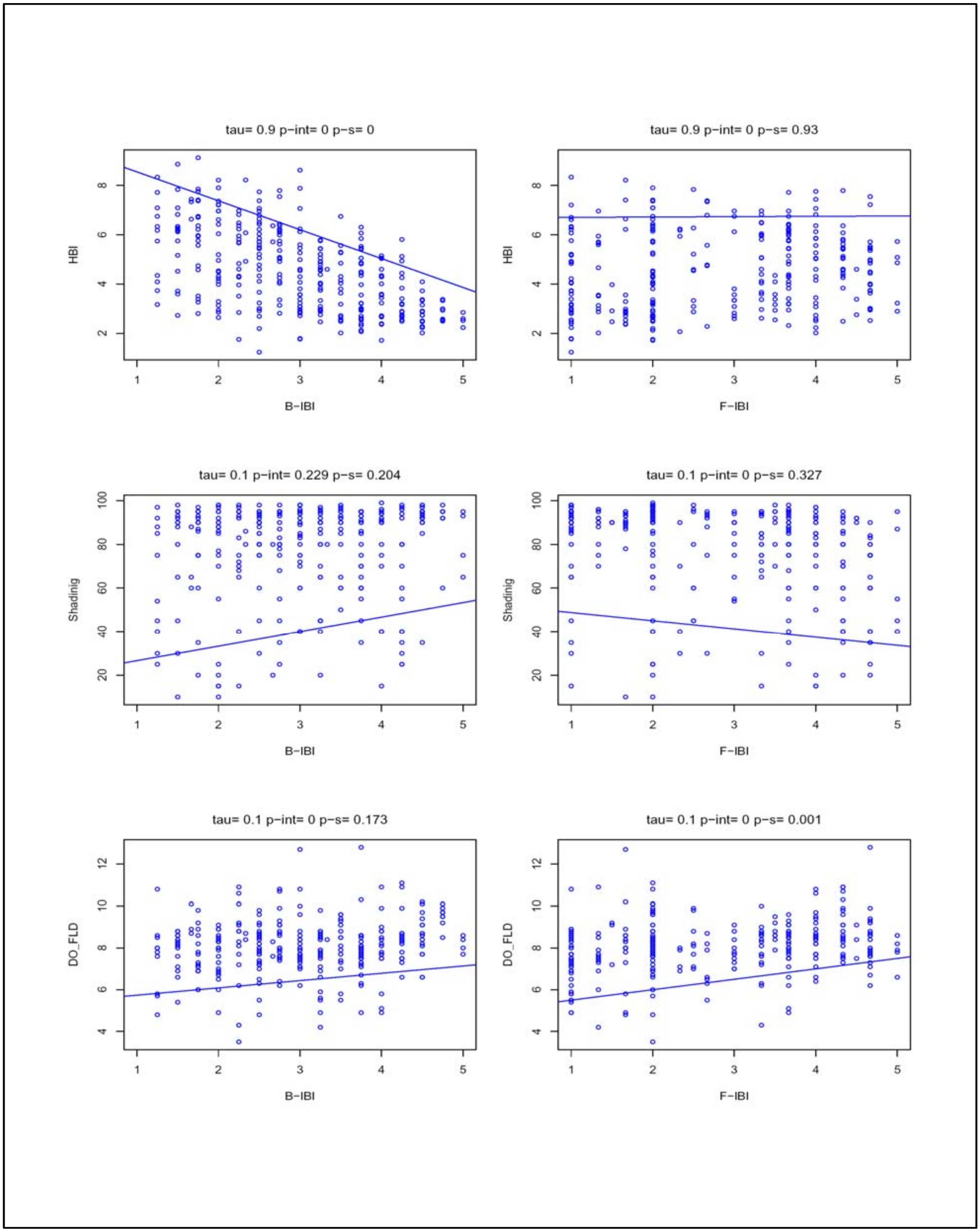


Figure E-3: Highland HBI, Shading, and DO Values vs. IBI Score Regressions

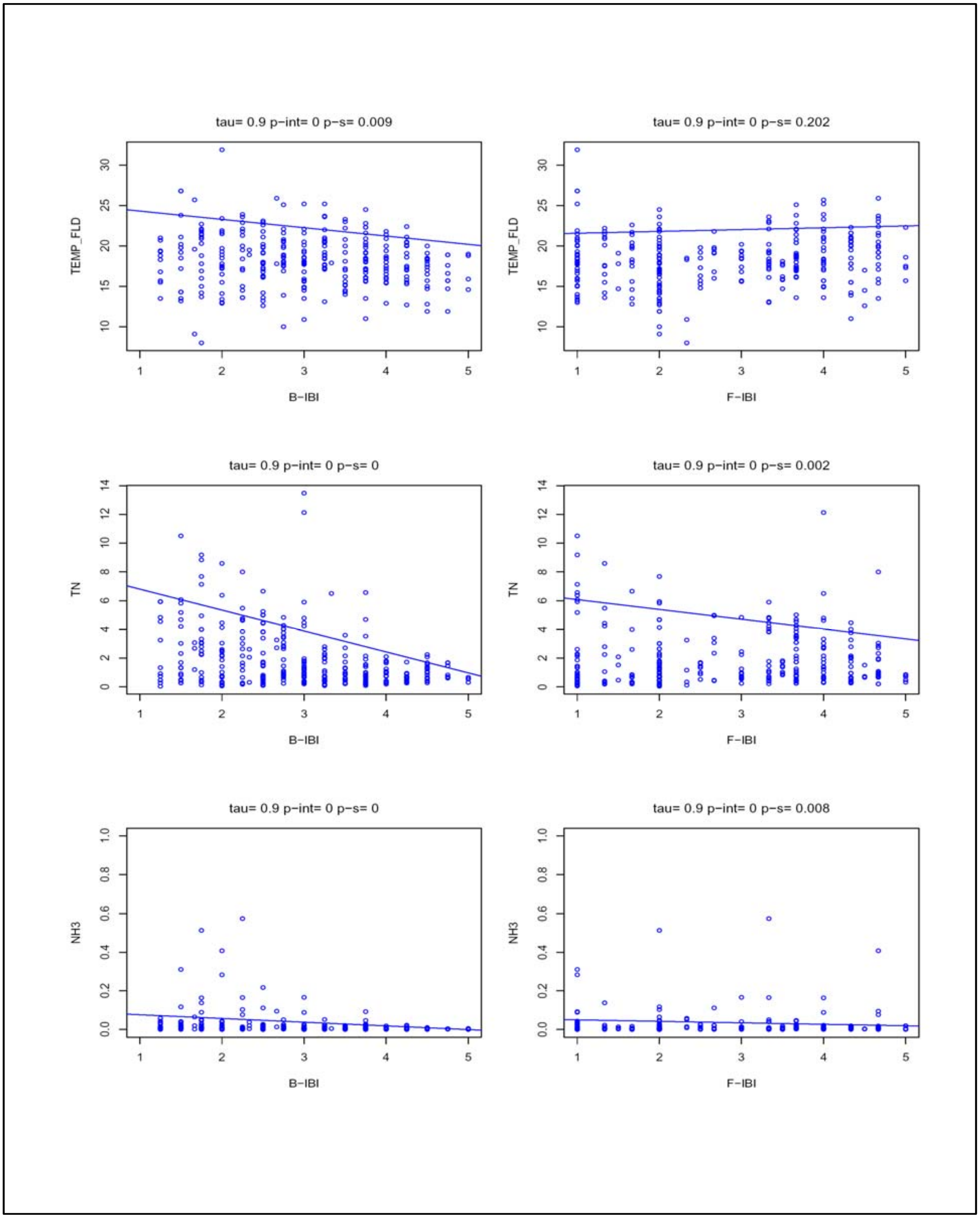


Figure E-4: Highland Temperature, TN, and NH3 Values vs. IBI Score Regressions

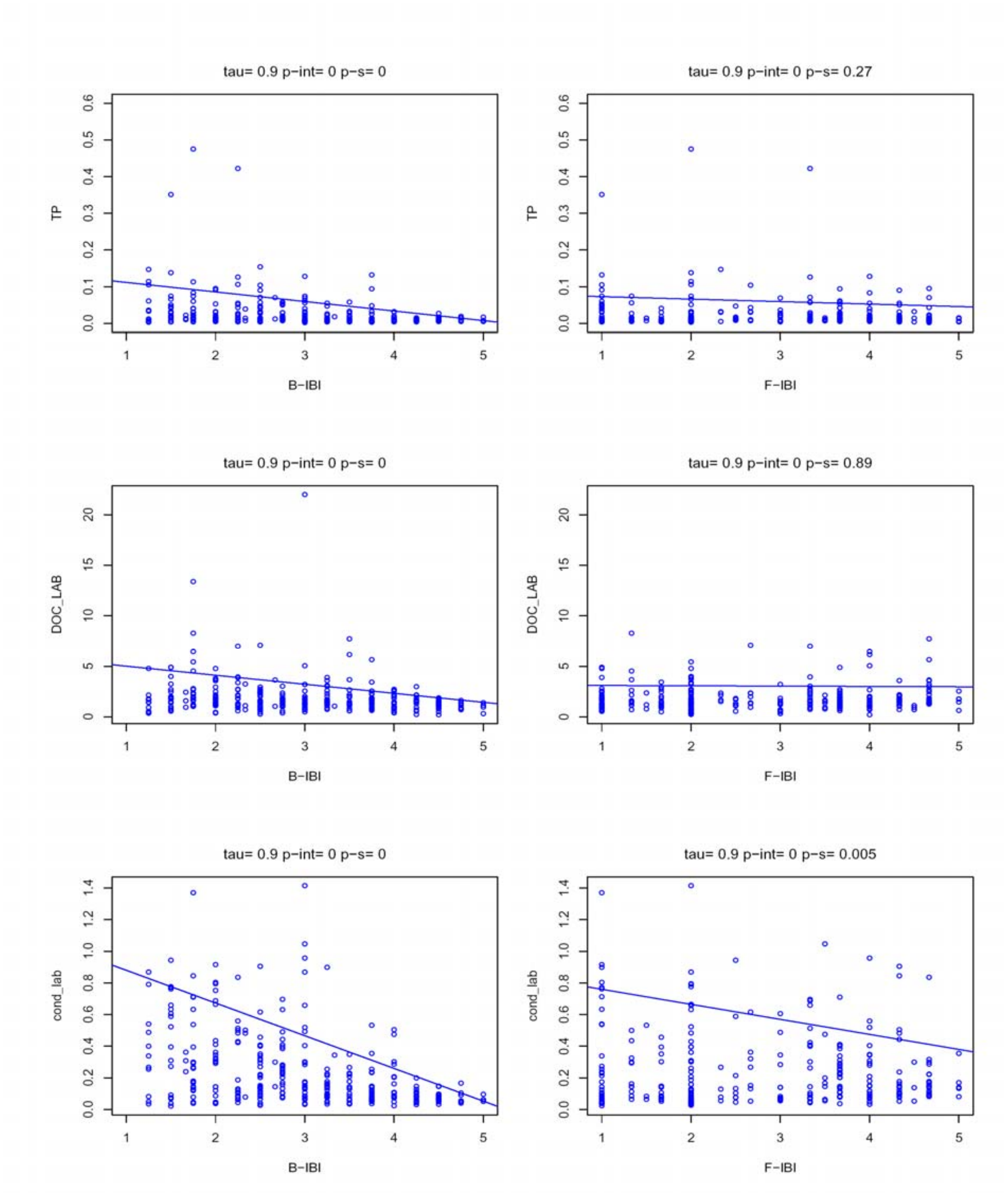


Figure E-5: Highland TP, DOC, and Conductivity Values vs. IBI Score Regressions

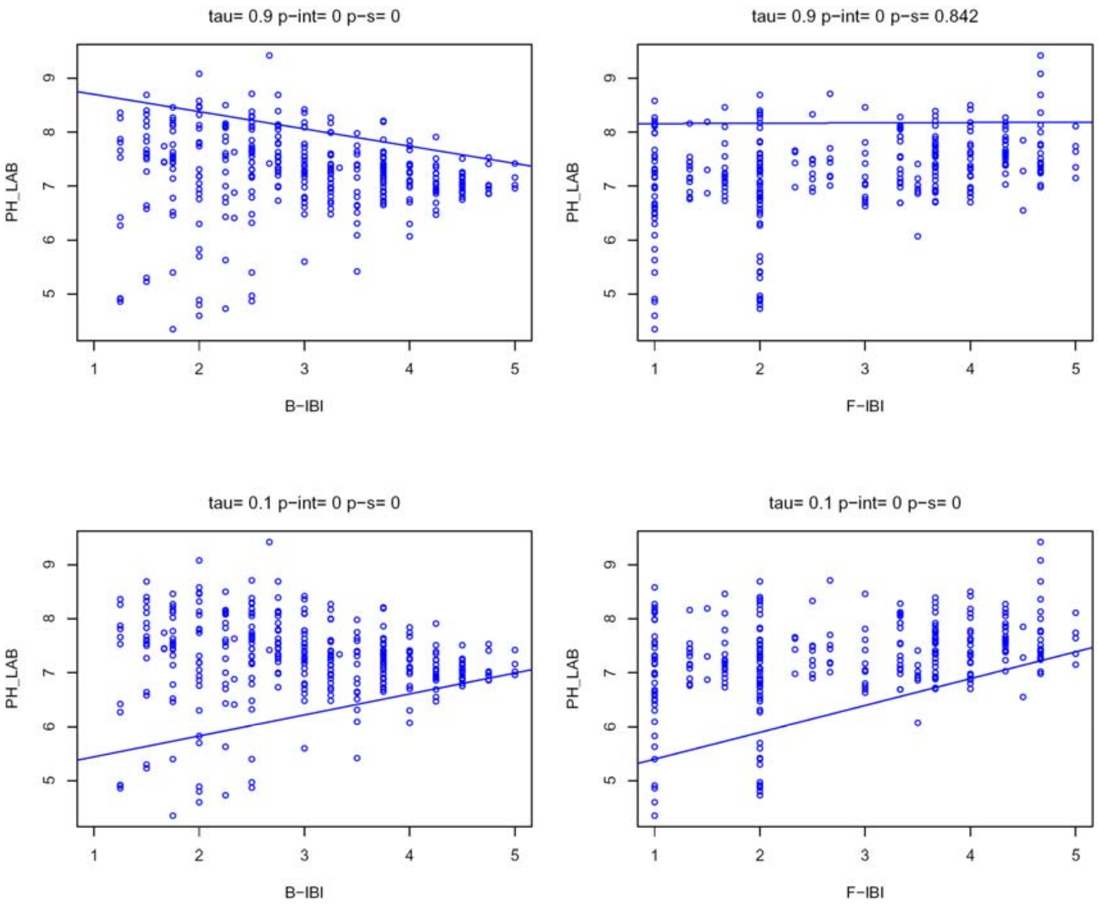


Figure E-6: Highland pH Values vs. IBI Score Regressions

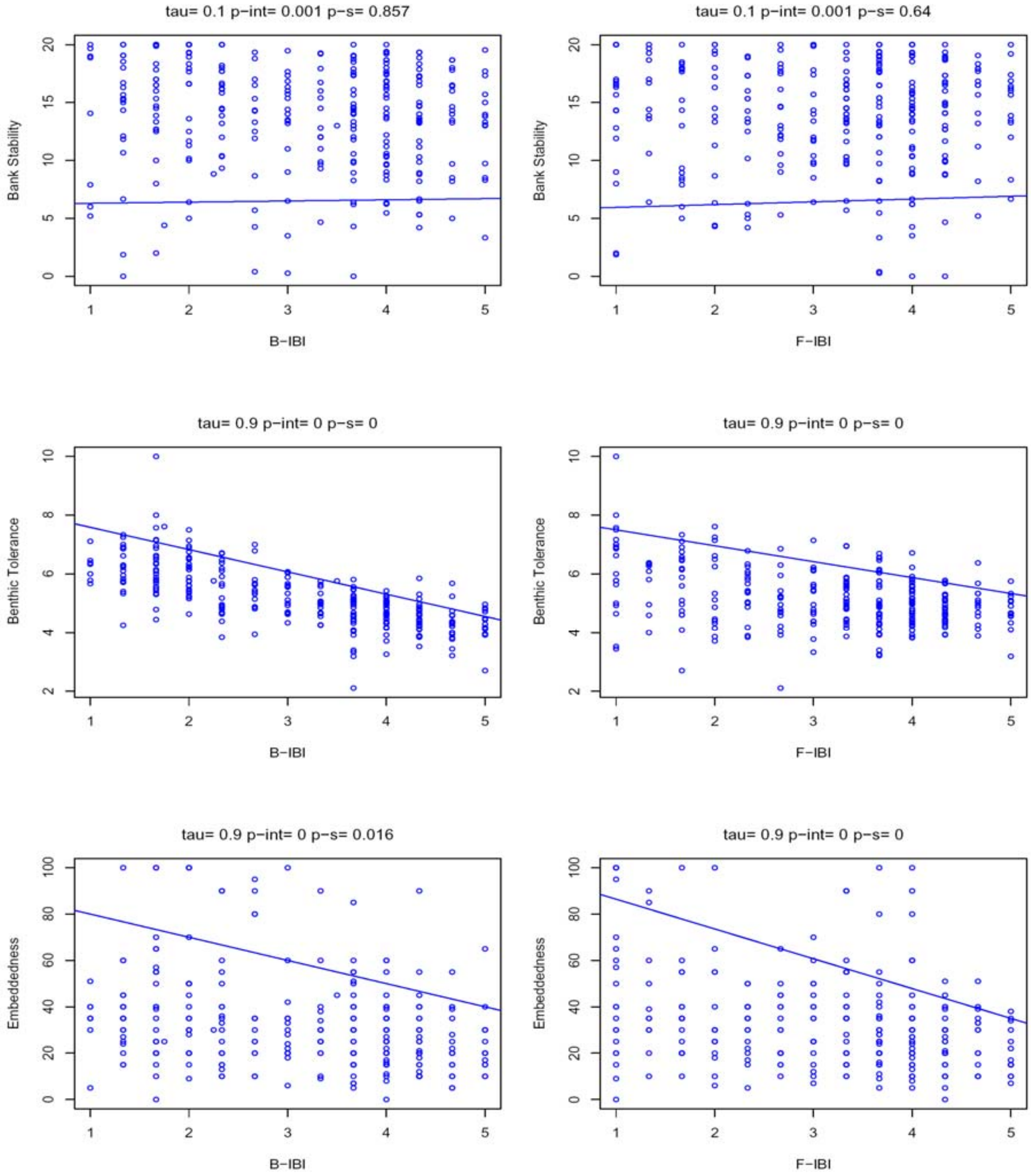


Figure E-7: Piedmont Bank Stability, Benthic Tolerance, and Embeddedness Values vs. IBI Score Regressions

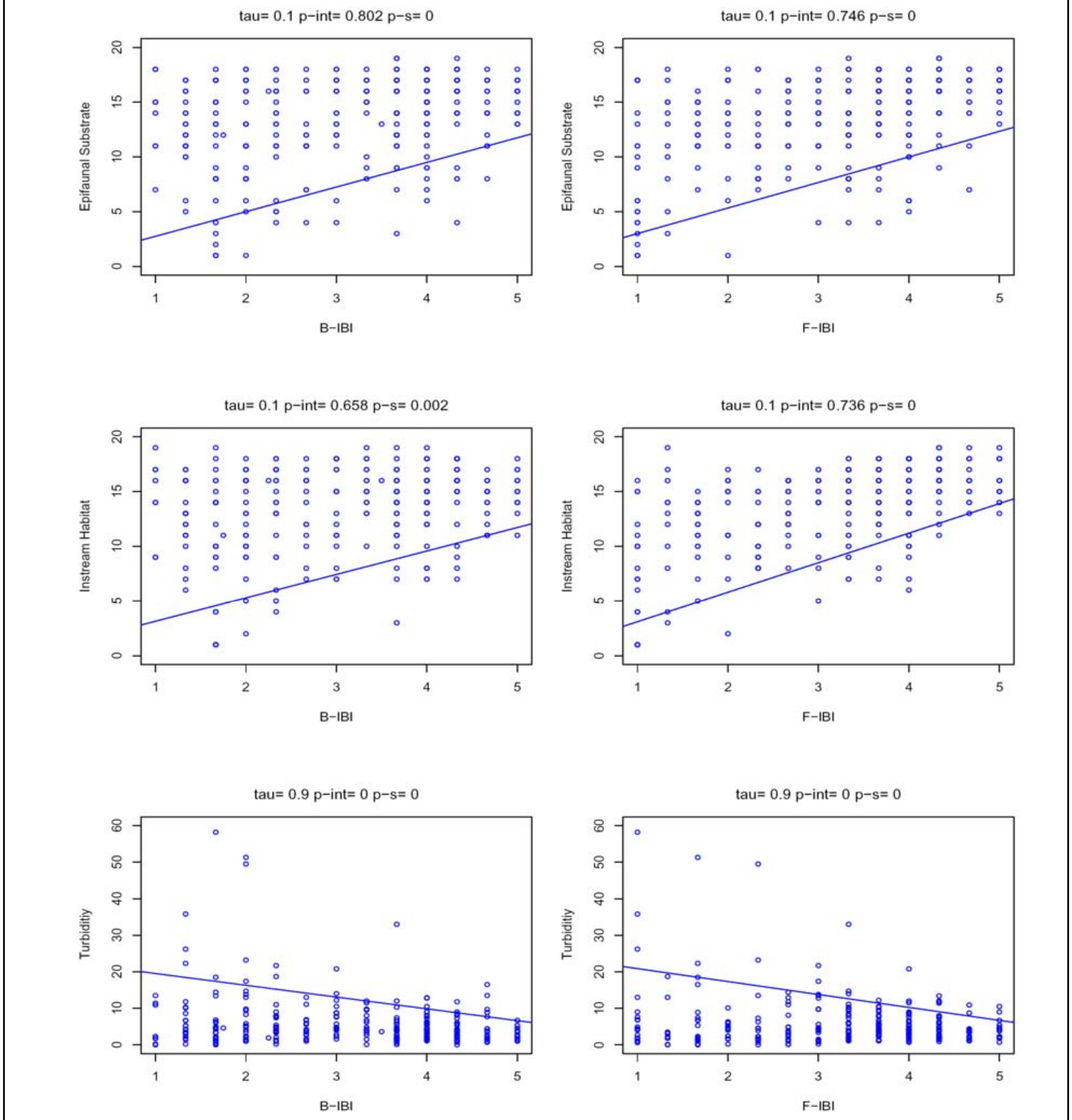


Figure E-8: Piedmont Epifaunal Substrate, Instream Habitat, and Turbidity Values vs. IBI Score Regressions

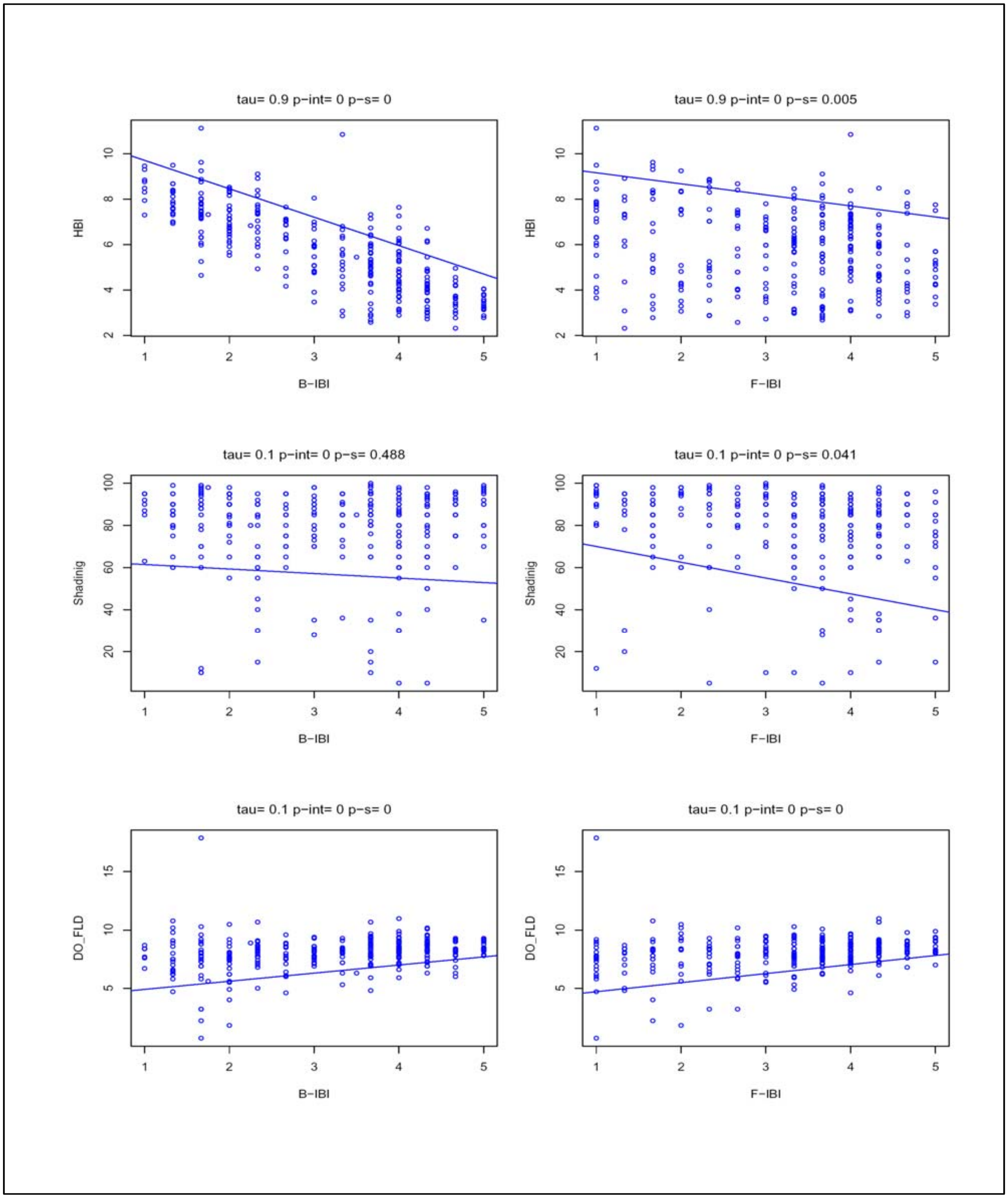


Figure E-9: Piedmont HBI, Shading, and DO Values vs. IBI Score Regressions

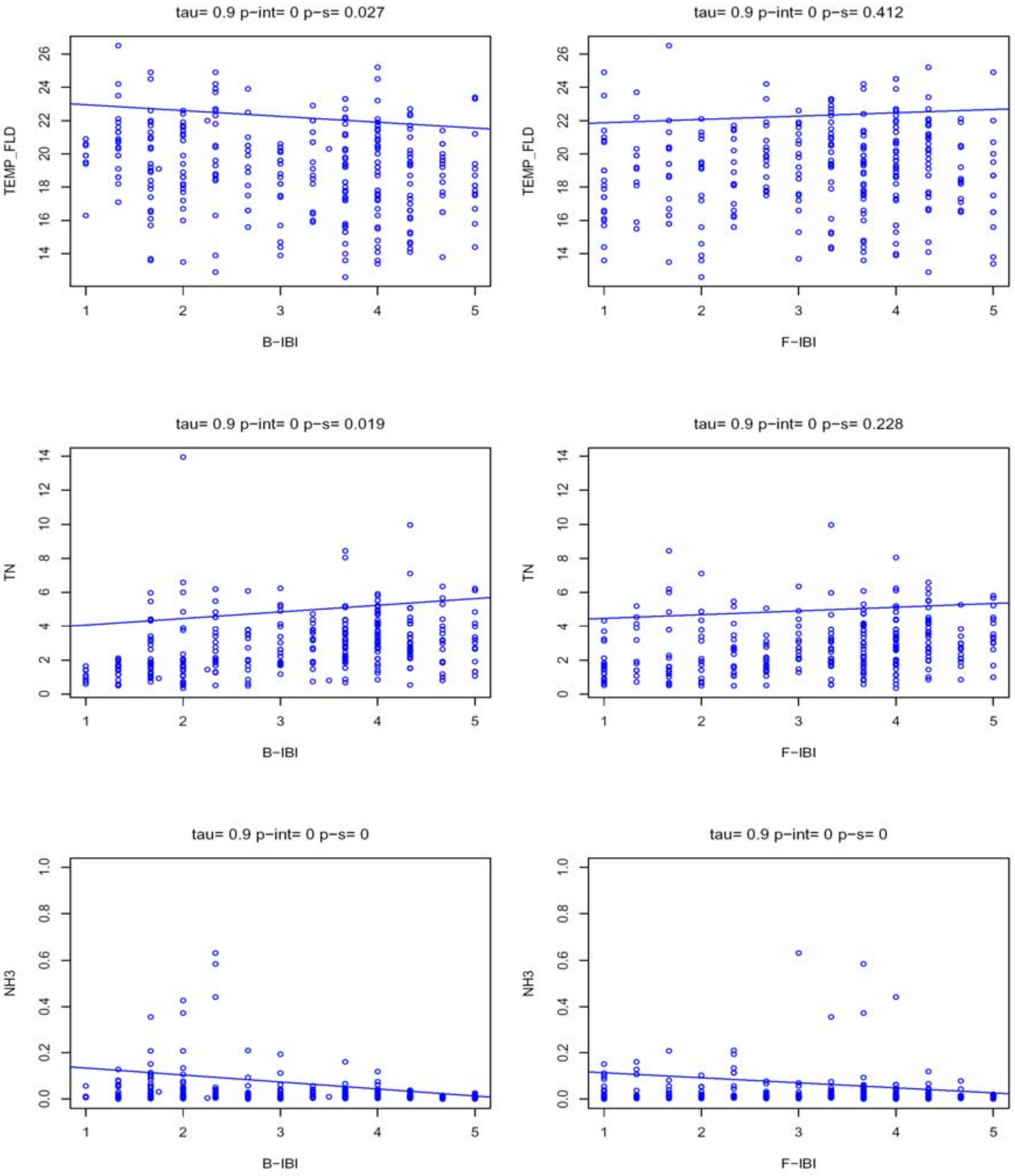


Figure E-10: Piedmont Temperature, TN, and NH3 Values vs. IBI Score Regressions

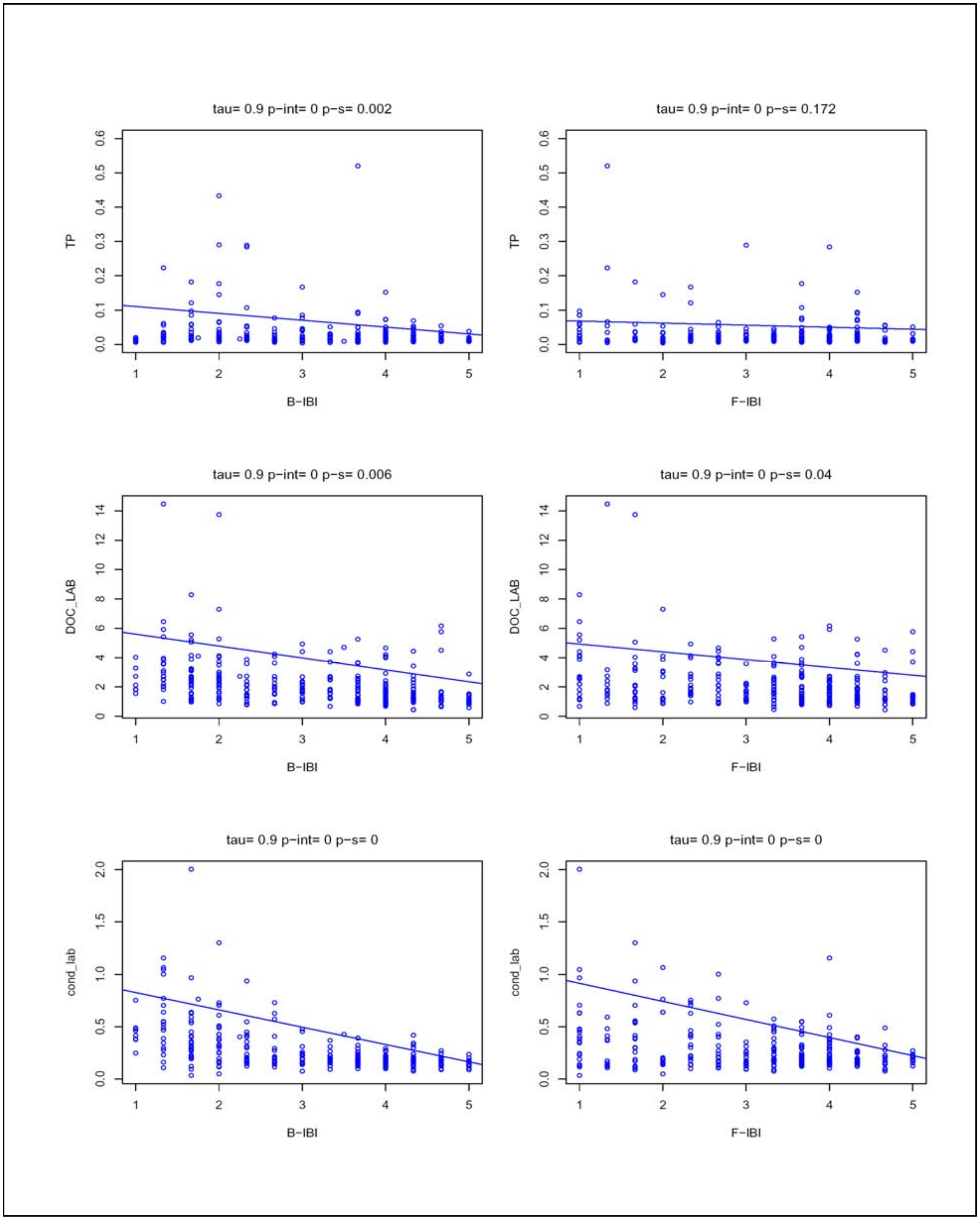


Figure E-11: Piedmont TP, DOC, Conductivity Values vs. IBI Score Regressions

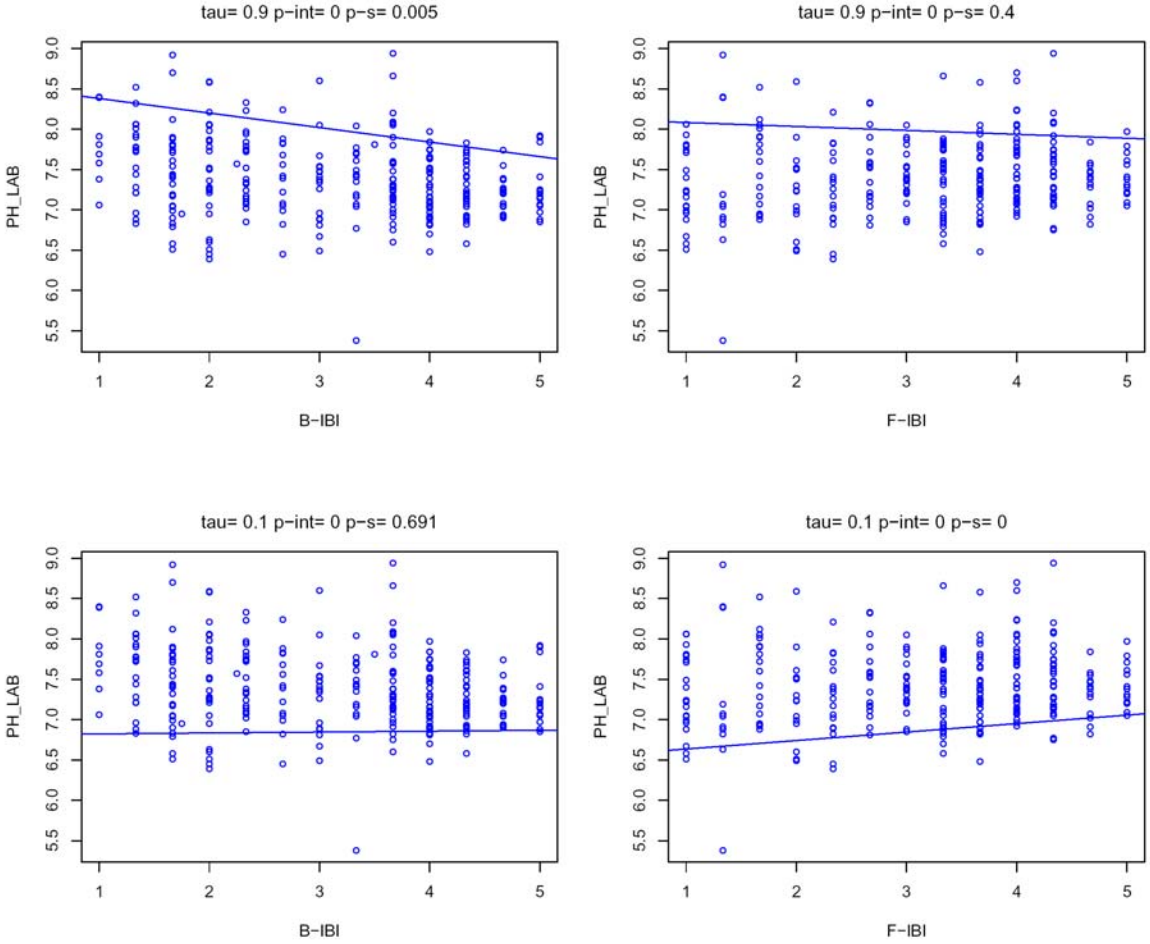


Figure E-12: Piedmont pH Values vs. IBI Score Regressions

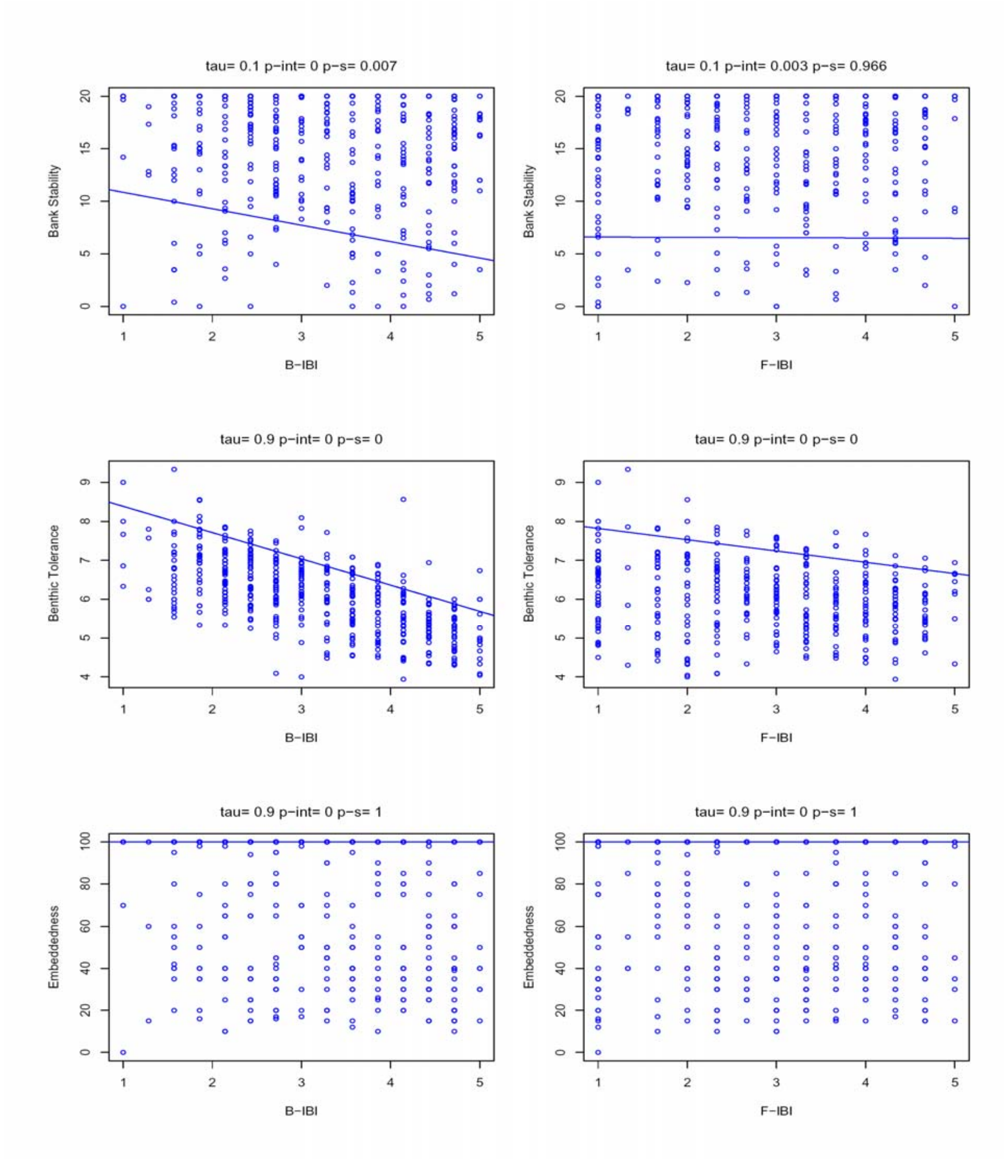


Figure E-13: Coastal Plain Bank Stability, Benthic Tolerance, and Embeddedness Values vs. IBI Score Regressions

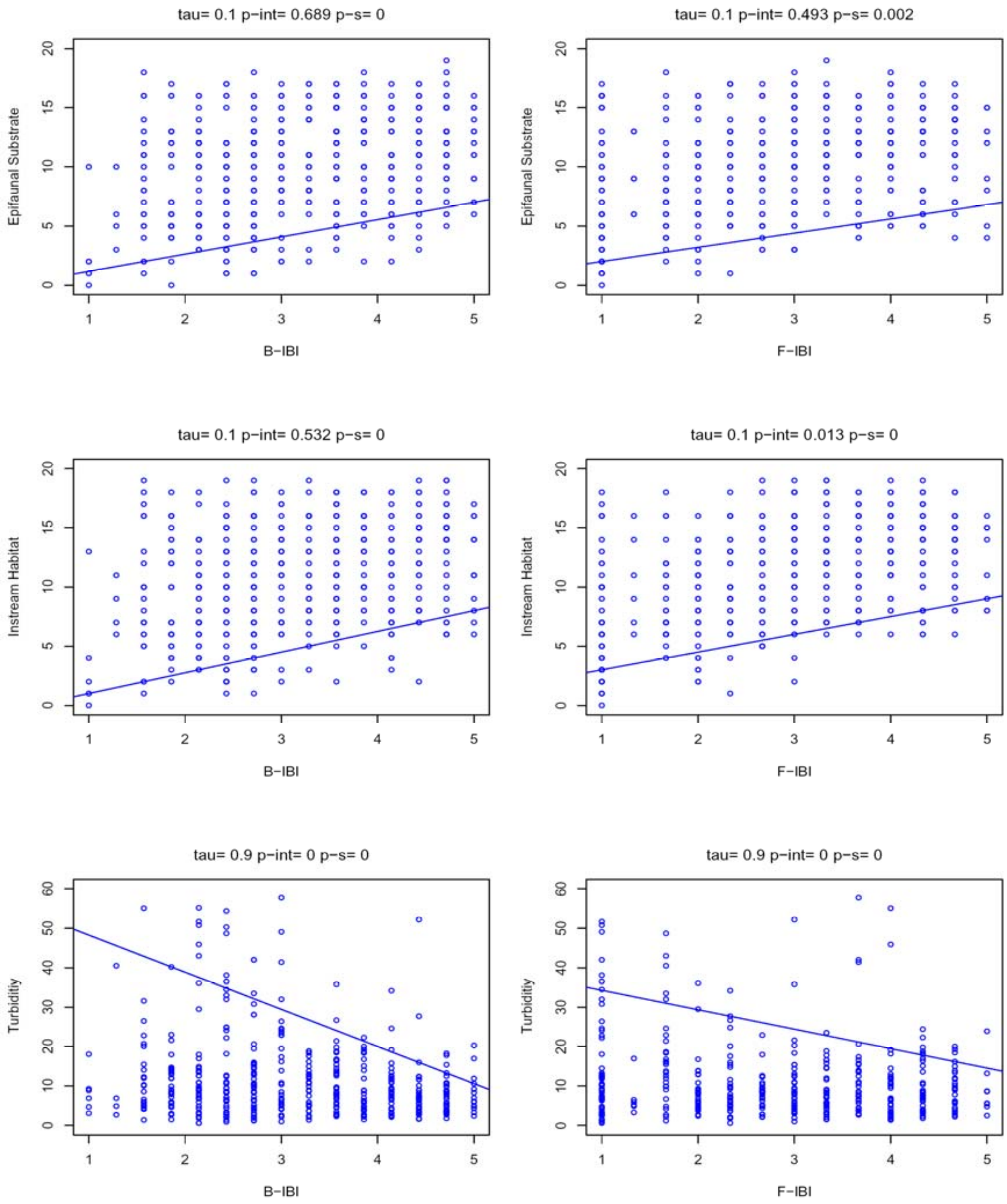


Figure E-14: Coastal Plain Epifaunal Substrate, Instream Habitat, and Turbidity Values vs. IBI Score Regressions

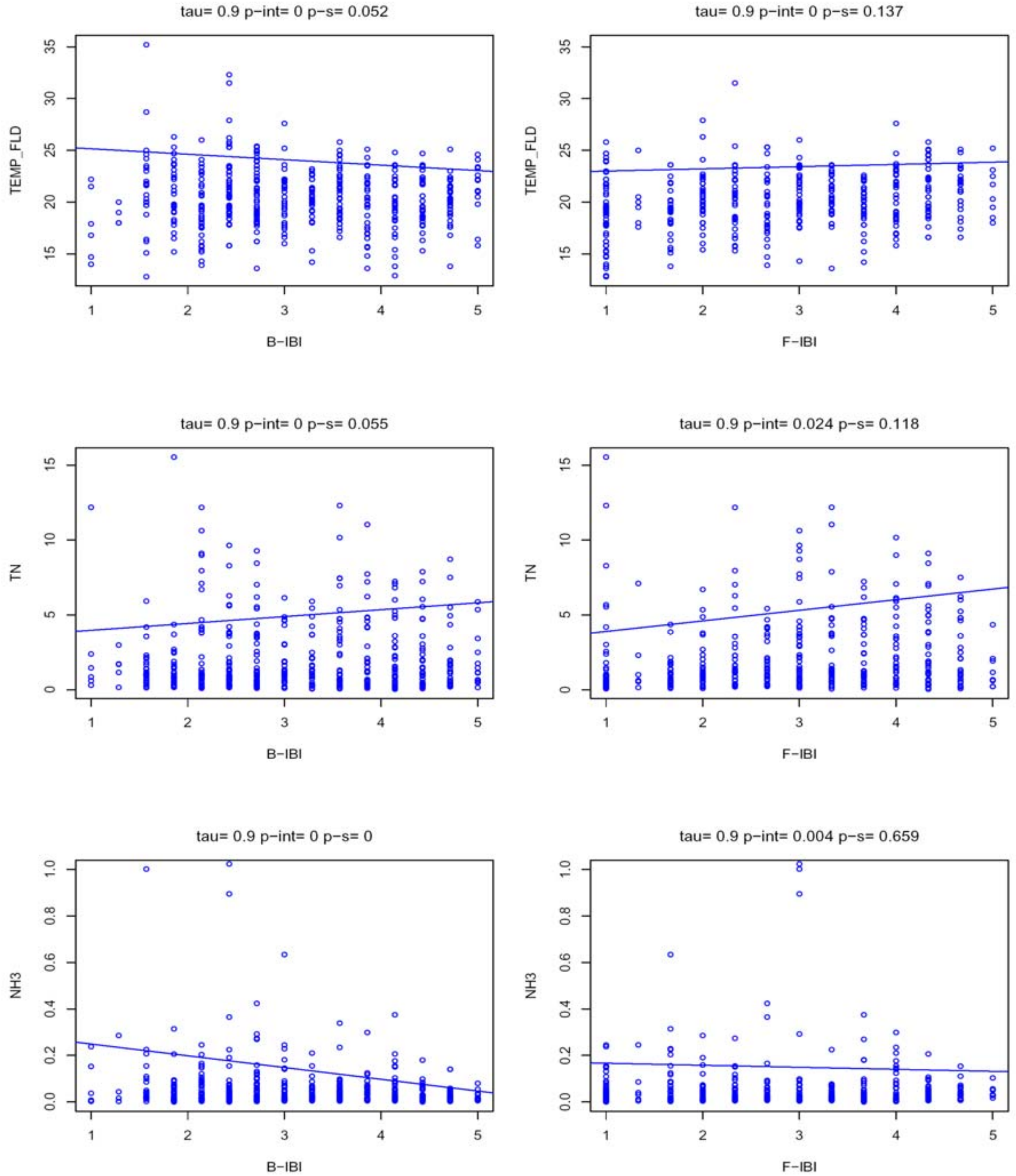


Figure E-15: Coastal Plain Temperature, TN, and NH3 Values vs. IBI Score Regressions

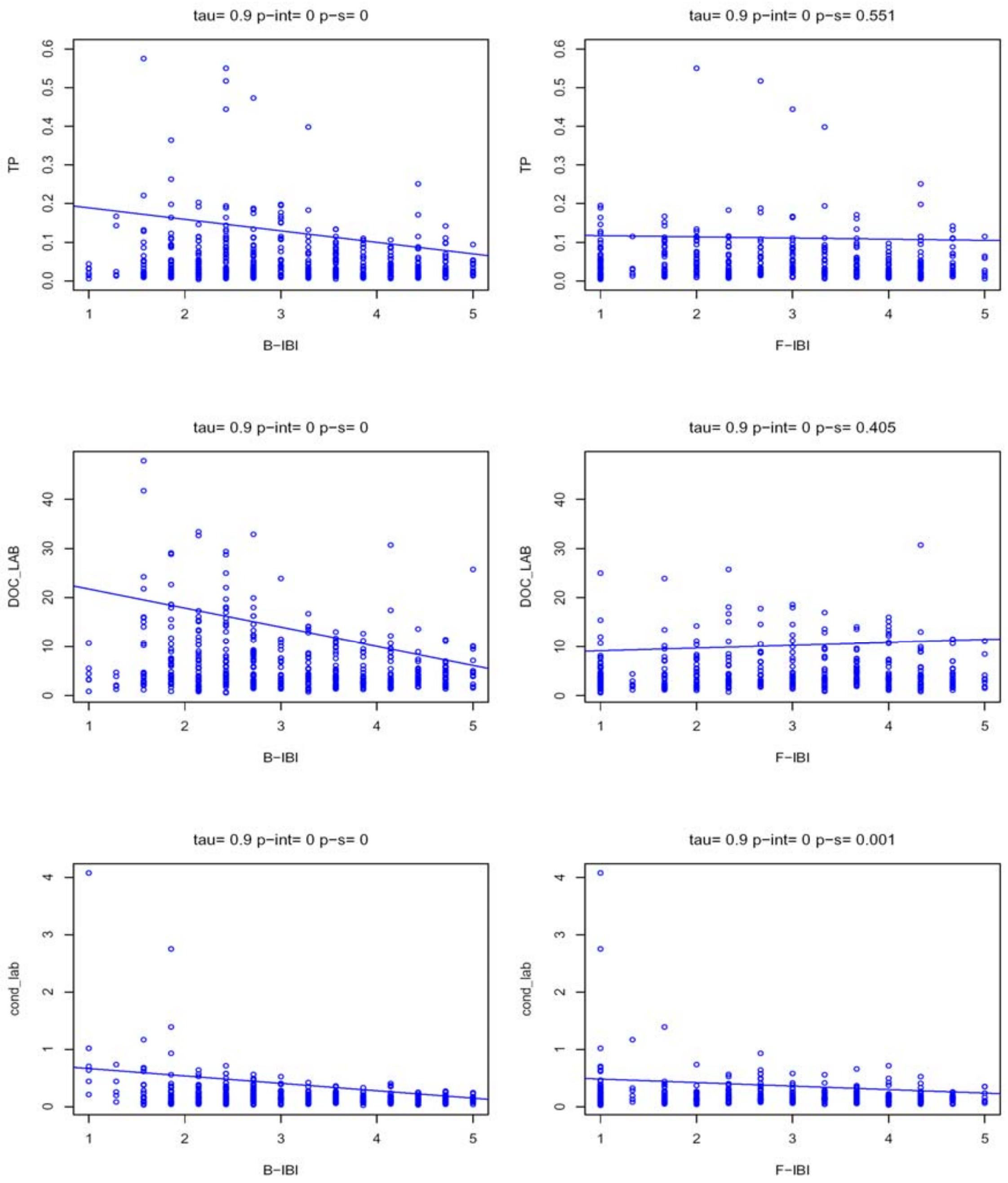


Figure E-16: Coastal Plain TP, DOC, and Conductivity Values vs. IBI Score Regressions

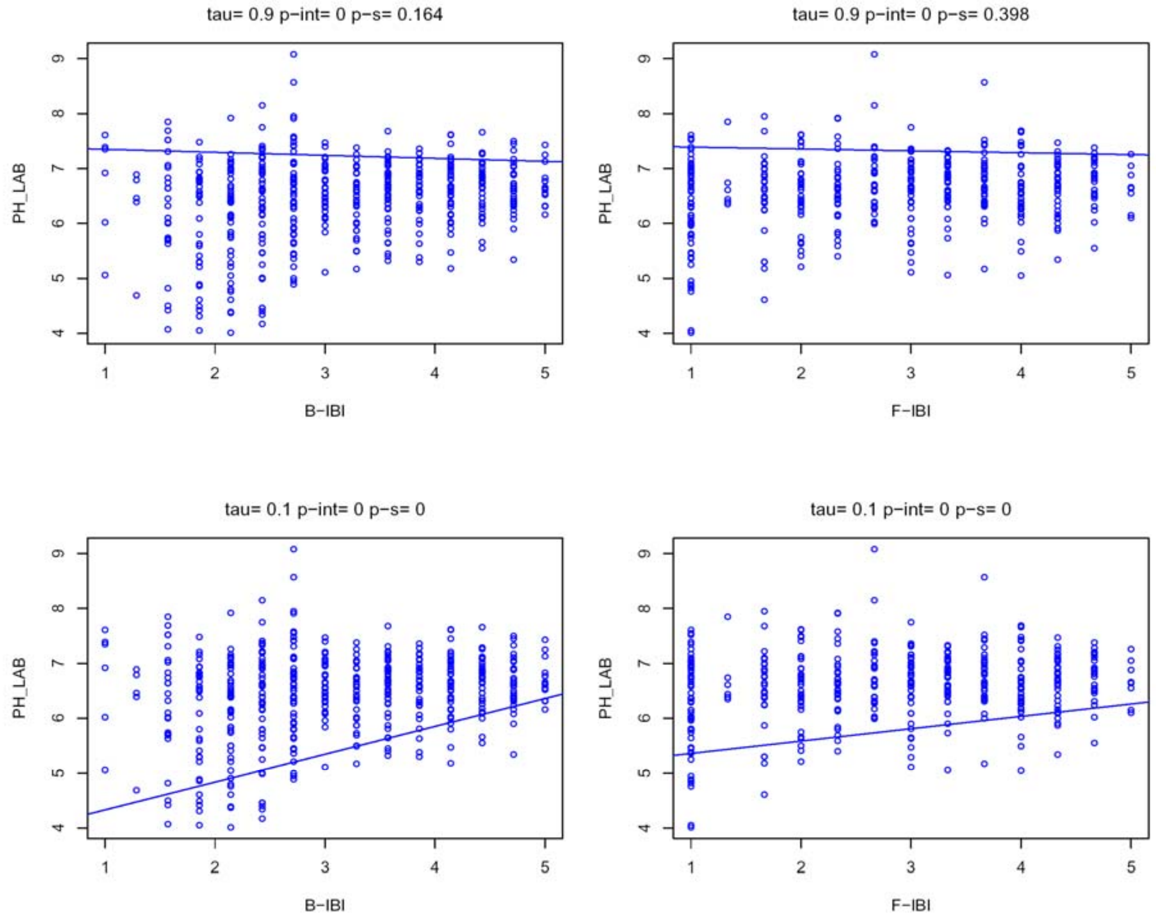


Figure E-17: Coastal Plain pH Values vs. IBI Score Regressions

Appendix F

Appendix F
Stream Disturbance Indicator Results
By Watershed

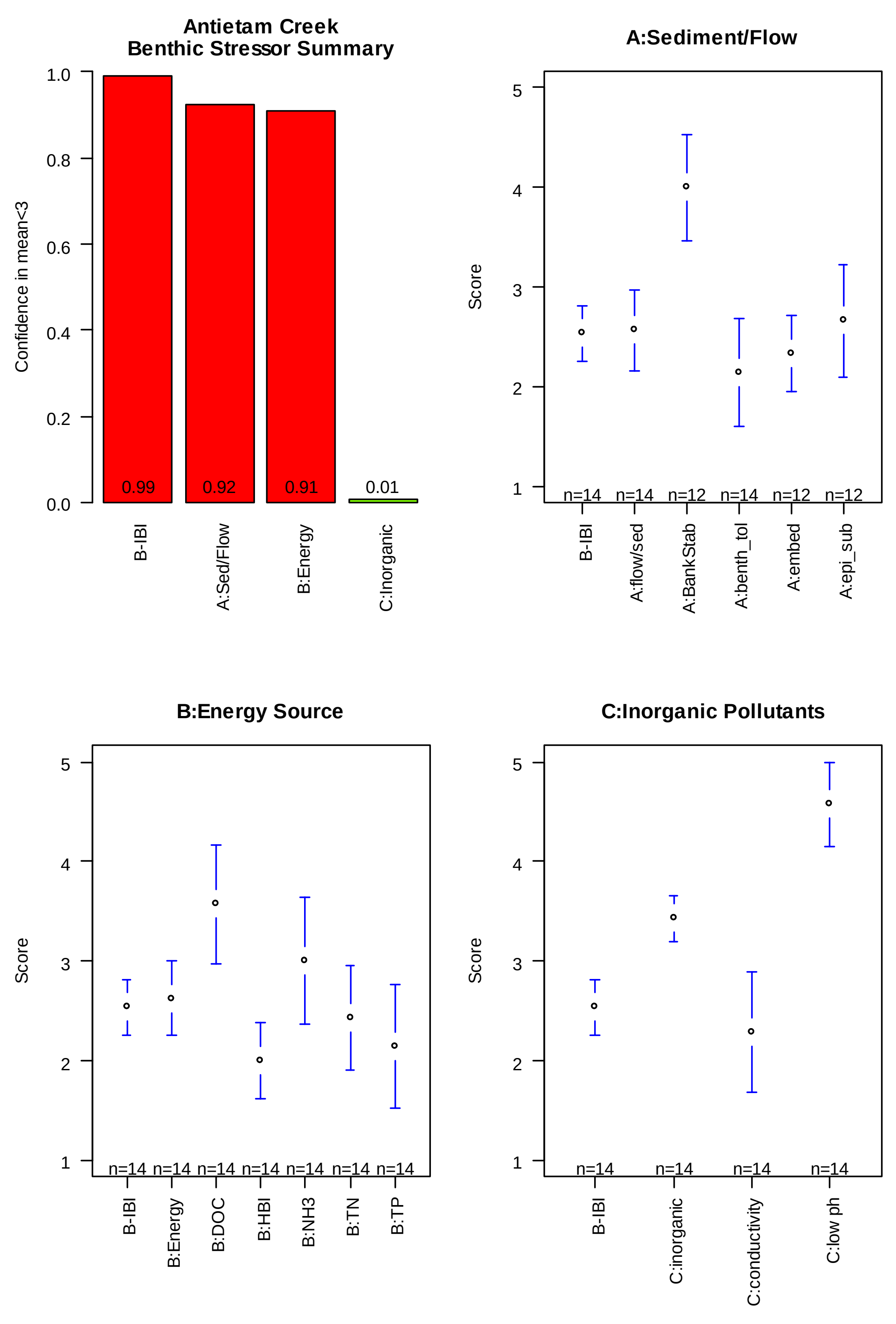


Figure F-1: Antietam Creek Benthic Stressor Results

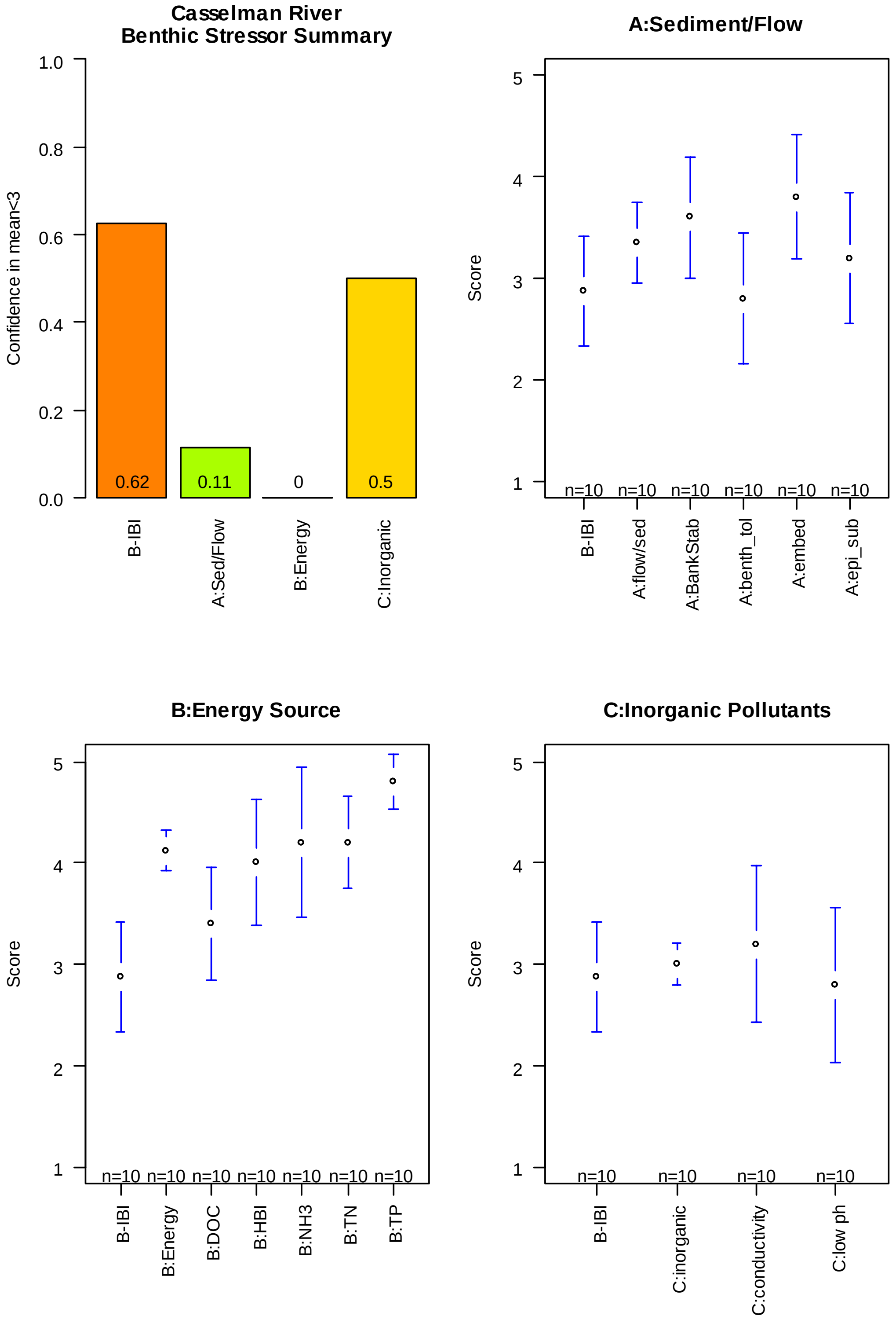


Figure F-2: Casselman River Benthic Stressor Results

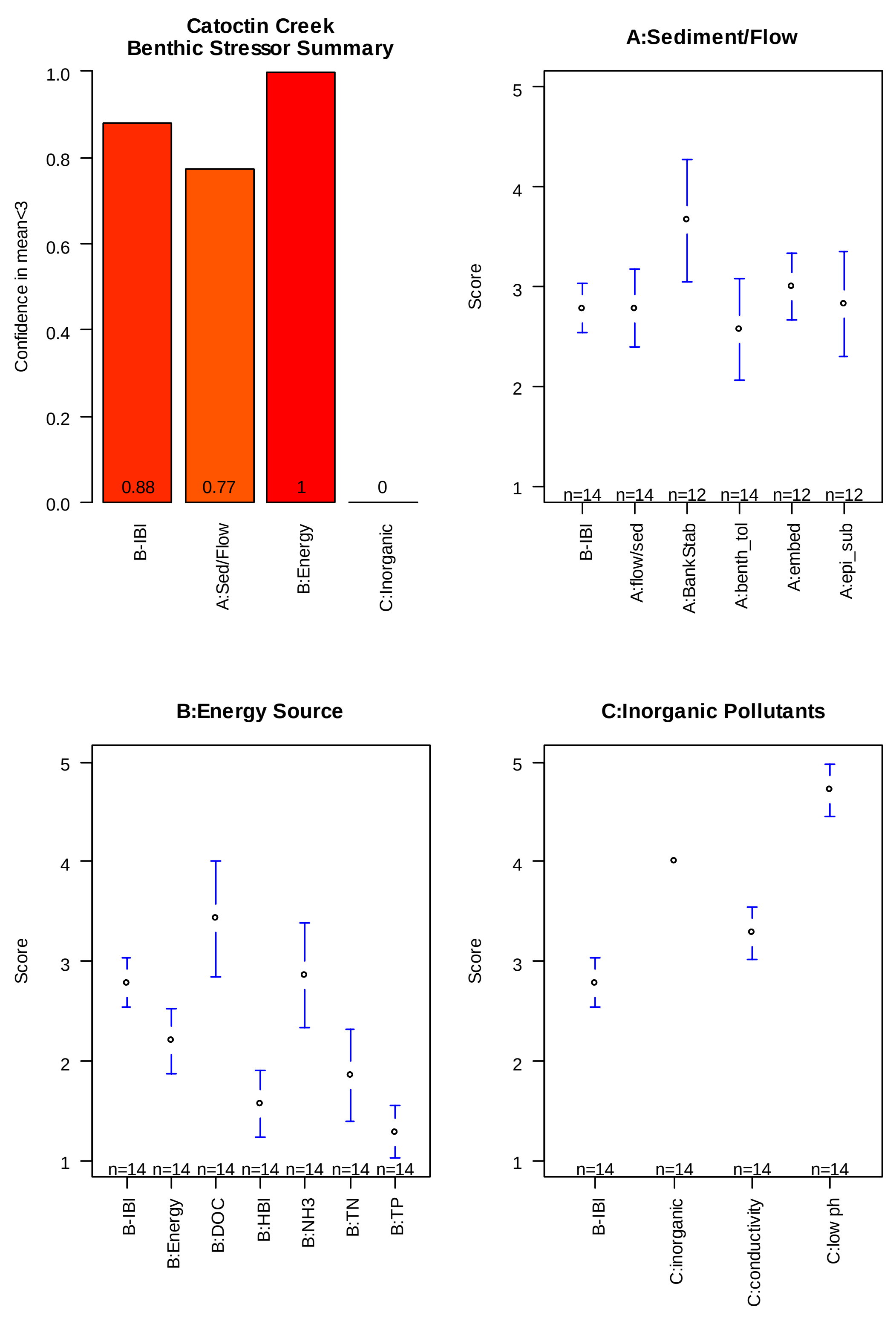


Figure F-3: Catoctin Creek Benthic Stressor Results

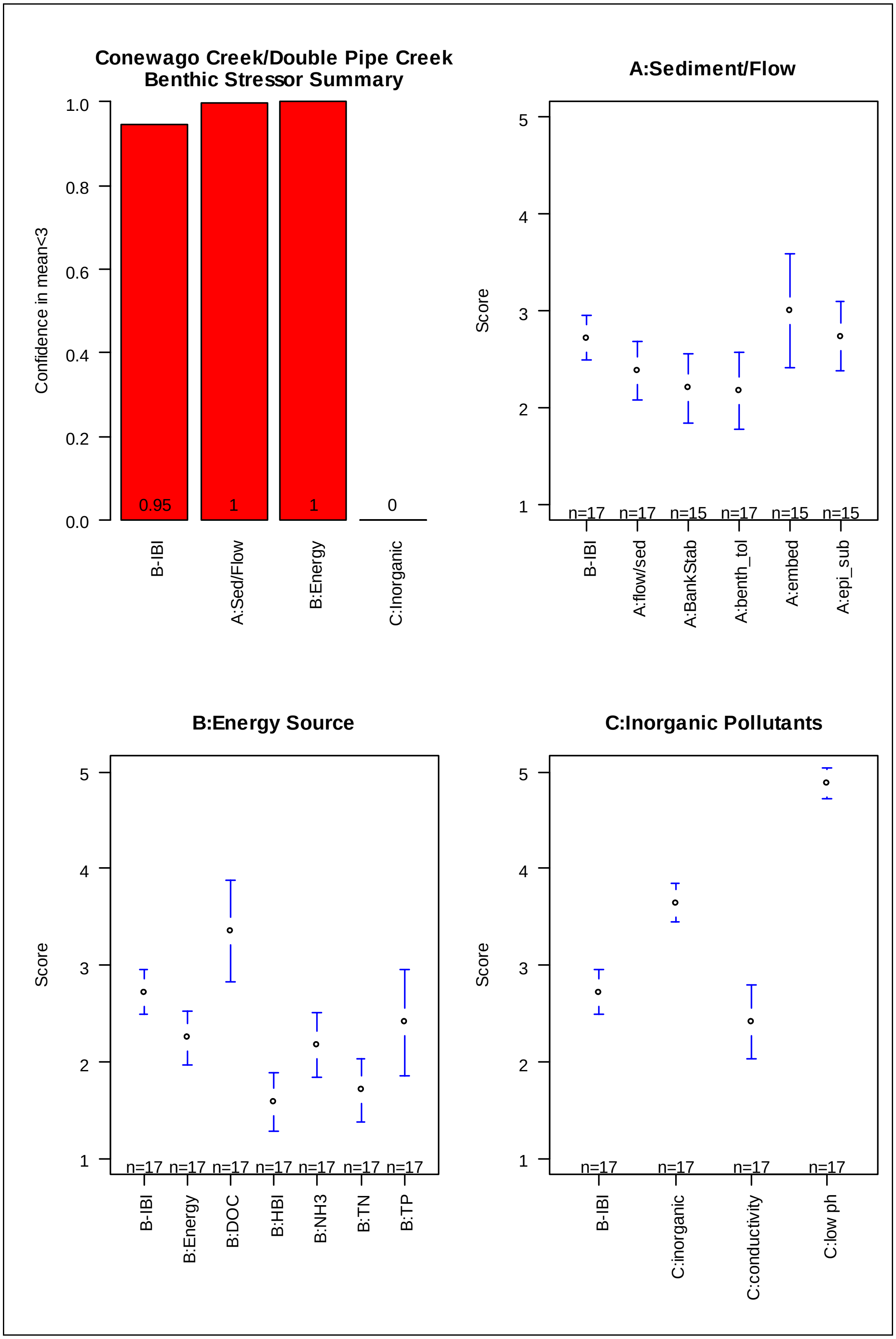


Figure F-4: Conewago/Double Pipe Creek Benthic Stressor Results

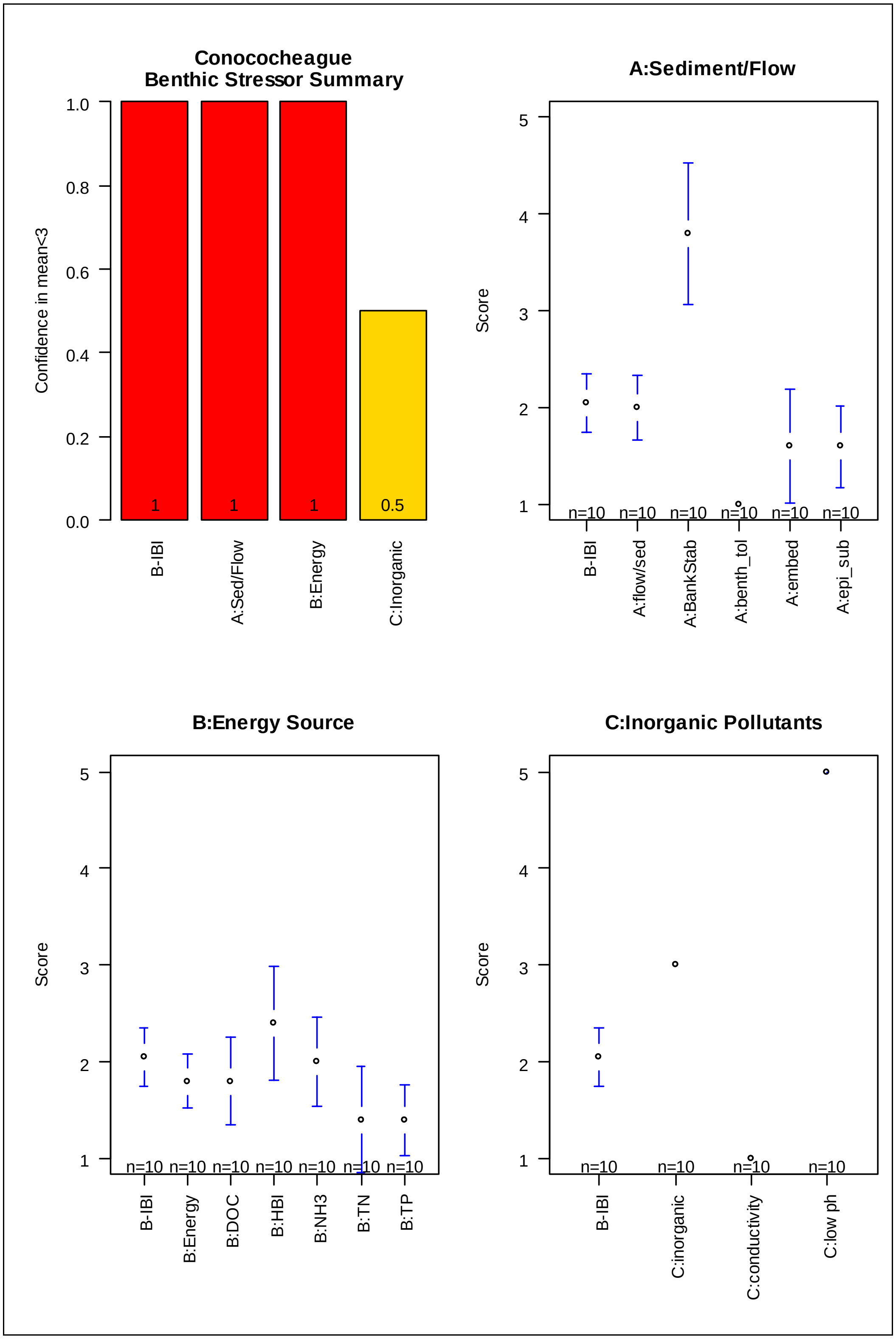


Figure F-5: Conococheague Creek Benthic Stressor Results

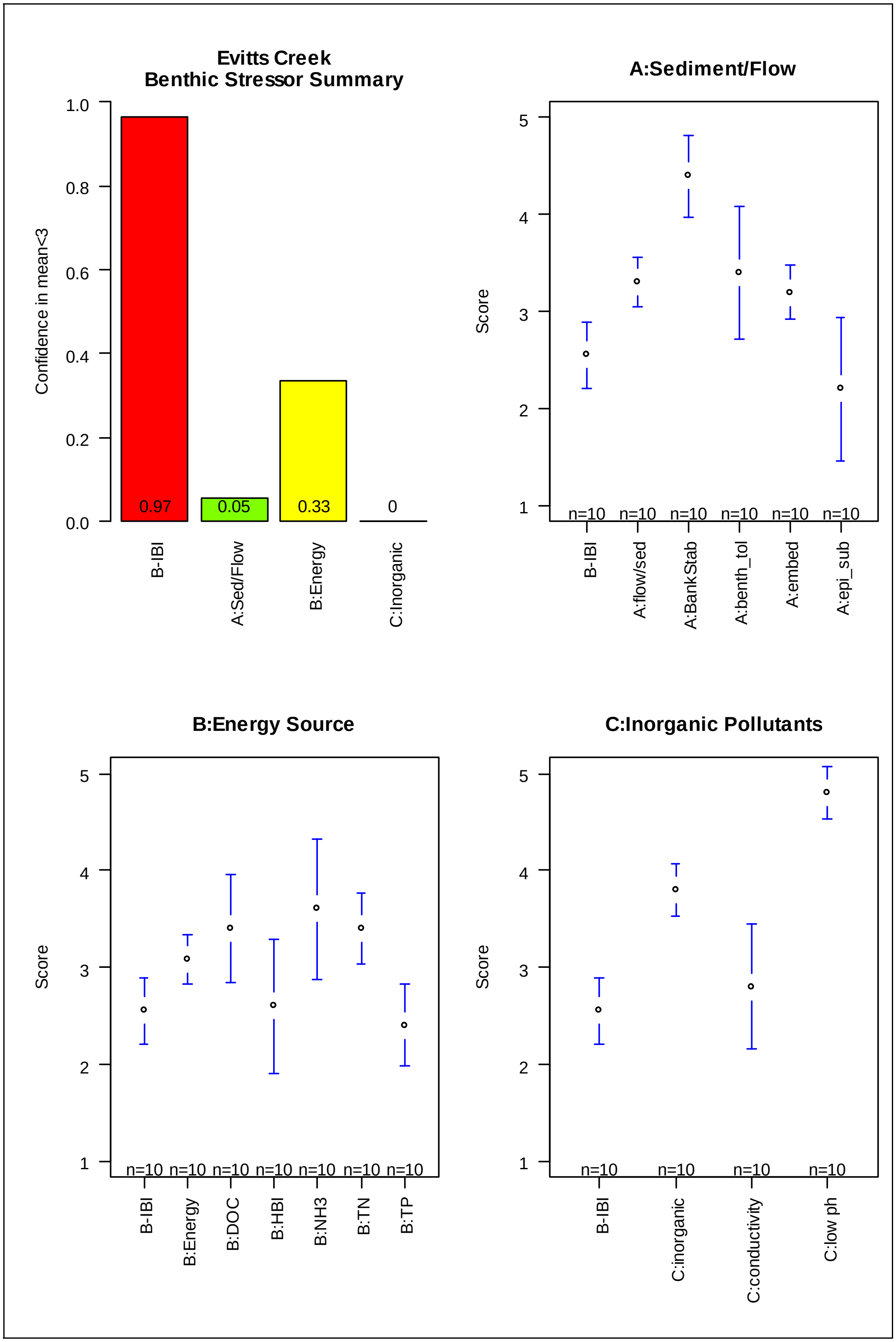


Figure F-6: Evitts Creek Benthic Stressor Results

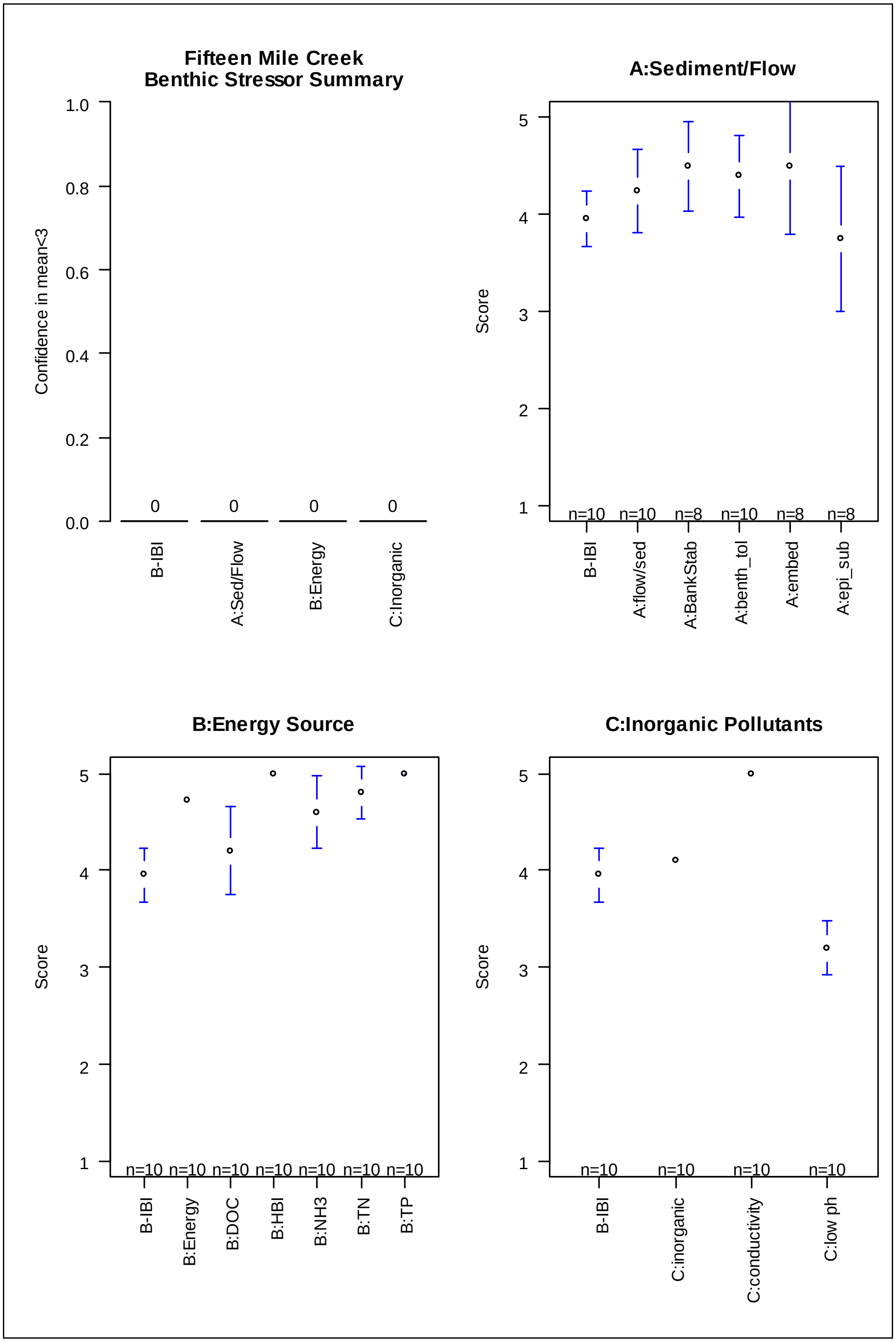


Figure F-7: Fifteen Mile Creek Benthic Stressor Results

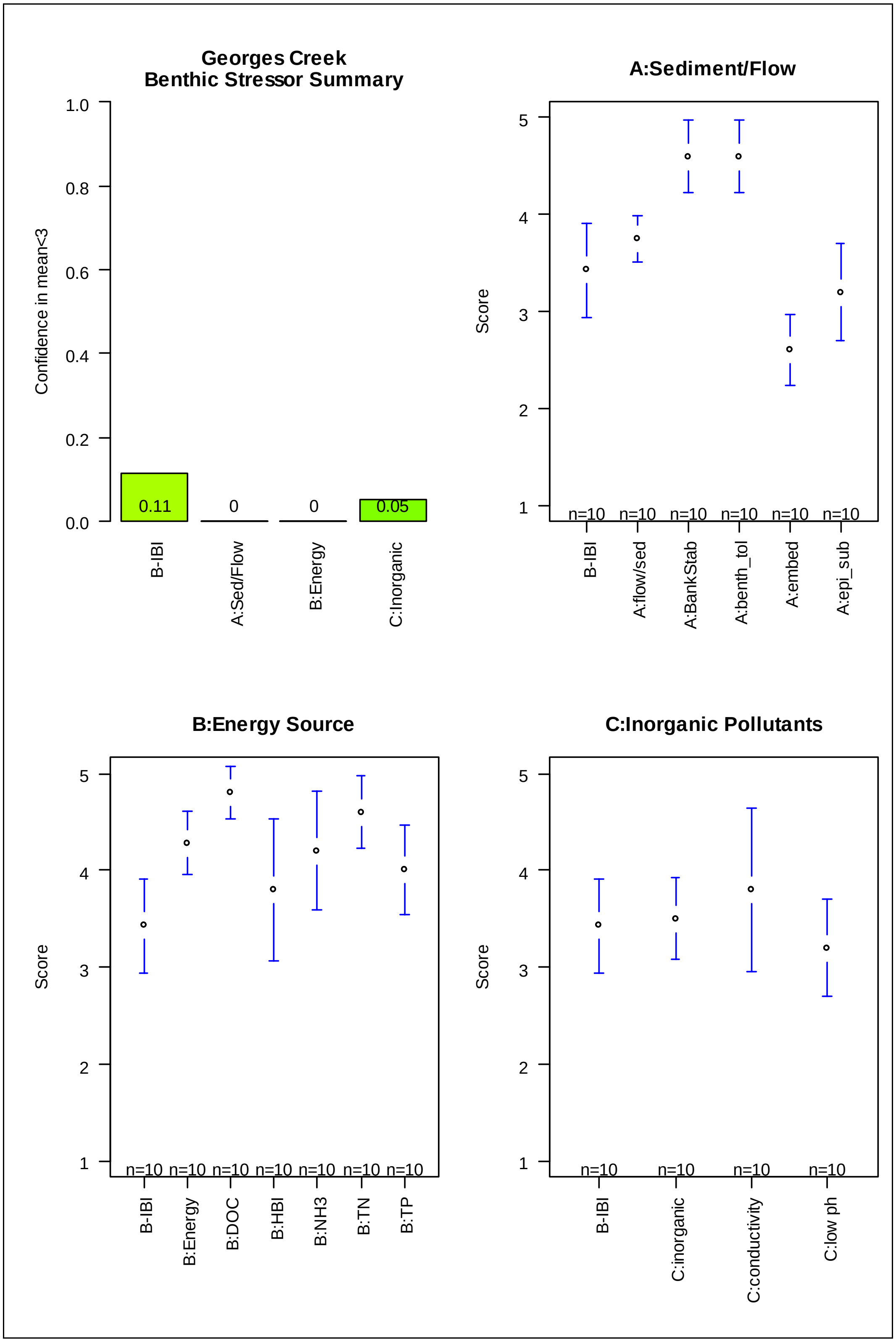


Figure F-8: Georges Creek Benthic Stressor Results

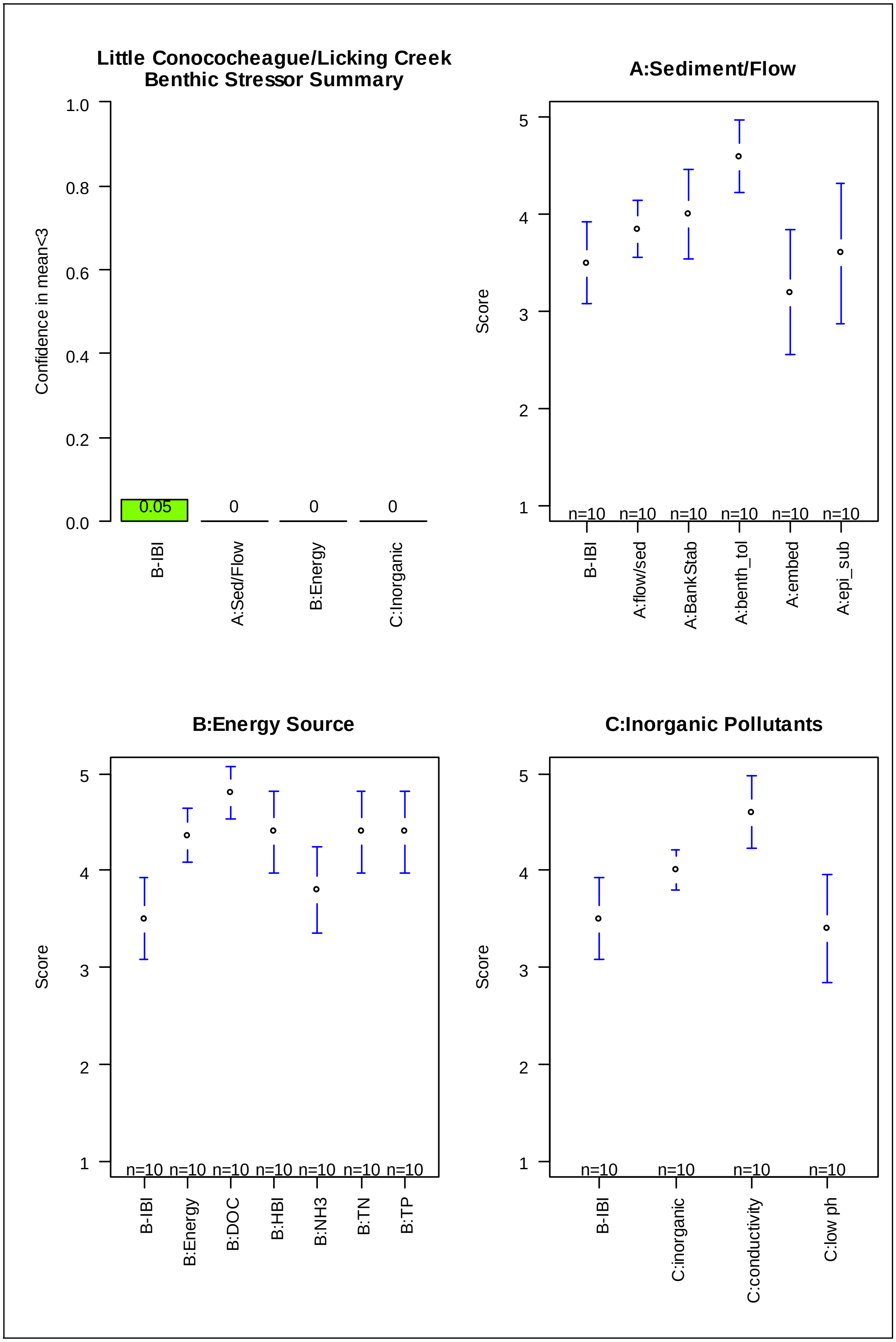


Figure F-9: Little Conococheague/Licking Creek Benthic Stressor Results

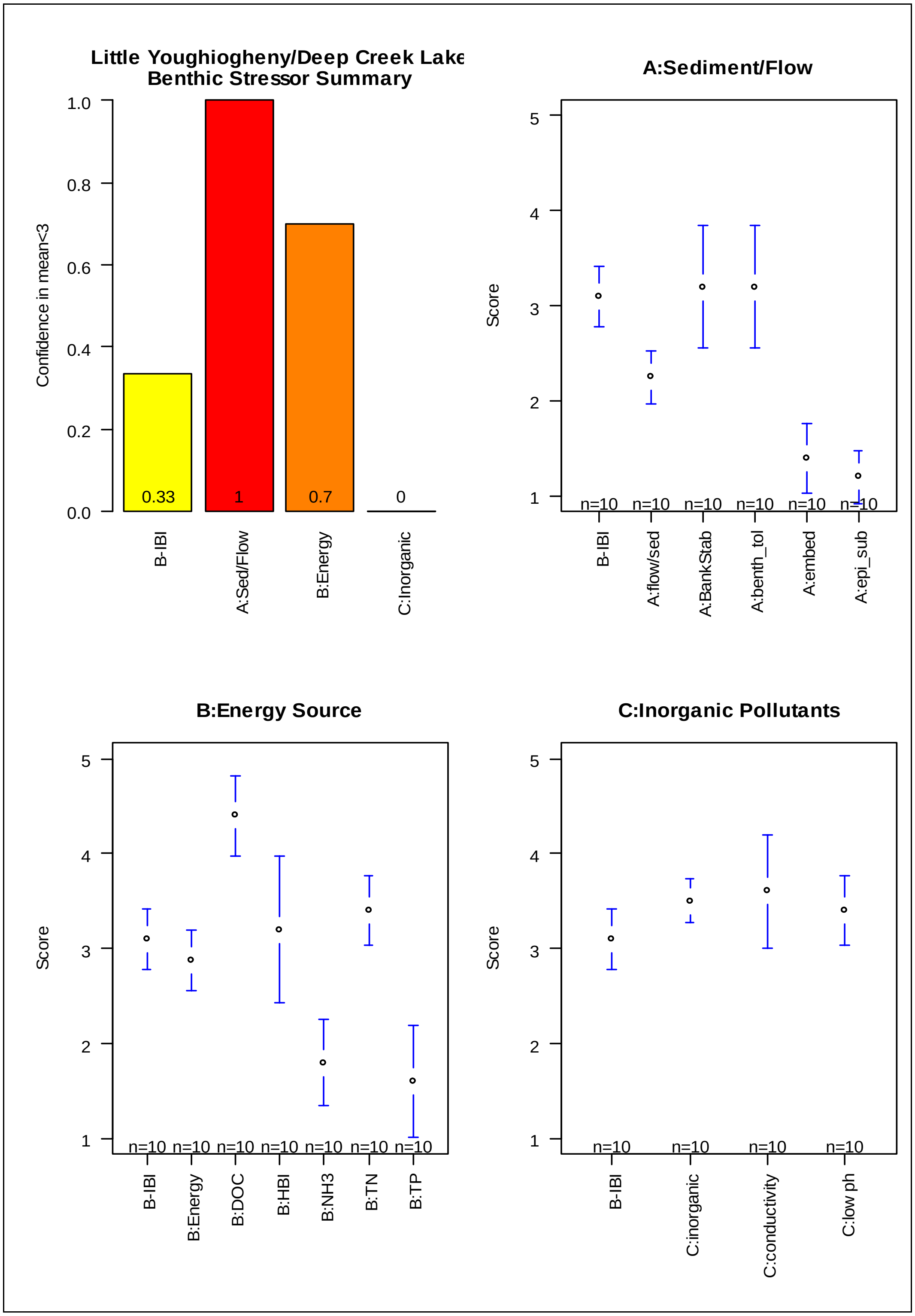


Figure F-10: Little Youghiogheny/Deep Creek Lake Benthic Stressor Results

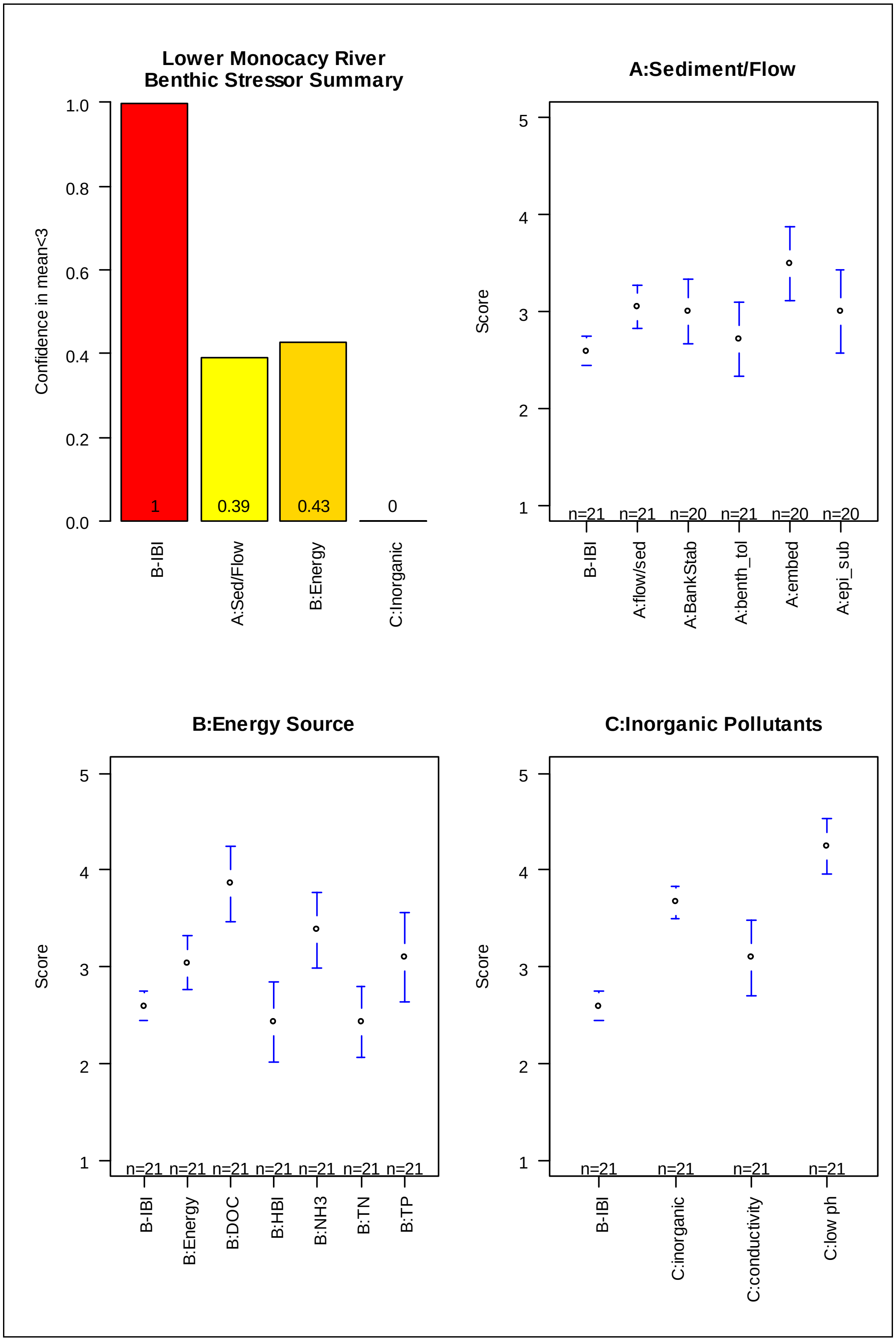


Figure F-11: Lower Monocacy River Benthic Stressor Results

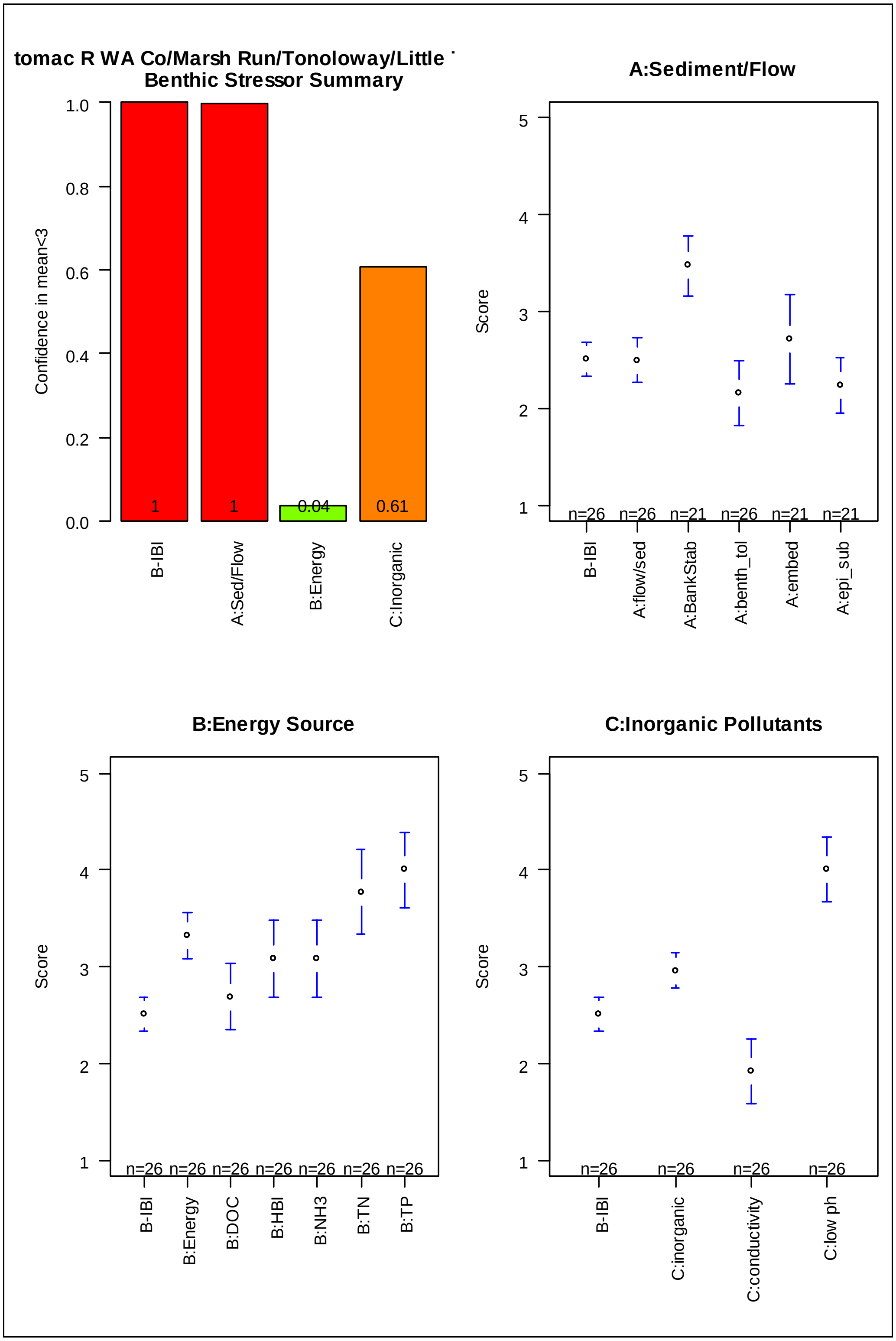


Figure F-12: Potomac River WA County/Marsh Run/Tonoloway/Little Tonoloway Benthic Stressor Results

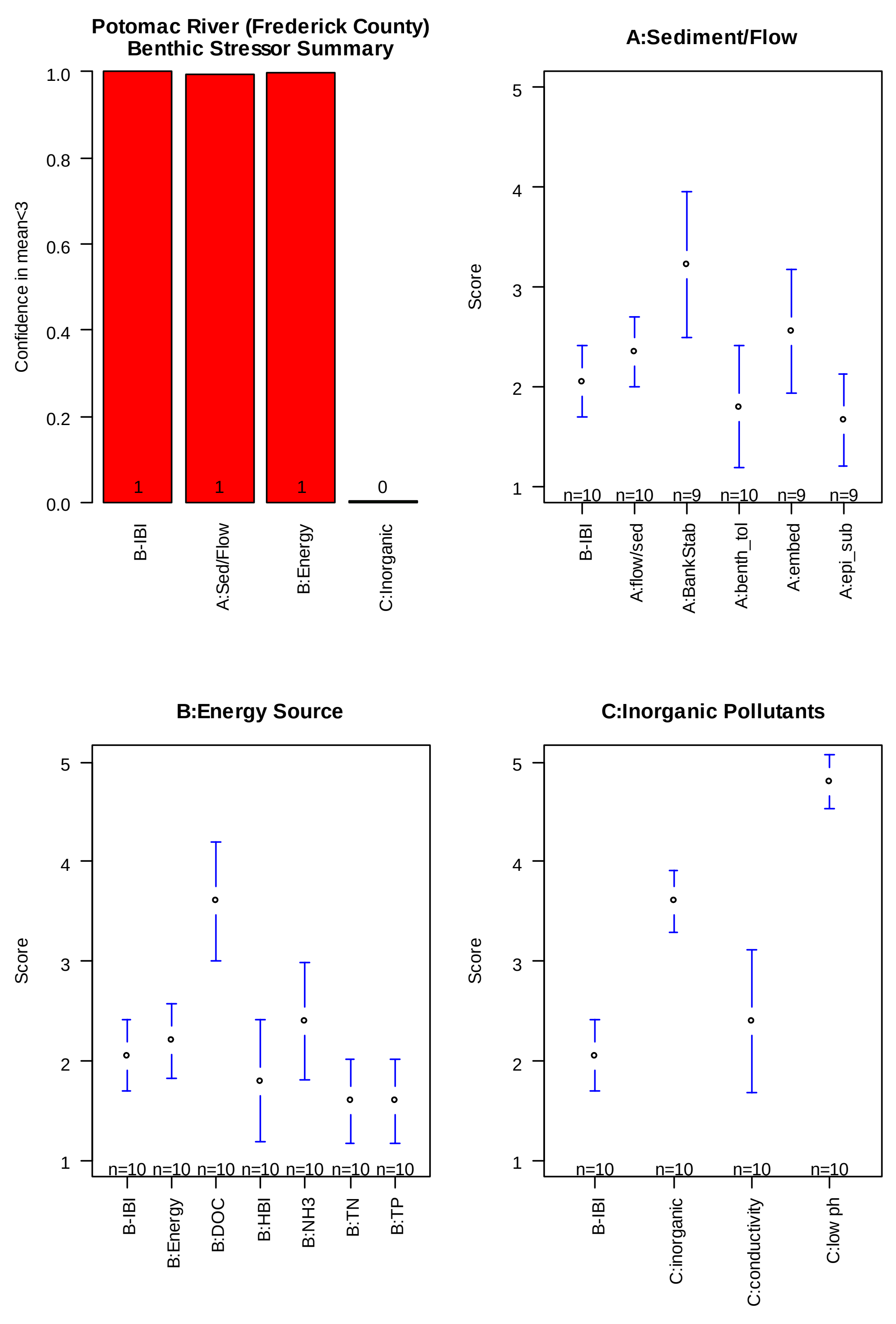


Figure F-13: Potomac River Frederick County Benthic Stressor Results

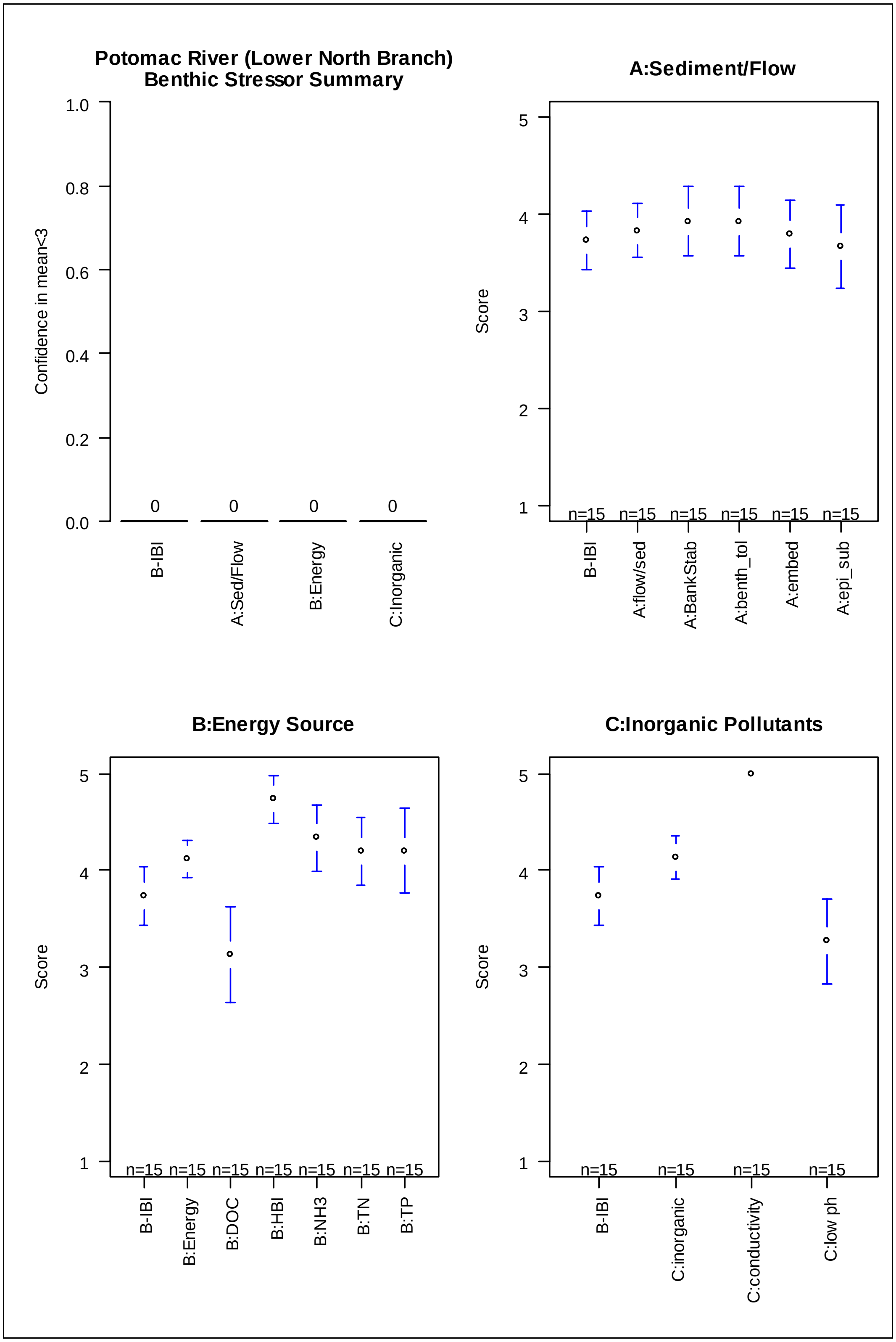


Figure F-14: Potomac River Lower North Branch Benthic Stressor Results

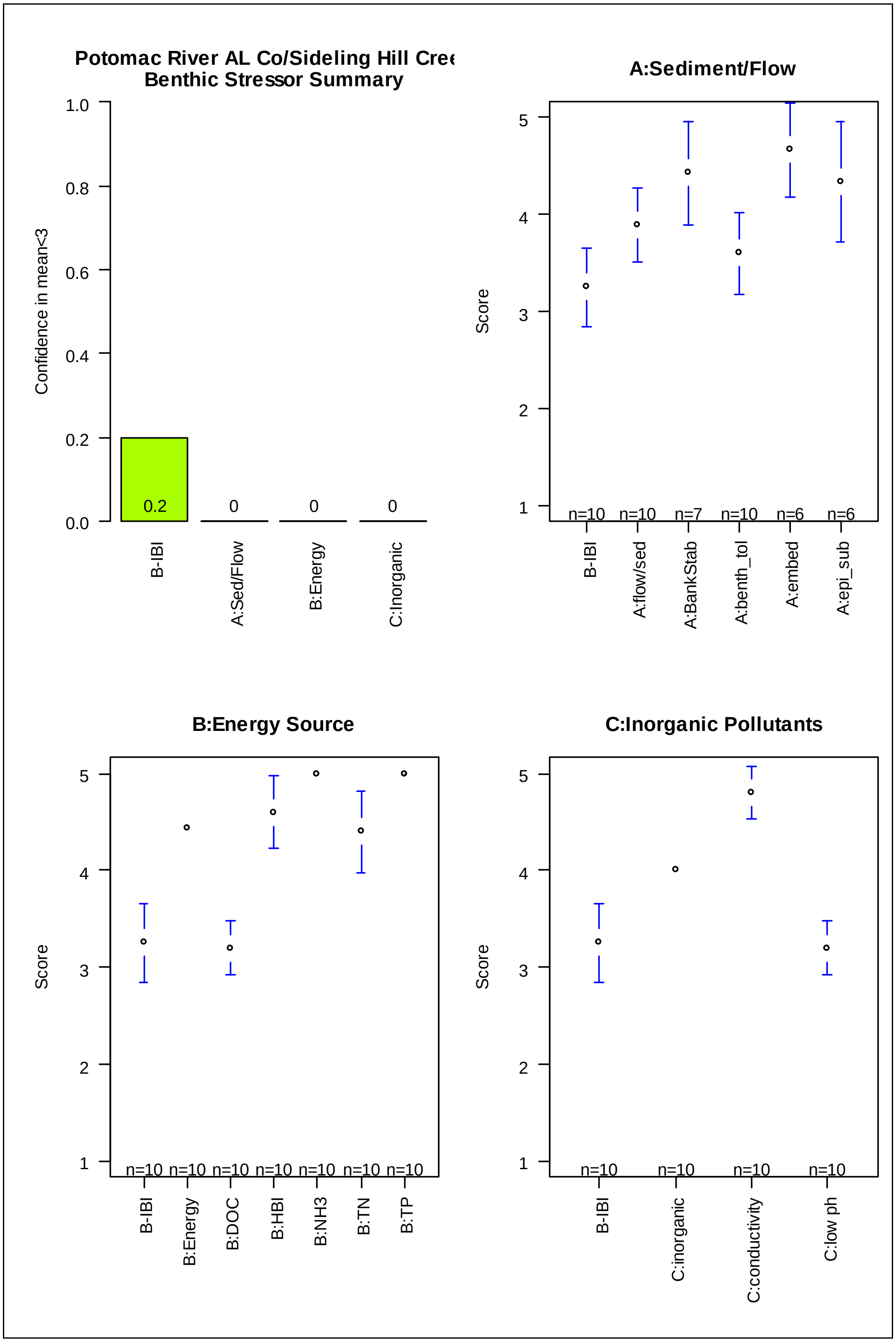


Figure F-15: Potomac River AL County/Sideling Hill Creek Benthic Stressor Results

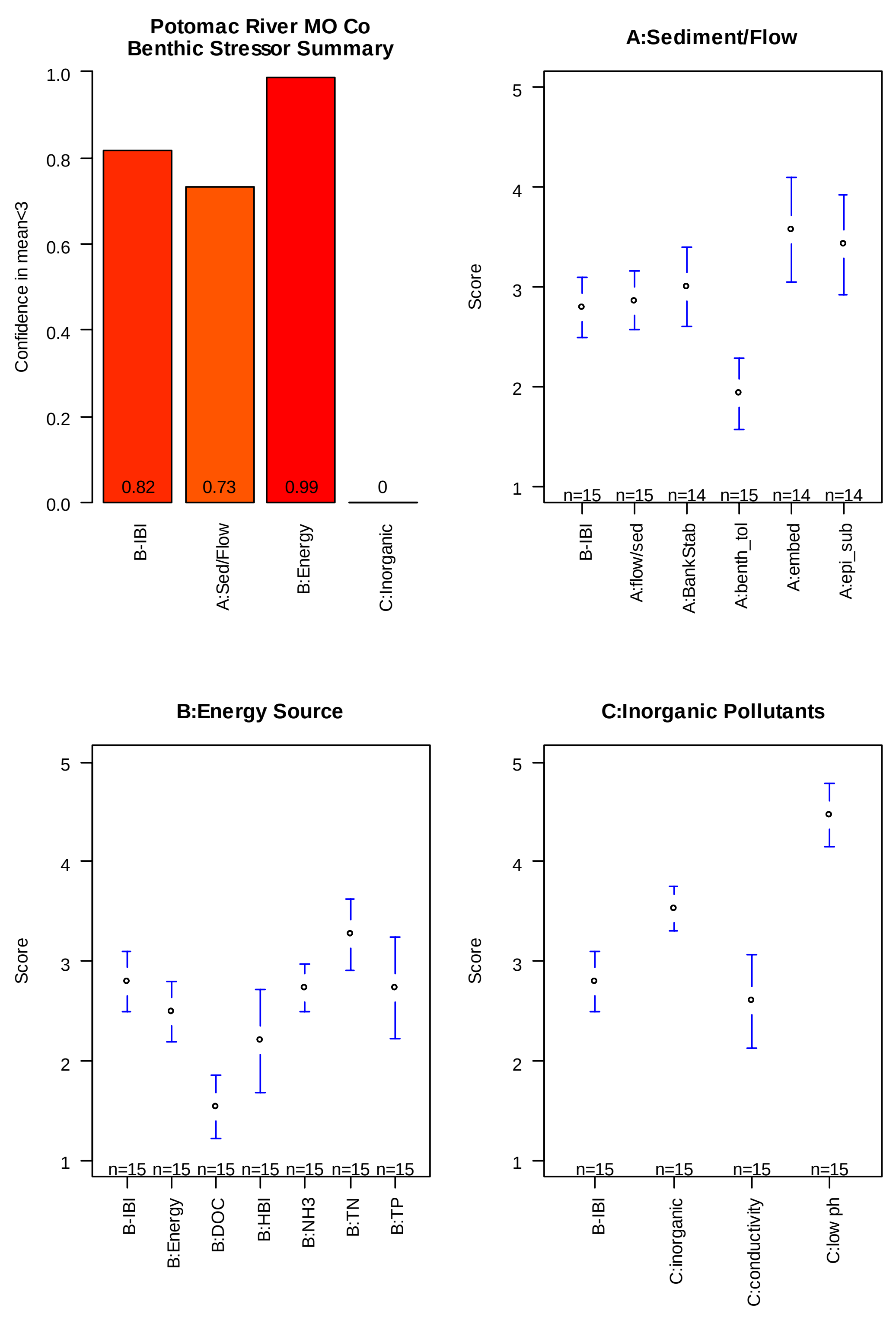


Figure F-16: Potomac River MO County Benthic Stressor Results

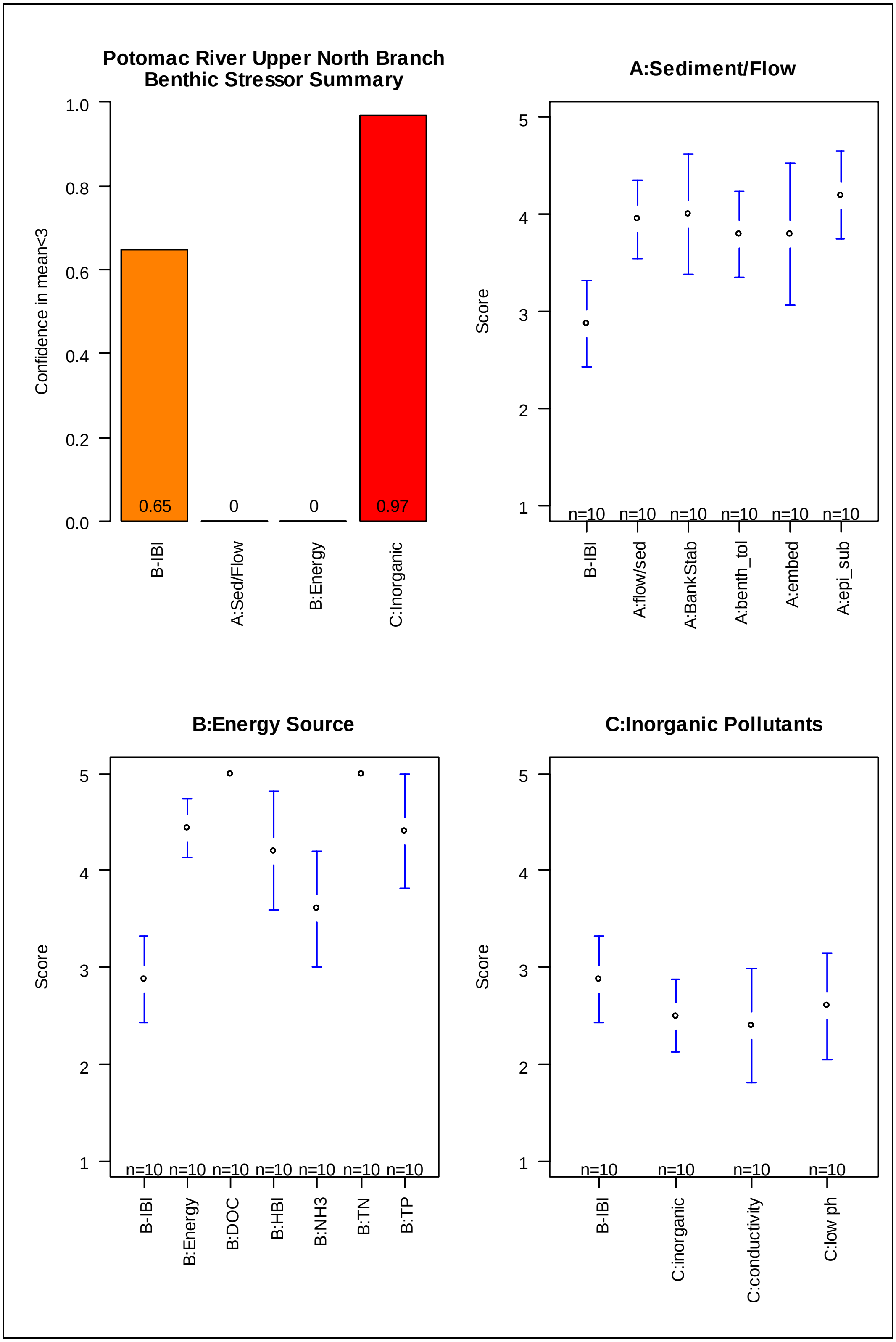


Figure F-17: Potomac River Upper North Branch Benthic Stressor Results

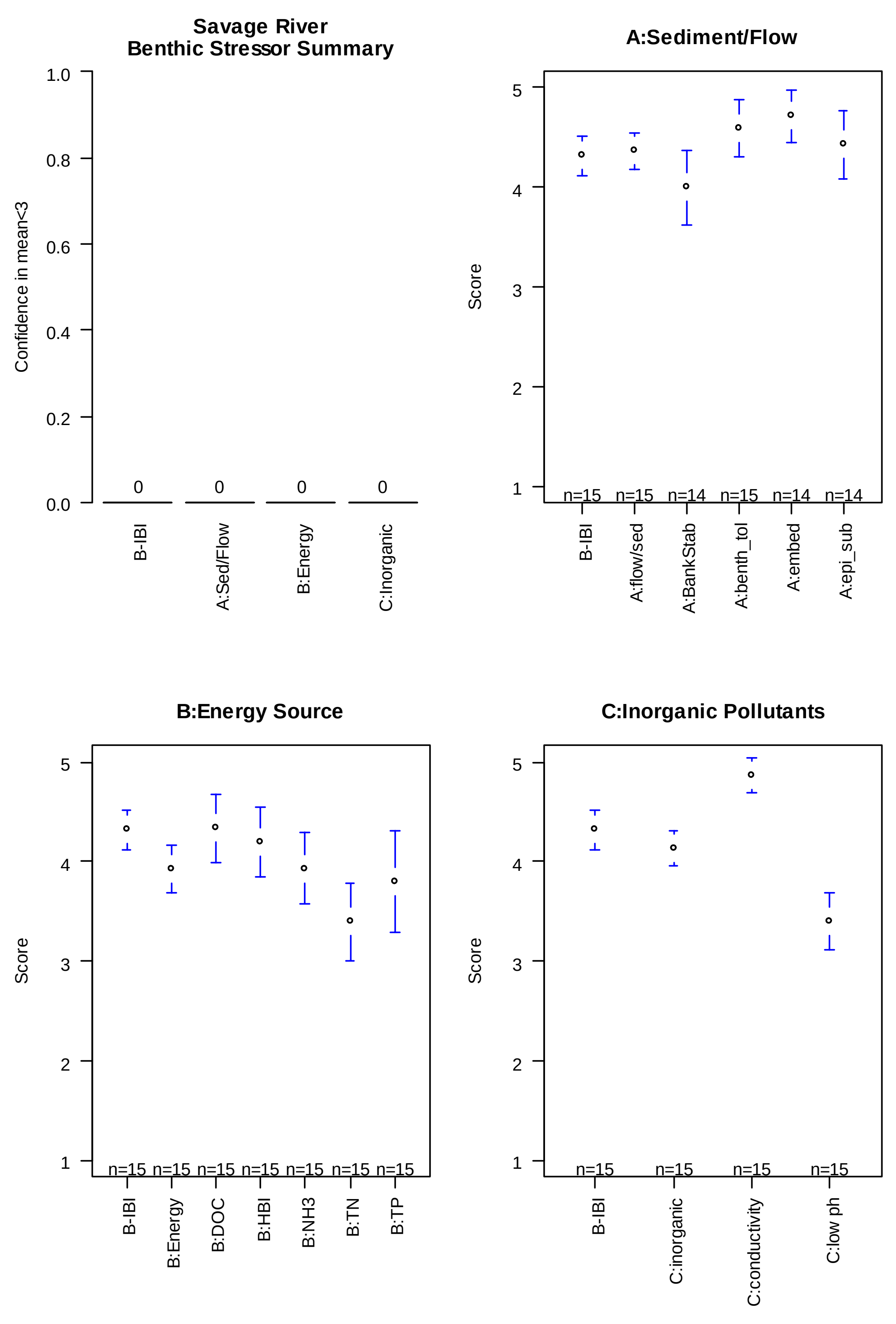


Figure F-18: Savage River Benthic Stressor Results

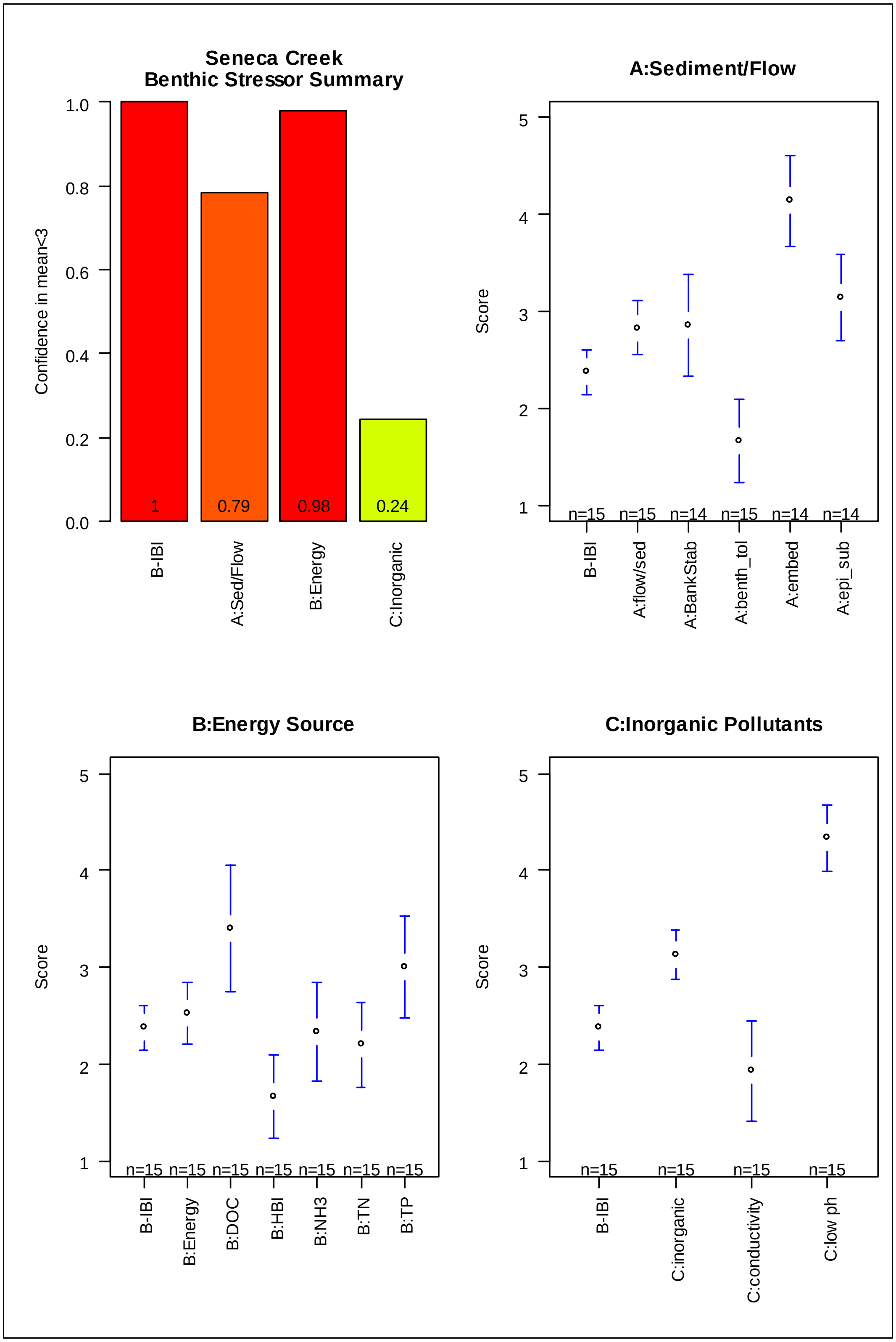


Figure F-19: Seneca Creek Benthic Stressor Results

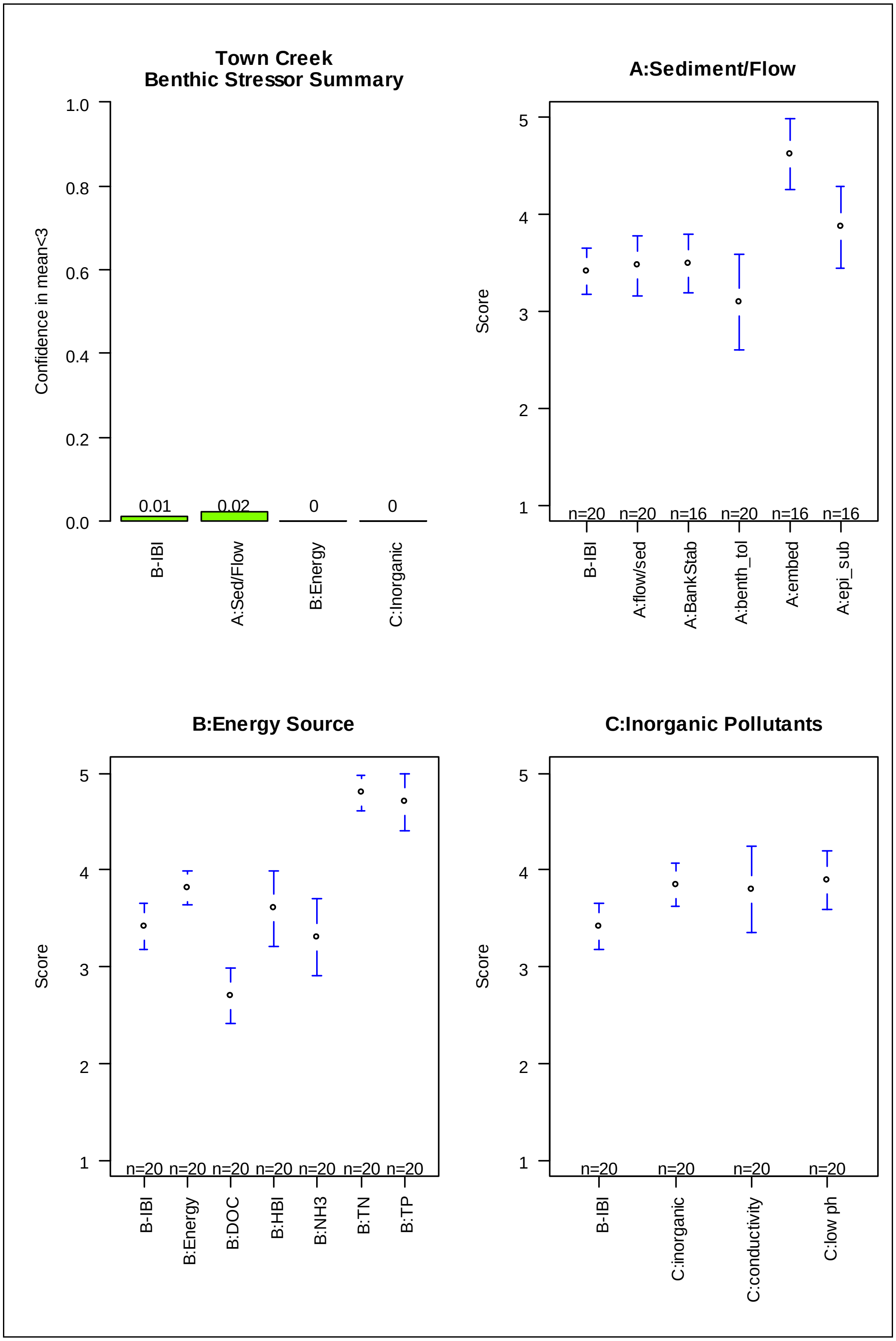


Figure F-20: Town Creek Benthic Stressor Results

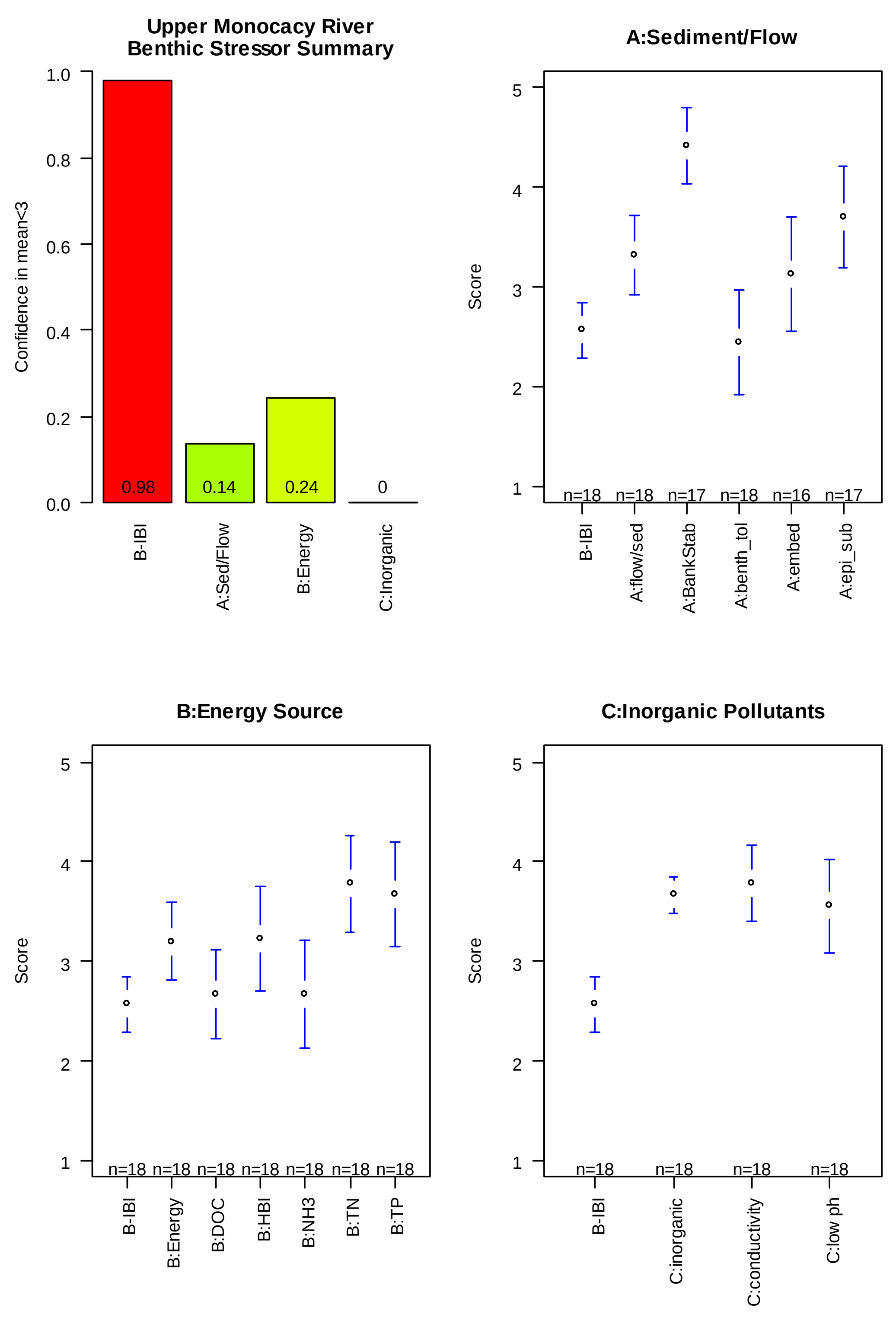


Figure F-21: Upper Monocacy River Benthic Stressor Results

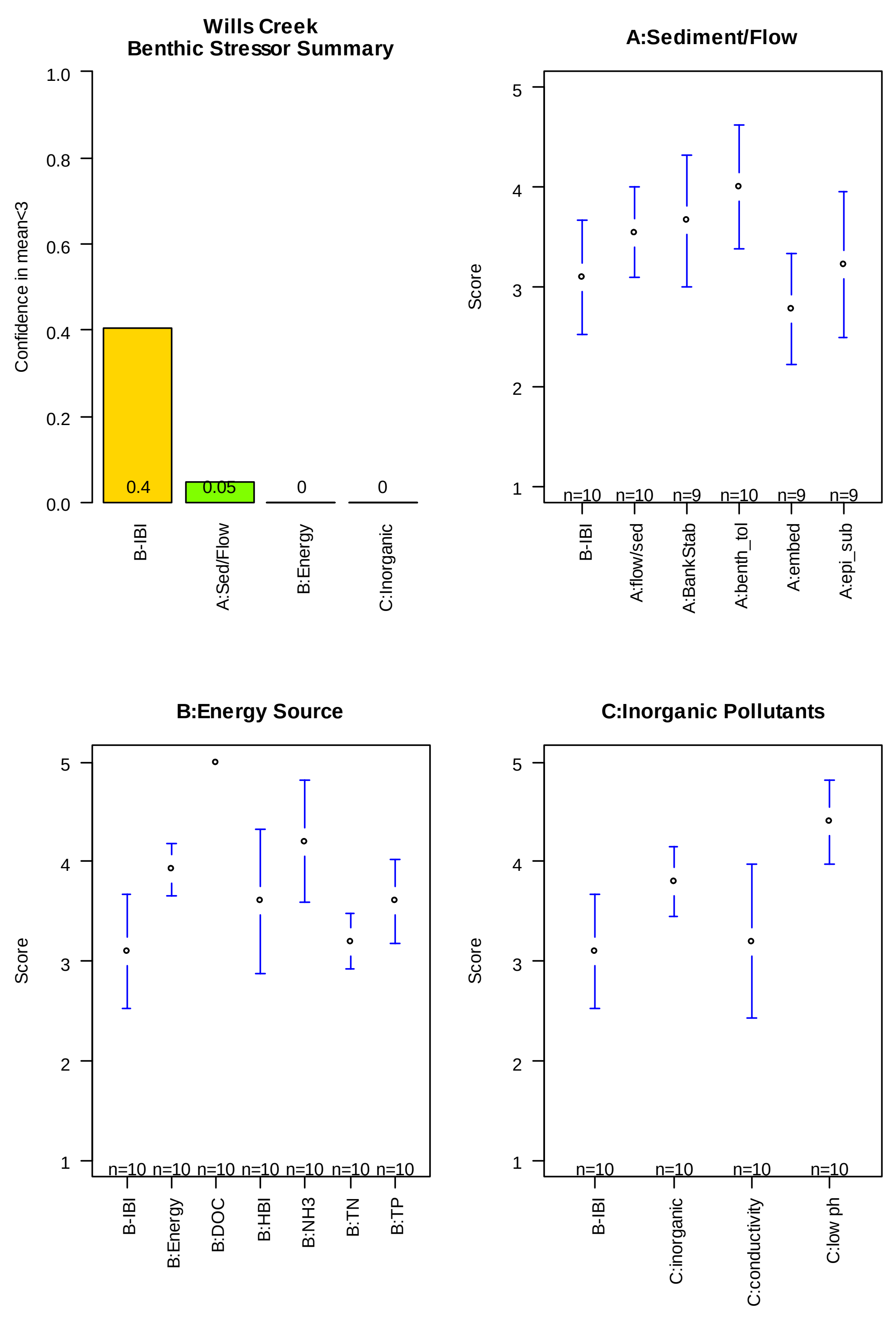


Figure F-22: Wills Creek Benthic Stressor Results

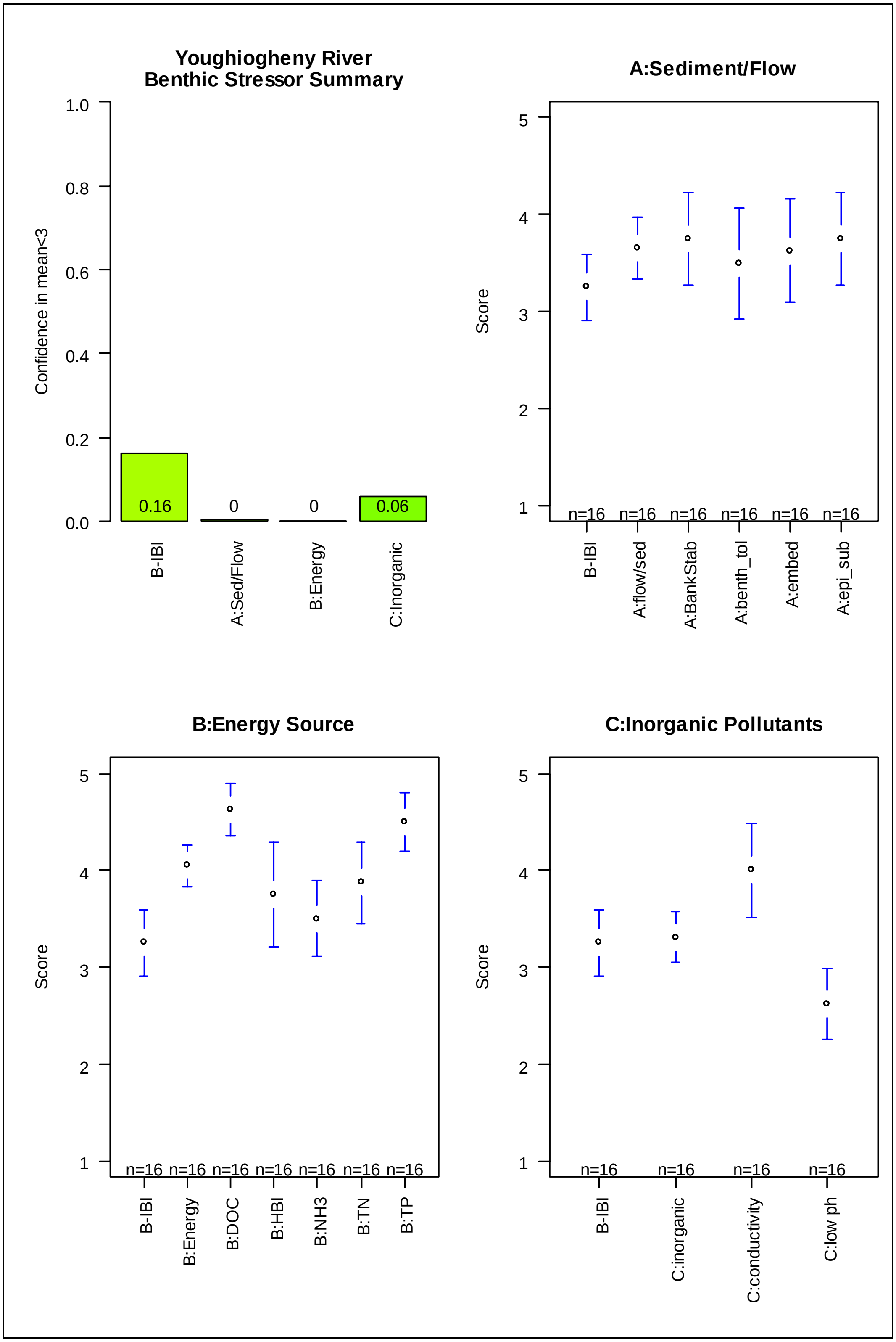


Figure F-23: Youghiogheny River Benthic Stressor Results

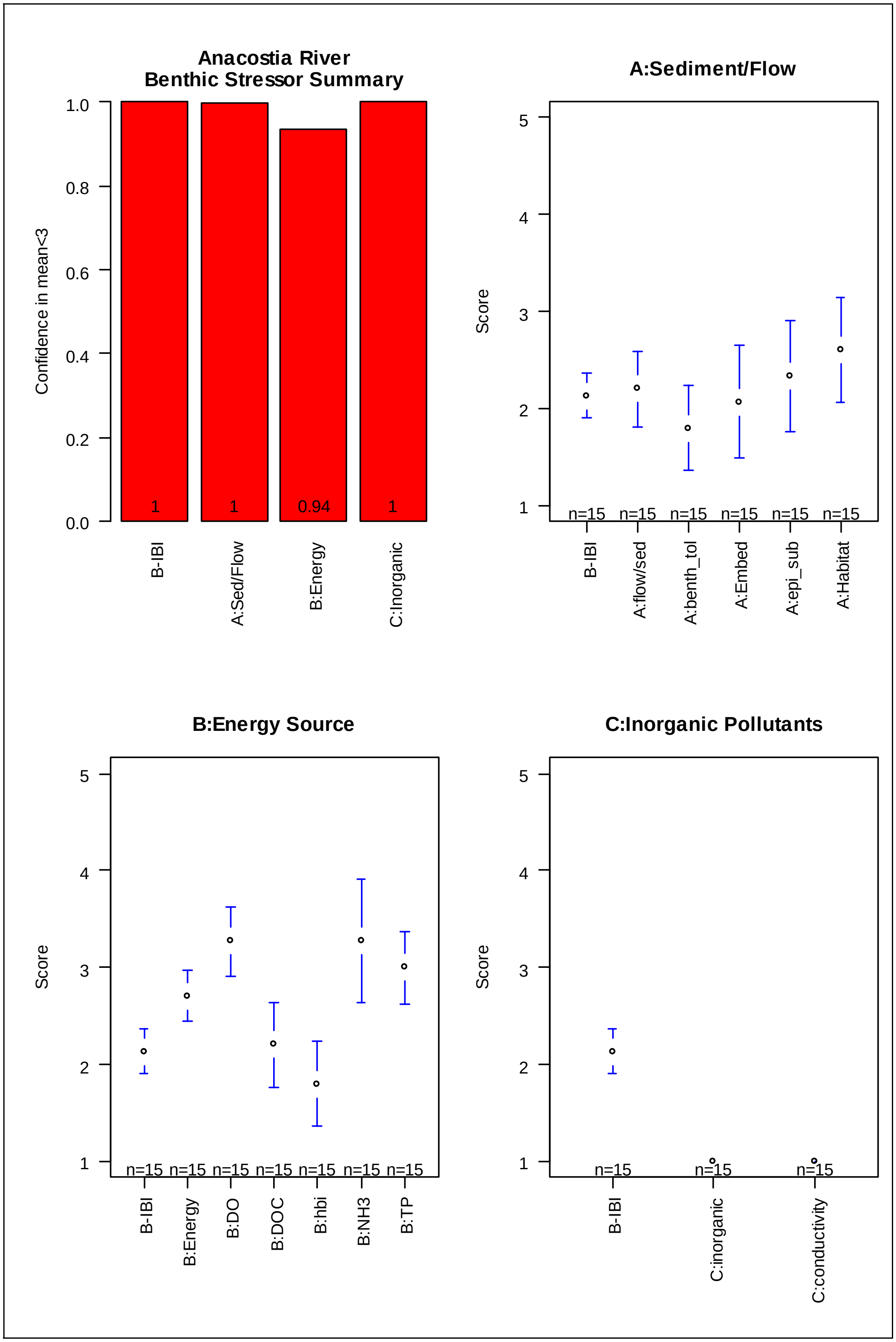


Figure F-24: Anacostia River Benthic Stressor Results

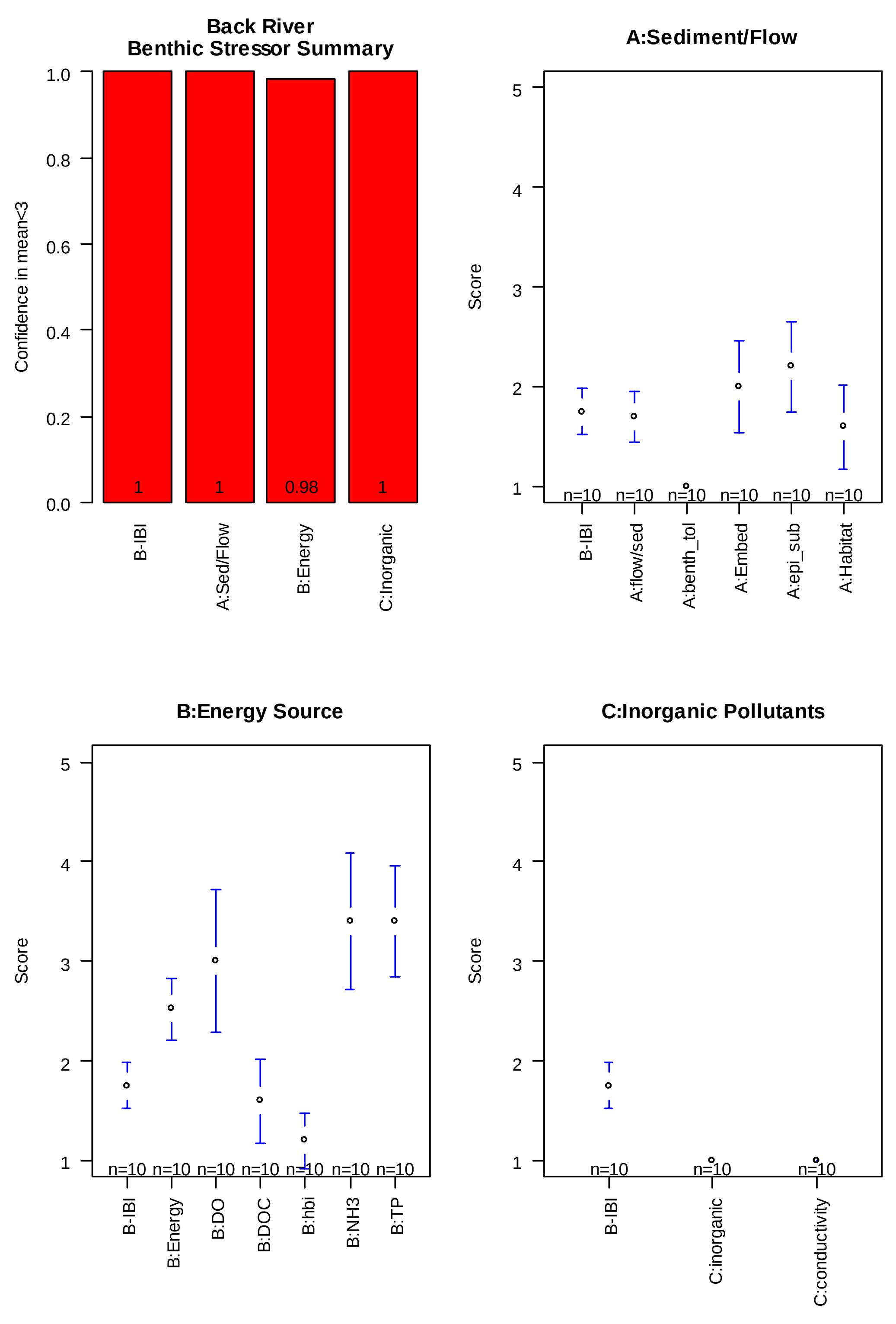


Figure F-25: Back River Benthic Stressor Results

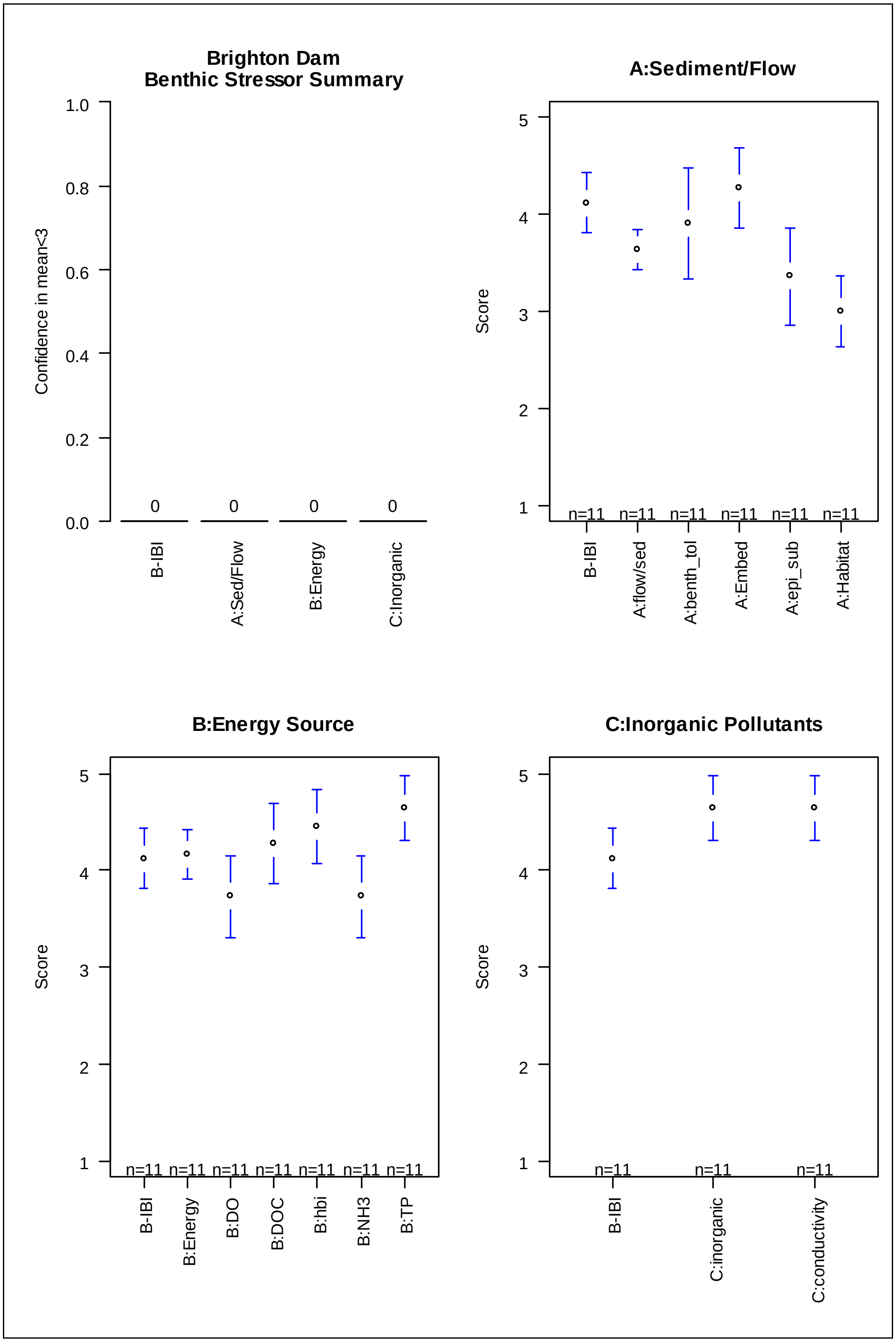


Figure F-26: Brighton Dam Benthic Stressor Results

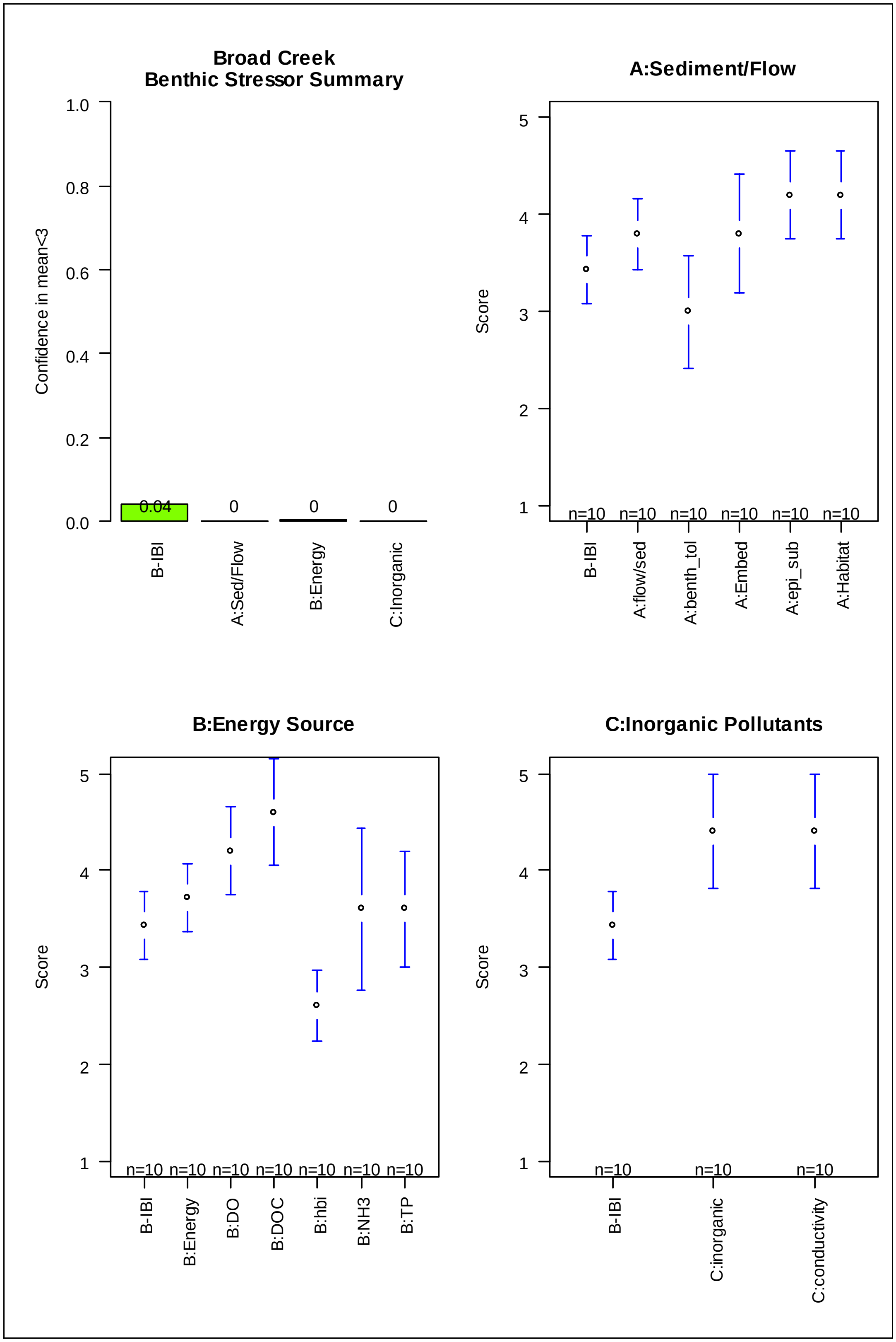


Figure F-27: Broad Creek Benthic Stressor Results

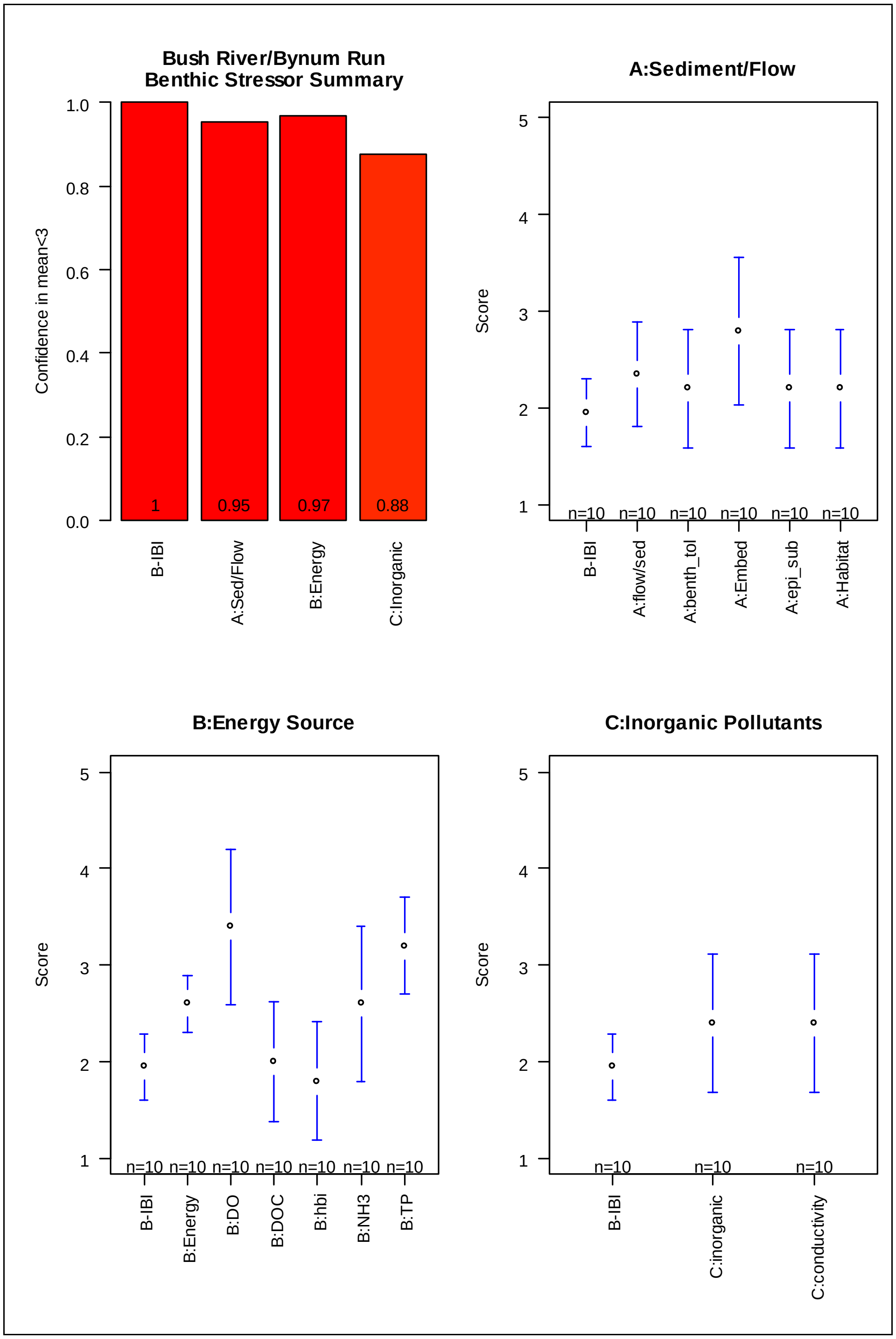


Figure F-28: Bush River/Bynum Run Benthic Stressor Results

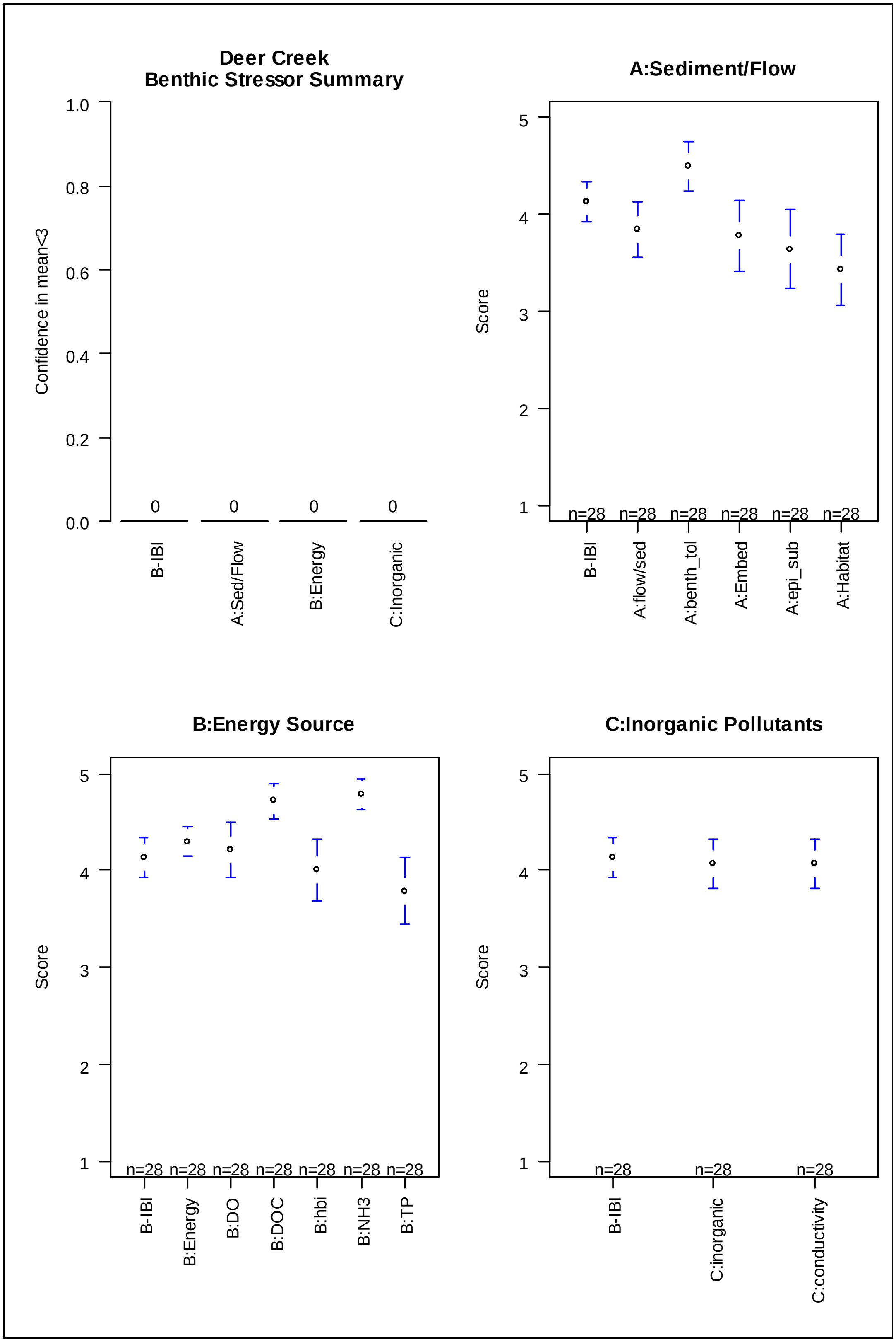


Figure F-29: Deer Creek Benthic Stressor Results

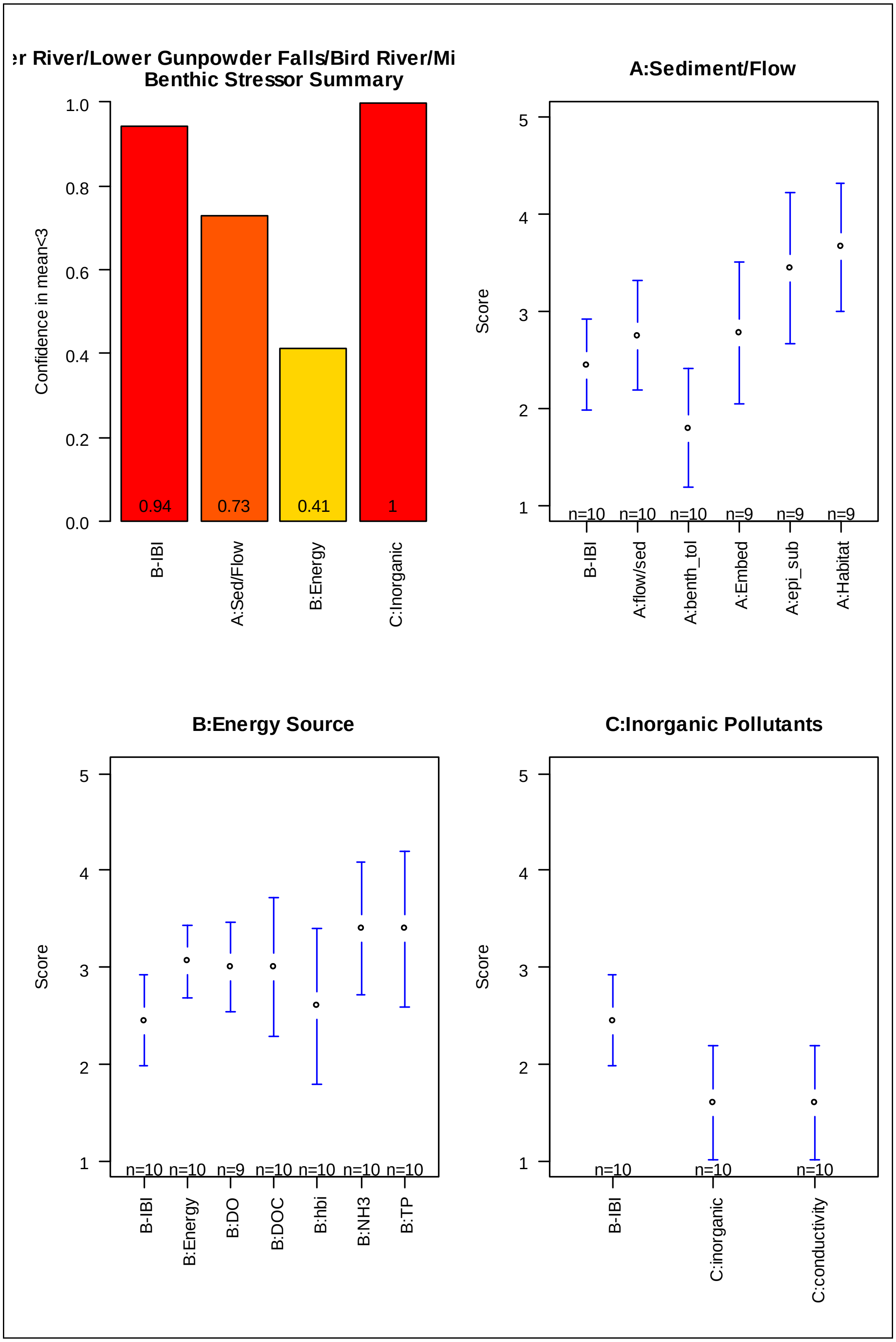


Figure F-30: Gunpowder River/Lower Gunpowder Falls/Bird River/Middle River Benthic Stressor Results

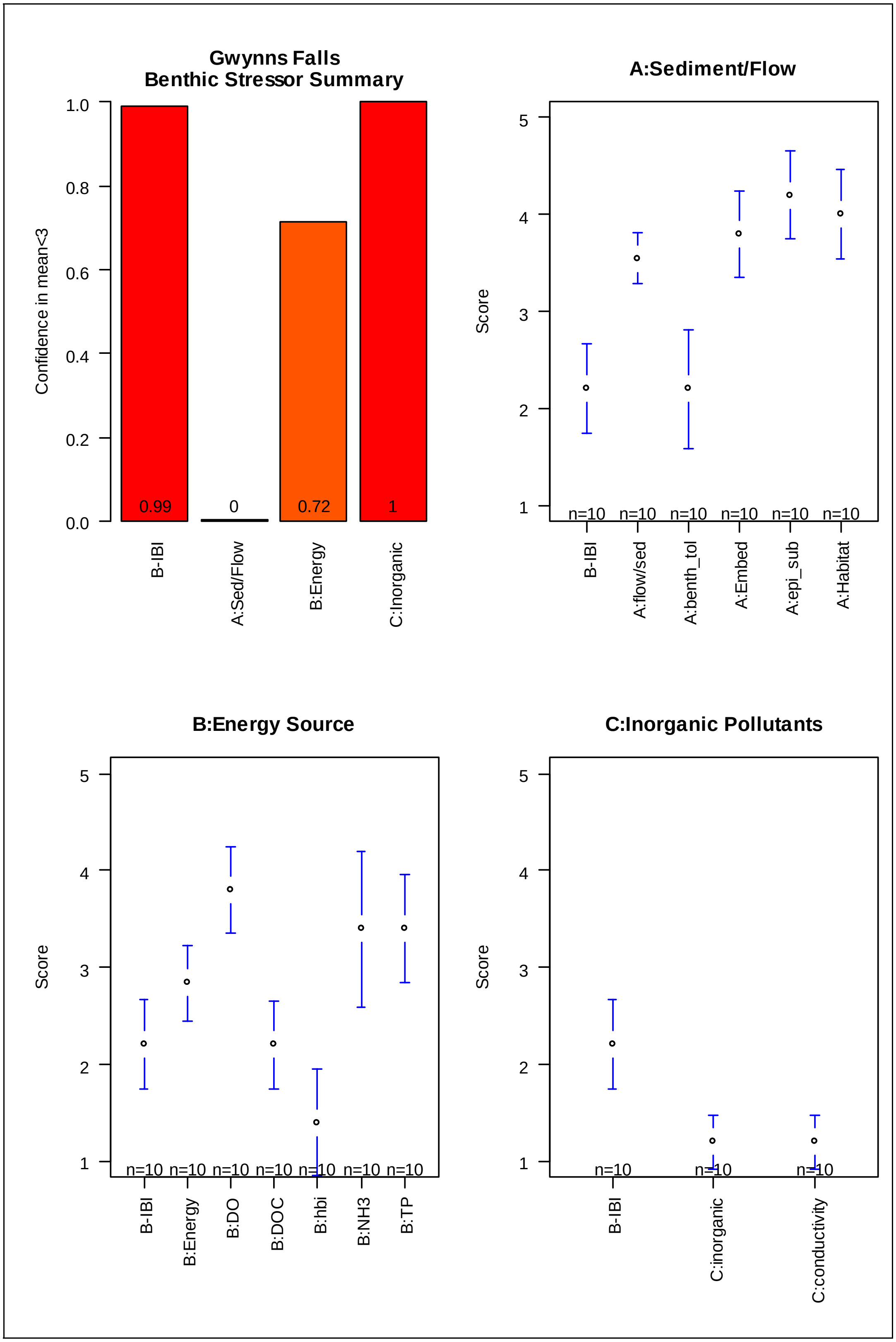


Figure F-31: Gwynns Falls Benthic Stressor Results

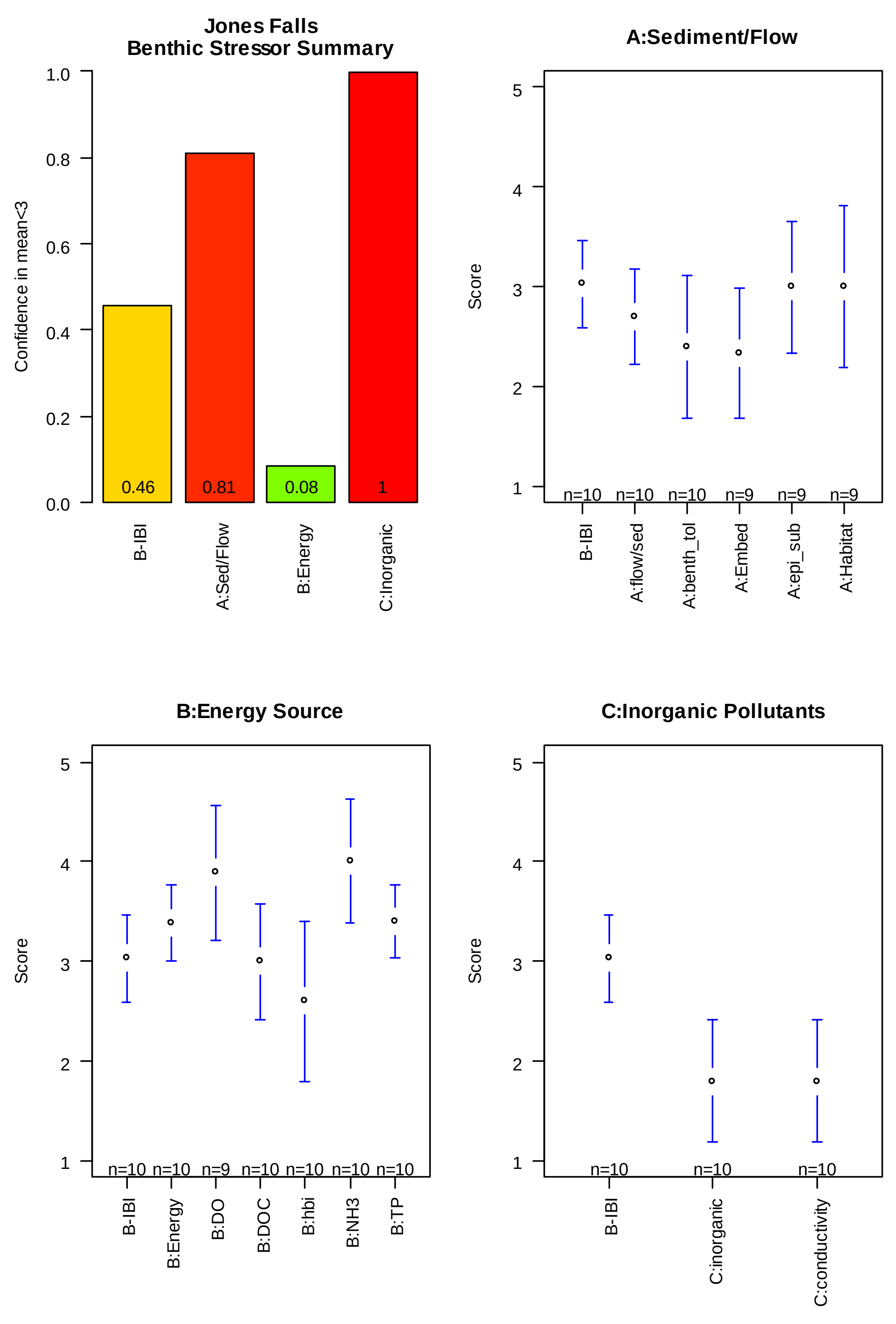


Figure F-32: Jones Falls Benthic Stressor Results

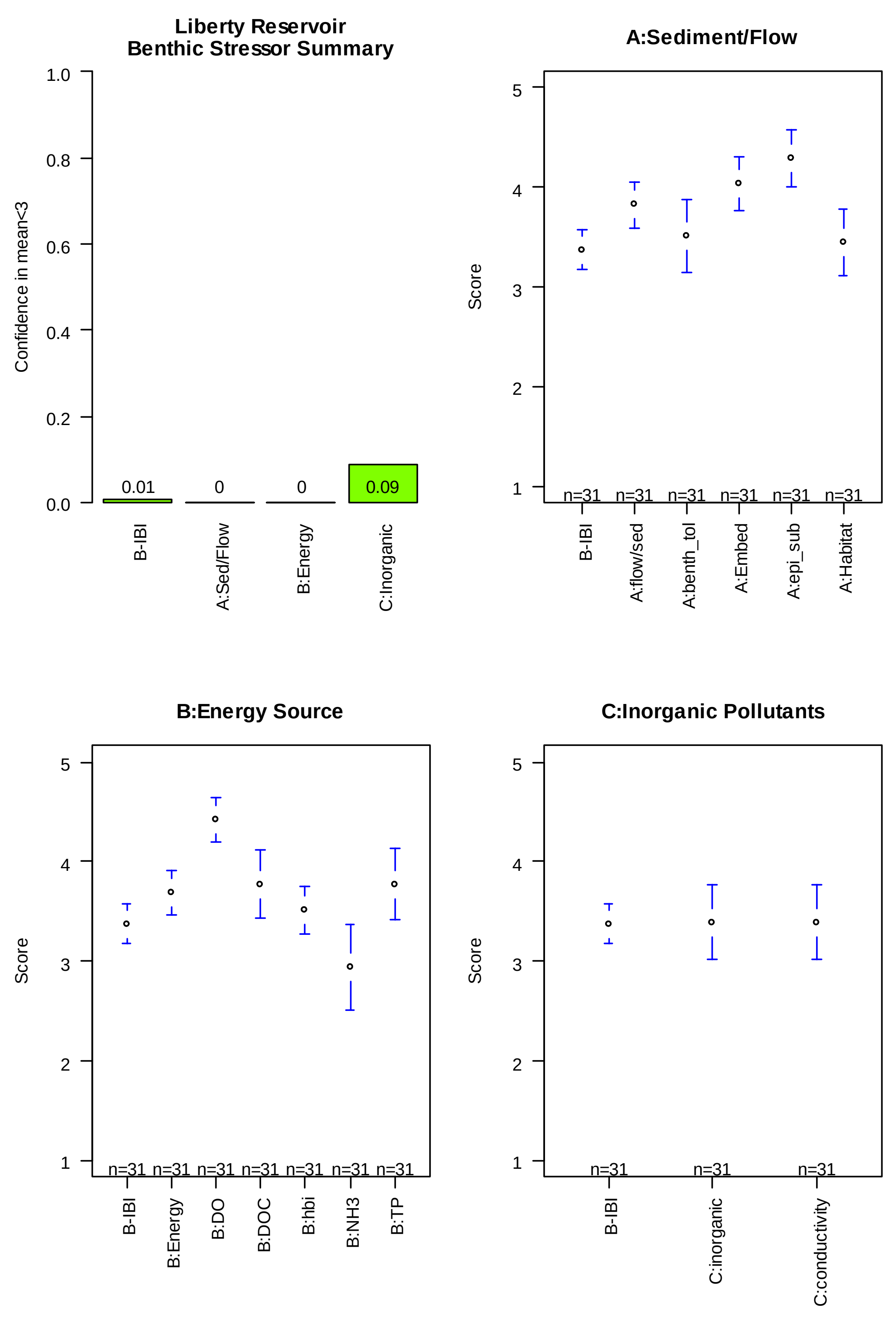


Figure F-33: Liberty Reservoir Benthic Stressor Results

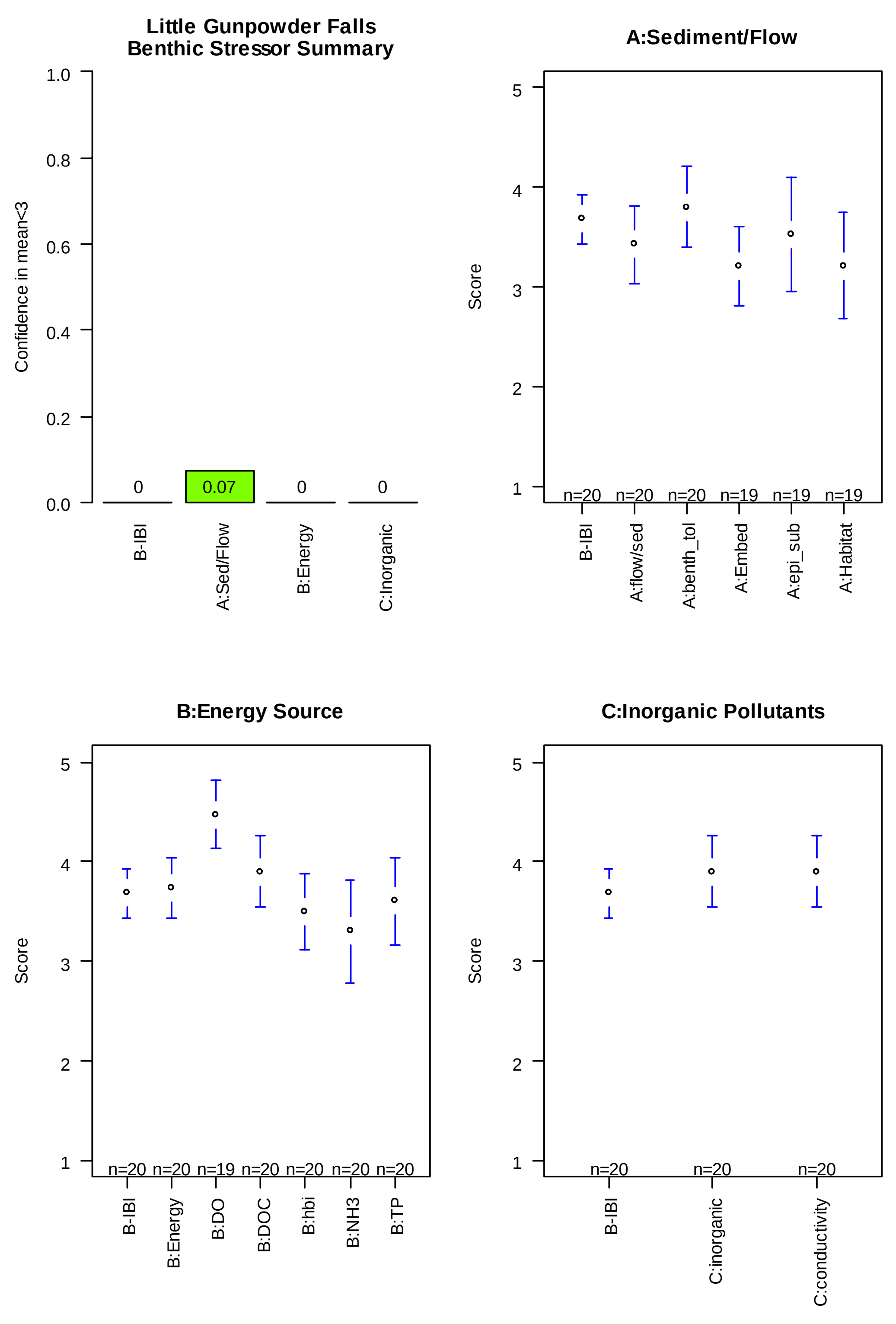


Figure F-34: Little Gunpowder Falls Benthic Stressor Results

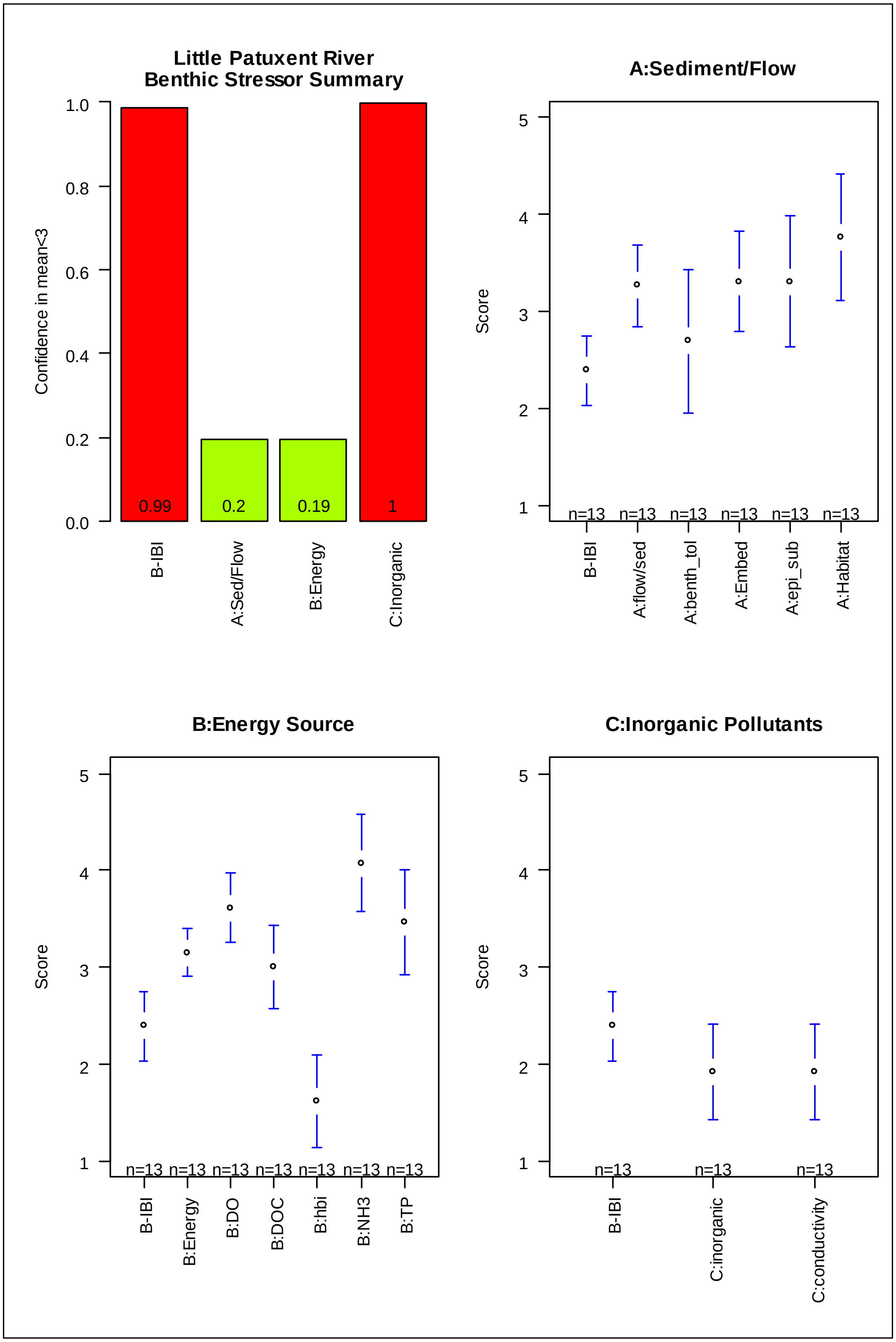


Figure F-35: Little Patuxent River Benthic Stressor Results

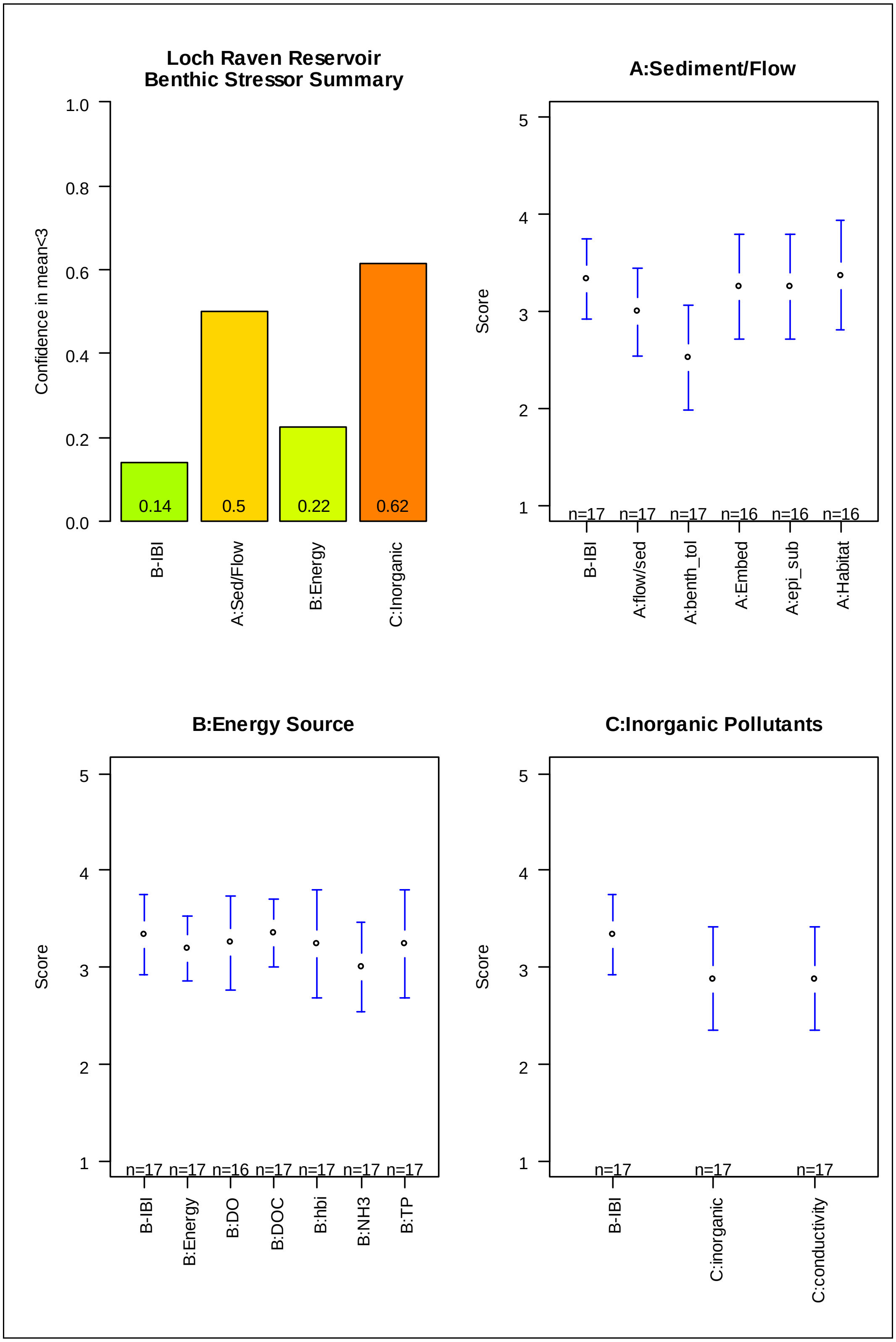


Figure F-36: Loch Raven Reservoir Benthic Stressor Results

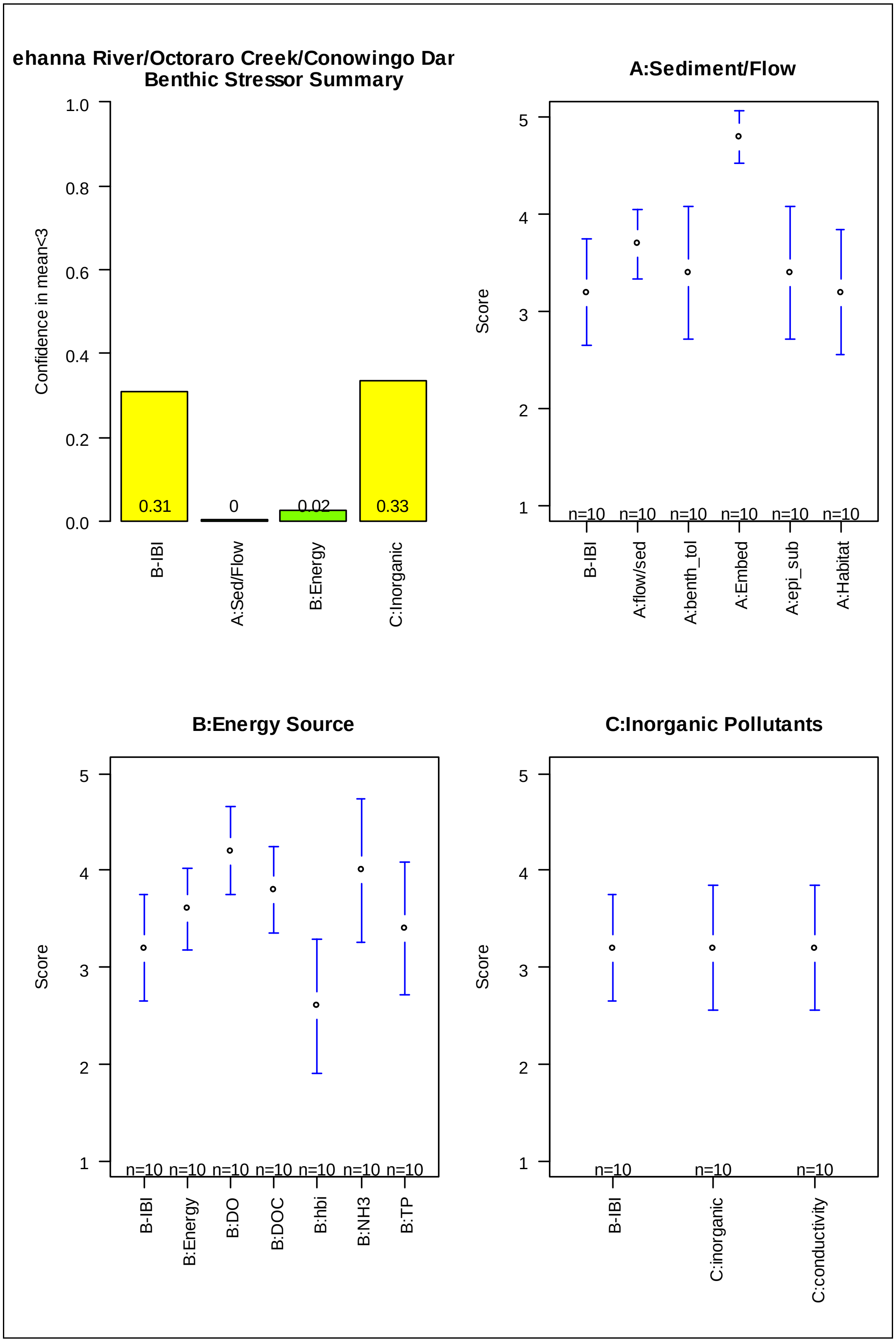


Figure F-37: Susquehanna River/Octoraro Creek/Conewago Dam Benthic Stressor Results

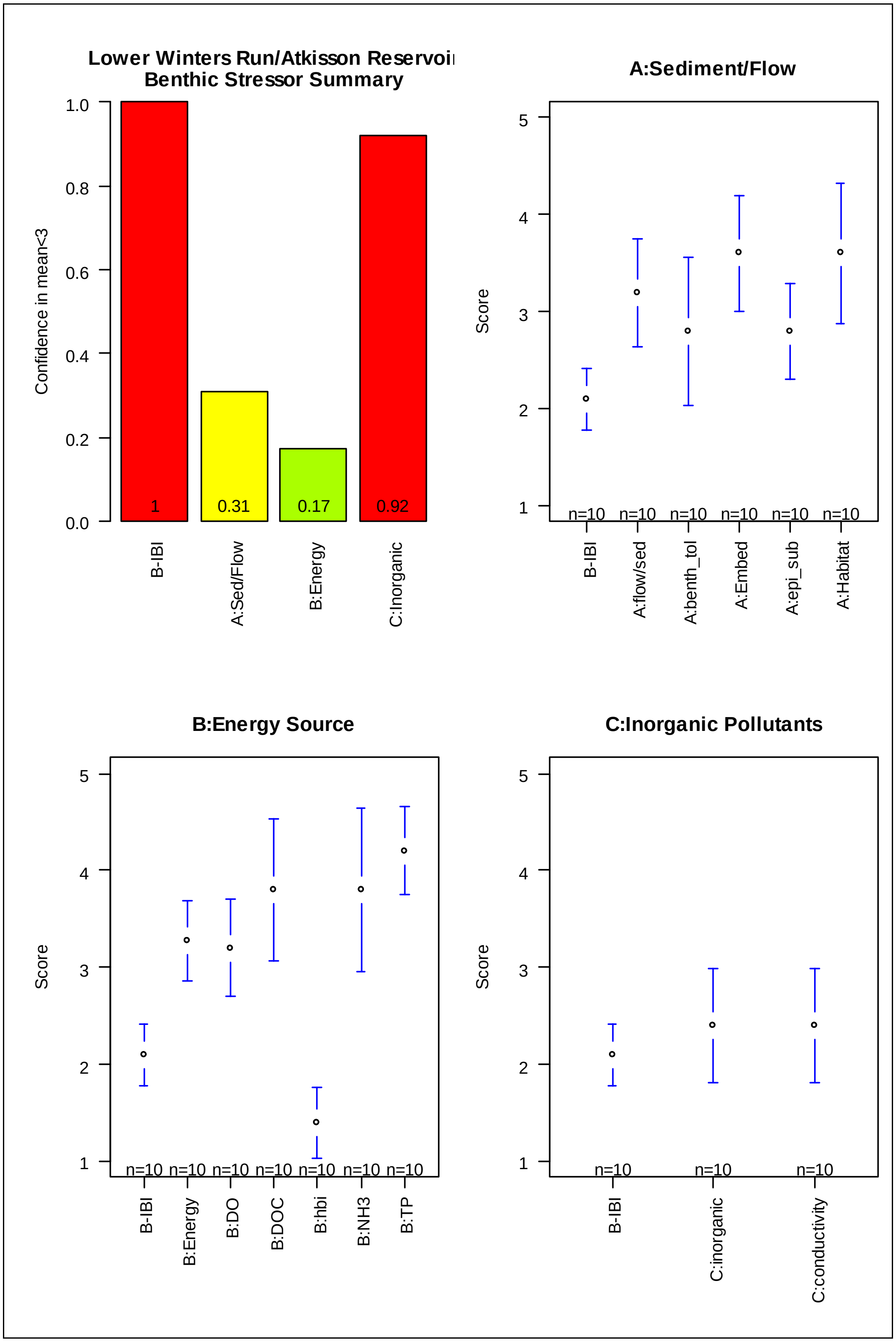


Figure F-38: Lower Winters Run/Atkisson Reservoir Benthic Stressor Results

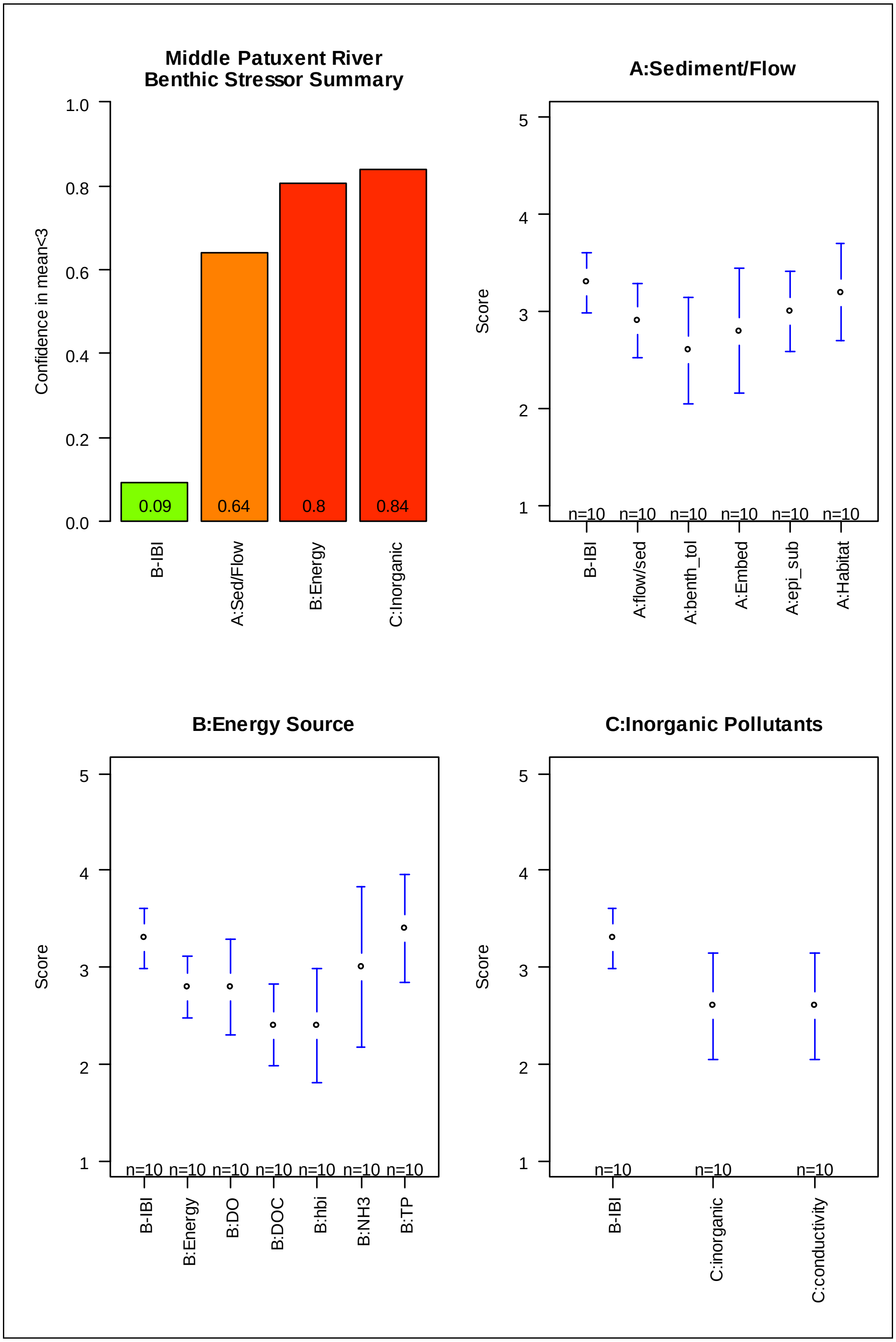


Figure F-39: Middle Patuxent River Benthic Stressor Results

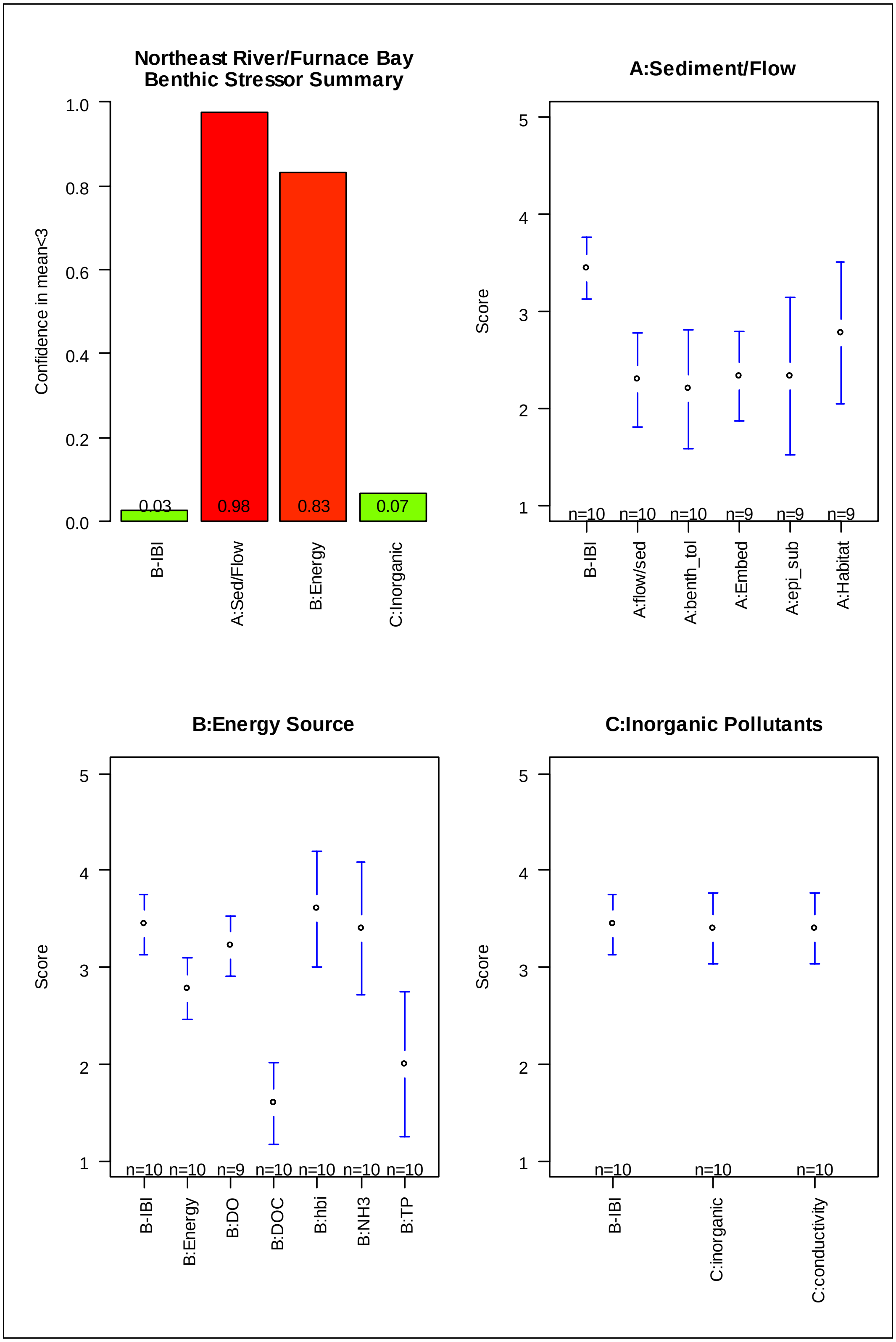


Figure F-40: Northeast River/Furnace Bay Benthic Stressor Results

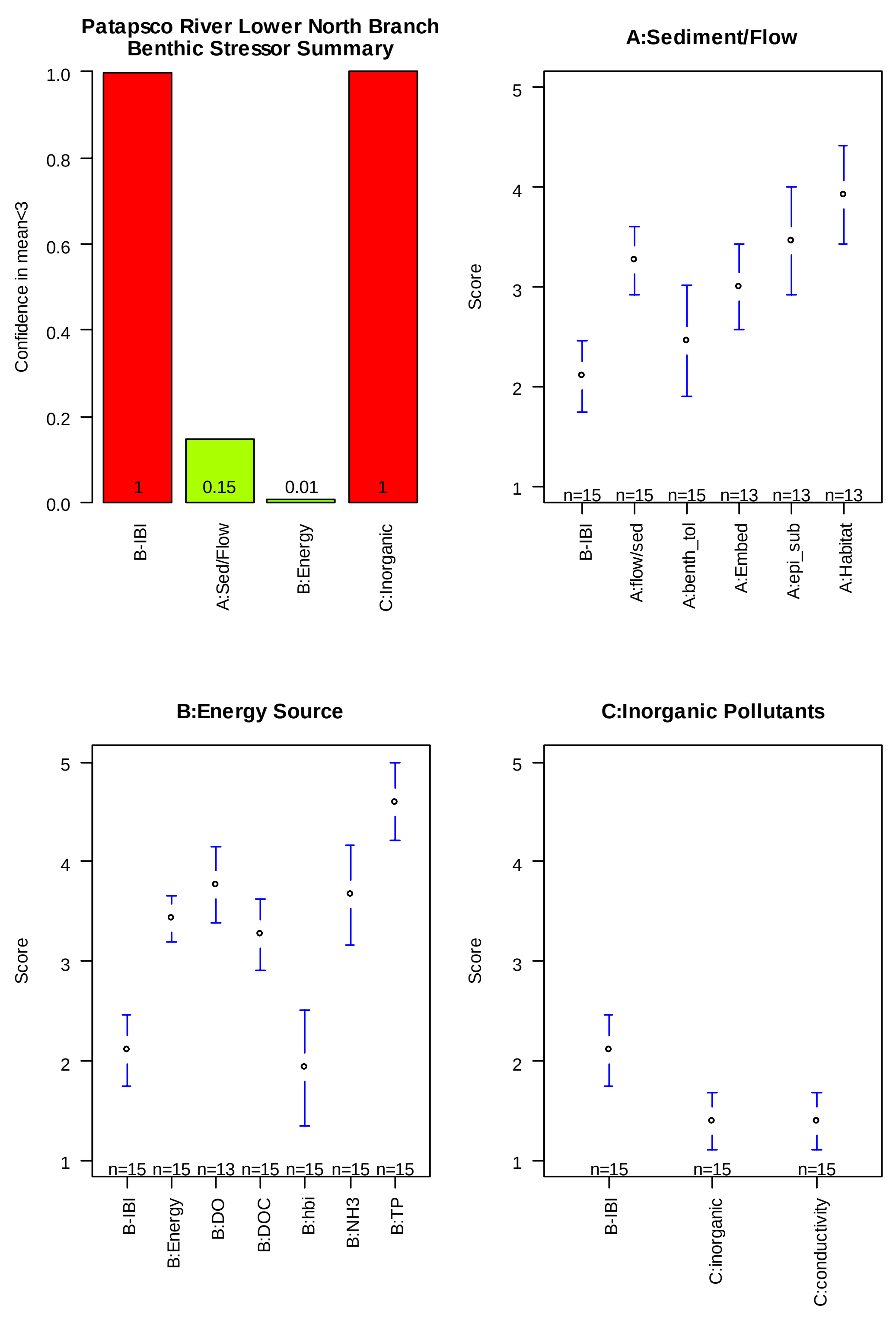


Figure F-41: Patapsco River Lower North Branch Benthic Stressor Results

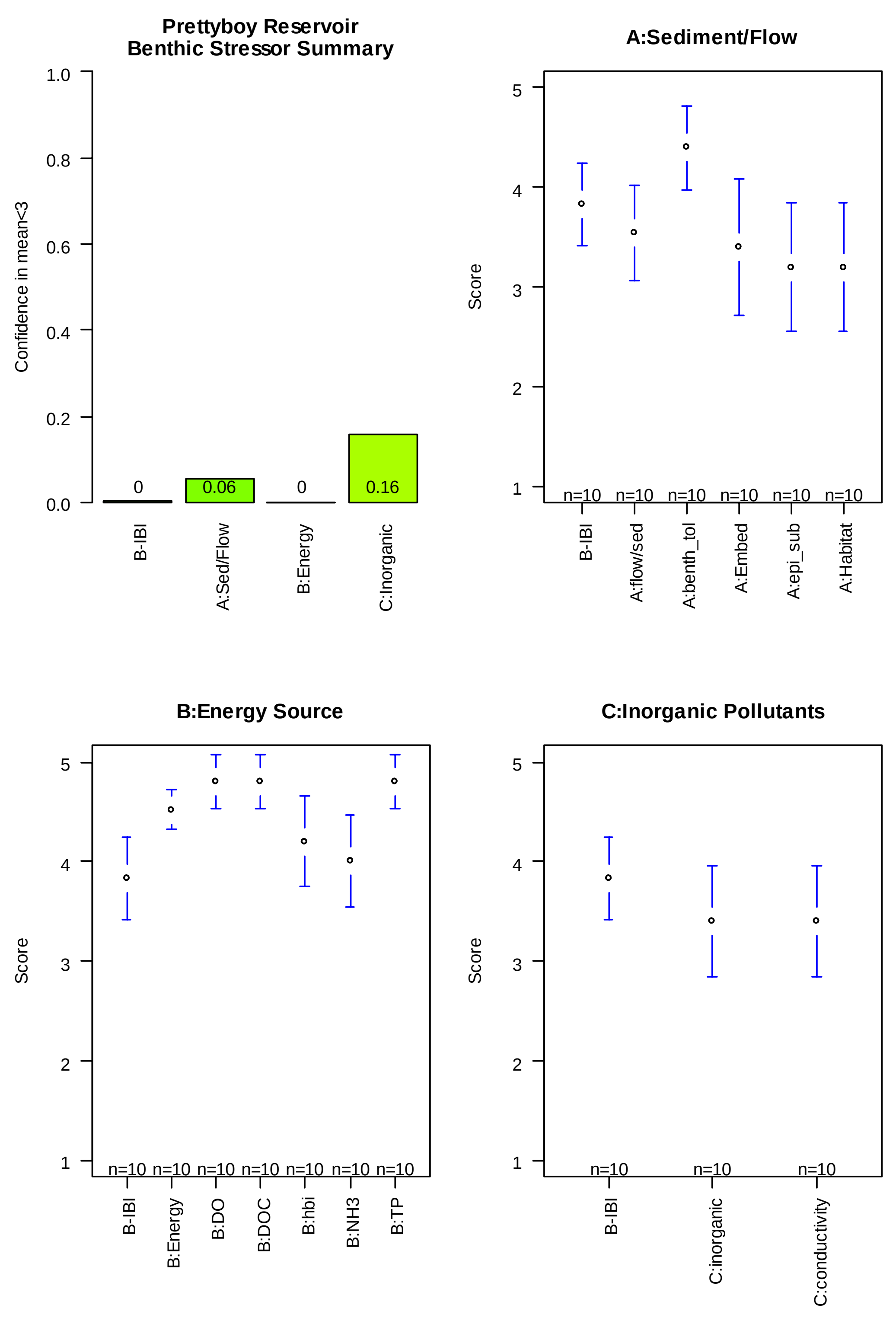


Figure F-42: Prettyboy Reservoir Benthic Stressor Results

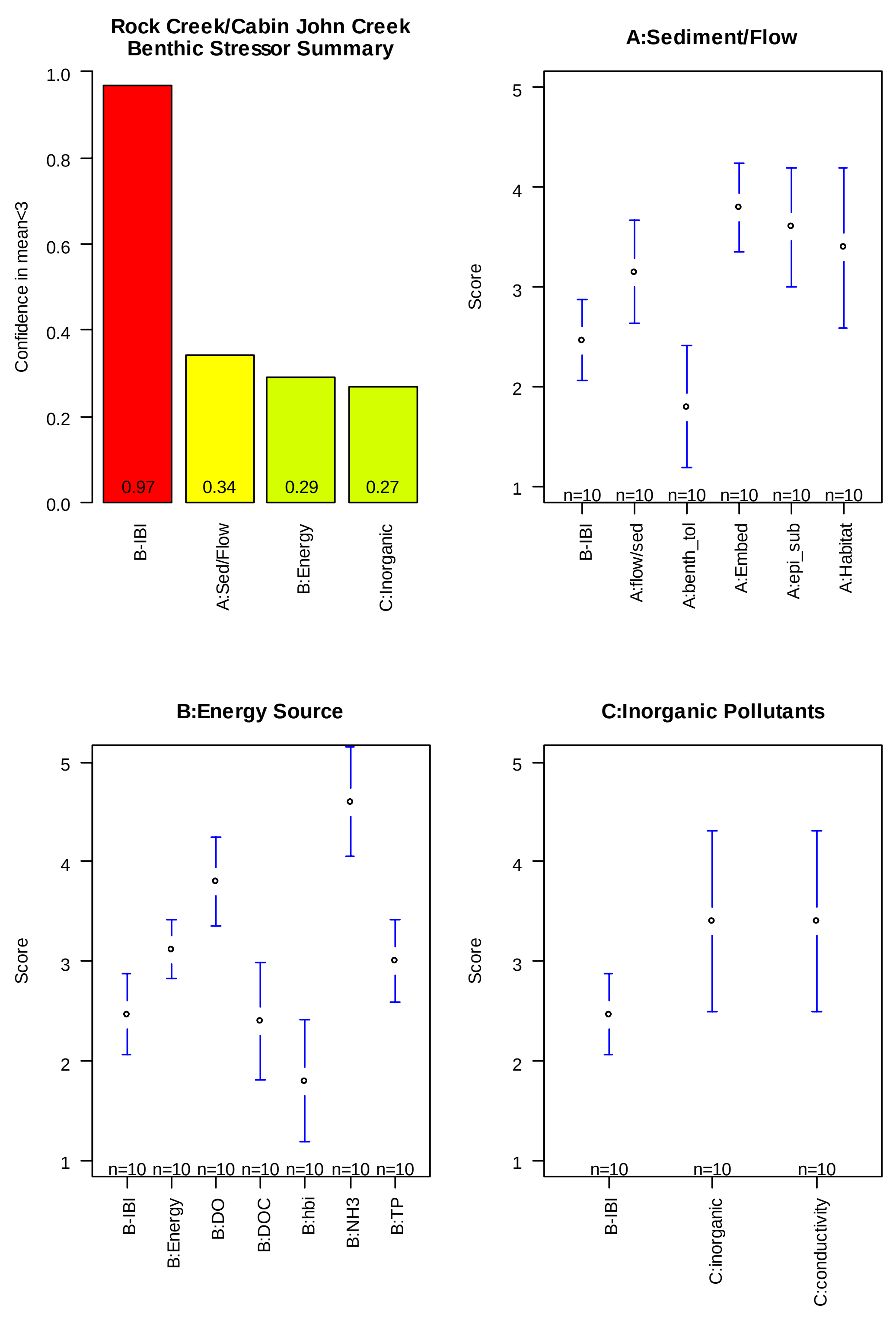


Figure F-43: Rock Creek/Cabin John Creek Benthic Stressor Results

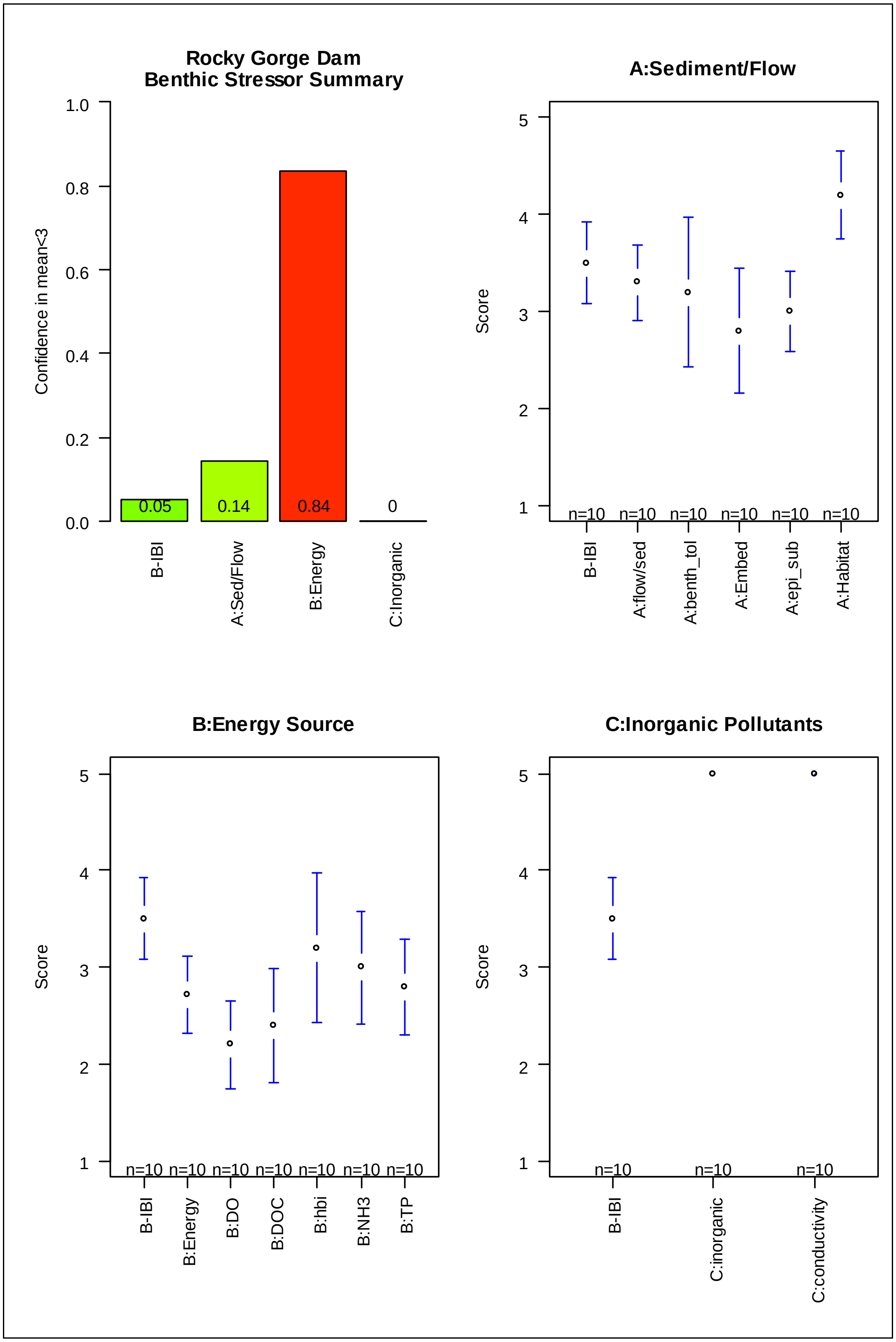


Figure F-44: Rocky Gorge Dam Benthic Stressor Results

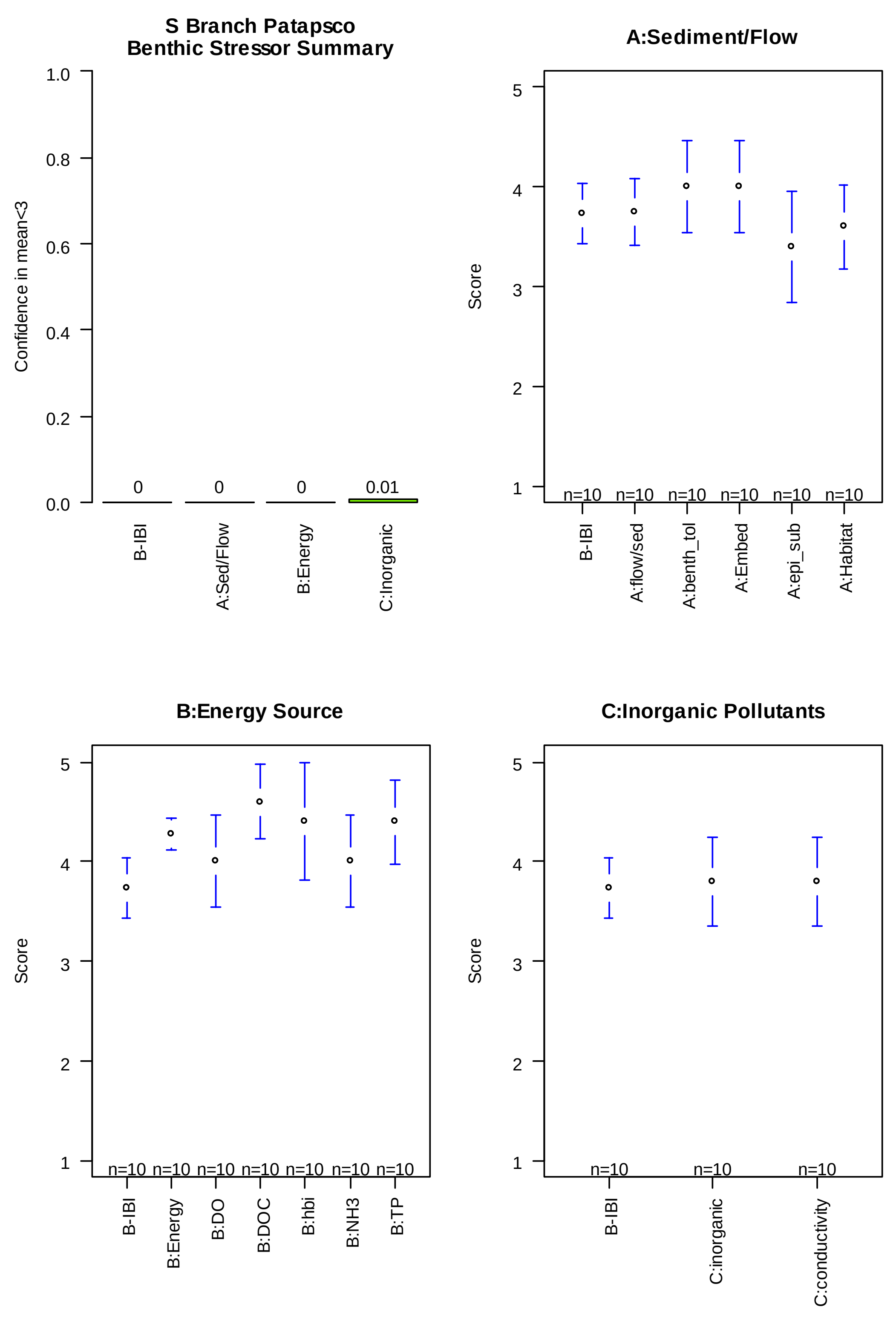


Figure F-45: South Branch Patapsco Benthic Stressor Results

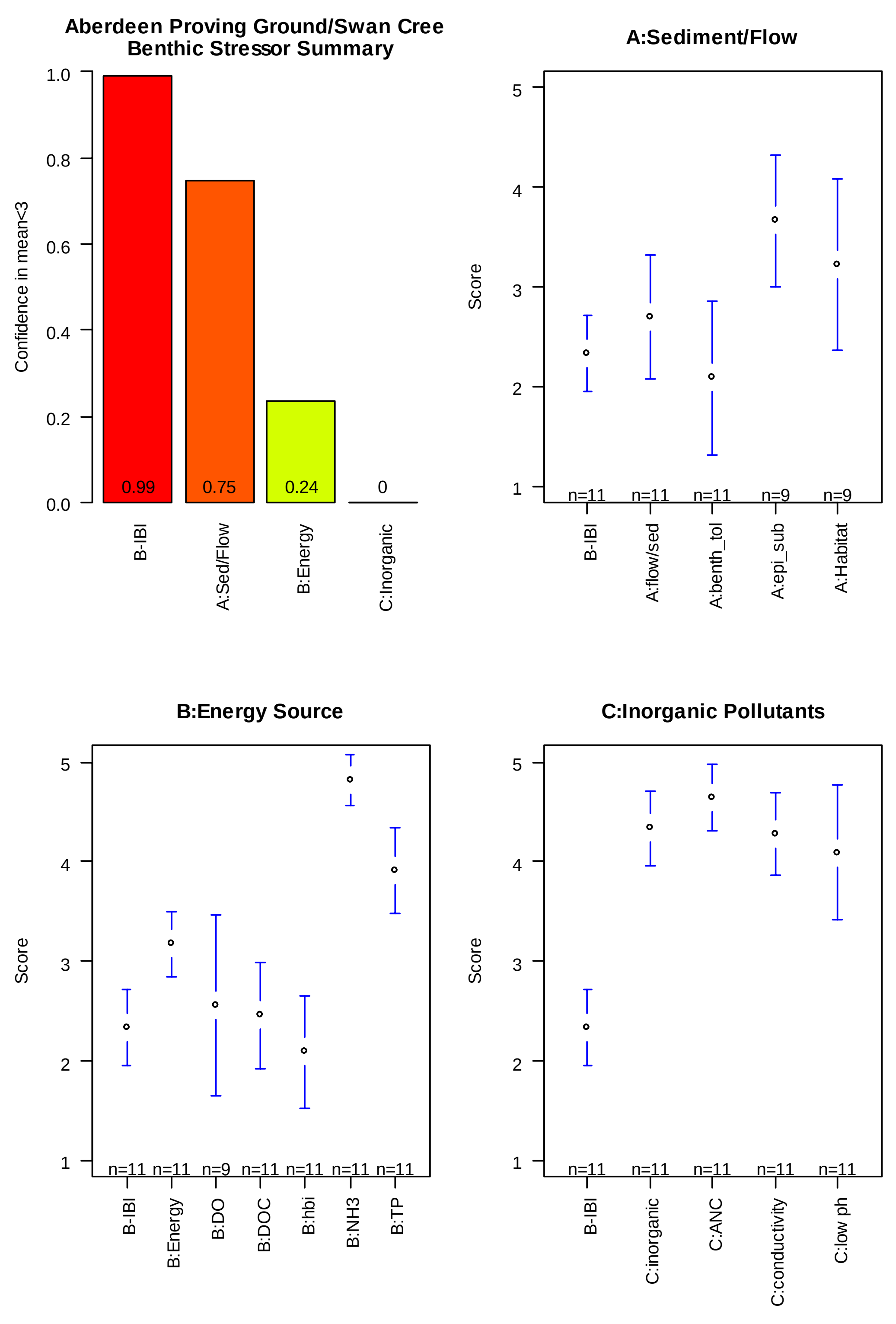


Figure F-46: Aberdeen Proving Ground/Swan Creek Benthic Stressor Results

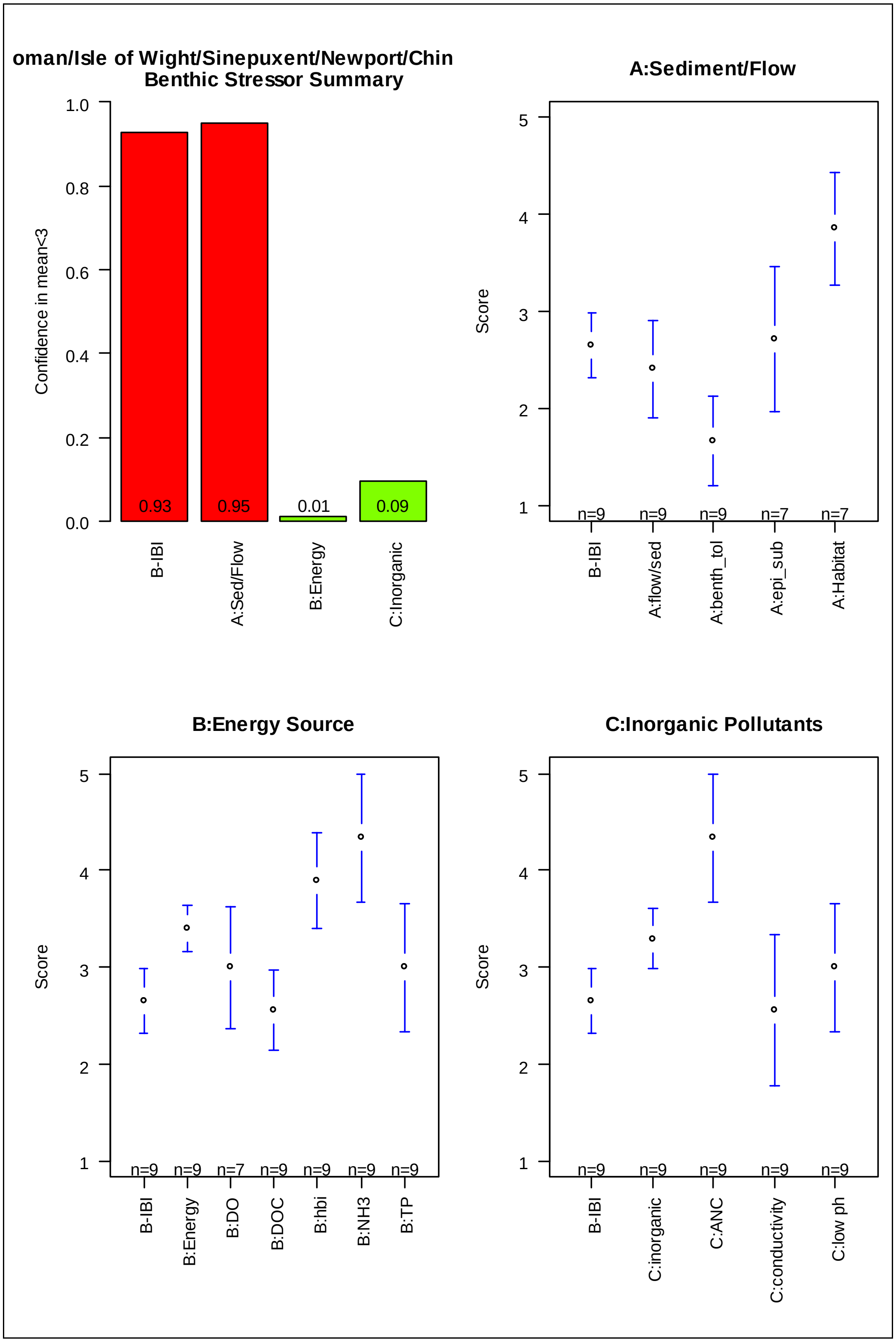


Figure F-47: Assowoman/Isle of Wight/Sinepuxent/Newport/Chincoteague Bays Benthic Stressor Results

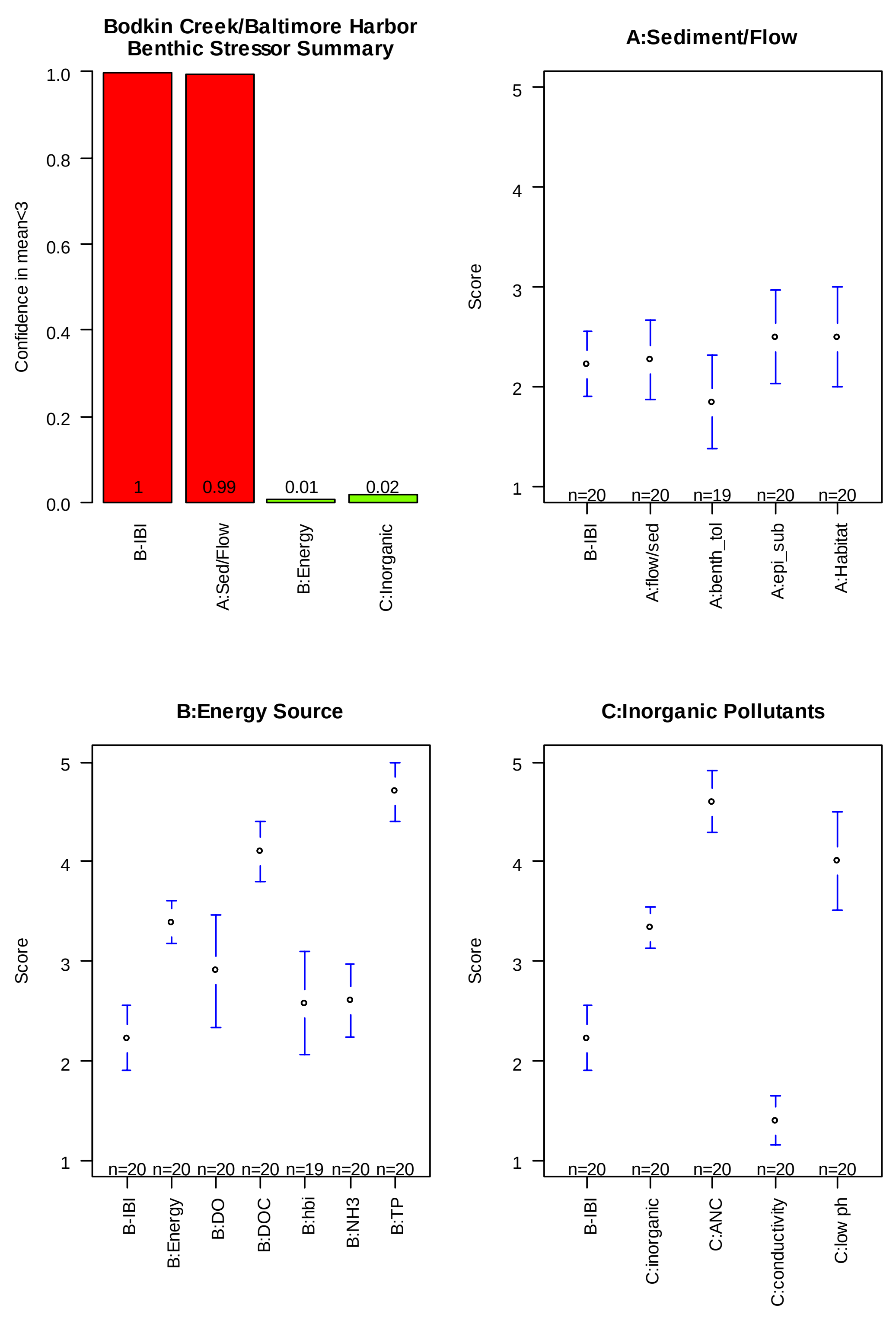


Figure F-48: Bodkin Creek/Baltimore Harbor Benthic Stressor Results

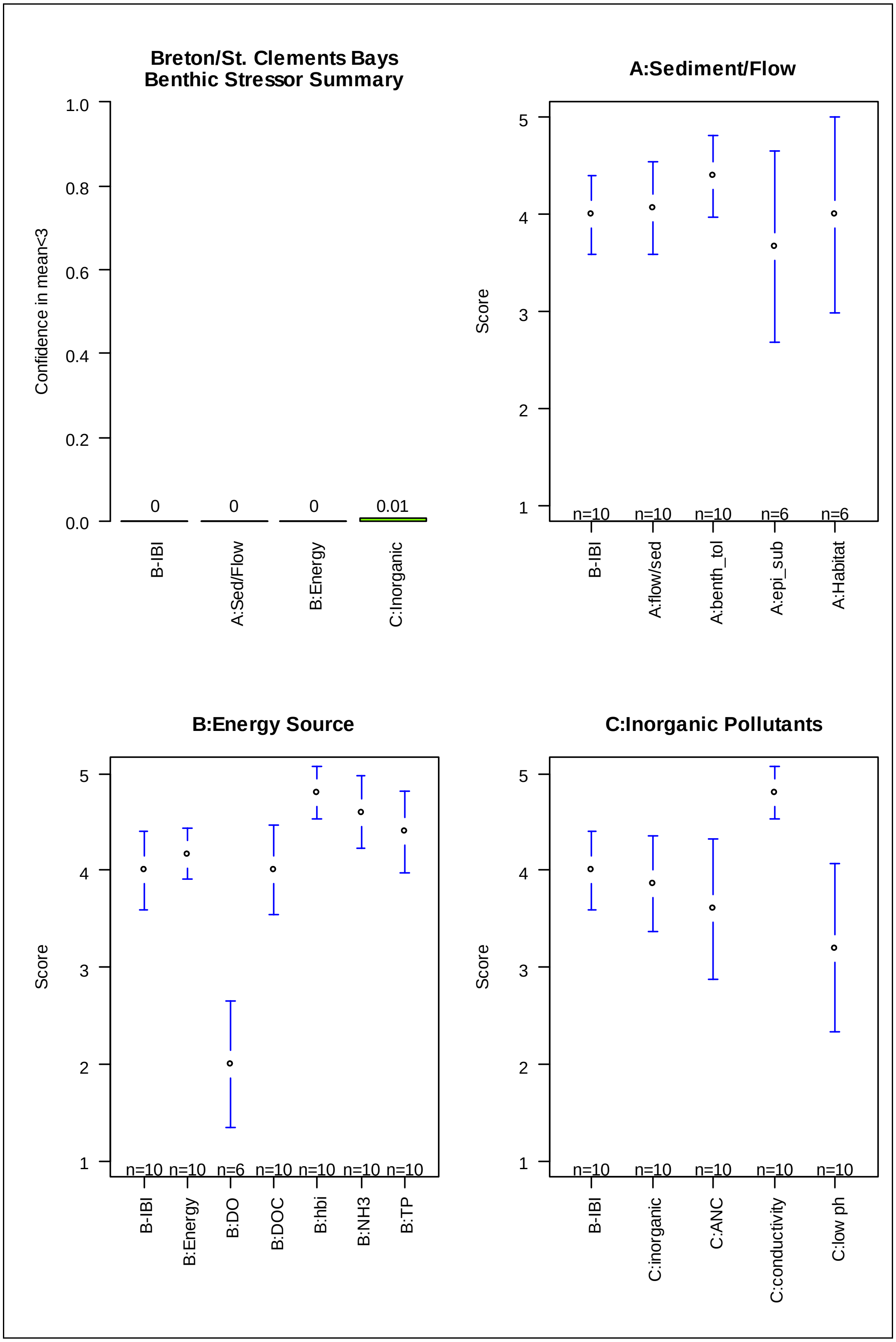


Figure F-49: Breton/St. Clements Bays Benthic Stressor Results

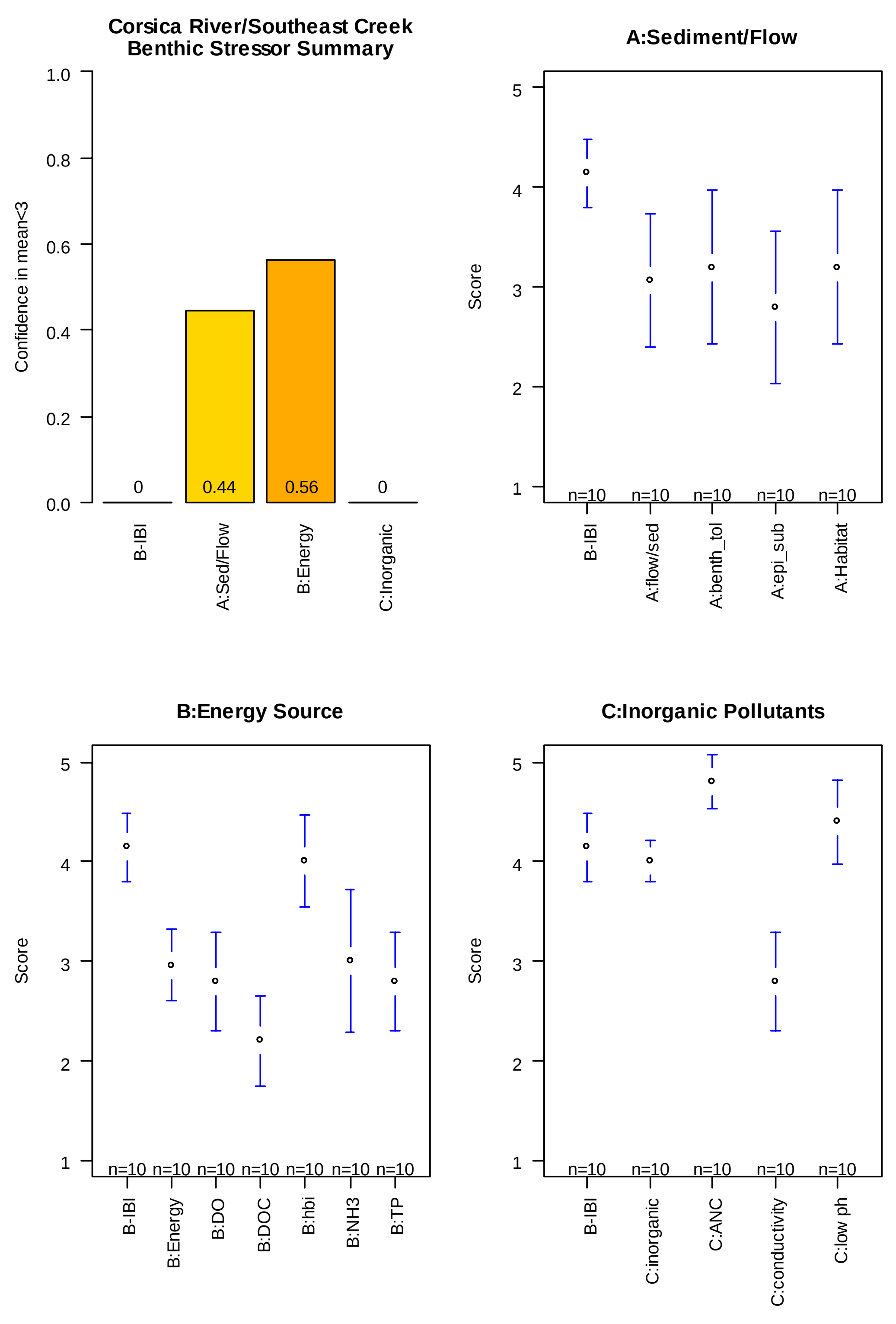


Figure F-50: Corsica River/Southeast Creek Benthic Stressor Results

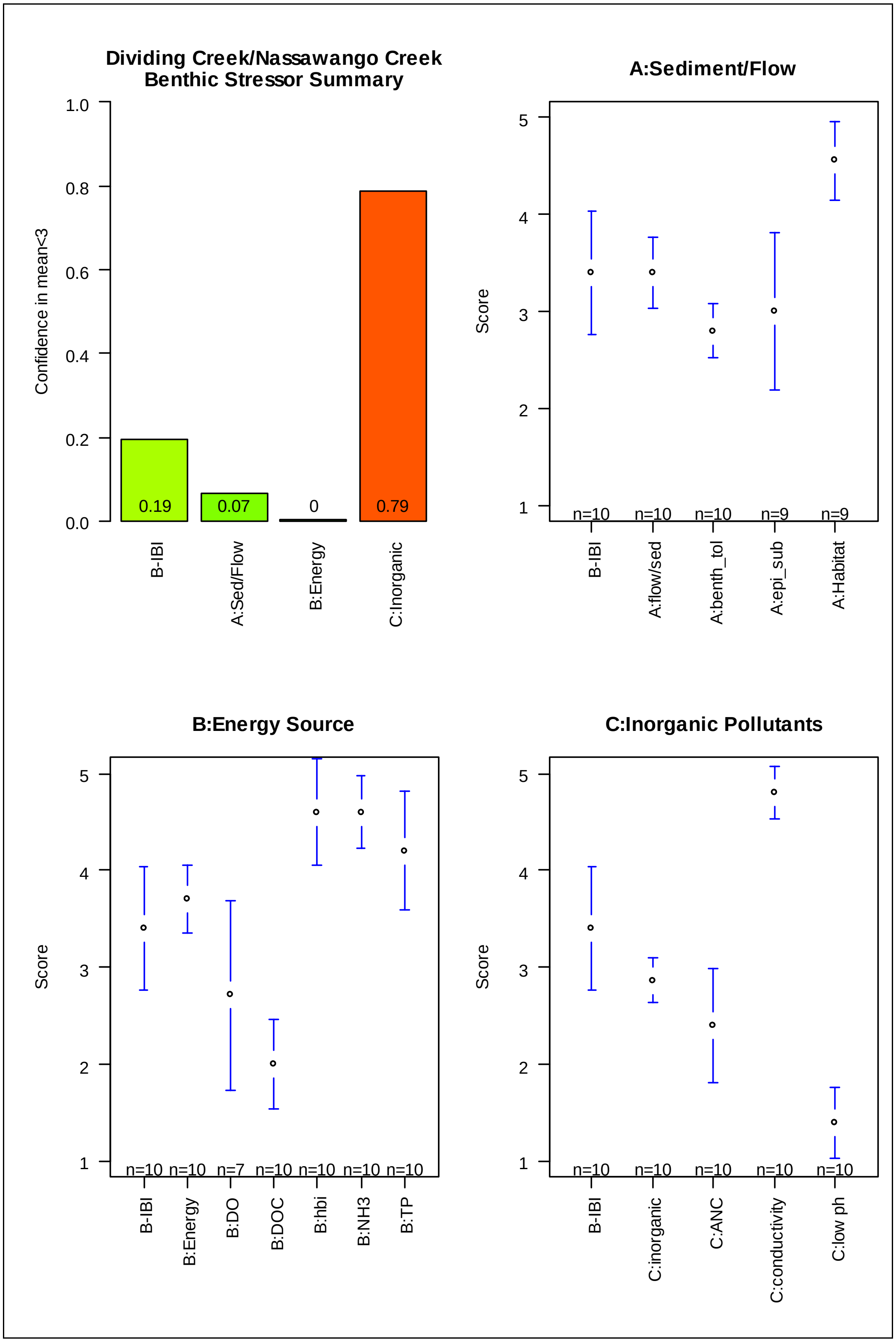


Figure F-51: Dividing Creek/Nassawango Creek Benthic Stressor Results

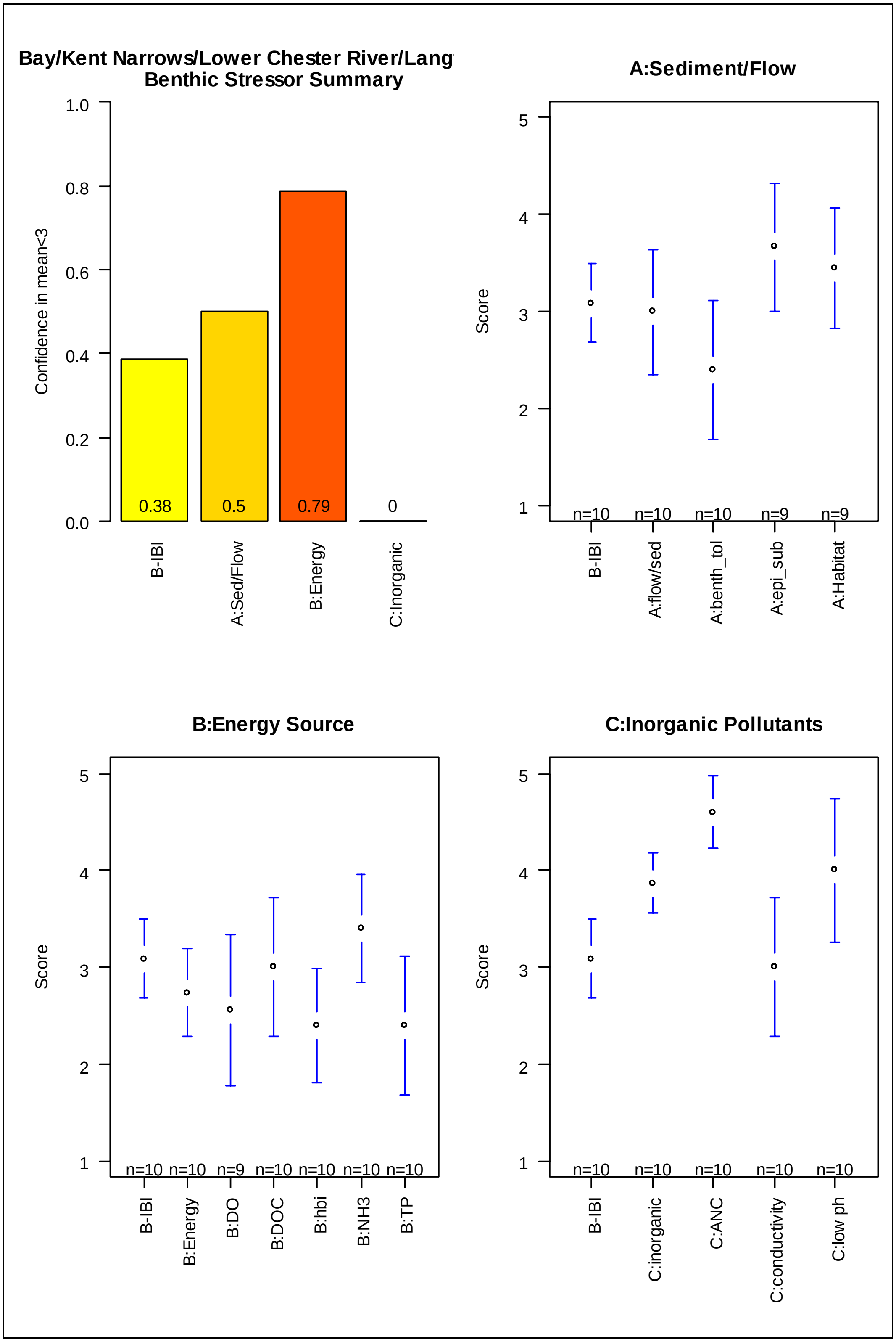


Figure F-52: Eastern Bay/Kent Narrows/Lower Chester River/Langford Creek Benthic Stressor Results

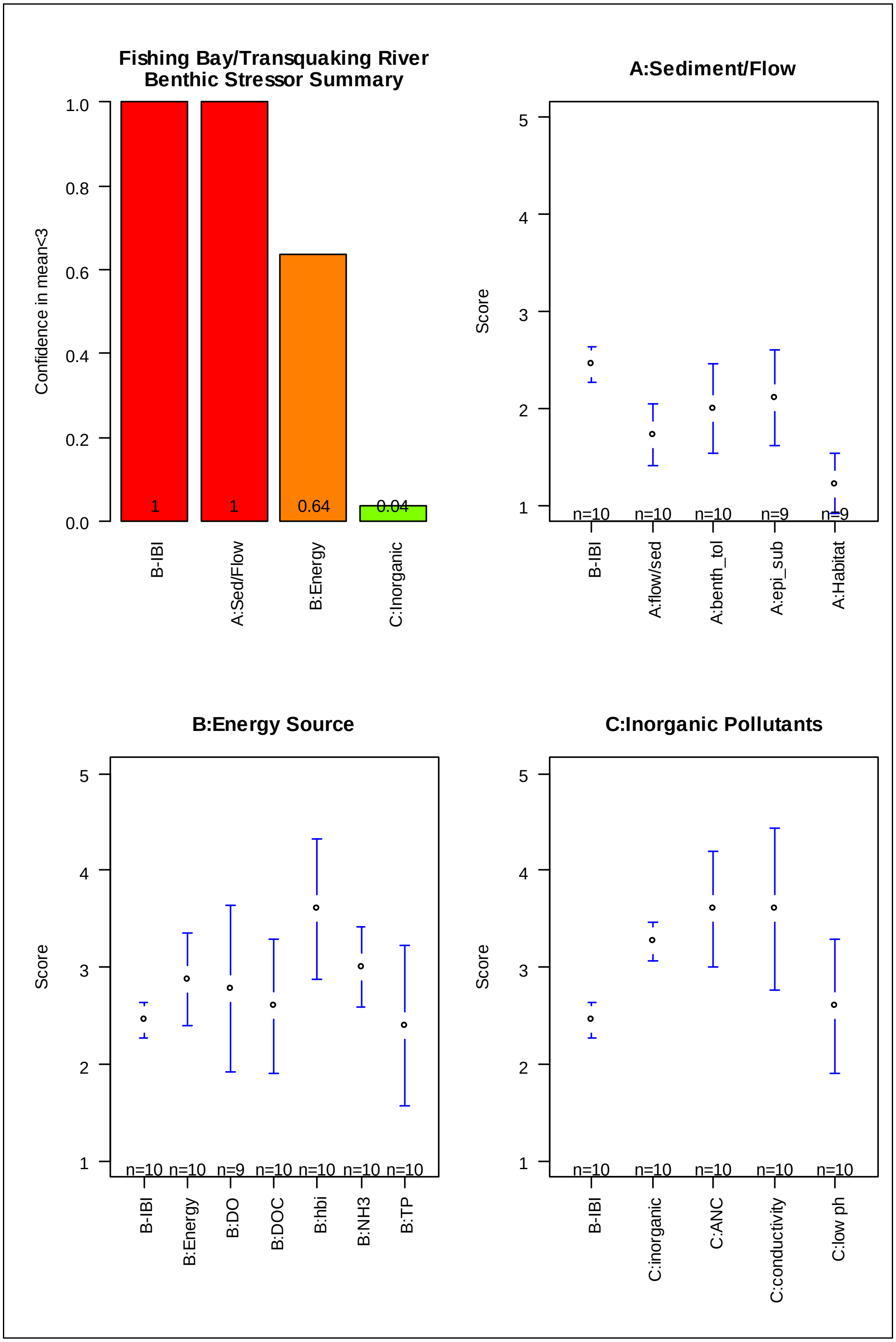


Figure F-53: Fishing Bay/Transquaking River Benthic Stressor Results

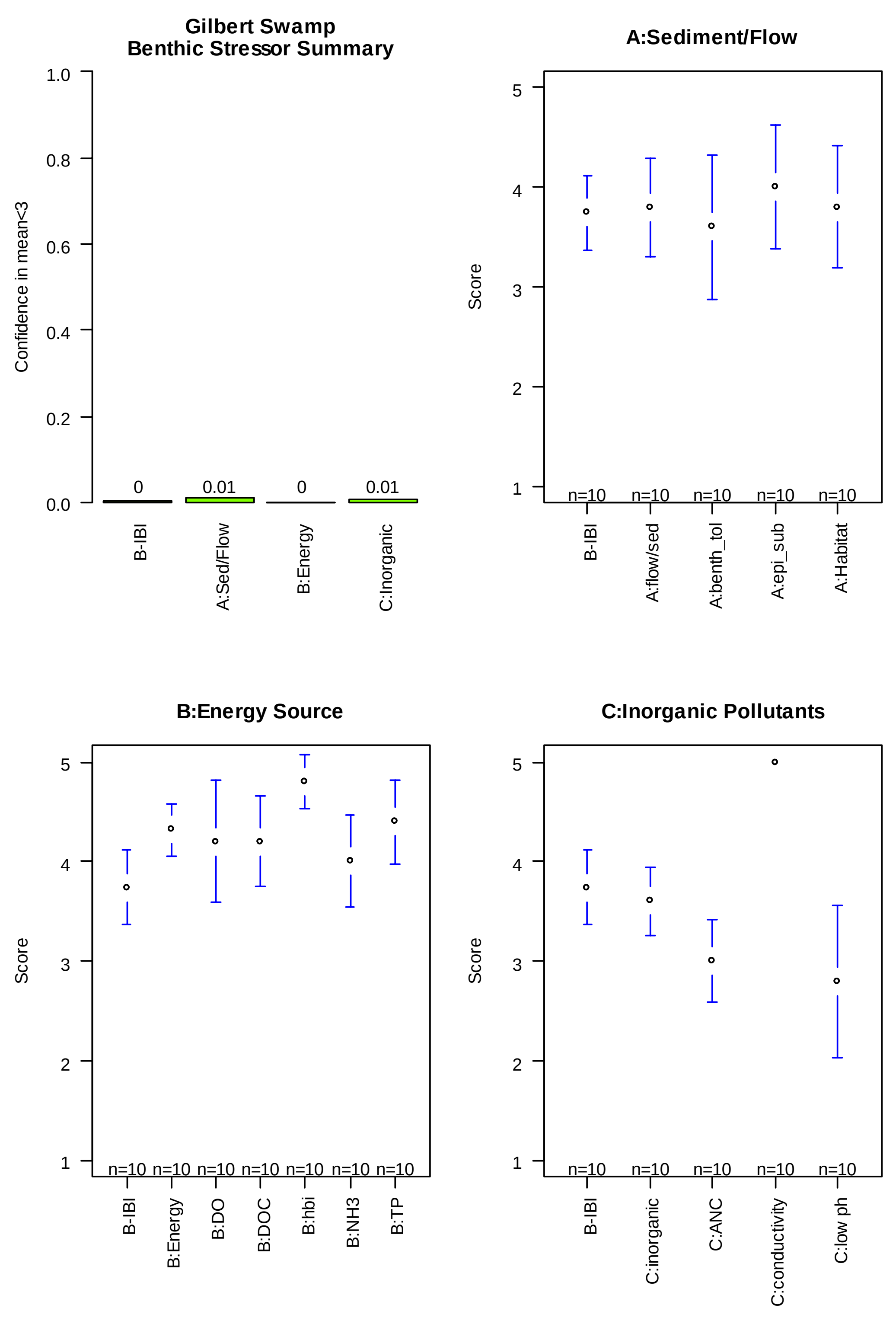


Figure F-54: Gilbert Swamp Benthic Stressor Results

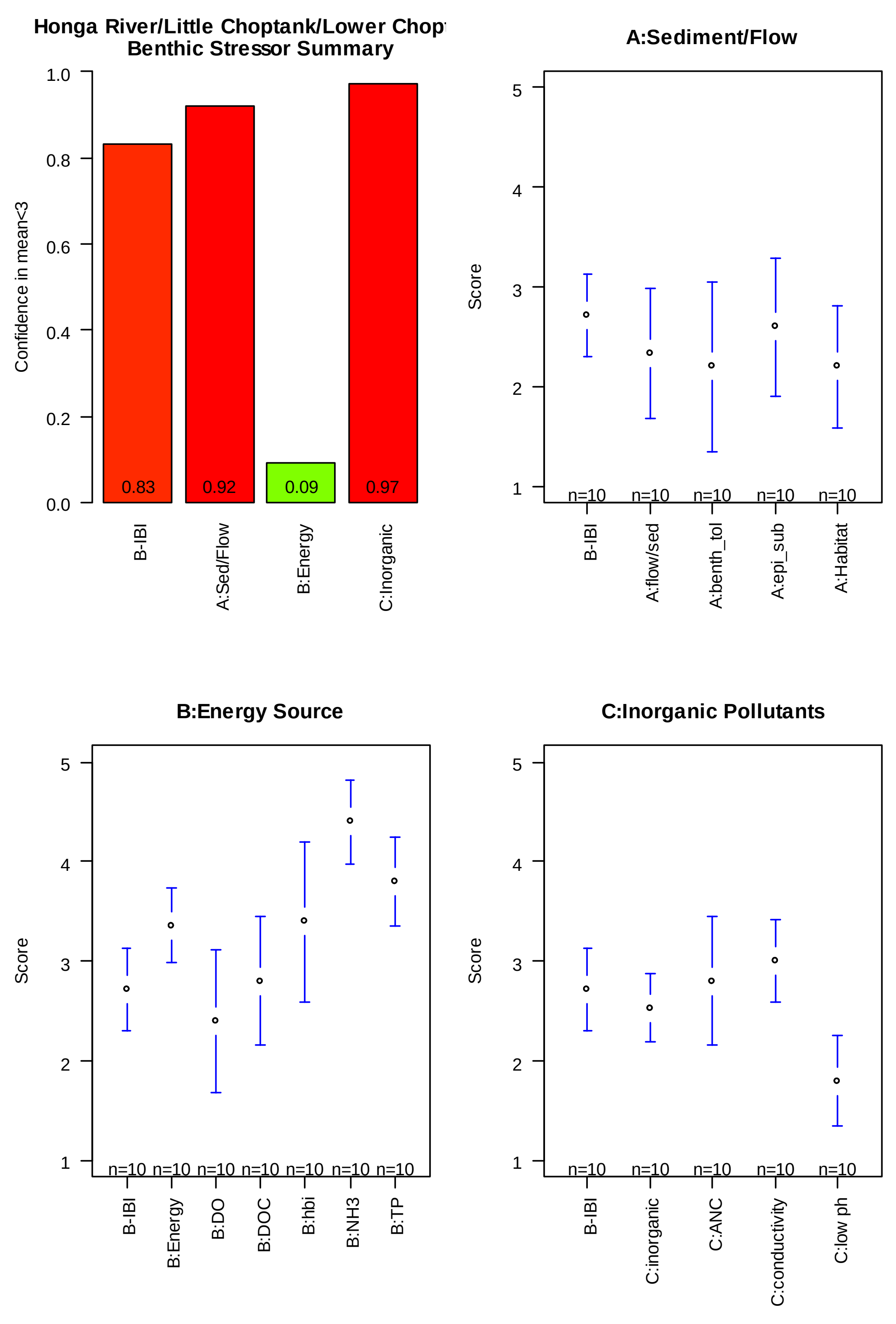


Figure F-55: Honga River/Little Choptank/Lower Choptank Benthic Stressor Results

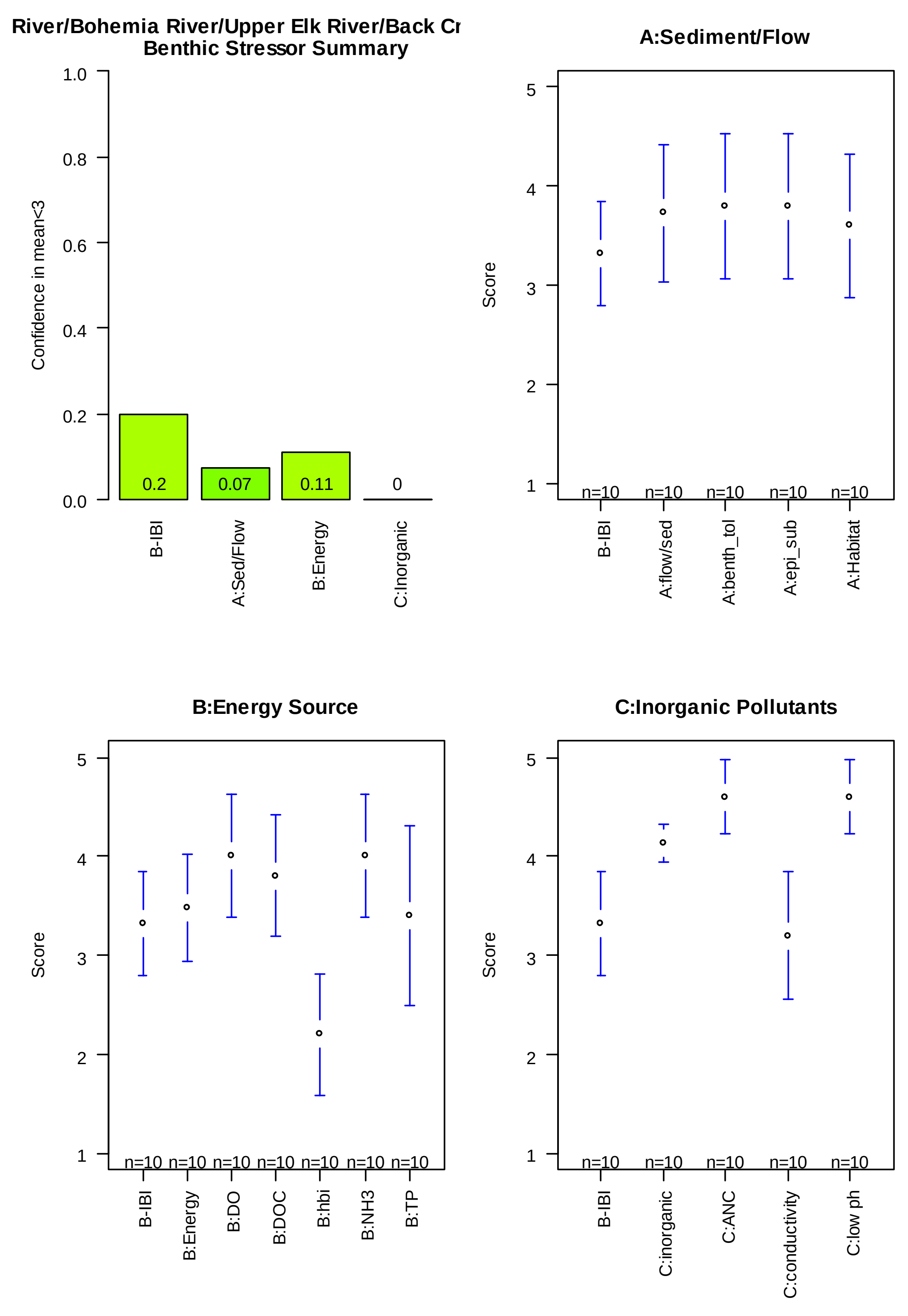


Figure F-56: Elk River/Bohemia River/Upper Elk River/Back Creek Benthic Stressor Results

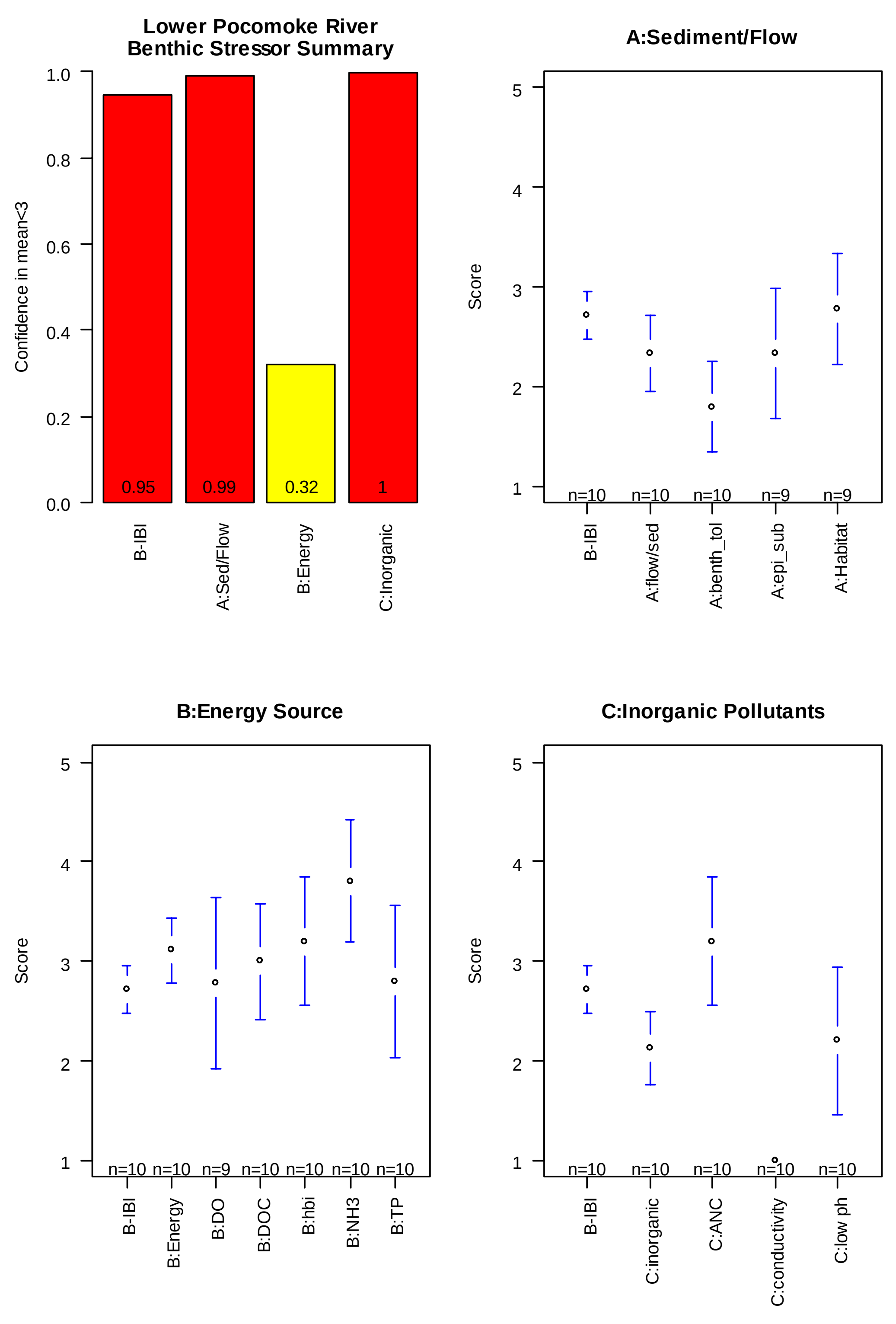


Figure F-57: Lower Pocomoke River Benthic Stressor Results

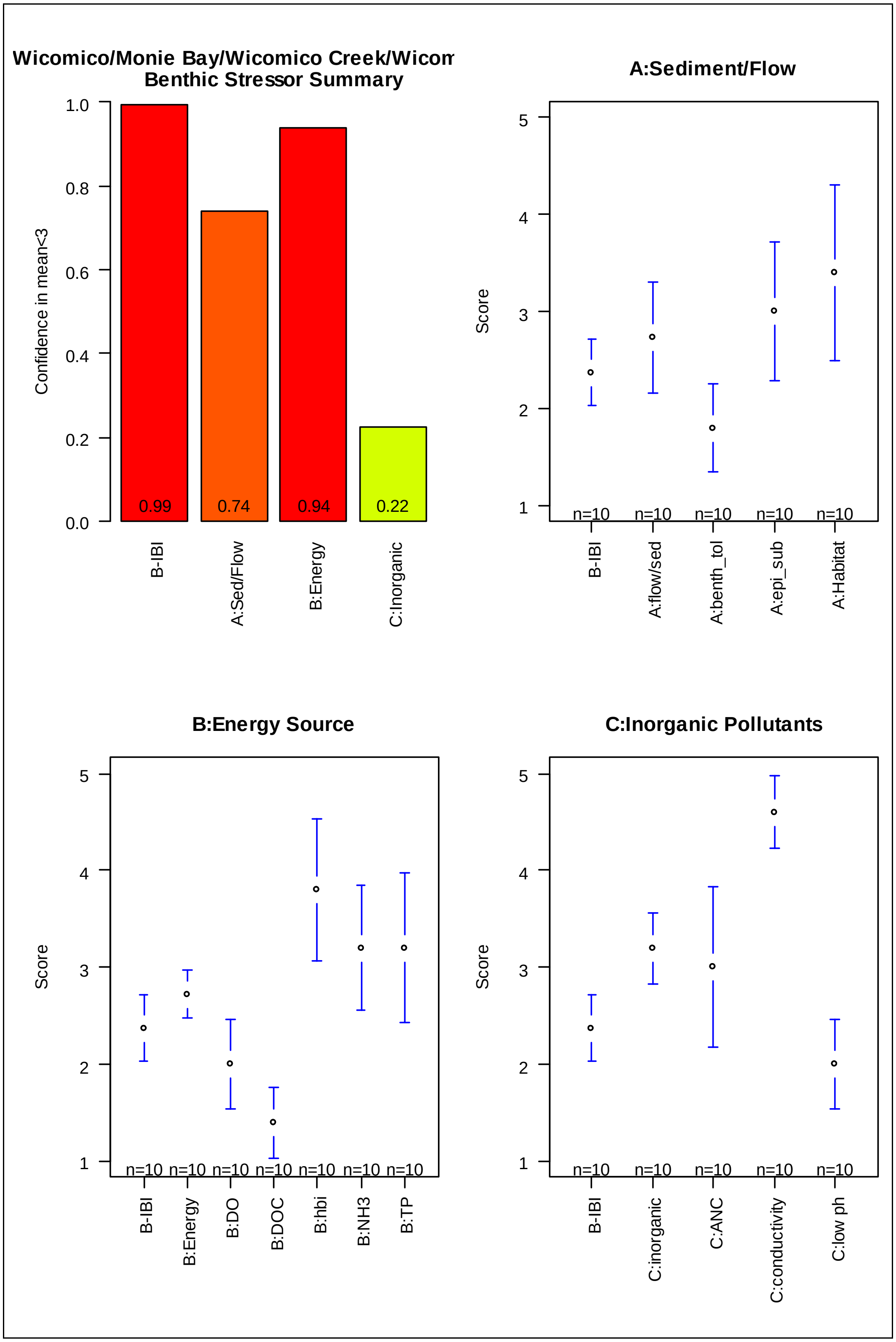


Figure F-58: Lower Wicomico River/Monie Bay/Wicomico Creek/Wicomico River Headwaters Benthic Stressor Results

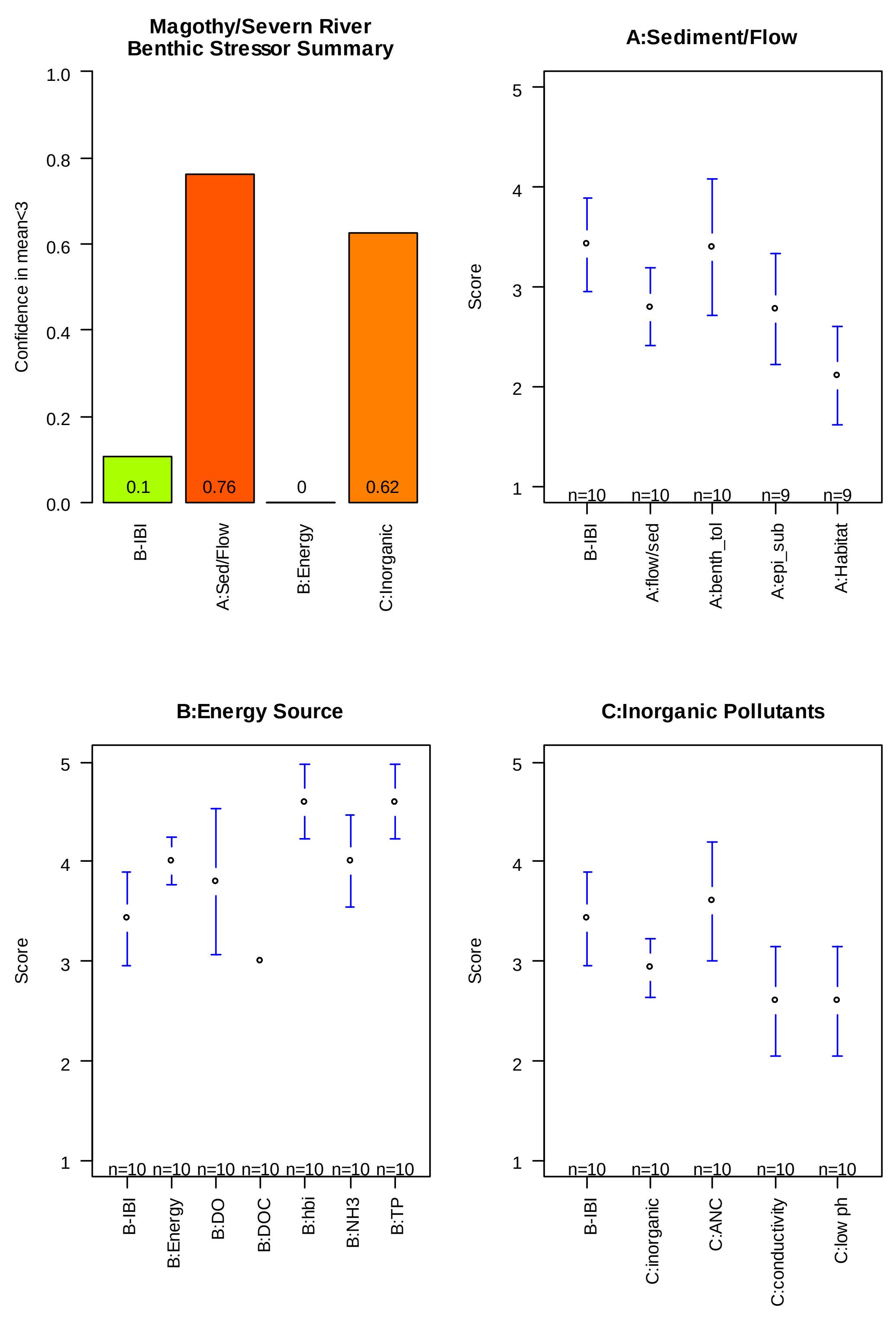


Figure F-59: Magothy/Severn River Benthic Stressor Results

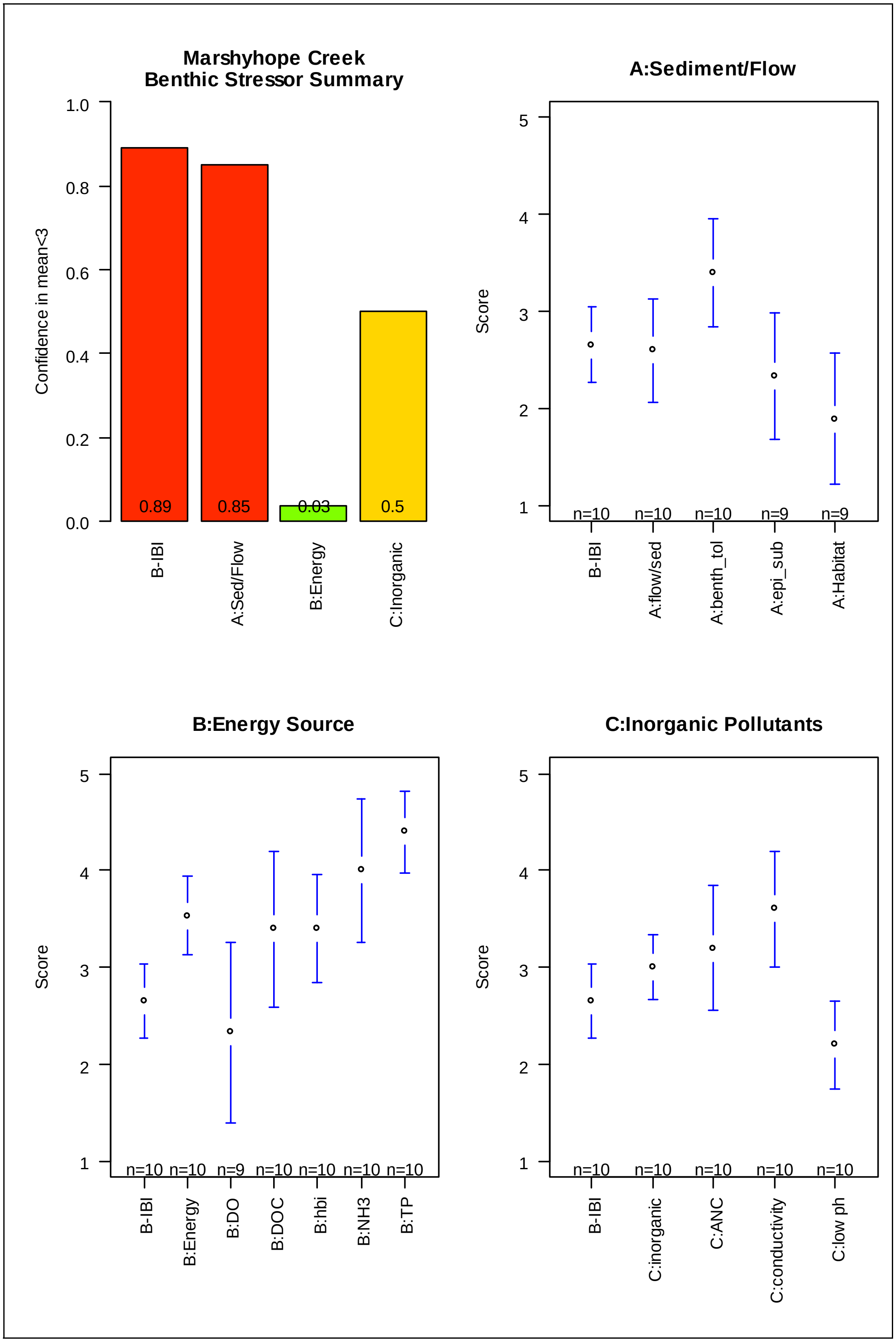


Figure F-60: Marshyhope Creek Benthic Stressor Results

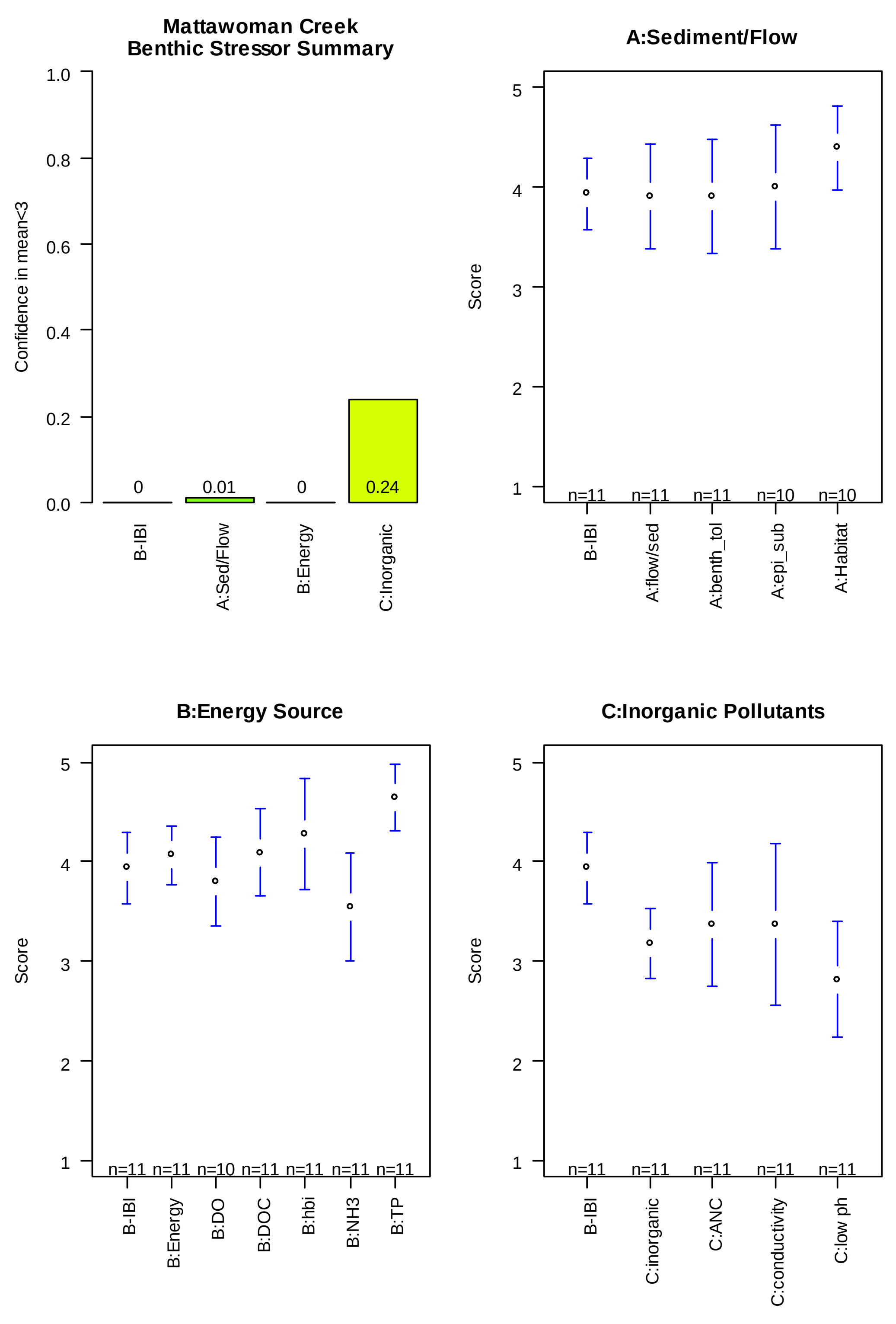


Figure F-61: Mattawoman Creek Benthic Stressor Results

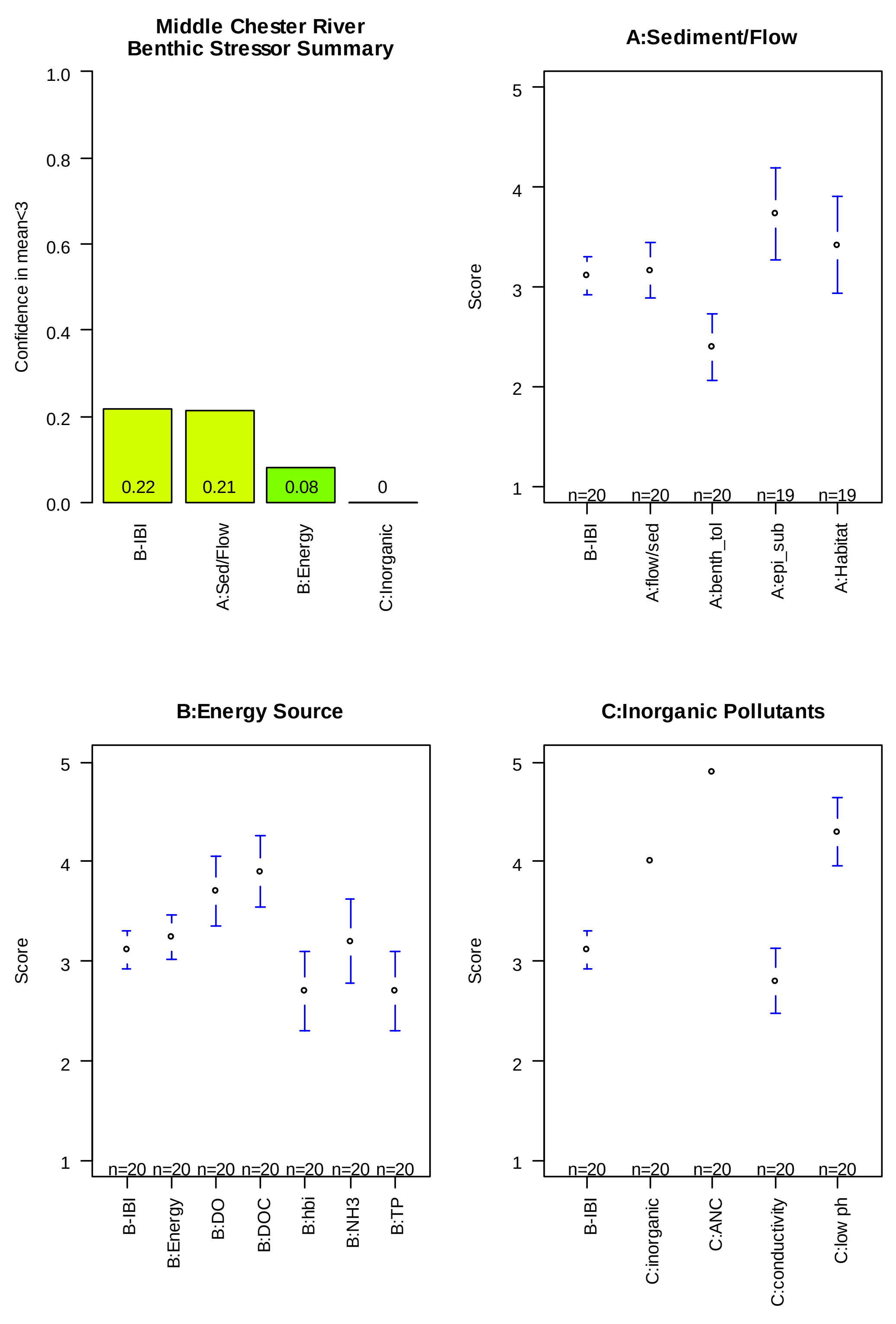


Figure F-62: Middle Chester River Benthic Stressor Results

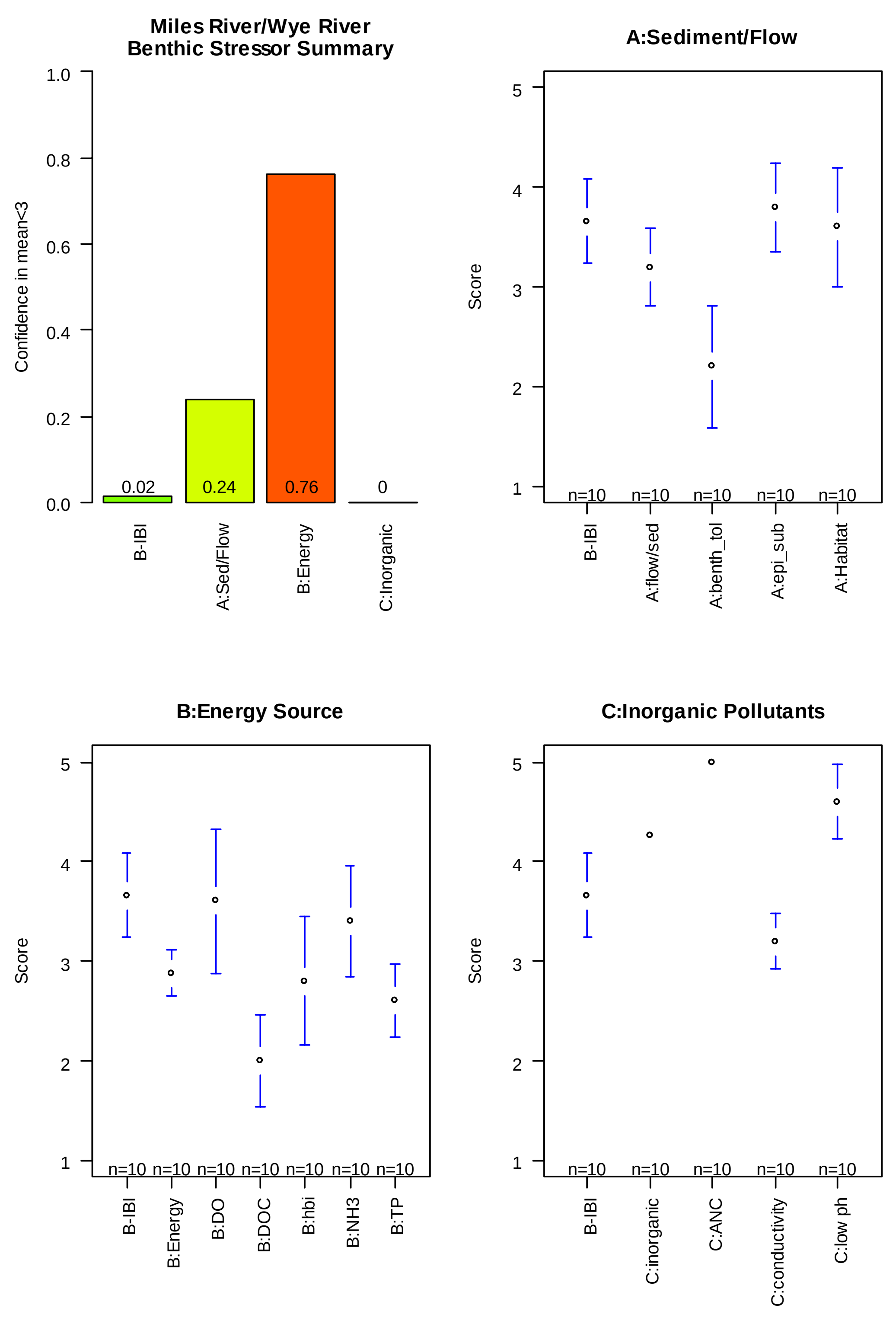


Figure F-63: Miles River/Wye River Benthic Stressor Results

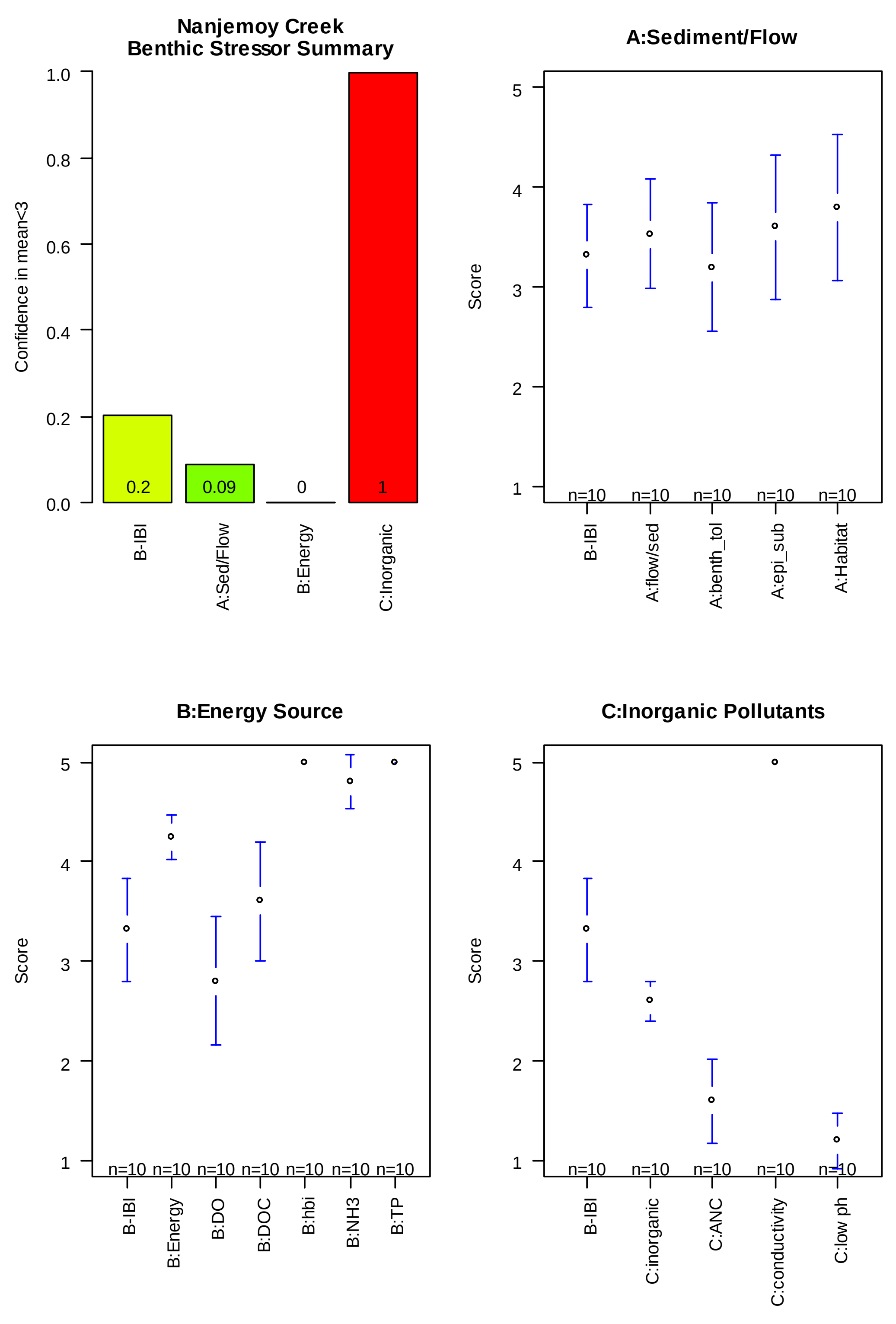


Figure F-64: Nanjemoy Creek Benthic Stressor Results

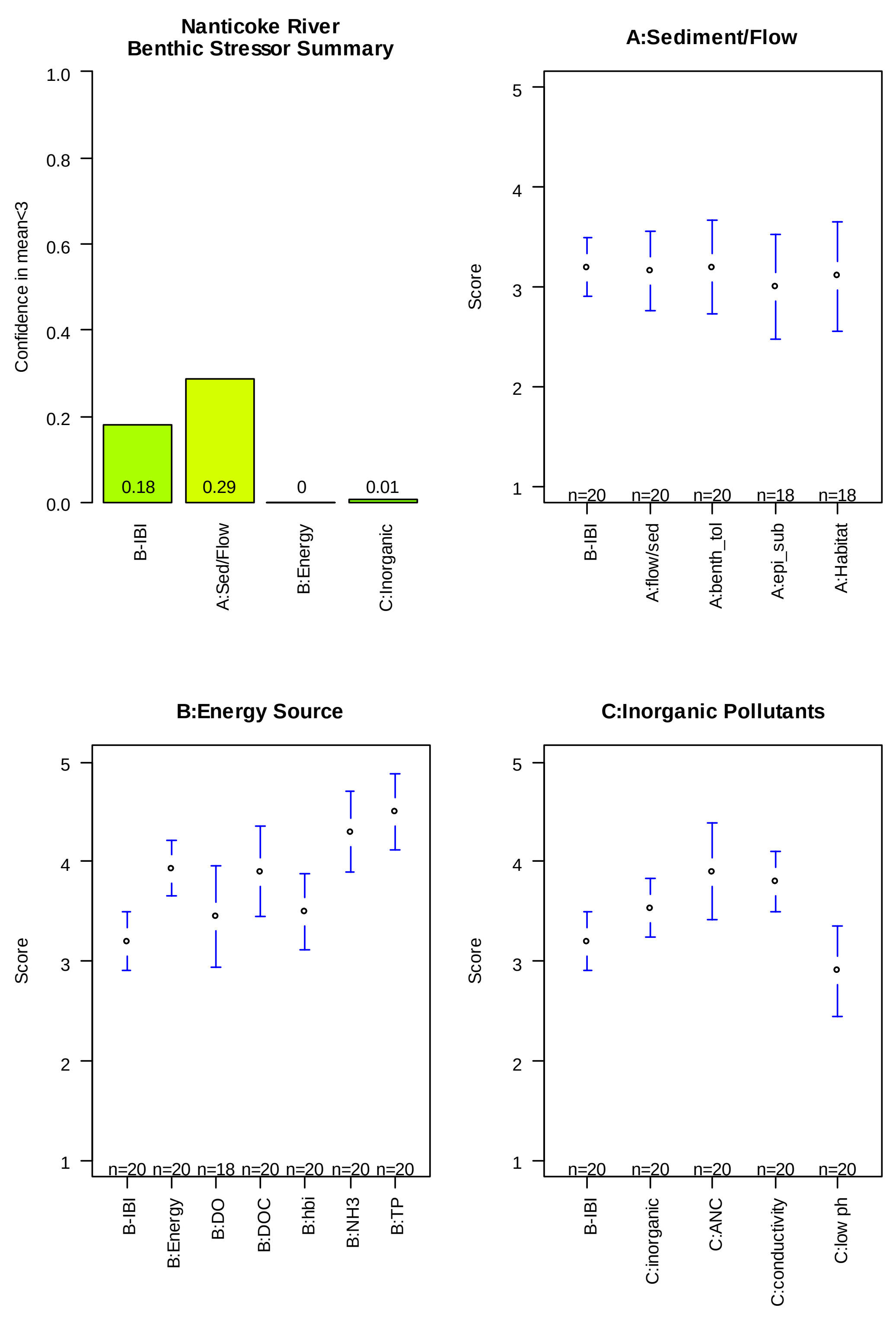


Figure F-65: Nanticoke River Benthic Stressor Results

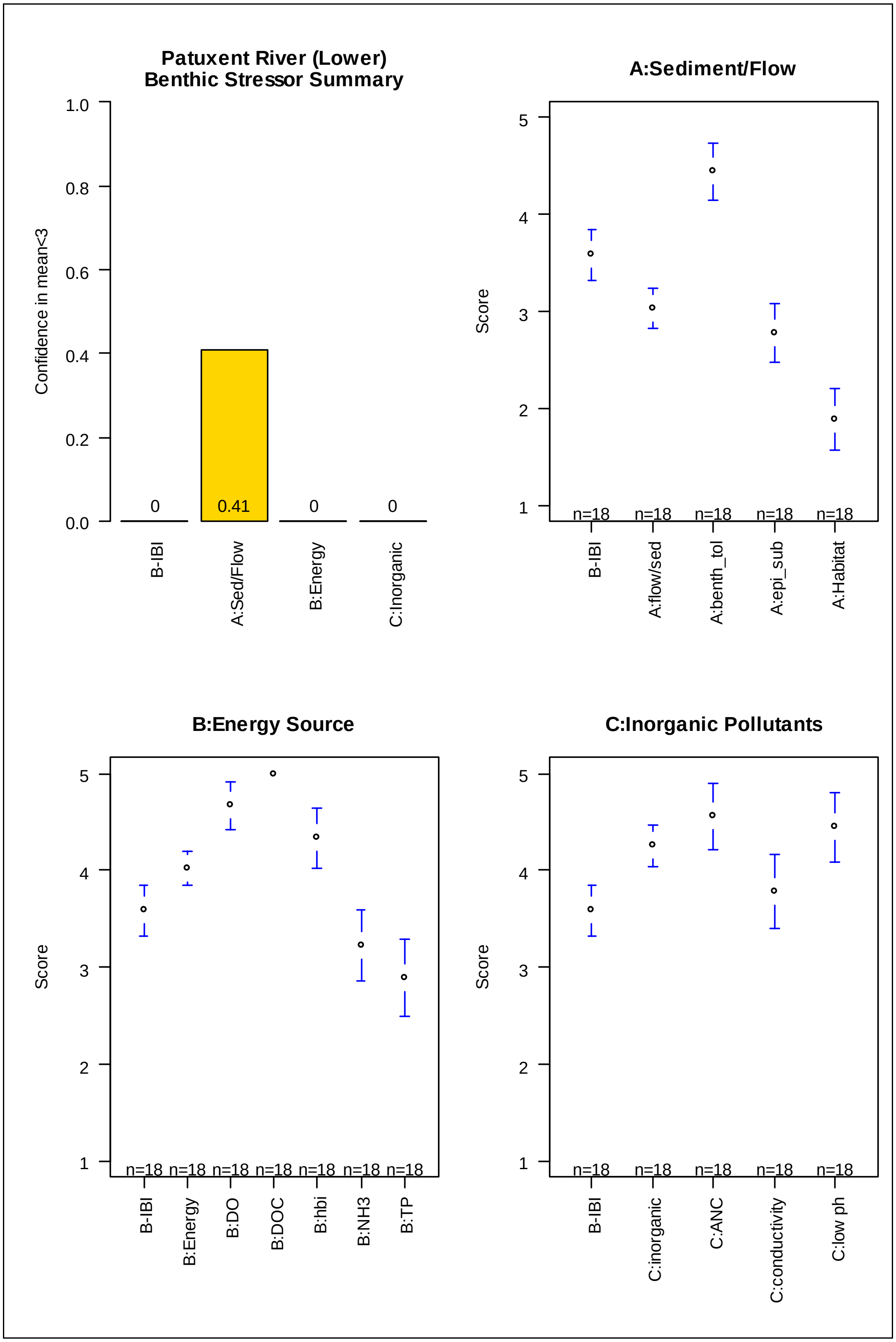


Figure F-66: Patuxent River Lower Benthic Stressor Results

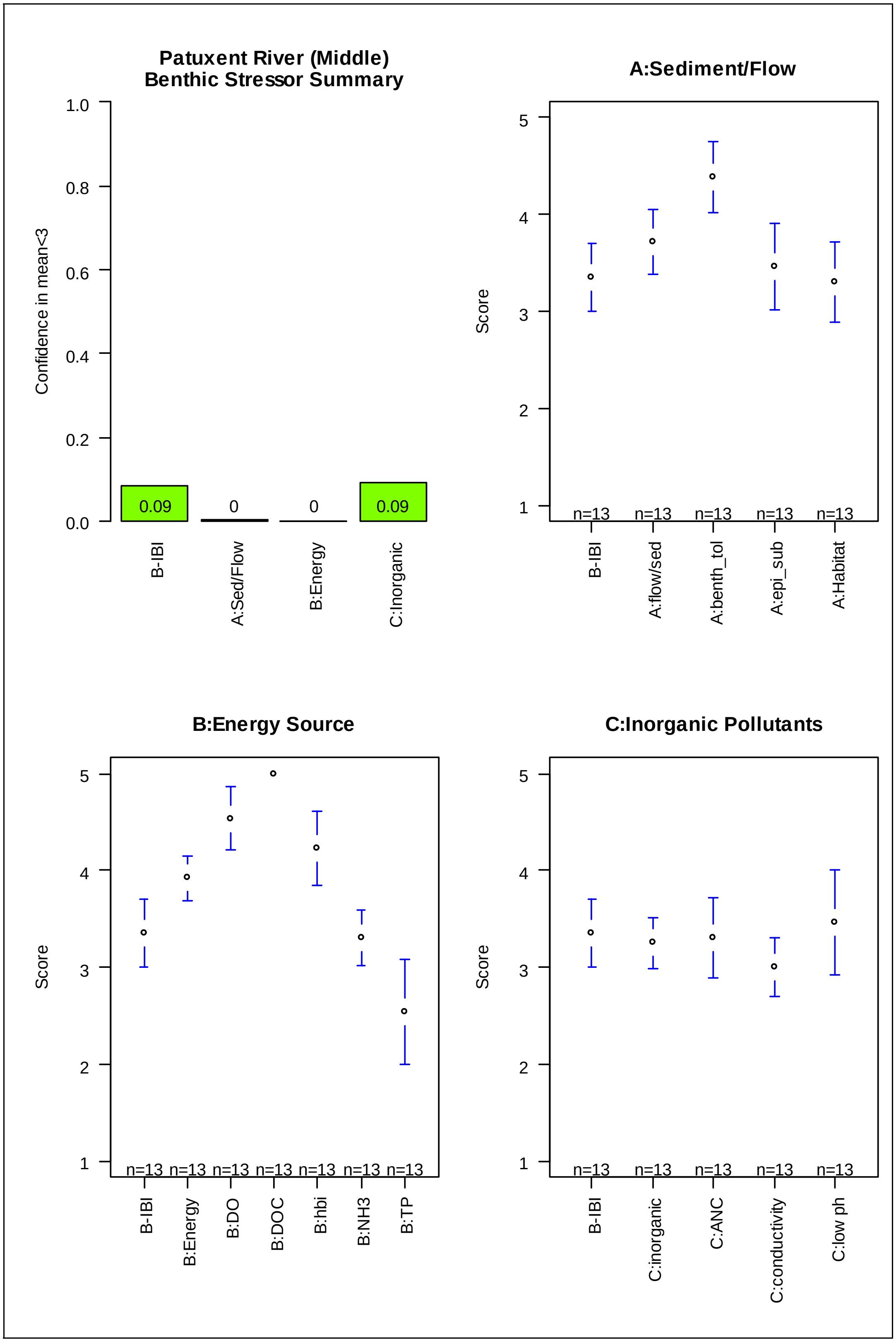


Figure F-67: Patuxent River Middle Benthic Stressor Results

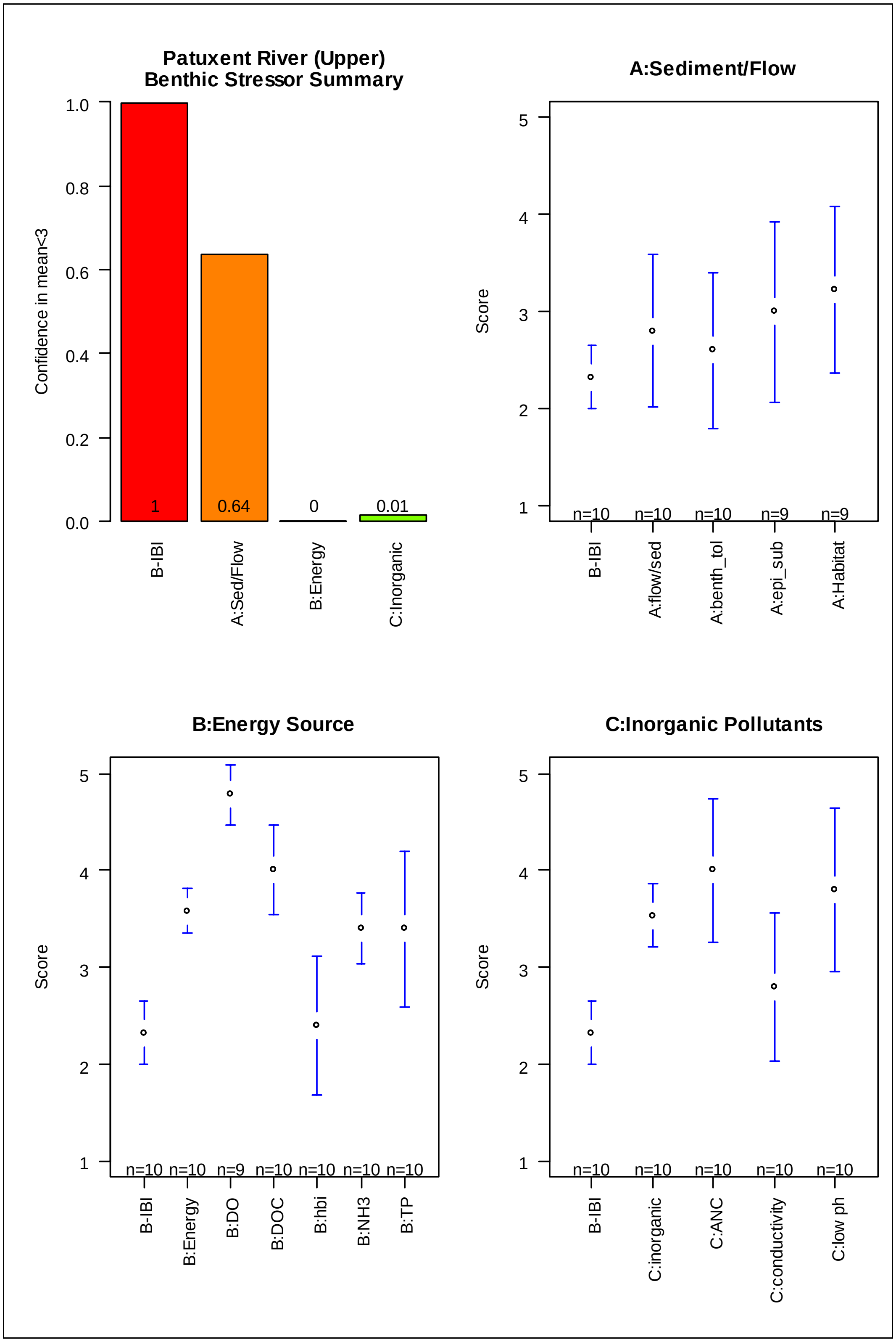


Figure F-68: Patuxent River Upper Benthic Stressor Results

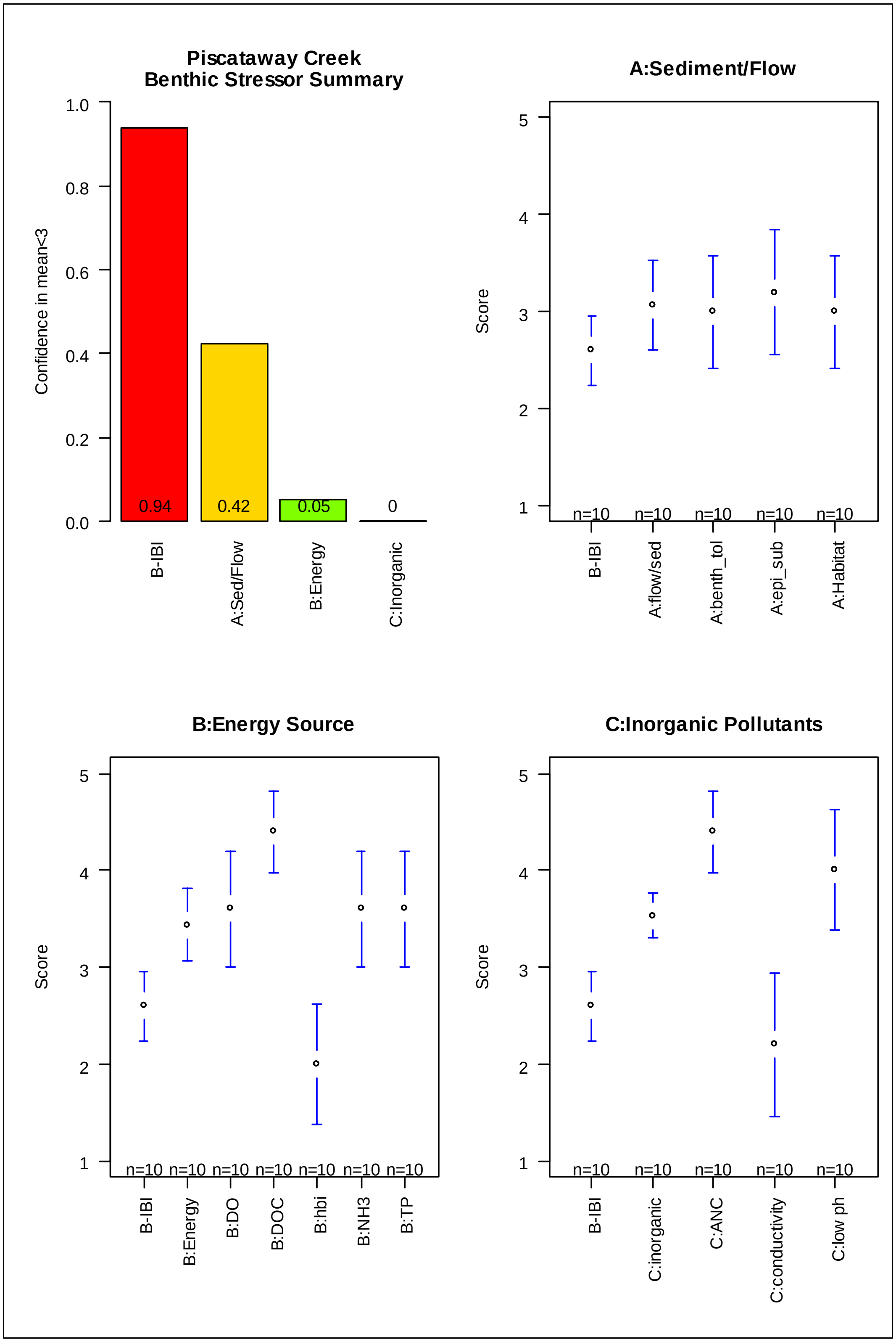


Figure F-69: Piscataway Creek Benthic Stressor Results

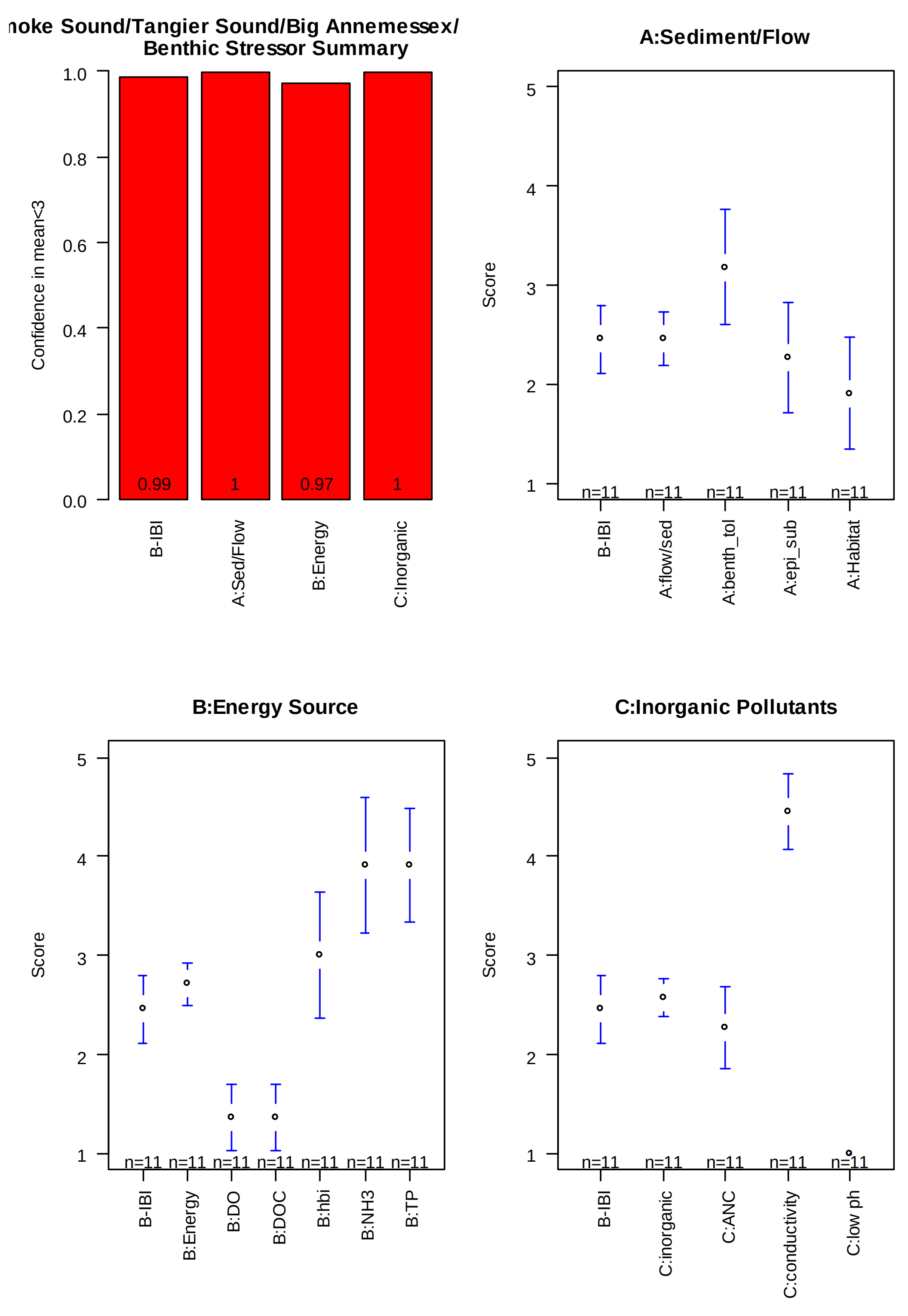


Figure F-70: Pocomoke Sound/Tangier Sound/Big Annemessex River/Manokin River Benthic Stressor Results

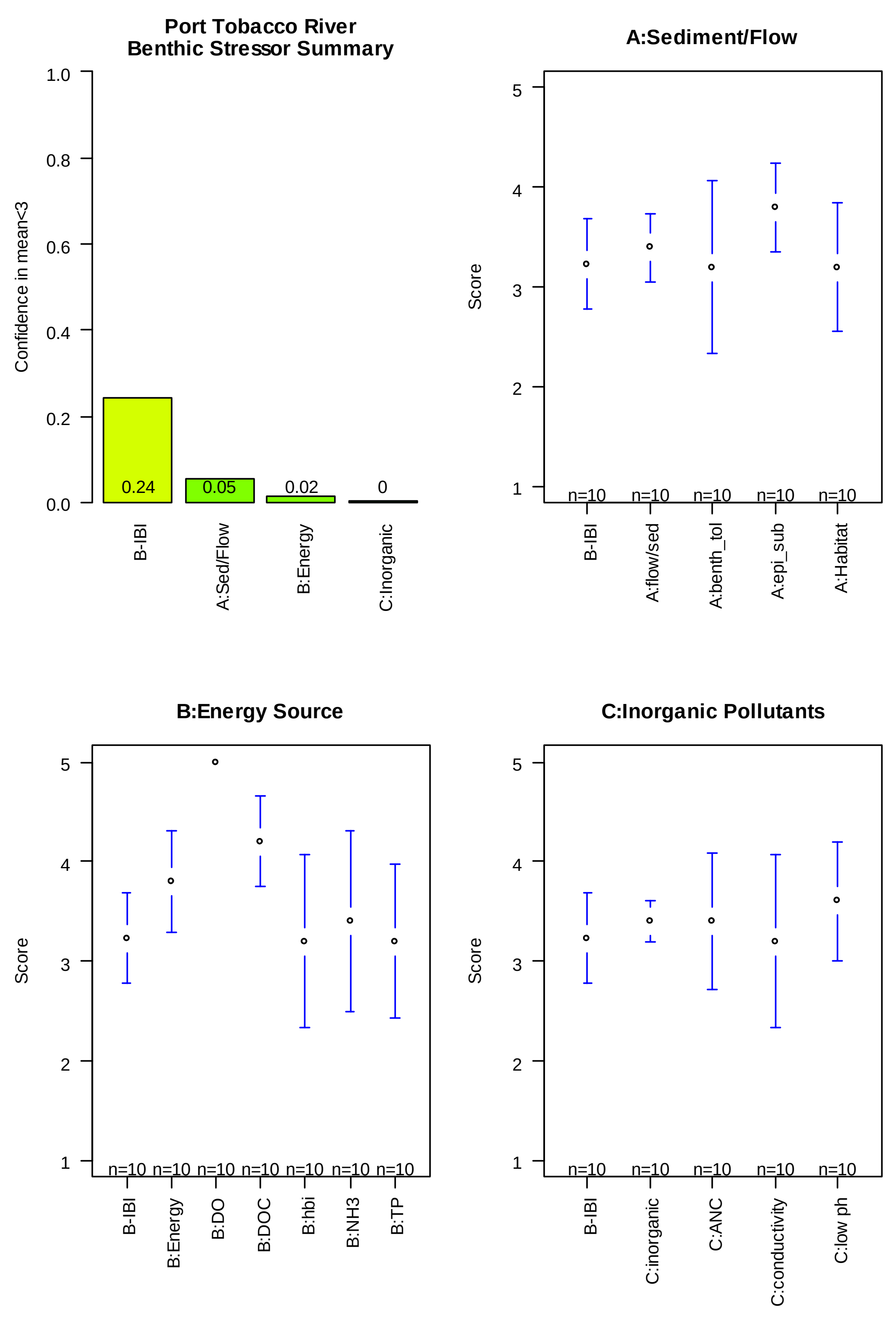


Figure F-71: Port Tobacco River Creek Benthic Stressor Results

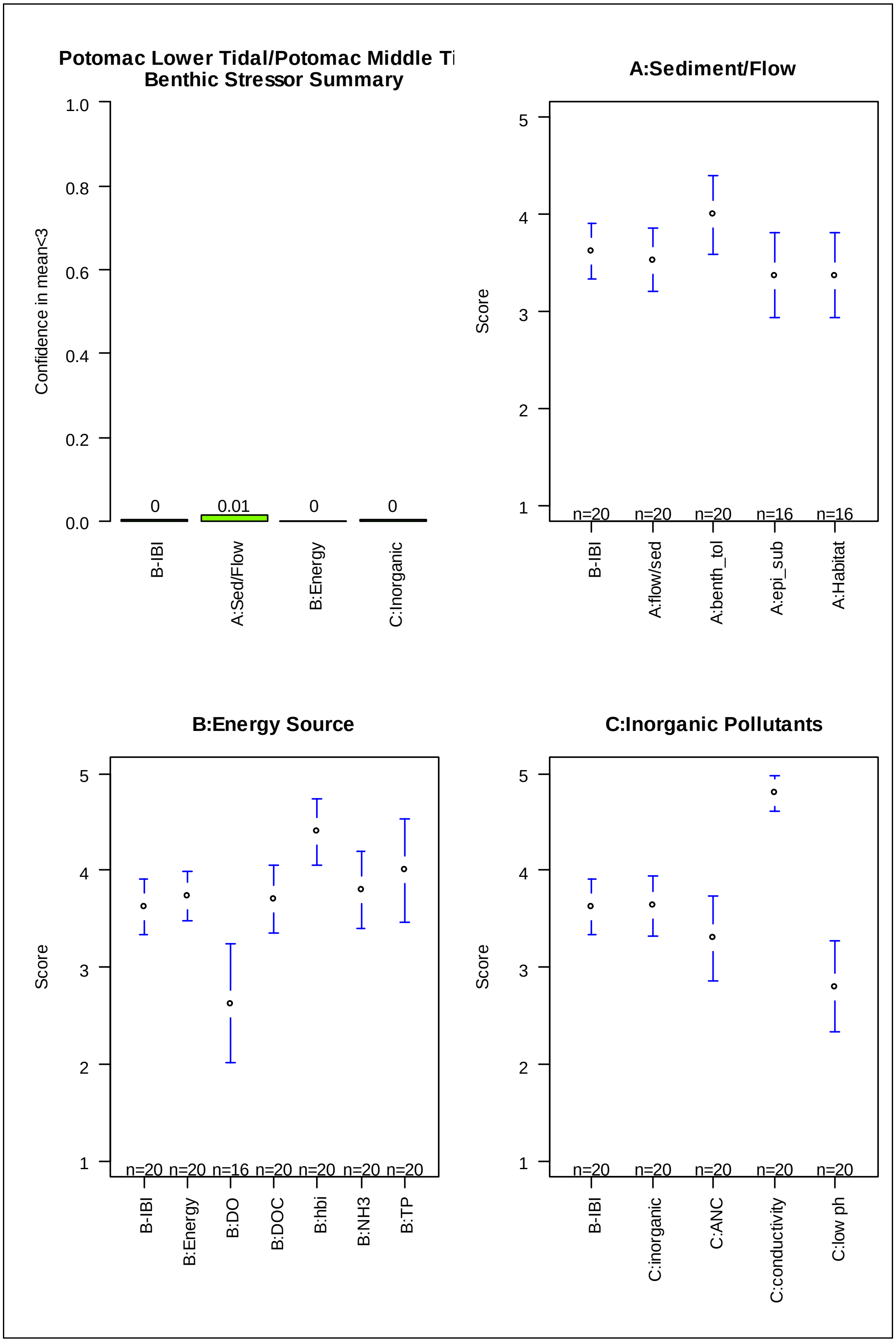


Figure F-72: Potomac Lower Tidal/Potomac Middle Tidal Benthic Stressor Results

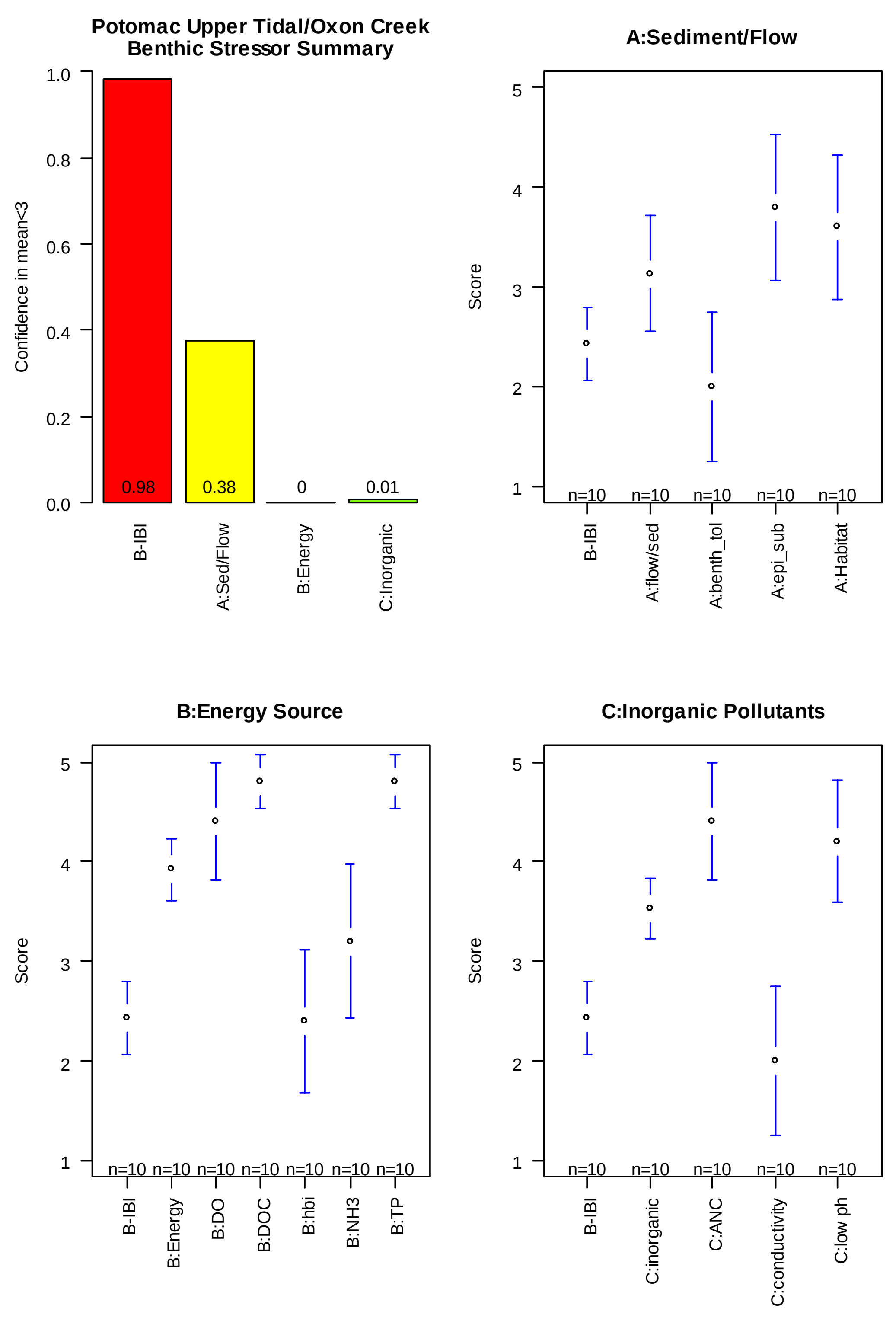


Figure F-73: Potomac Upper Tidal/Oxon Creek Benthic Stressor Results

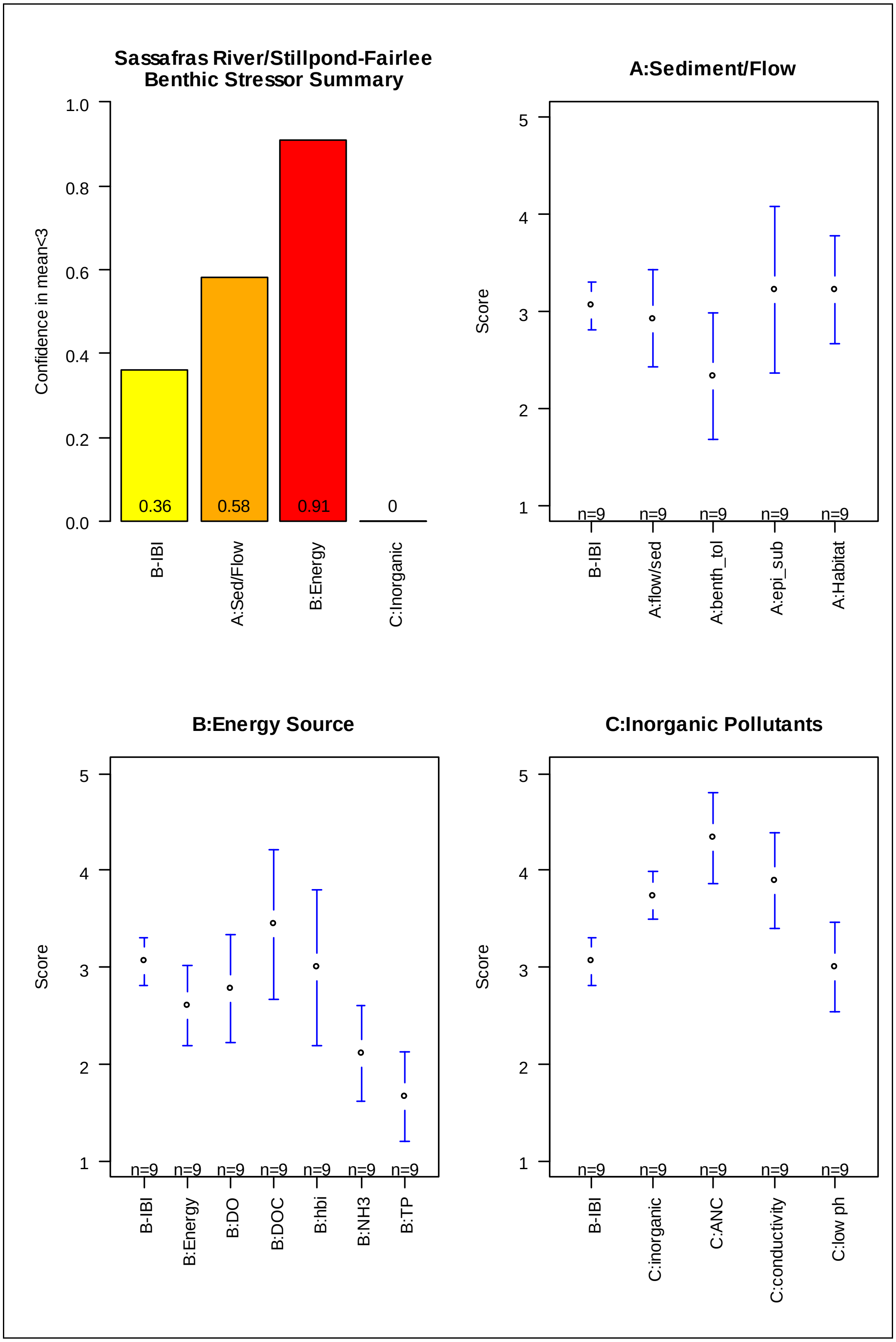


Figure F-74: Sassafras River/Stillpond-Fairlee Benthic Stressor Results

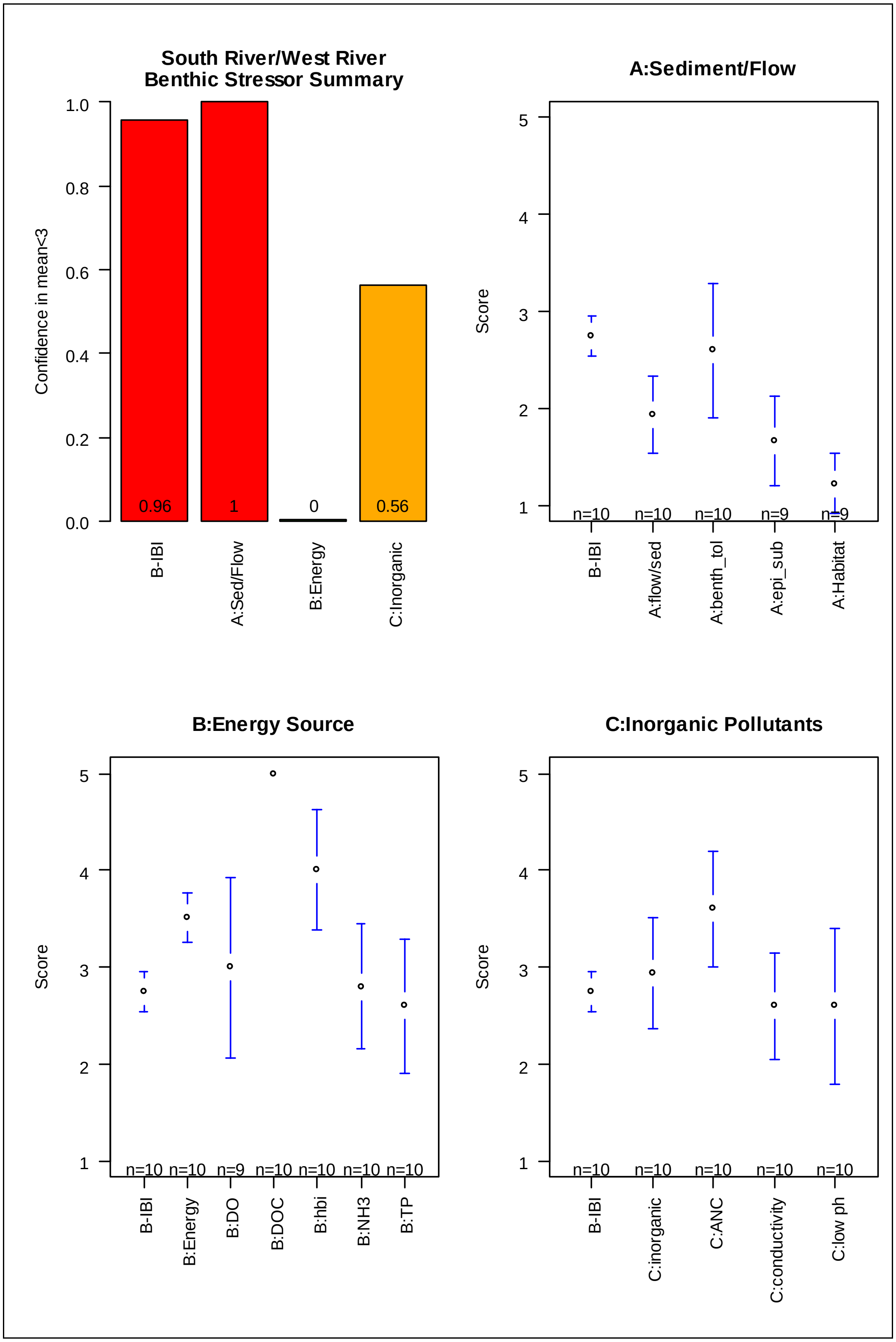


Figure F-75: South River/West River Benthic Stressor Results

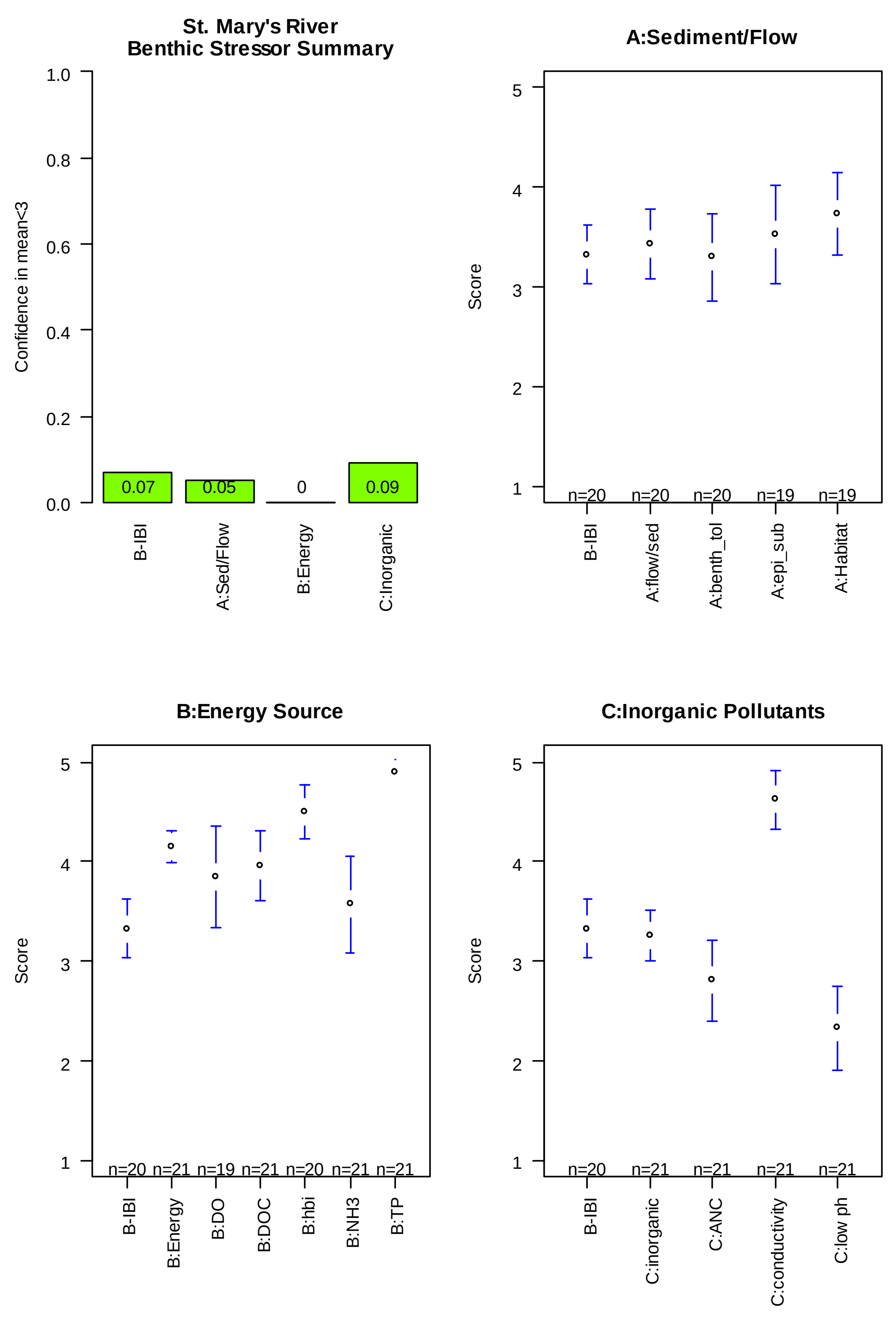


Figure F-76: St. Mary's River Benthic Stressor Results

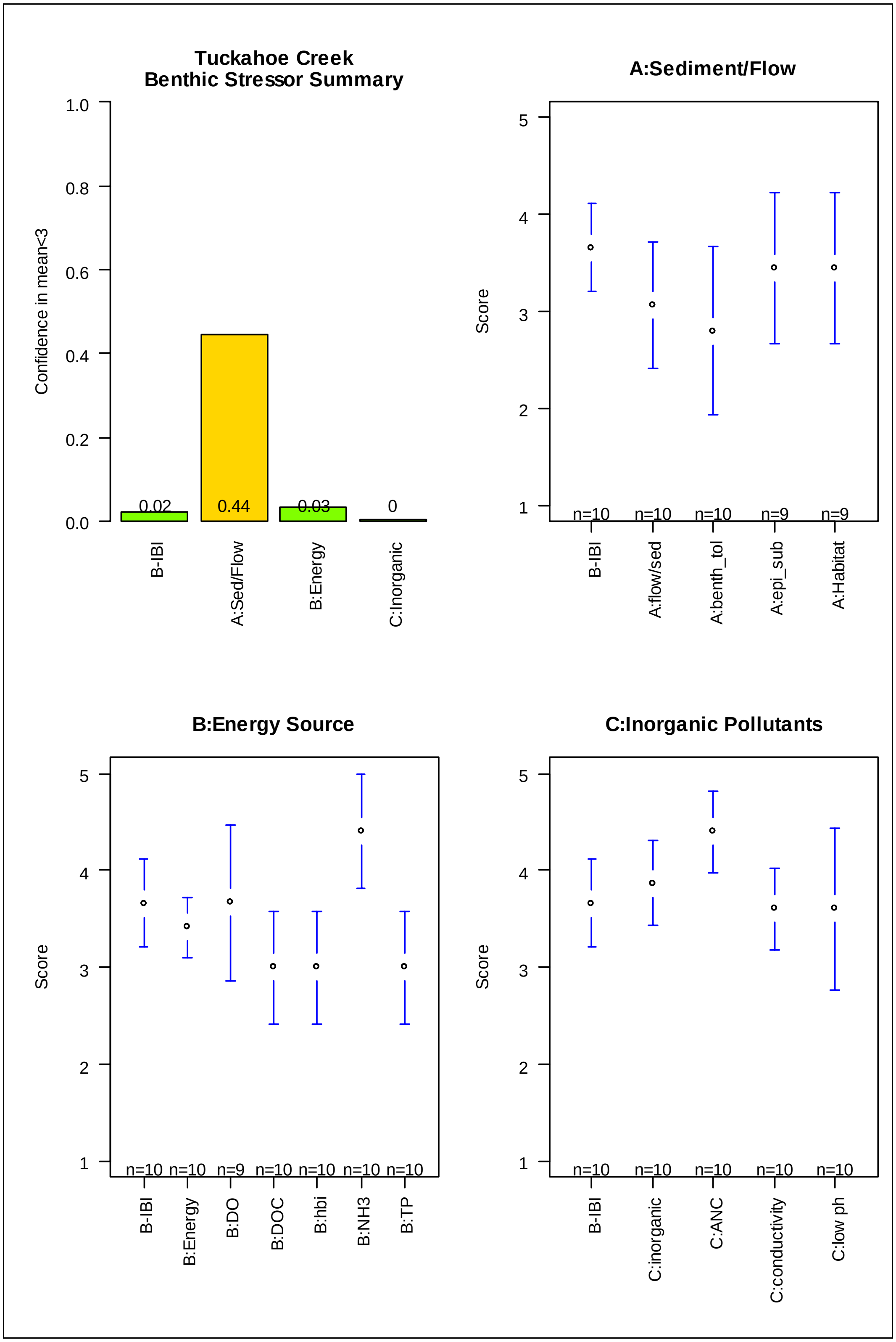


Figure F-77: Tuckahoe Creek Benthic Stressor Results

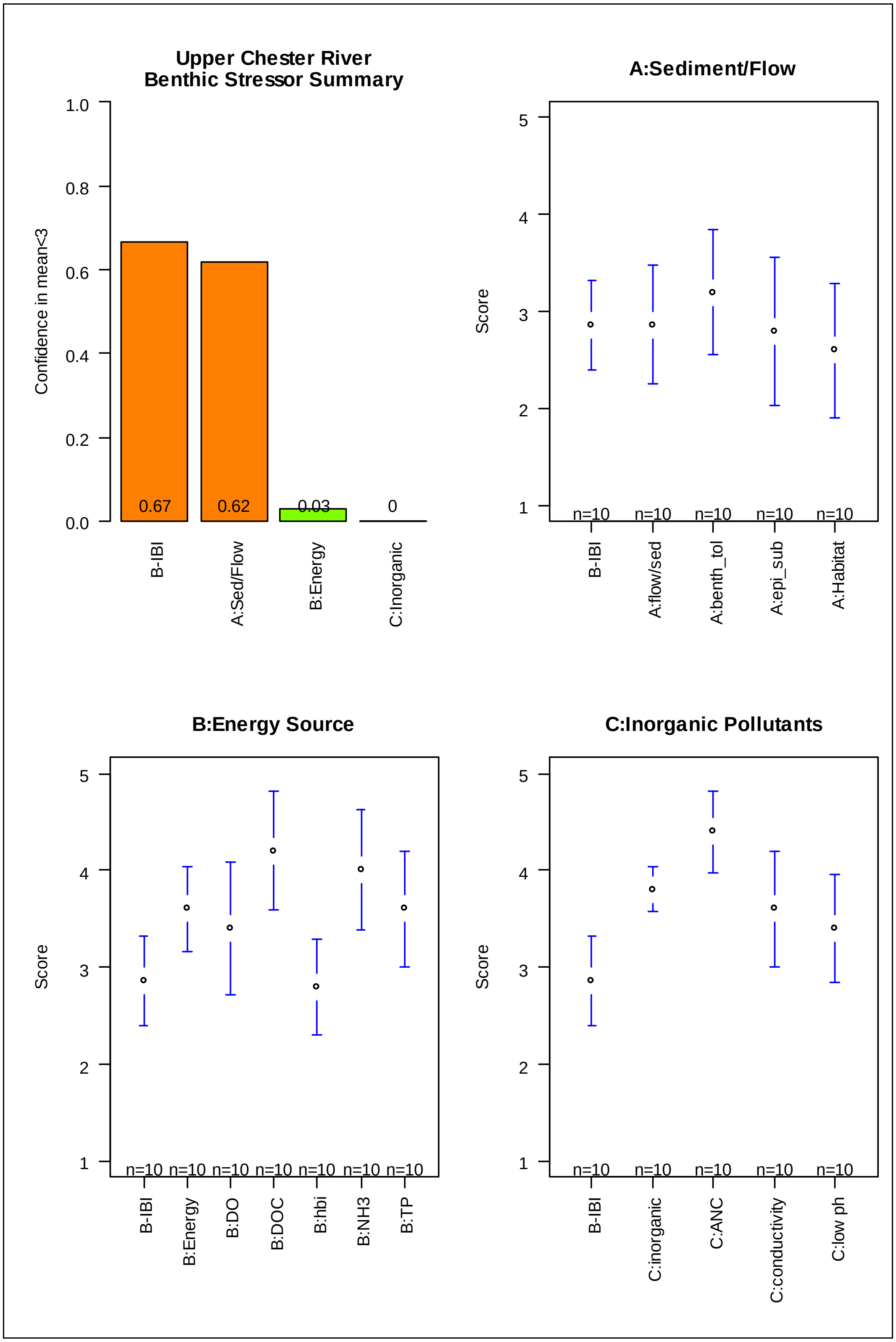


Figure F-78: Upper Chester River Benthic Stressor Results

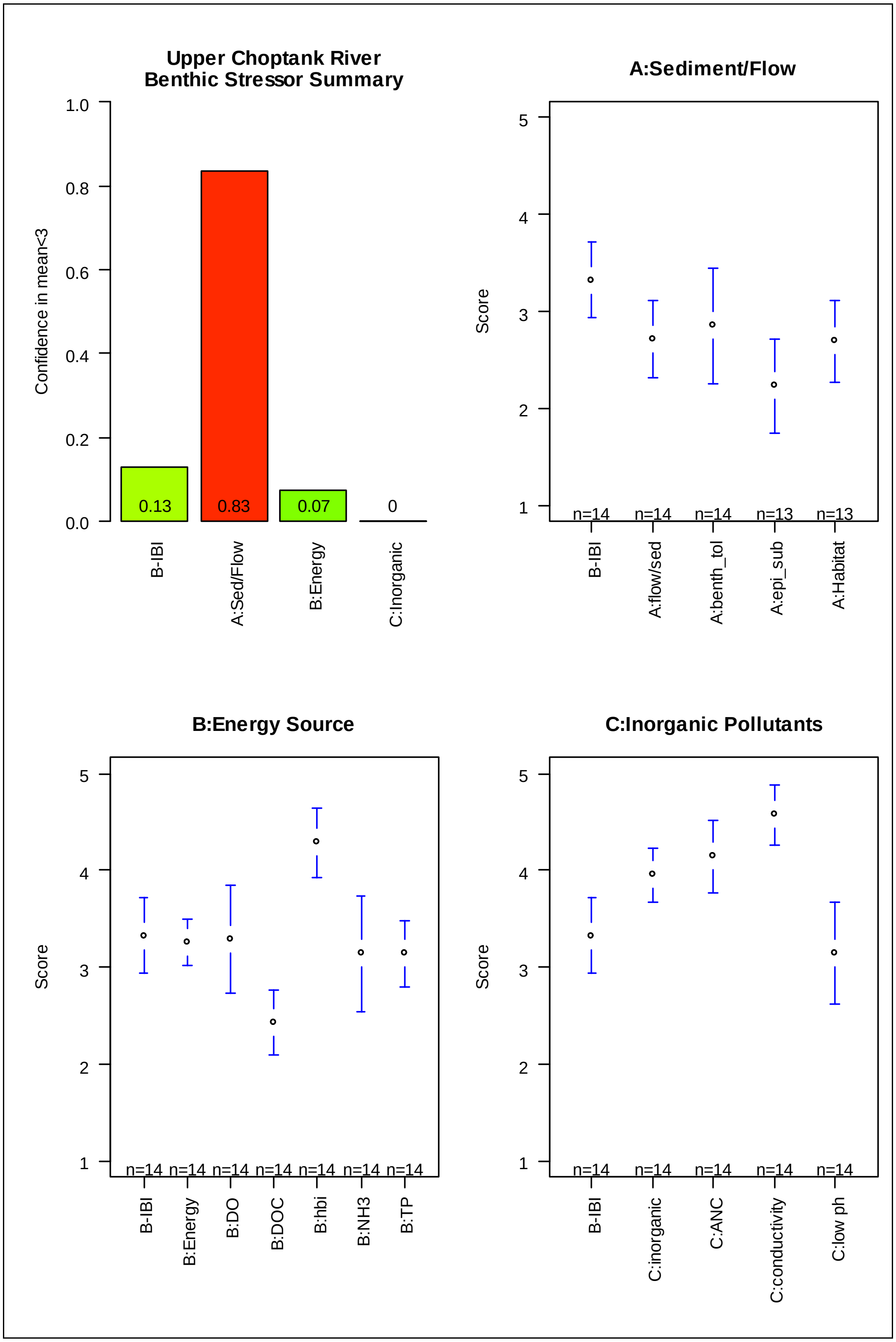


Figure F-79: Upper Choptank River Benthic Stressor Results

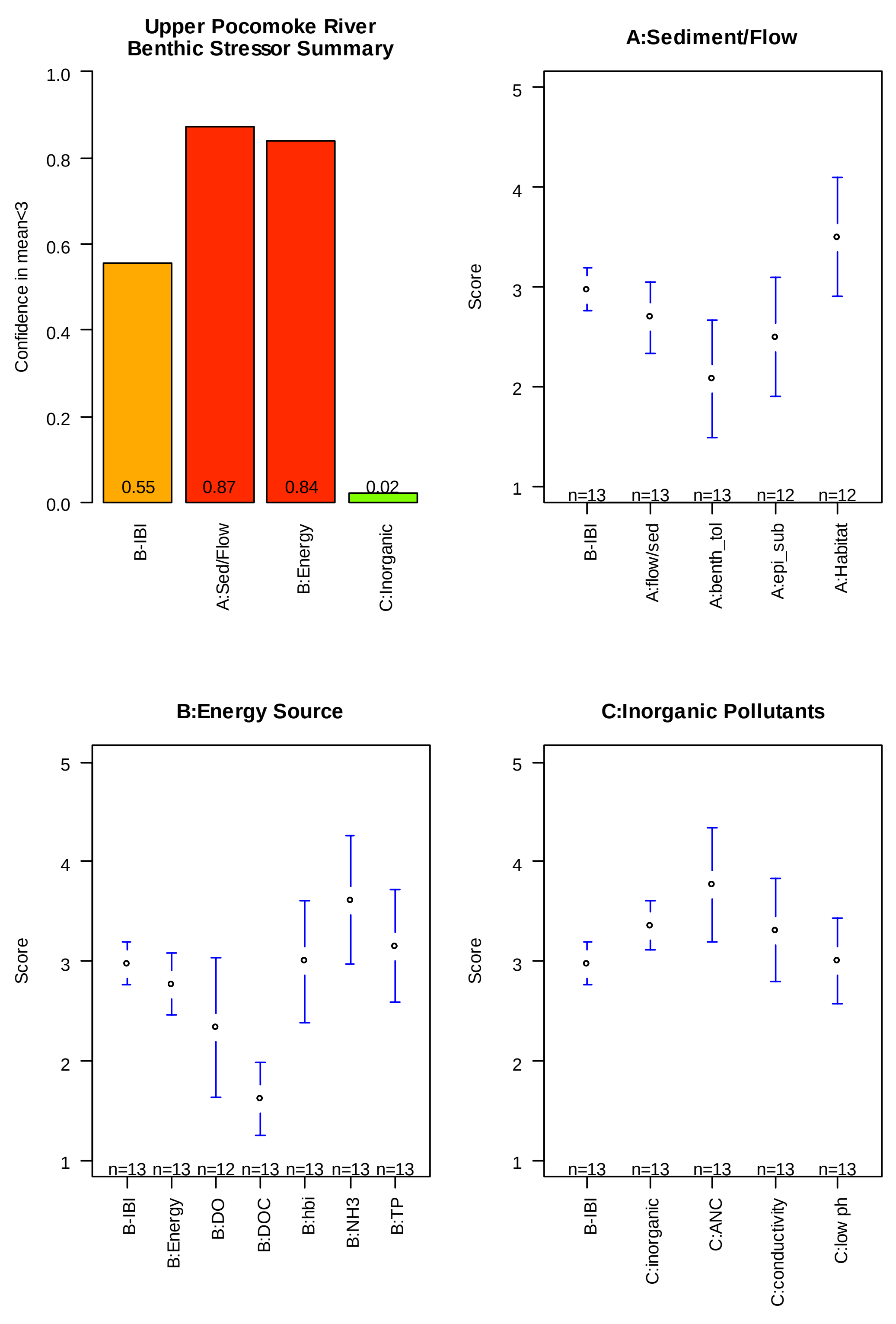


Figure F-80: Upper Pocomoke River Benthic Stressor Results

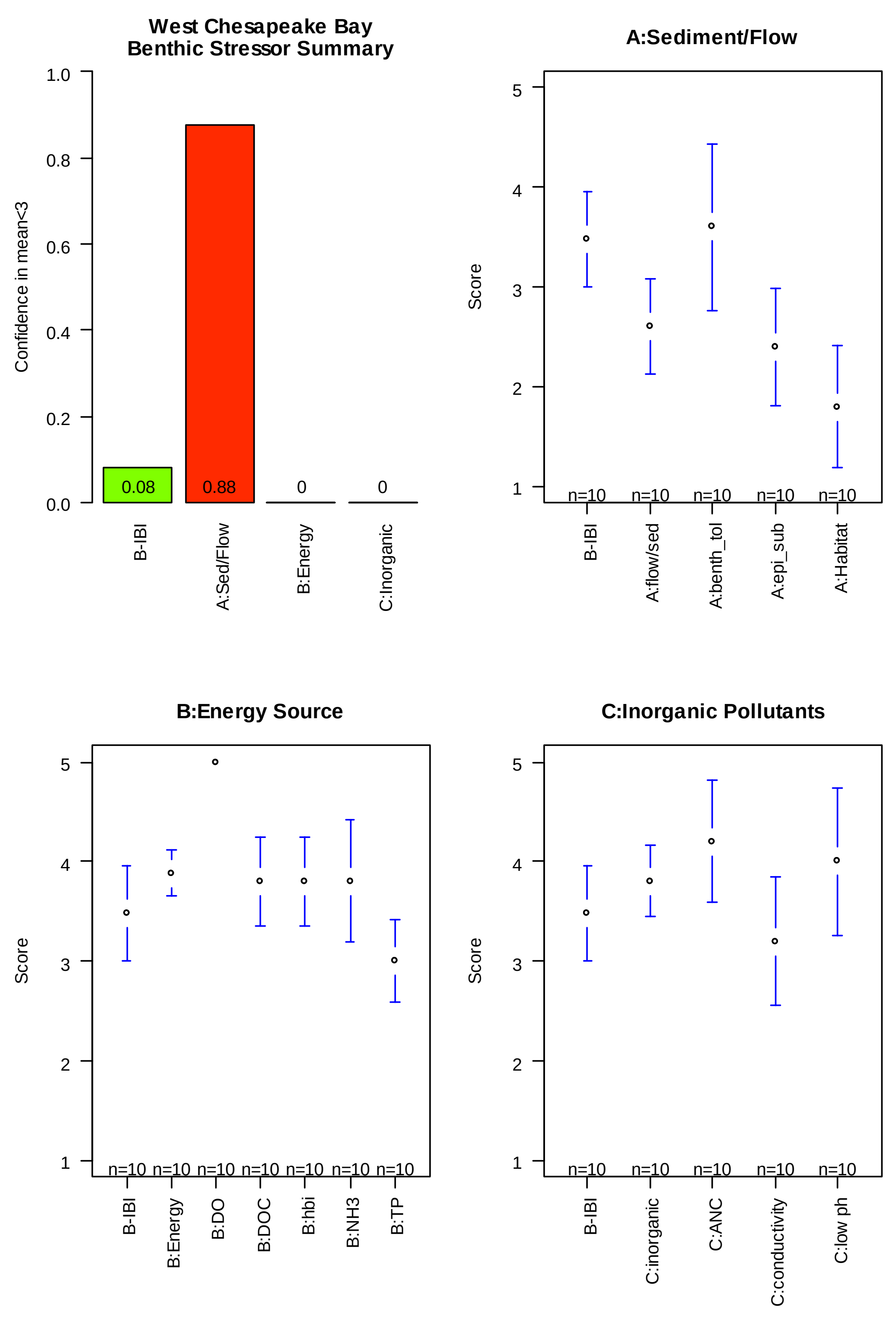


Figure F-81: West Chesapeake Bay Benthic Stressor Results

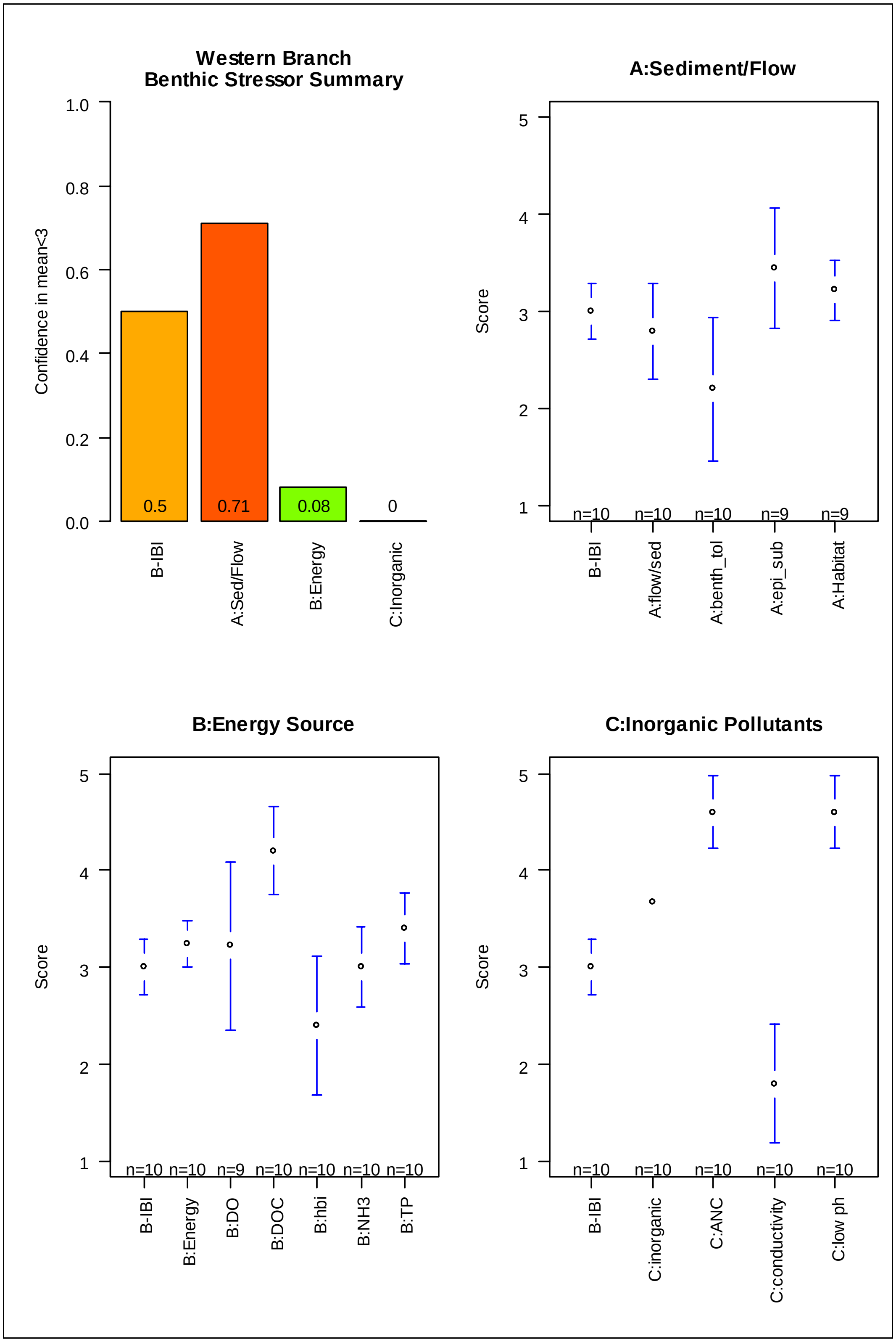


Figure F-82: Western Branch Benthic Stressor Results

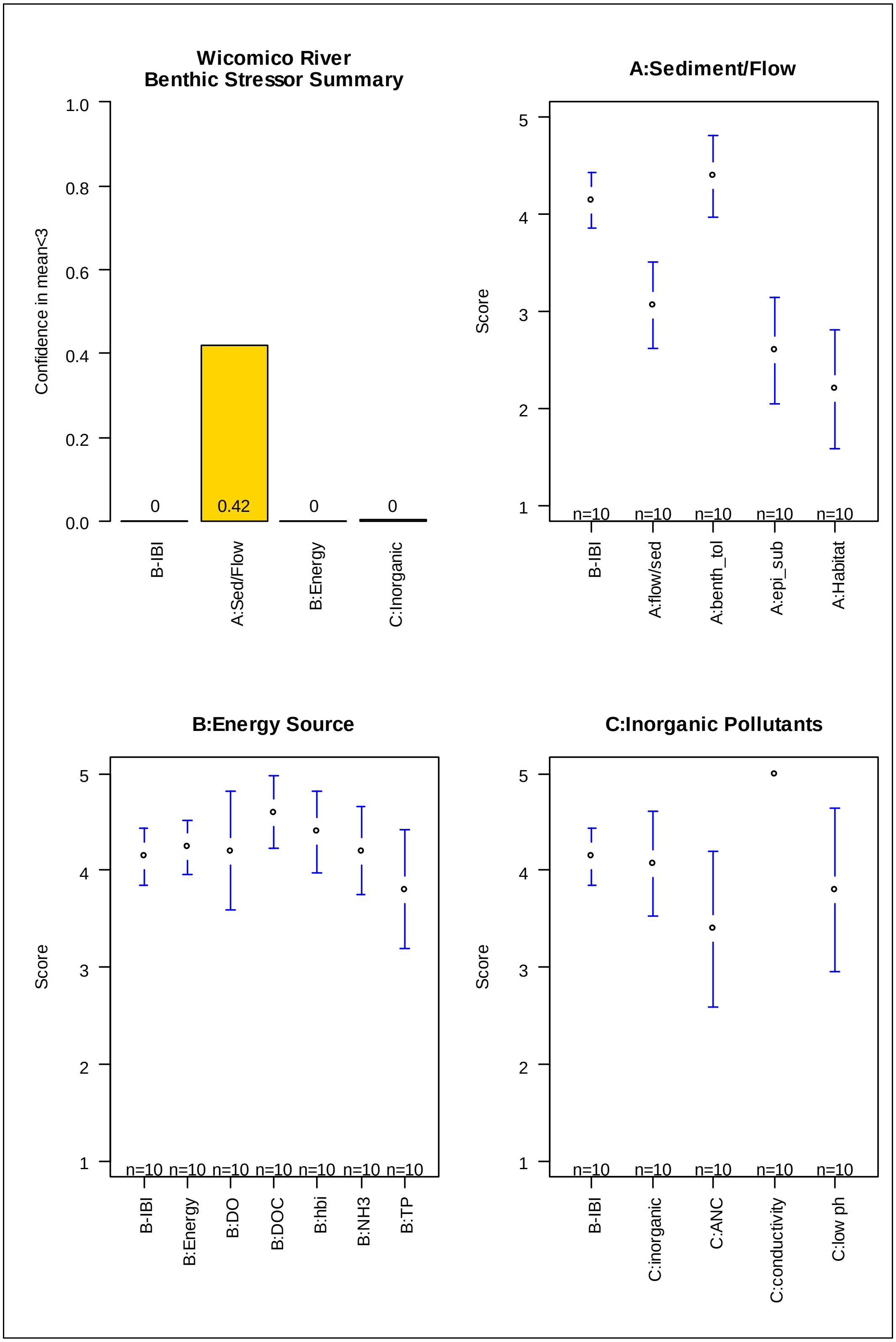


Figure F-83: Wicomico River Benthic Stressor Results

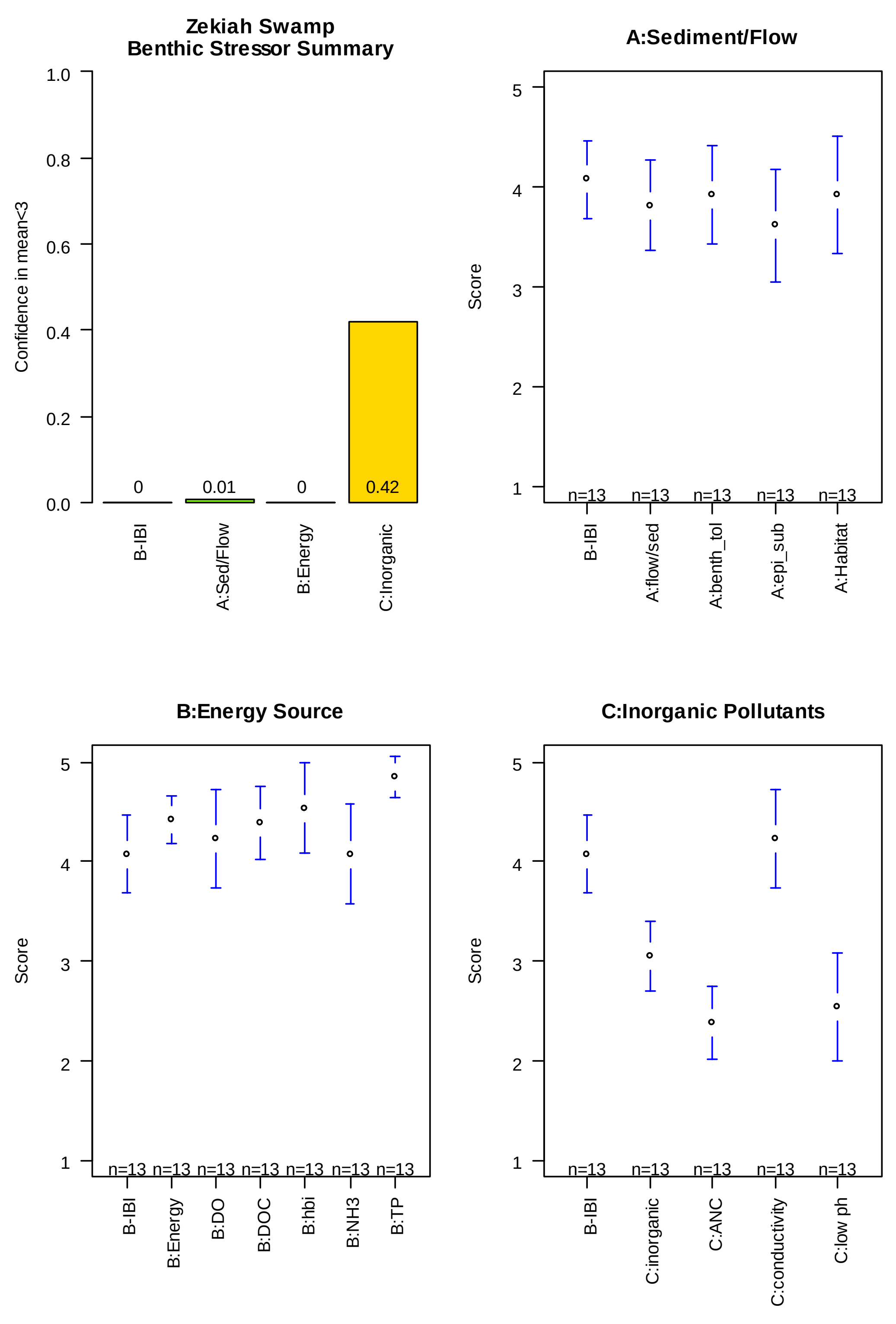


Figure F-84: Zekiah Swamp Benthic Stressor Results

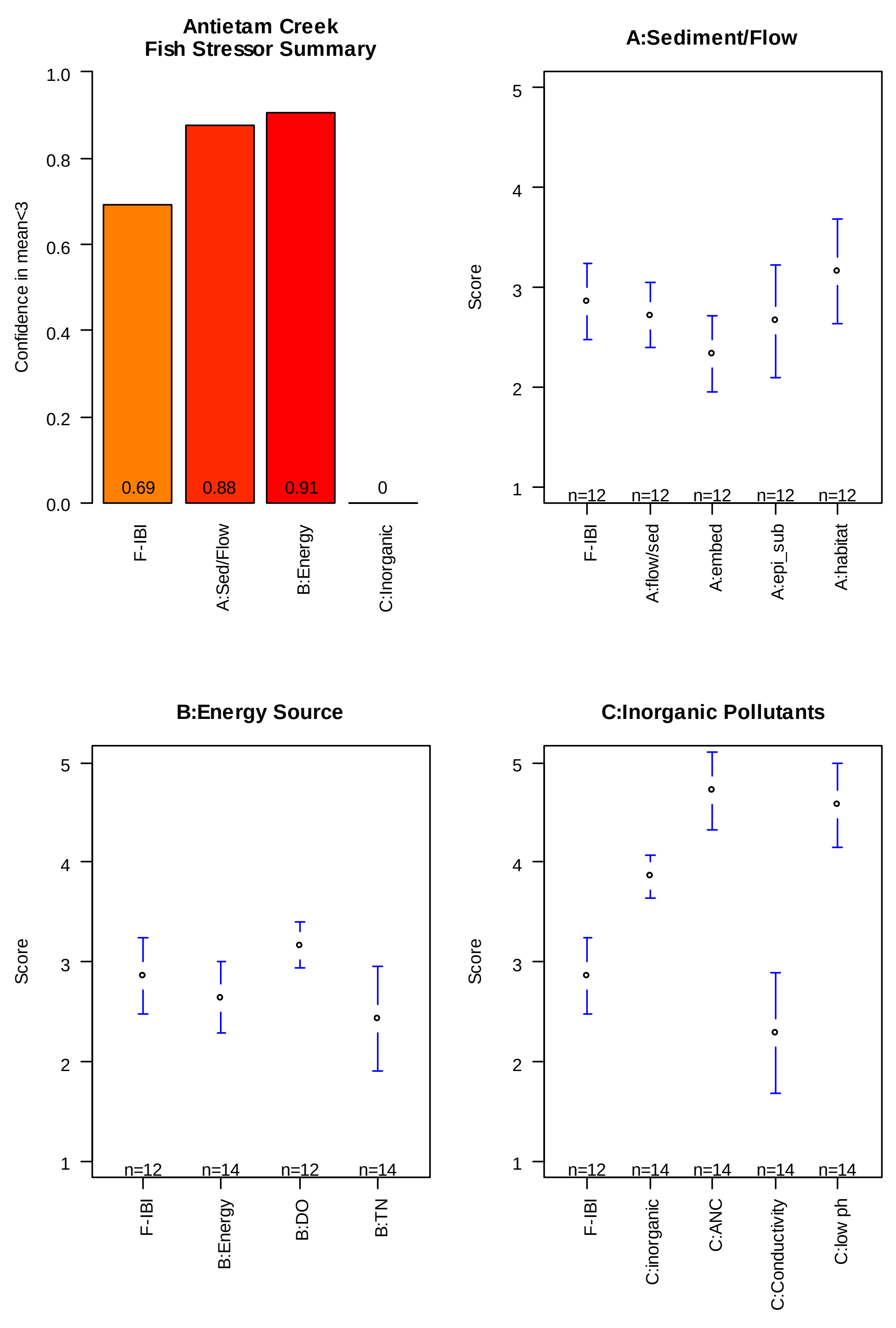


Figure F-85: Antietam Creek Fish Stressor Results

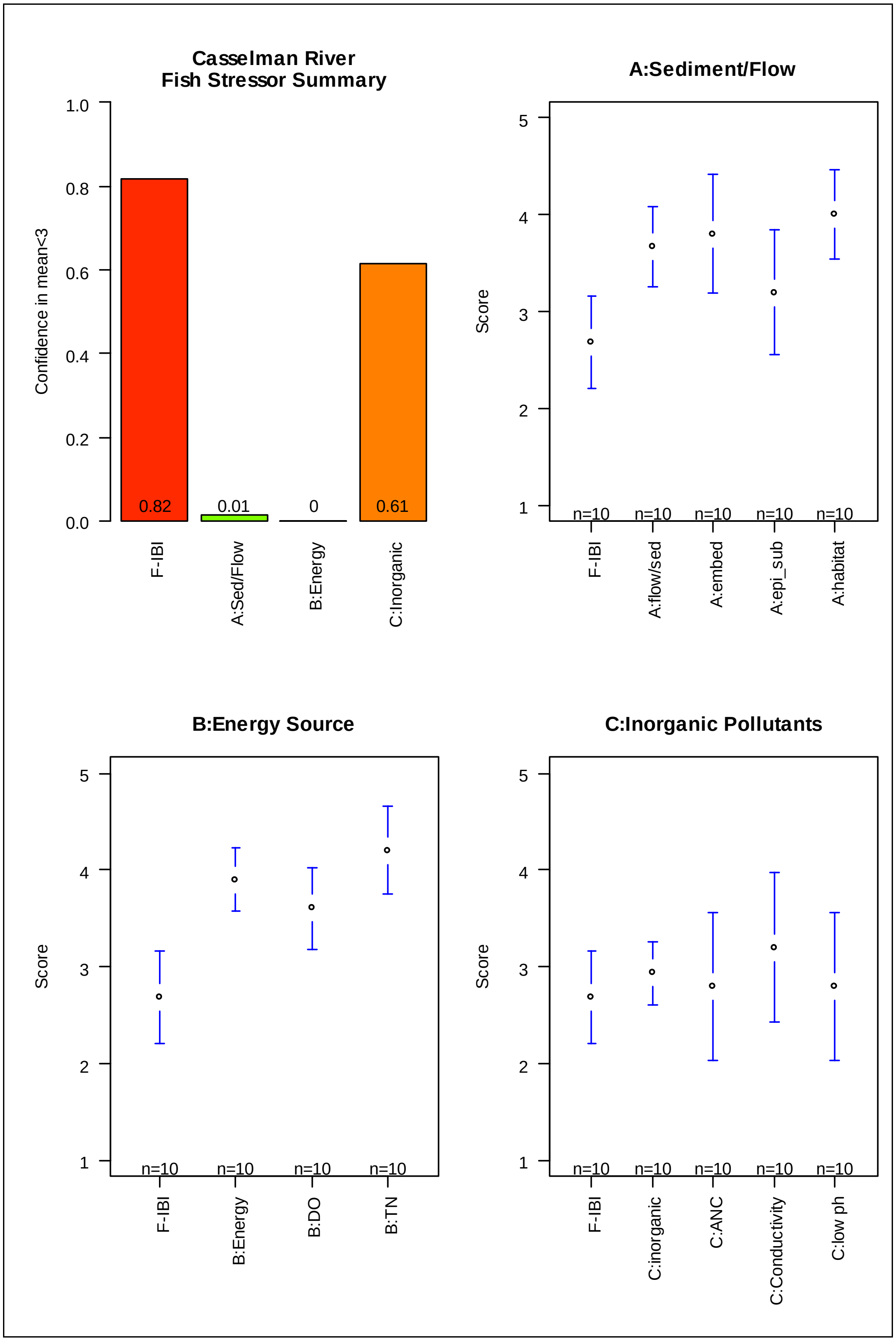


Figure F-86: Casselman River Fish Stressor Results

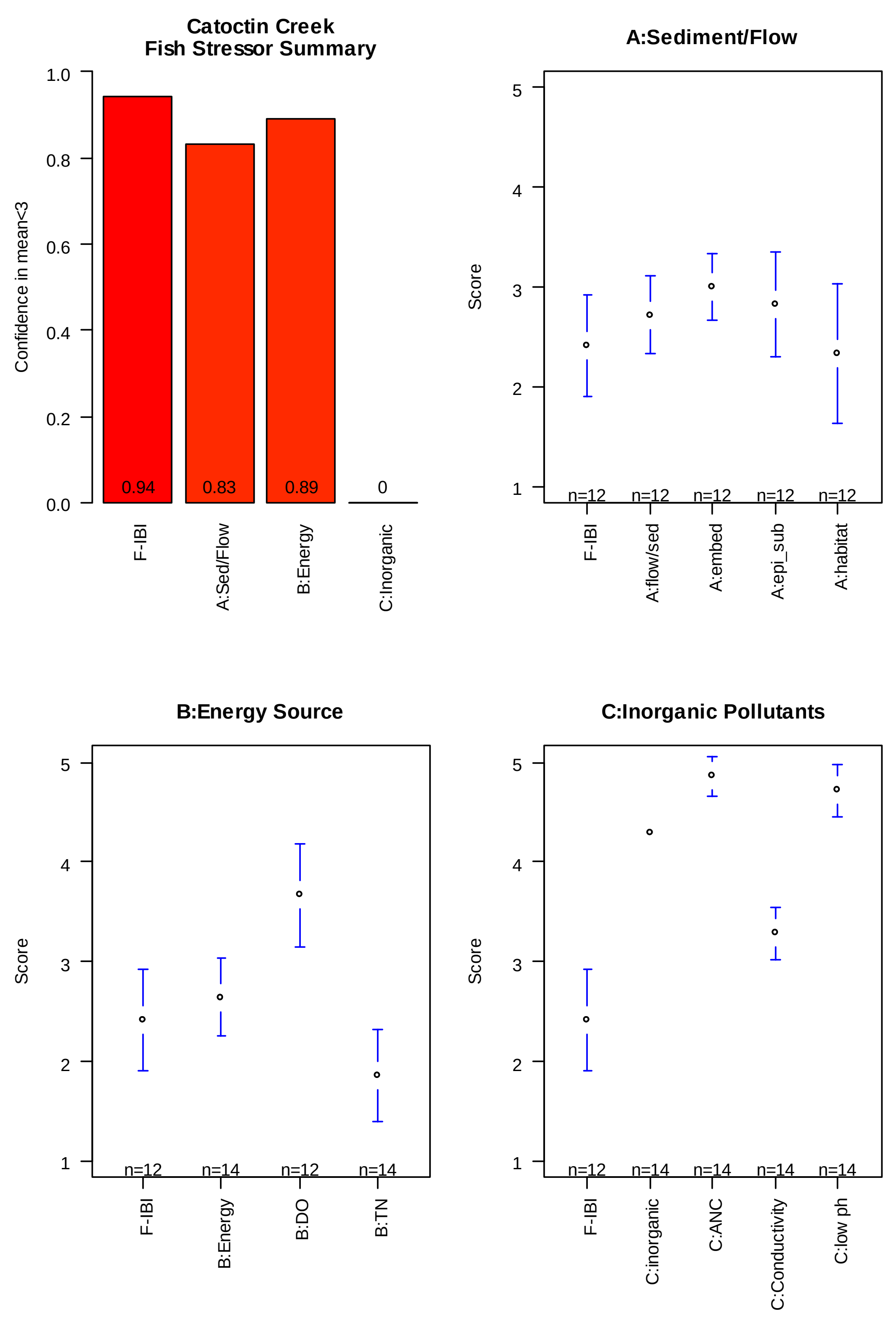


Figure F-87: Catoctin Creek Fish Stressor Results

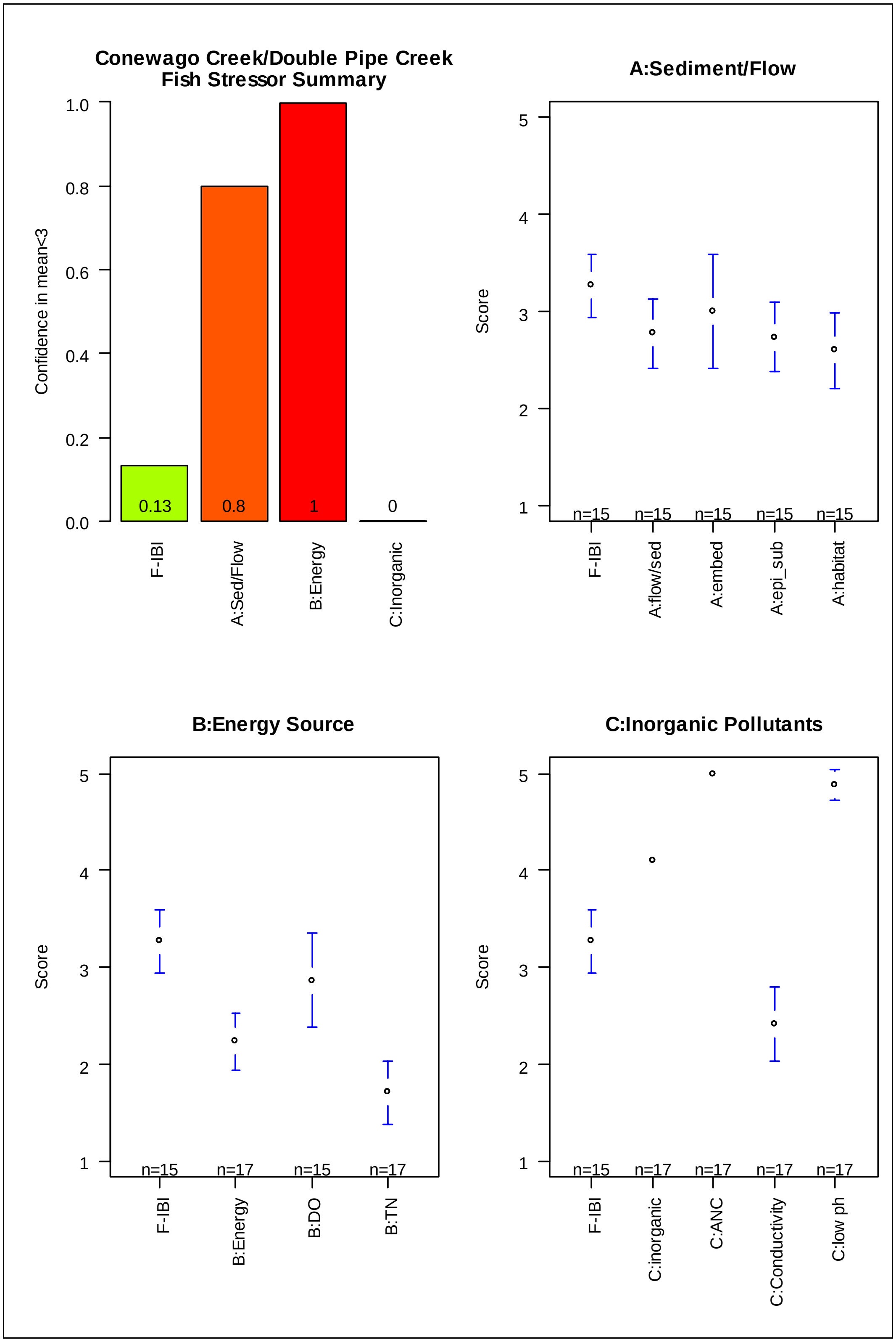


Figure F-88: Conewago Creek/Double Pipe Creek Fish Stressor Results

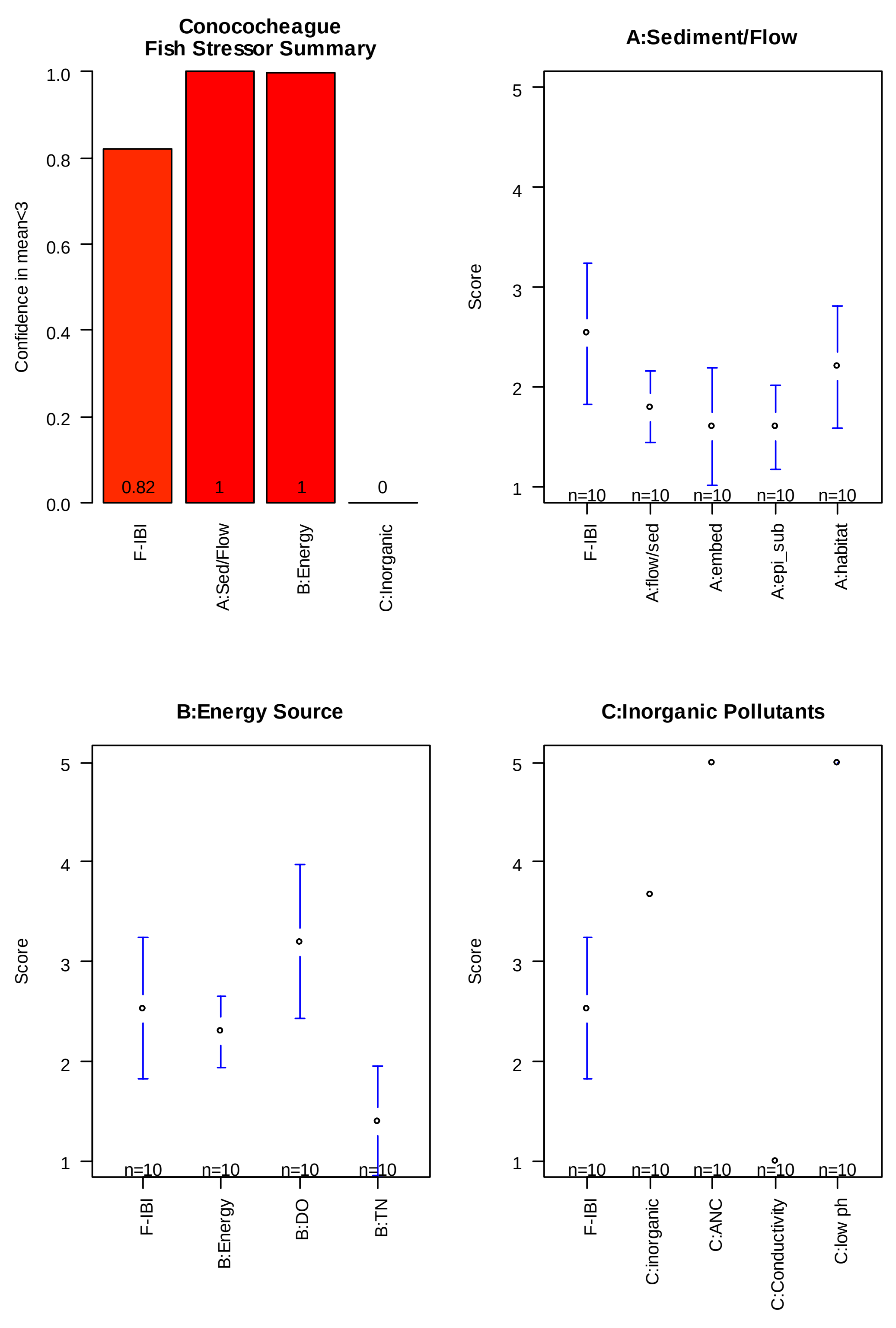


Figure F-89: Conococheague Fish Stressor Results

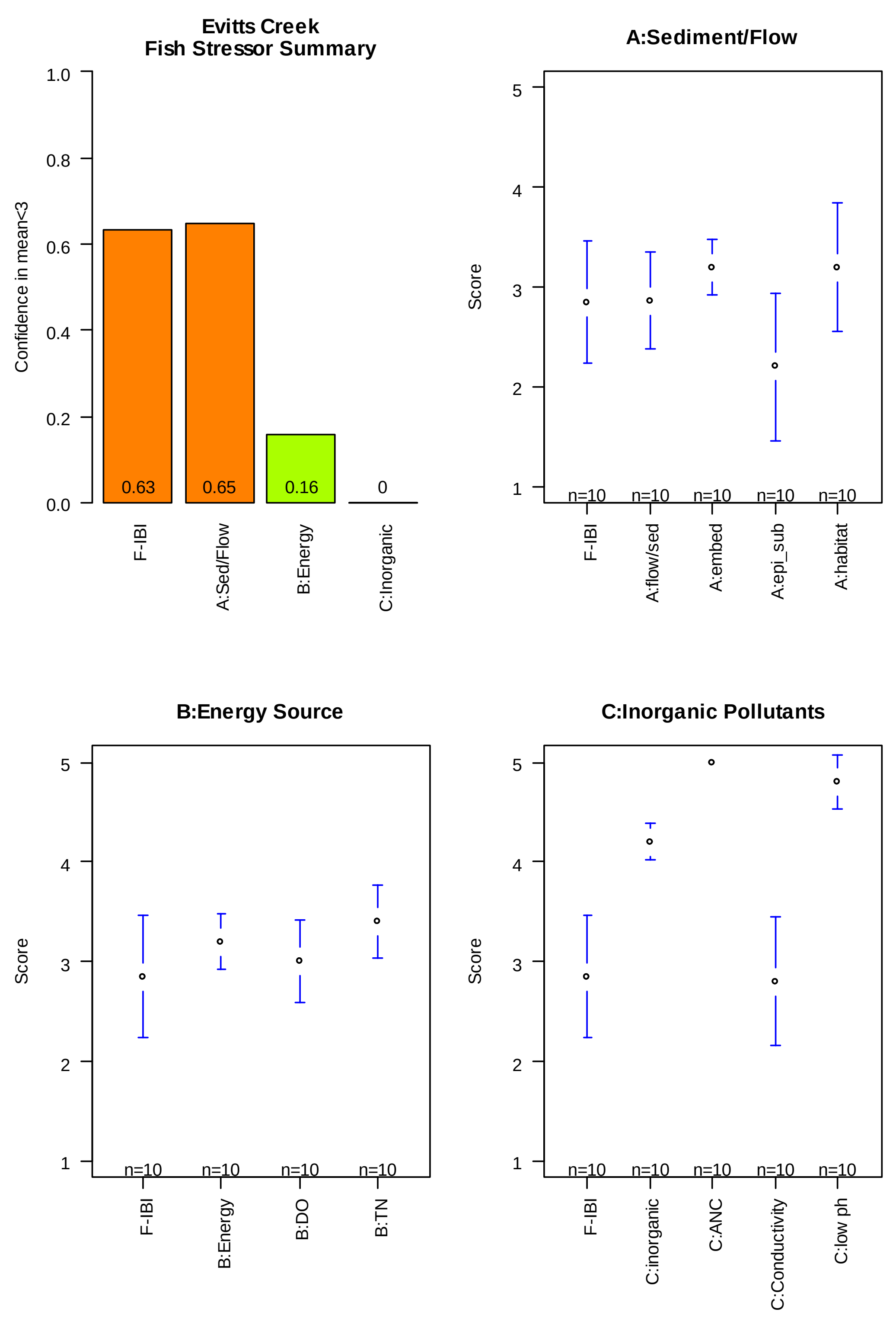


Figure F-90: Evitts Creek Fish Stressor Results

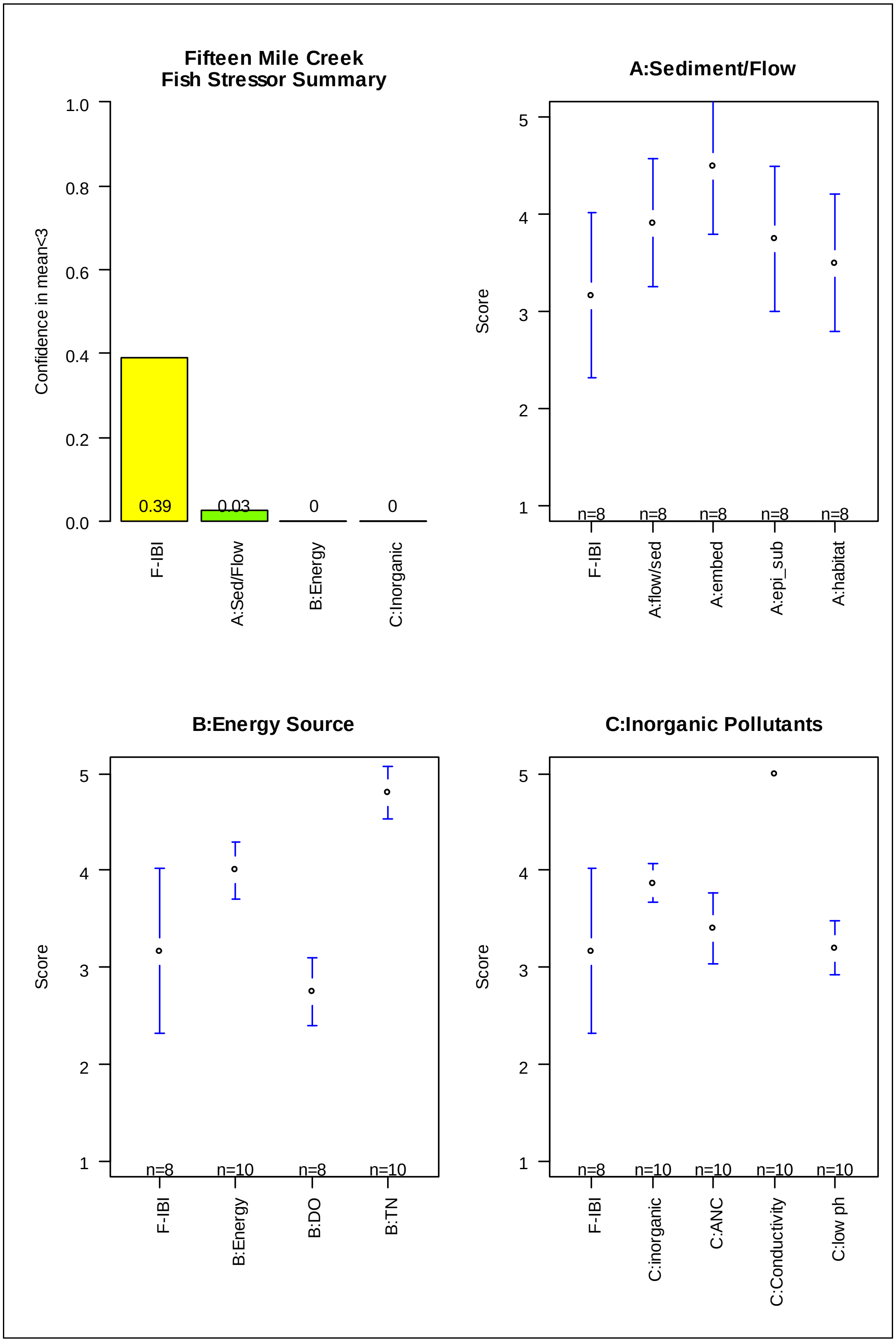


Figure F-91: Fifteen Mile Creek Fish Stressor Results

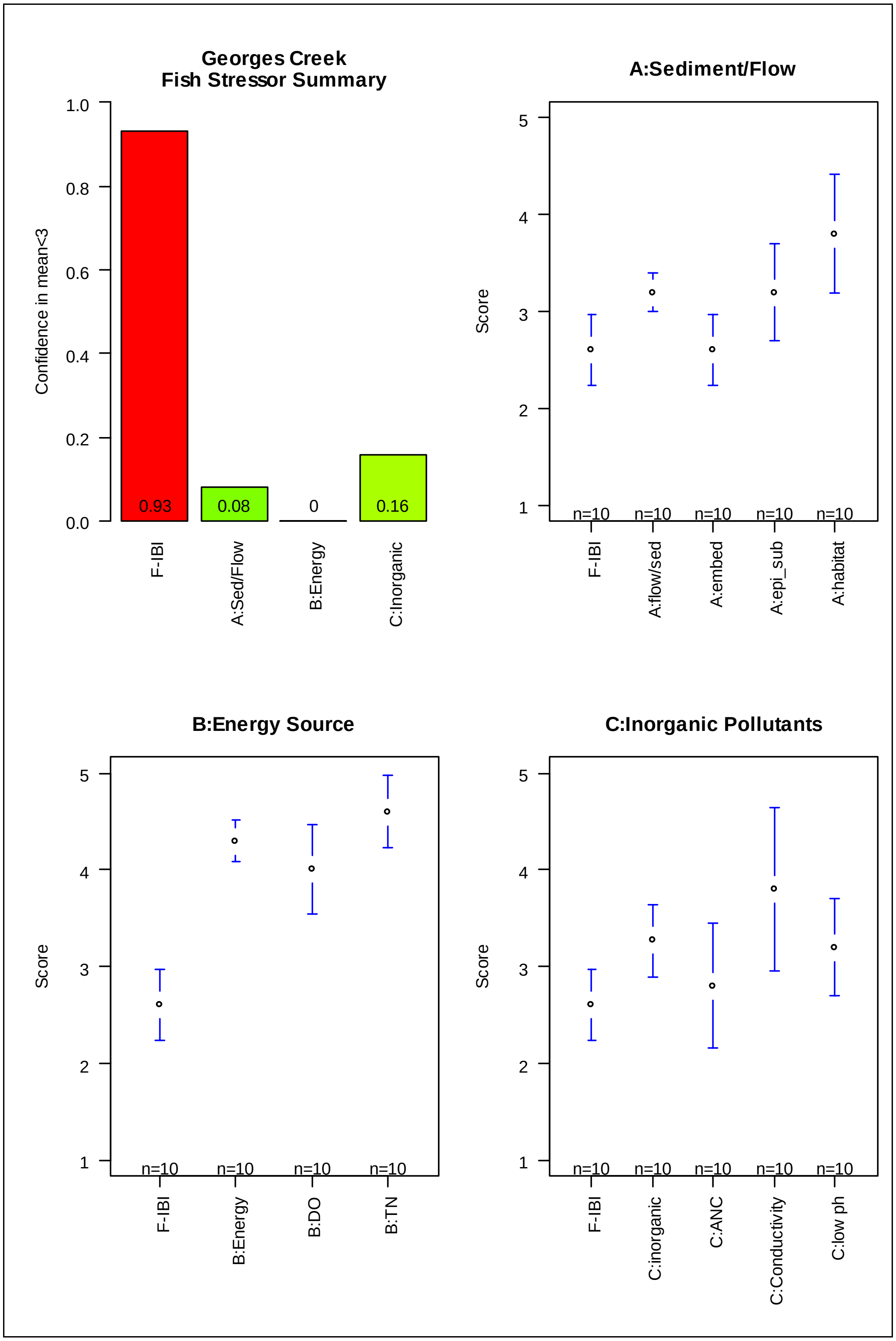


Figure F-92: Georges Creek Fish Stressor Results

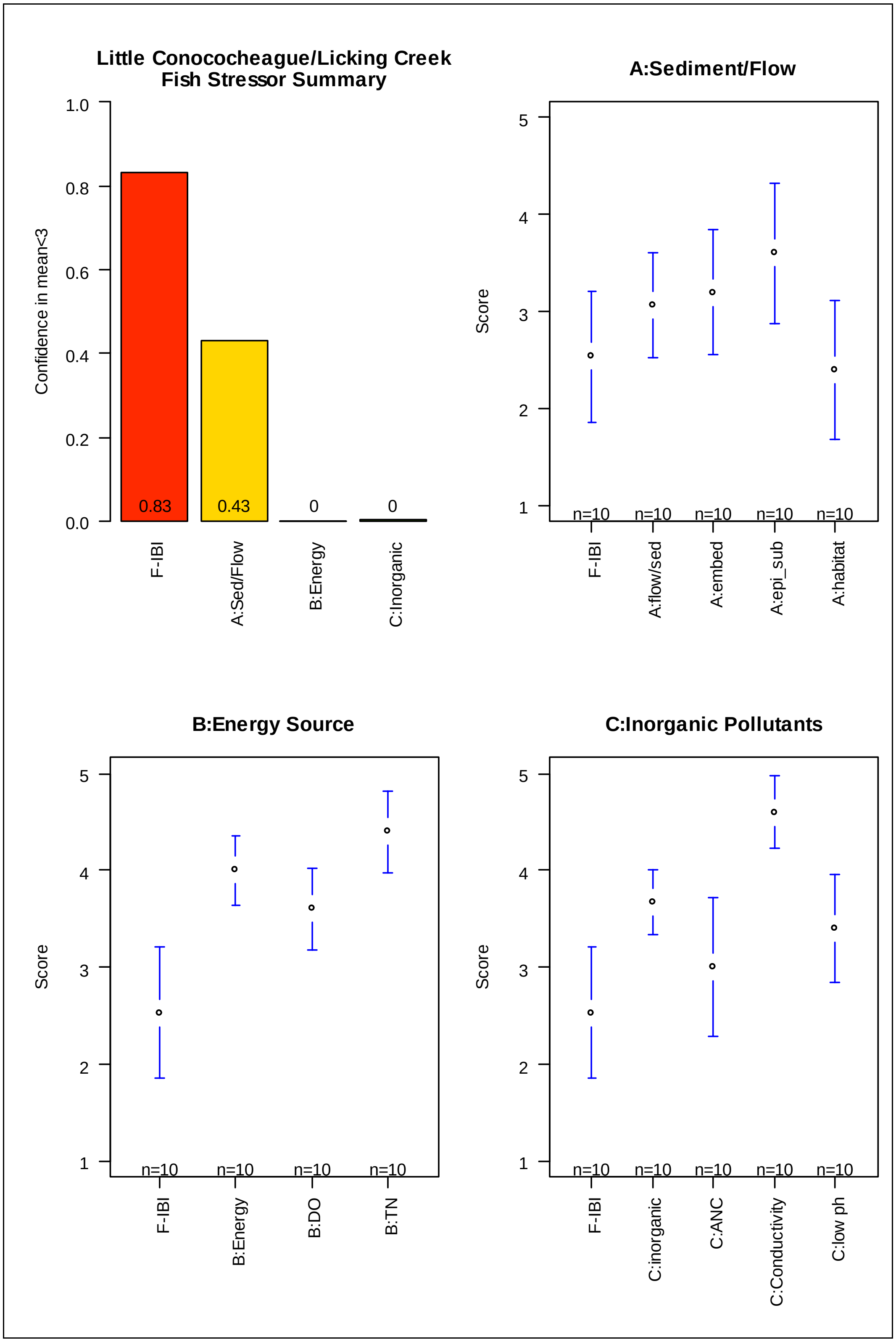


Figure F-93: Little Conococheague/Licking Creek Fish Stressor Results

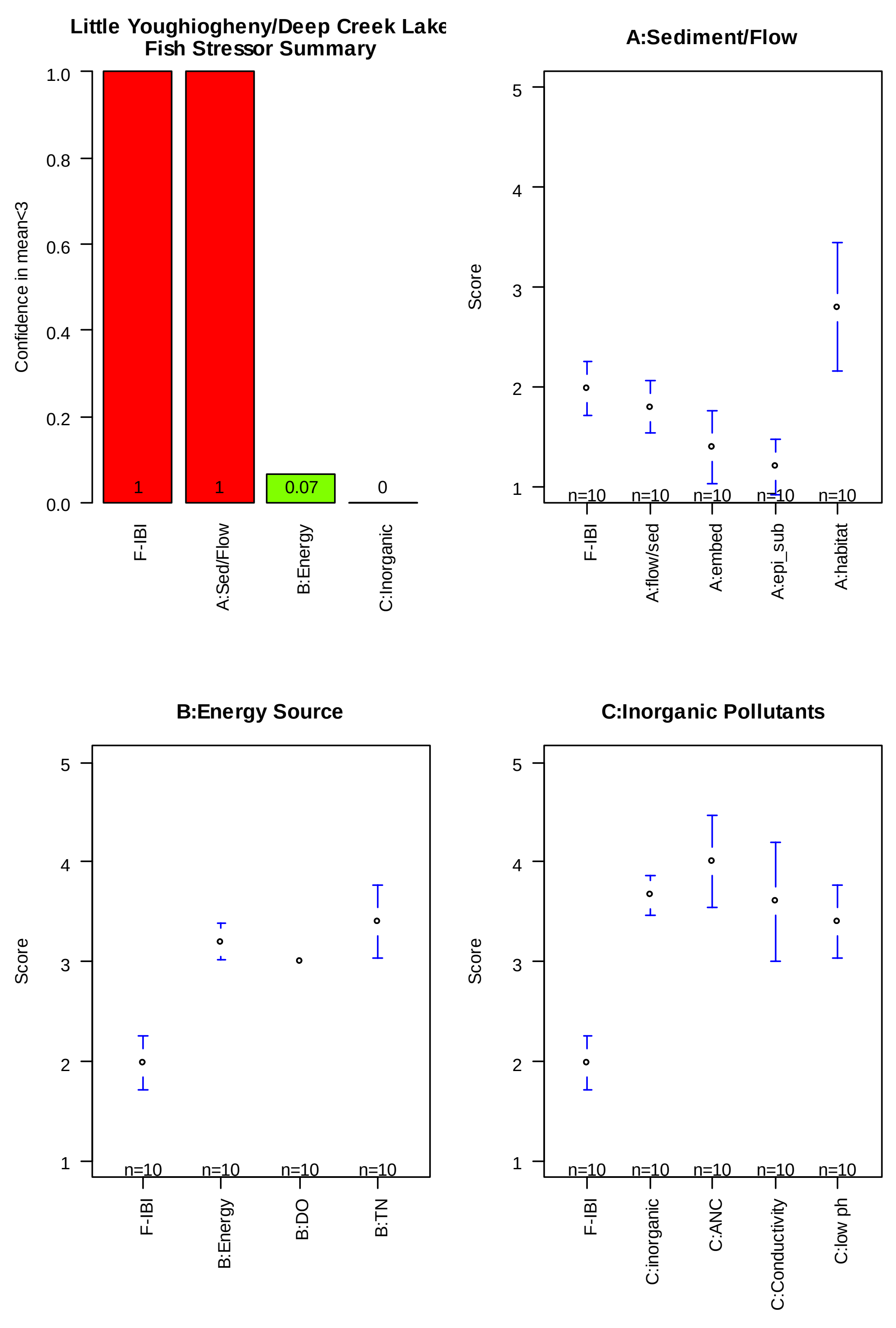


Figure F-94: Little Youghiogheny/Deep Creek Lake Fish Stressor Results

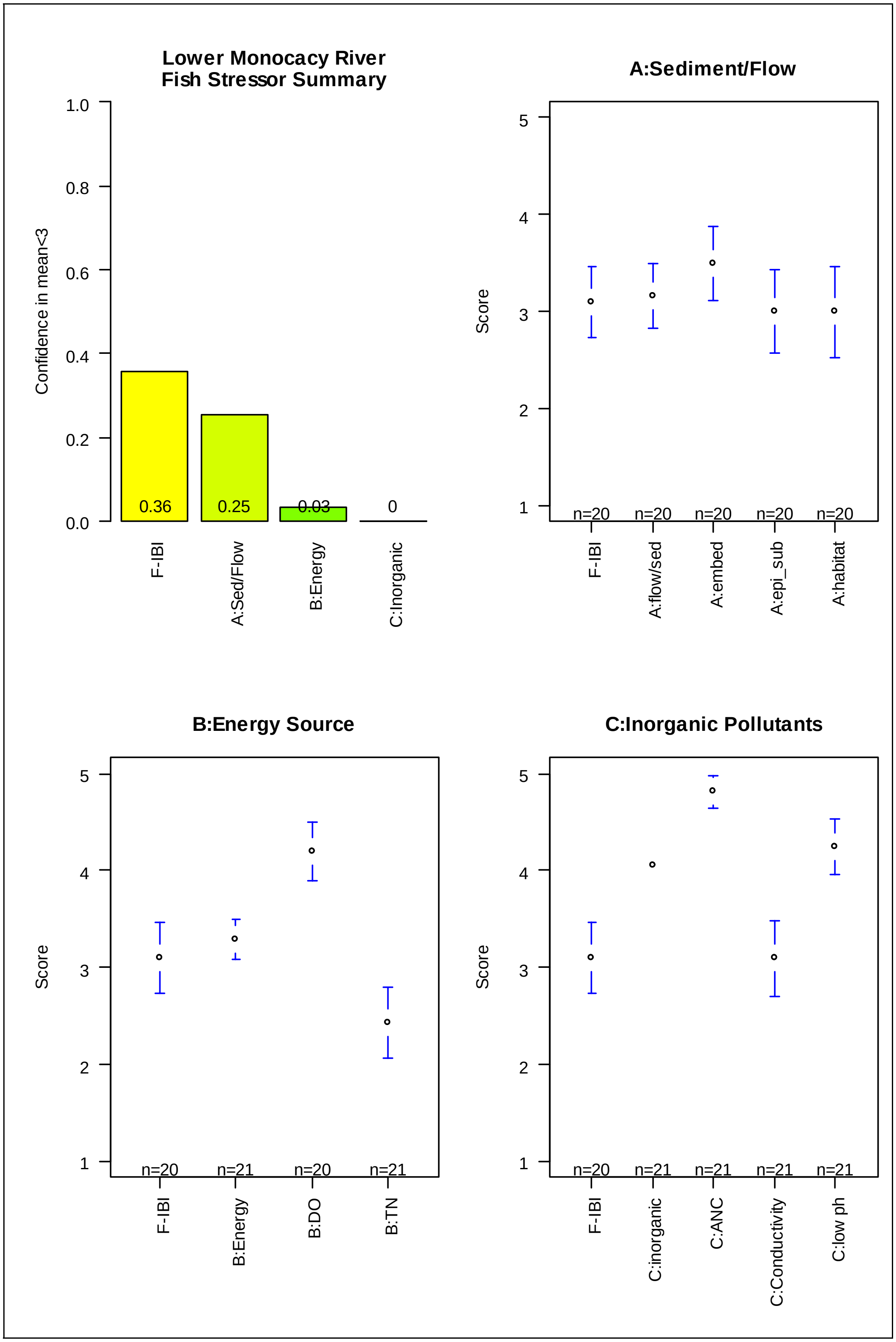


Figure F-95: Lower Monocacy River Fish Stressor Results

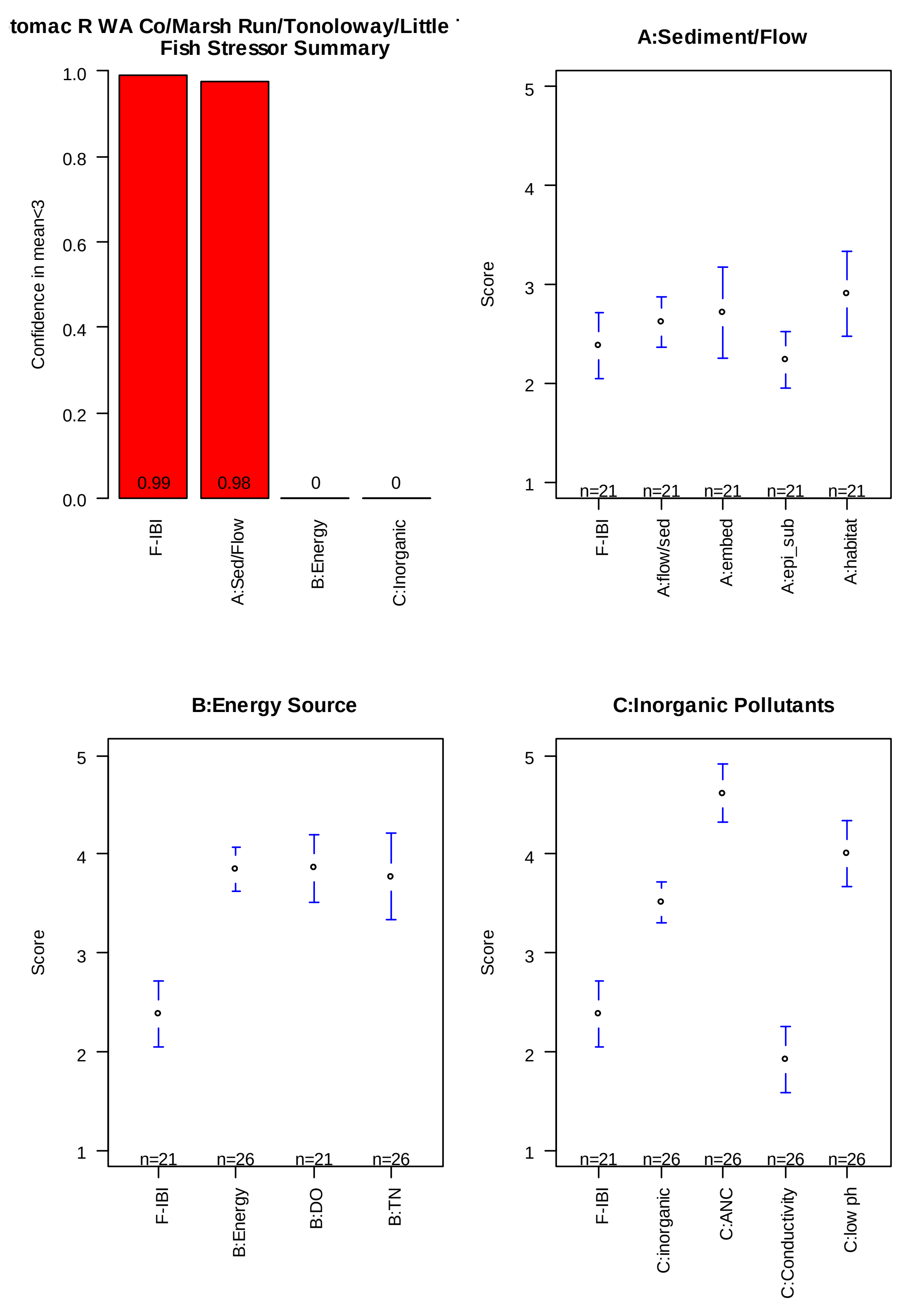


Figure F-96: Potomac River WA County/Marsh Run/Tonoloway/Little Tonoloway Fish Stressor Results

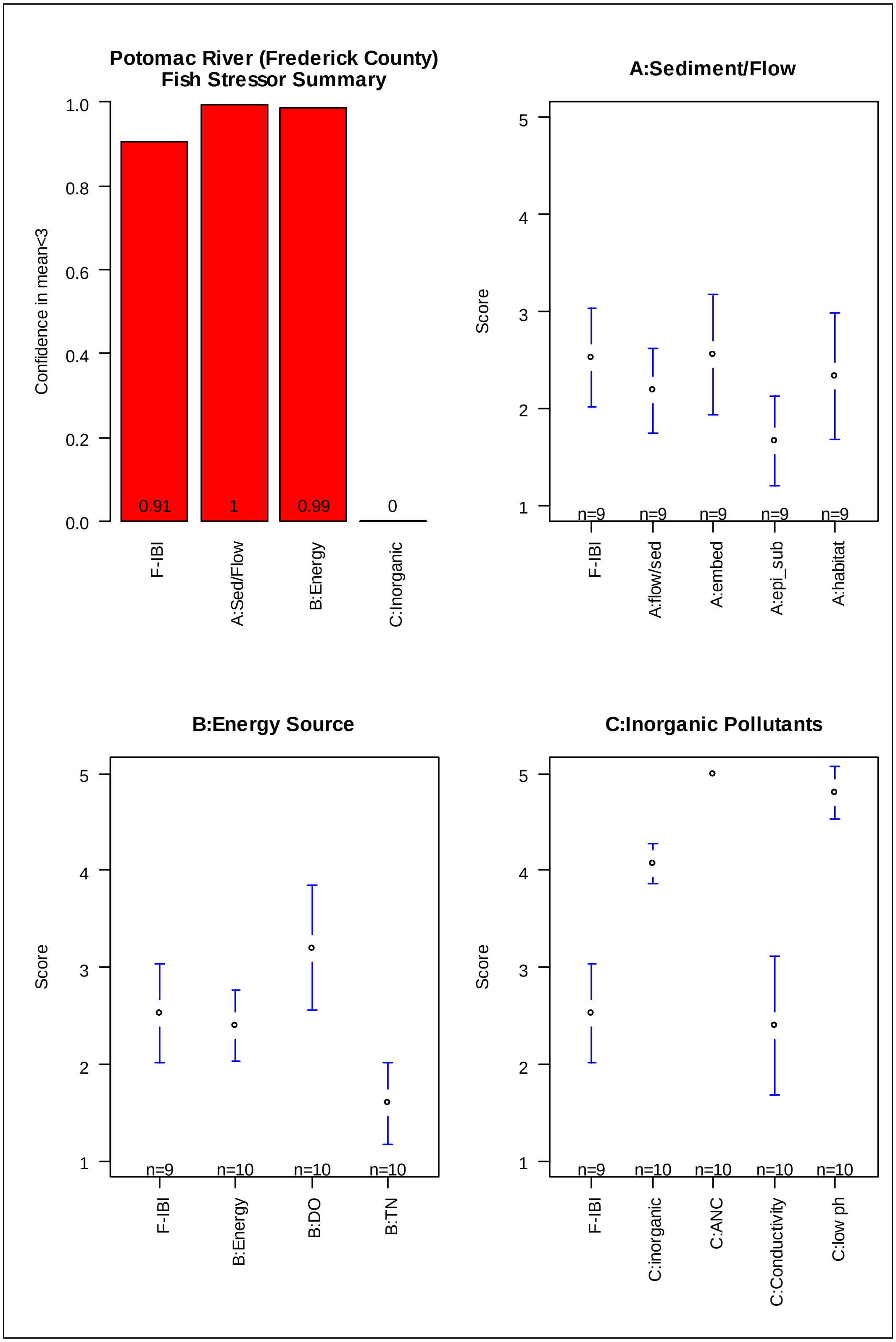


Figure F-97: Potomac River (Frederick County) Fish Stressor Results

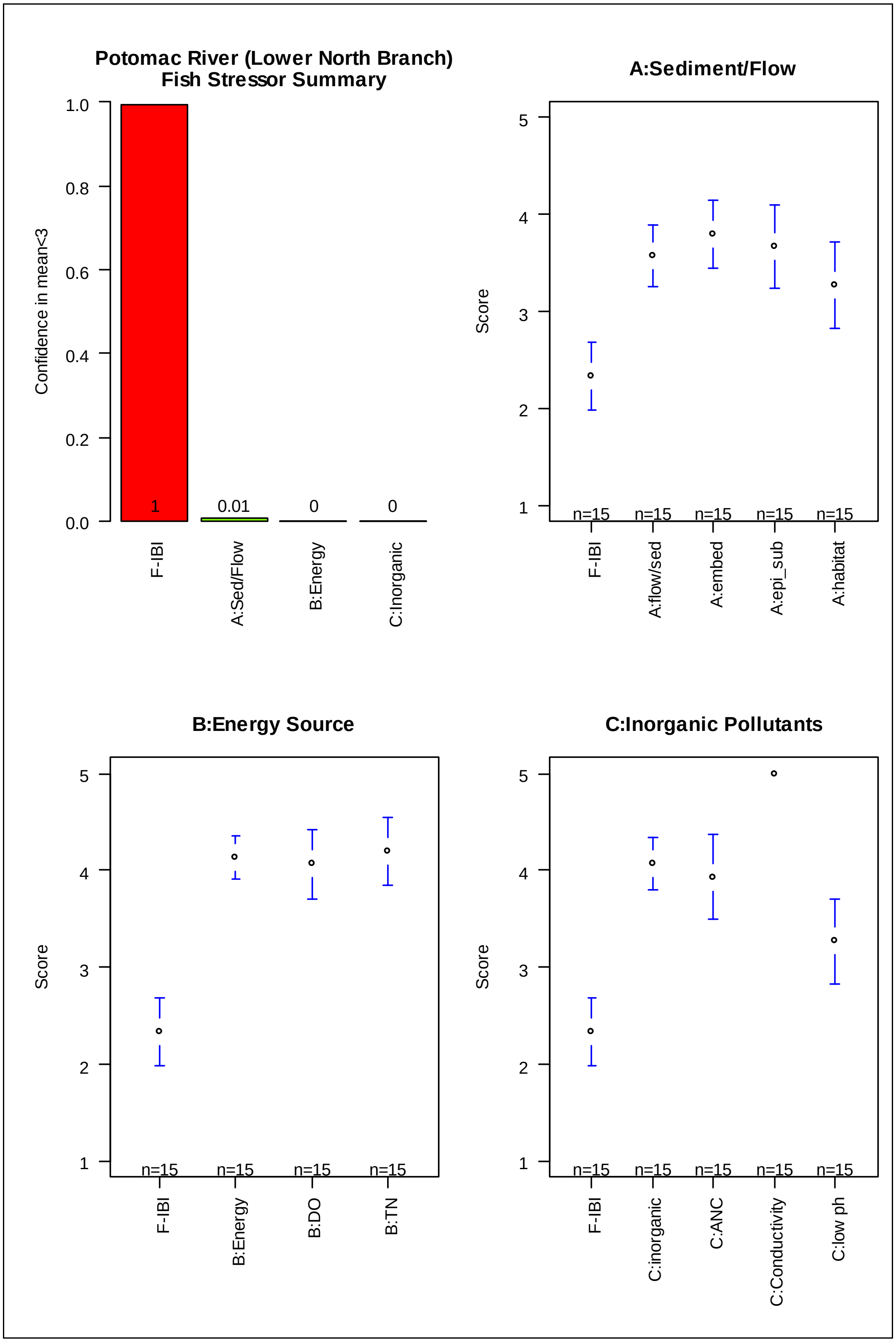


Figure F-98: Potomac River Lower North Branch Fish Stressor Results

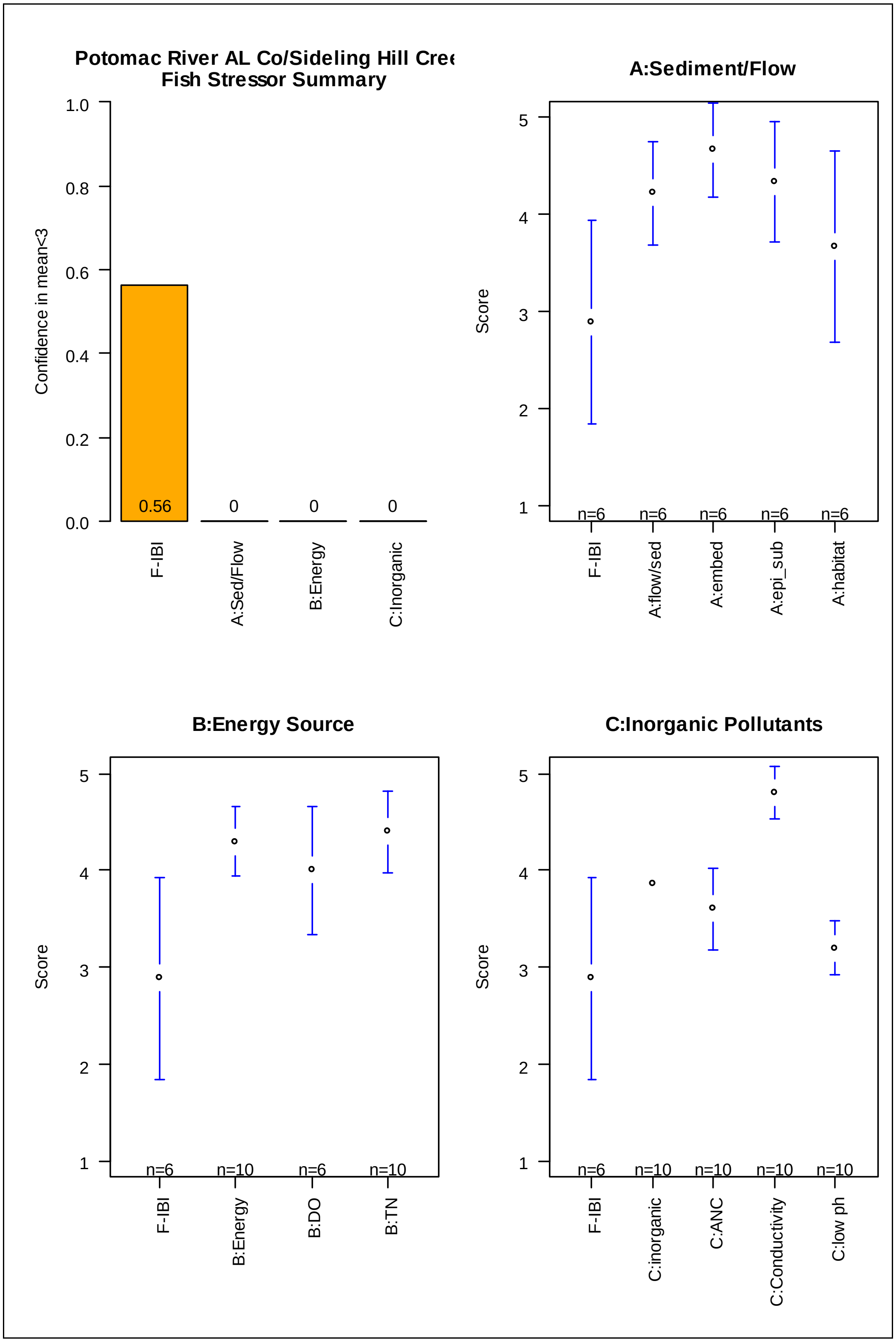


Figure F-99: Potomac River Allegany County/Sideling Hill Creek Fish Stressor Results

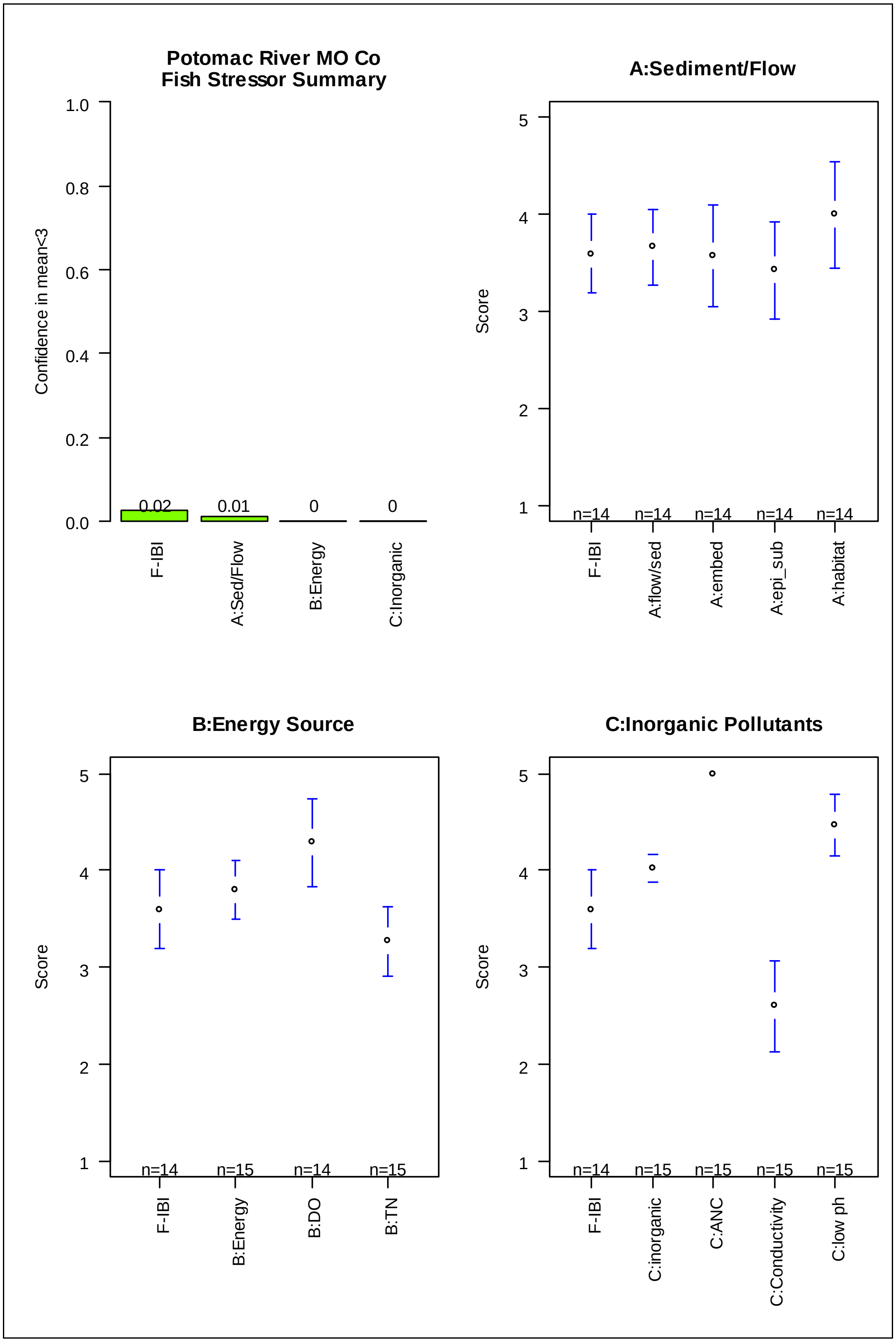


Figure F-100: Potomac River MO County Fish Stressor Results

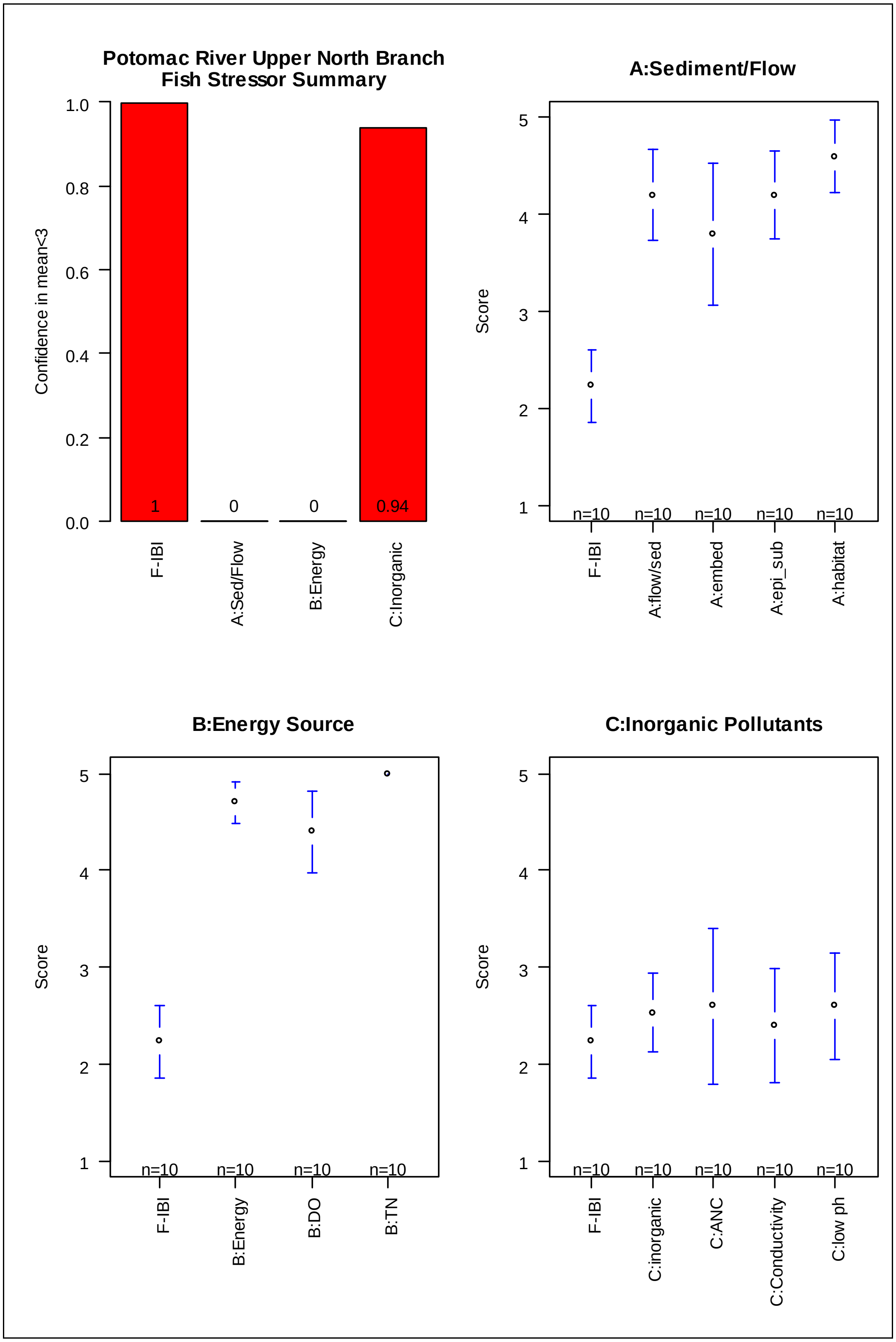


Figure F-101: Potomac River Upper North Branch Fish Stressor Results

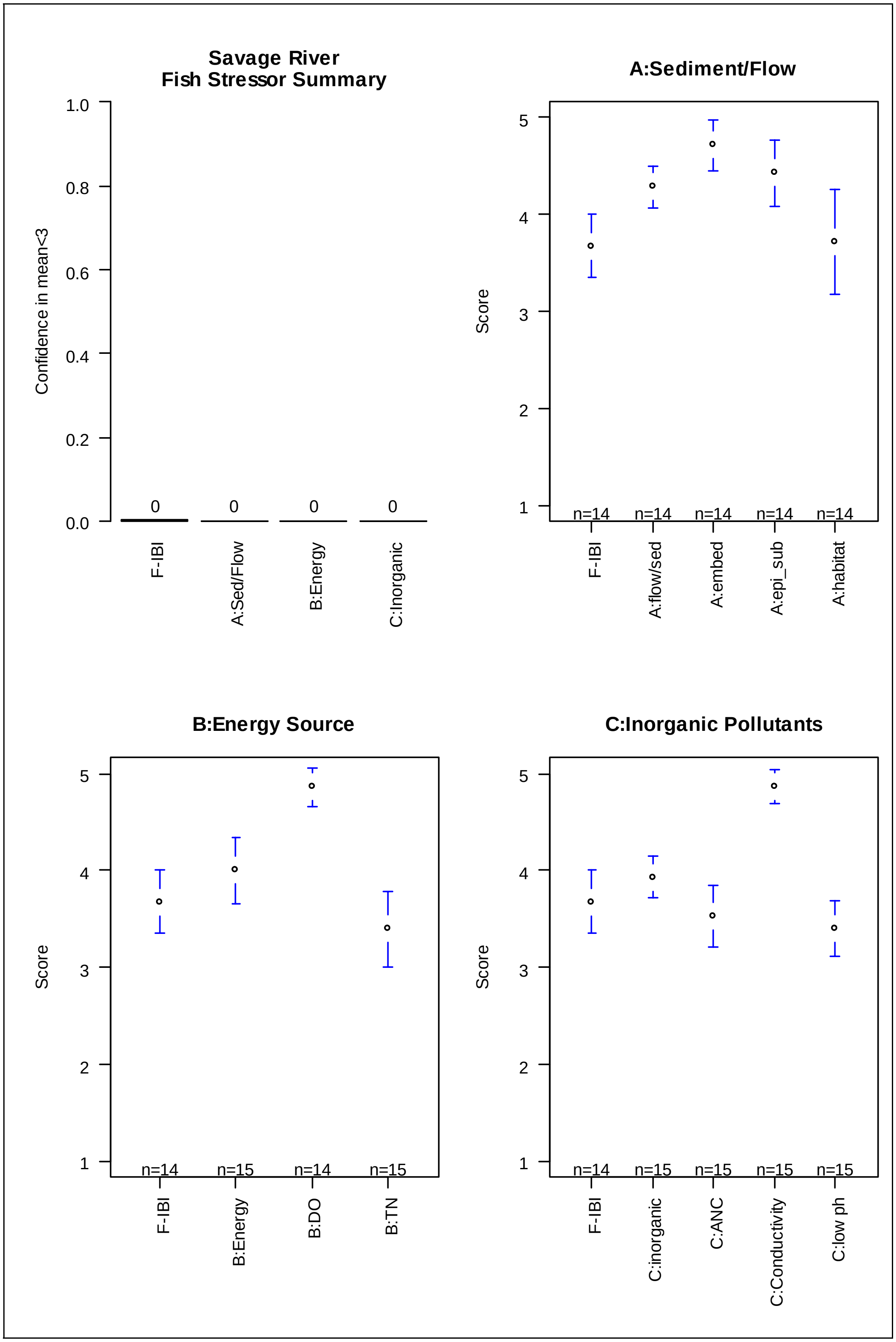


Figure F-102: Savage River Fish Stressor Results

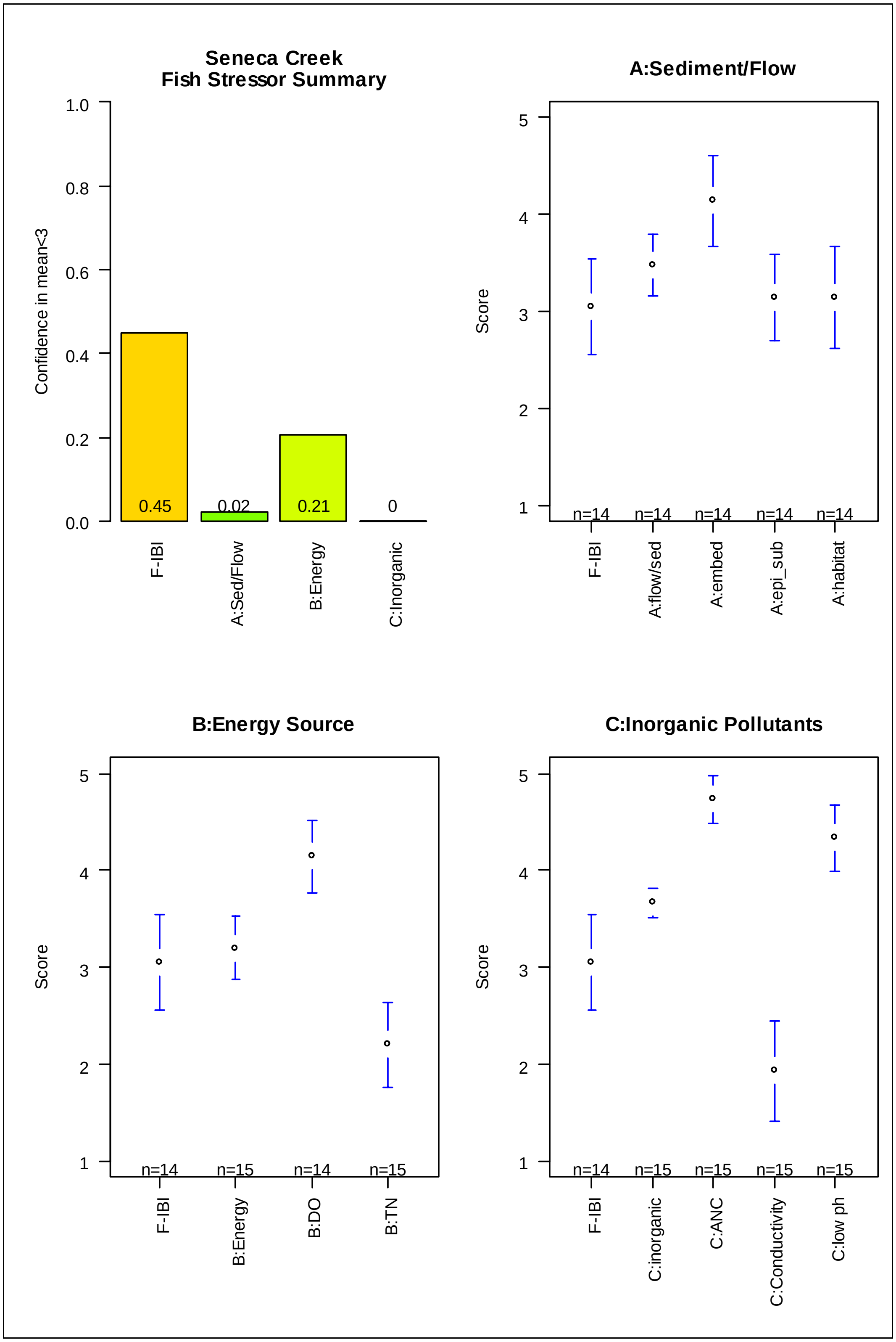


Figure F-103: Seneca Creek Fish Stressor Results

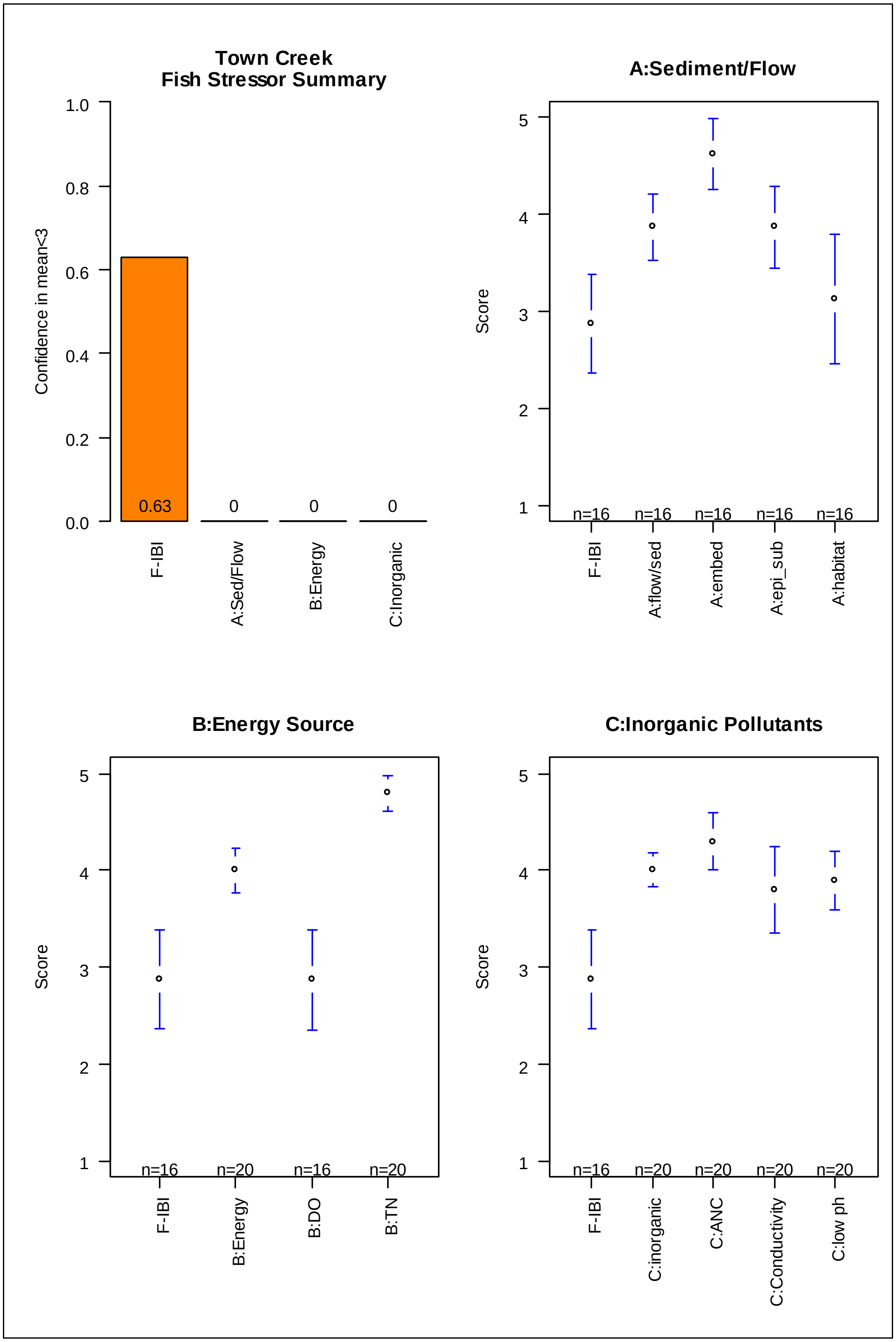


Figure F-104: Town Creek Fish Stressor Results

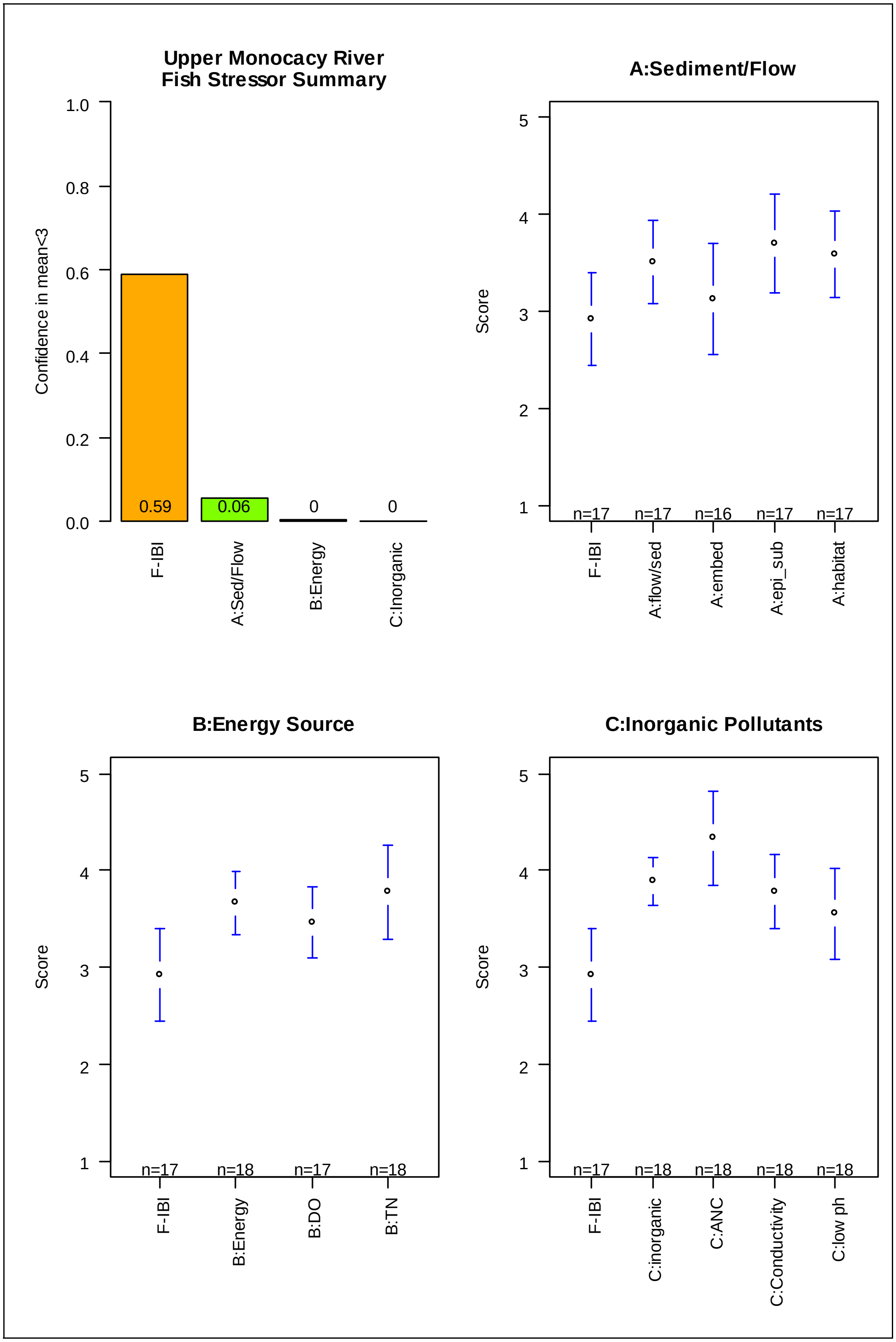


Figure F-105: Upper Monocacy River Fish Stressor Results

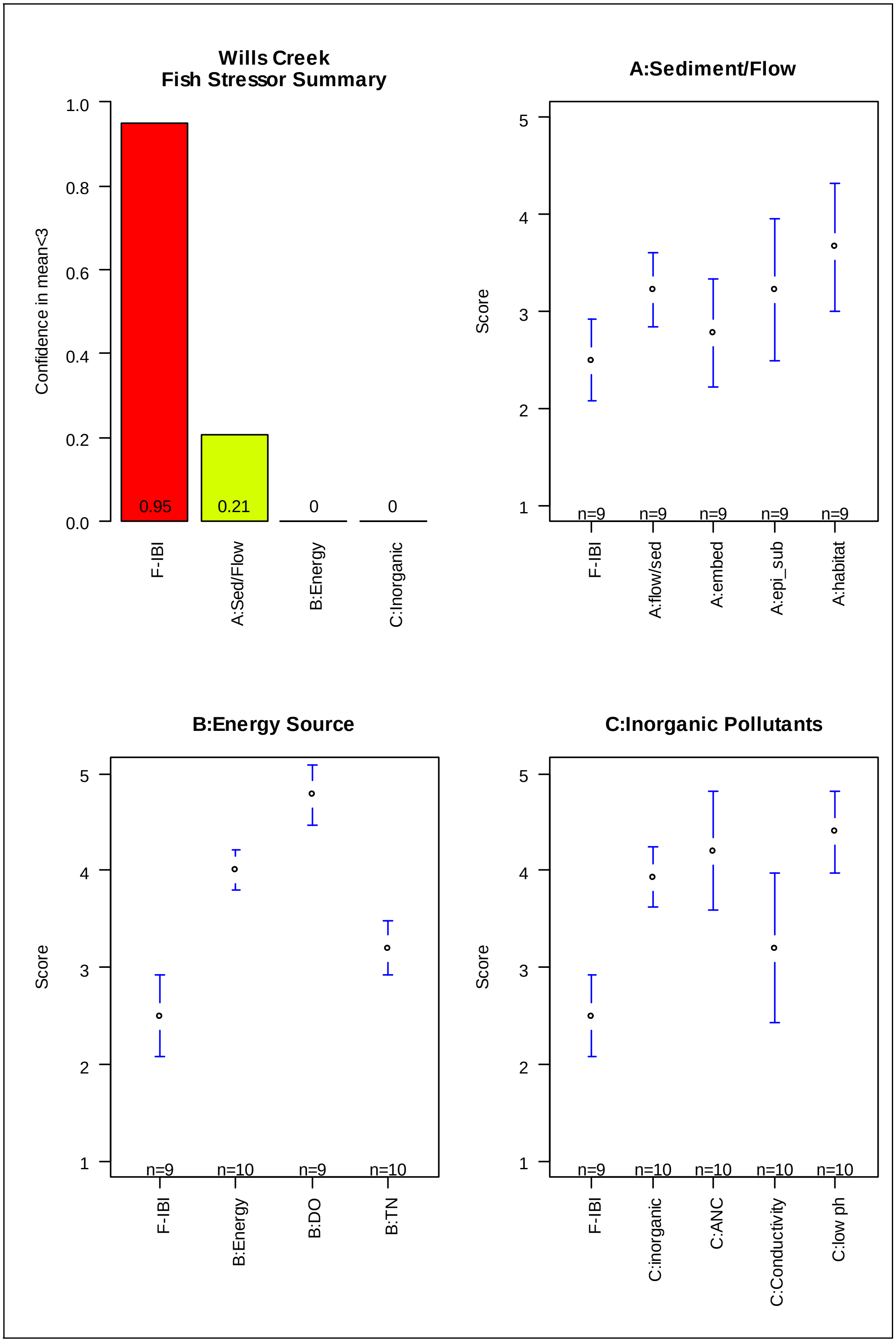


Figure F-106: Wills Creek Fish Stressor Results

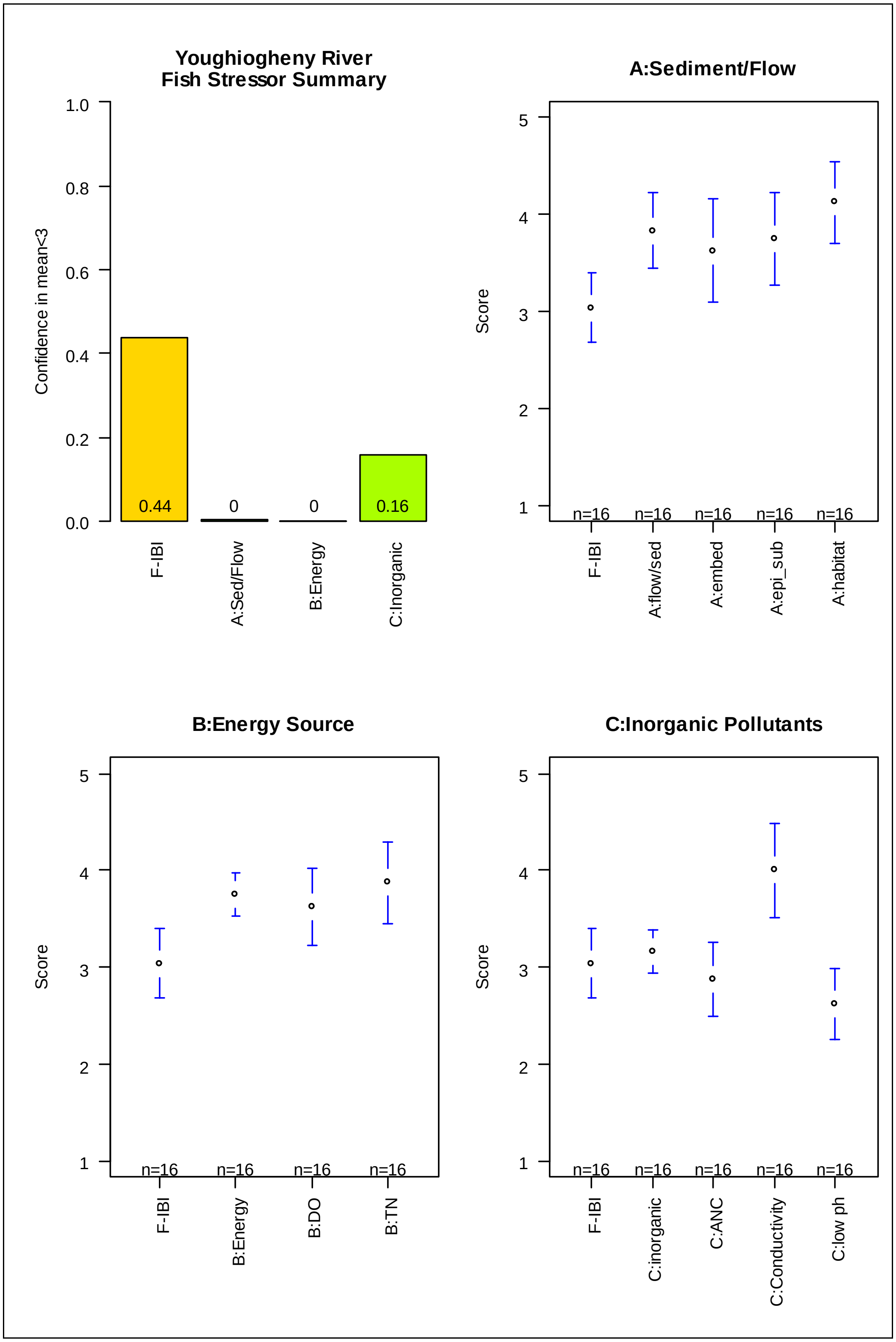


Figure F-107: Antietam Creek Fish Stressor Results

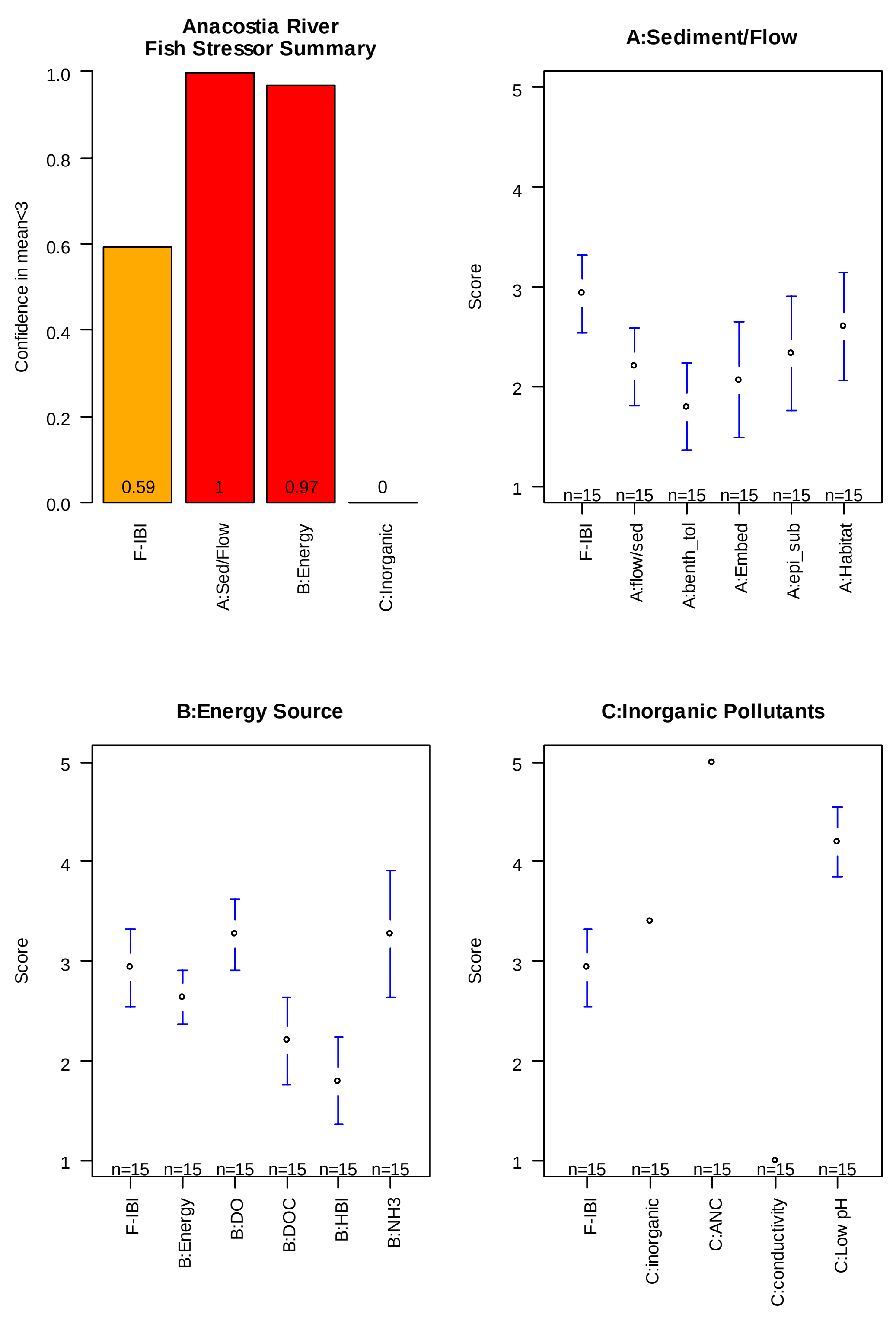


Figure F-108: Anacostia River Fish Stressor Results

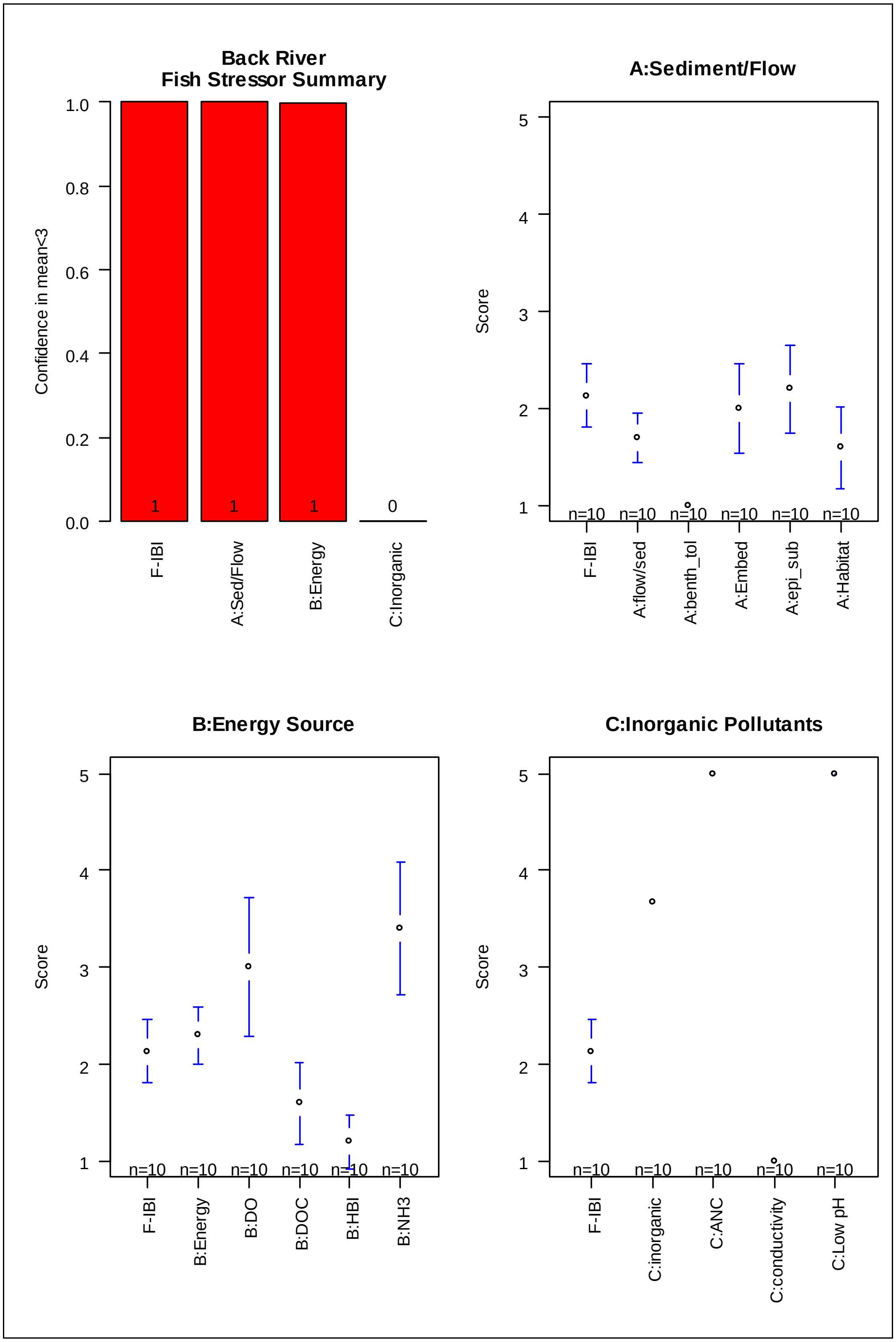


Figure F-109: Back River Fish Stressor Results

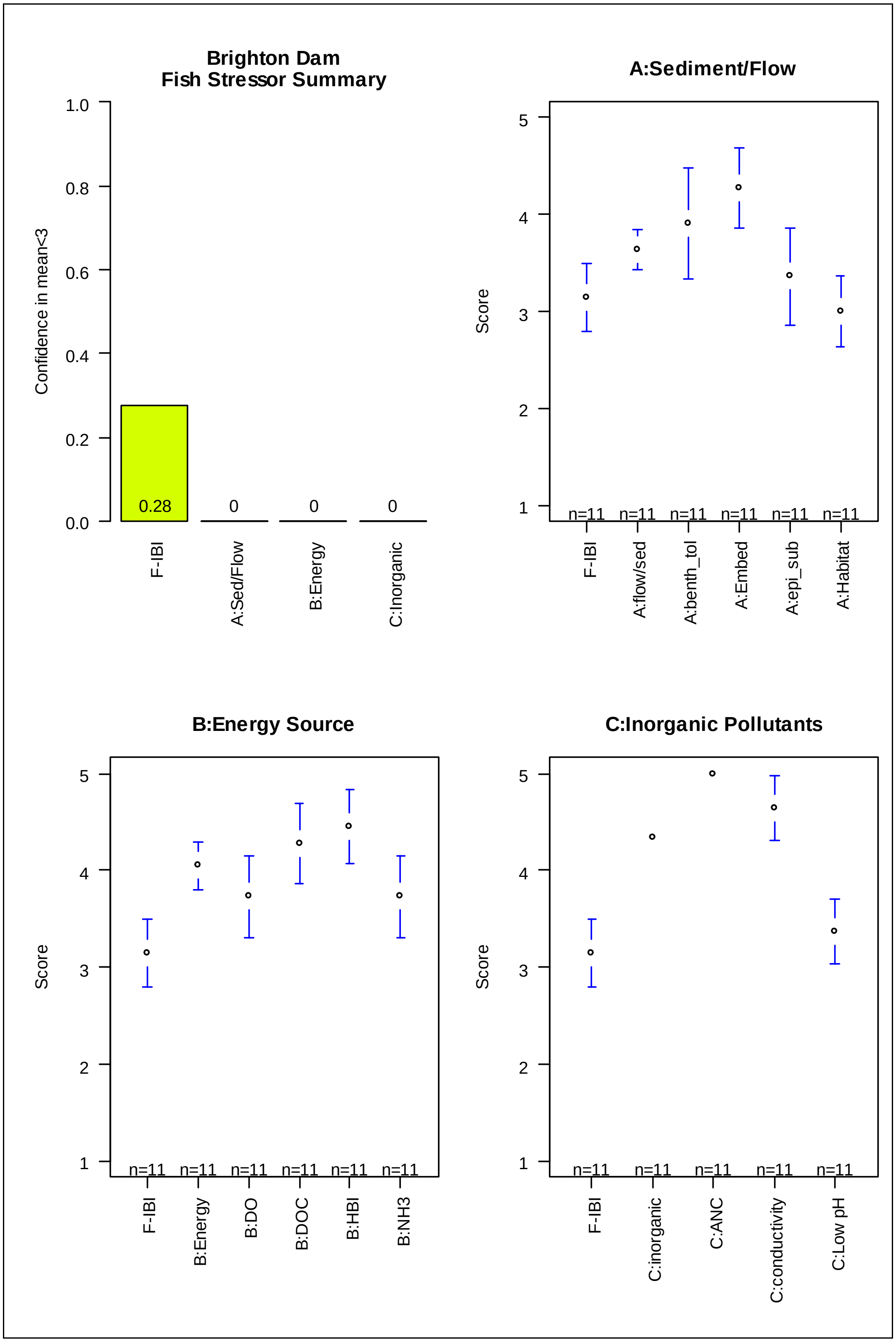


Figure F-110: Brighton Dam Fish Stressor Results

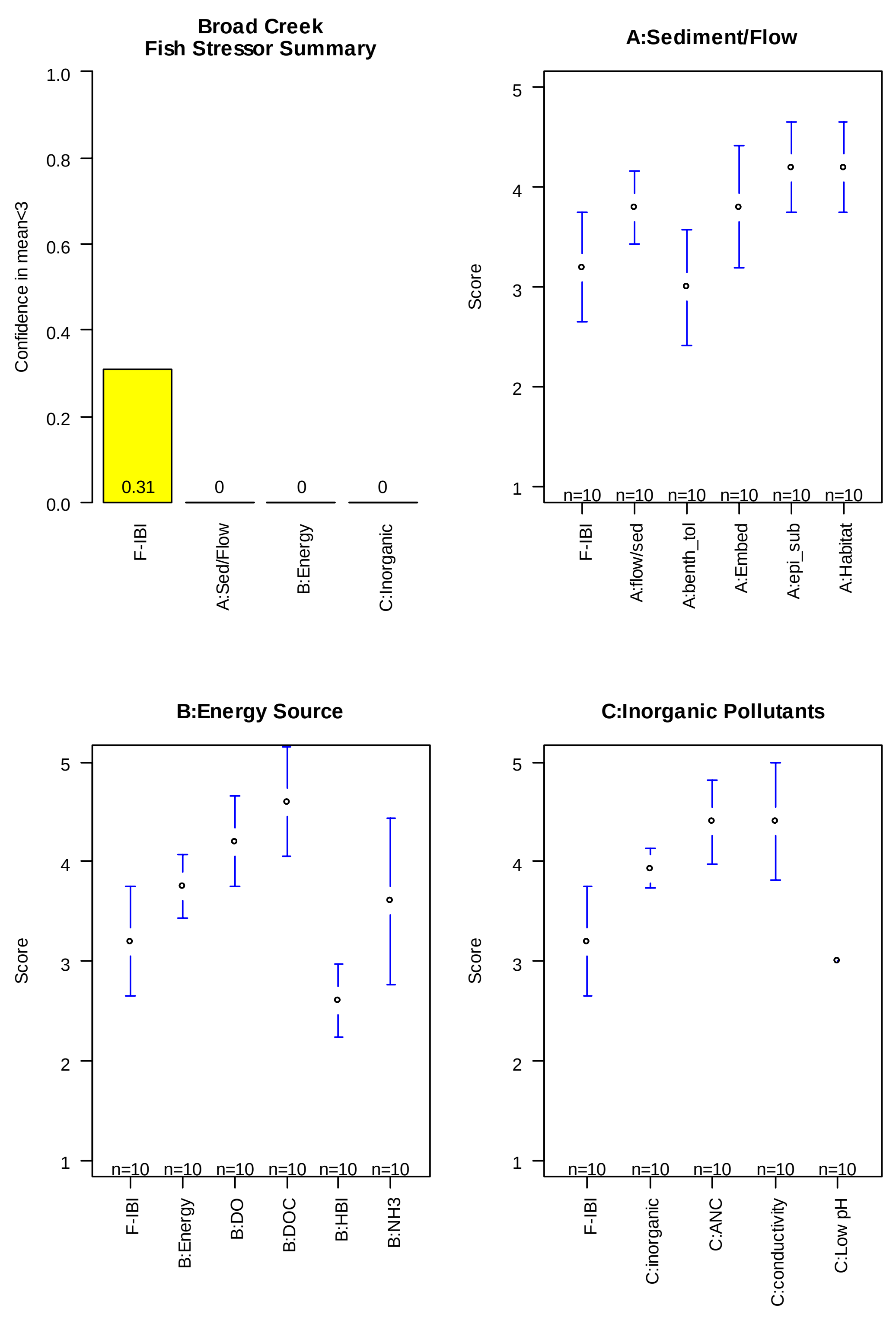


Figure F-111: Broad Creek Fish Stressor Results

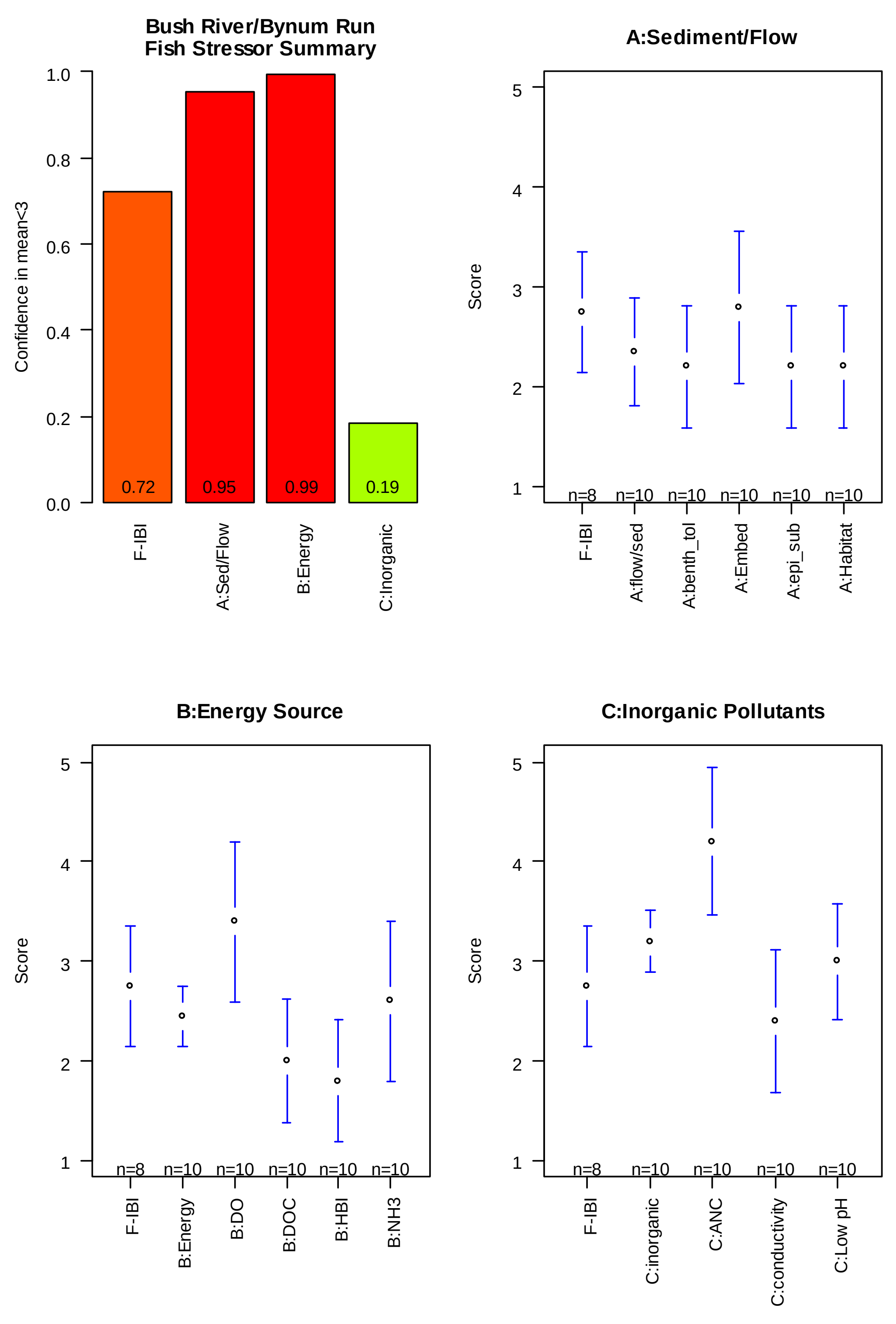


Figure F-112: Bush River/Bynum Run Fish Stressor Results

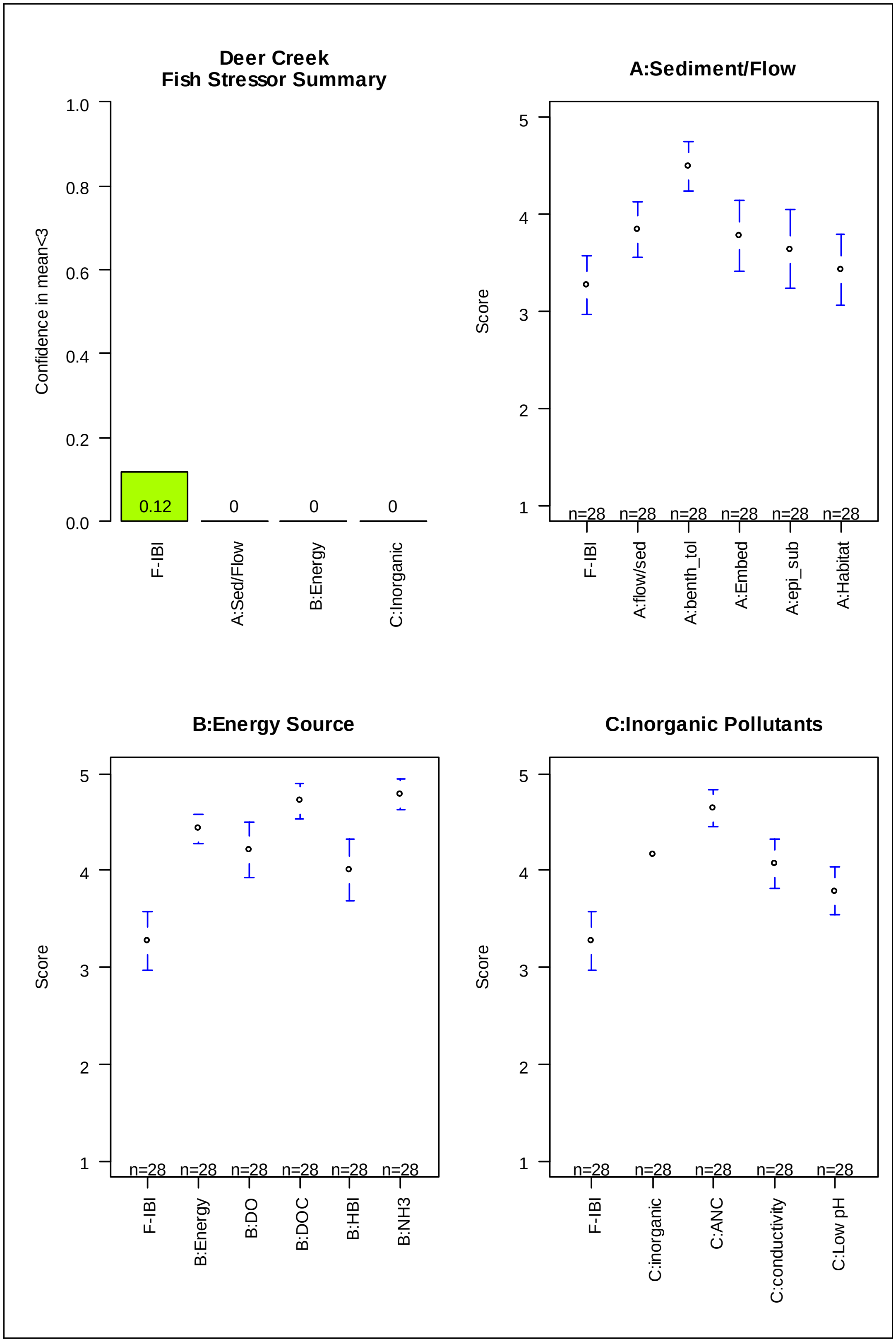


Figure F-113: Deer Creek Fish Stressor Results

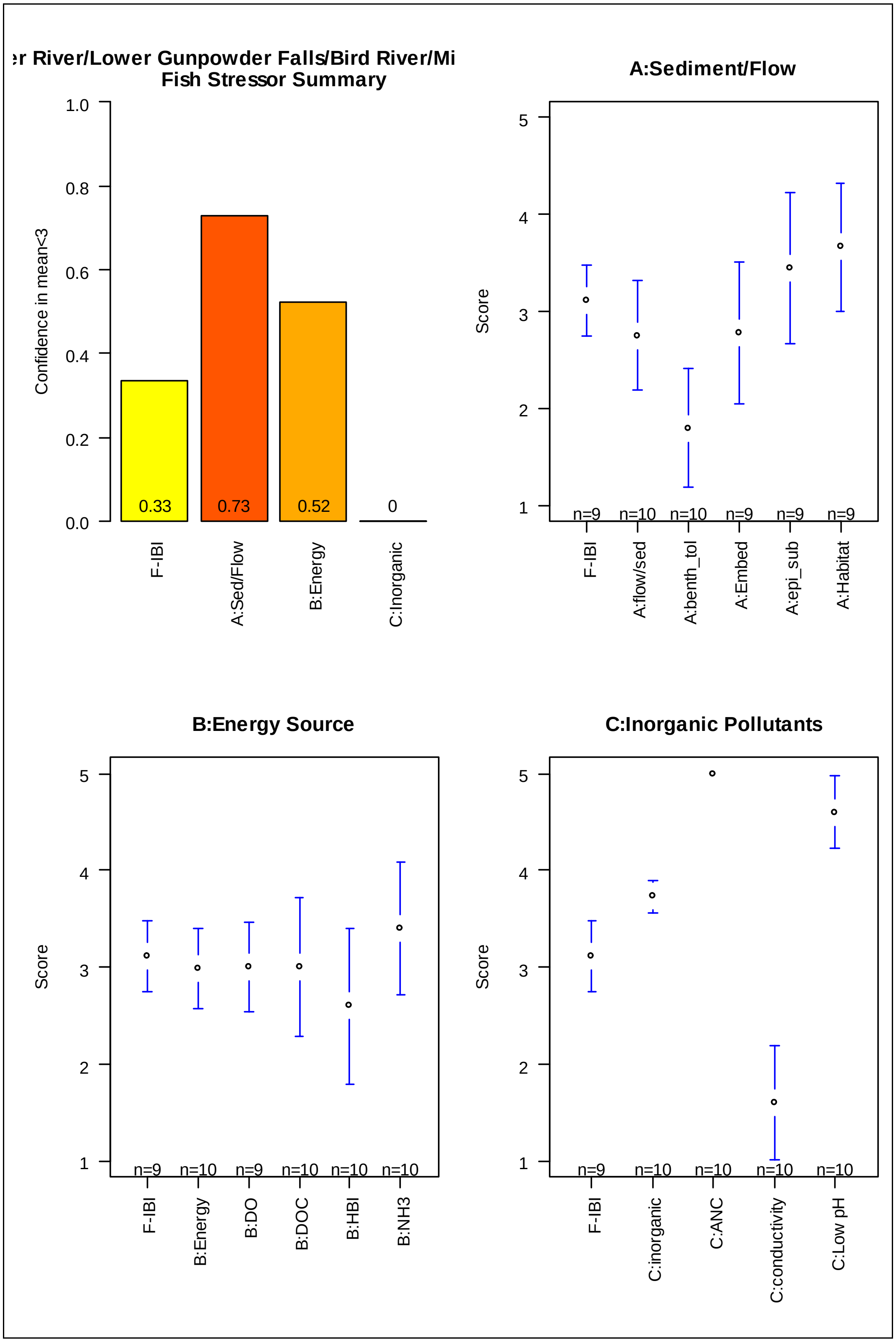


Figure F-114: Gunpowder River/Lower Gunpowder Falls/Bird River/Middle River Fish Stressor Results

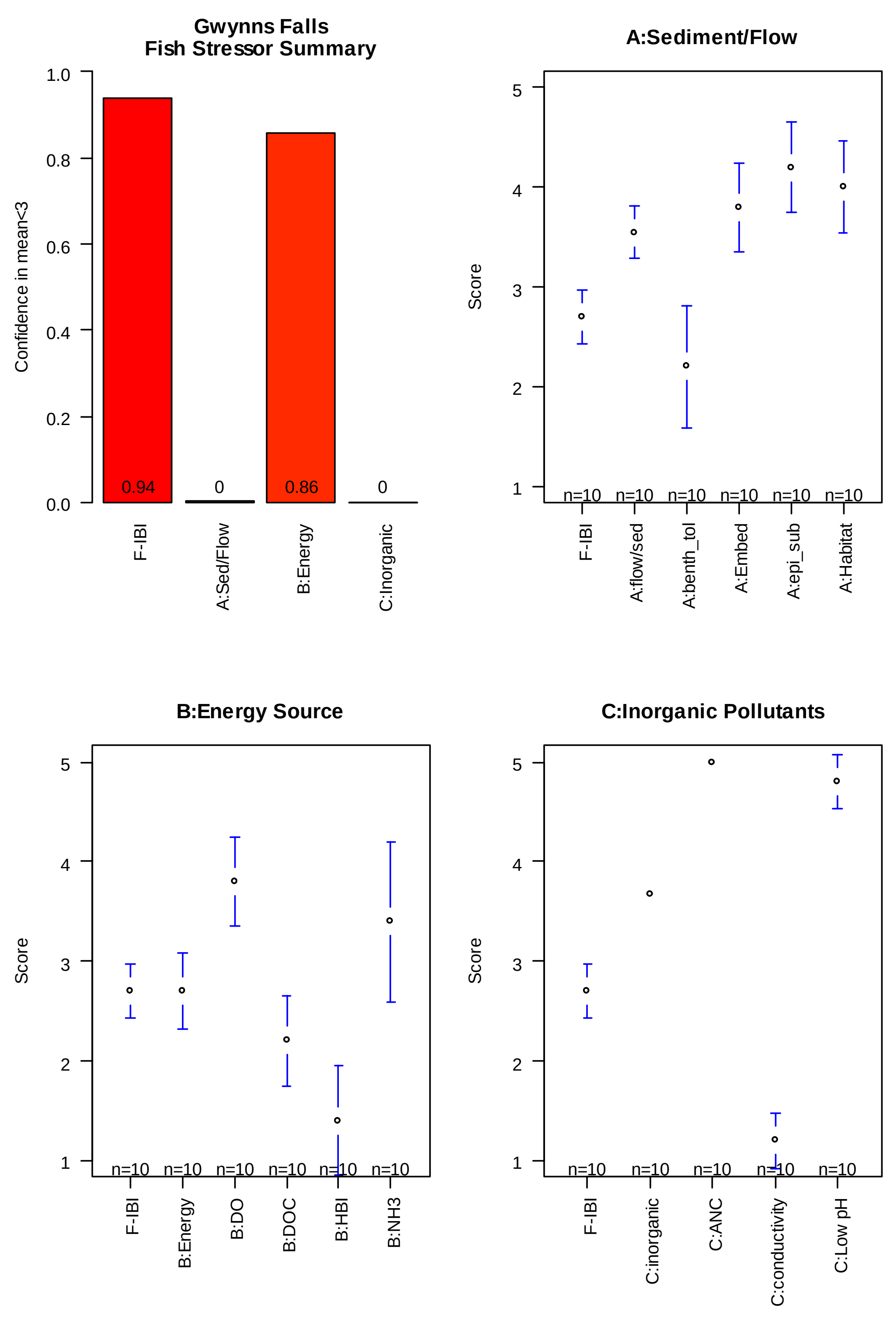


Figure F-115: Gwynns Falls Fish Stressor Results

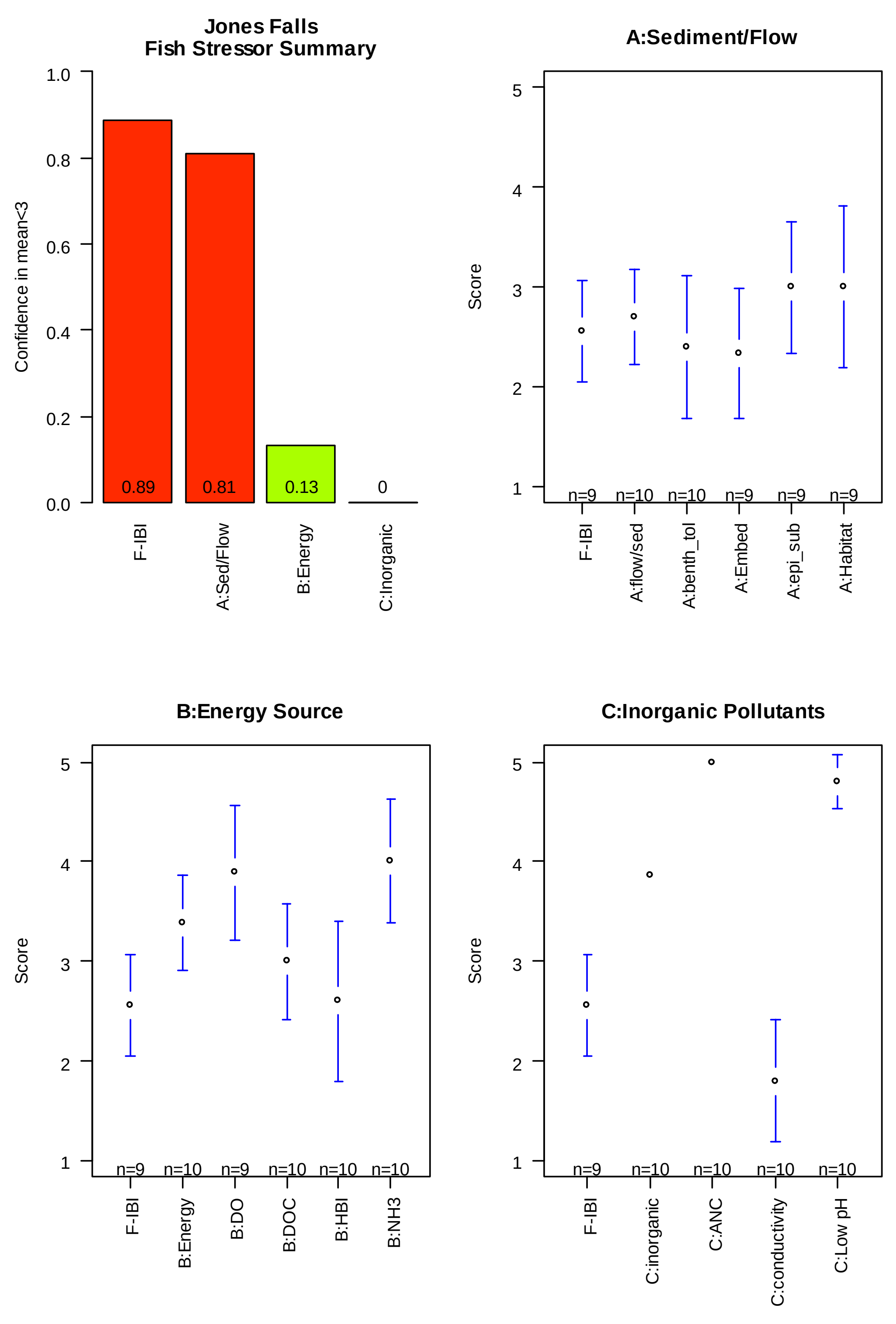


Figure F-116: Jones Falls Fish Stressor Results

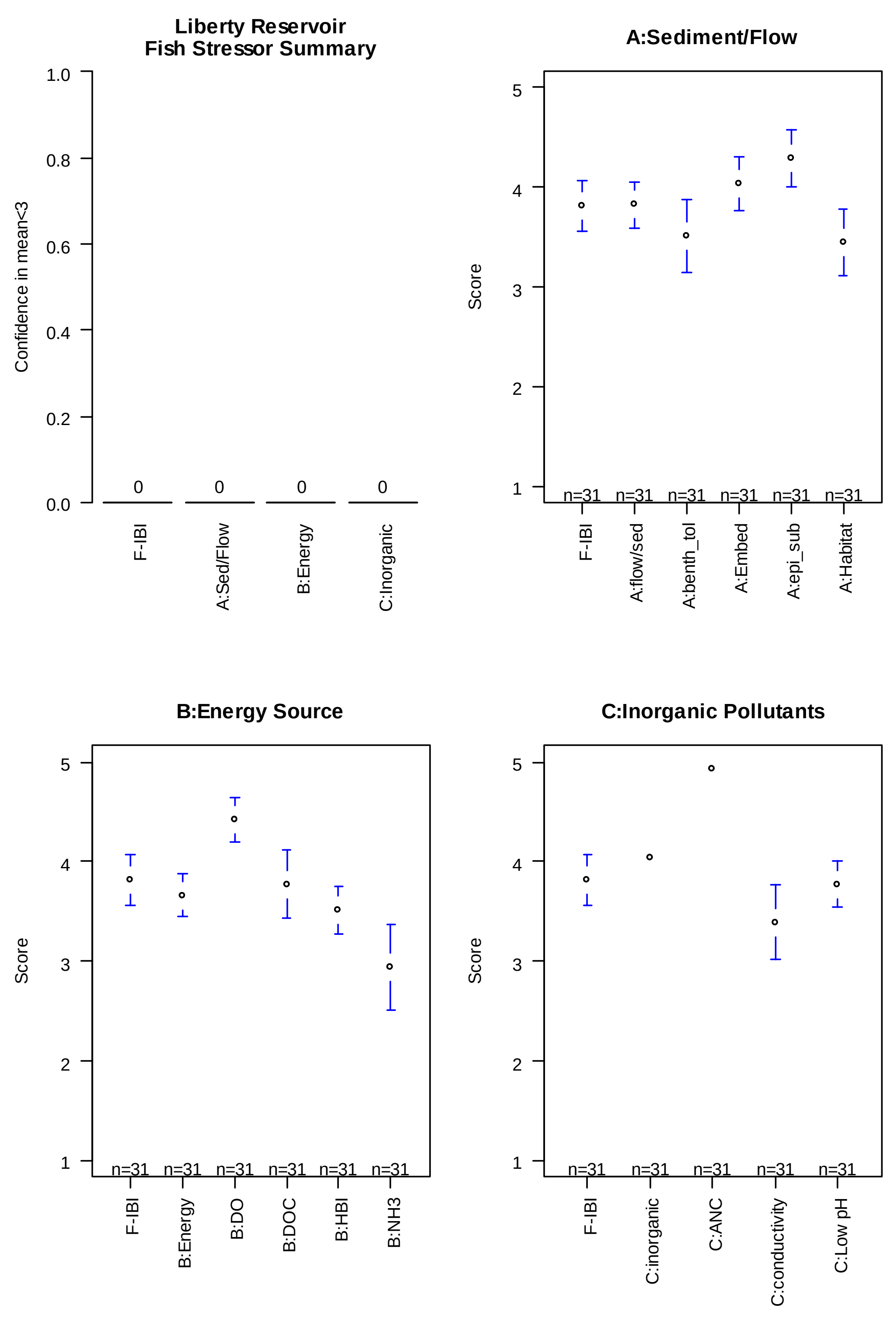


Figure F-117: Liberty Reservoir Fish Stressor Results

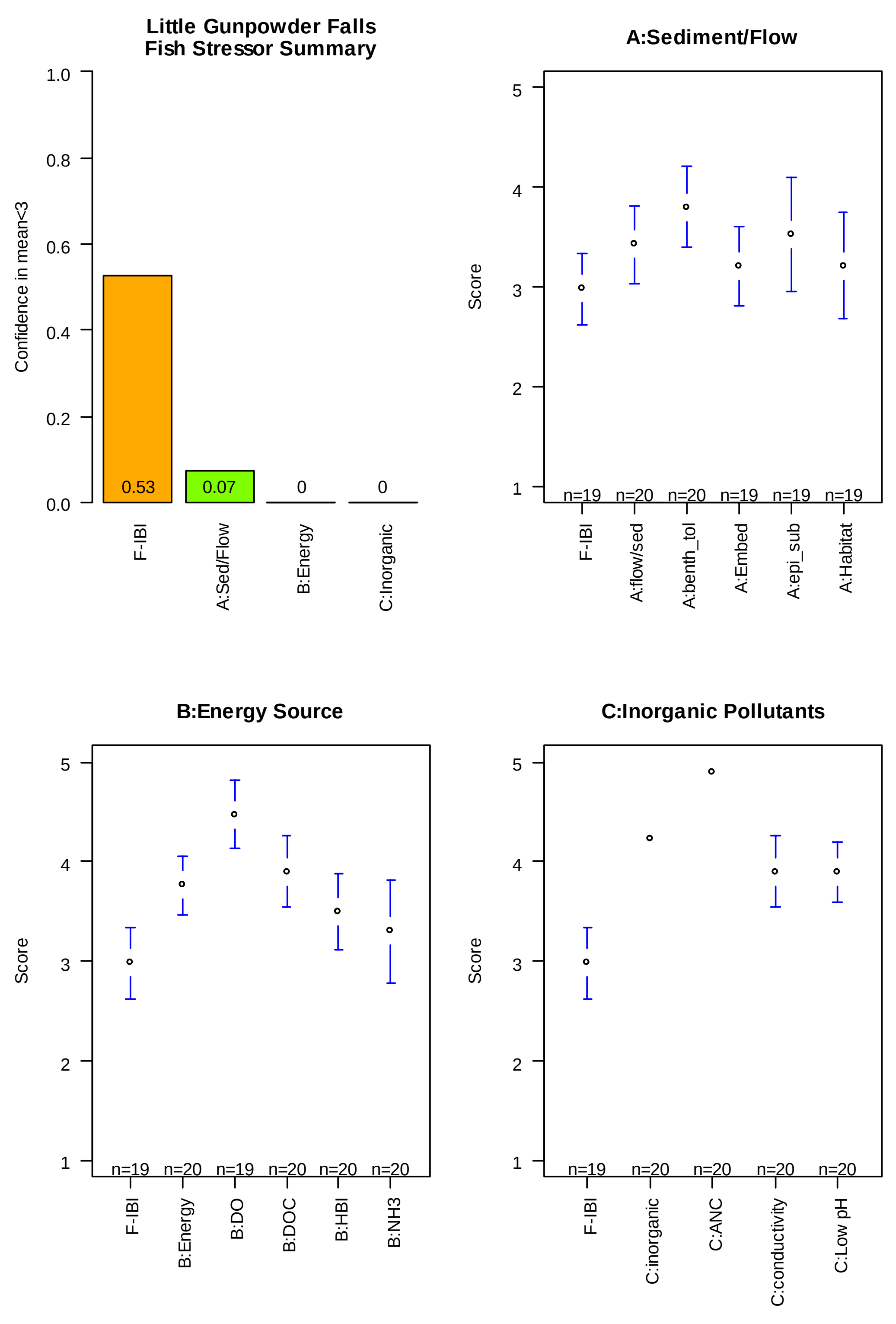


Figure F-118: Little Gunpowder Falls Fish Stressor Results

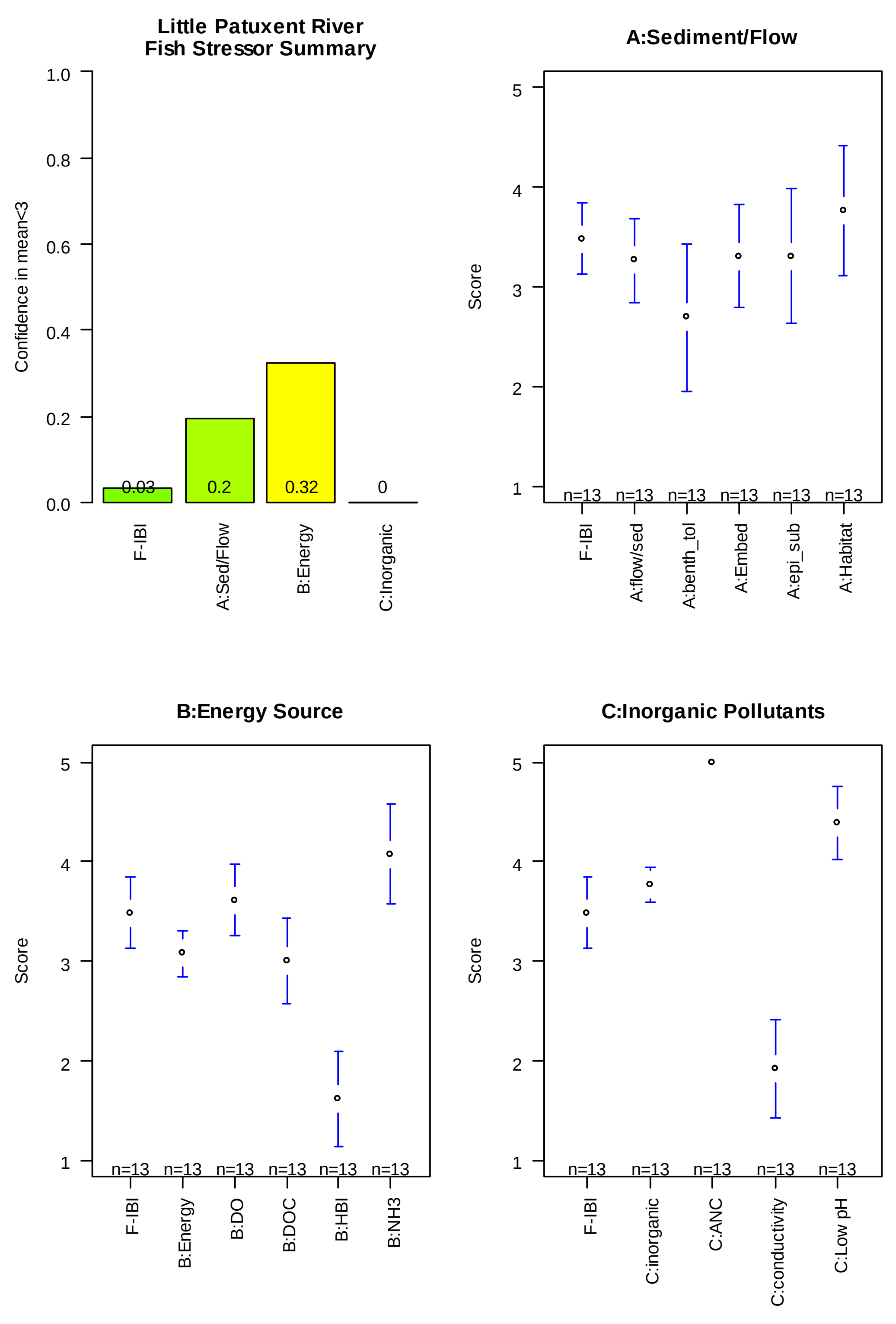


Figure F-119: Little Patuxent River Fish Stressor Results

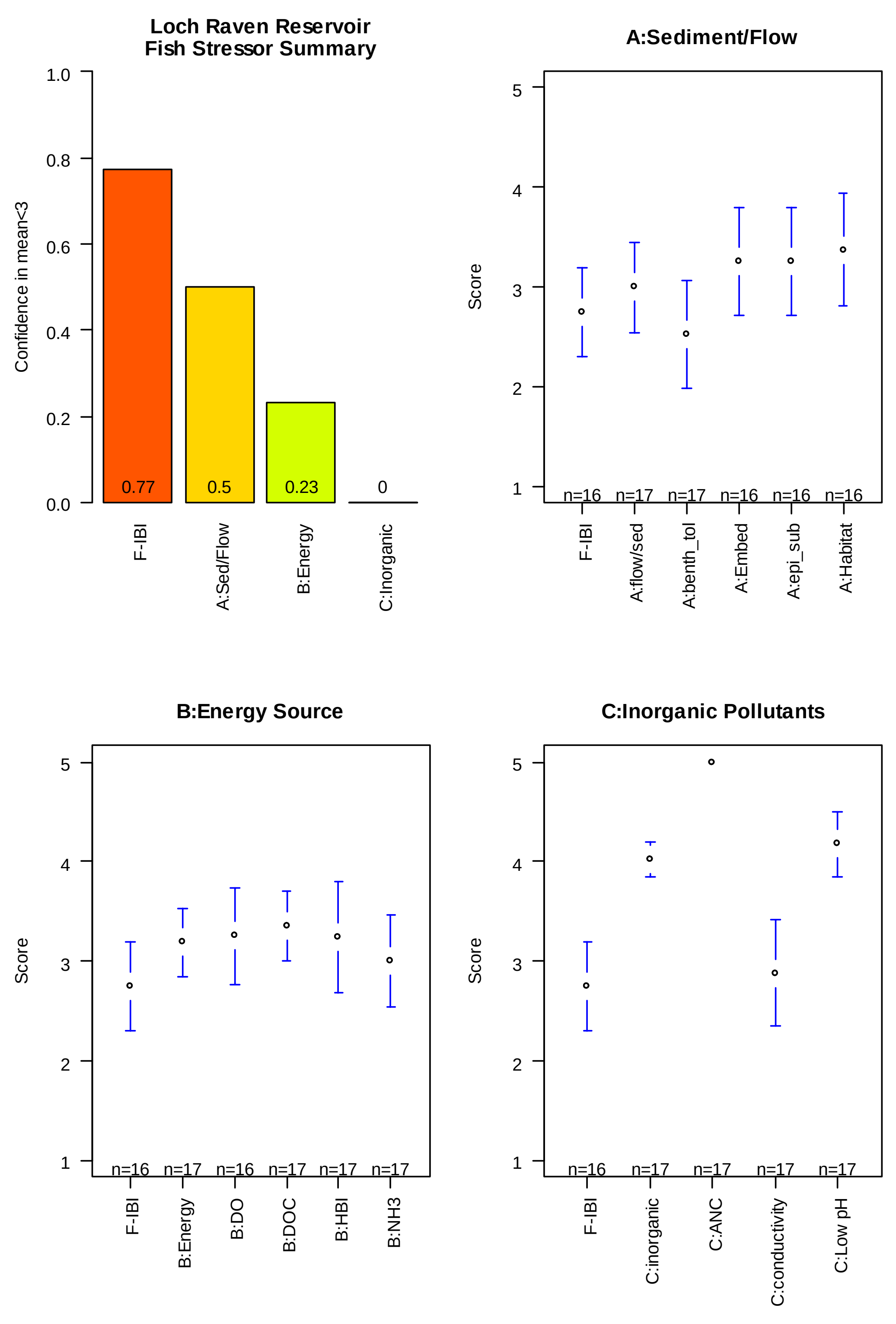


Figure F-120: Loch Raven Reservoir Fish Stressor Results

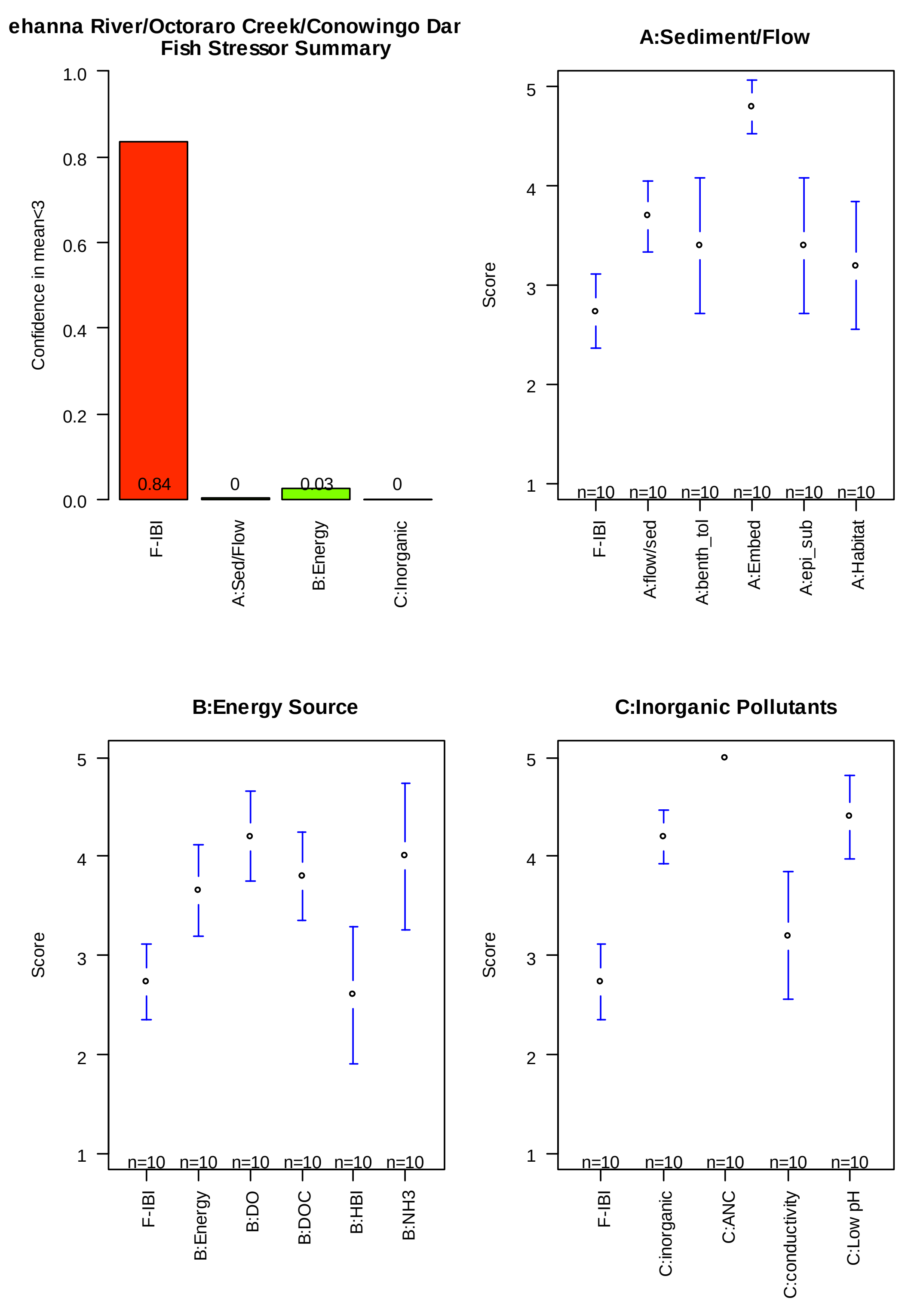


Figure F-121: Susquehanna River/Octoraro Creek/Conowingo Dam Fish Stressor Results

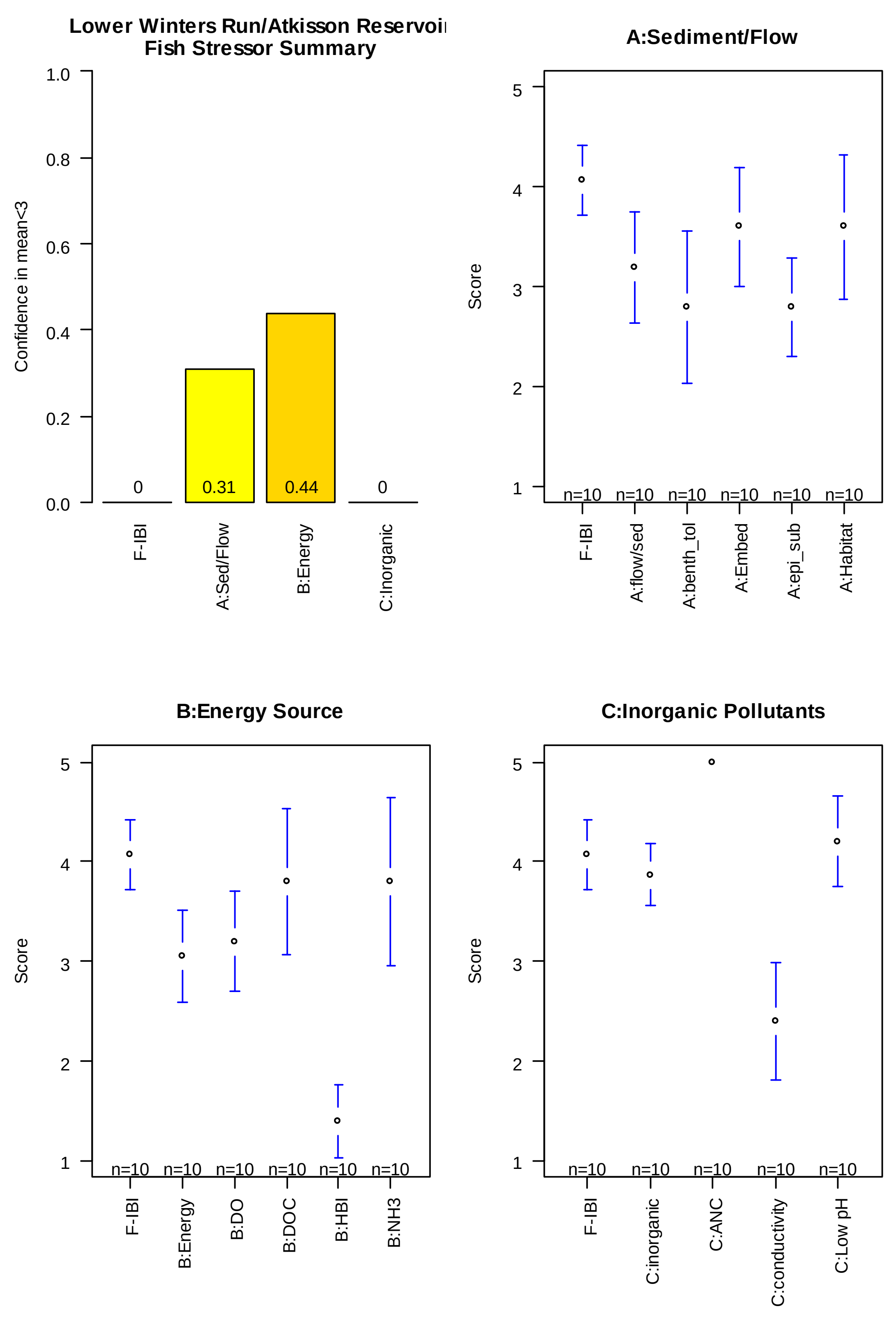


Figure F-122: Lower Winters Run/Atkisson Reservoir Fish Stressor Results

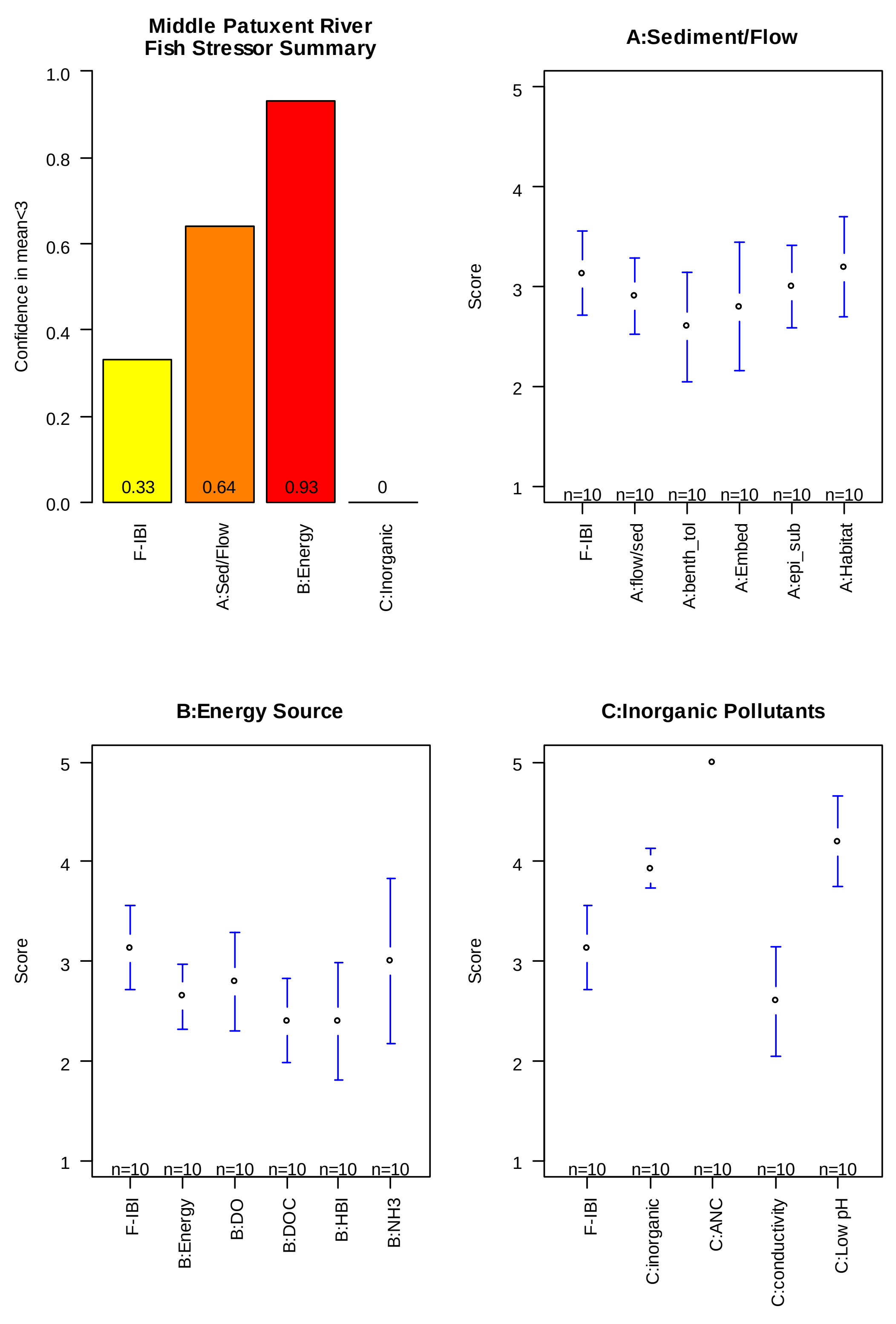


Figure F-123: Middle Patuxent River Fish Stressor Results

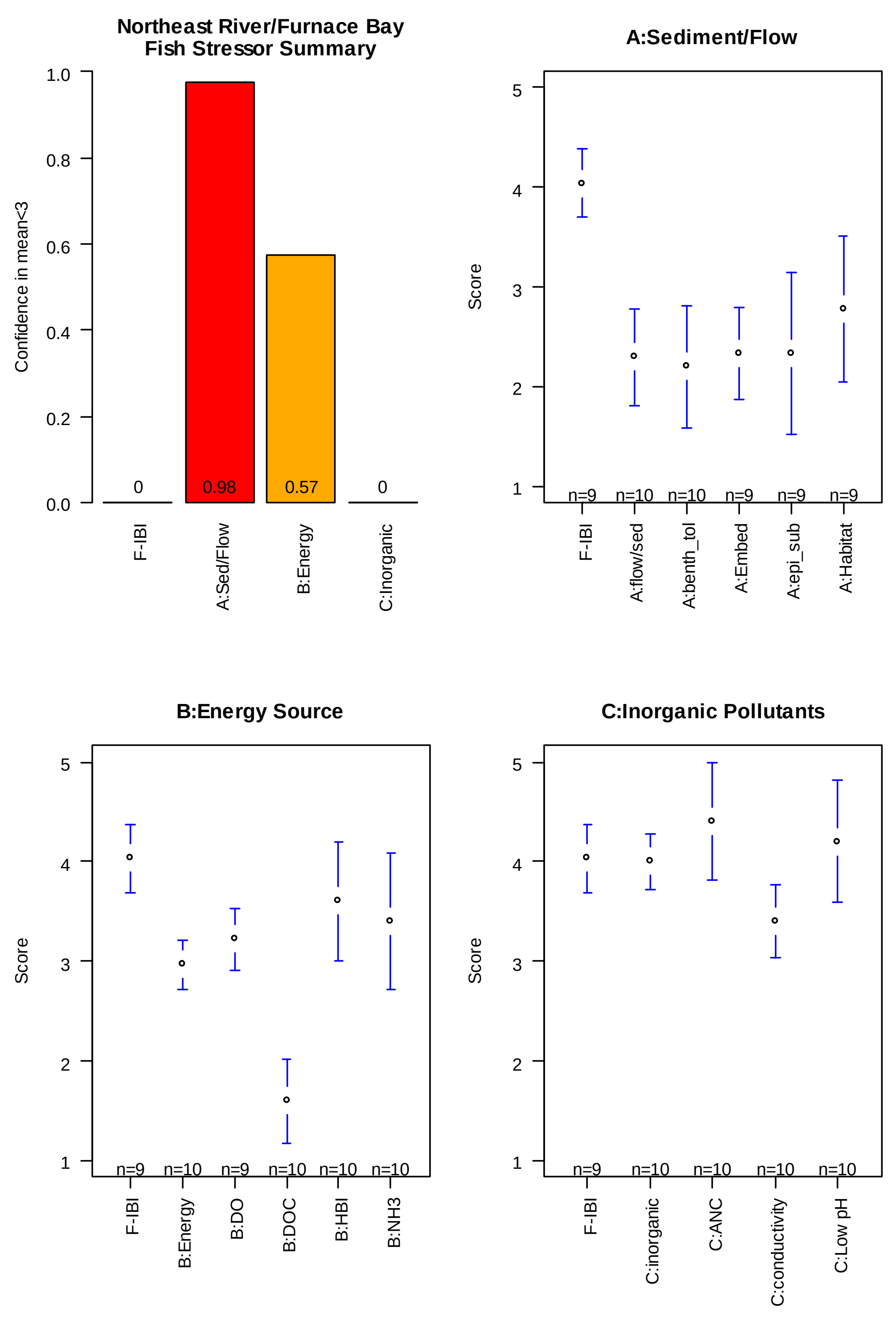


Figure F-124: Northeast River/Furnace Bay Fish Stressor Results

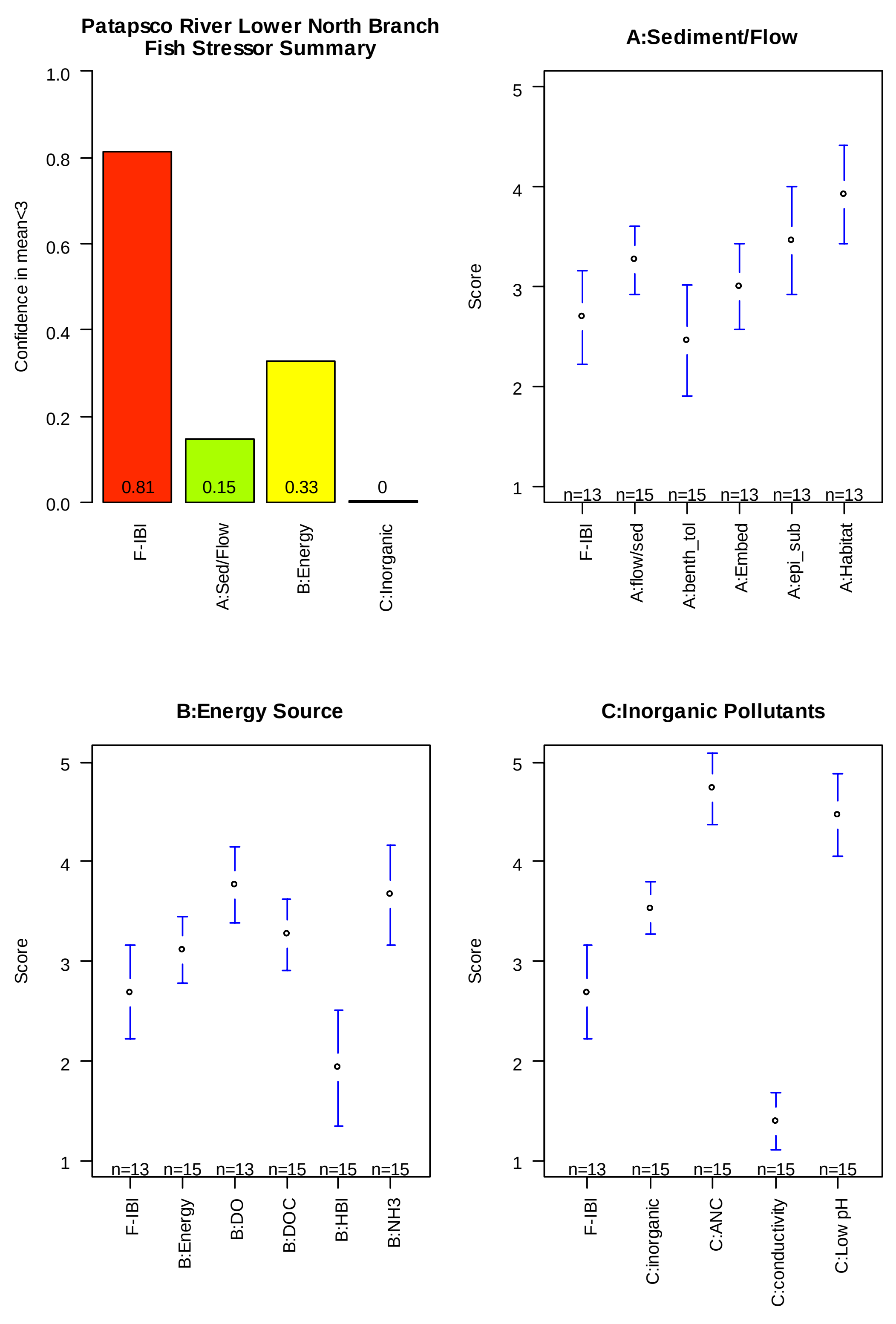


Figure F-125: Patapsco River Lower North Branch Fish Stressor Results

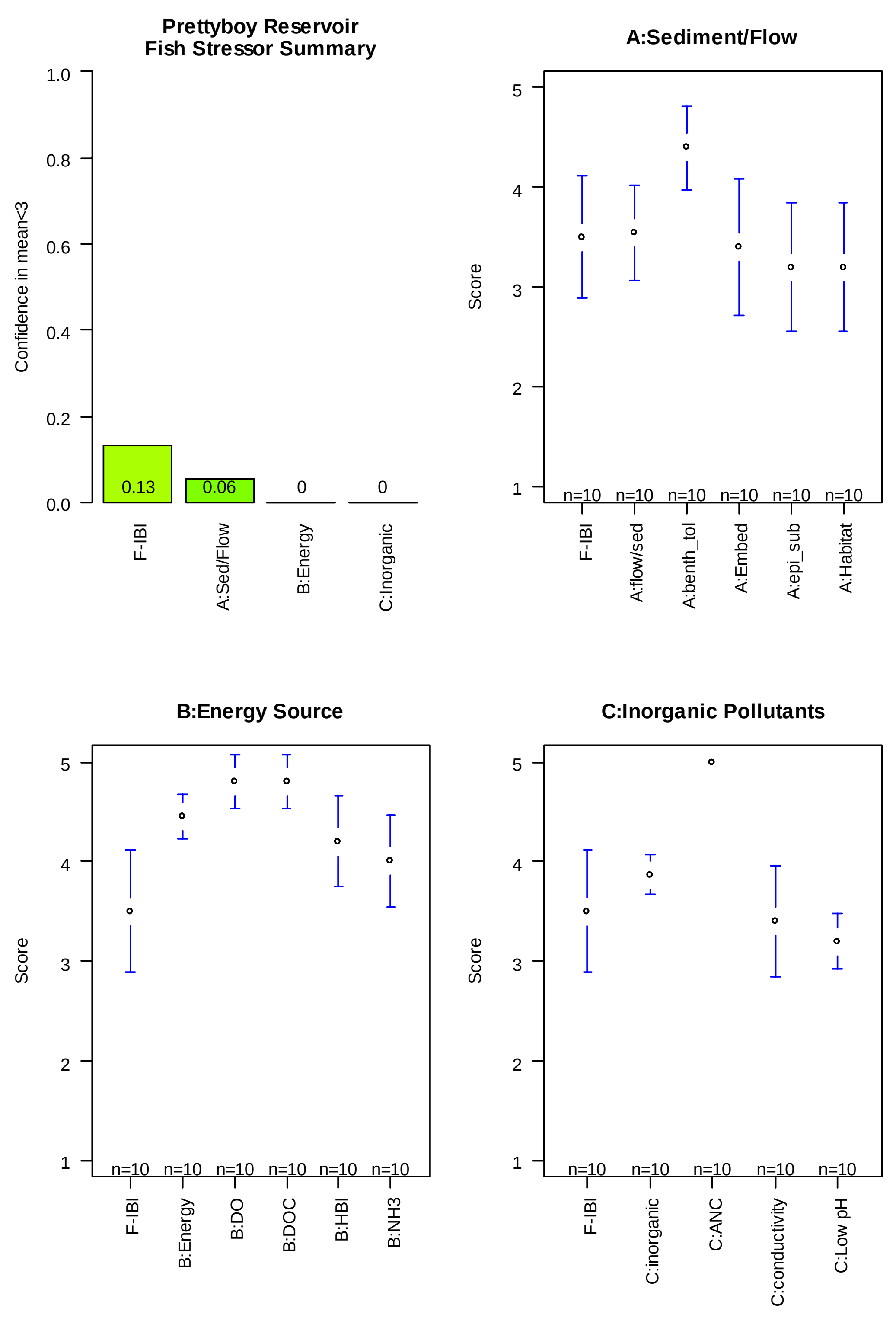


Figure F-126: Prettyboy Reservoir Fish Stressor Results

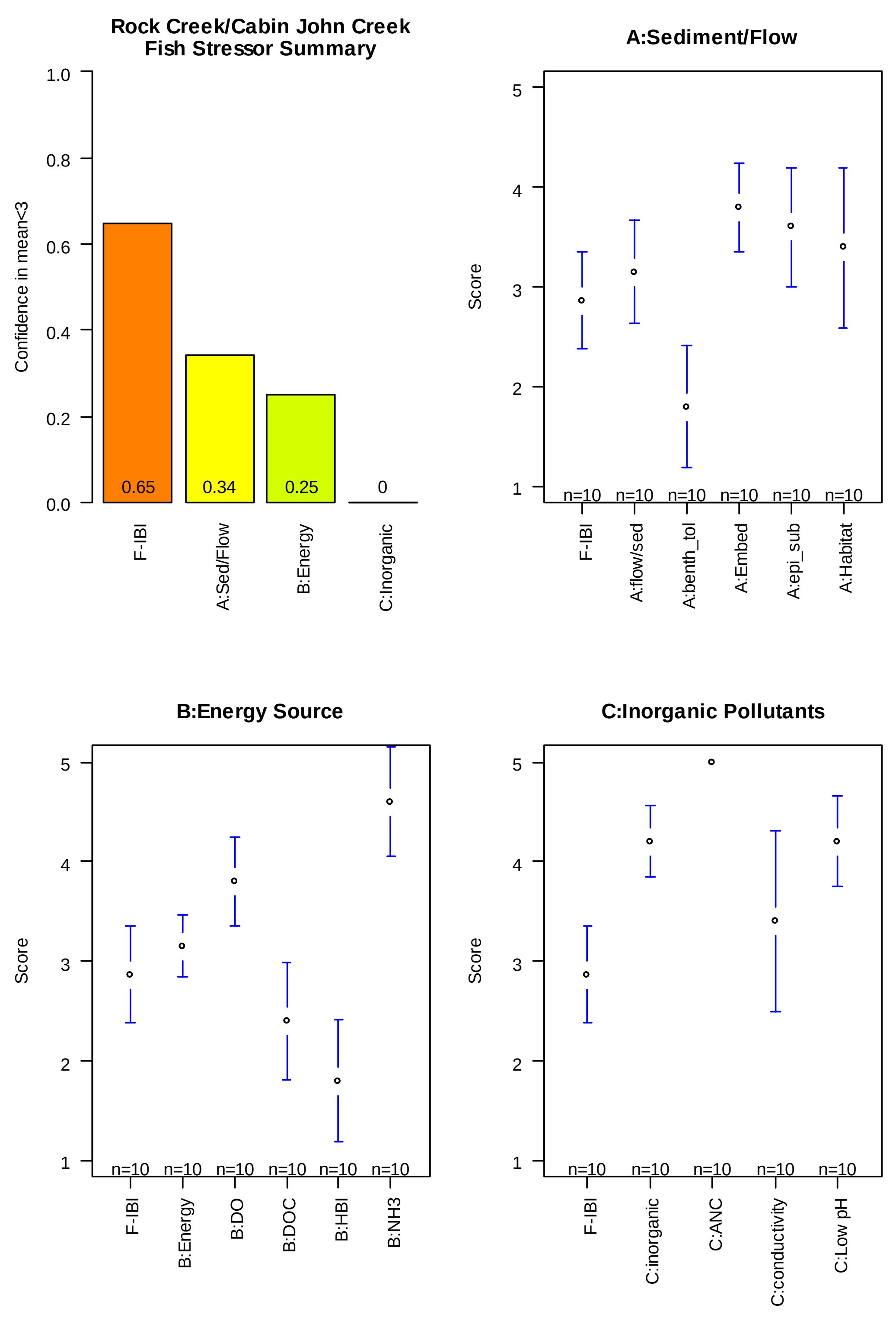


Figure F-127: Rock Creek/Cabin John Creek Fish Stressor Results

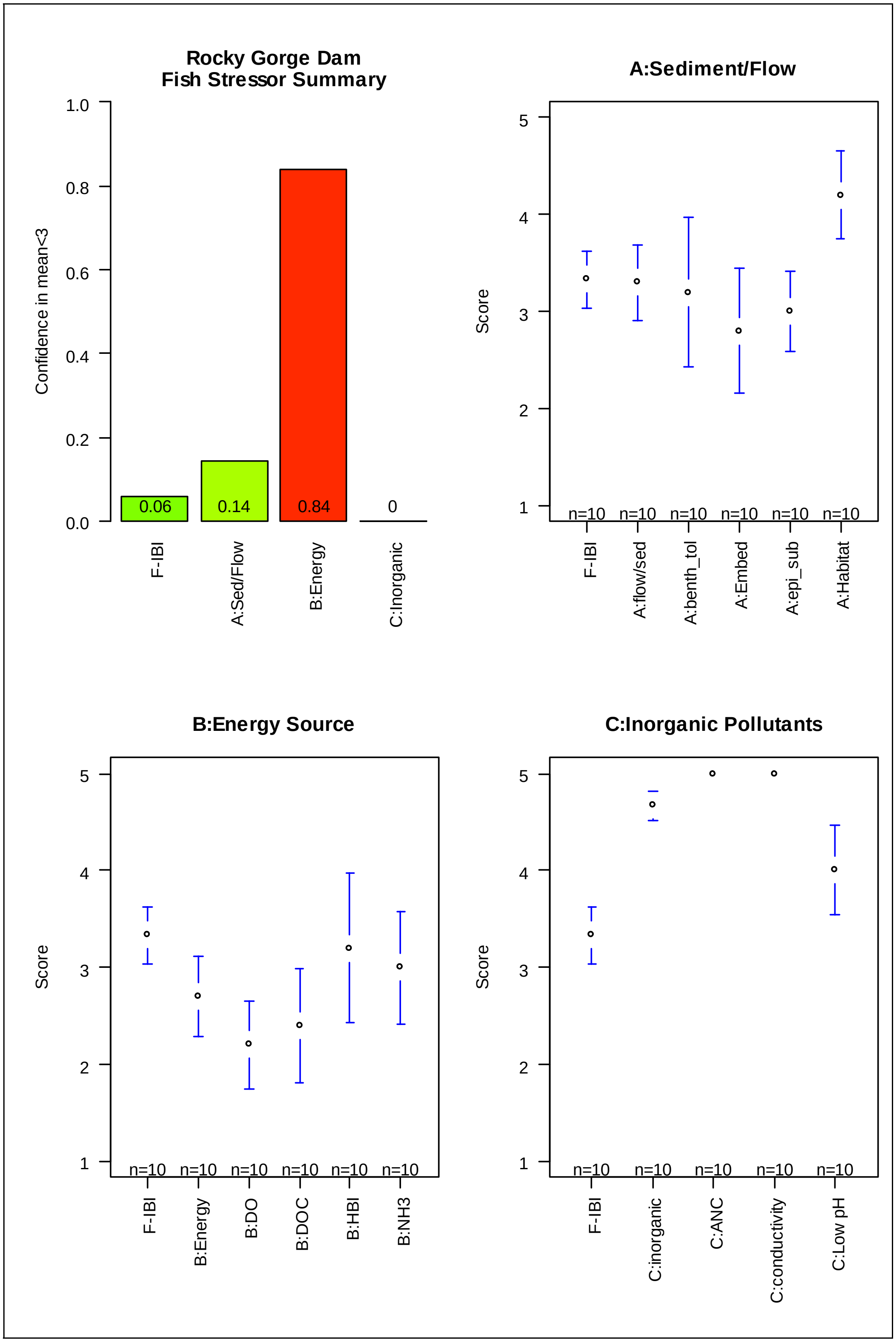


Figure F-128: Rocky Gorge Dam Fish Stressor Results

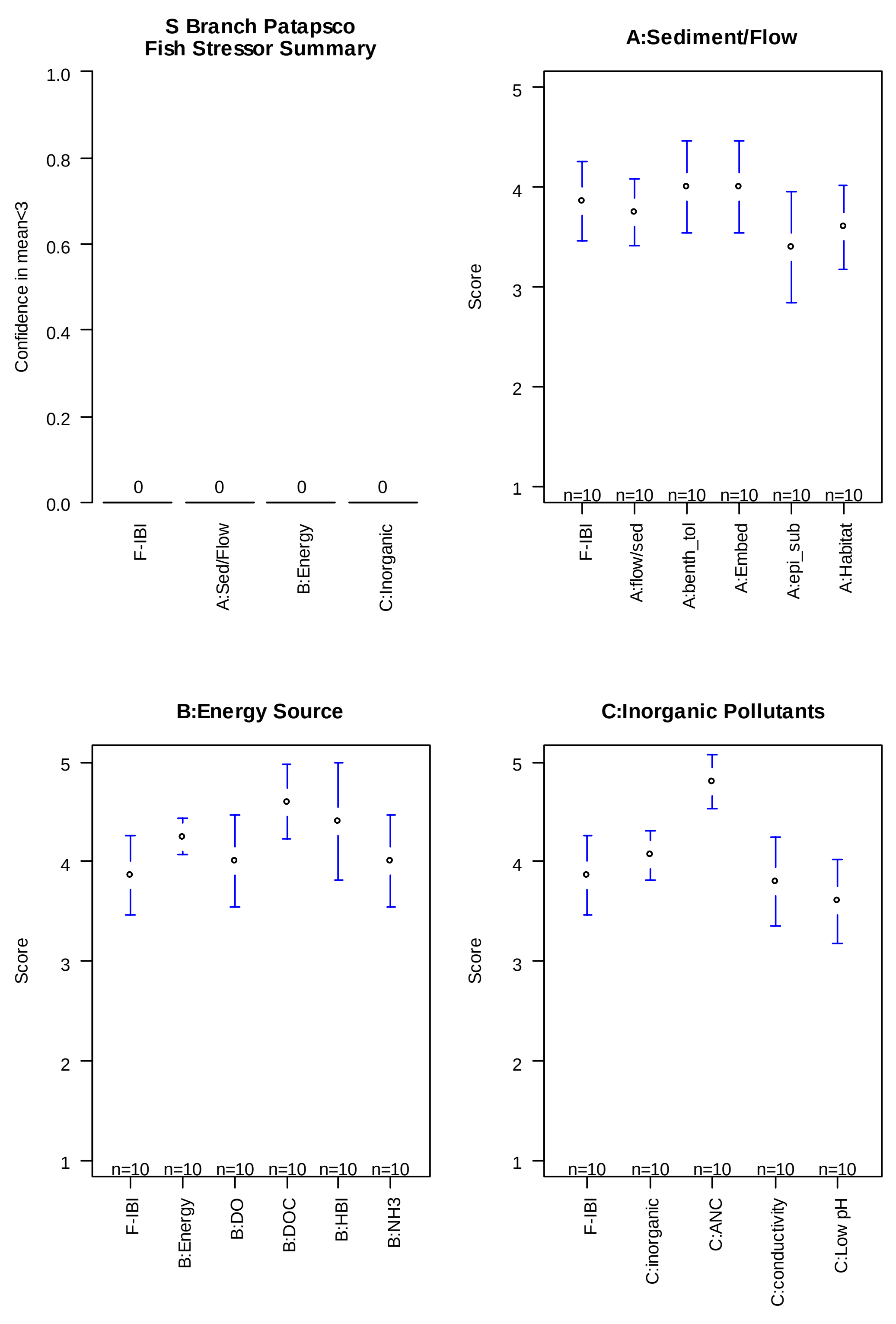


Figure F-129: South Branch Patapsco Fish Stressor Results

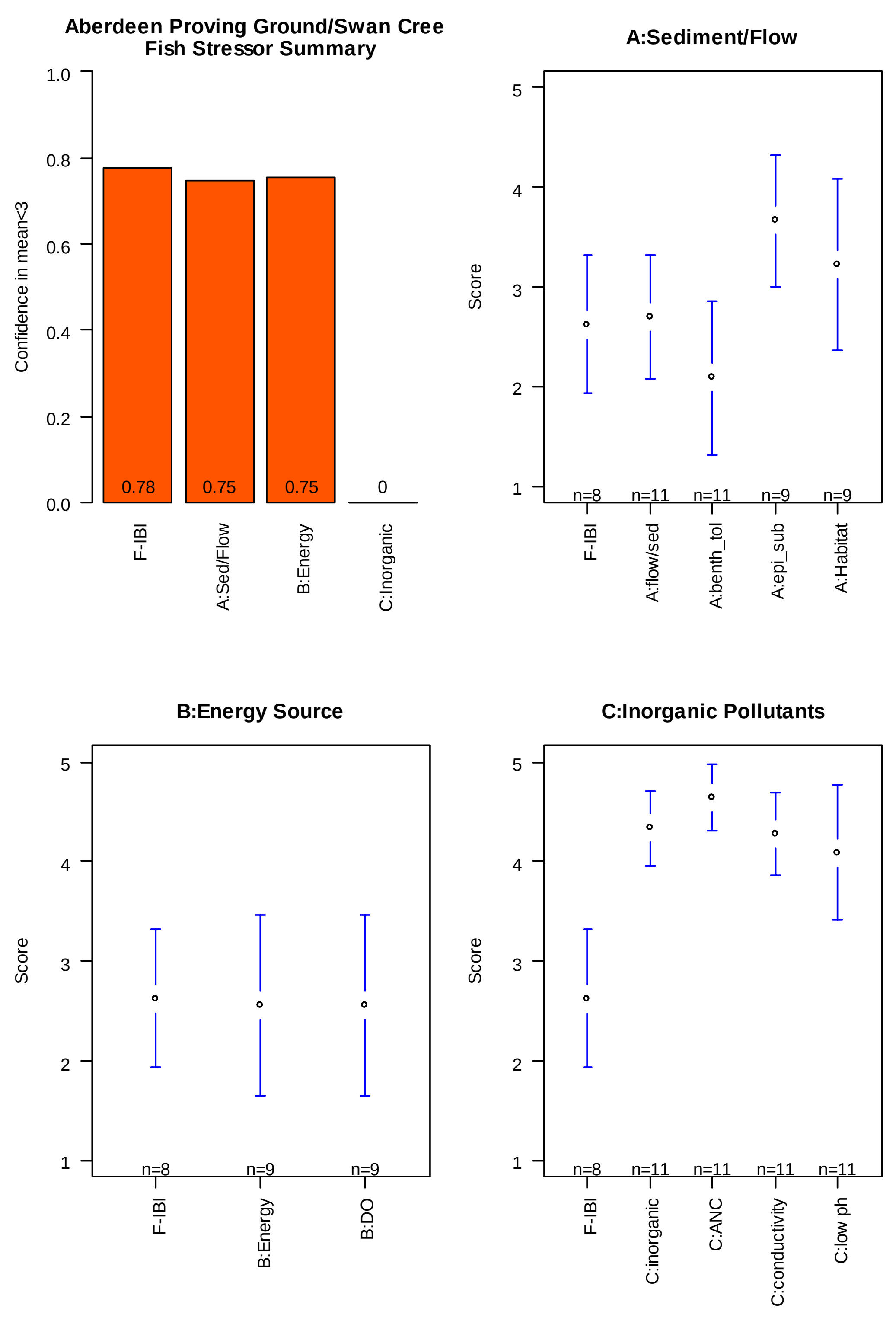


Figure F-130: Aberdeen Proving Ground/Swan Creek Fish Stressor Results

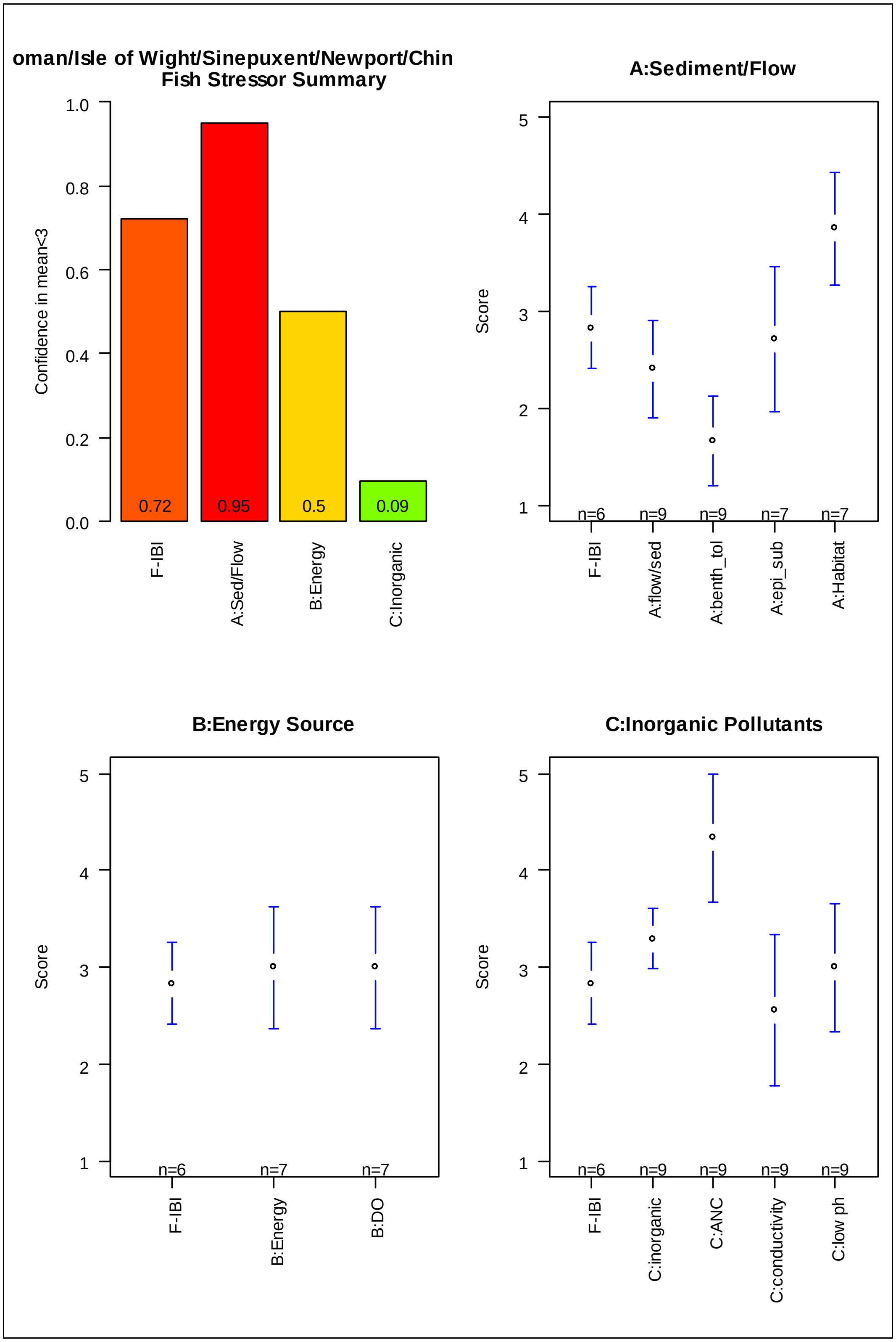


Figure F-131: Assowoman/Isle of Wight/Sinepuxent/Newport/Chincoteague Bays Fish Stressor Results

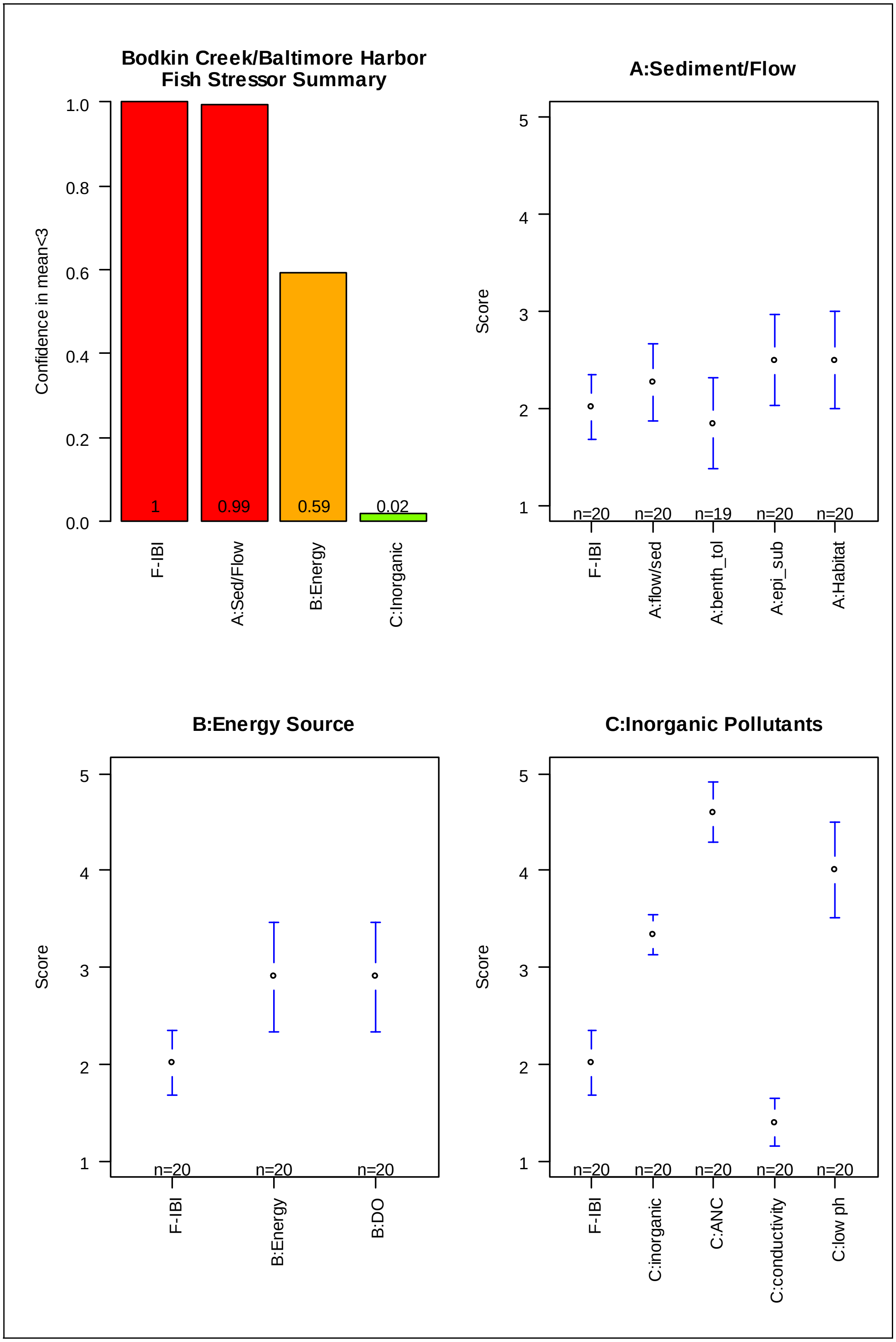


Figure F-132: Bodkin Creek/Baltimore Harbor Fish Stressor Results

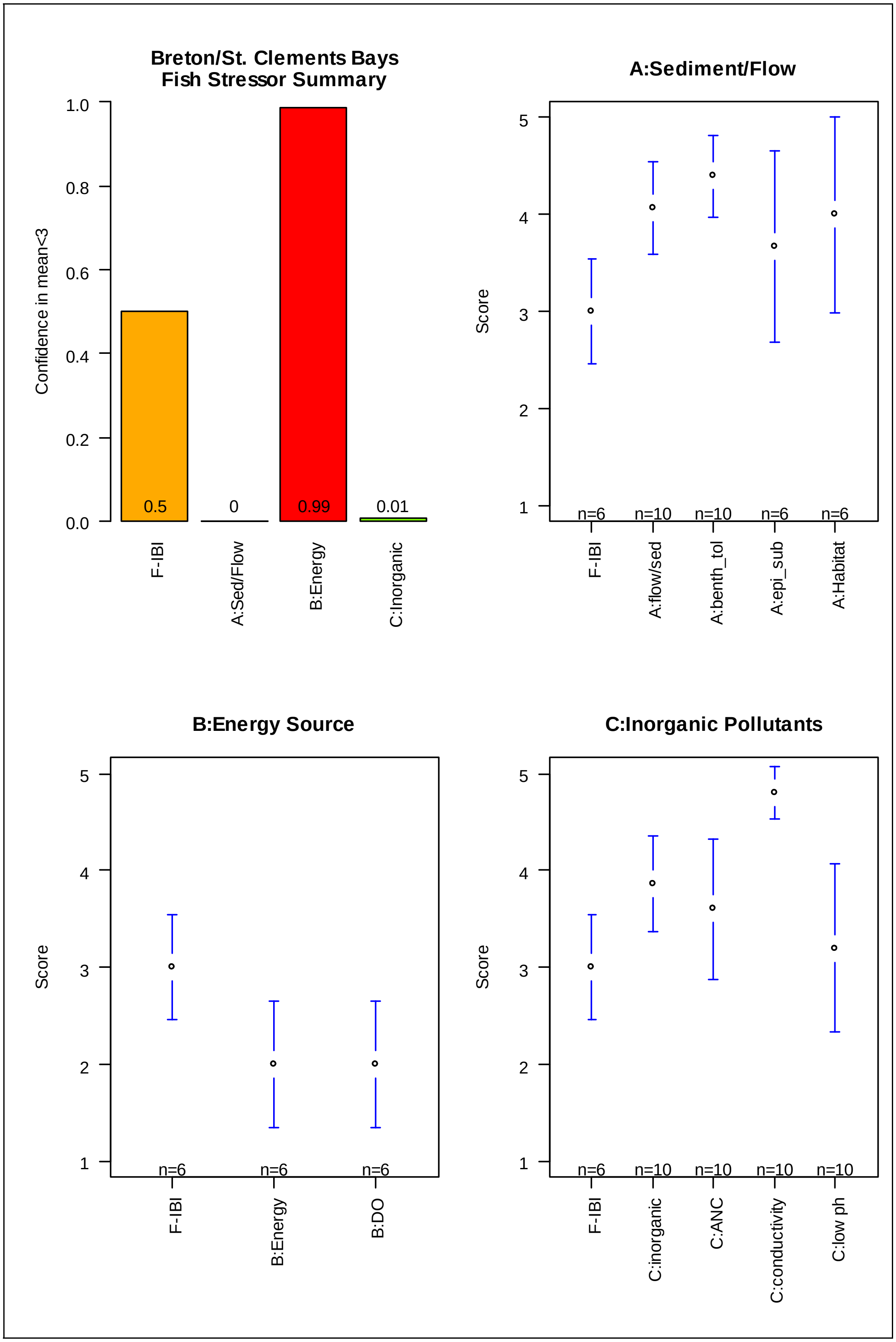


Figure F-133: Breton/St. Clements Bays Fish Stressor Results

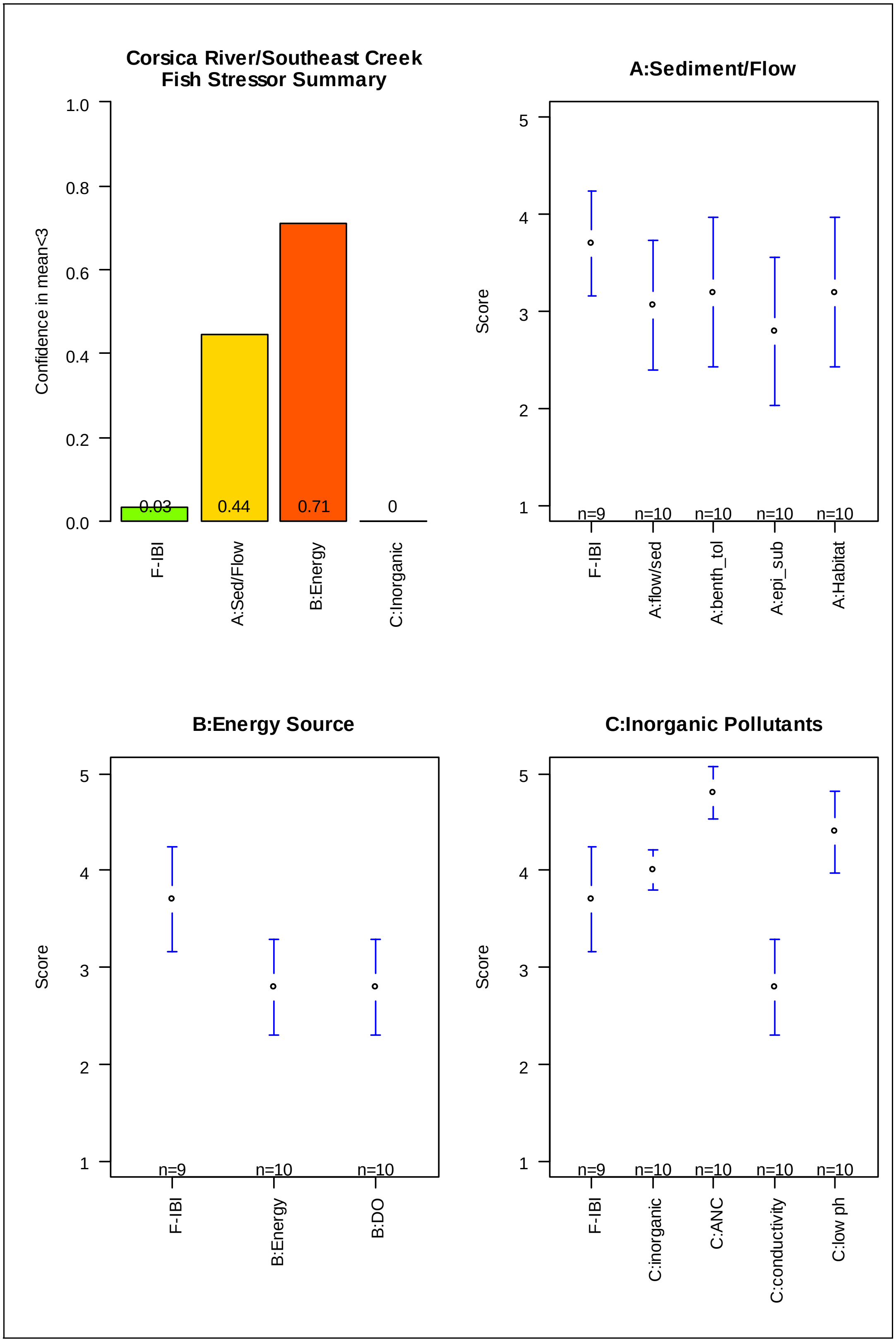


Figure F-134: Corsica River/Southeast Creek Fish Stressor Results

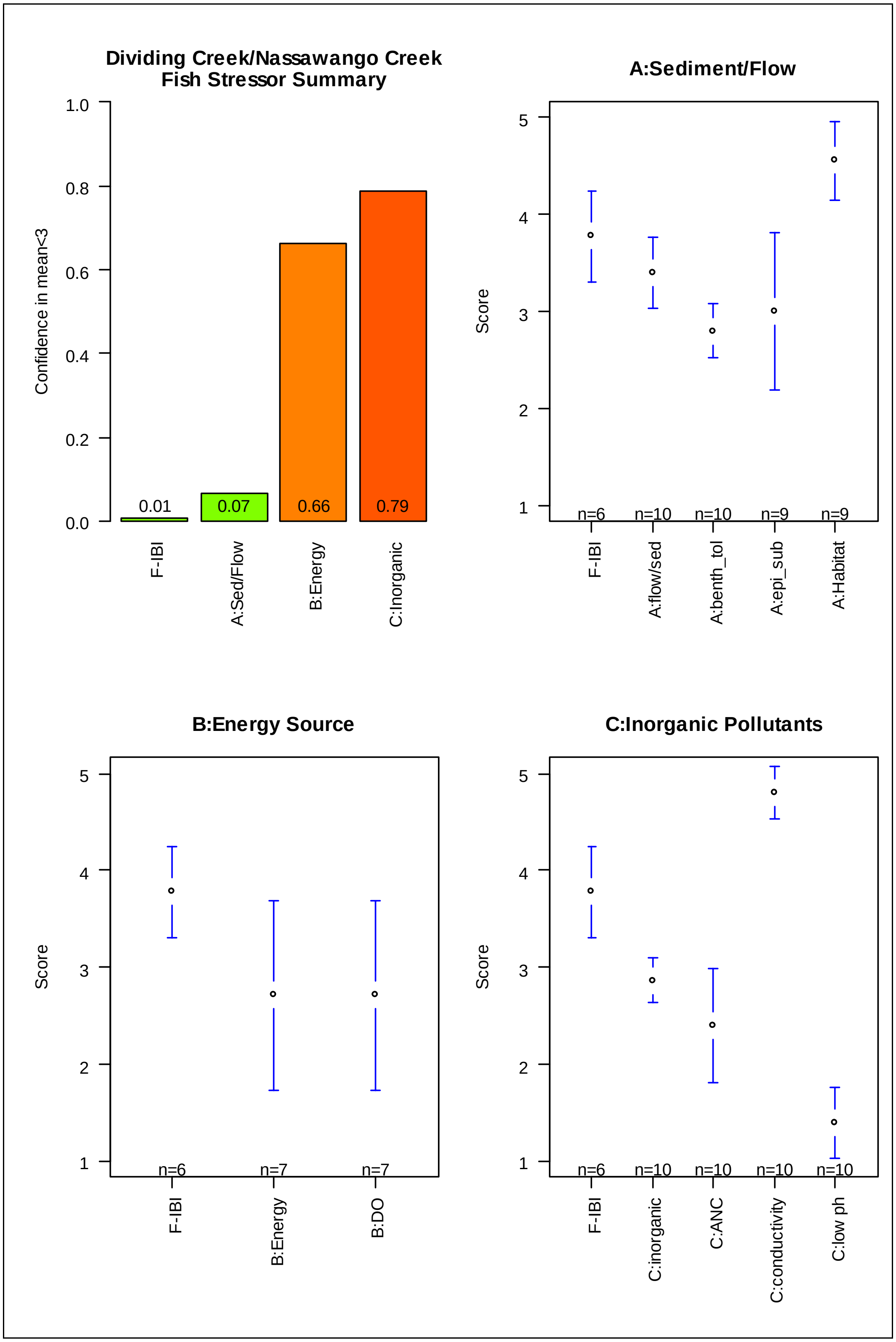


Figure F-135: Dividing Creek/Nassawango Creek Fish Stressor Results

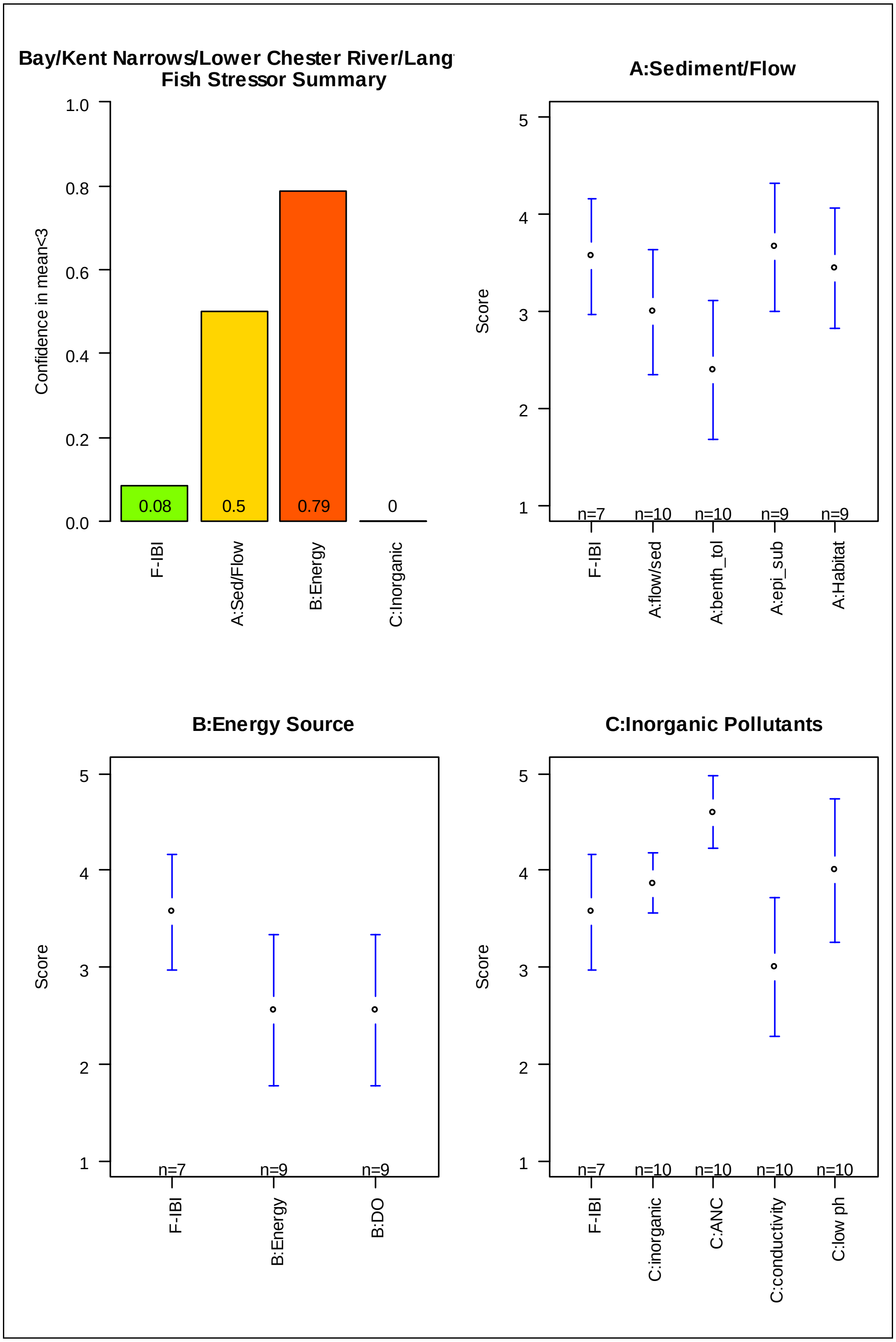


Figure F-136: Eastern Bay/Kent Narrows/Lower Chester River/Langford Creek Fish Stressor Results

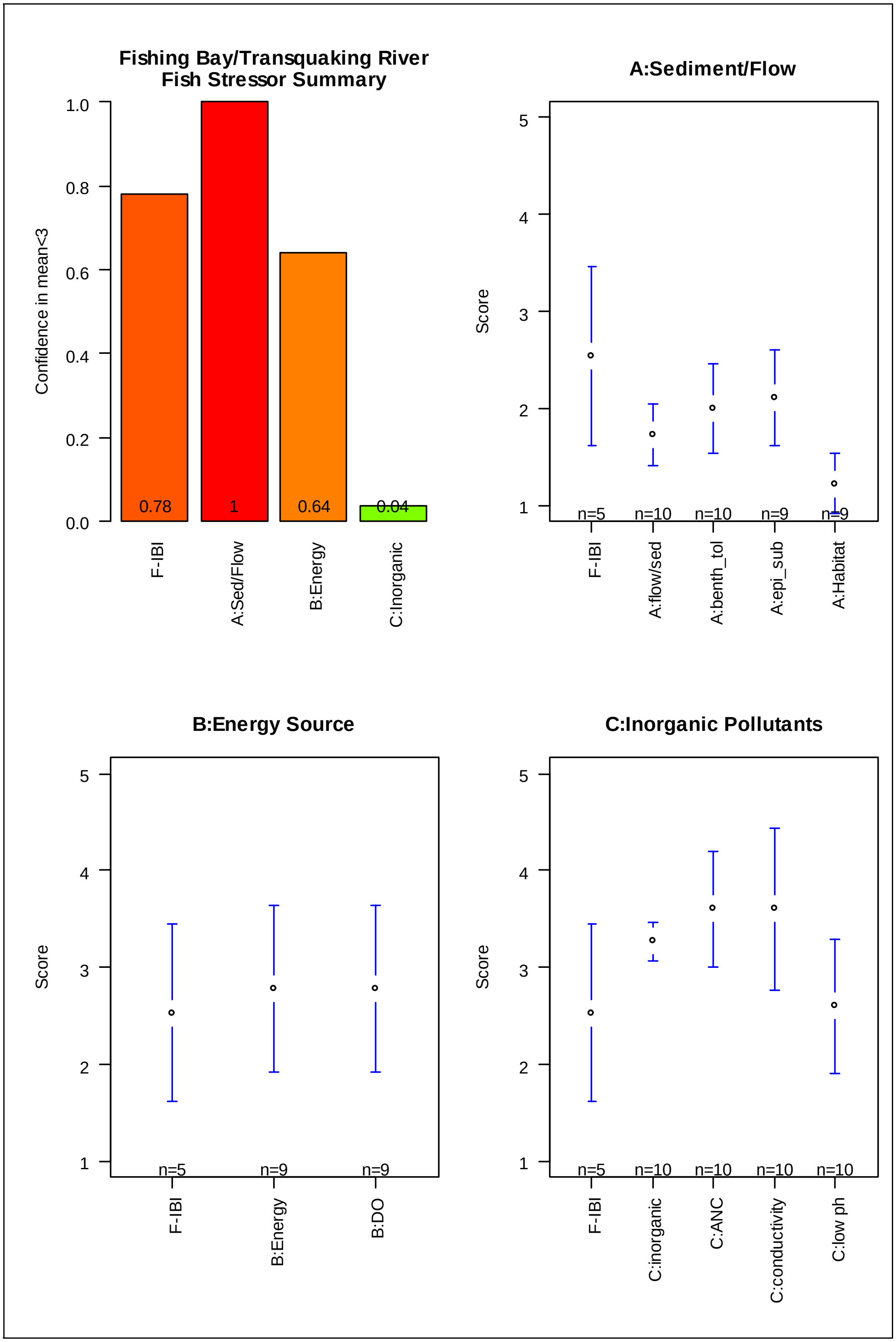


Figure F-137: Fishing Bay/Transquaking River Fish Stressor Results

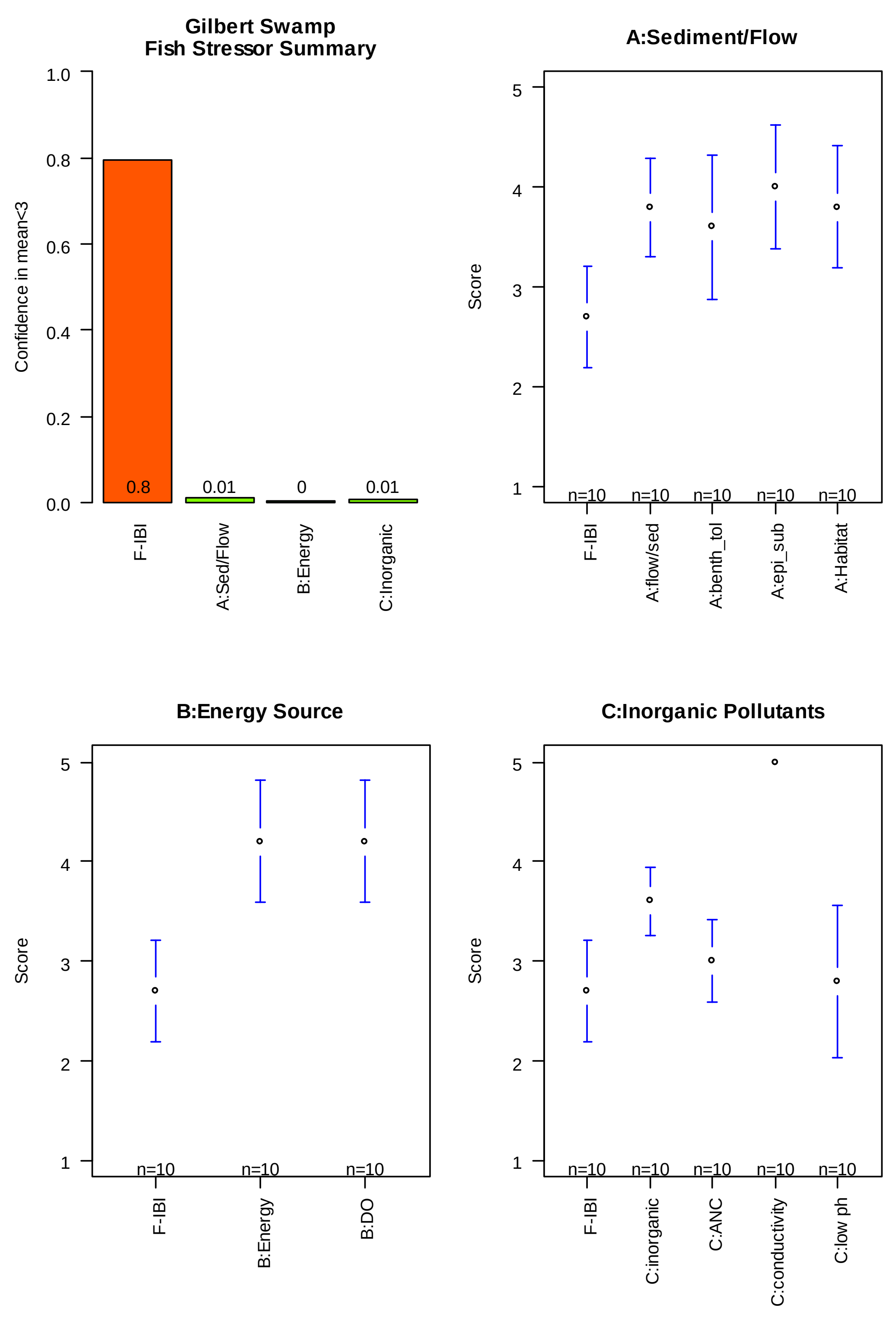


Figure F-138: Gilbert Swamp Fish Stressor Results

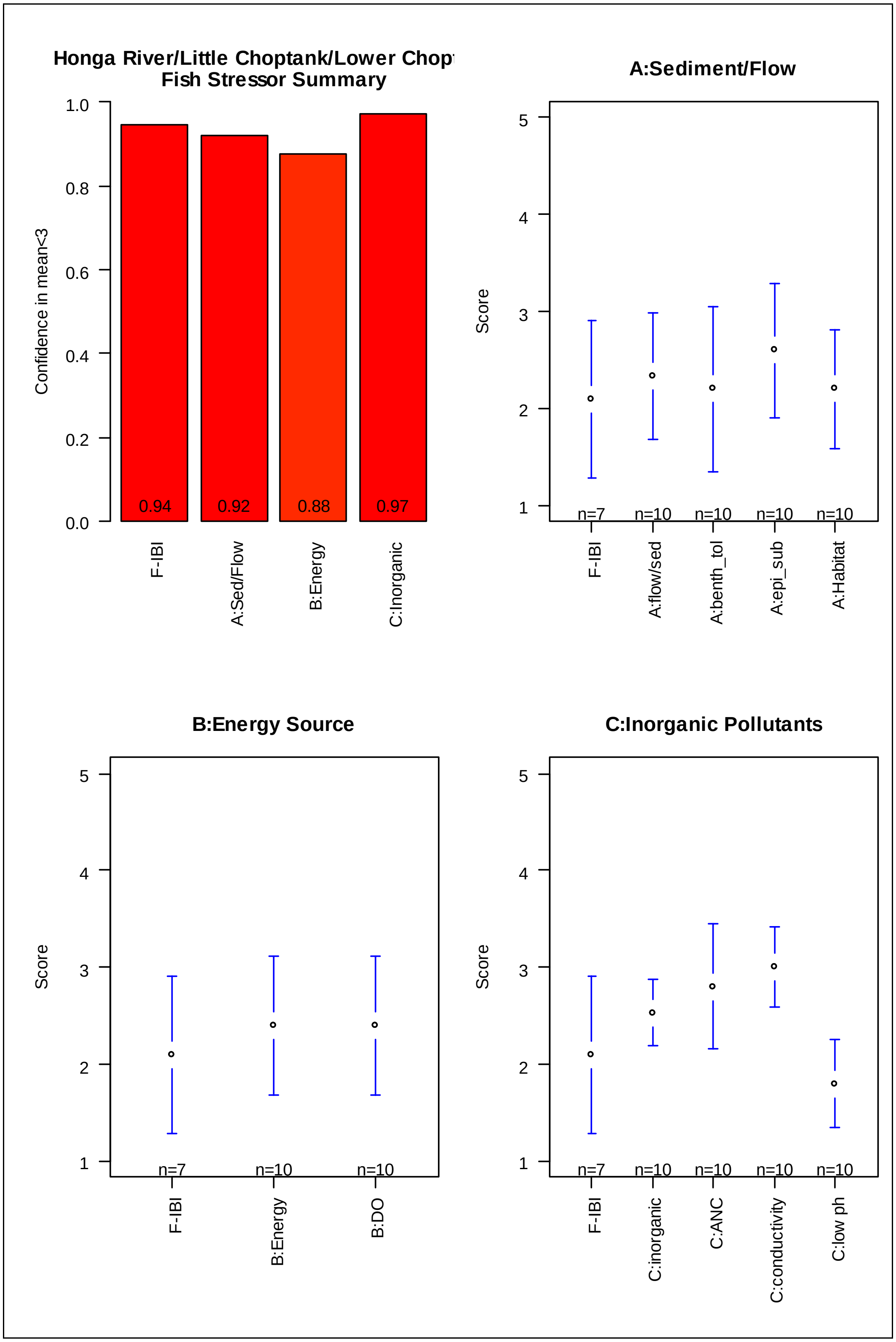


Figure F-139: Hong River/Little Choptank/Lower Choptank Fish Stressor Results

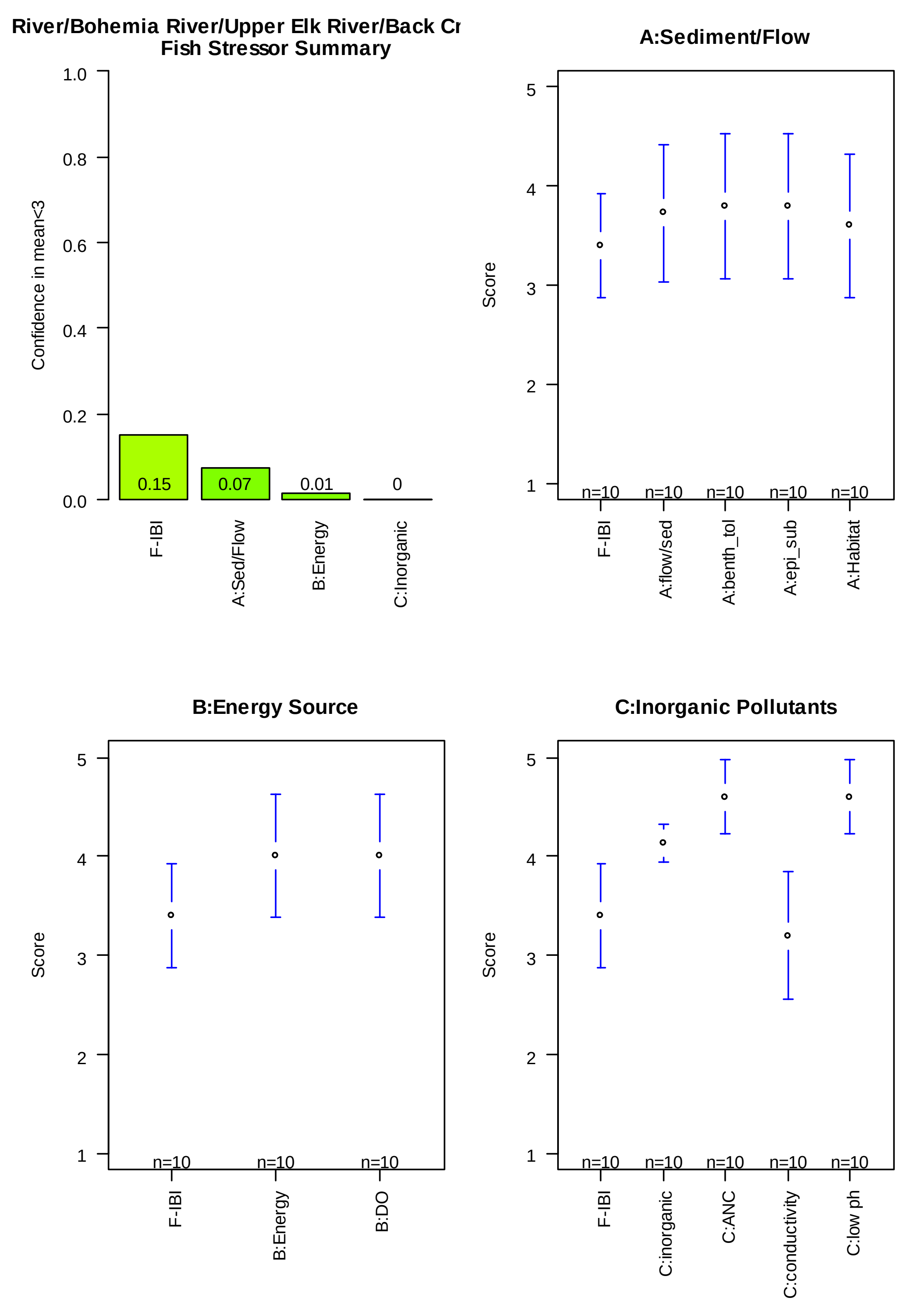


Figure F-140: Elk River/Bohemia River/Upper Elk River/Back Creek Fish Stressor Results

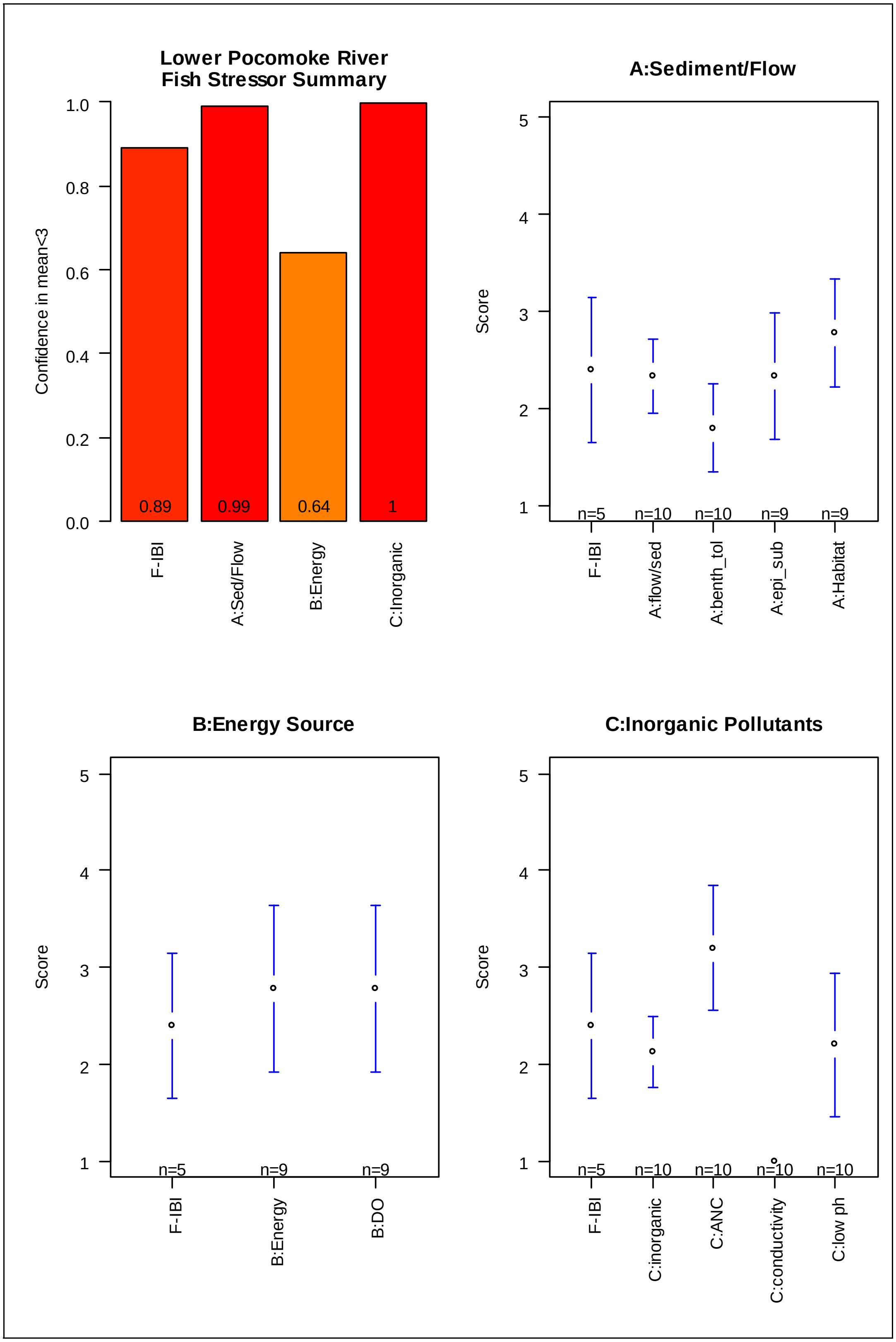


Figure F-141: Lower Pocomoke Sound Fish Stressor Results

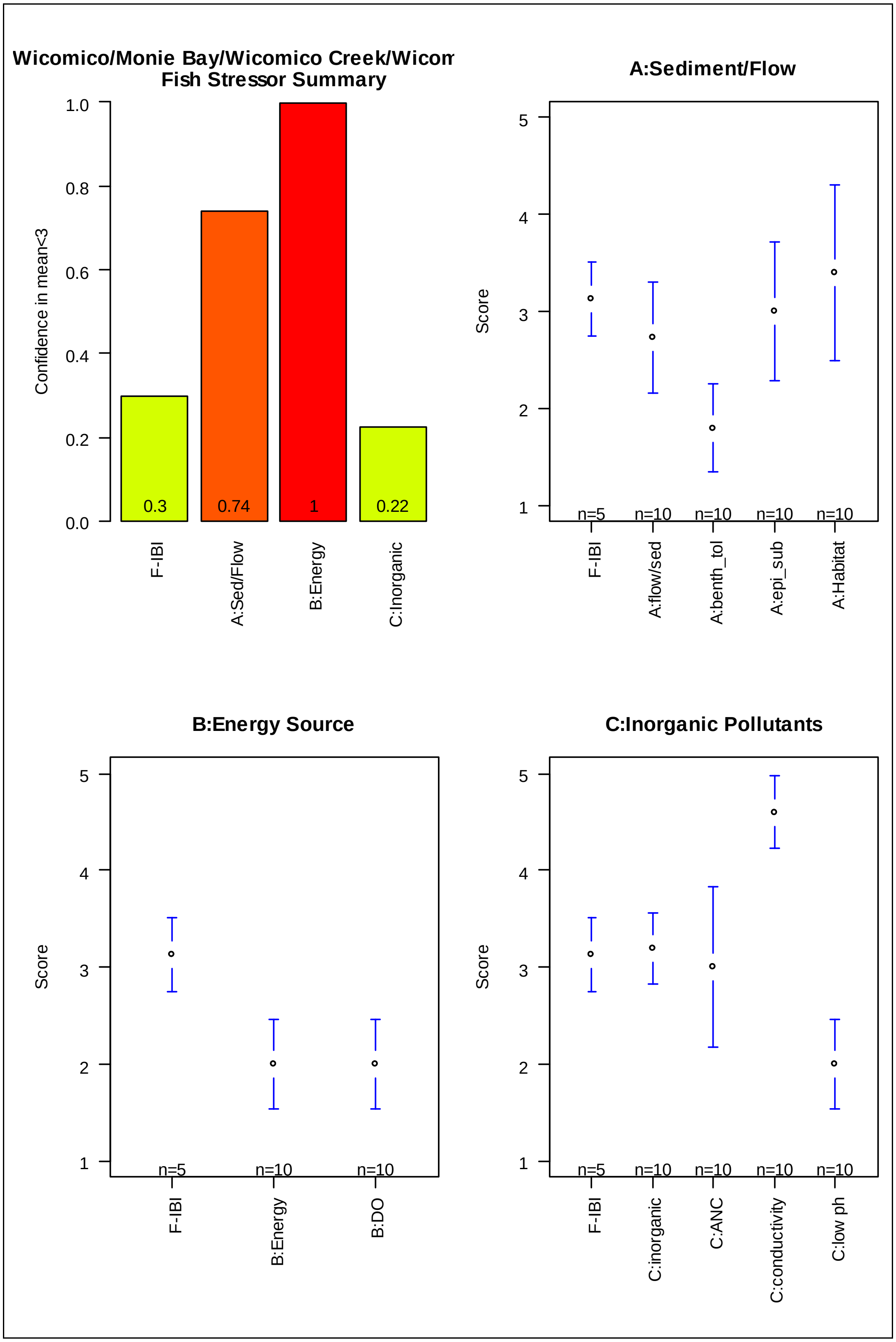


Figure F-142: Lower Wicomico/Monie Bay/Wicomico Creek/Wicomico River Headwaters Fish Stressor Results

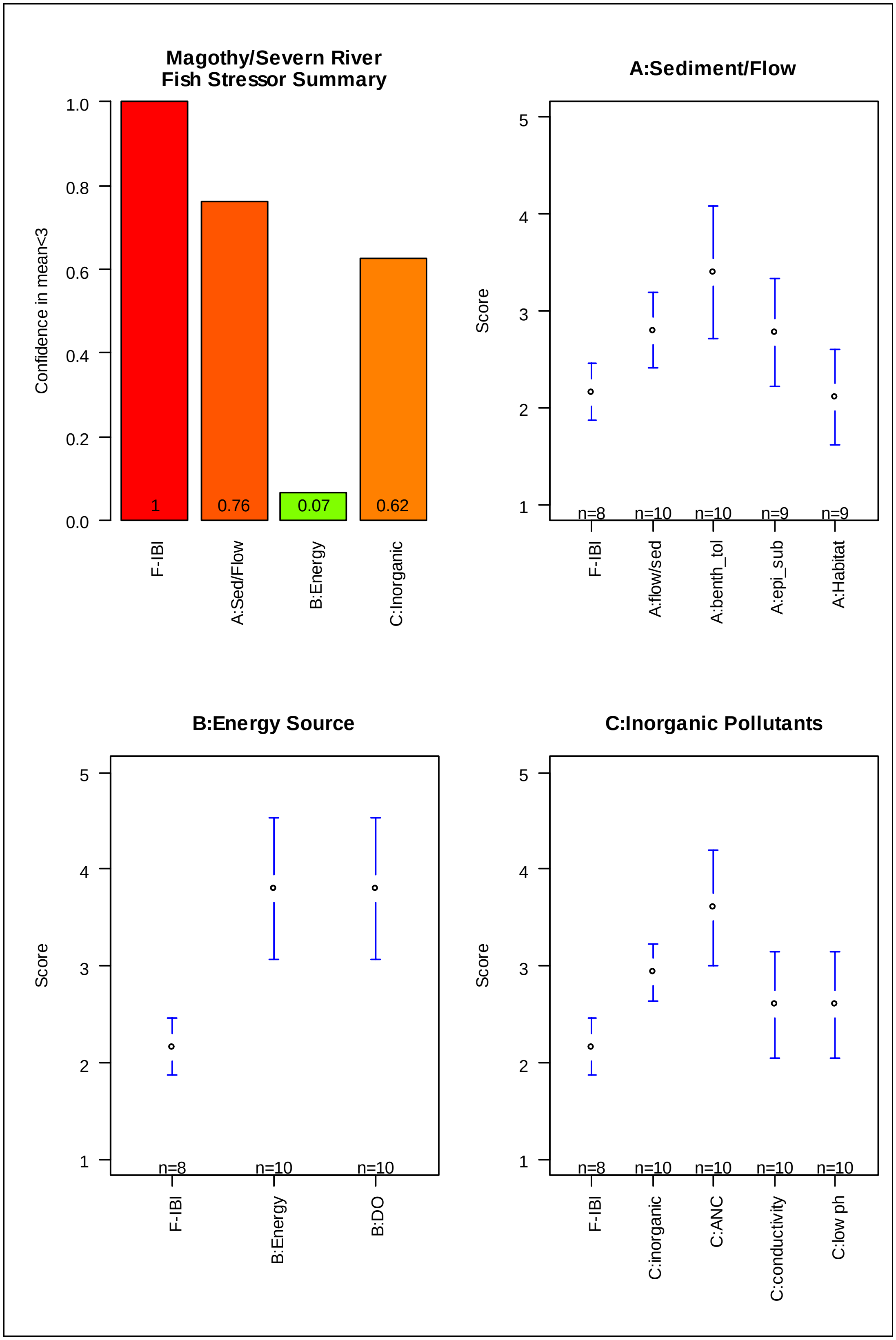


Figure F-143: Magothy/Severn River Fish Stressor Results

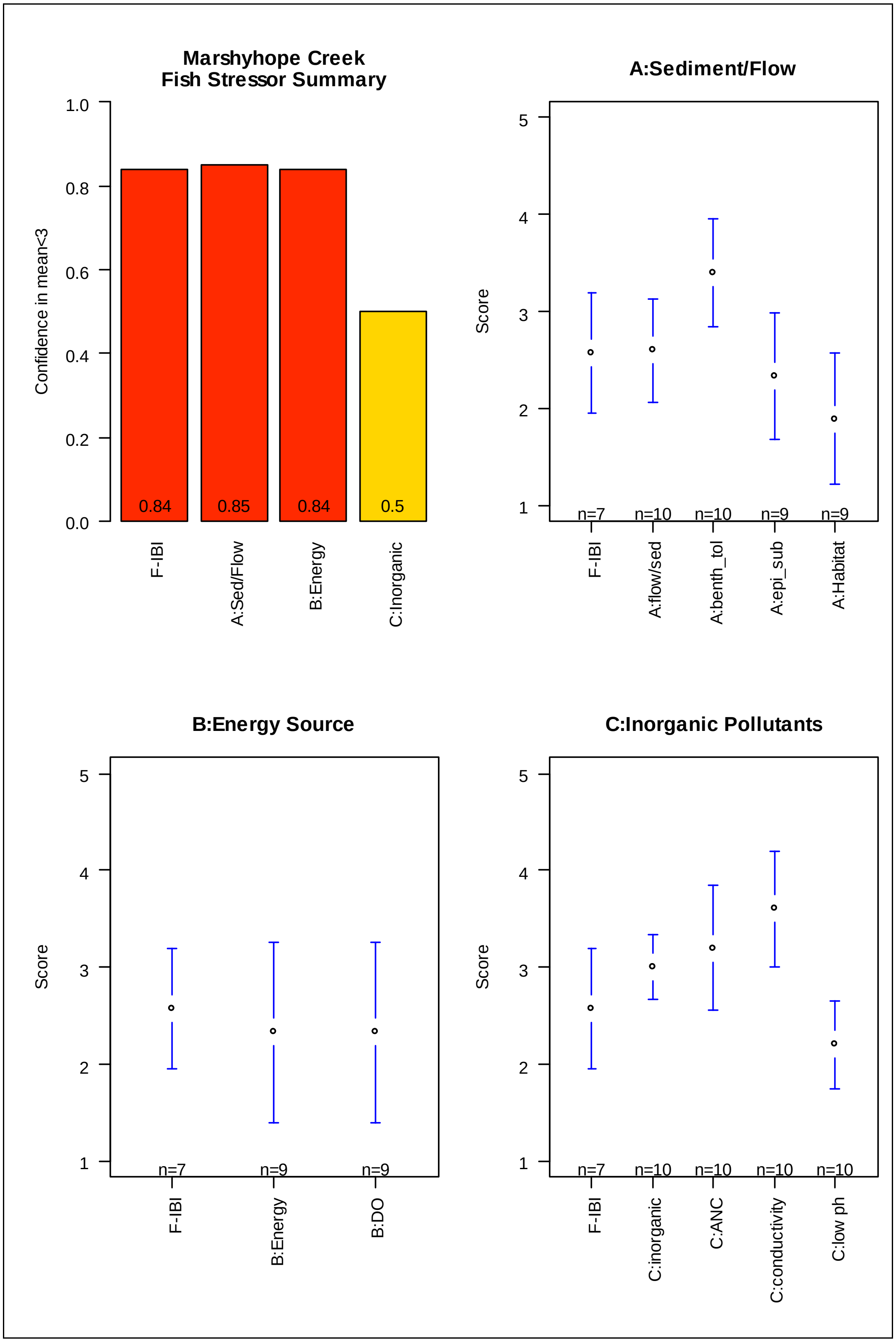


Figure F-144: Marshyhope Creek Fish Stressor Results

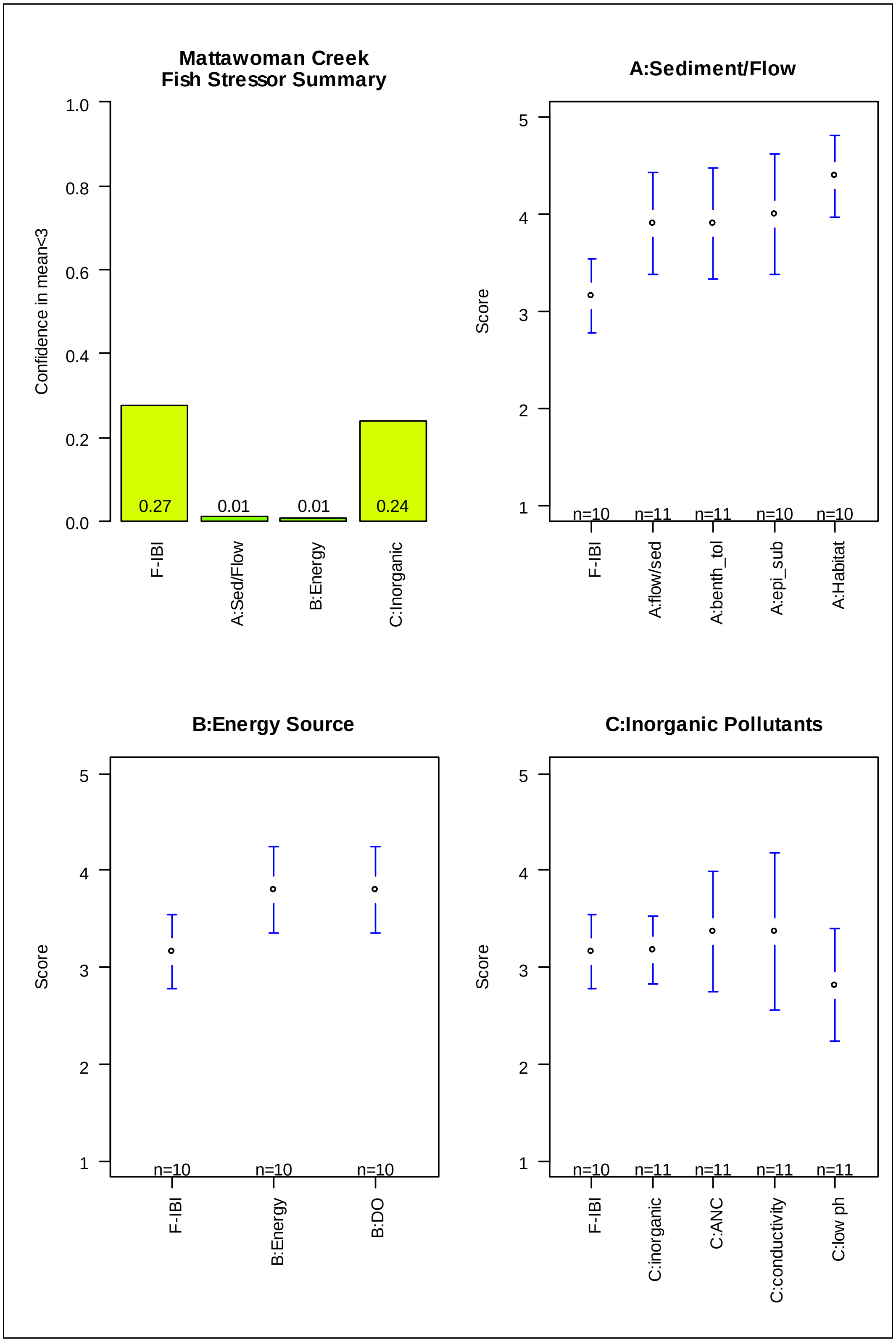


Figure F-145: Mattawoman Creek Fish Stressor Results

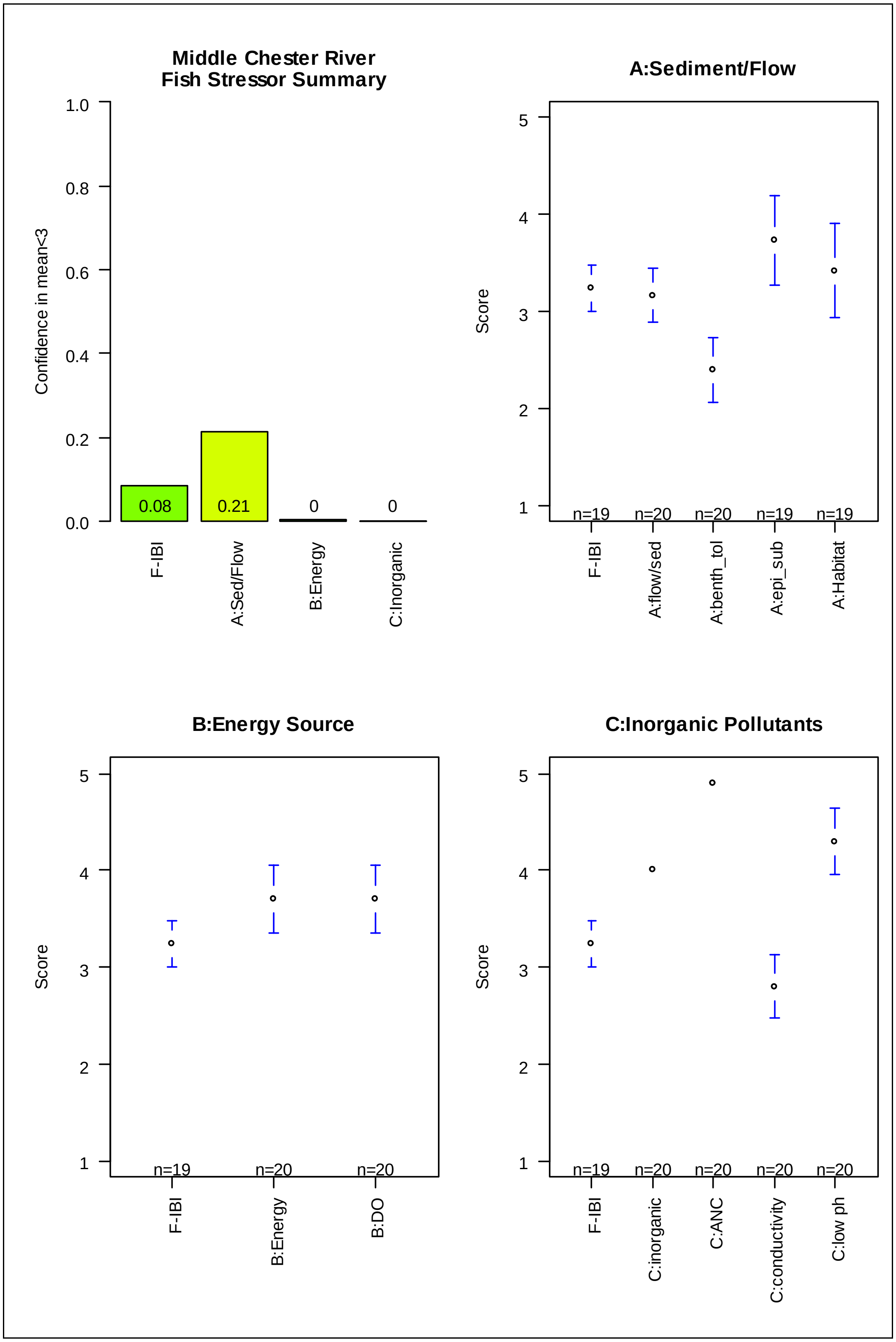


Figure F-146: Middle Chester River Fish Stressor Results

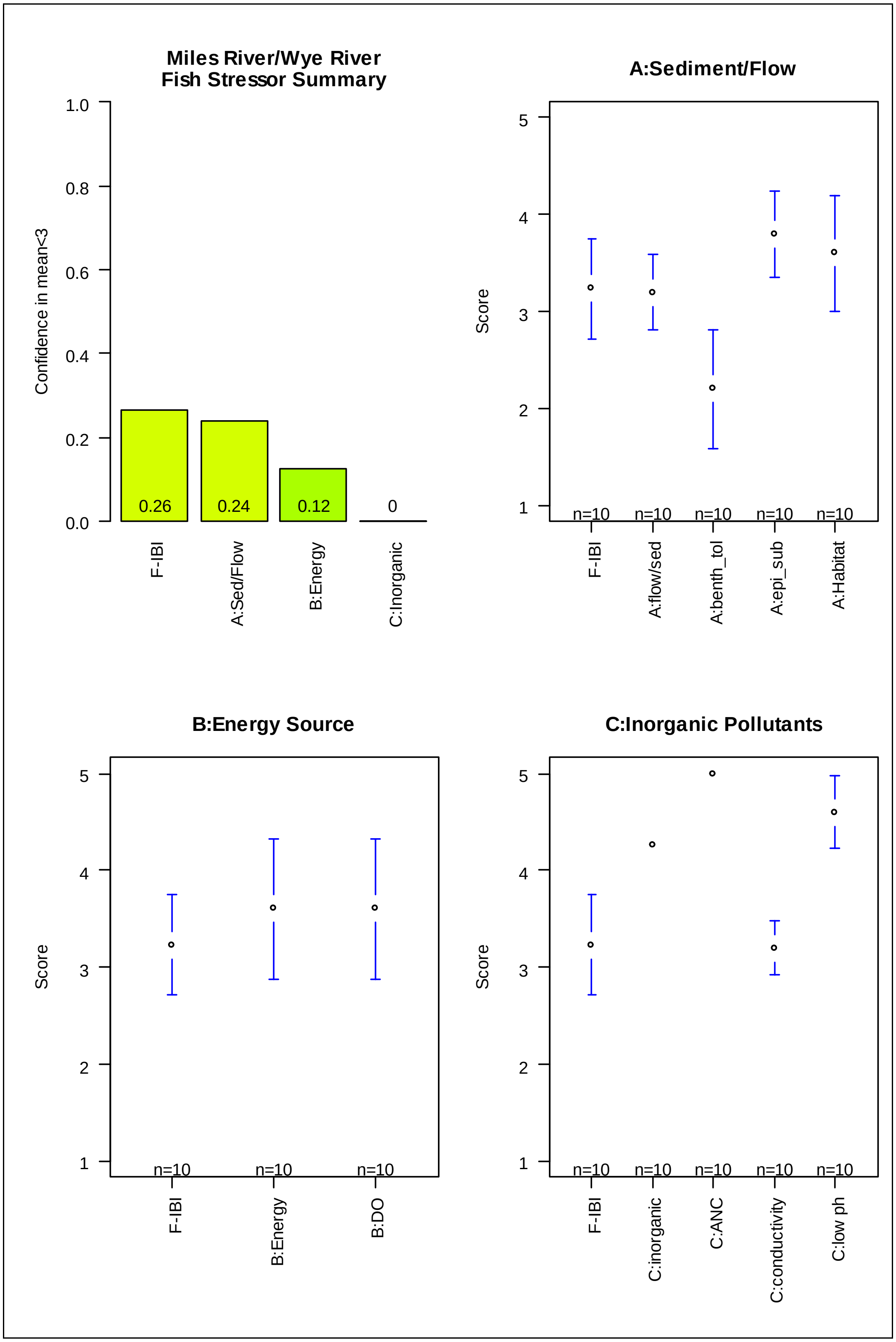


Figure F-147: Middle River/Wye River Fish Stressor Results

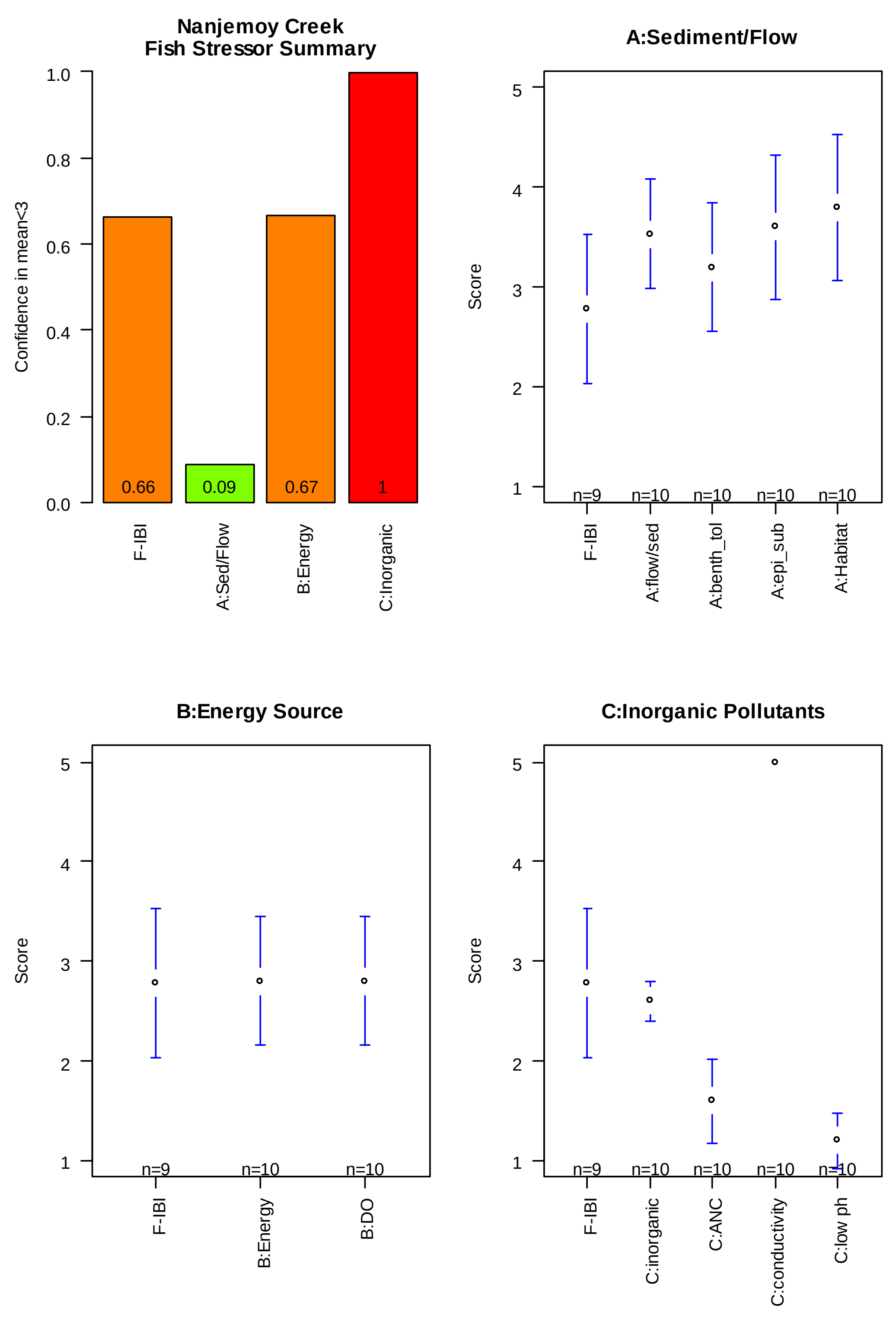


Figure F-148: Nanjemoy Creek Fish Stressor Results

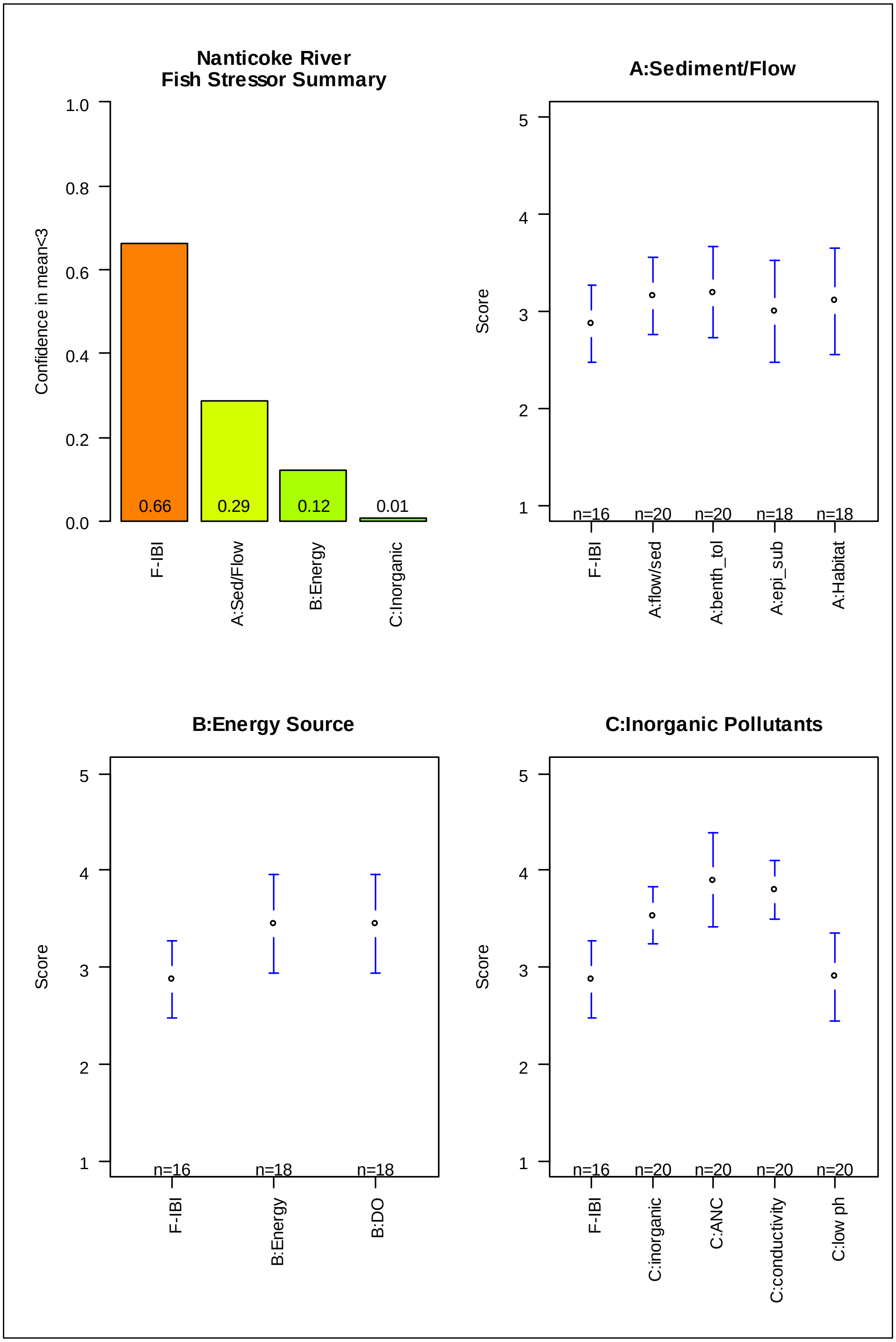


Figure F-149: Nanticoke River Fish Stressor Results

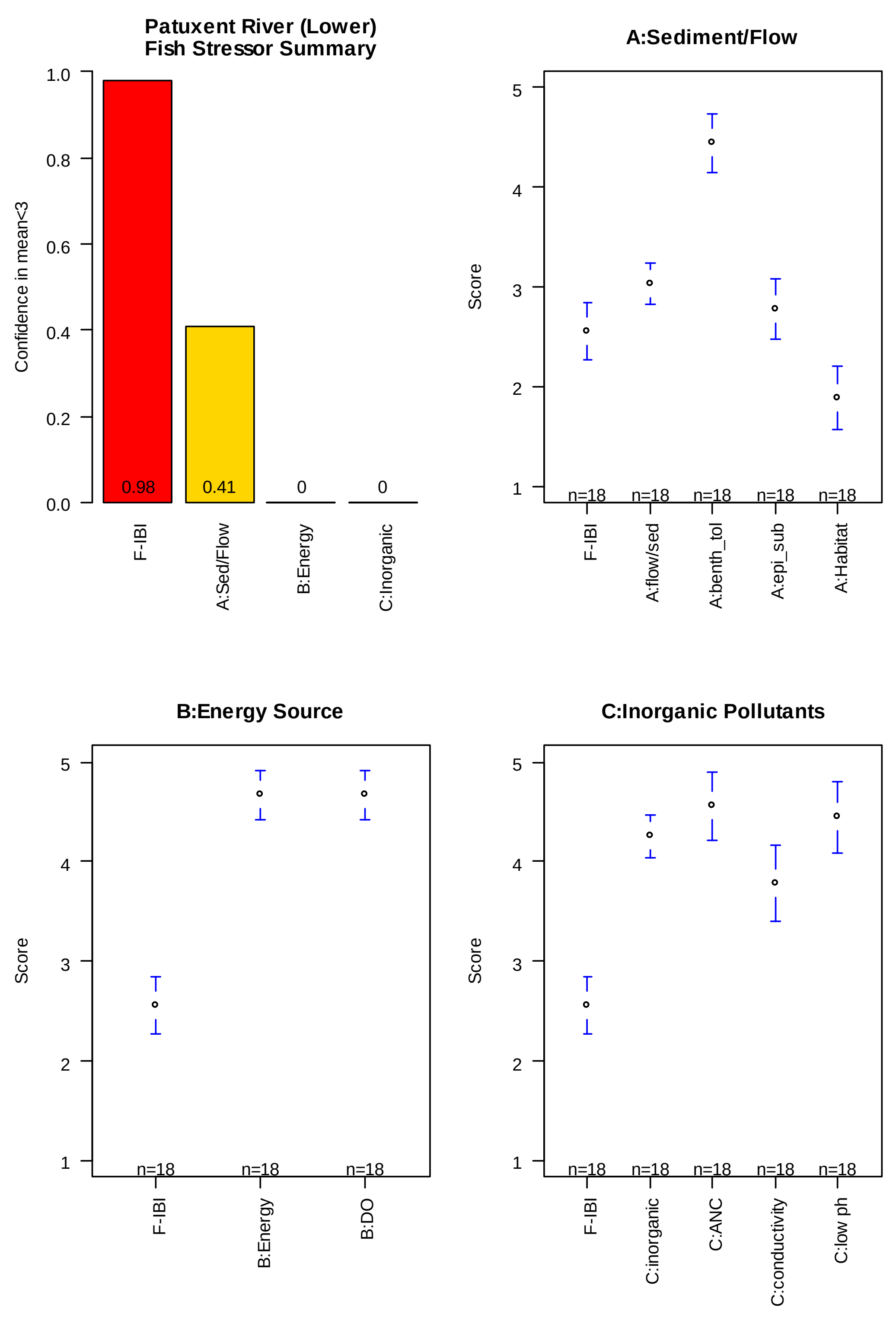


Figure F-150: Patuxent River Lower Fish Stressor Results

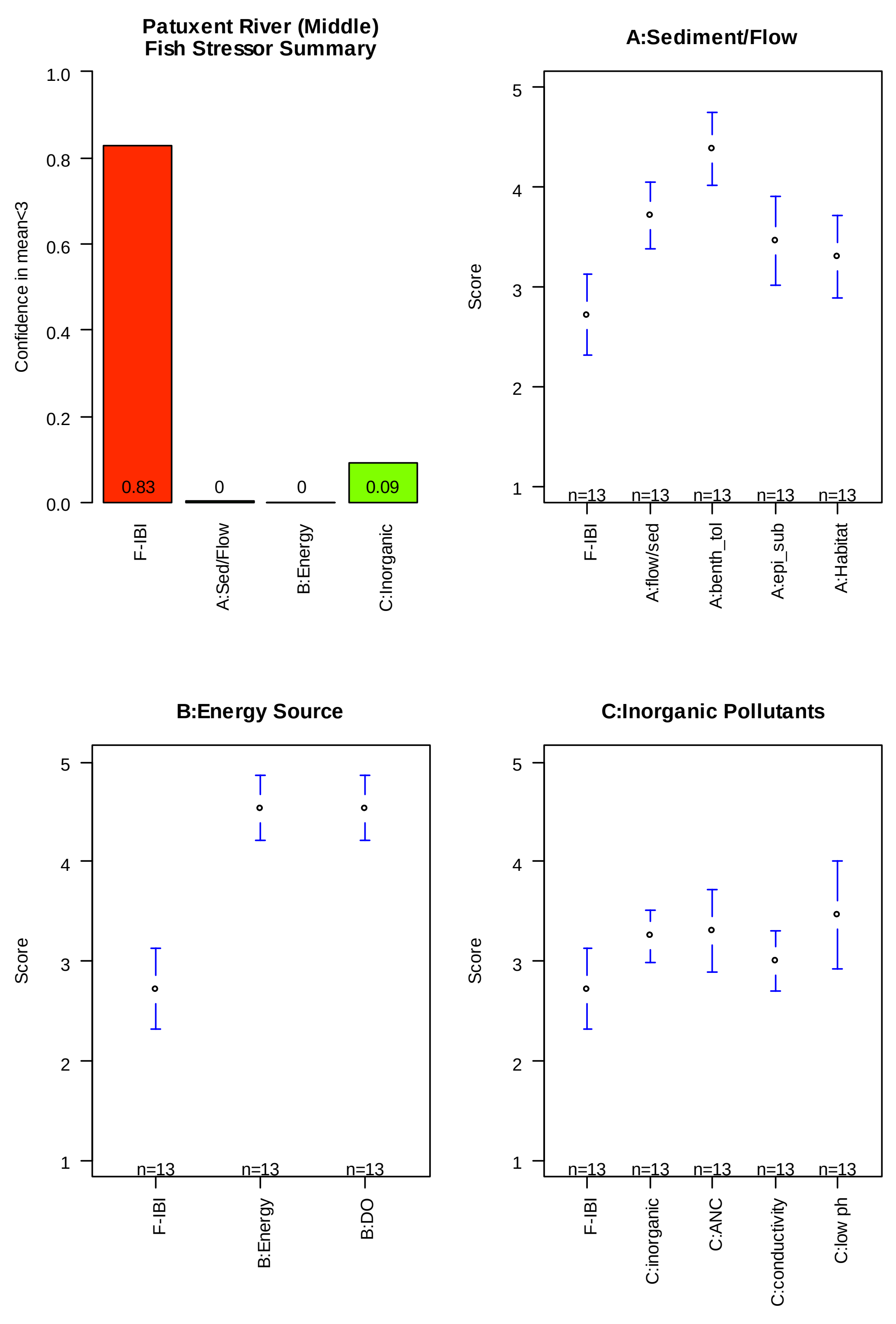


Figure F-151: Patuxent River Middle Fish Stressor Results

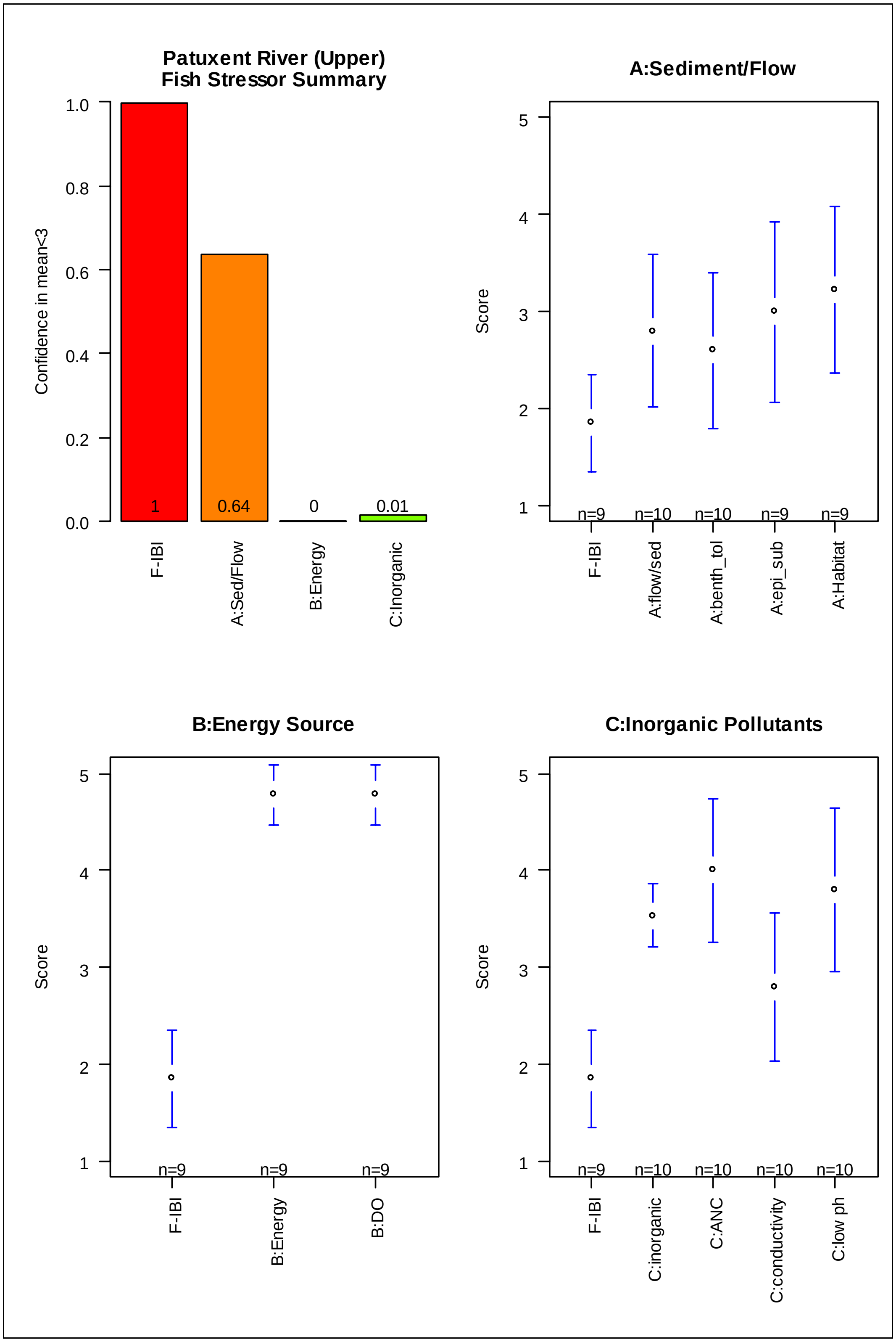


Figure F-152: Patuxent River Upper Fish Stressor Results

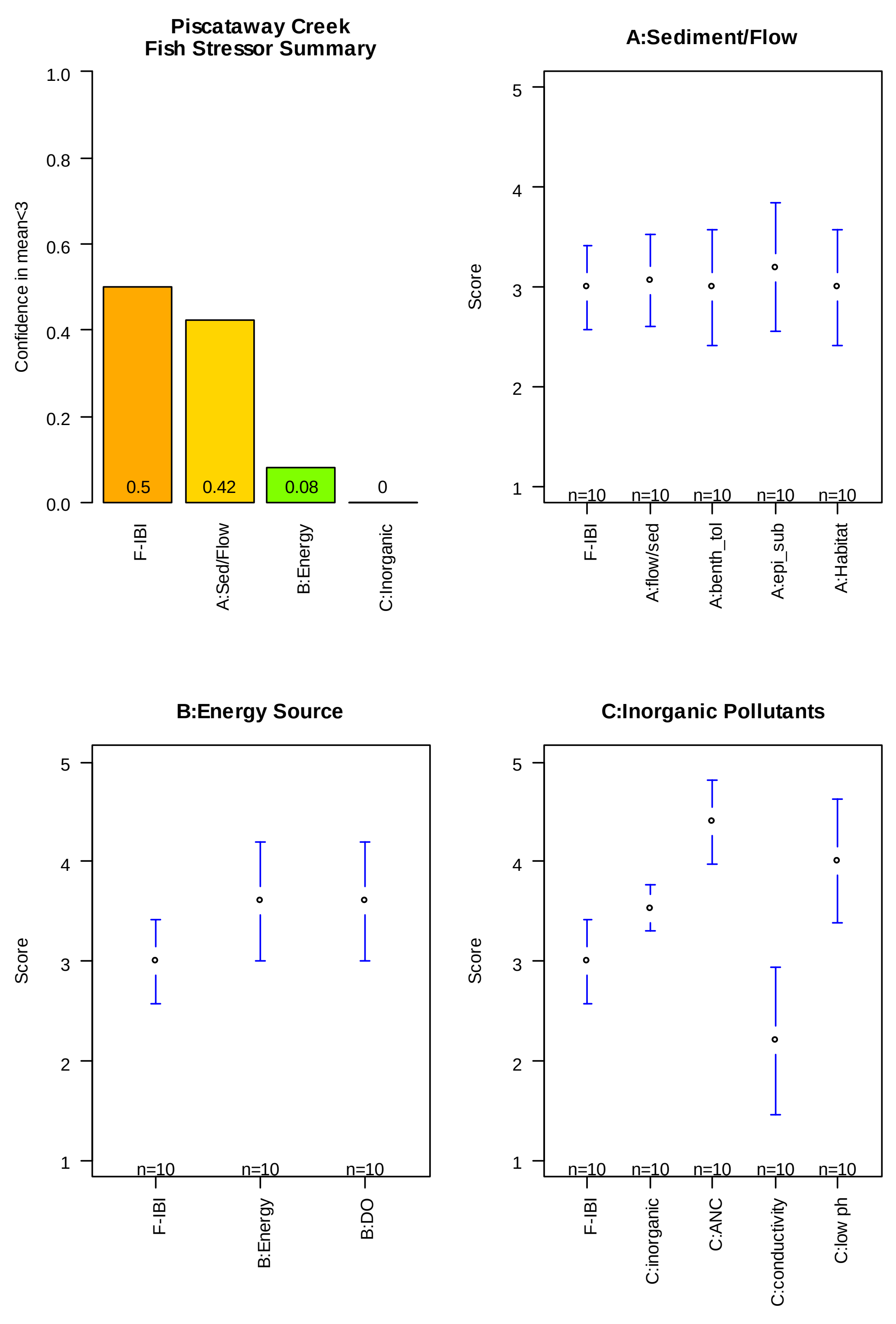


Figure F-153: Piscataway Creek Fish Stressor Results

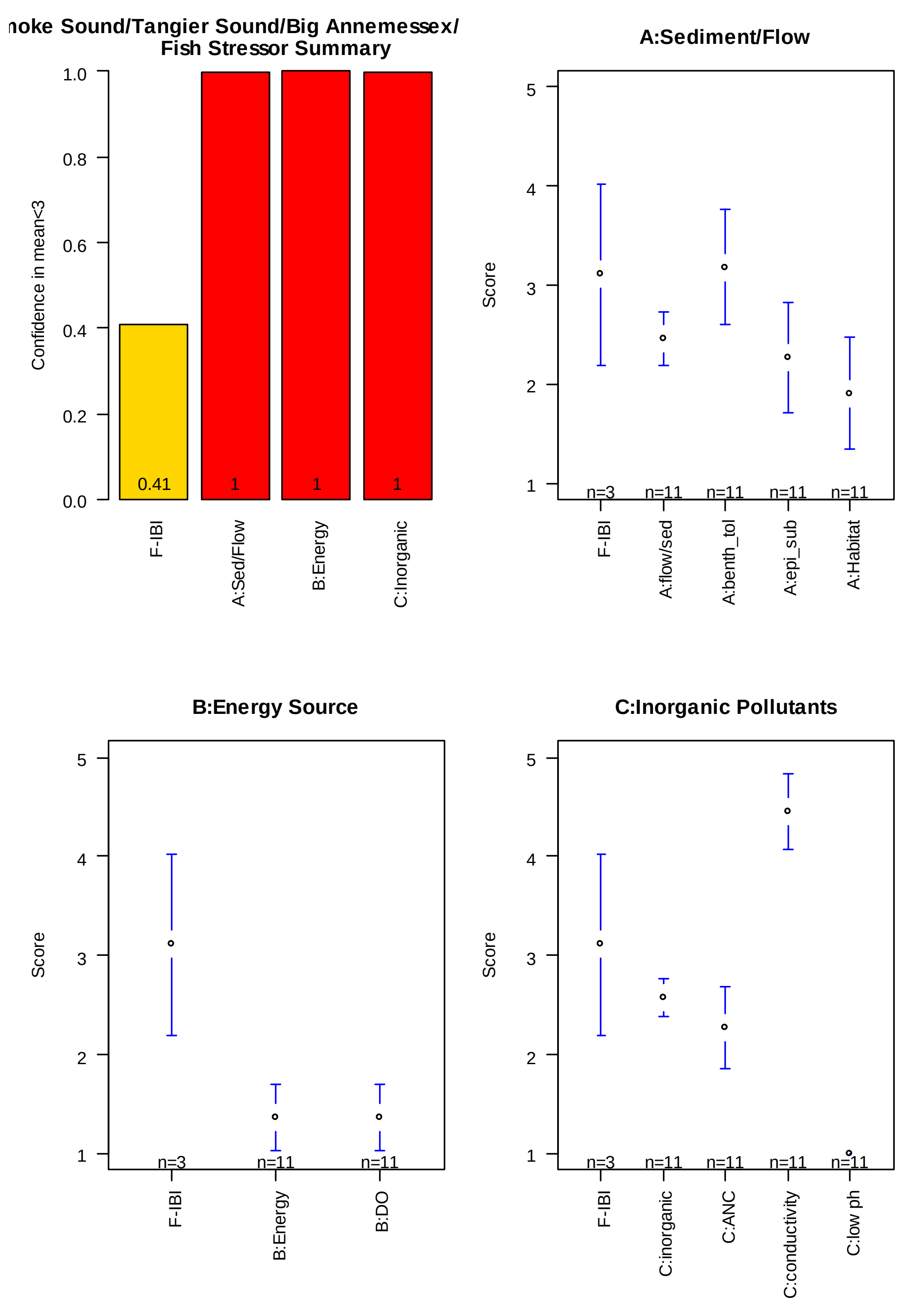


Figure F-154: Pocomoke Sound/Tangier Sound/Big Annemessex/Manokin River Fish Stressor Results

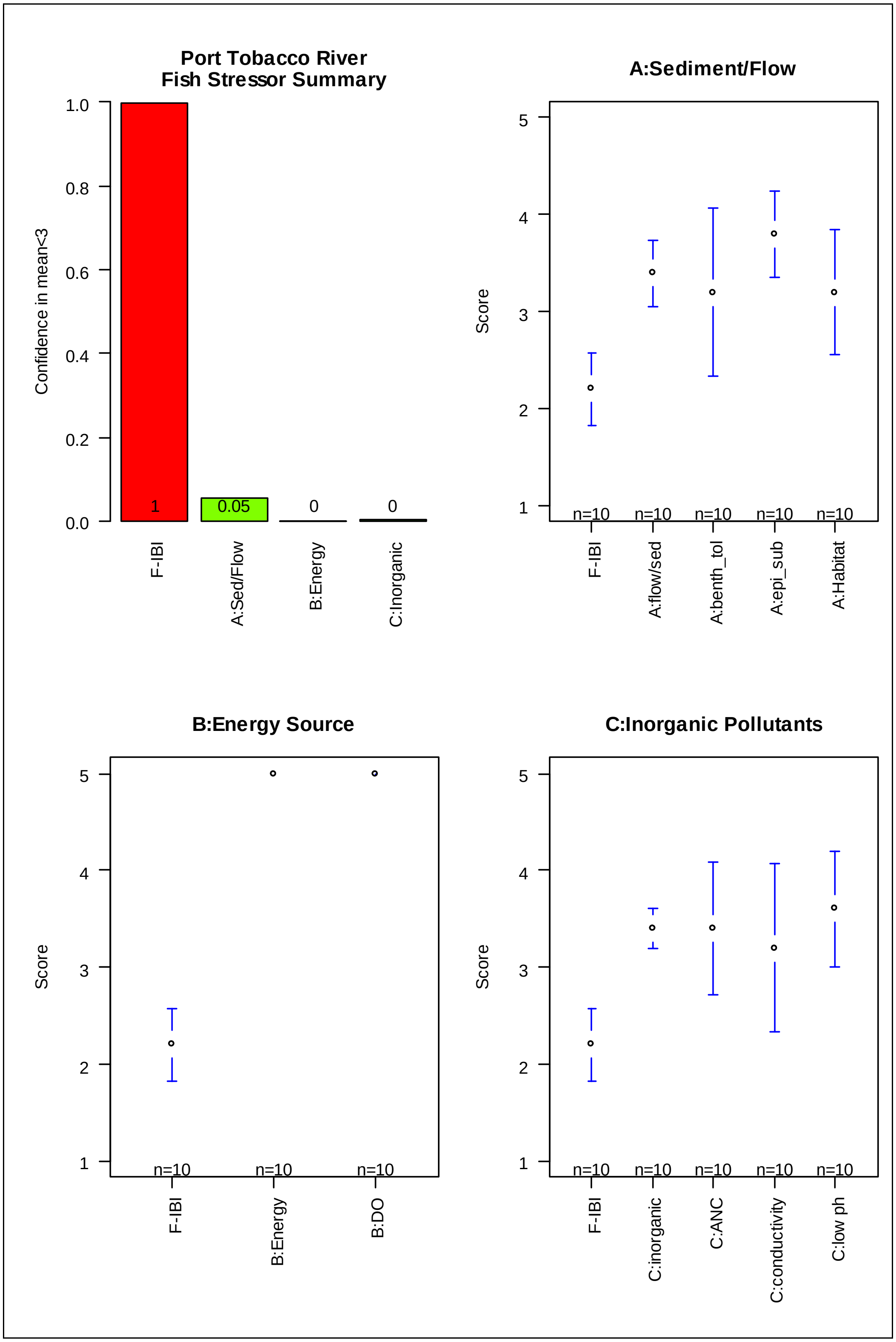


Figure F-155: Port Tobacco River Fish Stressor Results

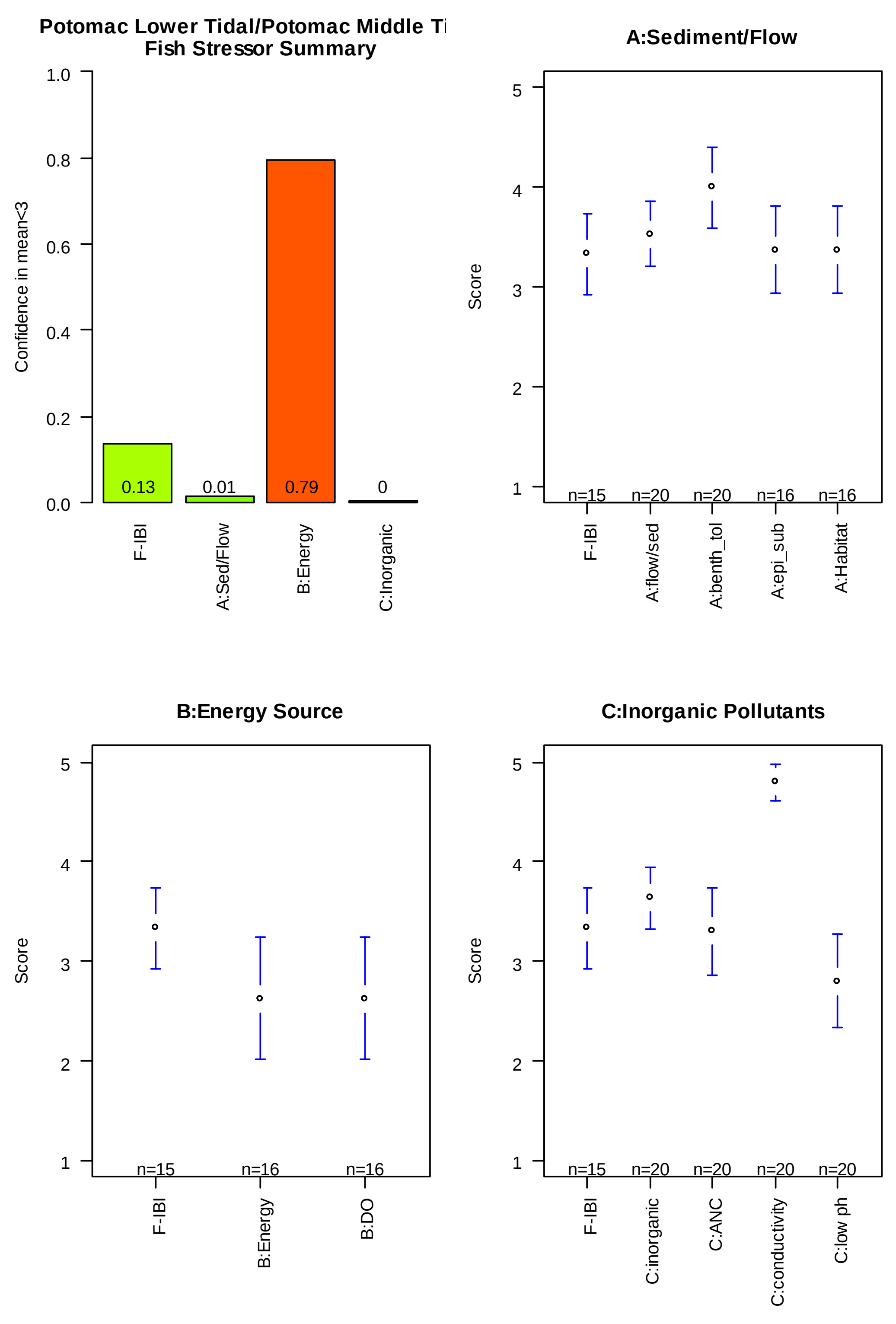


Figure F-156: Potomac Lower Tidal/Potomac Middle Tidal Fish Stressor Results

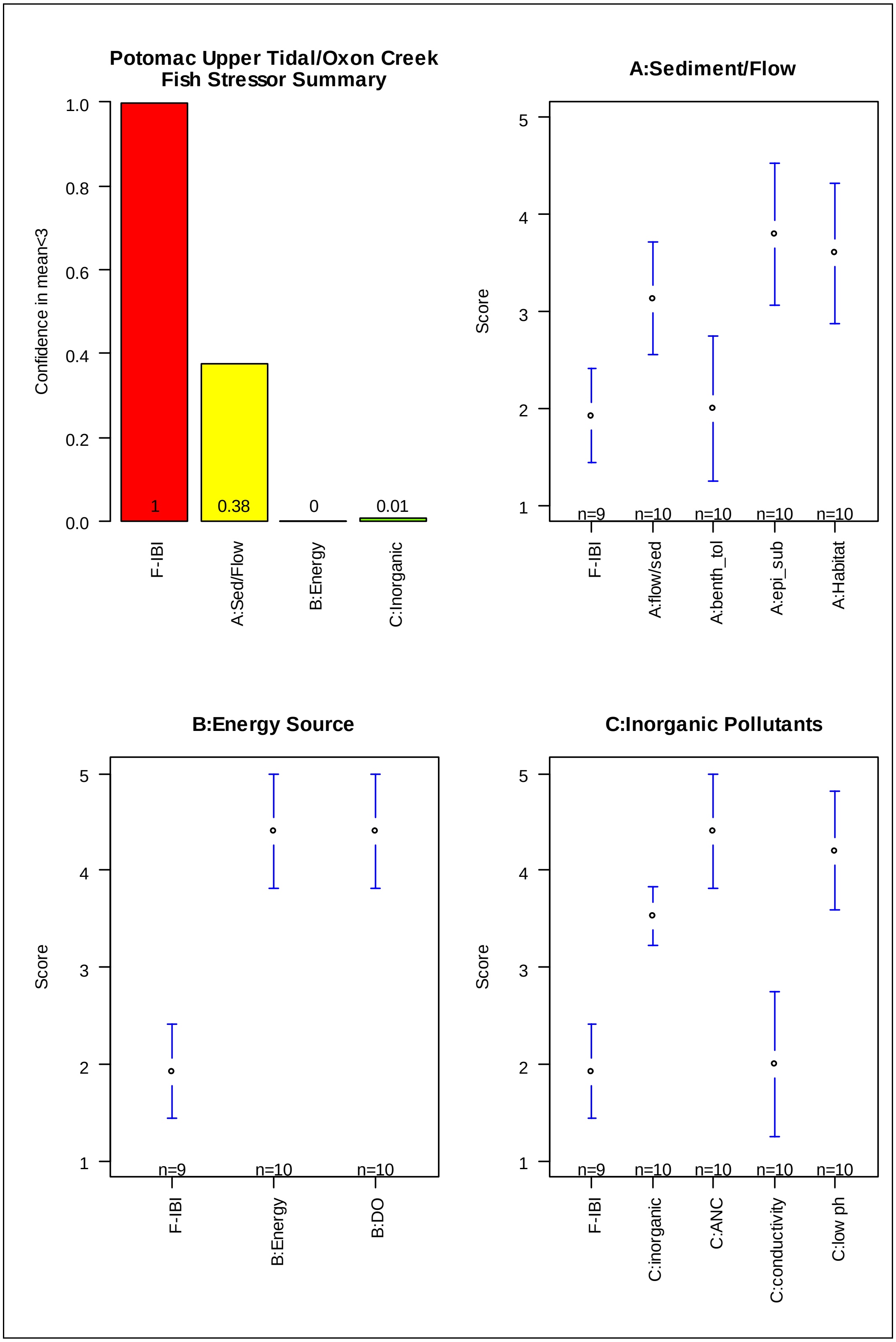


Figure F-157: Potomac River Upper Tidal/Oxon Creek Fish Stressor Results

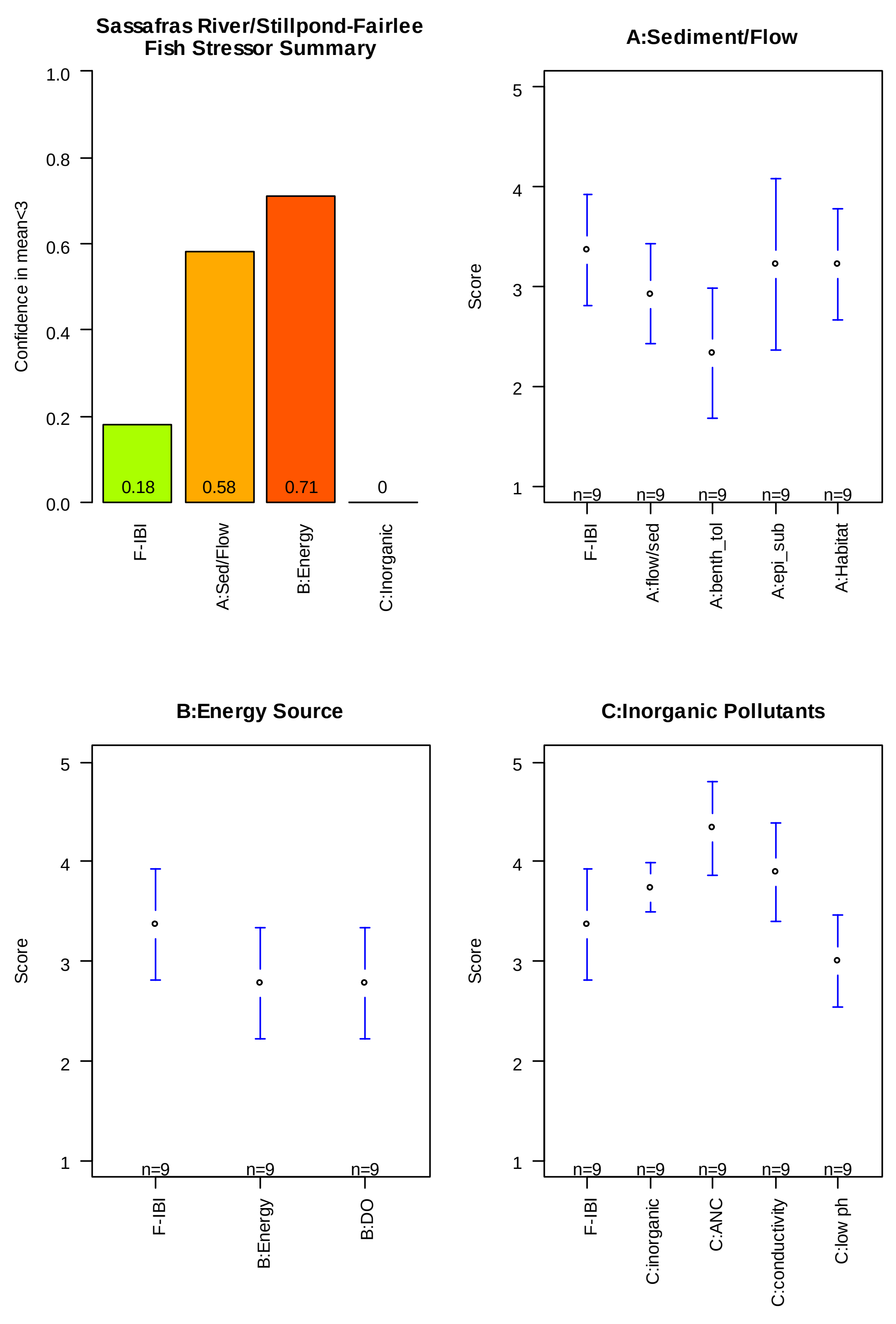


Figure F-158: Sassafras River/Stillpond-Fairlee Fish Stressor Results

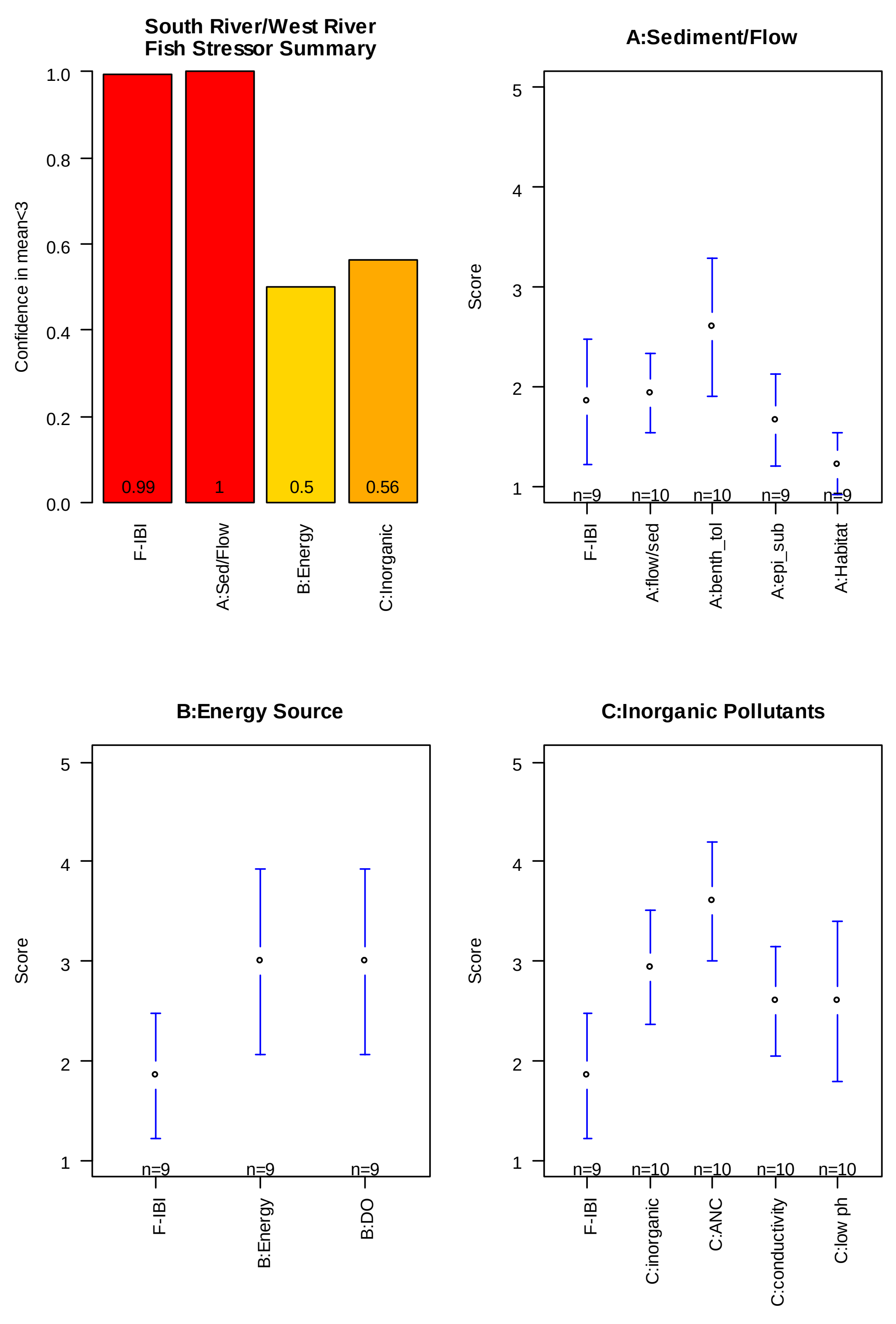


Figure F-159: South River/West River Fish Stressor Results

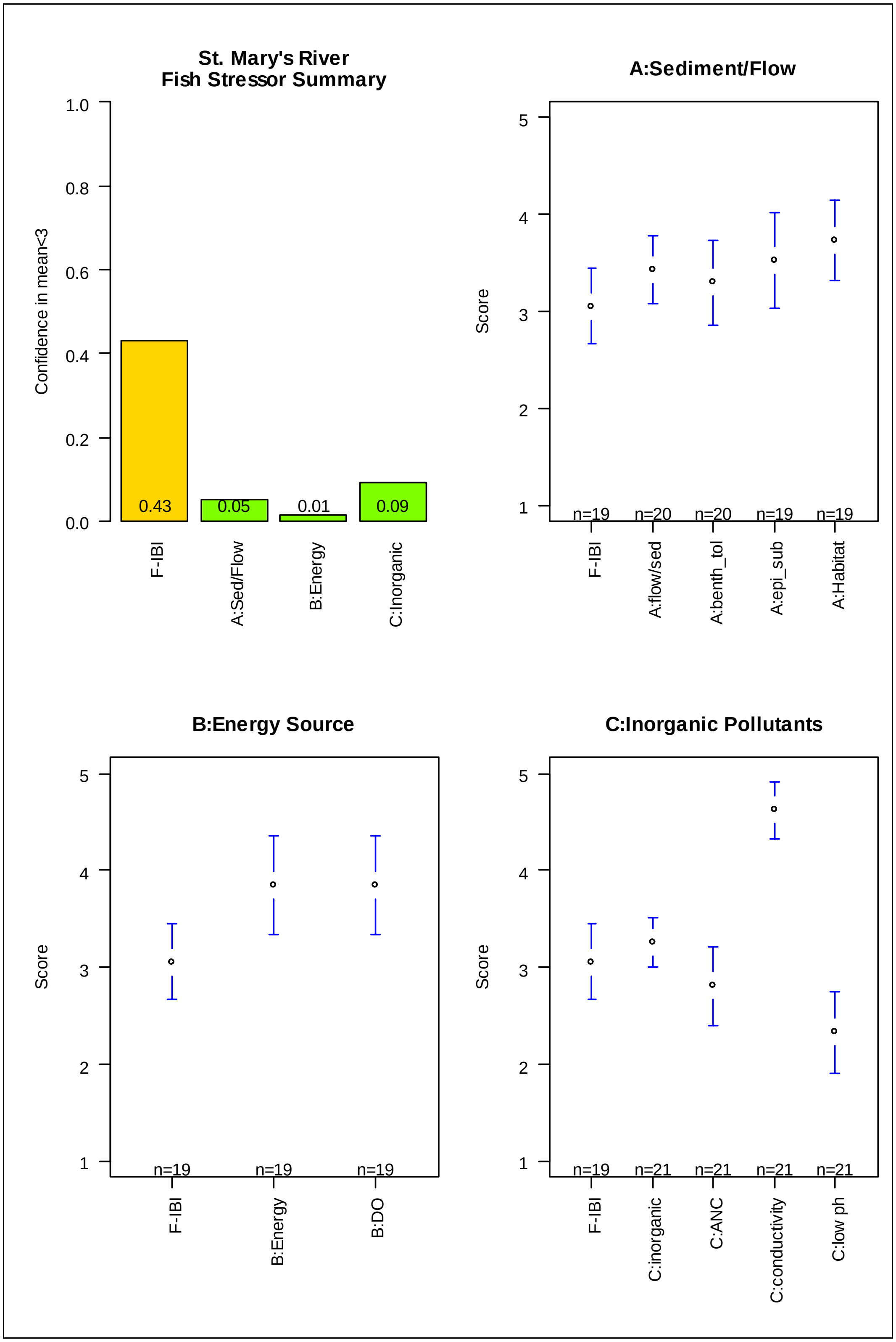


Figure F-160: St. Mary's River Fish Stressor Results

]

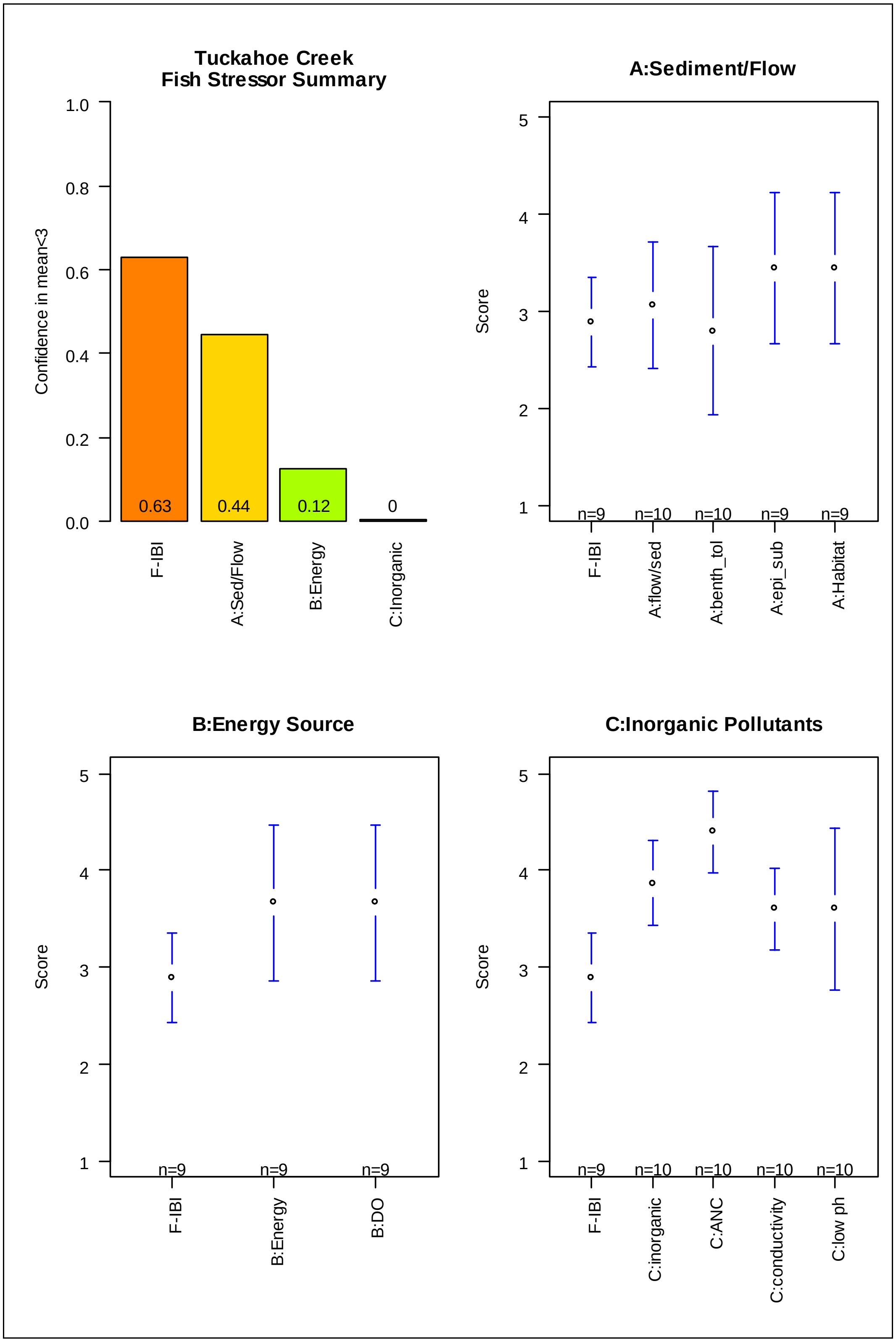


Figure F-161: Tuckahoe Creek Fish Stressor Results

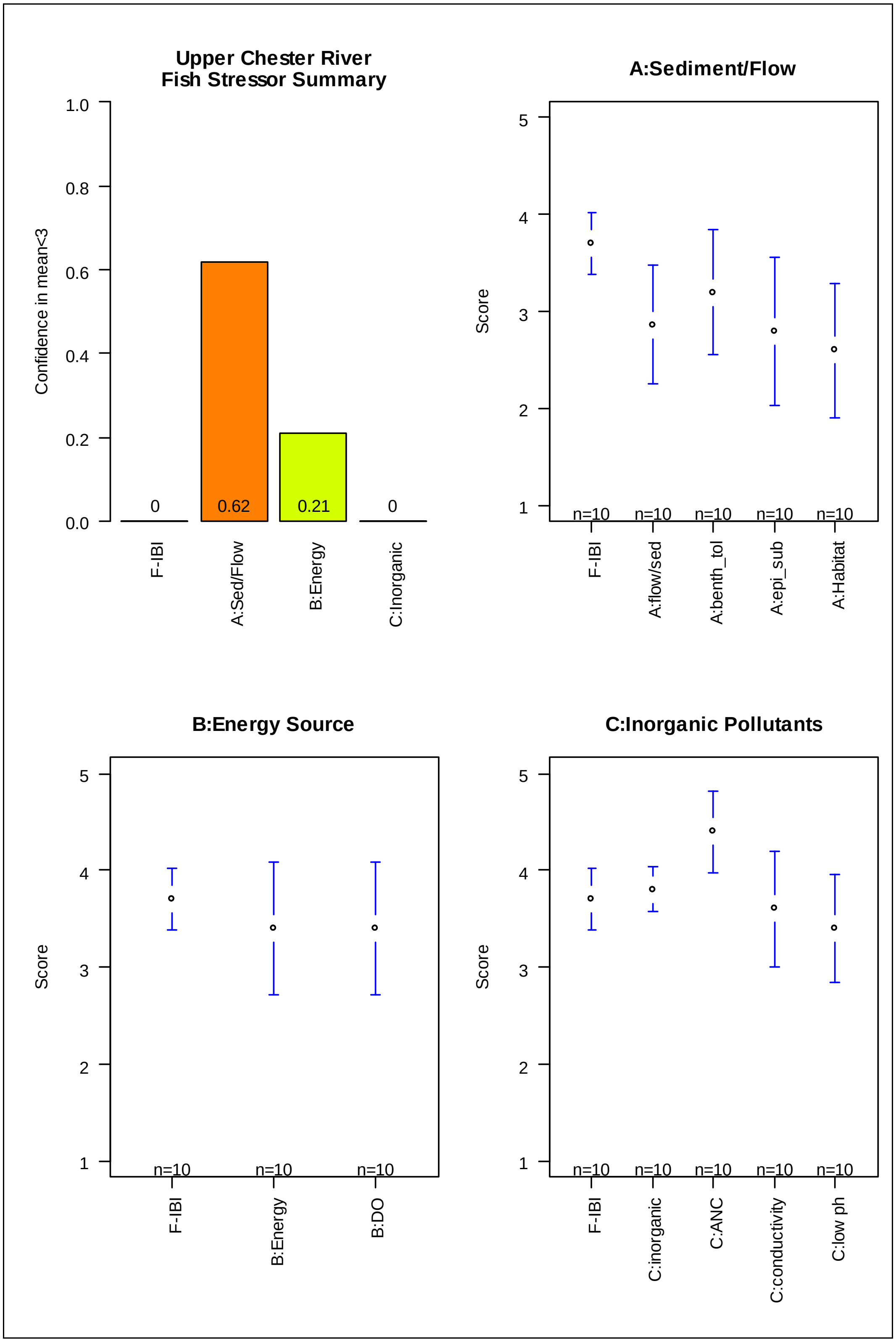


Figure F-162: Upper Chester River Fish Stressor Results

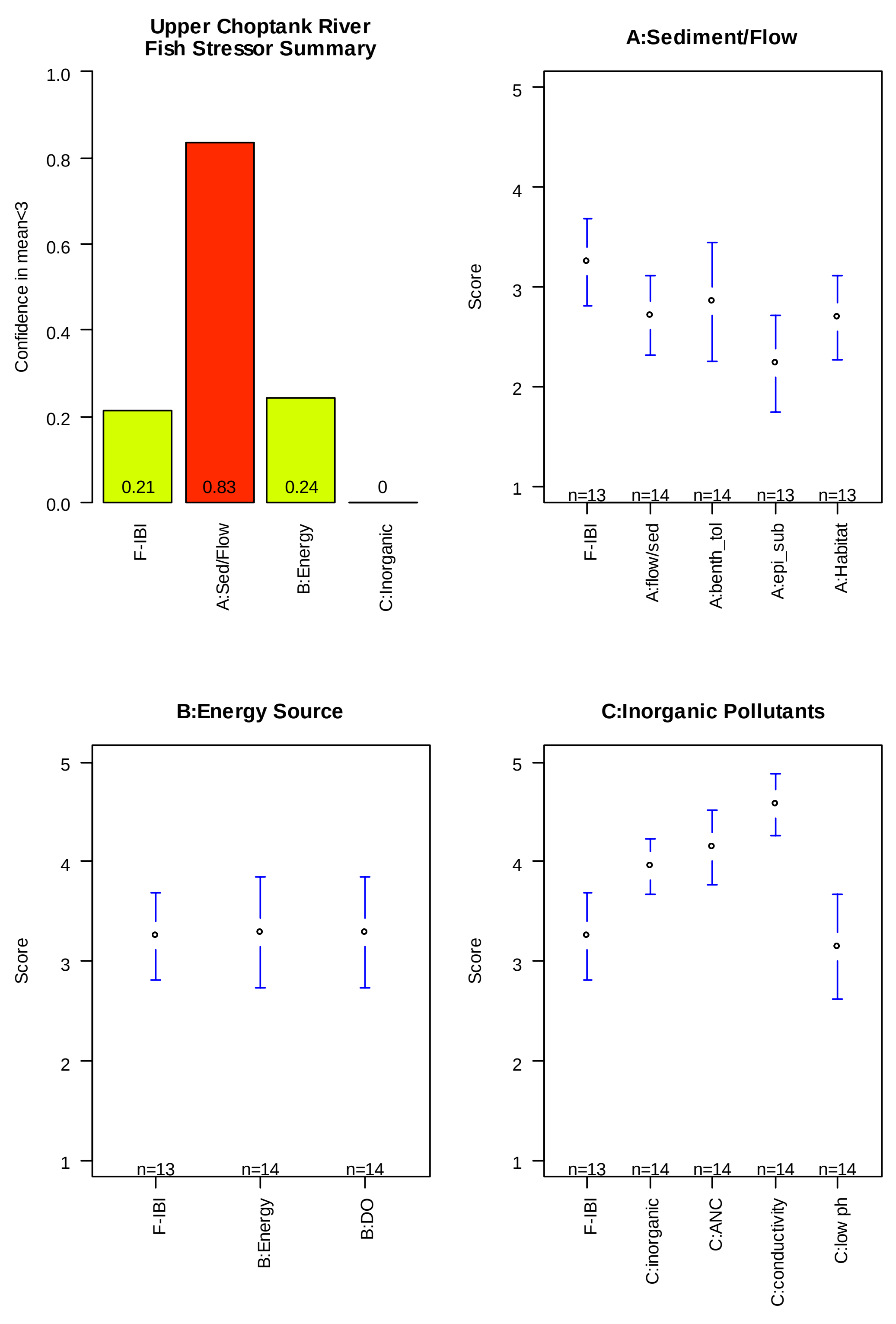


Figure F-163: Upper Choptank River Fish Stressor Results

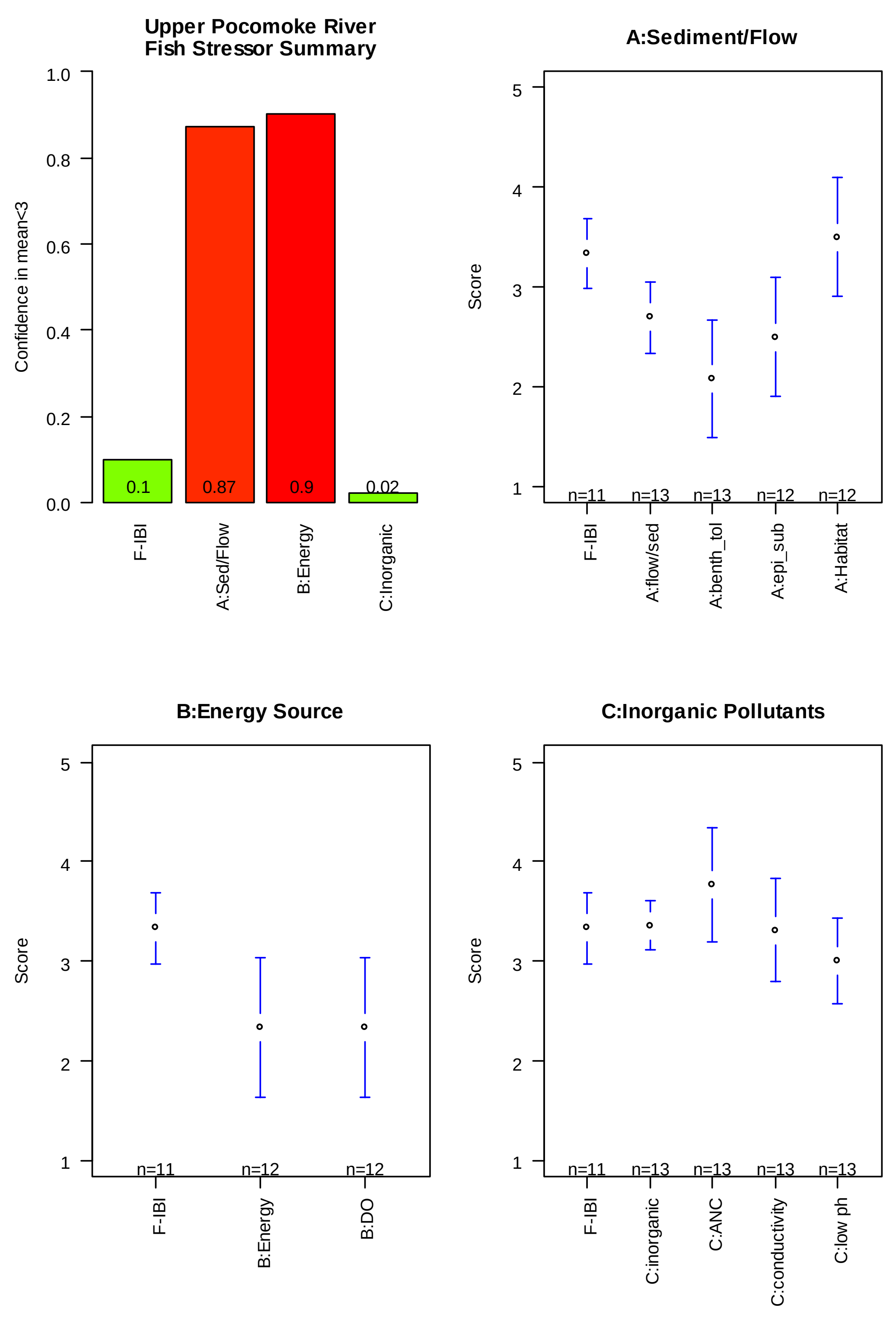


Figure F-164: Upper Pocomoke River Fish Stressor Results

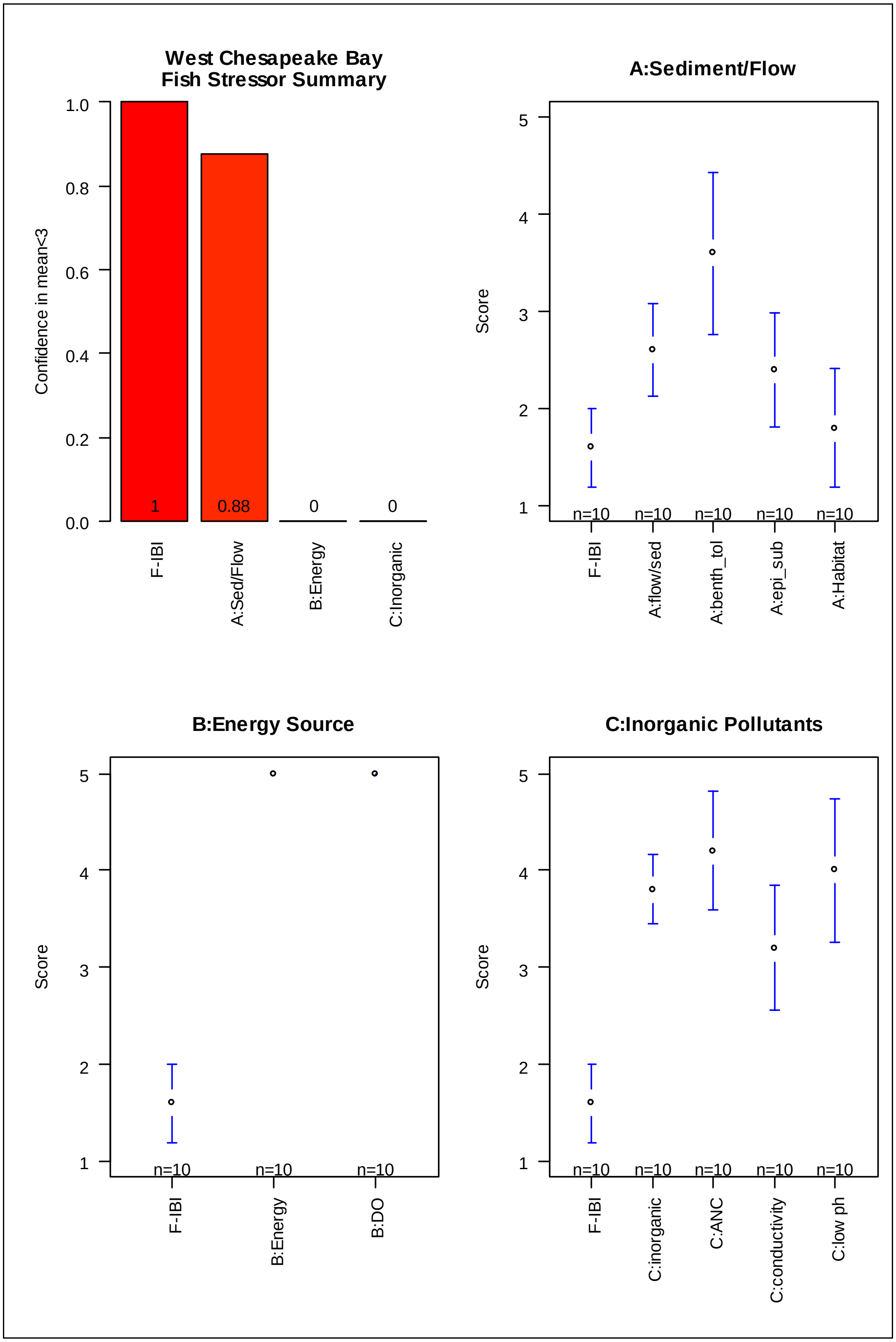


Figure F-165: West Chesapeake Bay Fish Stressor Results

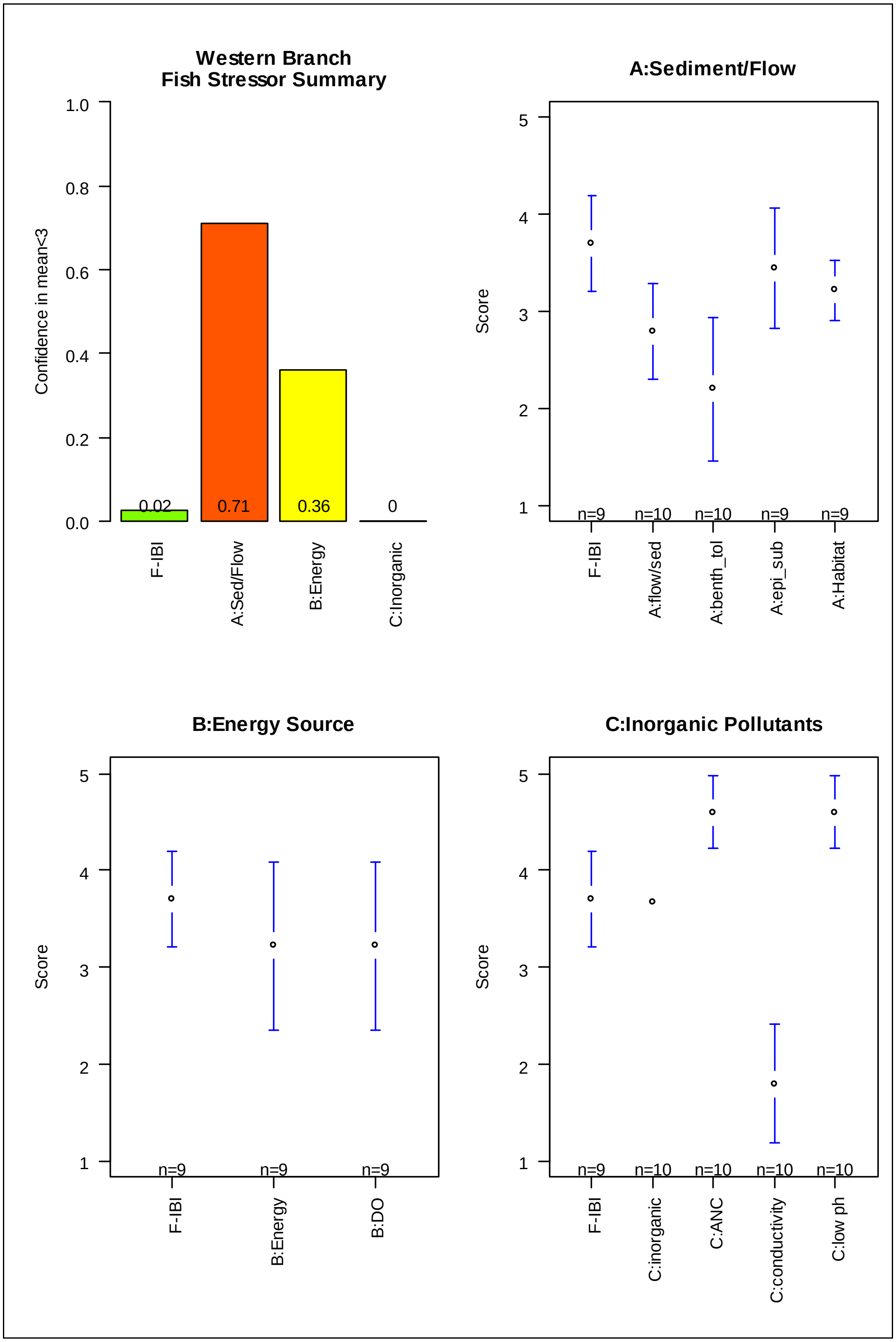


Figure F-166: Western Branch Fish Stressor Results

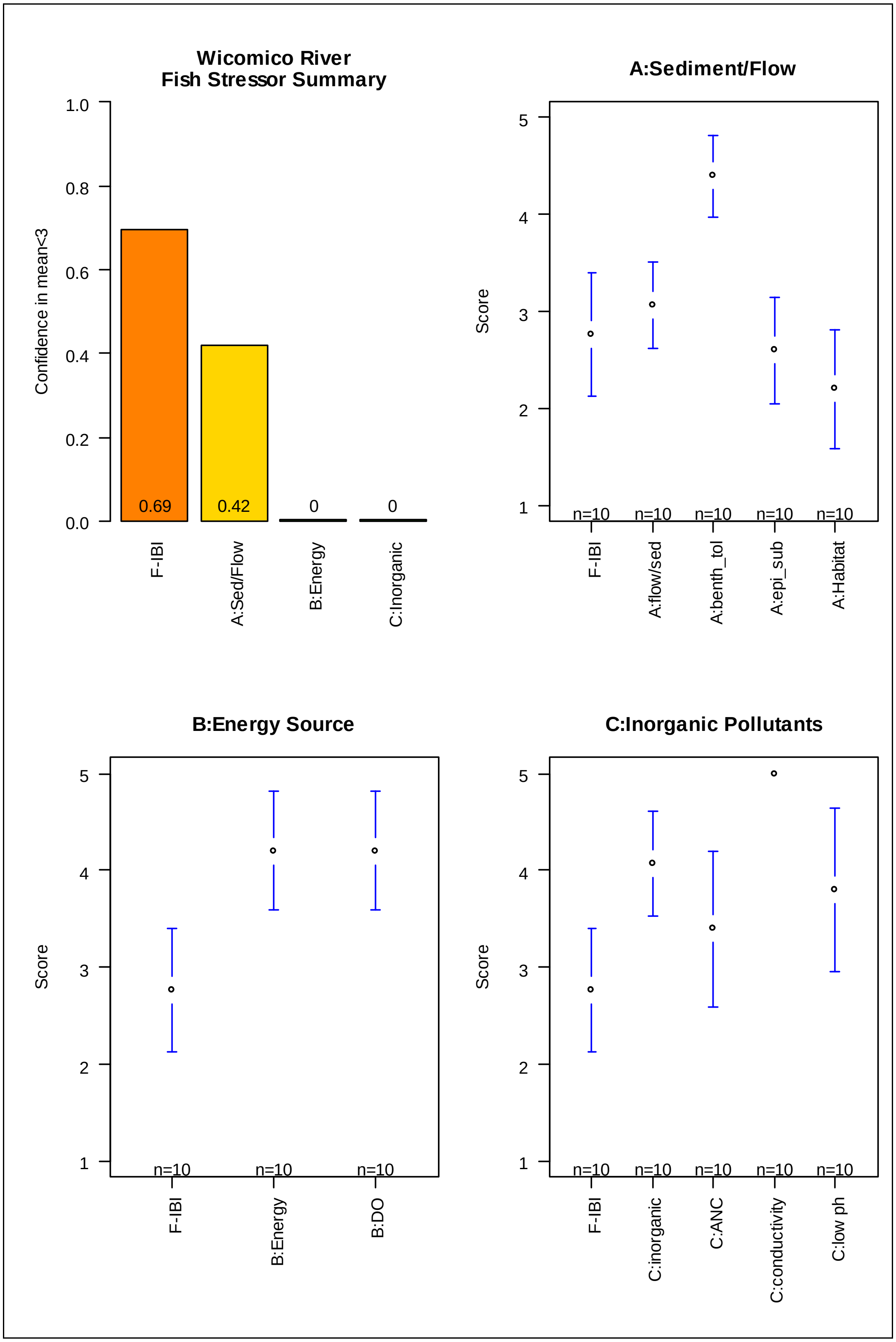


Figure F-167: Wicomico River Fish Stressor Results

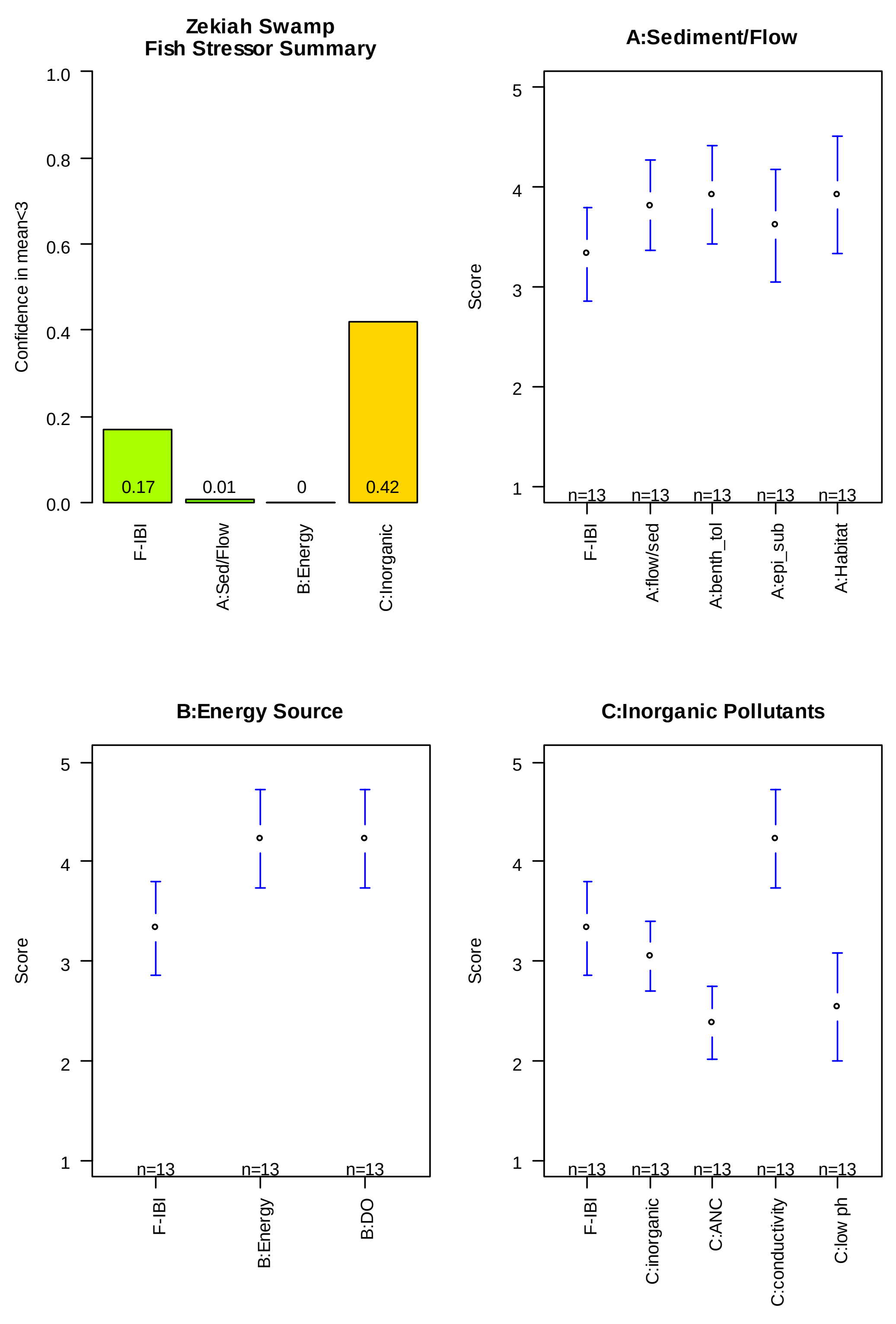


Figure F-168: Zekiah Swamp Fish Stressor Results