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Causal Assessment of Biological Impairment in the Bogue Homo River, Mississippi Using the U.S. EPA's Stressor Identification Methodology

National Center for Environmental Assessment
Office of Research and Development, Washington, DC 20460

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Cincinnati, OH 45268

NOTICE

ABSTRACT

This assessment of biological impairment in the Bogue Homo River, Mississippi is taken from more than 700 court ordered assessments of the causes of impairments requiring development of a total maximum daily load (TMDL). A TMDL is the calculation of the maximum amount of a pollutant that a body of water can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. The calculation of a TMDL is required for all waters that are listed as impaired, in accordance with §303(d) of the Clean Water Act.

The Bogue Homo, a stream in southeast Mississippi, was initially listed as impaired based upon an evaluation of information with no in situ measurements. Follow up biological monitoring of benthic macroinvertebrates by the Mississippi Department of Environmental Quality (MDEQ), confirmed that the stream was impaired. The MDEQ chose to use the U.S. Environmental Protection Agency (U.S. EPA) stressor identification (SI) process to aid in determining probable causes of biological impairment in aquatic ecosystems. A conceptual diagram was developed to present the most common sources of pollutants, causal pathways, proximate causes and specific biological effects in the Bogue Homo. The candidate causes evaluated in this process included decreased dissolved oxygen (DO) and altered food resources (organic matter), unsuitable habitat, increased temperature, increased ionic strength, and/or increased toxicity.

Data used to support the causal analysis process included benthic macroinvertebrate-community metrics, sediment particle-size counts, various water quality measurements, land use and land cover percentages, and other watershed information. Tables were developed to compare observed parameter levels for the impaired site to the 25th or 75th percentiles of a least-disturbed condition for the bioregion (references sites selected on the basis of similar biological communities) or site class (references sites selected on the basis of similar physical and chemical characteristics), depending upon the parameter of concern. Biotic and abiotic conditions from Bogue Homo were also compared to those of nearby unimpaired sites. Lastly, scatter plots of biotic and abiotic site-class data were used to assess regional stressor-response relationships. To add to the strength-of-evidence analysis, Bogue

Homo data were then compared to biological metrics of regional stressor-response relationships that tended to be associated with different stressors.

This case study describes impairments, identifies candidate causes, evaluates relationships between causes and biological response variables, and identifies the most likely causes of impairment through a combined approach of elimination and strength of evidence. The MDEQ identified altered food resources (which include organic enrichment and nutrient enrichment and could lead to decreased DO) as probable causes of impairment. Subsequent to this assessment, TMDLs were developed for the applicable causes of impairment to Bogue Homo as identified through this causal analysis process.

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LIST OF ABBREVIATIONS

BI	biotic index
CADDIS	Causal Analysis/Diagnosis Decision Information System
COD	chemical oxygen demand
CWA	Clean Water Act
DO	dissolved oxygen
EPT	Phylogenetic Orders Ephemeroptera, Plecoptera and Trichoptera
GIS	geographic information systems
HBI	Hilsenhoff Biotic Index
LD	least disturbed
LULC	land use and land cover
M-BISQ	Mississippi Benthic Index of Stream Quality
MDEQ	Mississippi Department of Environmental Quality
msl	mean sea level
NPDES	National Pollution Discharge Elimination System
NTU	nephelontric turbidity units
r	Pearson product moment correlation coefficient
SI	stressor-identification
SSC	site-specific comparison
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TMDL	total maximum daily load
TOC	total organic carbon
U.S. EPA	U.S. Environmental Protection Agency
WQS	Water Quality Standard

PREFACE

This is a causal assessment of a biologically impaired river in the state of Mississippi. The case was investigated by the Mississippi Department of Environmental Quality (MDEQ) as a result of court ordered mandates to determine the causes and to propose resolutions for more than 700 river segments that were listed as impaired on the §303d list as required by the Clean Water Act. The causal assessment of the Bogue Homo River was one of the first cases conducted by the MDEQ and resulted in a determination of the impairment and completion of a total maximum daily load (TMDL) as required by the court mandate. As may be expected, these early cases provided opportunities to fine tune MDEQ's causal assessment process and the U.S. Environmental Protection Agency (U.S. EPA) methodology which was revised in 2006 appearing in Web form at www.epa.gov/caddis. For the most part, the assessment presented here is based on the earlier methods that were available at the time of the assessment. It is presented here to illustrate how a causal assessment was performed using the U.S. EPA (2000) *Stressor Identification* process and the lessons learned that have since been incorporated into the Causal Analysis/Diagnosis Decision Information System (CADDIS) Web site. The analysis was restructured from the original TMDL (MDEQ, 2005) during a workshop at Canaan Valley, West Virginia in May of 2005 and in subsequent discussions. The intention was to share and develop some of the lessons learned. The sampling, analysis, and conclusions are those of researchers who were employed by the MDEQ. Comments appearing in text boxes were prepared by the U.S. EPA's National Center for Environmental Assessment (NCEA) except where noted. NCEA provided editorial and formatting assistance to make the original MDEQ report similar to four other case studies solicited as examples to include on through the CADDIS Web site for other practitioners of causal assessment.

The Bogue Homo River case study is one of five causal analyses that were completed prior to 2005 by states. These early cases determined the probable causes of a biological impairment as required by the TMDL rule. Data for these cases were limited. And yet, for the Bogue Homo, MDEQ developed evidence to show that some causes co-occurred with the biological impairment, were a part of a larger causal chain of events, occurred at sufficient levels known to cause the observed effects, and were coherent with general ecological and scientific theory. Although available evidence was not equivalent in amount or quality for all candidate causes, it was enough to identify some probable causes and to suggest what additional, targeted data might improve the confidence in the determination.

This case, as in all cases, could be improved, but represents the capabilities and level of analysis that was available in 2005. Since then, additional analytical tools and databases have become more readily available. States, tribes, and territories continue to reduce the uncertainty of their analyses using the U.S. EPA's stressor-identification process and CADDIS Web site. This and other case studies from the Canaan Valley Workshop defined the impairment based on a biological index rather than more specific impairments. This practice diminishes the ability to detect associations because summing the metrics into an index dampens the overall signal from individual metrics and species that are responding differently to environmental conditions or stressors. In the Bogue Homo River case, individual metrics of the index were analyzed after the fact, at the workshop in 2005. Although the causal associations were not fully developed, using the individual metrics allowed some causes to be identified and to improve subsequent cases.

To address these and other issues, comment boxes have been inserted throughout the Bogue Homo case study to supply important considerations or to suggest other approaches that could strengthen the case. The analyses in the cases cannot be modified as they are already a part of the MDEQ's public record. To make this easier, the case studies are linked to relevant tools and guidance on the U.S. EPA Web site: www.epa.gov/caddis.

In summary, the case study of the Bogue Homo River presents a very realistic example of the difficulties of assigning specific causes to biological impairments. The Bogue Homo River Case Study is a good example of several strategic techniques to use for expediting causal analyses and TMDLs. Highlights include

1. Developing a list of commonly encountered causes in this region of the United States and measurements that can be used to evaluate them.
2. Rationales for differentiating between deferred causes due to insufficient data or the practical consideration, and elimination of causes based on logical implausibility.
3. Evaluating spatial/temporal co-occurrence using two pieces of evidence from the site and demonstrating a new type of evidence: spatial/temporal co-occurrence using data from elsewhere.
4. Classification of field data prior to the development of stressor-response relationships (termed stratification by MDEQ).
5. Using scatter plots to screen for potential stressor-response associations, and box plots and regression plots to evaluate plausible stressor responses using data from regional monitoring data.
6. The conclusions of the assessment were limited to a screening level assessment by the low sampling density and lack of stream chemistry data and upstream biological monitoring data.

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1. DEFINE THE CASE

1.1. REGULATORY CONTEXT FOR THE CASE

The Clean Water Act (CWA) requires states to identify waters that are impaired. These waters are published in the State's §303(d) List of Impaired Water Bodies. The CWA also requires that a total maximum daily load (TMDL) be completed for each waterbody pollutant combination on the §303(d) List. The U.S. Environmental Protection Agency (U.S. EPA) was sued for not enforcing the TMDL requirements of the CWA in the majority of states, including Mississippi. The lawsuit resulted in a settlement that included a court-ordered 10-year schedule for TMDL development for all water bodies on Mississippi's 1996 §303(d) List.

1.1.1. Mississippi's 1996 §303(d) List of Impaired Water Bodies

The 1996 §303(d) list consisted of over 700 bodies of water. Approximately 20% of the listed waters were classified as impaired based on actual biological or chemical monitoring data. The other 80% of the listed waters were based on anecdotal information indicating potential impairment, but not on measured data. However, all waters were part of the settlement, even those that were listed without data to support actual impairment. The settlement set out a 10-year schedule: address water bodies identified as impaired based on actual monitoring data by the end of the first 5 years, and address water bodies identified as impaired, but not based on monitoring data, by the end of the second 5 years.

1.1.2. Process to Address 1996 §303(d) List of Impaired Water Bodies

Mississippi Department of Environmental Quality (MDEQ) identified two tasks to address before TMDL development for impaired waters. The first task was to revisit the 1996 list and confirm or refute the listing of the impaired waters, especially those where monitoring data were lacking. Beginning in 2001, MDEQ implemented a statewide monitoring strategy to collect biological, physical, and chemical data from listed waters. MDEQ then used those data to determine, with a higher degree of certainty, those waters that were impaired. The second task was to determine the specific cause/s of impairment of those waters that were confirmed as impaired (see Comment 1). In 2003, MDEQ developed a causal analysis process to identify specific causes of impairment, so that actions could be taken to improve water quality. Depending on the identified causes of impairment, TMDL development was often the action taken.

Comment 1. About the Comment Boxes. At various points in this document, the U.S. EPA editor provides comments. These are not meant to indicate that the MDEQ causal analysis is in error. The stressor-identification (SI) process does not address every possible option, nor does it provide details on implementation, so there are many opportunities for interpretation (U.S. EPA, 2000). The U.S. EPA encourages states and tribes to improve and interpret the methodology in ways that are appropriate to their circumstances. Hence, the inserted comments are meant to help other SI users by indicating alternative approaches that they might apply to their cases.

1.1.3. Regulatory Context of the Site

Bogue Homo is one of 11 water bodies in Mississippi for which the causal analysis process has been completed. The water use classification for Bogue Homo, as established by the State of Mississippi in the *Water Quality Criteria for Intrastate, Interstate and Coastal Waters* regulation, is Fish and Wildlife Support (MDEQ, 2003a). The designated beneficial use for Bogue Homo is aquatic life support.

1.2. DESCRIPTION OF THE WATERSHED

Bogue Homo is a tributary to the Leaf River and its headwaters are near Heidelberg in southeast Mississippi. It flows south to the Leaf River, a total distance of approximately 86-km. Bogue Homo is slightly sinuous and lies within a watershed of 689-km^2. Elevations of the stream range from around 150 m mean sea level (msl) near its headwaters, to about 46 m msl at its confluence with Leaf River. The main stem of Bogue Homo is impounded east of Laurel, Mississippi (Lake Bogue Homo). Bogue Homo has several small feeder streams. The largest of these, Mill Creek, is also impounded (Masonite Lake). The Bogue Homo watershed is mostly rural, dominated by forest and pasture. There are several National Pollution Discharge Elimination System (NPDES)-permitted facilities that discharge to the upper part of Bogue Homo. There is no centralized wastewater collection and treatment service in the Bogue Homo watershed. A map of the Bogue Homo watershed and some watershed characteristics are shown in Figure 1.

Bogue Homo was on the state’s 1996 §303(d) List of Impaired Water Bodies. The entire watershed of Bogue Homo fell under the listing, and the evaluated causes initially listed were pesticides, nutrients, and siltation. This listing was based primarily on review of evaluated anecdotal and land use information (i.e., no in stream measured data were available or used to list the site). In response to the court ordered mandate, limited stream sampling was conducted throughout Mississippi. In stream measurements from Bogue Homo (sampling station 487) in 2001 indicated impairment based on the resulting Mississippi benthic index of stream quality (M-BISQ) score. Based on this assessment, Bogue Homo remained on the §303(d) List of Impaired Water Bodies. The previously listed causes—pesticides, nutrients, and siltation—were removed, and “biological impairment” was identified as the basis for the listing. This triggered the causal analysis process (MDEQ, 2001).

1.3. POTENTIAL SOURCES OF STRESSORS

Potential sources of stressors were identified using data and information from land use and land cover (LULC) characteristics of the Bogue Homo watershed and field reconnaissance of the watershed. Additional watershed characteristics, such as locations of NPDES discharges, septic tanks, and other miscellaneous sources of pollution, were evaluated. Predominant land cover classes and uses in the Bogue Homo watershed at the time of the study were forest (55.7% of the watershed area) and

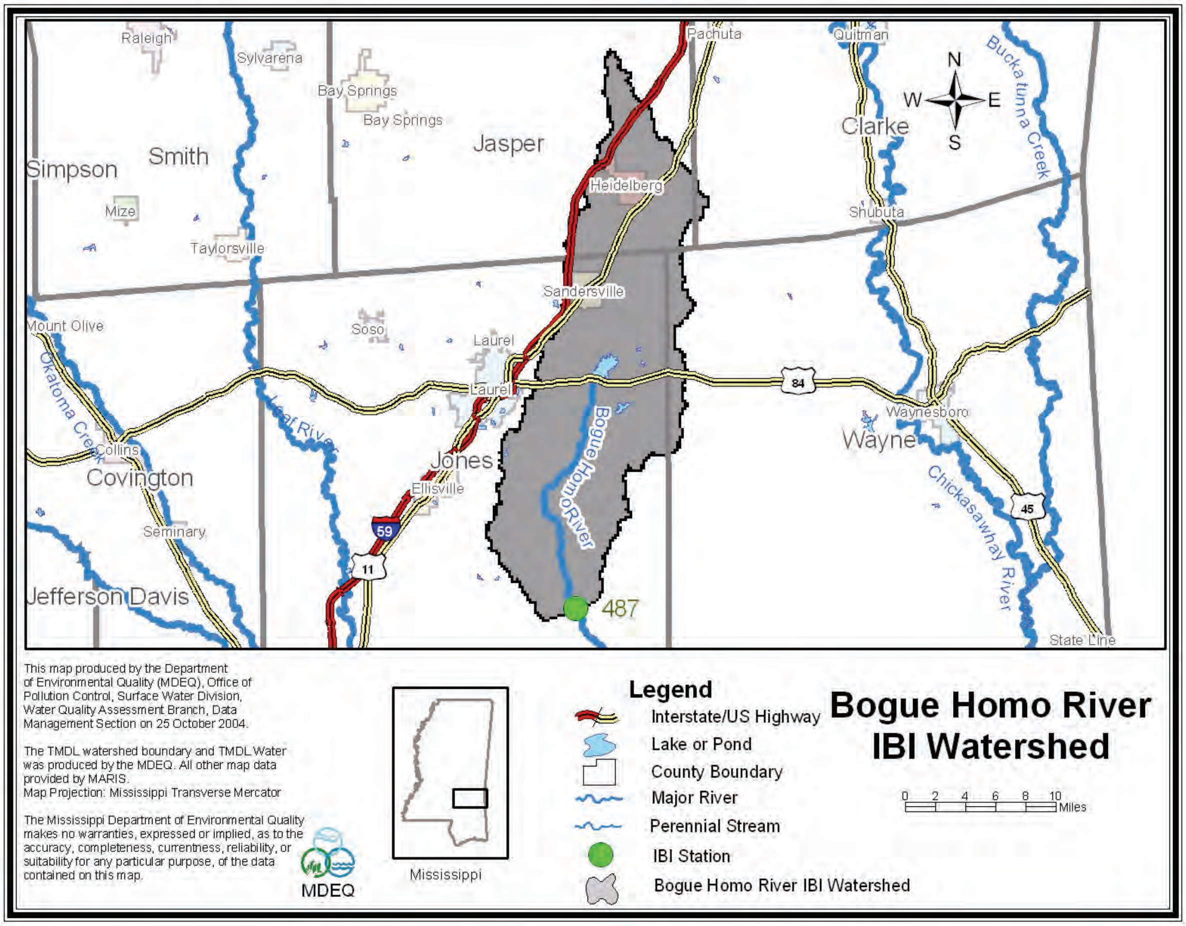

FIGURE 1

Bogue Homo Watershed and Surrounding Area. In this study, the watershed highlighted in grey is evaluated for biotic condition at site 487 using an index of biotic integrity (IBI) based on invertebrates, termed the M-BISQ.

pasture land (21.1% of the watershed area; see Figure 2). Percentage totals of LULC for Bogue Homo are summarized in Table 1.

Anthropogenic land uses (urban cover, crops, pasture, and scrub/barren areas) comprised 40.8% of the entire watershed upstream of the sampling station on Bogue Homo. This value was 28.1% for the 100-m buffer zone of the waterbody channel in the watershed of Bogue Homo, upstream of the sampling station. However, the 100-m buffer zone in a 1-km upstream of the sampling site had no urban land use, and only 11.6% of that land was composed of crops, pasture, scrub/barren land cover.

Results from field reconnaissance, geographic information systems (GIS)−mapping analysis, and MDEQ file review revealed several more site-specific candidates for potential sources, including several upstream NPDES discharges, nonsewer areas, transportation corridors, an impoundment release, poultry and cattle operations, and silviculture operations.

Land-use activities of note in the watershed include silviculture and a small lumberyard. Excess nutrients, pesticides, and sediment can be delivered to nearby streams from silviculture lands, especially when best management practices are not used. Runoff from silviculture lands, agricultural lands and roads, as well as historic landscape alteration and impoundments, can affect stream flow and result in increased erosion, bank destabilization, and an excess deposition of sediment. Runoff from road surfaces also can carry contaminants such as oil, gas, and metals associated with automobile and road-maintenance activities (e.g., platinum, palladium, and zinc). Poultry operators are permitted dischargers in the watershed and are a potential source of nutrients, food additives, and organic matter. Urban and disturbed lands can produce multiple physical and chemical stressors from residential, commercial, and industrial areas in which different stressors are cumulative over time (temporal) and are distributed further downstream in the watershed (spatial).

In summary, the following potential sources of stressors in the Bogue Homo watershed were identified:

- Impoundment
- Nonsewer areas
- Lumberyard
- Silviculture practices
- Historic landscape alteration
- Pasture/grassland
- Upstream point source discharges
- Poultry operations
- Transportation/roadside ditches

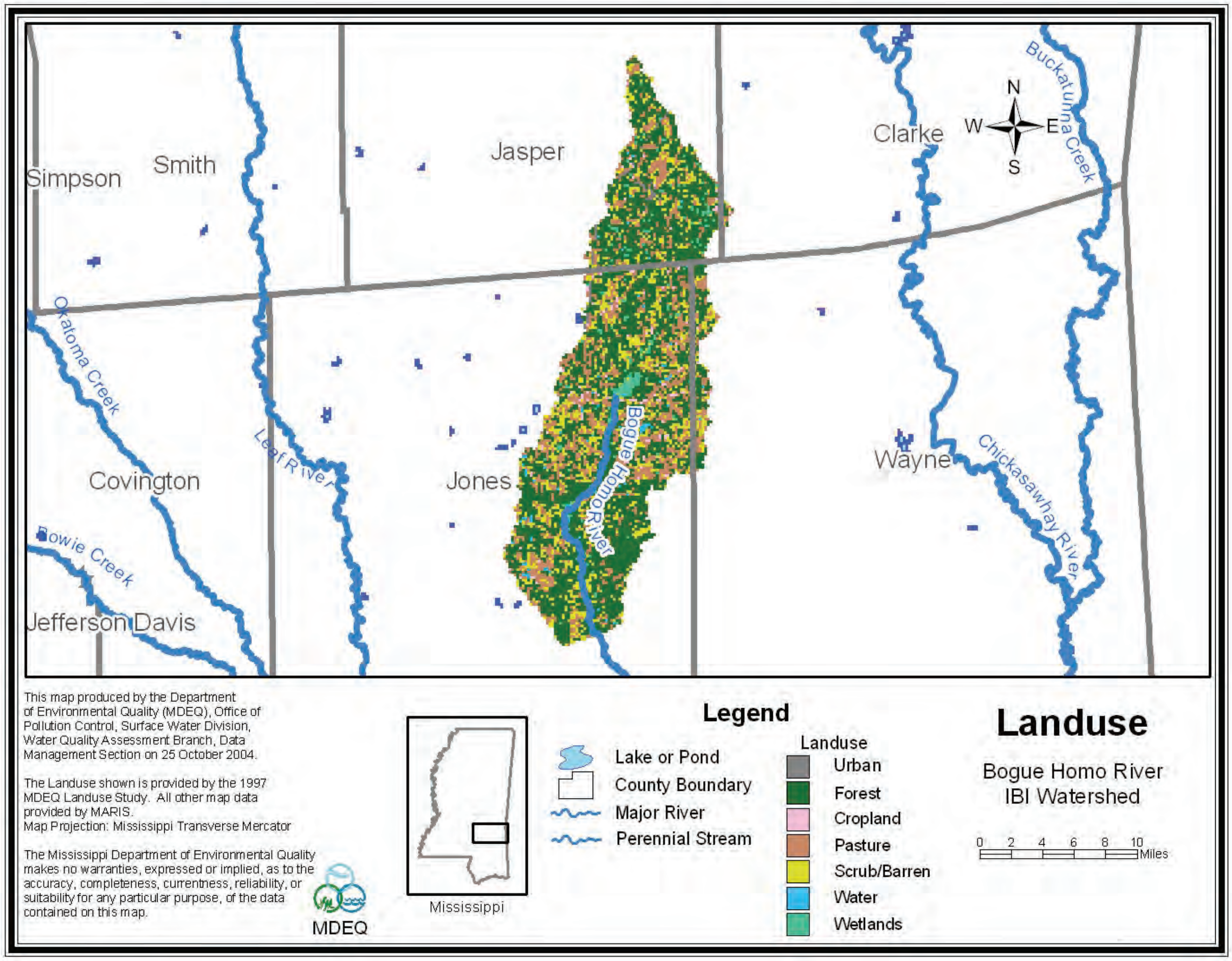

FIGURE 2

LULC of the Bogue Homo Watershed

TABLE 1

LULC Data as Percentages for the Bogue Homo Watershed and Riparian Zones

Land Cover	Entire Watershed (EW)		100-m Buffer EW		100-m Buffer 1-km upstream of site	
	Acres	% Area	Acres	% Area	Acres	% Area
Urban	1,141	0.7%	206	0.5%	0	0%
Forest	94,992	55.7%	25,024	66.1%	149	88.4%
Cropland	2,846	1.7%	197	0.5%	0	0%
Pasture/Grassland	35,985	21.1%	4,445	11.7%	12	6.9%
Scrub/Barren	29,433	17.3%	5,851	15.4%	8	4.7%
Water	1,709	1.0%	628	1.7%	0	0%
Wetland	4,344	2.5%	1,533	4.0%	0	0%
Cloud/Shadow	0	0%	0	0%	0	0%
Total	170,450	100.0%	37,885	100.0%	169	100.0%

1.4. SPECIFIC BIOLOGICAL IMPAIRMENT

Impairment of Bogue Homo was defined in terms of its M-BISQ score and associated biological metric values, as compared to the least disturbed (LD) condition for the region (see Appendix A). The specific impairment of selected M-BISQ metrics was based on differences in metric scores between local and two types of regional comparison sites (see Comment 2). The six site classes with Bogue Homo M-BISQ site and comparison locations are seen in Figure 3. The six bioregions with Bogue Homo M-BISQ site and comparison locations are seen in Figure 4.

1.4.1. Site-Specific Comparisons (SSC)

Observations from selected site-specific comparison (SSC) stations were used for comparisons with the Bogue Homo site. SSC stations were in close proximity to the Bogue Homo monitoring station (i.e., <30-km) and were similar to Bogue Homo with respect to physical, chemical, and geological characteristics. However, they were unimpaired, based on a biological community assessment.

> **Comment 2. Comparison Sites.**
> The selection of reference or comparison sites based on different selection factors focuses the evidence on different parts of the causal pathway; that is, land use and stressor related (site class) versus biological response related sets of sites (bioregion). Both data sets are used to evaluate stressor response from other field studies. When both data sets support or weaken the cause, there is more confidence than with just one line of evidence.
> As an exploratory effort, two methods were used to present the information: scatter plots with regression, and box plots. Scatter plots have the advantage of showing all the data for the candidate cause and the biological response measure, along with the site of interest. The disadvantage is that the complexity of the plot may be overwhelming for communicating to a less experienced audience. The box plots are simpler for communication purposes, but do not provide a way to graphically display both the value of the biological response and the candidate cause from the site. For ease of communication, it would probably be best to choose one mode of communication.

1.4.2. Regional Comparisons

In addition to comparisons at the site specific scale, two types of regional comparisons were made using reference sites with similar physical and chemical characteristics (Site Class 6 comparison sites) and another with reference sites with similar biological communities (East Bioregion comparison sites). For modeling and assessment purposes, geographic strata of Mississippi were identified based on natural variation in physical, chemical, and biological stream characteristics, as well as on landscape variables such as soil type and natural vegetative land cover. MDEQ sought to maximize inter-strata variability and minimize intra-strata variability. Two stratification schemes for the state were identified and used in the assessment process; one based on abiotic variability, termed *Site Classes*, and the other based on biotic variability, termed *Bioregions*.

Abiotic variability refers to frequency and magnitude of changes in environmental factors such as temperature, turbidity, and levels of nutrients. Biotic variability refers to the frequency and magnitude of changes in the abundances of organisms in various taxa. The process used to develop site class and bioregional stratification was

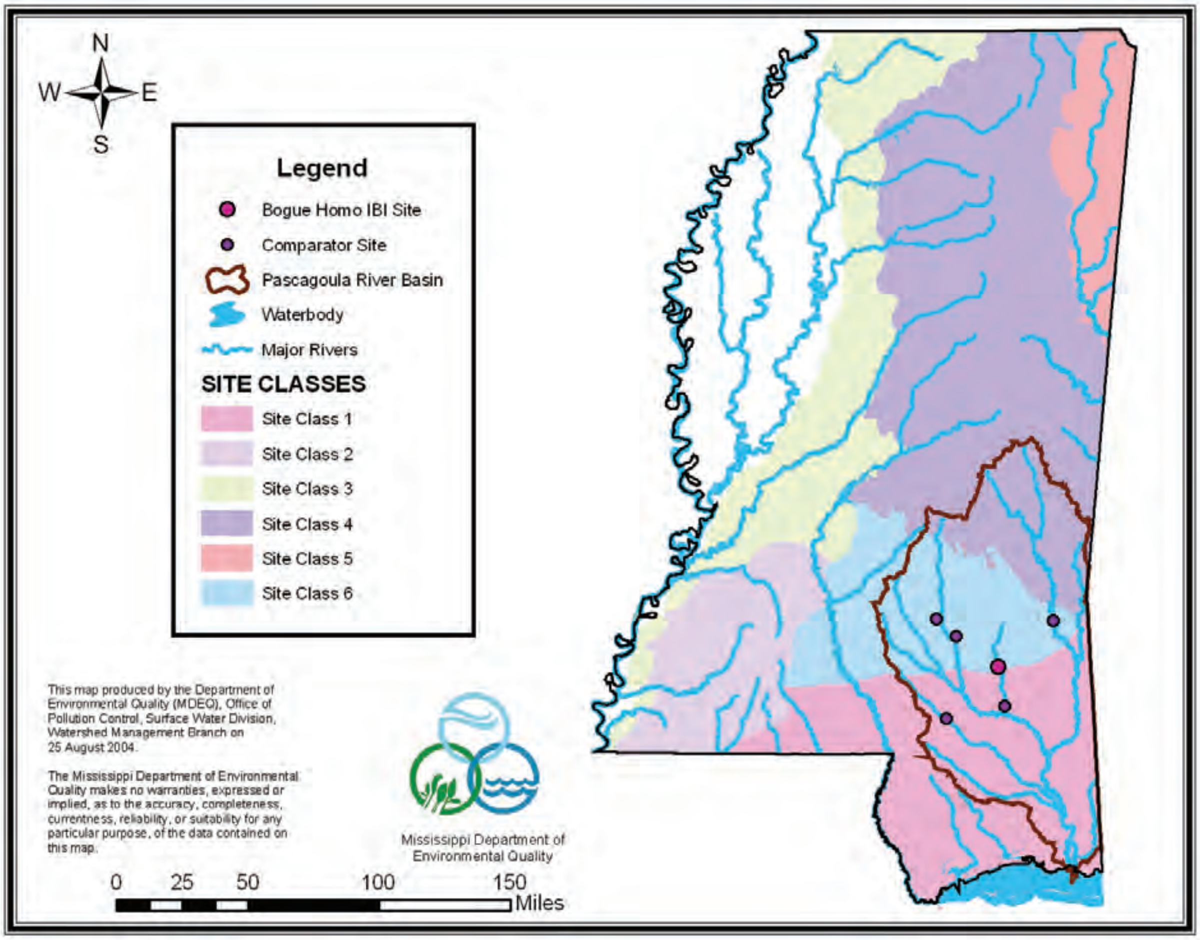

FIGURE 3

Site Classes, a Classification Based on Physical and Chemical Characteristics. The Bogue Homo M-BISQ Site is in site class 6 and Comparison Locations reside in site Classes 6 and 1.

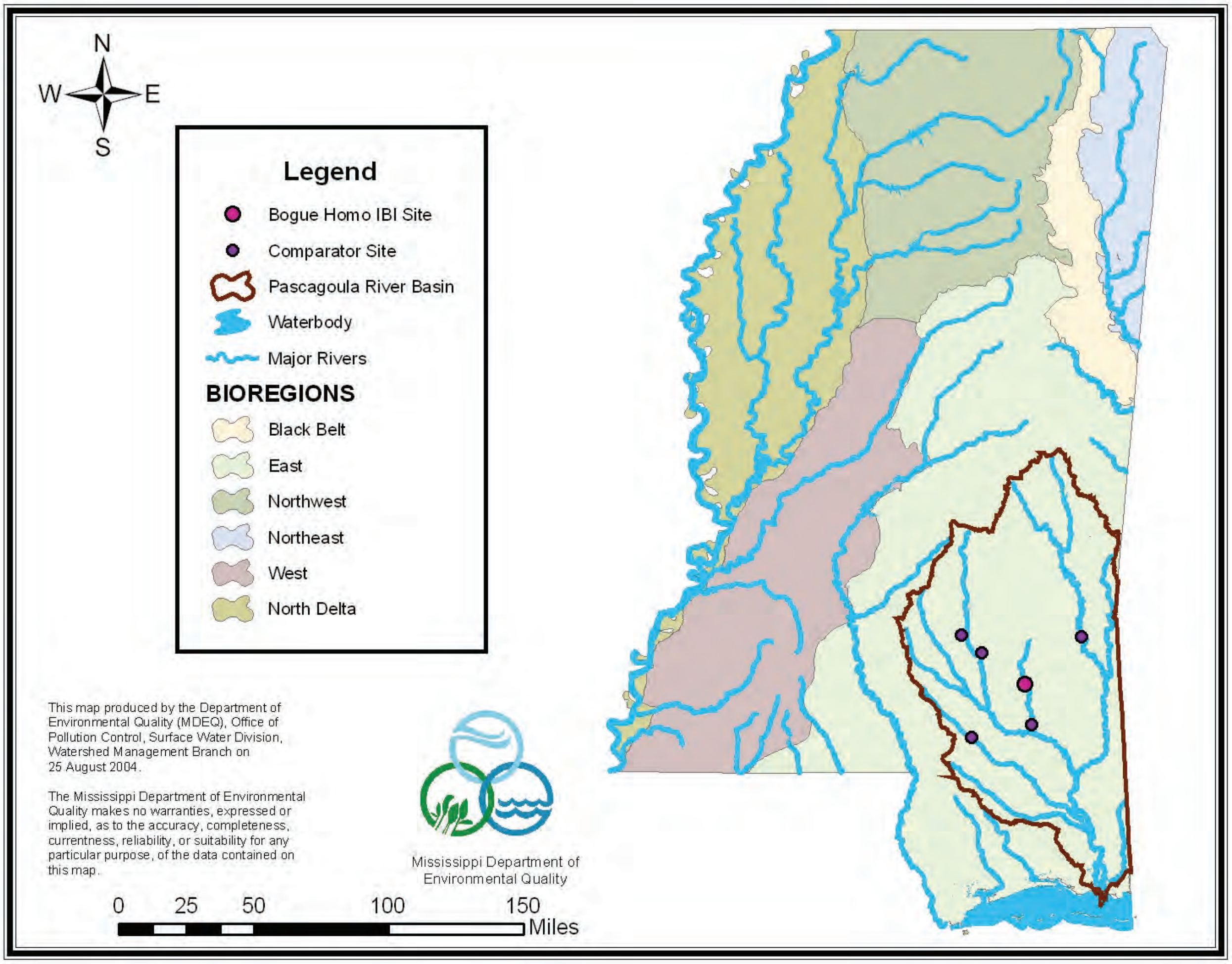

FIGURE 4

Bioregions, a Classification Based on Similar Biological Communities. The Bogue Homo M-BISQ site and comparison locations reside in the east bioregion.

described in detail in MDEQ (2003b). In general, site classes were areas of the state containing streams with naturally similar physical, chemical, and land use characteristics. Bioregions were areas of the state containing streams with naturally similar benthic macroinvertebrate taxa and communities. They were identified by first looking at similarity among Site Classes, then lumping or splitting Site Classes in order to delineate regions with naturally similar benthic macroinvertebrate taxa composition.

Bogue Homo is located in Site Class 6 and the East Bioregion. For each site class and bioregion, LD conditions have been defined for biological, habitat, sediment particle size, water quality, and LULC data. In short, LD conditions were based on the quartile distribution of the particular metric values from streams considered to be least disturbed for each site class and bioregion. The upper quartile (75th percentile) of the range of values from least disturbed streams was used to define LD biological metrics that cause a decline in the M-BISQ score as their value increases (e.g., percent Amphipoda). The lower quartile (25th percentile) of the range of values from least disturbed streams was used to define LD conditions for biological metrics that increase as the M-BISQ score increases (e.g., percent Plecoptera). The 50th percentile was selected for some functional feeding groups and habitat preferences. For chemical measures, the 25th percentile was selected for agents that increase as M-BISQ score increases (e.g., dissolved oxygen [DO]). The 75th percentile was selected when an increase in the agent was expected to cause a decrease in the M-BISQ (e.g., ammonia). The 50th percentile was selected for agents that were proportional (percent silt).

Assessment of water quality status and subsequent placement of Bogue Homo on the §303(d) List involved the comparison of the 2001 M-BISQ score for Bogue Homo to the impairment threshold of the East Bioregion. The impairment threshold was defined as the 25th percentile value of the range of M-BISQ scores from LD sites in the East Bioregion. The M-BISQ score for Bogue Homo (50.07) was lower than the LD impairment threshold value for the East Bioregion (61.35). This difference was great enough to classify Bogue Homo as impaired. More specifically, several biological metric values from Bogue Homo were considerably lower or higher than metric values for LD conditions and site-specific comparison stations (see Table 2). Those metrics are described below and in Appendix B, with reasons for considering them suggestive of impairment based on the data in Table 2 (see Comment 3).

Comment 3. Summary of Impairment.
Determining exactly what biological changes have occurred at an impaired site facilitates causal analysis. A clear sign of the impaired biological community at Bogue Homo is the low number of EPT taxa. The number of EPT taxa (3) is less than half of the regional least disturbed conditions and only 19–30% of the local reference (SSC) values. The related parameters, percent EPT and percent Plecoptera, are also clearly low. Another notable attribute is the high percentage of amphipods. Most SSC sites have none, but the impaired site has 13%. Therefore, assessors may choose to seek the cause(s) of these particular shifts in the benthic assemblage rather than all of the differences (see Appendix B).

1.4.3. Beck's Biotic Index (BI)

This metric is based on individual tolerance values for each benthic macroinvertebrate taxon. It results in a total

TABLE 2

Biological Metrics, Bogue Homo, and Comparison Conditions

East Bioregional Metrics	Bogue Homo	Difference from LD condition: East Bioregion	Difference from LD condition: Site Class 6	Least Disturbed Condition: East Bioregion	Least Disturbed Condition: Site Class 6	percentile used for LD
MBISQ	50.07	lower	lower	61.35	61.85	25th
Beck's BI	18.00	comparable	lower	18.00	18.75	25th
HBI	4.68	higher	higher	4.34	4.35	75th
# Tanytarsini Taxa	1.00	lower	lower	2.00	1.99	25th
% Caenidae	0.00	lower	lower	0.43	0.42	75th
% EPT (No Caenidae)	3.65	lower	lower	9.10	12.51	25th
% Clingers	40.10	lower	lower	51.20	55.17	50th
% Filterers	26.56	higher	higher	19.43	17.12	50th
Additional Biological Metrics						
% Amphipoda	13.02	higher	higher	1.95	2.57	75th
# EPT taxa	3.00	lower	lower	6.95	7.56	25th
% Plecoptera	0.52	lower	lower	0.94	1.13	25th
% Predators	28.65	higher	higher	16.28	19.08	75th
% Sprawlers	26.56	higher	higher	19.57	15.39	75th

East Bioregional Metrics	Bogue Homo	Site Specific Comparators: Black Creek	Bogue Homo (downstream)	Big Creek	Oakahay Creek	Yellow Creek
MBISQ	50.07	72.24	64.65	72.31	66.01	82.46
Beck's BI	18.00	28.00	23.00	16.00	22.00	34.00
HBI	4.68	4.46	4.41	3.98	4.45	3.81
# Tanytarsini Taxa	1.00	2.99	2.00	3.00	2.00	3.87
% Caenidae	0.00	0.00	0.00	0.00	0.00	0.40
% EPT (No Caenidae)	3.65	28.15	12.00	14.07	26.42	16.53
% Clingers	40.10	54.20	57.33	73.37	51.22	65.73
% Filterers	26.56	28.99	39.11	50.75	29.27	55.24
Additional Biological Metrics						
% Amphipoda	13.02	2.10	0.00	0.00	0.00	0.40
# EPT taxa	3.00	13.47	9.91	12.00	10.75	15.87
% Plecoptera	0.52	1.26	1.33	1.51	1.22	3.63
% Predators	28.65	6.30	12.00	7.54	5.28	14.52
% Sprawlers	26.56	9.66	10.67	9.05	10.57	7.66

Bolded metrics are those judged to be components of the impairment based on difference.

tolerance value score for the sample, based on the individual tolerance values and abundance of each taxon in the sample (Beck, 1954). A decrease in Beck's biotic index (BI) indicates an increase in stress. The Beck's BI calculated from the sample taken from Bogue Homo (18.0) is similar to the LD conditions for the East Bioregion (18.0) and Site Class 6 (18.75). However, the Bogue Homo Beck's BI value is lower than most of the SSC station values.

1.4.4. Number of Ephemeroptera, Plecoptera, and Trichoptera (EPT) Taxa

This metric is the number of taxa representing three phylogenetic orders, Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddis flies) (EPT). In Bogue Homo, only 3.0 EPT taxa are found. This value is lower than the number of EPT taxa found either in LD conditions (East: 6.95, Site Class 6: 7.56) or the SSC stations (9.9−15.9).

1.4.5. Percent Ephemeroptera, Plecoptera, and Trichoptera (EPT) (No Caenidae)

This metric is the percentage of individuals representing the phylogenetic Orders EPT, compared to the total number of individuals in the sample, excluding members of the Family Caenidae (mayfly). The percentage of EPT (no Caenidae) from Bogue Homo (3.65) is lower than LD condition percentages (East: 9.10, Site Class 6: 12.51) and SSC station values (12−28).

1.4.6. Percent Plecoptera

This metric is the number of stoneflies (Plecoptera) compared to the total number of individuals in the sample, expressed as a percentage. The percentage of Plecoptera found in Bogue Homo is 0.52. This value is lower than LD conditions (East: 0.94, Site Class 6: 1.13) and SSC stations (1.2−3.6).

1.4.7. Percent Amphipoda

This metric is the calculated percentage of amphipods (Order Amphipoda; common name, scuds or side swimmers) relative to the total number of individuals in the sample. In most small-to-medium-sized streams in Mississippi, amphipods comprise a relatively small percentage of the total number of benthic macroinvertebrates. The percentage of amphipods from Bogue Homo (13.0) is substantially greater than the proportion of amphipods defined by LD conditions (East: 1.95, Site Class 6: 2.57) and from the samples of SSC stations (0−2).

1.4.8. Percent Predators

This metric is the percentage of organisms that are classified as "predators," relative to the total number of individuals in the sample. The term "predators" refers to a type of functional feeding group classification (Merritt and Cummins, 1996). The percentage of predators from the Bogue Homo sample (28.65) is greater than the percentage of predators in LD conditions (East: 16.28, Site Class 6: 19.08) and the SSC stations (5.3−14.5).

1.4.9. Percent Sprawlers

This metric is the percentage of the total sample that is made up of organisms that are classified as “sprawlers” (Merritt and Cummins, 1996). Sprawlers live on the surfaces of leaves or fine sediments, and usually have body shapes or appendages modified for staying on top of the substrate and maintaining respiratory surfaces free of silt potentially giving them traits that make them more sediment tolerant. The percentage of sprawlers from Bogue Homo (26.6) is greater than the corresponding values for LD conditions (East: 19.57, Site Class 6: 15.39) and the SSC stations.

2. LISTING THE CANDIDATE CAUSES

Developing the list of candidate causes involved consideration of sources of stressors and the way in which they could lead to and cause the observed biological impairment. It also included evaluation of LULC data for the Bogue Homo watershed at various spatial scales; field observations during 2001; observations from a watershed reconnaissance in 2004; and physical, chemical, and biological data from Bogue Homo. Based on known linkages between the sources and proximate causes of impairment information and ecological and watershed data, MDEQ cautiously eliminated unlikely causes of impairment. In cases where data were lacking, the cause was not eliminated unless there was overwhelming evidence to support the idea that the cause and/or causal pathway in question could not contribute to the impairment. Data quality and quantity were also considered when eliminating potential but unlikely causes of impairment. Examples of reasons for eliminating a potential cause included lack of data of sufficient quality, quantities that were not different than those of background or LD conditions, and if the stressor or a source of the stressor was believed to be either mechanistically implausible or absent from the watershed (see Comment 4).

2.1. MISSISSIPPI'S STANDARD LIST OF CAUSES OF IMPAIRMENT

MDEQ developed a standardized list of causes of impairment commonly encountered in streams and rivers throughout Mississippi. The purpose of creating this list was to avoid accidentally omitting possible causes. The standard list provided consistency to MDEQ's causal analysis process on the impaired waters from the §303(d) List of Impaired Water Bodies. Although the list was most likely not all-inclusive, it was comprehensive enough for these applications, as it was based on the knowledge and experience of several MDEQ scientists and engineers who have dealt with streams and water quality issues for many years. The standard list of prospective causes of impairment developed for Mississippi streams, and their associated monitoring indicators, is given in Table 3.

Comment 4. Elimination Versus Deferment.
The Bogue Homo River assessment was based on the original SI process (U.S. EPA, 2000). Updates to the process more clearly distinguish elimination, a logical disproof of a candidate cause, from deferment, a postponement of assessment.
In the Bogue Homo assessment, lack of data of sufficient quality required deferment. Evidence that the candidate cause was at background levels or was mechanistically implausible was considered reasons for elimination. The U.S. EPA recommends eliminating causes later during analysis rather than when planning the assessment to ensure that the rationale and evidence for elimination is fully documented.

2.2. PROCESS OF ELIMINATION

Elimination of very unlikely stressors was recommended in the U.S. EPA *Stressor Identification Guidance Document* (U.S. EPA, 2000) to keep the causal analysis process from becoming unmanageable. To refine the stressor list early on, very unlikely causes of impairment were eliminated. The elimination process involved the use of LULC data, NPDES discharger source locations, aerial photography, and

TABLE 3 MDEQ Standard List of Candidate Causes and More Related Processes	
Standard Candidate Causes	Related Processes
Oxygen Concentration and Oxygen Demand	Alteration to photosynthesis/respiration balance Decrease in oxygen and increase in oxygen demand Temperature alteration Alteration to natural flow regime Increase in organic enrichment Disruption of nutrient cycles
Organic Carbon	Increase in organic enrichment Change in food source characteristics Alteration to photosynthesis/respiration balance Decrease in oxygen and increase in oxygen demand
Nutrients	Disruption of nutrient cycles Alteration to photosynthesis/respiration balance Decrease in oxygen and increase in oxygen demand Change in food source characteristics
Temperature	Alteration to thermal regulation Alteration to photosynthesis/respiration balance Decrease in oxygen and increase in oxygen demand
Turbidity	Increase in amount and duration of suspended sediment Alteration to natural flow regime Decrease in suitable in-stream habitat Alteration to channel morphology Decrease in riparian vegetation
Sediment Particle Size	Increase in deposited sediment Alteration to natural flow regime Decrease in suitable in-stream habitat Alteration to channel morphology
Habitat Evaluation	Alteration to natural flow regime Decrease in suitable in-stream habitat Decrease in riparian vegetation Alteration to channel morphology Increase in suspended and deposited sediment Change in food source characteristics Decrease in suitable floodplain habitat Temperature alteration Alteration to groundwater interaction
Conductivity, TDA and Chlorides	Increase ion concentrations Alteration to natural freshwater/saltwater interaction
pH	Increase in alkalinity or decrease in hydrogen ion activity Increase in acidity or hydrogen ion activity
None	Increase in toxic substance concentrations

field reconnaissance information. Examples of reasons to eliminate a specific cause during this process included: the causal pathway was believed to be mechanistically implausible, or the causal agent and/or source for the cause did not occur within the watershed (see Comment 5).

Based on the proximity of the potential sources of stress to the Bogue Homo sampling station and evaluation of watershed characteristic data, only one candidate cause was eliminated: extremes of acidity or alkalinity. Change in natural activity of hydrogen ions (pH) in the water was used as the indicator for this cause. Values of pH were at background levels in Bogue Homo, due to naturally acidic soils (a common, statewide occurrence) or blackwater streams, which are characterized in part by a naturally low pH (i.e., pH 4.5−6.0).

For the purpose of developing the final list of candidate causes, MDEQ considered causes of two types: proximate causes and intermediate causes. Proximate causes are defined as the immediate and effective cause(s) of the biological impairment(s), such as low DO leading to asphyxiation. Intermediate causes are those that are part of the causal pathway, but do not directly lead to the immediate cause of impairment, such as a lack of riffles causing reduced aeration and decreased DO. Figure 5 shows the final list of candidate causes of impairment for Bogue Homo, with their link(s) to their respective proximate causes.

Comment 5. Listing Candidate Causes.
MDEQ's approach to eliminating candidate causes has been effective because they were very conservative when eliminating them. The process of elimination involves analyzing types of evidence during the planning phase. In essence, the assessors listed a cause and performed a de facto analysis with a type of evidence they believed would refute the candidate cause, namely spatial co-occurrence. Then, they returned to listing and evaluating candidate causes. In either approach, the evidence for refuting a cause is collected, analyzed, evaluated, and documented. The use of a standard list of potential causes is an excellent idea, but during planning, other case specific causes should also be hypothesized. Also, candidate causes should not be eliminated without very strong proof. The list is better used as a tool to prompt assessors to add candidate causes to the list that are plausible, rather than to eliminate them. Other lists may be found on the Causal Analysis/Diagnosis Decision Information System (CADDIS) Web site.

2.3. CONCEPTUAL MODEL OF CAUSAL PATHWAYS

After development of the candidate list of causes of impairment, a conceptual model was developed that outlined the plausible relationships between potential sources of stress, intermediate causes, proximate causes, and the biological response variables. The conceptual model was used to further verify the list of candidate causes through visual observation. In addition, it was used during subsequent evaluation of candidate causes to identify probable causes of impairment. The conceptual model for Bogue Homo is shown in Figure 6.

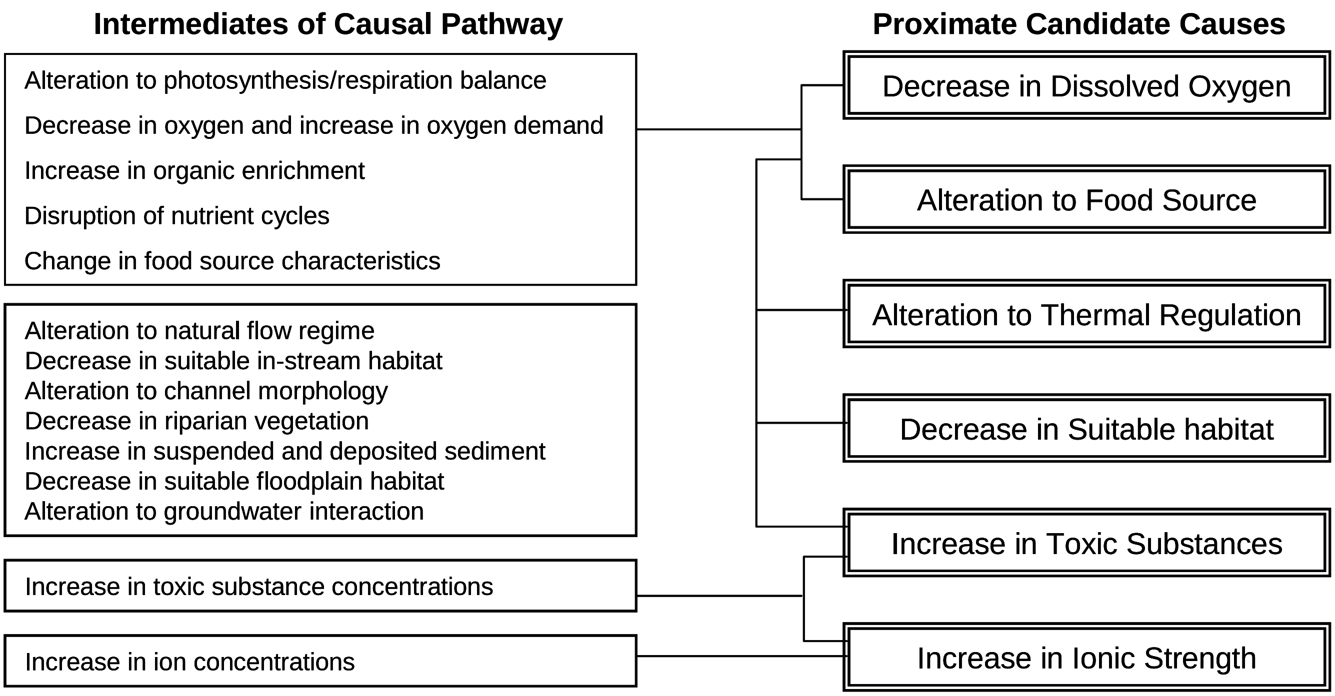

FIGURE 5

Causal Pathways Related to Proximate Causes Analyzed in this Case

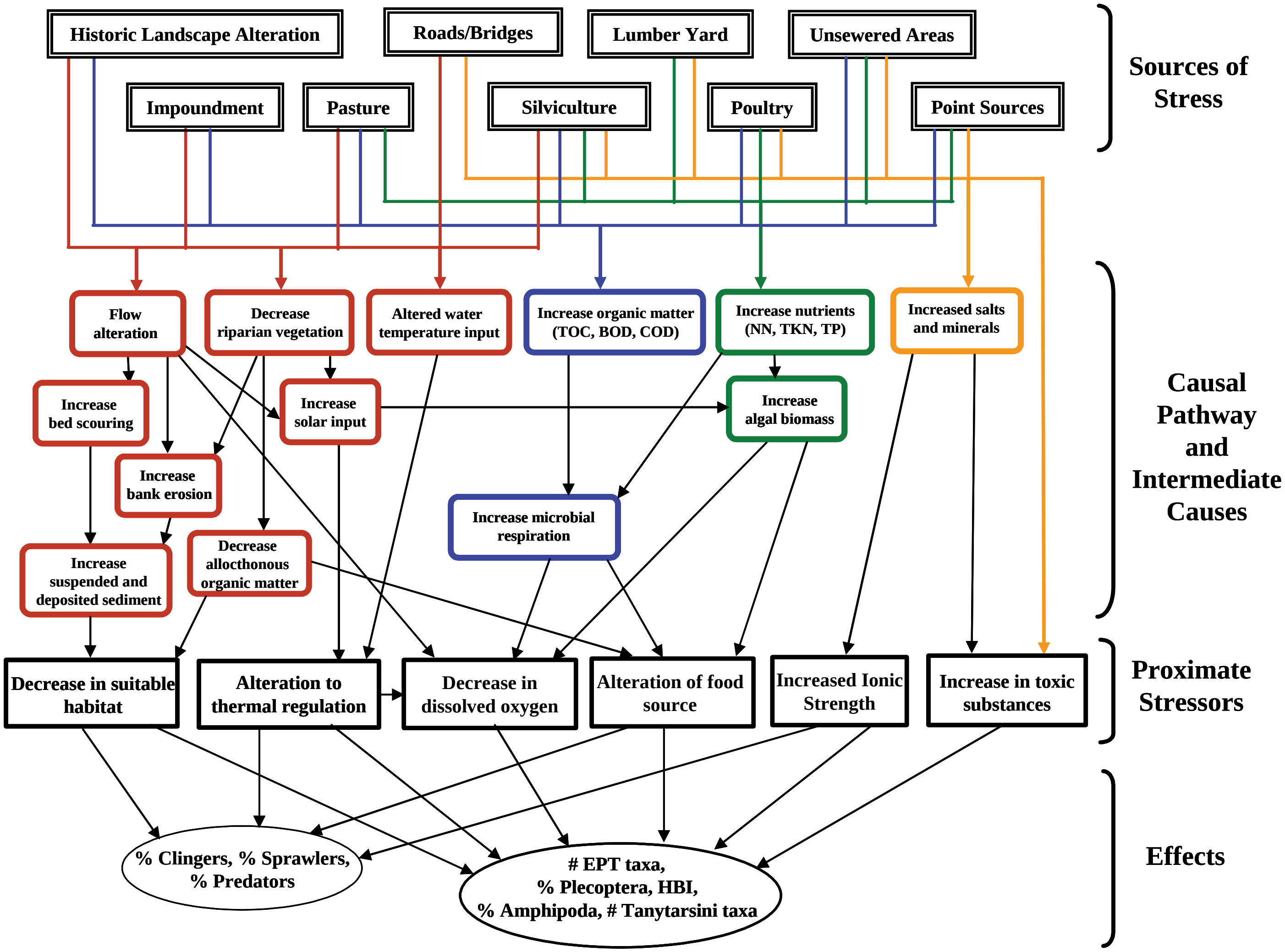

FIGURE 6

Conceptual Model for Bogue Homo

3. EVALUATE DATA FROM THE CASE

Two types of evidence using data from the case were employed in the causal analysis of the Bogue Homo:

1. **Spatial/Temporal Co-occurrence** of proximate causal agents and biological effects.

2. **Causal Pathway**, which includes the occurrence of intermediate causal agents that are components of the hypothetical causal pathway.

3.1. SPATIAL/TEMPORAL CO-OCCURRENCE OF PROXIMATE CAUSAL AGENTS AND BIOLOGICAL EFFECTS

This type of evidence is an evaluation of the coincidence in space and time of the impairment and the individual candidate causes (see Comment 6). The candidate cause is not responsible for the impairment if it is not present at the impaired site. The candidate cause is supported if it is present at the impaired site. MDEQ's method for determining whether causal agents co-occurred with the impairment was to compare water quality data from the impaired portion of the Bogue Homo to LD conditions and SSC values from the same time period. Water quality data used were in the form of indicator parameters of specific proximate causes. Comparison results used for evaluation of spatial co-occurrence are presented in Table 4.

Comment 6. Spatial/temporal Co-occurrence from the Case and from Elsewhere

Spatial/temporal co-occurrence provides evidence that the biological effect was observed where and when the cause was observed, and was not observed where and when the cause was absent. When considering spatial co-occurrence from the case, the impairment and stressor at the site is compared to sites within a close geographic proximity, ideally from a location within a few kilometers from the site. Preferably, measurements of the proximate stressor and the effect are also simultaneously collected at a site on the same day. Likewise, comparisons among sites should be made with data that were collected within a reasonably similar time frame, using similar methods. Pairing data for location and date is a matter of judgment, but generally stream reaches are compared to nearby or upstream reaches, watersheds are compared to other watersheds, and multiple watersheds to other sets of watersheds.

For the Bogue Homo case, the MDEQ compared the Bogue Homo site to other nearby sites, SSCs. We would consider this as evidence from the case. The MDEQ also compared the impaired site to LD conditions from a larger geographical region. We would consider this as evidence from elsewhere, another separate and important type of evidence. This is useful for increasing confidence that co-occurrence seen with limited sampling at local sites is also reflected in a larger population of sites.

3.1.1. Decrease in Suitable Habitat

Physical habitat was evaluated by visually assessing ten habitat parameters that describe in stream habitat quality and quantity, channel form and stability, and riparian condition. These visual assessments were calculated as scores for each of the ten parameters, and a total habitat score was calculated as the sum of the ten scores. The

TABLE 4
Water Quality Data, Bogue Homo and Comparison Conditions

Chemical Parameters	Bogue Homo	Difference from LD condition		Least Disturbed Condition		percentile used for LD
		East Bioregion	Site Class 6	East Bioregion	Site Class 6	
Turbidity	8.91	lower	lower	17.65	20.50	75th
Dissolved Oxygen (% saturation)	86.4	lower	lower	91.40	93.40	25th
Dissolved Oxygen (mg/l)	8.7	lower	lower	10.20	10.10	25th
pH	6.25	higher	lower	6.20	6.50	75th
Water Temperature (Celsius)	15.11	NA	NA	17.65	7.80	50th
Ammonia (mg/l)	0.3	higher	higher	0.22	0.20	75th
Nitrate-Nitrite (mg/l)	0.06	lower	lower	0.21	0.30	75th
Total Kjeldahl Nitrogen (mg/l)	0.79	higher	higher	0.64	0.70	75th
Total Phosphorus (mg/l)	0.04	lower	lower	0.07	0.10	75th
Chemical Oxygen Demand (mg/l)	36	higher	higher	21.00	20.80	75th
Total Organic Carbon (mg/l)	12	higher	higher	7.00	7.00	75th
Total Chlorides (mg/l)	30.5	higher	higher	6.00	6.40	75th
Total Dissolved Solids (mg/l)	98.8	higher	higher	27.30	29.90	75th
Physical Parameters						
Total Habitat Score	125	lower	lower	155.00	151.30	25th
Instream Habitat Score	31	lower	lower	43.50	38.75	25th
Morphological Habitat Score	55	lower	lower	64.00	59.75	25th
Riparian Habitat Score	39	lower	lower	45.50	44.50	25th
% Silt/Clay	10	lower	lower	11.00	11.00	50th
% Sand	90	higher	higher	72.00	57.50	50th
% Hardpan Clay	0	comparable	comparable	0.00	0.00	50th
% Gravel	0	comparable	lower	0.00	9.50	50th

Chemical Parameters	Bogue Homo	Site Specific Comparators				
		Black Creek	Bogue Homo (downstream)	Big Creek	Oakahay Creek	Yellow Creek
Turbidity	8.91	8.00	10.00	9.00	18.00	8.00
Dissolved Oxygen (% saturation)	86.40	87.80	99.30	91.20	91.20	93.10
Dissolved Oxygen (mg/l)	8.70	9.05	11.01	9.60	9.55	9.90
pH	6.25	6.10	6.37	6.46	6.47	6.90
Water Temperature (Celsius)	15.11	14.03	10.70	13.04	13.29	13.50
Ammonia (mg/l)	0.30	0.21	0.10	0.10	0.10	0.21
Nitrate-Nitrite (mg/l)	0.06	0.12	0.14	0.50	0.35	0.17
Total Kjeldahl Nitrogen (mg/l)	0.79	0.85	0.68	0.48	0.68	0.53
Total Phosphorus (mg/l)	0.04	0.07	0.12	0.04	0.07	0.10
Chemical Oxygen Demand (mg/l)	36.00	19.00	29.00	10.00	22.00	19.00
Total Organic Carbon (mg/l)	12.00	9.00	10.00	3.00	9.00	6.00
Total Chlorides (mg/l)	30.50	10.70	22.80	8.20	6.40	50.20
Total Dissolved Solids (mg/l)	98.80	59.15	239.20	35.75	46.15	130.65
Physical Parameters						
Total Habitat Score	125.00	169.00	126.00	116.00	137.00	184.00
Instream Habitat Score	31.00	52.00	44.00	33.00	53.00	57.00
Morphological Habitat Score	55.00	66.00	43.00	48.00	58.00	77.00
Riparian Habitat Score	39.00	51.00	39.00	35.00	26.00	50.00
% Silt/Clay	10.00	9.09	18.18	27.00	13.00	6.00
% Sand	90.00	57.58	46.46	66.00	68.00	83.00
% Hardpan Clay	0.00	0.00	0.00	0.00	0.00	11.00
% Gravel	0.00	33.33	35.35	7.00	19.00	0.00

Bolded parameters are those judged to possibly give information as to cause of impairment based on difference. The 75th percentile was used for parameters that, as they increased, biological quality decreased (e.g., ammonia). The 25th percentile was used for parameters that, as they increased, the biological quality increased (e.g., dissolved oxygen).

scale of the total habitat score was from 0 to 200, with increasing scores reflecting an increase in habitat condition. The total habitat score from Bogue Homo (125) was lower than most SSC station habitat scores (MDEQ, 2001). However, a monitoring station on Bogue Homo downstream of the impaired site had an almost identical total habitat score (126) as the impaired site, but was assessed as nonimpaired based on its M-BISQ score. Although MDEQ reduces sampler subjectivity by training and through the use of standard operating procedures, sampling variability is an inherent factor of any qualitative assessment method and may be the reason for this lack of consistent co-occurrence.

Suspended sediment was considered a component of habitat. However, turbidity values from Bogue Homo do not suggest that elevated suspended sediment co-occur with the impairment. Turbidity was low in 2001 (8.9 nephelometric turbidity units [NTU]) and is lower than LD condition values and most SSC station values in 2001, including the downstream (nonimpaired) Bogue Homo site (10.0 NTU). Turbidity data from Bogue Homo collected in 1997 were lower than or comparable to turbidity values for the LD condition and the SSC stations. However, turbidity measurements can vary dramatically with flow. Furthermore, base-flow conditions sometimes have low turbidity levels, even in cases where suspended sediment has a negative effect on the biological community. Measured levels of turbidity are therefore time-dependent. MDEQ recommends collecting biological samples during base-flow conditions (i.e., not immediately after an intense precipitation event, which can cause the water level to fluctuate). To help ensure representative sampling, MDEQ sampled Bogue Homo only during base-flow conditions (see Comment 7). Thus, the turbidity data may not adequately characterize storm-related suspended sediment problems, if such problems exist.

Comment 7. Episodic Events.
A peer reviewer indicated that most monitoring programs reflect base flow, rather than episodic events. Historical water quality might not indicate the importance of episodic events in biological impairment.

Particle size-distribution data for Bogue Homo substrates (10% silt/clay, 90% sand) also did not suggest sediment as a major potential cause of impairment. However, in the habitat assessment scoring procedure, the field crew observed, scored and recorded the amount of sediment deposition as “not optimal.”

In summary, low habitat quality and the impairment of Bogue Homo do not consistently co-occur, but this result is uncertain (see Comment 8).

Comment 8. Substrate Texture.
Percent sand at the impaired site (90%) was higher than at any SSC site (46.5−83%) and higher than the regional LC conditions (57 and 72%). Percent gravel (0%) was lower than all but one SSC site (0−35.3%) and lower than the Site Class 6 LC conditions (9.5%). Hence, if a sand substrate with no admixture of gravel was defined as a candidate cause, it could be said to co-occur with the impairment. This is an example of the use of specific causes rather than the more inclusive candidate cause of suitable habitat.

3.1.2. Altered Temperature Regime

Evaluation of co-occurrence of altered temperature regime and biological effects was problematic, because some measurements of temperature were made in the winter, and the collection methods did not address diel variability. However, temperatures were higher in the impaired segment of Bogue Homo than in SSC sites. The mechanism for increased temperature was not identified.

3.1.3. Altered Food Resources and/or Decreased Dissolved Oxygen

Concentrations of DO from Bogue Homo in 2001 were 8.7 mg/L (86.4%, saturation). These values were lower than any of the SSC sites (9.0 to 11.0 mg/L and 87.8 to 99.3% saturation, respectively). Of the SSC stations, the nonimpaired Bogue Homo downstream site had the highest levels of DO (11.0 mg/L, 99.3% saturation). The chemical oxygen demand (COD) value (36 mg/L) for the impaired site, in 2001, was greater than all SSC sites (COD range, 10−29 mg/L). In the summer of 1997, at the Bogue Homo impaired site, DO was low (5.5 mg/L, 68.6% saturation) and COD levels were elevated (29 mg/L) in the summer.

Food resource availability and composition can also have a significant direct and indirect impact on stream metabolism, including primary and secondary production and oxygen concentrations. No direct indicators of food resource availability or composition are available. However, the low DO and high COD are suggestive of a different trophic status at the impaired site.

3.1.4. Increase in Ionic Strength and/or Increase in Toxic Substances

Total dissolved solids (TDS) concentration at the impaired site are within the range of SSC sites, and are less than half those of the unimpaired downstream site. Total chlorides were greater at the impaired Bogue Homo site than at all but one of the five SSC sites. Historical data indicate slightly elevated total chlorides at the impaired Bogue Homo site, but not elevated TDS or specific conductance values. Water from the impaired site was not tested for toxicity, and no historical data are available for toxic substance concentrations at this site. Hence the impairment does not consistently co-occur with these limited measures of chemical contamination. However, given the paucity of measurements of potentially toxic chemicals, this candidate cause was not scored.

3.2. CAUSAL PATHWAY

A causal pathway is the sequence of events that begins with the release or production of a stressor from a source, and ends with a biological response. To determine a complete causal pathway, MDEQ evaluated indirect causes, intermediate steps, and the presence of sources that could account for the indirect causes leading to the proximate causes.

3.2.1. Decrease in Suitable Habitat

The causal pathway to decreased habitat quality consists of two components: hydrology and sediment.

3.2.2. Sources of Hydrologic Alteration

There was little evidence to support an altered hydrological regime as a component of the causal pathway to impairment of Bogue Homo. There was evidence that the main channel was connected to the floodplain. Only minor erosion/bank instability was noted in 2001 and during a reconnaissance visit in 2004. A large impoundment (Lake Bogue Homo) is located above the impaired site, but the effects, if any, of that impoundment on hydraulic conditions at the impaired site are unmeasured and the lake is more than 40-km from the site.

3.2.3. Sediment Sources

Potential sources of alteration in sediment transport in the Bogue Homo include land-disturbing activities that cause upland sediment runoff and bank failure, water level fluctuations, and sediment barriers. Soils in the Bogue Homo watershed tend to be naturally erodible. Watershed features that could increase inputs of sediment to the impaired site include silviculture operations, direct access of livestock to the stream, major drainage ditches along Highway 15, and commercial/residential development outside of the cities of Laurel and Ellisville. Lake Bogue Homo traps sediment, but the hydrologic effects of its release frequency and rate might increase bank and channel erosion. Significant channel evolution can continue for many years after geomorphic, hydrologic, or floodplain changes.

3.2.4. Altered Temperature Regime

Two potential sources of thermal alteration to Bogue Homo are identified: Lake Bogue Homo, and decreased riparian canopy cover. Lake Bogue Homo is located approximately 47-km upstream of the monitoring station on Bogue Homo. Therefore, it is unlikely that Lake Bogue Homo has an effect on the thermal regime of the impaired segment, but no data exist to evaluate this. Riparian canopy disturbance is observed upstream of the impaired site and may allow for increased exposure of the stream to solar radiation. The importance of this possibility, too, could not be determined with available measurements.

3.2.5. Altered Food Resources and/or Decreased Dissolved Oxygen

Dissolved oxygen is depressed by decomposition of dissolved and particulate organic matter and at night by algal respiration. Hence, dissolved and particulate organic matter and nutrients that promote algal growth are components of the causal pathway to low DO. In addition, they are components of the causal pathway leading to altered food resources.

3.2.5.1. *Sources.*

Because predominant land uses in the watershed are not agricultural, agricultural practices are probably not a primary source of excess nutrients or organic enrichment.

However, some poultry and cattle operations are observed in the watershed. Residential growth around the Laurel-Ellisville area, increased application of fertilizers in residential areas, septic tank leachate, the few point sources located upstream of the M-BISQ site, and Lake Bogue Homo itself are potential sources of elevated nutrients and organic enrichment.

3.2.5.2. *Organic Matter.*

In 2001, the total organic carbon (TOC) level measured from Bogue Homo (12 mg/L) is greater than the LD condition values and all SSC station values for TOC. However, historical TOC values from Bogue Homo are not higher than comparison conditions.

3.2.5.3. *Nutrients.*

Nutrient (nitrogen and phosphorus) concentrations from Bogue Homo during 2001 provided varying results in comparison to LD conditions and SSC station values, depending on specific water quality indicators. Concentrations of total Kjeldahl nitrogen (TKN) (0.8 mg/L) and ammonia (0.3 mg/L) were higher than LD condition values and all SSC station values. However, nitrite-nitrate and total phosphorus values were low, in comparison to the LD conditions and all SSC station values. In addition, all historical nutrient data were lower than LD condition levels.

3.2.6. Increase in Ionic Strength and/or Increase in Toxic Substances

Causal pathway components regarding toxic substances were not considered due to a lack of data. However, the sources noted for nutrients, above, could also potentially contribute toxic substances to Bogue Homo River.

4. EVALUATE DATA FROM ELSEWHERE

Two types of evidence using data from elsewhere were used in the causal analysis of the Bogue Homo:

1. **Mechanistically Plausible Cause**, which is based on evidence from other studies or basic biological principles, and
2. **Stressor-Response Relationships from Other Field Studies**, which is based on a regional database.

4.1. MECHANISTICALLY PLAUSIBLE CAUSE

This type of evidence evaluates the plausibility that the effect resulted from the cause, given what is known about the mechanisms involved in biotic and abiotic interactions and the environment in which the interactions occur. This process involves a logical evaluation of the ways in which a particular stressor could affect the biological community, at the site where the impairment occurs. The effects can be direct (e.g., toxic) or indirect (e.g., food chain, energy regime) (see Comment 9). It does not necessarily provide Bogue Homo specific evidence, rather it documents scientific knowledge that the candidate cause could occur and result in the types of impairments noted in the case.

4.1.1. Decrease in Suitable Habitat

Habitat alterations can affect community composition, and habitat alteration is considered to be one of the major stressors on aquatic systems (Karr et al., 1986). Poor-quality or homogenous stream habitat reduces the amount of cover, promotes instability, and changes the sources and availability of food. In addition to direct physical habitat alteration, intermediate causal pathway components capable of contributing to unsuitable habitat include increased suspended sediment, elevated turbidity, and altered hydrologic processes. Increases in turbidity or suspended sediments can interfere with oxygen uptake by clogging gills, reduce primary production by lowering water clarity, alter trophic structure, and increase temperature. Each of these situations can adversely impact benthic macroinvertebrate communities. Flow alteration, especially decreased flow and channelization, detrimentally affect in-stream biota and/or alter community composition (Hart and Finelli, 1999).

Comment 9. Not All Evidence is Equally Informative.
A mechanistically plausible cause is a weak argument unless there is actual evidence that a mechanism occurs at the site or is impossible at the site or in general. If all the candidate causes are mechanistically plausible, it does not alter the outcome of the assessment but simply documents that none are implausible. A statement to that effect can help shorten the report and can be briefly included when giving reasons for listing candidate causes.

4.1.2. Altered Temperature Regime

The changes in abundance of taxa and functional groups that characterize the impairment may be affected directly by natural or anthropogenic alterations of stream temperature, because of differences in the temperature tolerances of aquatic invertebrates, and indirectly by the effects of temperature on in-stream primary production and decomposition (Vannote and Sweeney, 1980; Galli and Dubose, 1990).

4.1.3. Altered Food Resources and/or Decreased Dissolved Oxygen

Organic matter, other than leaf detritus, affects aquatic invertebrates in several ways. Organic matter from inadequate waste treatment is a different energy source than leaf biofilms that may change the relative abundances of species promoting filterers and scrapers rather than shredders. Organic matter may promote algal and bacterial growth and biomass which is also a different food source that can lead to a change in the invertebrate assemblage. Furthermore, untreated organic matter or decaying algae can cause episodic levels of low DO that directly affect aquatic invertebrate abundances through asphyxiation.

4.1.4. Increase in Ionic Strength and/or Increase in Toxic Substances

Increased chemical concentrations and ionic strength can cause lethal and sublethal toxic effects in benthic organisms, and can change community structure (see Comment 10).

4.2. STRESSOR-RESPONSE RELATIONSHIPS FROM OTHER FIELD STUDIES

This type of evidence consists of comparisons of Bogue Homo data to regional stressor-response relationships. Stressor-response relationships were examined in two ways:

1. Scatter plots of biological metrics and abiotic parameters from sites in Site Class 6.
2. Box plot distribution of biological data from the East Bioregion with low and high ranges of abiotic values.

> **Comment 10. Mechanistic Specificity.**
> Since particular toxic substances are not specified, it is not possible to be more specific about mechanistic plausibility. For example, since amphipods are relatively salt tolerant, the ionic strength component of this candidate cause is consistent with the observed impairment, which includes increased amphipod abundance. Amphipods are, however, sensitive to cholinesterase-inhibiting pesticides, which are also potentially part of this candidate cause. Hence, without a more specifically defined cause, we can go no further than to say that increased chemical concentrations are a plausible mechanism of benthic invertebrate community impairment in the Bogue Homo.

4.2.1. Scatter Plots

Associations in other field studies between candidate causes and the effects that characterize the impairment can support a causal relationship at the site. Because of the potential for extraneous differences among sites, stressor-response relationships were not derived for comparison to quantitative relationships at the site. Rather, linear correlations were used to determine the strength and sign of associations of biotic and abiotic variables in Site Class 6.

Three steps were taken to identify specific stressor-response relationships that are potentially indicative of causation. The first step was to derive the Pearson product moment correlation coefficient (*r*) for combinations of biological metric values and various physical and chemical values in Site Class 6. The total number of discrete sampling events used to derive correlation coefficients and scatter plots was 63 (n = 63). The correlation matrix of all data is given in Appendix C. Most correlations were weak, <0.25. Using a selection value of either 40 or 35 included the same candidate causes. By choosing pairs that were $\geq$0.35, a manageable number of associations could be examined (see Comment 11).

The second step was to plot the data as scatter plots and the linear model for those pairings of variables with a positive or negative *r*-value of $\geq$0.35. Scatter plots were visually examined for the nature and distribution of data for each pairing of variables. Scatter plots whose correlation values appeared to be heavily influenced by a few outlier data that, if not included, would result in a much smaller *r*-value, were not considered for the third step.

Comment 11. Selecting Evidence of Causal Relationships.
Alternatively, the strongest correlations could be selected for evaluation and may have reflected the sensitivities of each metric to particular physical or chemical characteristics. Correlations are not used for hypothesis testing, but as a descriptive statistic to select associations for further analysis. For most environmental data, the rank correlation is usually more suitable (Spearman) rather than Pearson parametric method.

The third step was to look at Bogue Homo biological values plotted against the biological pairing of variables considered to be of positive or negative correlation and of potential meaning. The consistency of study site values was compared to biotic and abiotic variables from Site Class 6. The Pearson correlation coefficients of scatter plots are shown in Table 5. A summary of the conclusions drawn based on comparison of Bogue Homo values to select scatter plot curves is shown in Table 6, and the scatter plots used for this evaluation, with plotted Bogue Homo values, are shown in Appendix D.

4.2.2. Box Plot Distributions

Bioregion-wide field data were used to evaluate exposure-response relationships and determine whether they support or weaken evidence for candidate causes (see Comment 12). The data within the bioregion data were confounded by other stressors; therefore, it was judged that analysis of functional relationships, like linear correlations applied to regional data, would not be appropriate. Rather, biological effects of extreme high and low values of variables related to the causes were examined.

For specific abiotic variables, MDEQ identified low and high value using best professional judgment. Low and high value ranges were identified by examining the

TABLE 5

Pearson Correlation Coefficients (*r*-values) of Biological Metrics and Physical/Chemical Parameters Used for Scatter Plot Evaluation (*n* = 63)

	Total Organic Carbon (mg/L)	Chemical Oxygen Demand (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Total Chlorides (mg/L)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Silt Substrate (% Total)	Gravel Substrate (% Total)
M-BISQ Score	**−0.58**	**−0.50**	**−0.46**	**−0.36**	−0.24	−0.30	**−0.57**	**−0.39**	**0.53**
# Chironomidae Taxa	−0.24	−0.09	−0.25	−0.37	**−0.48**	−0.48	−0.09	−0.21	0.05
# Oligochaeta Taxa	0.17	0.28	0.32	0.09	0.03	0.02	0.21	**0.37**	−0.32
# EPT Taxa	−0.53	**−0.52**	−0.36	−0.20	−0.09	−0.19	−0.42	−0.31	0.36
# Filterer Taxa	−0.44	−0.33	−0.23	−0.26	−0.31	−0.41	−0.36	−0.35	**0.52**
# Plecoptera Taxa	−0.33	−0.38	**−0.41**	−0.09	0.18	−0.11	−0.32	−0.18	0.17
# Collector Taxa	−0.07	0.08	0.08	−0.13	**−0.46**	−0.40	0.10	−0.10	−0.11
# Diptera Taxa	−0.16	0.02	−0.18	−0.33	−0.50	**−0.50**	−0.03	−0.20	−0.01
% Noninsects	**0.44**	0.41	**0.49**	0.30	0.06	0.08	**0.44**	0.44	−0.31
% Caenidae	−0.06	−0.15	−0.18	−0.06	0.46	**0.46**	−0.01	−0.10	−0.22
Beck’s Biotic Index	−0.39	−0.38	−0.39	−0.30	−0.22	−0.33	**−0.51**	−0.32	0.30
Hilsenhoff Biotic Index	0.40	0.28	0.32	**0.38**	0.39	0.46	**0.51**	**0.47**	−0.59

Bold values are *r*-values of associations used in the evaluation.

TABLE 6

Summary of Stressor-Response Relationships from Linear Correlation of Various Biotic Variables Against Variables Associated with Candidate Causes

	Total Organic Carbon (mg/L)	Chemical Oxygen Demand (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Total Chlorides (mg/L)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Silt Substrate (% Total)	Gravel Substrate (% Total)
M-BISQ	+ +	+ +	+	-			- -	- -	+
# Chironomidae taxa					+				
# Oligochaeta taxa								- -	
# EPT taxa		+ +							
# Filterer taxa									+
# Plecoptera taxa			+						
# Collector taxa					+				
# Dipteran taxa						0			
% Noninsect individuals	0		+				-		
% Caenidae individuals						-			
Beck's Biotic Index							- -		
Hilsenhoff's Biotic Index				-			- -	- -	
Summary	+	+ +	+	-	+	-	- -	- -	+

++ = strong evidence as cause
+ = week evidence as cause
0 = unclear
- = weak evidence as not cause
-- = strong evidence as not cause

Comment 12. Box Plots.

The use of box plots to create exposure-response relationships from field data and relate them to site data might be clarified by further explanation. First, this use presumes a monotonically increasing or decreasing relationship. If conditions are optimal at an intermediate level of the causal agent and sub-optimal at the extremes, the technique is inappropriate. Second, box plots support a candidate cause if the following are true:

1. Boxes do not overlap. If they do overlap, it suggests that they are not a significant cause in the region because the levels of response do not greatly differ between extremely high and low levels of the candidate cause.
2. The boxes are small. If the cause were important, one would expect a relatively consistent response. This is a weaker criterion than 1.
3. The response at the impaired site falls on the box for the extreme level predicted by the causal hypothesis. For example, the number of EPT taxa at the impaired site falls within the inter-quartile range of EPT taxa for extremely high turbidity sites in the region, which supports turbidity as a cause.
4. The level of the candidate cause at the impaired site falls within the appropriate regional extreme range. That is, if the biological response at the impaired site corresponds to the levels seen at an extreme level of the candidate cause (i.e., Criterion 3 is met), then the level of the candidate cause should be extreme at the impaired site.
5. Criteria 1–4 are true for most, if not all, of the response metrics that define the impairment. That is, if the candidate cause is responsible for the impairment, it should be associated with most or all of its components.

MDEQ applies Criteria 1–3 in their analysis to obtain the results in Table 8, thus inspiring us to more fully describe the use of box plots in causal analysis. The MDEQ analysis provides evidence to strengthen or weaken candidate causes, but adding the other two criteria would provide more complete evidence. For example, the number of EPT taxa and the percent crustacean/mollusk individuals are clearly differentiated at extreme turbidity levels (1–2), and the levels of those biological metrics are as expected for high turbidity levels (3), but the turbidity levels at the impaired site are not high (4). These conditions suggest that turbidity is not the only cause of the impairment that is discussed by MDEQ in a later section entitled "Identify the Probable Cause."

entire data set for each parameter and selecting ranges on the extreme ends. Among the factors considered were: the amount of data in the range, and judgment as to whether the range of values would be considered low or high based on existing water quality criteria, literature, and professional judgment. For each abiotic parameter, stations with data falling in the established low and high ranges were identified. Biological metric data from these stations were displayed using two box plots, one showing the range of biological metric data from stations in the high range and one showing the range of biological metric data from stations in the low range. The pairings of box plots for each biological metric were visually evaluated as to whether the metric response coincided with the abiotic categorization. Evaluation of the box plots involved noting whether the 25^{th} and 75^{th} percentile values overlapped, and if not, how close they were. In addition, the spread of the inter-quartile range of individual boxes was evaluated, with large inter-quartiles spreads being interpreted as high variability in response, resulting in less confidence in that particular metric. Table 7 gives abiotic parameters evaluated; low and high range values; number of data used for each range; and corresponding biological metrics. The behaviors of sites in the bioregion were compared to Bogue Homo data.

TABLE 7

Parameters Evaluated Using Box Plots

Parameter	Low range	n value	High range	n value	Biological metrics with good response
Total Organic Carbon (mg/l)	≤ 1.0	53	> 10.0	52	% Tanytarsini individuals % Non-Insect individuals # EPT taxa # Crustacean/Molluscan taxa
Chemical Oxygen Demand (mg/l)	≤ 10.0	298	> 30.0	47	# EPT taxa % Non-Insect individuals
Dissolved Oxygen (% Saturation)	< 85%	64	100-103%	146	# Ephemeroptera taxa % EPT individuals
Total Nitrogen (mg/l)	< 0.3	65	> 2.0	44	M-BISQ Beck's Biotic Index % Tolerant individuals % Intolerant individuals % Filterer individuals # Clinger taxa # EPT taxa # Plecoptera taxa # Orthocladinae taxa
Total Phosphorus (mg/l)	≤ 0.01	45	> 0.30	30	M-BISQ Hilsenhoff's Biotic Index % Tolerant individuals % Intolerant individuals % Tanytarsini individuals % Oligochaeta individuals # EPT taxa # Orthocladinae taxa % Filterer individuals % Clinger individuals
Total Chlorides (mg/l)	< 3.0	99	> 50.0	20	Beck's Biotic Index # Chironomidae taxa
Turbidity (NTU)	< 5	74	> 70	33	M-BISQ Hilsenhoff's Biotic Index % Tolerant individuals % Intolerant individuals % Dipteran individuals % Crustaceans/Molluscan individuals % Collector individuals % Filterer individuals % Clinger individuals # EPT taxa
Silt substrate (percent total)	< 5	162	> 75	56	# Crustacean/Molluscan taxa # Tanytarsini taxa # Clinger taxa
Total Habitat Score	< 70	54	> 160	67	M-BISQ NCBI % Tolerant individuals % Intolerant individuals # Total taxa # Plecoptera taxa % Filterer individuals # Clinger taxa

Biological metric data from Bogue Homo were compared to the suite of selected box plots given above. Visual observation of the Bogue Homo values relative to the ranges of high and low values, as indicated by the box plots, was performed to determine if the particular abiotic variable may be indicative of biotic effects that comprise the impairment (see Comment 13). A summary of the conclusions drawn based on comparison of Bogue Homo values to select box plots is shown in Table 8. All box plots, including the plotted Bogue Homo values, are shown in Appendix E.

Comment 13. Specificity.
In addition to the evidence noted in Section 4.2.3., none of the specific biological responses that characterize the impairment - decreased taxa richness of EPT, relative abundance of EPT, relative abundance of EPT taxa, or increased abundance of amphipods (the latter also being represented by % noninsects)—correlate strongly with a habitat variable. Also, the most prominent habitat characteristic at the impaired site, a high percentage of sand, is not well correlated with any biological response. Hence, at the bioregion scale, the specific responses at the impaired site are not related to habitat, and the distinguishing habitat characteristic is not related to the measured biological responses.

4.2.3. Decrease in Suitable Habitat

There is supporting and weakening evidence for a less suitable habitat as the cause of biological impairment in the Bogue Homo. Based on scatter-plot and box plot analyses, evidence was weak or inconclusive for a decrease in suitable habitat as a potential stressor. Scatter plot analyses suggested suspended sediment (turbidity) and percentage of silt substrate were not causative agents of impairment to Bogue Homo. The only habitat related stressor-response correlation that suggested a potential cause of impairment was percentage of gravel substrate. In contrast, box plot analyses suggested that percentage of silt substrate was a potential causative agent. Also, there was weak evidence for habitat degradation as a cause. This was based on the total habitat assessment score, which includes many aspects of habitat quality. Box plot analyses provided no evidence that suspended sediment was a cause of impairment.

4.2.4. Altered Temperature Regime

Biologic metrics related to temperature either did not correlate strongly with abiotic parameters, or were correlated because of the presence of a few outlier data points that “drove” the overall relationship. When the latter situation occurred, the correlations were considered to be unreliable for making conclusions about potential causes of stress. In some cases, too, data from Bogue Homo were not consistent with the observed overall correlation gradient.

4.2.5. Altered Food Resources and/or Decreased Dissolved Oxygen

Decreased oxygen concentration, increased organic loading, and increased nitrogen are suggested as potential stressors based on scatter plot and box plot analyses. Only phosphorus concentration was not suggested as a causative agent. Evidence was strongest with regard to chemical oxygen demand (scatter plot and box plot) and dissolved oxygen concentration (box plot).

TABLE 8

Summary of Stressor-Response Relationships from Box Plots of Various Biotic Variables Based on Low and High Ranges of Variables Associated with Candidate Causes

	Total Organic Carbon (mg/l)	Chemical Oxygen Demand (mg/l)	Dissolved Oxygen (% Saturation)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Total Chlorides (mg/l)	Turbidity (NTU)	Silt substrate (% total)	Total Habitat Score
M-BISQ				-	0		0		+
# Total taxa									0
# Crustacean/Molluscan taxa	++							+	
# Chironomidae taxa						-			
# Orthocladinae taxa				0	0				
# Tanytarsini taxa								++	
# EPT taxa	++			+	+		+		
# Ephemeroptera taxa		++	++						
# Plecoptera taxa				-					++
# Clinger taxa				+				+	++
% Non-Insect individuals	+	+							
% Crustaceans/Molluscan individuals							++		
% Oligochaeta individuals					0				
% Dipteran individuals							--		
% Tanytarsini individuals	--				--				
% EPT individuals			++						
% Collector individuals							-		
% Filterer individuals				--	--		--		-
% Clinger individuals					0		0		
Beck's Biotic Index				--		--			
Hilsenhoff's Biotic Index					0		-		
NCBI									+
% Tolerant individuals				--	--		--		--
% Intolerant individuals				-	-		-		0
Summary	+	++	++	-	-	--	-	++	+

++ = strong evidence as cause
+ = week evidence as cause
0 = unclear
- = weak evidence as not cause
-- = strong evidence as not cause

4.2.6. Increase in Ionic Strength and/or Increase in Toxic Substances

Total chlorides and total dissolved solids were evaluated. Scatter plot analyses resulted in weak evidence for total chlorides as a potential cause; however, box plot analyses resulted in strong evidence against total chlorides. In addition, scatter plot analyses resulted in weak evidence against total dissolved solids as a cause (see Comments 14 and 15).

Comment 14. Stressor-Response Relationships for Laboratory Studies.
MDEQ did not use laboratory data as a type of evidence from elsewhere. Laboratory test data are available for suspended sediment, temperature, dissolved oxygen, and total dissolved solids. Like many others, MDEQ found these data difficult to obtain. CADDIS has since attempted to make this easier through links in sections on stressor-response and for individual stressors.

Comment 15. Symptoms.
The identification of assemblage or community level characteristics would greatly benefit eco-epidemiological investigations. The MDEQ's attempt to apply that approach is illustrative (see Appendix B). At this time, the U.S. EPA does not recommend using community metrics levels as symptomatic of specific stressors at this time because indices and metrics respond to too many stressors. However, this is an active area of research (Relyea et al., 2000; Yuan, 2006).

5. COMPARISON OF CANDIDATE CAUSES

This analysis provides a consistent and systematic approach for evaluating whether available evidence supports, or does not support, each candidate cause. Furthermore, for multiple causes, the process identifies the stressor(s) that are most strongly supported by the evidence with a level of confidence assigned to each stressor by the investigators. This is done according to the types of evidence adapted from the U.S. EPA *Guidance Document* (U.S. EPA, 2000) and U.S. EPA Web site (www.epa.gov/caddis.) A set of symbols were used to score the importance of various causal relationships that describe the most prominent candidate causes.

After scores were assigned for each type of evidence from the case and from types of evidence that use data from elsewhere, two additional types of evidence were evaluated to score the overall pattern or tendency of the facts in the case. The two types of evidence for comparing all the evidence for a candidate cause were

- Consistency of evidence, in which investigators evaluated the degree to which assessments of relationships between impairment and stressors were consistent, and
- Explanation of evidence, in which the investigators evaluated whether inconsistencies can be explained by other information, in keeping with the stressor hypothesis.

The strength-of-evidence table for Bogue Homo is shown in Table 9. Strength-of-evidence analyses led us to conclude that multiple stressors may be contributing to biological impairment in Bogue Homo. Most of the chemical and physical parameters measured in Bogue Homo suggested possible causes; however, a few stood out as being probable causes. These included altered food resources and low dissolved oxygen associated with organic and nutrient enrichment. Decreased suitable habitat was identified as an additional possible cause of impairment. However, evidence for habitat alteration, such as sediment inputs or hydrologic regime alteration, was not very strong. However, gravel substrates were absent and waters were turbid.

Increased ionic strength and/or increase in toxic substances were identified as less-probable causes for impairment based on land use and the moderate impairment at the site. However, little evidence existed for these factors and none for pesticides, metals, or other potentially toxic compounds. Evidence that suggests that elevated temperature contributed to the impairment was inconsistent and/or unsubstantiated.

TABLE 9

Strength of Evidence for Bogue Homo, Mississippi

Type of Evidence		Unsuitable Habitat		Increased Temperature		Altered Food Resources (Organic Matter) and/or Decreased Dissolved Oxygen		Increased Ionic Strength and/or Increased Toxicity	
		Evidence	Score	Evidence	Score	Evidence	Score	Evidence	Score
From the Case	Spatial Co-occurrence	Uncertain	0	Uncertain	0	Compatible	+	No evidence	NE
	Causal Pathway	Evidence for some steps	+	Ambiguous	0	Evidence for all steps	++	Evidence for some steps	+
From Elsewhere	Mechanistically Plausible Cause	A plausible mechanism exists	+	A plausible mechanism exists	+	A plausible mechanism exists	+	A plausible mechanism exists	+
	Stressor-Response, Other Field Studies	Unclear	0	Unclear	0	Qualitative agreement	+	Unclear	0
Multiple Types of Evidence	Consistency of Evidence	Some consistent	+	No evidence	NE	All consistent	+++	Some consistent	+
	Explanation of Evidence	Not applicable	NA	Not applicable	NA	Not applicable	NA	Not applicable	NA

6. IDENTIFY THE PROBABLE CAUSE

6.1. PROBABLE PRIMARY CAUSE

6.1.1. Increased Organic and Nutrient Enrichment Altering Food Resource and Leading to Low Dissolved Oxygen

COD and TOC levels were greater than LD conditions and greater than all of the SSC streams in 2001, and were elevated in 1997 based on review of the historical data at Ovett, Mississippi. Levels of ammonia and TKN at the impaired site were consistently greater than the 75^{th} percentile of the East Bioregion, Site Class 6 reference conditions, and most of the SSC sites (see Table 4). Concentrations of nitrite, nitrate, and phosphorus were similar to those for the LD condition and at all of the SSC sites. DO and DO percent saturation concentrations at the impaired site in 2001 were lower than those in LD conditions and all SSC sites. Historical data also show that low values of DO and DO percent saturation periodically occurred at the impaired site. However, they were not low enough to violate the state's Water Quality Standard (WQS) criterion. .Biological metric values from Bogue Homo that supported increased nutrients, decreased DO, and organic enrichment as stressors included percent and number of EPT taxa; percent Plecoptera (low DO, increased nutrients and organic enrichment); and percent Amphipoda (decreased oxygen and organic enrichment). Comparison of Bogue Homo data to regional stressor-response relationships also suggested elevated nutrients, low DO, and organic enrichment as possible factors. Decreased levels of DO and/or altered food resources, in association with their intermediate pathway of organic and nutrient enrichment, were indicated as the most likely causes of biological impairment based on the weight of evidence. This included the presence of potential sources (poultry and cattle operations, residential growth in the Laurel-Ellisville area, septic tank leachate, Lake Bogue Homo, and point sources) and elevated levels of nutrients (specifically ammonia and TKN).

6.2. PROBABLE SECONDARY CAUSES

6.2.1. Decrease in Suitable Habitat

The habitat quality score for the Bogue Homo impaired site was lower than the LD conditions for the East Bioregion and Site Class 6 sites, and lower than the habitat scores for most of the SSC stations (see Table 4). Especially in comparison to the SSC sites, the lower overall score was influenced by the low in-stream habitat score. Interestingly, the total habitat score at the downstream Bogue Homo site was nearly identical to that of the impaired site, but the downstream site was not impaired. This result suggests that habitat quality in Bogue Homo did not contribute much to the impairment. However, the downstream site had a higher in-stream habitat score and a significant amount of gravel substrate, as well as reduced levels of some other stressors, which would contribute to the better biological rating.

The comparison of Bogue Homo data to regional stressor-response relationships resulted in weak or inconclusive evidence for decrease in suitable habitat as a potential stressor. Potential sources of habitat degradation in the watershed included land-disturbing activities such as clearing for silviculture; watershed construction activities that cause upland sediment runoff and stream bank failure; livestock access to streams; extensive drainage ditches along Highway 15; increased commercial and residential development; naturally erodible soils; in-stream sources of sediment; releases of water from Lake Bogue Homo; and historic alteration of the landscape. After reviewing all available evidence, MDEQ concluded that a decrease in suitable habitat is plausible as a secondary cause of biological impairment.

Sediment and hydrologic characteristics typically associated with reduced habitat suitability were considered to be less likely to contribute to the impairment (see Comment 16). Turbidity measurements for Bogue Homo did not suggest suspended sediment as a potential cause of impairment. Neither the 2001 data (see Table 4) nor the historical data indicated that turbidity was elevated. In the habitat assessment scoring procedure, the field crew observed, scored, and recorded the amount of sediment deposition as suboptimal. However, few signs of other sediment or hydrologic alteration effects (i.e., high erosion/bank instability, channel alteration, rapid water level fluctuation, incision, and/or low flow) were noted in 2001 or during the reconnaissance in 2004. The downstream comparative site on Bogue Homo had a similar sediment deposition score and a higher level of turbidity, but was not impaired.

Comment 16. Suitable Habitat.
In sandy bottom streams where gravel substrates do not naturally occur, woody debris can provide more stable substrates. No data were available to evaluate the relative amount of woody debris.

6.3. LESS PROBABLE OR UNLIKELY CAUSES

6.3.1. Altered Thermal Regime

Water temperature data from M-BISQ at the two Bogue Homo sites, plus limited historical data, did not point to temperature as a likely stressor. Similarly, biological data did not suggest elevated water temperature as a cause of impairment. Because of lack of co-occurrence (similar temperature levels at downstream site in 2001 with nonimpaired biology), lack of regional stressor-response relationships, and lack of a causal pathway (few potential sources), water temperature was not considered a stressor of Bogue Homo.

6.3.2. Increase in Ionic Strength and/or Increase in Toxic Substances

Concentrations of TDS and chlorides at the impaired site were elevated, compared to LD levels and to those at most of the SSC sites in 2001 (see Table 4). However, even the elevated values were far below state WQS. The downstream Bogue Homo SSC site had chloride levels similar to the impaired site, and a much higher TDS concentration (239 mg/L) than the impaired site, in 2001, with no biological impairment. Neither TDS nor chlorides were associated with impairments in the regional data sets.

Potential sources of TDS and chlorides in Bogue Homo included upstream point sources, agriculture operations, sand/gravel mining, soil disturbance from clear-cutting, and some possible petroleum activities. However, no definitive sources were identified. Because co-occurrence was inconsistent and obvious sources were limited, MDEQ concluded that increased ionic strength was not a major stressor of Bogue Homo.

MDEQ found no evidence for or against toxics, oil/grease, or soaps/surfactants as stressors. Concentrations of these pollutants cannot be evaluated until adequate data on these compounds in the water and/or sediments are collected. Lack of identified toxic releases or pollution incidents, and the abundance of benthic organisms at the sampling site, suggest minimal or no impact from toxic substances. Sources for toxics are present in the watershed as similarly identified for ionic strength; however, these sources are relatively few and generally far removed from the study site. As a result, MDEQ felt that increased toxics probably were not a likely cause of biological impairment.

7. DISCUSSION AND HIGHLIGHTS

Application of the causal analysis process to Bogue Homo allowed MDEQ to determine the most probable cause(s) of biological impairment in the §303(d)-listed reach. This process identified organic and nutrient enrichment leading to an altered food resource and low dissolved oxygen as probable causes and a decrease in suitable in-stream habitat as a possible cause. Following the causal analysis process, MDEQ developed TMDLs of Bogue Homo for organic matter and nutrients loadings.

Through the development of this case study, MDEQ later improved and strengthened their routine causal analysis process. The conceptual model provided in this report has been revised to better depict potential links between sources of pollutants and biological response indicators, including a more comprehensive and explicit distinction between proximate causes and their associated intermediate causal pathways and indicators. Additionally, through better understanding of the intended causal analysis process, MDEQ modified the strength-of-evidence analyses and the associated scoring tables.

As illustrated in this revised case study, emphasis now is placed on ensuring that data (and their associated analyses) developed for one type of evidence, are used to support *only* one type of evidence. The purpose of this effort is to avoid inappropriately overemphasizing a prospective cause by "double counting" data and/or their analyses. Careful consideration is given to determine which type of evidence a type or group of data and associated analyses reveals. To highlight and disseminate only pertinent data and information used in strength-of-evidence analyses, MDEQ no longer reports types of evidence that are not used due to lack of data or to inapplicable data.

Two types of screening methods were identified during the analysis that might strengthen the overall causal analysis process in the future. One screening method involves refining the causal analysis process to be more time-efficient, and to allow the user to quickly evaluate data to identify causal pathways that need intensive data collection to fill data gaps. This screening method would be helpful when users are not comfortable with the amount or quality of data (spatial coverage, number of samples, temporality) available for the TMDL process. The other screening method involves visiting multiple stream reaches throughout the watershed to better determine the spatial scale of the impairment. This method allows the investigators to focus on a reduced set of more-likely causes. This application would be used when data are limited in spatial and temporal scale, but differs from the data collection effort noted previously in that the spatial-assessment effort is much less. In general, the method would involve rapid assessment of multiple stream reaches using benthic community sampling, water quality sampling, and physical stressor evaluation. A field screening technique would be used to collect, identify, and collate benthic data, resulting in immediate benthic assemblage assessment and no samples to process in the lab. While on site, physical and chemical measurements would be made and water quality grab samples would be collected as resources allow.

The causal analysis procedure used by MDEQ was based on methods outlined in the U.S. EPA *Stressor Identification Guidance Document* (U.S. EPA, 2000). MDEQ developed a standard process of data consideration to support or refute candidate causes. The process entails prioritizing prospective causes based largely on weight of evidence, with the end result usually involving placing each of the candidate causes in one of four possible categories: Probable Primary Cause/s, Probable Secondary Cause/s, Less Probable Cause/s, or Unlikely Cause/s.

MDEQ has an extensive §303(d) List of Impaired Waters. For many of these bodies of water, the causes of impairment are unknown. For most, classification as impaired was based on a single sample of benthic macroinvertebrates. In addition, a lawsuit involving these waters has resulted in a strict deadline for completing the TMDLs. Because of the large number of impaired waters in need of stressor identification, the similarity of amount and type of data to be used for causal analysis associated with each site, and the short amount of time available to perform the analyses, MDEQ has developed several techniques for making the analysis faster, more routine, and more consistent. These are described below.

A "standard" list of potential stressors of Mississippi waters was initially developed. This list was prepared following round-table discussions involving MDEQ scientific and water quality staff. The list was framed in the context of five major groups of environmental factors that are known to affect biological community structure or function: chemical processes, physical processes, hydrological processes, biological interactions, and energy regimes.

Within each group, related causes of impairment that might stress aquatic biota in streams and rivers were identified. Only indicators that MDEQ uses in its surface water quality monitoring program strategy were included. This list became the "universal list of causes of impairment" that was used to start all causal analysis efforts in Mississippi. Use of a "standard list" resulted in a more consistent, timely evaluation of data for determining probable causes of impairment.

MDEQ used a work-team approach to perform causal analyses. Attempts were made to engage multi-disciplinary staff as members of the work teams for each waterbody. To achieve causal analysis process results of the highest possible quality, MDEQ formed and engaged a multi-disciplinary team composed of biologists, engineers, water quality scientists, and geographers. The intent was to incorporate expertise in physical, hydrological, chemical, and biological processes that were applicable to aquatic ecosystems in Mississippi. The use of this team was intended to reduce individual bias, increase the breadth of experience and knowledge, and increase objectivity in an inherently subjective process. This multidisciplinary approach hopefully strengthened the causal analysis and subsequent TMDL process by increasing the breadth of exploration of potential causes and effects, given the implicit complexity of aquatic ecosystems and factors that are involved in changes to biological community structure and function. GIS data were included in the SI process, and information and analysis tools were used throughout the process. MDEQ explored, refined and gained needed experience in the causal analysis process by taking on the first impaired waterbody as a pilot project, and engaging the entire team in the pilot causal analysis process. This proved to be very useful in ensuring consistent and adequate performance as well as covering many issues at the start of the process that might otherwise have been missed.

MDEQ relied heavily on the quality of data to add strength to the TMDL process. Scientifically sound and robust biological data collection methods and sample analysis techniques were developed before the causal analysis process. This greatly improved confidence in conclusions drawn about the data. The ability to use comprehensive biological assemblage data has been especially advantageous in light of the small number of chemical and physical samples available for most impaired sites. Much of the strength of the evidence process employed by MDEQ was based on stressor-response relationships, which are very informative due to the high quality of biological data. MDEQ also used various spatial stratification schemes for the state, depending on modeling of chemical, physical, and biological data. These strata were developed as part of the development of the state's biological monitoring and assessment program.

Presently, MDEQ is exploring additional methods for diagnosing causes of impairment using benthic community data. These include the use of stressor-specific tolerance values, stressor-specific models of community taxonomic composition, and conditional probability analysis. As causes are verified through the SI process, the results of this characterization must be summarized and confidence level assessed, in either quantitative or qualitative terms. The level of confidence is stated primarily through identification of uncertainties for each cause. In many cases, especially if the causal inferences are based mostly on the strength-of-evidence analysis, uncertainties cannot be quantified, because the stressor identification conclusion is not based on a single source of uncertainty, but rather, on multiple types of evidence sometimes supported by more than one line of evidence. In such cases, the degree of uncertainty for the decision is characterized qualitatively as the best estimate of causation with an accompanying disclosure of uncertainties and evidential proof. The final decision, in terms of determining whether the causal evidence presented is adequate to justify applicable management actions (e.g., TMDL, restoration strategies) to address the suspected cause and/or prioritize remediation actions for multiple causes, then becomes the responsibility of the regulatory or administrative authority.

In order to increase confidence in the evaluation of data in these SI analyses, it is recommended that

- M-BISQ should be recalibrated using more data, which will increase the accuracy of LD condition values and decrease the confidence intervals associated with individual metrics and M-BISQ scores.
- Sampling performance should be continually maintained and strengthened through training, measurement, evaluation of sampler performance, and implementing corrective actions when necessary.

- More physical/chemical samples should be collected at study sites to increase the probability that samples are representative of actual stream conditions, and effort should be invested to capture diel, seasonal, and flow-dependent fluctuations where applicable.
- Quantitative data regarding habitat, hydrologic, and geomorphologic characteristics should be collected.

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APPENDIX A

DATA USED FOR CAUSAL ANALYSIS

All available water quality data, other environmental data, and information for the Bogue Homo watershed were gathered and reviewed. These data were compiled from various MDEQ databases and the U.S. EPA Legacy STORET database. Data used in the causal analysis included benthic macroinvertebrate assemblage metrics, taxonomic information, qualitative habitat assessment scores, sediment particle-size percentages, measurements of various water quality parameters, LULC percentages, and other miscellaneous watershed information. The majority of data were collected during the winter of 2001 as part of a statewide monitoring and assessment strategy for the purpose of assessing the 1996 §303(d) List of Impaired Water Bodies. Some water quality data evaluated were collected in 1997, as part of MDEQ's Ambient Monitoring Program.

A.1. 2001 STATEWIDE MONITORING AND ASSESSMENT STRATEGY

In 2001, MDEQ implemented a statewide monitoring and assessment strategy that involved collection of data on biological and habitat condition, sediment particle size, various water quality characteristics, remotely sensed land use, and land cover percentages. All data collected were used in a multi-step process to develop a regionally calibrated Index of Biological Integrity, which MDEQ refers to as the M-BISQ. The M-BISQ process allowed each sampling site to be scored based on selected biological metric values, and to be compared to least disturbed conditions. The least disturbed condition was defined by combining certain metric values from streams in each particular region considered to be least disturbed, calculating overall M-BISQ scores, and using the 25th percentile value of the range of all least disturbed scores for each particular region. Individual site scores were then compared to the least disturbed condition for their region. If the score fell below the least disturbed condition, the site was considered impaired.

A.2. BIOLOGICAL DATA

Collection and processing of benthic macroinvertebrate samples and benthic macroinvertebrate taxonomy were performed using Standard Operating Procedures outlined in MDEQ (2001). Over 60 different biological metrics describing various characteristics of the macroinvertebrate communities were derived from the taxonomic data. A suite of regional specific metrics was used to calculate an overall M-BISQ score according to methods outlined in the M-BISQ QAPP (MDEQ, 2001). Biological data used for analyses included individual metric values and the overall M-BISQ score.

A.3. HABITAT DATA

Quality of the physical habitat was assessed using a visually based scoring procedure in which ten habitat parameters were rated on a continuous scale. The scores for these ten parameters were summed to calculate the overall habitat score (MDEQ, 2001). Scores for individual habitat parameters also were summed in three subcategories describing the stream environment: in-stream habitat conditions, stream morphology characteristics, and riparian habitat condition.

A.4. SEDIMENT PARTICLE SIZE DATA

Sediment particle size was measured using a method based on the 100-particle Wolman pebble count method (MDEQ, 2001). Data are presented as the percent of silt/clay, sand, gravel, cobble, boulder, and/or hardpan clay, relative to the total number of particles.

A.5. WATER QUALITY DATA

Various physical and chemical parameters were measured using U.S. EPA-approved methods, both in the field and via laboratory analyses (MDEQ, 1999, 2001). MDEQ water-quality criteria and/or historic target thresholds were used for comparisons.

A.6. WATERSHED CHARACTERIZATION DATA

Land use and land cover percentages were calculated using GIS based data layers developed as part of the Mississippi Land Cover Project (MDEQ, 1997). The land-use and land-cover percentages were calculated for the entire watershed area, a 100 m buffered area around the channel for the entire watershed, and a 100 m buffered area around the channel for an area defined by a 1-km radius from the monitoring station. Other watershed characterization data include census information; forestry and agricultural statistics; soil survey results; permitted facilities database; and watershed investigations.

APPENDIX B

COMMUNITY SYMPTOMOLOGY

Many attempts have been made to interpret benthic macroinvertebrate community responses as symptomatic of specific stressors. The MDEQ's attempt to use seven M-BISQ metrics and additional metrics in that way is presented below and summarized in Table B-1.

These interpretations are based on MDEQ's synthesis of the following publications: Barbour et al. (1999), Cummins et al. (1989), DeShon (1995), Fore et al. (1996), Hayslip (1993), Hilsenhoff (1987), Kerans and Karr (1994), Plafkin et al. (1989), Resh et al. (1995), Shackelford (1988) and Smith and Voshell (1997).

B.1. BECK'S BIOTIC INDEX (BI)

A decrease in this metric is thought to indicate an increase in stress. However, this metric does not necessarily discriminate among types of stress. Bogue Homo's Beck's BI value gives little information as to the specific cause of impairment.

B.2. HILSENHOFF BIOTIC INDEX (HBI)

Bogue Homo's Hilsenhoff Biotic Index (HBI) value gives little information as to the specific cause of impairment. However, this index was originally developed as an indicator of organic enrichment (Hilsenhoff, 1987).

B.3. NUMBER OF TANYTARSINI TAXA

In general, members of the Tribe Tanytarsini are pollution sensitive. Therefore, a decrease in their numbers may suggest an increase in perturbation that affects niche space, habitat, and/or food source for this particular group of taxa. It may also reflect other stressors such as increased nutrients, alteration of sediment regime, and decreased oxygen. It is difficult to pinpoint a specific stressor as the cause of change in this metric. The number of Tanytarsini taxa from the Bogue Homo sample gives little information as to the specific cause of impairment, as the differences seen are small.

B.4. PERCENT CAENIDAE

Many mayfly taxa are considered to be intolerant to pollution and stress. Members of the family Caenidae are considered to be generally more tolerant than other mayflies to many stressors, as indicated by the higher tolerance values derived for these taxa. An increase in the Percent Caenidae metric suggests an increase in stress, in particular slight to moderate nutrient enrichment, reduction in levels of DO, and/or decrease in habitat availability and/or complexity. The percent of Caenidae from the Bogue Homo sample gives little information as to the specific cause/s of impairment.

TABLE B-1 Summary of Biological Metrics from Bogue Homo and Potential Associated Causes					
	Disturbed Habitat (including sediment and hydrology	Decreased Dissolved Oxygen	Altered Food Resource	Increased Temperature	No Information
Beck's Biotic Index (BI)					X
Hilsenhoff Biotic Index (HBI)					X
Number of Tanytarsini Taxa					X
Percent Caenidae					X
Percent EPT (no Caenidae	X	X	X	X	X
Percent Clingers	X				
Percent Filterers			X		
Percent Amphipoda			X		
Number of EPT Taxa	X	X	X	X	X
Percent Plecoptera	X	X	X	X	X
Percent Predators			X		
Percent Sprawler	X (hydrology)				

B.5. PERCENT EPHEMEROPTERA, PLECOPTERA, AND TRICHOPTERA (EPT) (NO CAENIDAE)

Mayflies, stoneflies, and caddisflies are generally considered, as a group, to be intolerant of pollution and stress. Caenidae taxa were subtracted because this family of mayflies is considered to be more tolerant to various stressors as compared to most other EPT. Thus, it could have skewed this metric. A decrease in percent EPT generally is viewed as evidence for an increase in stressors. Many specific stressors, such as decrease in ambient DO concentration; increase in temperature; decrease in stable, suitable and/or diverse habitats; and increase in sediment deposition have been shown to result in elimination of EPT taxa. In addition, alterations to natural food resources, increase in nutrient concentrations, increase in toxic substances, and increase in organic enrichment have been found to alter the community structure and composition of EPT. Elucidation of a specific cause based on a decrease in this metric is difficult because EPT respond to many stressors.

B.6. PERCENT CLINGERS

Clinging organisms rely on structure and physical habitat, so a decrease in this metric suggests a decrease in available structure and habitat. The relatively low clinger abundance suggests that a decrease in stable, suitable, and diverse habitats may be a cause of impairment. However, due to the slight differences seen, the evidence is not strong.

B.7. PERCENT FILTERERS

The percentage of filter-feeding organisms in moderate-sized streams typically is on the order of 20−50%. The natural variability of feeding group metrics is not well understood. Thus, only extreme variances from LD conditions and levels at comparison sites should be considered. Changes in the relative abundance of filterers suggest that an alteration of food resources may be a contributing cause of impairment in Bogue Homo; however, the evidence is not consistent or strong.

B.8. PERCENT AMPHIPODA

Streams characterized by a large number of Amphipods can be the result of multiple factors, including decreased predation (fewer predators or increased cover for predator avoidance) and a shift in food resource. Most often, the food resource of amphipods is detritus material—fine particulate organic matter or coarse particulate organic matter. A larger number of amphipods could indicate a relative increase in the abundance of detritus that they can use as food. Amphipods can withstand elevated levels of chloride. Thus, elevated salinity may be a contributing factor to impairment of Bogue Homo.

B.9. NUMBER OF EPT TAXA

Most mayflies, stoneflies, and caddisflies are considered to be relatively intolerant of pollution and stress. Low taxa richness could suggest a decrease in stable, suitable, and diverse habitats, a decrease in DO concentration, increased temperature, and/or altered food resource. However, elucidation of a specific cause in a decrease in this metric is difficult.

B.10. PERCENT PLECOPTERA

As a group, stonefly taxa generally are thought to be relatively intolerant of pollution, compared to most other families of benthic macroinvertebrates. Stoneflies depend on swift, cool waters for high concentrations of DO and cool temperatures. Along a gradient of stress, stoneflies are usually the first to drop out of the community make-up. Thus, a decrease in this metric suggests possible reductions in DO or water velocity, or increases in temperature. The percent of Plecoptera from the Bogue Homo sample suggests that there has been a decrease in stable, suitable, and diverse habitats; a decrease in DO concentration; altered food resources; and/or increased temperatures. However, the differences seen are small; therefore, evidence is weak.

B.11. PERCENT PREDATORS

The response of this metric to stress is variable. In general, however, the percent of predators within a benthic macroinvertebrate community from a small to medium sized least degraded stream is between 10 and 20% (Davis and Simon, 1995). This relatively high abundance suggests a possible altered food resource as a contributing cause of impairment of Bogue Homo.

B.12. PERCENT SPRAWLERS

An increase in the proportion of sprawlers suggests a decrease in water velocity (i.e., an increase in the amount of stagnant area and depositional zone of a stream). Their high relative abundance in Bogue Homo suggests a decrease in water velocity in many habitats found there.

APPENDIX C

PEARSON CORRELATION COEFFICIENT MATRIX

TABLE C-1

Pearson Correlation Coefficient Matrix of Biological Metrics with Physical and Chemical Indicators

	M-BISQ Score	Shannon Diversity Index	% Amphipoda	% Bivalves	% Chironomidae	% Coleoptera	% Crustaceans and Molluscans	% Dipterans	% Gastropoda	% Isopods	% Non-insects	% Odonata	% Oligocaheta	Ratio of Orthocladinae to Chironomidae	% Plecoptera	% Tanytarsini	Ratio of Tanytarsini to Chironomidae	% Trichoptera	% Caenidae	% EPT (No Caendiae)	% Ephemeroptera No Caenidae
Turbidity (log, NTU)	-0.57	-0.06	0.35	0.42	-0.26	0.23	0.46	-0.19	0.13	0.30	0.44	-0.18	0.20	0.10	0.09	-0.28	-0.35	-0.39	-0.01	-0.40	-0.35
Dissolved Oxygen (percent saturation)	0.16	-0.11	0.10	-0.22	-0.15	-0.04	-0.02	-0.14	0.02	-0.04	-0.08	0.04	-0.16	-0.03	0.22	-0.09	-0.04	0.11	0.14	0.25	0.19
pH	0.02	-0.25	0.11	-0.06	-0.27	-0.02	0.09	-0.12	0.03	0.19	0.05	-0.08	-0.07	0.11	0.18	0.01	0.10	0.02	0.35	-0.01	-0.09
Total Nitrogen (log+1, mg/l)	-0.46	-0.07	0.34	0.36	-0.30	0.35	0.45	-0.31	0.29	0.28	0.49	0.04	0.34	-0.02	-0.18	-0.20	-0.28	-0.27	-0.18	-0.33	-0.22
Total Phosphorus (log+2, mg/l)	-0.36	-0.13	0.25	0.27	-0.34	0.27	0.30	-0.28	0.14	0.15	0.30	0.09	0.15	0.24	-0.02	-0.23	-0.26	-0.14	-0.06	-0.14	-0.10
Chemical Oxygen Demand (log, mg/l)	-0.50	-0.15	0.38	0.28	-0.23	0.10	0.38	-0.10	0.27	0.10	0.41	-0.25	0.31	0.09	-0.09	-0.28	-0.36	-0.29	-0.15	-0.36	-0.28
Total Organic Carbon (log, mg/l)	-0.58	-0.19	0.37	0.36	-0.21	0.14	0.45	-0.10	0.27	0.26	0.44	-0.15	0.21	0.12	-0.05	-0.23	-0.32	-0.47	-0.06	-0.48	-0.36
Total Chlorides (log, mg/l)	-0.24	-0.36	0.04	0.02	-0.24	-0.07	0.03	0.02	-0.09	0.00	0.06	-0.03	0.11	0.21	0.00	-0.02	0.10	-0.24	0.46	-0.26	-0.21
Total Dissolved Solids (log, mg/l)	-0.30	-0.44	0.05	0.15	-0.30	0.01	0.05	0.03	0.07	-0.09	0.08	-0.04	0.11	0.23	0.01	-0.05	0.05	-0.29	0.46	-0.32	-0.27
Total Habitat Score	0.27	0.28	-0.03	0.22	-0.06	0.14	0.02	-0.19	0.09	-0.09	-0.03	-0.01	-0.13	-0.06	0.19	-0.02	0.05	0.18	-0.12	0.28	0.21
Instream Habitat Score	0.34	0.26	-0.09	0.14	0.02	0.10	-0.02	-0.13	0.08	-0.04	-0.08	-0.04	-0.18	-0.06	0.05	0.07	0.16	0.25	-0.06	0.27	0.21
Morphological Habitat Score	0.16	0.19	-0.06	0.30	-0.20	0.12	0.04	-0.19	0.01	-0.03	0.03	-0.09	0.00	-0.05	0.19	-0.06	0.04	0.14	-0.10	0.23	0.16
Riparian Habitat Score	0.17	0.23	0.06	0.10	0.03	0.11	0.03	-0.14	0.12	-0.15	-0.02	0.10	-0.14	-0.04	0.22	-0.04	-0.05	0.07	-0.13	0.20	0.15
% silt/clay	-0.39	-0.10	0.05	0.38	-0.29	0.08	0.37	-0.25	0.09	0.51	0.44	-0.05	0.42	0.15	-0.16	-0.25	-0.23	-0.17	0.10	-0.32	-0.27
% sand	-0.11	0.06	0.13	-0.19	0.32	0.04	-0.12	0.26	-0.07	-0.28	-0.14	0.10	-0.13	-0.14	-0.24	0.18	0.04	-0.15	0.08	-0.25	-0.15
% hardpan clay	0.19	-0.07	-0.06	0.09	-0.12	-0.11	-0.07	0.03	-0.15	-0.07	-0.12	-0.10	-0.19	-0.03	0.65	-0.04	0.08	0.14	0.01	0.20	-0.05
% gravel	0.53	0.07	-0.20	-0.23	-0.03	-0.08	-0.26	-0.08	0.06	-0.21	-0.31	-0.01	-0.28	0.02	0.15	0.10	0.23	0.39	-0.22	0.65	0.59

TABLE C-1 cont.

	Beck's BI	Hilsenhoff Biotic Index	North Carolina Biotic Index	% Dominant Taxa	Ratio of Baetidae to Ephemeroptera	Ratio of Hydropsychidae to EPT	Ratio of Hydropsychidae to Trichoptera	% Intolerant	% Tolerant	# Total taxa	# EPT taxa	# Ephemeroptera taxa	# Plecoptera taxa	# Trichoptera taxa	# Diptera taxa	# Chironomidae taxa	# Orthocladinae taxa	# Tanytarsini taxa	# Coleoptera taxa	# Crustacean and Molluscan taxa	# Oligochaeta taxa
Turbidity (log, NTU)	-0.51	0.51	0.32	0.02	0.03	-0.13	-0.15	-0.38	0.44	-0.13	-0.42	-0.28	-0.32	-0.41	-0.03	-0.09	-0.24	-0.30	-0.02	0.33	0.21
Dissolved Oxygen (percent saturation)	0.17	-0.14	-0.22	0.10	0.07	0.12	0.17	0.14	-0.14	-0.03	0.23	0.17	0.40	0.05	-0.04	-0.08	0.29	-0.03	-0.05	-0.15	-0.19
pH	-0.20	0.25	0.06	0.28	-0.08	0.14	0.20	-0.20	0.15	-0.12	0.09	0.01	0.33	-0.04	-0.22	-0.23	-0.01	-0.06	0.02	-0.05	0.00
Total Nitrogen (log+1, mg/l)	-0.39	0.32	0.33	0.07	-0.23	-0.28	-0.22	-0.36	0.26	-0.06	-0.36	-0.23	-0.41	-0.28	-0.18	-0.25	-0.39	-0.37	0.25	0.41	0.32
Total Phosphorus (log+2, mg/l)	-0.30	0.38	0.34	0.10	-0.12	-0.14	-0.10	-0.27	0.37	-0.16	-0.20	-0.21	-0.09	-0.15	-0.33	-0.37	-0.31	-0.39	0.08	0.25	0.09
Chemical Oxygen Demand (log, mg/l)	-0.38	0.28	0.30	0.11	-0.18	-0.21	-0.18	-0.27	0.28	-0.22	-0.52	-0.41	-0.38	-0.43	0.02	-0.09	-0.19	-0.38	-0.12	0.31	0.28
Total Organic Carbon (log, mg/l)	-0.39	0.40	0.30	0.15	-0.19	-0.36	-0.39	-0.42	0.29	-0.27	-0.53	-0.43	-0.33	-0.46	-0.16	-0.24	-0.23	-0.42	-0.09	0.41	0.17
Total Chlorides (log, mg/l)	-0.22	0.39	0.28	0.32	-0.17	-0.24	-0.15	-0.34	0.40	-0.35	-0.09	-0.18	0.18	-0.10	-0.50	-0.48	-0.34	-0.35	-0.10	0.08	0.03
Total Dissolved Solids (log, mg/l)	-0.33	0.46	0.36	0.39	-0.16	-0.23	-0.12	-0.42	0.48	-0.42	-0.19	-0.25	0.11	-0.21	-0.50	-0.48	-0.25	-0.36	-0.13	0.08	0.02
Total Habitat Score	0.41	-0.26	-0.19	-0.27	-0.26	-0.19	-0.19	0.31	-0.15	0.23	0.27	0.24	0.16	0.22	0.10	0.08	0.03	0.14	0.20	0.00	-0.02
Instream Habitat Score	0.42	-0.30	-0.20	-0.25	-0.23	-0.15	-0.14	0.29	-0.21	0.25	0.25	0.23	0.13	0.21	0.16	0.14	0.05	0.26	0.28	-0.05	-0.05
Morphological Habitat Score	0.22	-0.15	-0.18	-0.21	-0.23	-0.20	-0.17	0.17	-0.03	0.11	0.22	0.20	0.13	0.18	-0.08	-0.11	-0.17	-0.06	0.23	0.00	0.08
Riparian Habitat Score	0.38	-0.19	-0.09	-0.22	-0.17	-0.13	-0.15	0.31	-0.13	0.20	0.19	0.16	0.12	0.15	0.16	0.17	0.20	0.15	0.00	0.05	-0.08
% silt/clay	-0.32	0.47	0.39	0.08	-0.13	-0.20	-0.24	-0.25	0.50	-0.11	-0.31	-0.28	-0.18	-0.26	-0.20	-0.21	-0.26	-0.28	0.06	0.32	0.37
% sand	0.05	0.03	0.11	-0.05	0.12	0.03	-0.03	-0.18	-0.11	0.11	0.00	-0.01	-0.11	0.08	0.21	0.18	0.08	0.12	-0.13	-0.06	-0.11
% hardpan clay	0.04	-0.03	-0.18	0.09	-0.07	0.10	0.09	-0.08	-0.11	-0.03	0.10	0.03	0.29	-0.01	-0.06	-0.08	0.16	-0.03	0.01	-0.04	-0.01
% gravel	0.30	-0.59	-0.58	-0.06	0.05	0.20	0.32	0.58	-0.40	0.02	0.36	0.38	0.17	0.24	-0.01	0.05	0.14	0.19	0.15	-0.32	-0.32

TABLE C-1 cont.

	# Collector taxa	# Filterer taxa	# Predator taxa	# Scraper taxa	# Shredder taxa	% Collectors	% Filterers	% Predators	% Scrapers	% Shredders	# Burrower taxa	# Climber taxa	# Clinger taxa	# Sprawler taxa	# Swimmer taxa	% Burrowers	% Climbers	% Clingers	% Sprawlers	% Swimmers
Turbidity (log, NTU)	0.10	-0.36	-0.26	-0.24	0.11	0.34	-0.28	-0.04	-0.23	-0.17	0.23	-0.04	-0.43	-0.07	-0.05	0.21	-0.08	-0.50	-0.04	-0.04
Dissolved Oxygen (percent saturation)	0.01	0.12	-0.06	-0.03	0.02	-0.13	0.04	0.02	0.17	0.11	-0.01	-0.22	0.20	-0.02	-0.13	-0.42	-0.18	0.22	-0.02	0.08
pH	-0.14	-0.14	-0.18	-0.02	0.11	-0.10	0.26	-0.20	0.01	-0.22	-0.15	-0.08	-0.03	-0.19	-0.11	-0.33	-0.08	0.09	-0.02	-0.06
Total Nitrogen (log+1, mg/l)	0.08	-0.23	-0.07	0.22	-0.10	0.21	-0.22	-0.08	-0.09	-0.18	0.01	-0.03	-0.26	-0.10	0.12	0.02	0.00	-0.33	-0.32	0.00
Total Phosphorus (log+2, mg/l)	-0.13	-0.26	-0.01	-0.09	0.02	0.10	-0.14	-0.01	0.06	-0.22	-0.07	0.09	-0.18	-0.16	0.13	-0.02	0.08	-0.25	-0.07	-0.01
Chemical Oxygen Demand (log, mg/l)	0.08	-0.33	-0.26	-0.07	-0.02	0.32	-0.18	-0.11	-0.18	-0.10	0.11	-0.17	-0.40	0.02	-0.12	0.09	-0.09	-0.39	-0.03	-0.13
Total Organic Carbon (log, mg/l)	-0.07	-0.44	-0.22	-0.24	-0.03	0.20	-0.26	0.02	-0.14	-0.06	0.02	-0.16	-0.51	-0.08	-0.05	-0.01	-0.01	-0.42	0.05	-0.23
Total Chlorides (log, mg/l)	-0.46	-0.31	-0.04	-0.30	-0.15	-0.06	0.19	-0.05	0.01	-0.24	-0.32	-0.17	-0.20	-0.32	-0.03	-0.29	-0.10	0.00	0.26	-0.28
Total Dissolved Solids (log, mg/l)	-0.40	-0.41	-0.20	-0.35	-0.08	-0.05	0.22	-0.12	0.00	-0.27	-0.26	-0.21	-0.29	-0.33	-0.13	-0.29	-0.13	0.00	0.19	-0.31
Total Habitat Score	0.17	0.38	0.07	0.18	0.01	-0.03	-0.02	0.13	0.09	-0.16	-0.15	-0.18	0.35	0.20	0.16	0.04	-0.13	0.05	-0.09	0.12
Instream Habitat Score	0.21	0.43	0.06	0.34	0.03	-0.09	0.03	-0.03	0.16	-0.09	-0.10	-0.15	0.40	0.23	0.09	0.01	-0.12	0.12	-0.06	0.03
Morphological Habitat Score	0.03	0.16	0.01	0.05	0.02	-0.08	0.06	0.12	0.02	-0.23	-0.17	-0.22	0.17	0.09	0.12	-0.06	-0.16	0.05	-0.11	0.08
Riparian Habitat Score	0.18	0.34	0.10	0.08	-0.02	0.07	-0.12	0.23	0.06	-0.07	-0.09	-0.08	0.31	0.17	0.17	0.13	-0.03	-0.04	-0.04	0.18
% silt/clay	-0.10	-0.35	0.01	0.02	0.05	0.18	-0.21	-0.04	-0.14	-0.18	0.04	0.18	-0.31	-0.18	0.01	-0.05	0.20	-0.41	0.08	-0.13
% sand	0.15	-0.02	0.10	-0.09	-0.03	0.14	-0.07	0.03	-0.11	0.25	0.10	-0.02	-0.03	0.21	-0.07	0.19	0.01	0.02	0.09	-0.08
% hardpan clay	0.06	-0.07	-0.10	-0.24	0.23	-0.24	0.21	0.12	-0.11	-0.06	0.00	-0.01	-0.02	-0.02	-0.06	-0.12	-0.08	0.26	-0.15	-0.12
% gravel	-0.11	0.52	-0.10	0.24	-0.15	-0.28	0.26	-0.09	0.39	-0.12	-0.17	-0.22	0.45	-0.04	0.16	-0.13	-0.23	0.36	-0.15	0.33

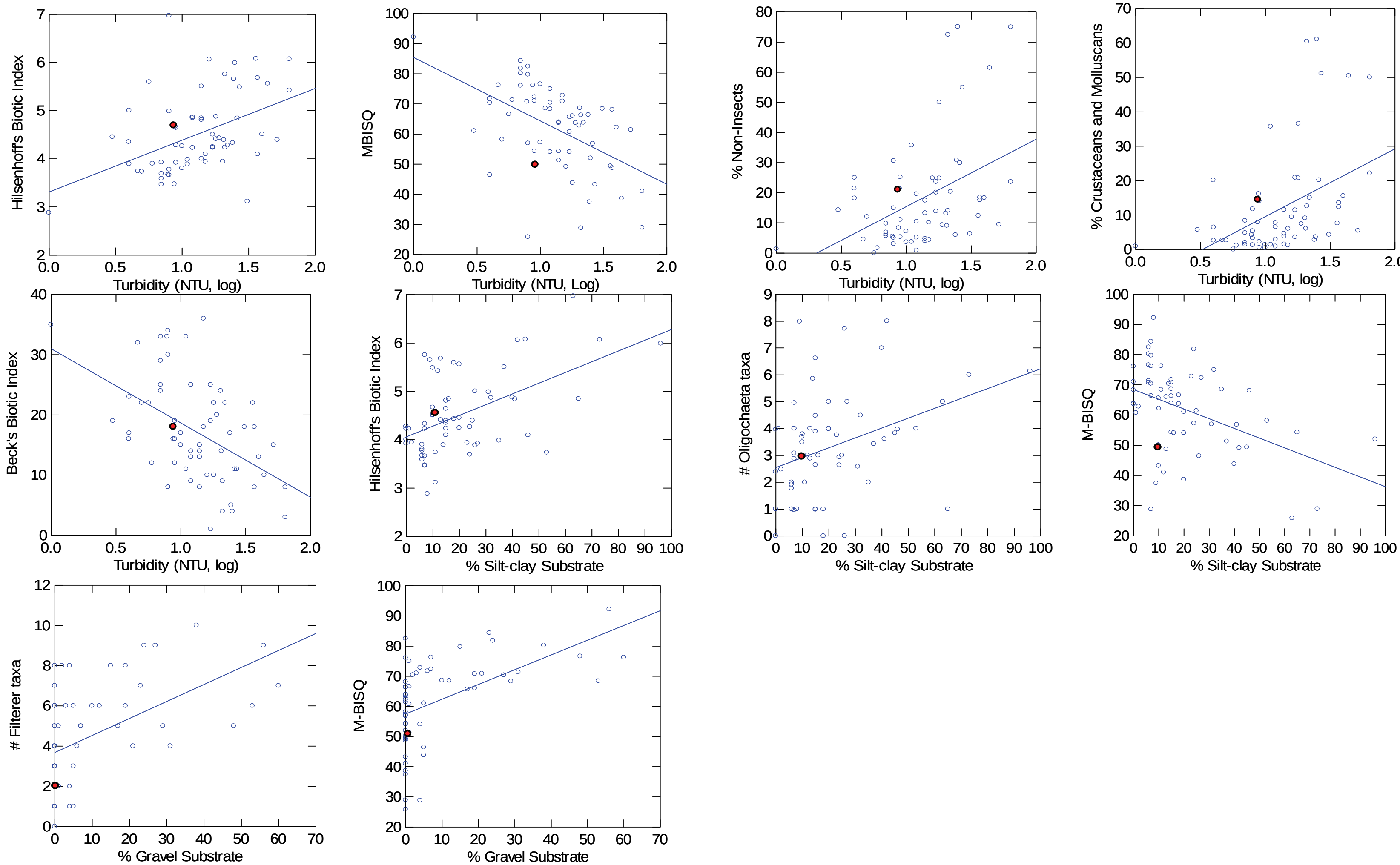
Each correlation is based on 63 observations.

APPENDIX D

STRESSOR-RESPONSE RELATIONSHIPS EXPRESSED AS SCATTER PLOTS OF BIOLOGICAL AND PHYSICAL/CHEMICAL DATA WITH BOGUE HOMO PLOT HIGHLIGHTED

FIGURE D-1

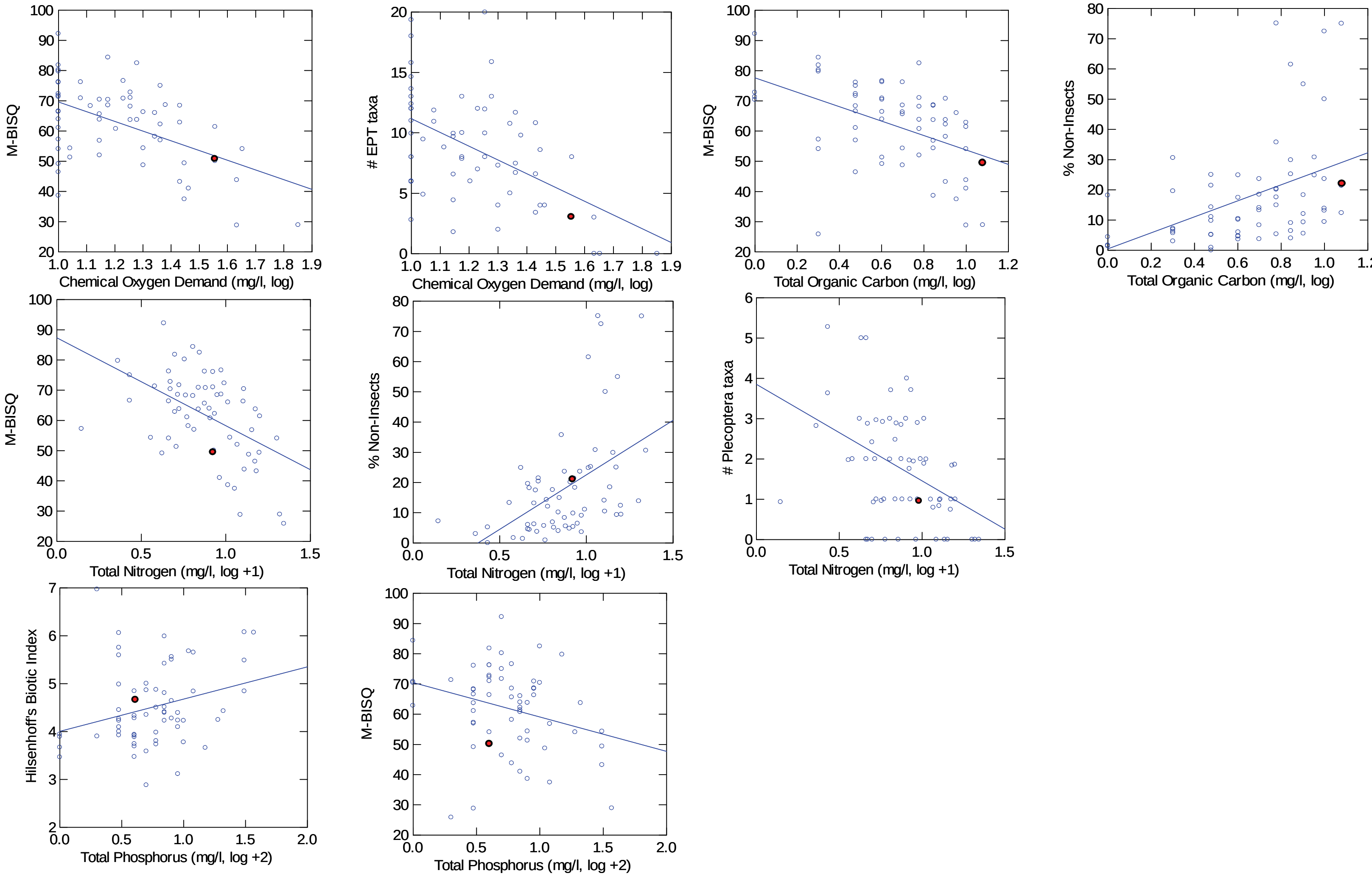
Stressor-Response Relationships, Shown as Scatter plots: Decrease in Suitable Habitat



Bogue Homo is indicated as a red symbol in each plot.

FIGURE D-2

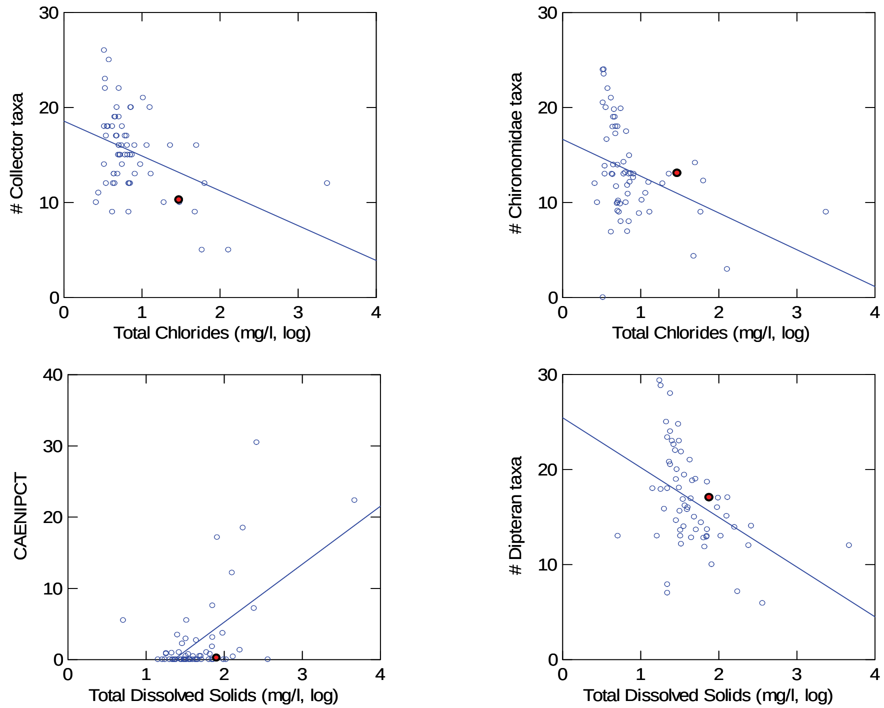
Stressor-Response Relationships, Shown as Scatter plots: Altered Food Resources (Organic Matter) and/or Decreased Dissolved Oxygen



Bogue Homo is indicated as a red symbol in each plot.

FIGURE D-3

Stressor-Response Relationships, Shown as Scatter plots: Increase in Ionic Strength and/or Increase in Toxic Substances



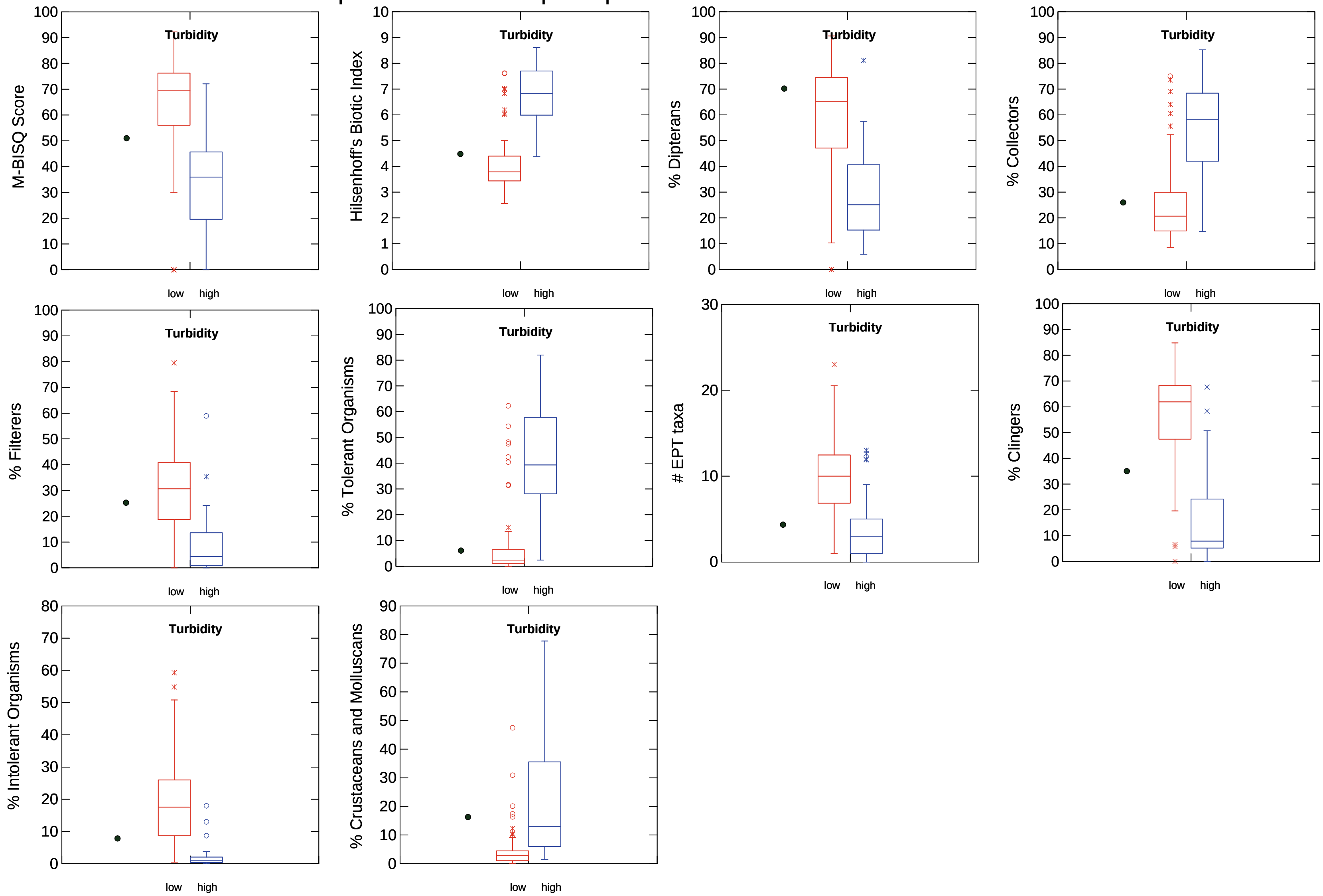
Bogue Homo is indicated as a red symbol in each plot.

APPENDIX E

STRESSOR-RESPONSE RELATIONSHIPS EXPRESSED AS BOX PLOTS OF BIOLOGICAL DATA

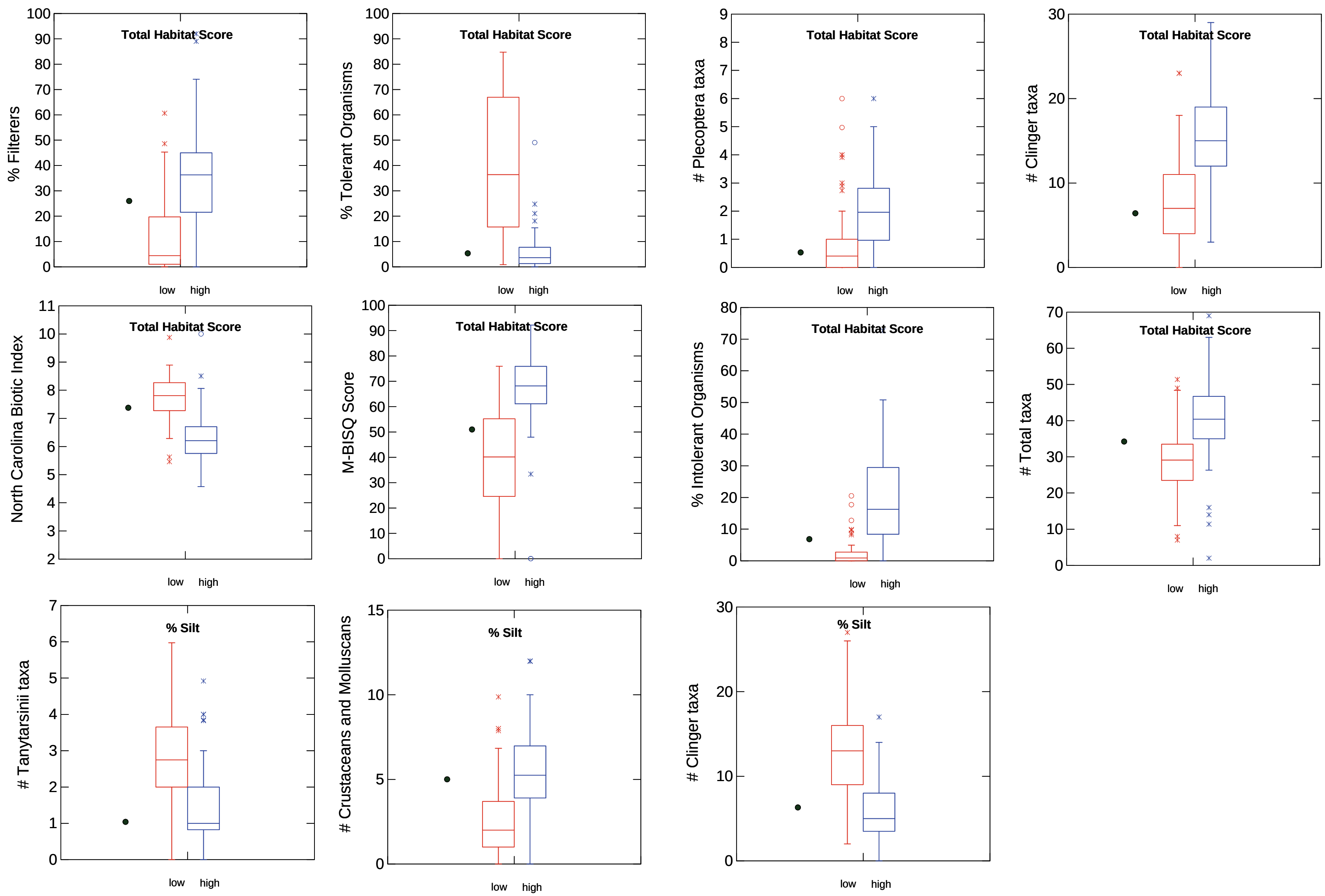
FIGURE E-1

Stressor-Response Relationships Expressed as Box Plots: Decrease in Suitable Habitat



Bogue Homo is represented by the black dot in each plot.

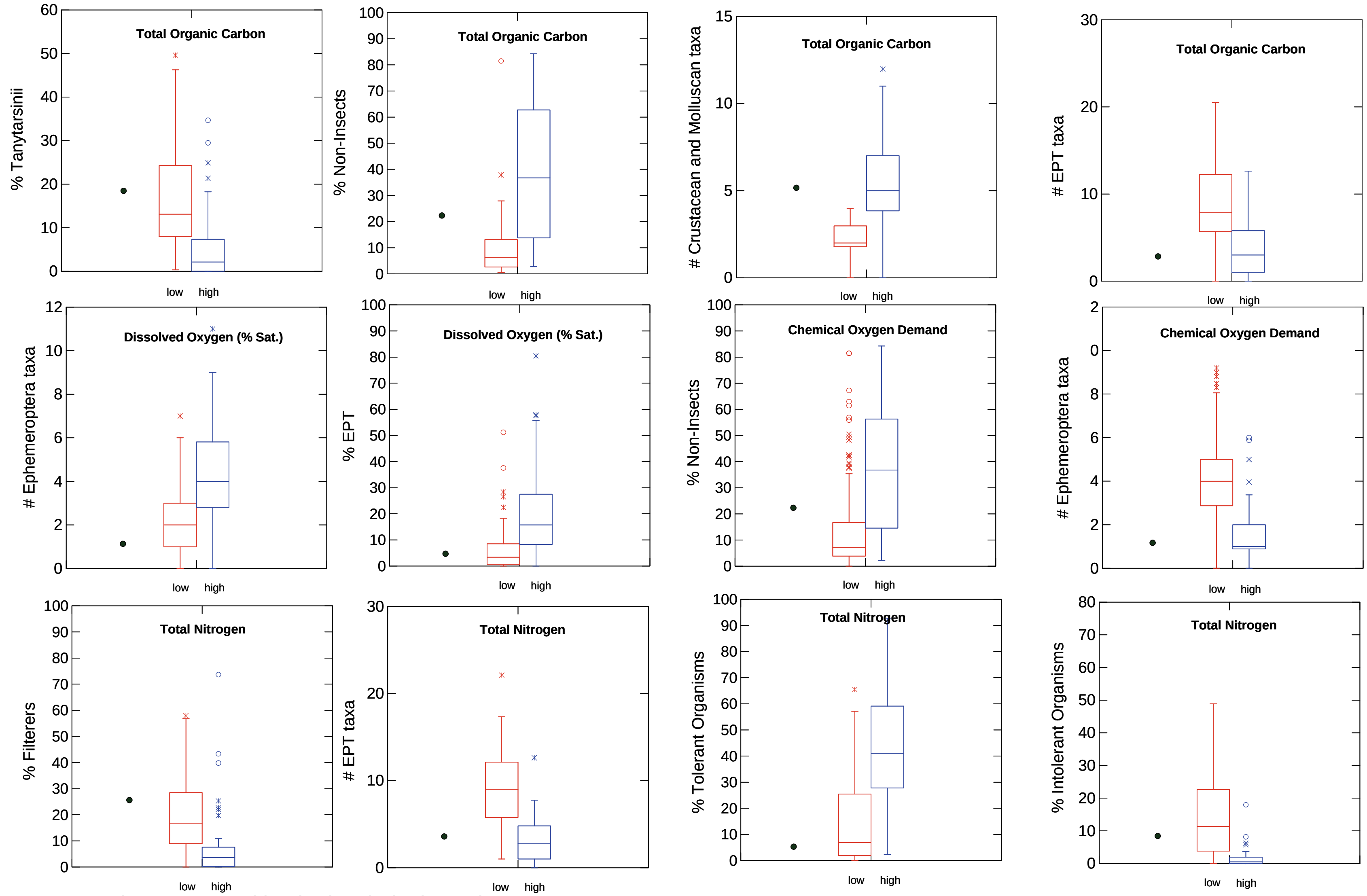
FIGURE E-1 cont.



Bogue Homo is represented by the black dot in each plot.

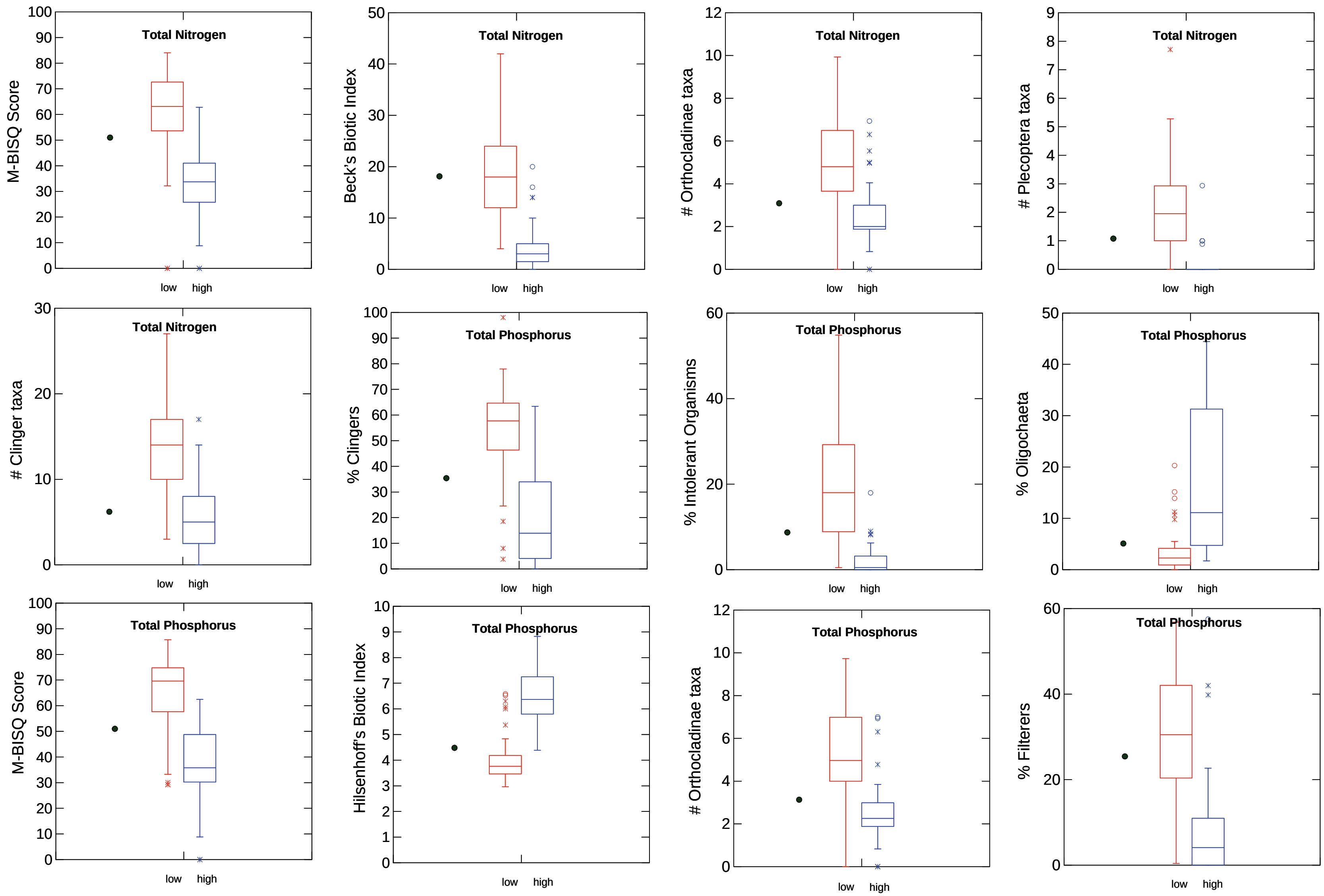
FIGURE E-2

Stressor-Response Relationships Expressed as Box Plots: Altered Food Resources and/or Decreased Dissolved Oxygen



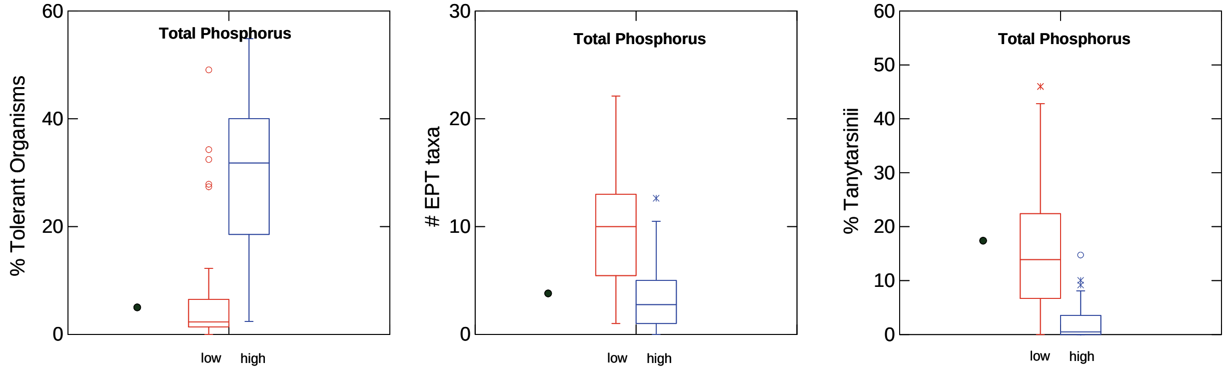
Bogue Homo is represented by the black dot in each plot.

FIGURE E-2 cont.



Bogue Homo is represented by the black dot in each plot.

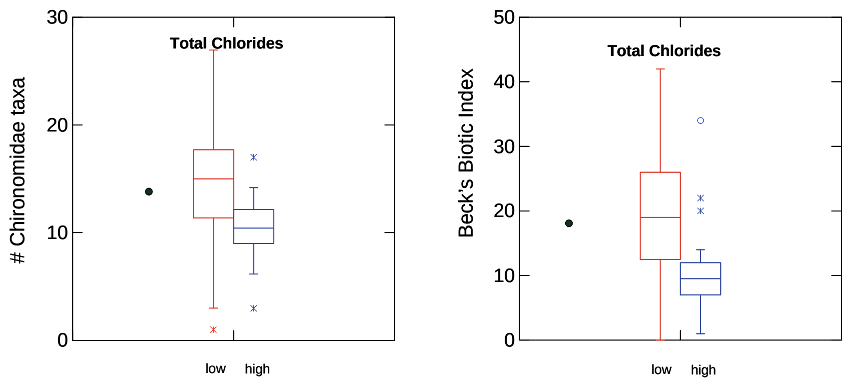
FIGURE E-2 cont.



Bogue Homo is represented by the black dot in each plot.

FIGURE E-3

Stressor-Response Relationships Expressed as Box Plots: Increase in Ionic Strength and/or Increase in Toxic Substances



Bogue Homo is represented by the black dot in each plot.