Appendix F

Implementation of a Probabilistic Stream/River Monitoring Sampling network for the State of Oklahoma

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IMPLEMENTATION OF A PROBABILISTIC STREAM/RIVER MONITORING SAMPLING NETWORK FOR THE STATE OF OKLAHOMA

Introduction

It is the intent of this Oklahoma Water Resources Board (OWRB) report to advance concepts and principles of the Oklahoma Comprehensive Water Plan (OCWP). Consistent with the OCWP data needs, this and other OWRB technical studies provide invaluable data crucial to the ongoing management of Oklahoma's water supplies as well as the future use and protection of the state's water resources. Oklahoma's decision-makers rely upon this information to address specific water supply, quality, infrastructure, and related concerns. Maintained by the OWRB and updated every 10 years, the OCWP serves as Oklahoma's official long-term water planning strategy. Recognizing the essential connection between sound science and effective public policy, incorporated in the Water Plan are a broad range of water resource development and protection strategies substantiated by hard data – such as that contained in this report – and supported by Oklahoma citizens.

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

The Environmental Protection Agency (EPA) has released guidance establishing the "10 Required Elements of a State Water Monitoring and Assessment Program" (USEPA, 2005). Among other things, the document states, "a State monitoring program will likely integrate several monitoring designs (e.g., fixed station, intensive and screening-level monitoring, rotating basin, judgmental and probability design) to meet the full range of decision needs. The State monitoring design should include probability-based networks (at the watershed or state-level) that support statistically valid inferences about the condition of all State water types, over time. EPA expects the State to use the most efficient combination of monitoring designs to meet its objectives." Until 2005, Oklahoma had several monitoring programs that met these requirements including the Beneficial Use Monitoring Program (BUMP) and the Rotating Basin Monitoring Program (RBMP) (OWRB, 2009b). Furthermore, the state has developed several programs to intensively monitor areas that have been listed on Oklahoma's 303(d) list of impaired waters (ODEQ, 2008).

In 2001, the State requested assistance with the design of a probabilistic approach to stream and river site selection from the U.S. Environmental Protection Agency, Office of Research and Development (ORD), Western Ecology Division (Olsen, 2001). Funding was provided through a variety of state and federal sources (Table 1). The probability-based survey was designed to assist Oklahoma's water quality managers in several ways. An unequal probability random tessellation stratified (RTS) survey design (Stevens 1997, Stevens and Olsen 2004) was used to select stream sample sites across the state (Olsen, 2001), and was weighted by Strahler stream order categories. For the study, a total of 284 randomly chosen sites were evaluated for candidacy. The survey was a three-year study (2005-2007) with one hundred twenty-six (126) sites sampled (Table 2).

Table 1. Breakdown of yearly funding and activity funded (OWRB, 2005a).

STUDY YEAR	FEDERAL 104(B)3	REMAP	STATE
SY-2005 (1)	$130,118— recon and sampling of 30 sites; supplies and equipment	No Funding	$55,882—the state 5% match to the 104(b)3 ($6,849); recon and sampling of 12 sites; final reports
SY-2006 (2)	No Funding	$180,000—recon and sampling of all 42 sites; project and data management activities; supplies and equipment	$100,000—project and data management
SY-2007 (3)	No Funding	$140,000—recon and sampling of 32 sites; project and data management; portion of final report	$54,000—recon and sampling of 10 sites (Upper Arkansas Planning Basin); project and data management; portion of final report
3 year Total ($660,000)	$130,118	$320,000	$209,882

Table 2. Numbers of sites originally targeted both statewide and within selected basins.

STUDY YEAR (SY)	GEOGRAPHIC SCALE	# SITES SAMPLED
SY-2005 (1)	Lower Red River	27
	Statewide Stations	15
SY-2006 (2)	Grand-Neosho River	15
	Upper North Canadian River	5
	Upper Canadian River	7
	Statewide Stations	15
SY-2007 (3)	Upper Arkansas River	10
	Lower Canadian River	6
	Cimarron River	11
	Statewide Stations	15
SY-2005-7	Total Stations	126

The current assessment allows Oklahoma to make a statistically valid assessment of the condition of all of Oklahoma's streams/rivers, as required under Section 305(b) of the Clean Water Act (CWA) (ODEQ, 2008). This sample size allows for a statewide as well as a regional estimate of fish, macroinvertebrate, and algal condition. Additionally, extent is evaluated for a number of potential environmental stressors at both the statewide and regional level. Lastly, under the guidelines of the Integrated Listing Methodology (ODEQ, 2006), data allow for the assessment of the Fish & Wildlife Propagation beneficial use on more waters of the state. Future work may allow for more comprehensive 303(d) assessments so that the support status of probabilistic sites may be fully vetted. Furthermore, the survey provides information that will allow for better long- and short-range planning and resource allocation. A benefit of probabilistic design is that data results can be applied

in a much broader context. For example, the relationship of condition can be associated with stressor extent through methodologies like relative risk analysis. The current study yields a wealth of biological, chemical, and physical data across a broad gradient of environmental conditions, supporting evaluation of these indicator relationships. Data can be used to calibrate existing biocriteria ranges, establish reference condition, and assist in nutrient criteria development. When integrated with fixed-station networks, it will assist in identifying local areas of concern. Also, although not accomplished by this report, landscape metrics can be associated with stressors and condition to develop predictive models. Third, probabilistic data will assist in efforts to regionalize environmental concerns. A bottom up approach to management identifies not only statewide issues but allows managers to identify local and regional concerns first, which often lead to issues farther down the watershed, and put resources where they are needed. The probabilistic methodology adds a valuable layer to that management approach.

In keeping with the environmental goals of the state as outlined in the OCWP, an effective long-term management strategy based on sound science and defensible data can be developed using this data. The four over-arching goals of the study were:

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

Study Design

The study was multi-faceted in that estimates were generated at both a statewide level and in three sub-state ecoregional groupings. To create the sub-state areas, Omernik Level III ecoregions were grouped based upon proximity. Several considerations were given when making these groupings. Foremost, water quality should be similar and habitat should not be greatly divergent. Secondly, groupings should be supported by some previously published sources such as Omernik Level II ecoregions. The final regional groupings are presented in Figure 1. They include the Western Plains/Tablelands, Temperate Forests, and Forested Plains/Flint Hills.

Figure 1 . Ecoregion groupings used for regional assessment of sites.

The study was spatially, temporally and hydrologically limited. Spatially, the study excluded all flowing waterbodies receiving major hydrological influence from oxbow lakes because of a lack of developed biological collection protocols. In southeastern Oklahoma, the lower Red River below its confluence with the Kiamichi River and the Little River below its confluence with the Mountain Fork River were excluded. In northeastern and east-central Oklahoma, the McClellan-Kerr Navigational System was excluded below its confluence with the Caney River, encompassing large portions of the lower Verdigris River and Arkansas River as they flow through the state. Temporal limitations were defined by biological index periods. The index period for the fish assemblage in Oklahoma was May 15th through September 15th with an optional extension to October 1st if the stream had not risen above summer seasonal base flow (OWRB, 2004). The index habitat period for the macroinvertebrate assemblage in Oklahoma was June 1st through August 30th with collections completed in as short a time period as possible (OWRB, 2006c). Hydrologically, the study was limited by both an extended drought in SY-2005 as well as excessive rains and flooding in SY-2006-2007. This impeded study progress in several ways. Sites originally verified as target sites were removed and an oversample site visited because of site changes between the period of reconnaissance and sampling. Additionally, several sites had partial collections because conditions changed between the period of macroinvertebrate/water sampling and fish sampling, or vice-versa. To assess ecological and human health, one-time collections were made for a variety of biological, chemical, and physical parameters. All target sites were visited once during a late spring to late summer index period. Variables outlined in Table 4 were collected at each site.

Table 3. Water quality variables included in study.

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

Data Analysis

For data analysis, sites were grouped statewide as well as by Omernik Level III ecoregions based upon proximity to produce estimates. A total of 284 randomly chosen sites were evaluated for candidacy representing a total of 34,379 stream miles. Using pie charts, results are illustrated for statewide and regional extent in Figure 2. Stream miles determined to be target, or sampleable, totaled 14,284 miles statewide (42%, +/- 6%). Regionally, the total stream miles assessed break out as follows: 4,846 of 10,544 total miles in the Forested Plains (46%, +/-12%), 4,411 of 10,569 total miles in the Temperate Forests (42%, +/-9%), and 5,027 of 13,276 total miles in the Western Plains (38%, +/-9%). Stream miles that did not meet the target criteria were divided into two categories—non-sampleable and no access. The non-sampleable stream length totaled 6,556 miles (19% +/-11%) and were divided into four sub-categories—dry channel (4,308 miles), impounded (1,026 miles), temporary/persistent flooding conditions (1,103 miles), and wetland (and 119 miles). Stream length with no access equaled 13,540 (39%, +/-7%), which was nearly equivalent to the totaled sampled length. Reasons for lack of access varied but can be divided into three general sub-categories—access permission denied (13,169 miles), physical barrier to access (231 miles), and no existing protocols (140 miles). The last category was for extremely large rivers (e.g., the Arkansas River portion of the McClellan-Kerr Navigational System) where attempting to apply rapid bioassessment protocols was neither feasible nor practical.

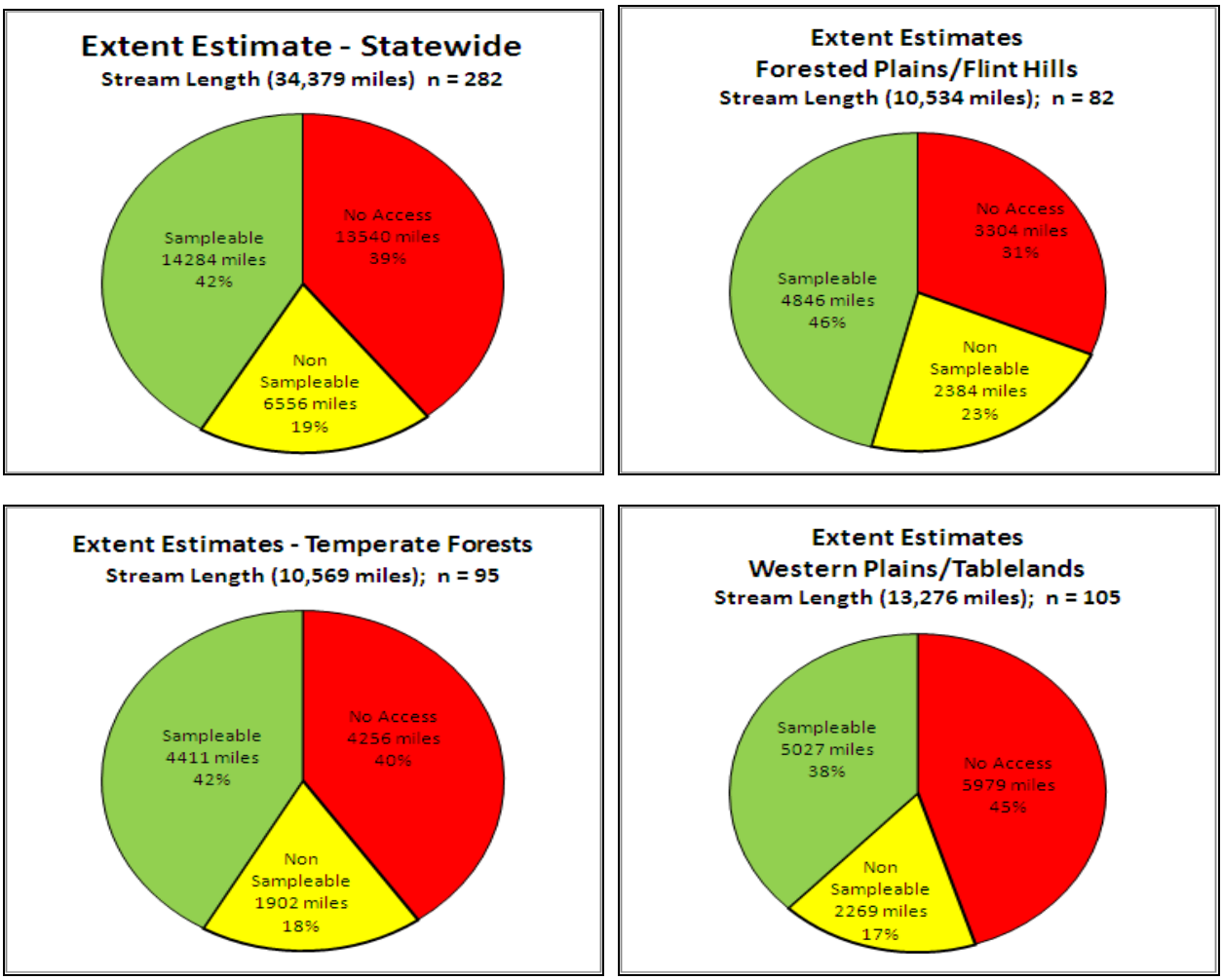

Figure 2. Statewide extent estimates representing considered and sampled stream miles.

Fish data were analyzed using two indices of biological integrity (IBI) commonly used in Oklahoma bioassessment studies—the OKFIBI and the OCCFIBI. Oklahoma's biocriteria methodology (OKFIBI) uses a common set of metrics throughout the state (Table 5). Each metric is scored a 5, 3, or 1 depending on the calculated value, and scores are summed to reach two subcategory totals for sample composition and fish condition (OWRB, 2008b). The two subcategories are then summed for a final IBI score. The score is compared to ecoregion biocriteria to determine support status. The OCCFIBI uses "a modified version of Karr's Index of Biotic Integrity (IBI) as adapted from Plafkin et al., 1989" (OCC, 2008). Metric scores are calculated in two ways for both the test site and composite reference metric values of high-quality streams in the ecoregion (OCC 2005). The OKFIBI estimated that nearly half of the state has a supporting fish condition over 47% (+/-8%) of the target population, 7% of the population is not supporting, while 28% are undetermined (Figure 3). An additional 16% of the population is lacking adequate biocriteria to determine condition. Conversely, the OCCFIBI estimates an excellent/good condition for 54% (+/- 8%) of the population, while 16% is in poor/very poor and 27% in fair condition (Figure 4).

Macroinvertebrate data were analyzed using a Benthic-IBI (B-IBI) developed for Oklahoma benthic communities (OCC, 2005a) and commonly used by the OCC and OWRB Water Quality Divisions (OCC, 2008; OWRB, 2009a). The metrics and scoring criteria are taken from the original "Rapid Bioassessment Protocols for Use in Streams and Rivers" (Plafkin et al., 1989). Metric scores are calculated in two ways for both the test site and the composite reference metric values of high-quality streams in each ecoregion (OCC, 2008). Macroinvertebrate taxonomic results for each site were analyzed to produce a percent of reference score for the OKBIBI. The OKBIBI estimates that 50% (+/-8%) of the population has a supporting macroinvertebrate condition and that 27% and 17% of the population is either slightly or moderately impaired, respectively (Figure 5).

To estimate condition of algal biomass, chlorophyll-a concentrations were compared to multiple screening levels. For benthic chlorophyll-a, several screening levels were used including: 1) 100 mg/m^2 which is a nuisance level (BenUSAPSL), and 2) 45.7 mg/m^2 representing the 25th percentile of all OWRB benthic data (BenP25). Similarly, three screening levels were established for sestonic chlorophyll-a including: 1)10 mg/m^3 which is the water quality standard for sensitive water supplies (SesChl10), 2) 25 mg/m^3 representing the value necessary to calculate a threshold trophic state index (TSI) of 62 (SesChl25), and 3) 19 mg/m^3, which is the mean of all OWRB sestonic chlorophyll data (SesChlMean). For both benthic and sestonic populations, the greater majority of sites are not exceeding any screening limit, approximately 65-66% (+/-8%) statewide. For the benthic population, the BenP25 is exceeded at a rate nearly twice that of the BenUSAPSL. The nuisance screening level is exceeded nearly 14% of the time, while the 25th percentile exceeds an estimated 29% of the time. For the sestonic screening limits, statewide estimated exceedances range from 15% to 35% (Figure 6).

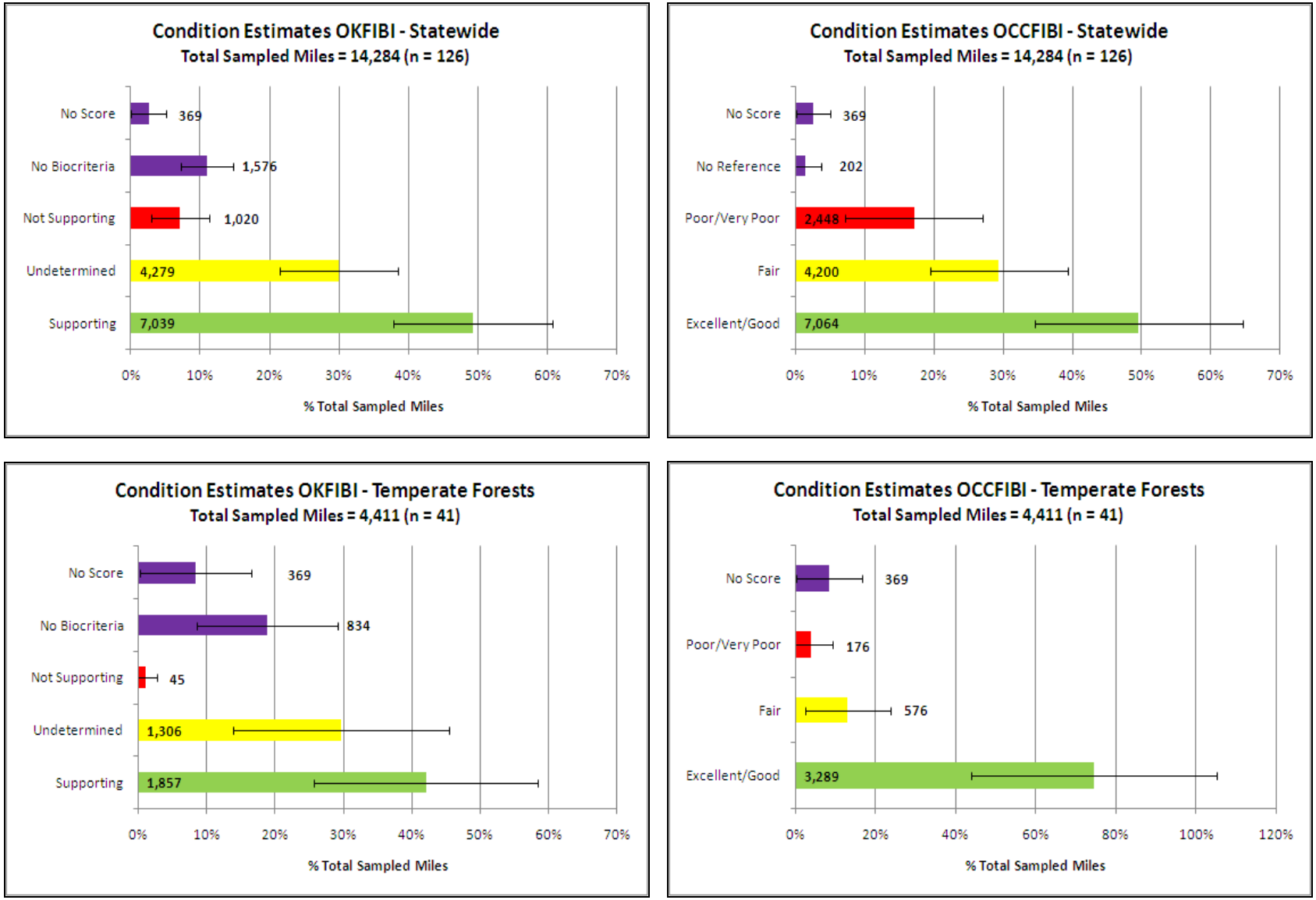

Figure 3. Fish condition estimated statewide and in the Temperate Forests region using the OKFIBI and OCCFIBI. (Label represents total sampled miles in particular category).

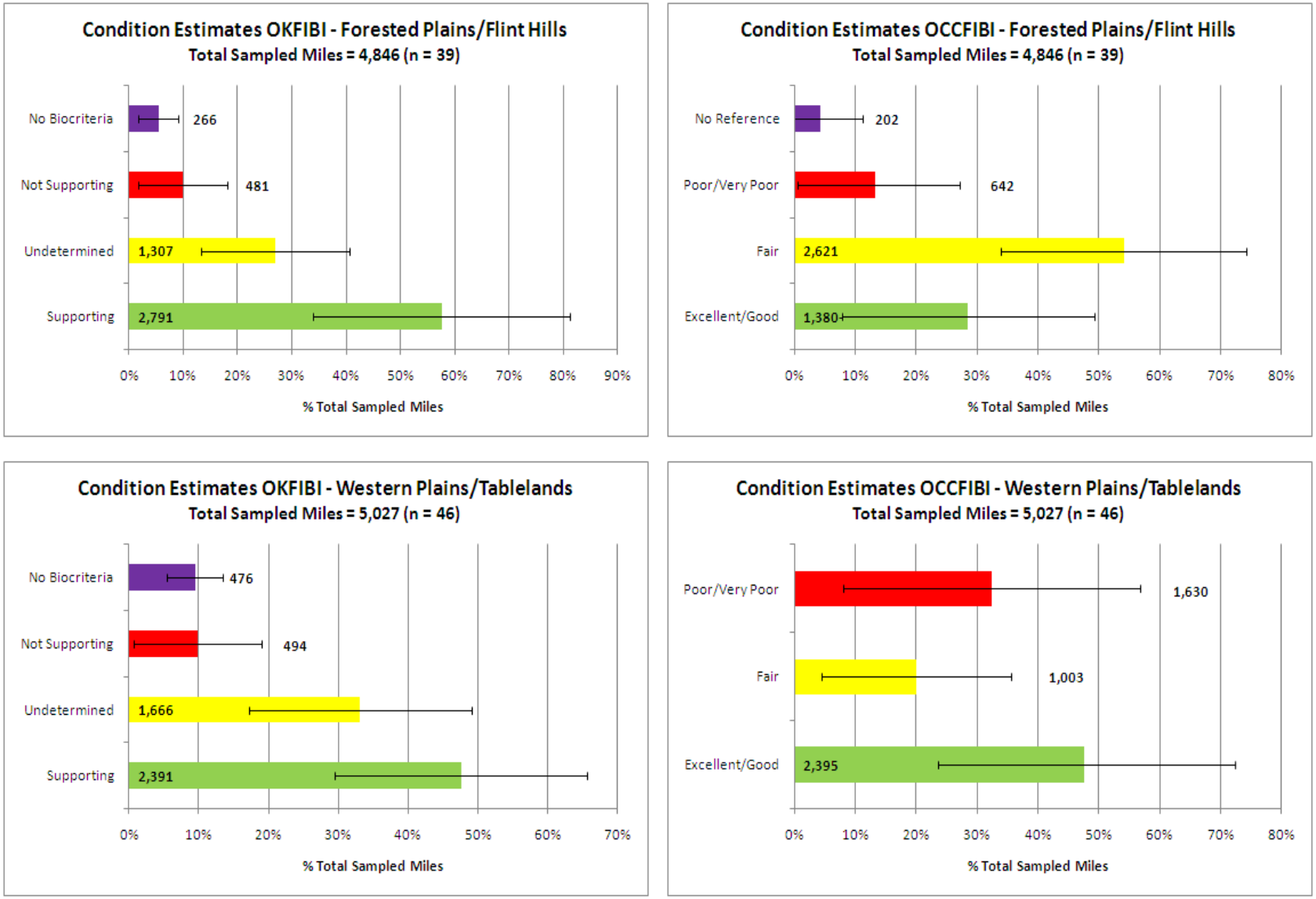

Figure 4. Fish condition estimated in the Forested Plains/Flint Hills and Western Plains/Tablelands. (Label represents total sampled miles in particular category).

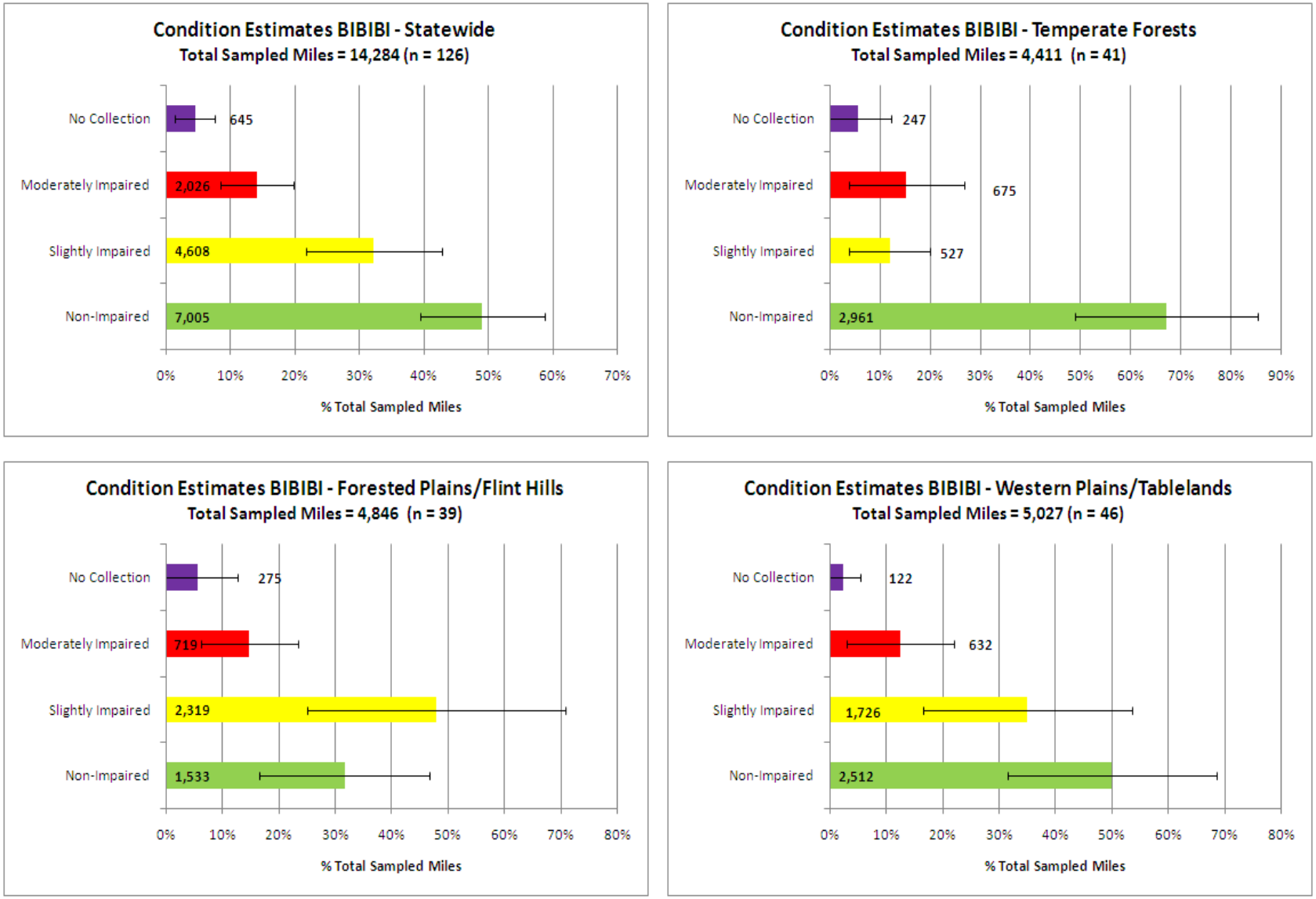

Figure 5. Macroinvertebrate condition estimated Statewide and in the Temperate Forests, Forested Plains/Flint Hills, and Western Plains/Tablelands using OKBIBI. (Label represents total sampled miles in particular category).

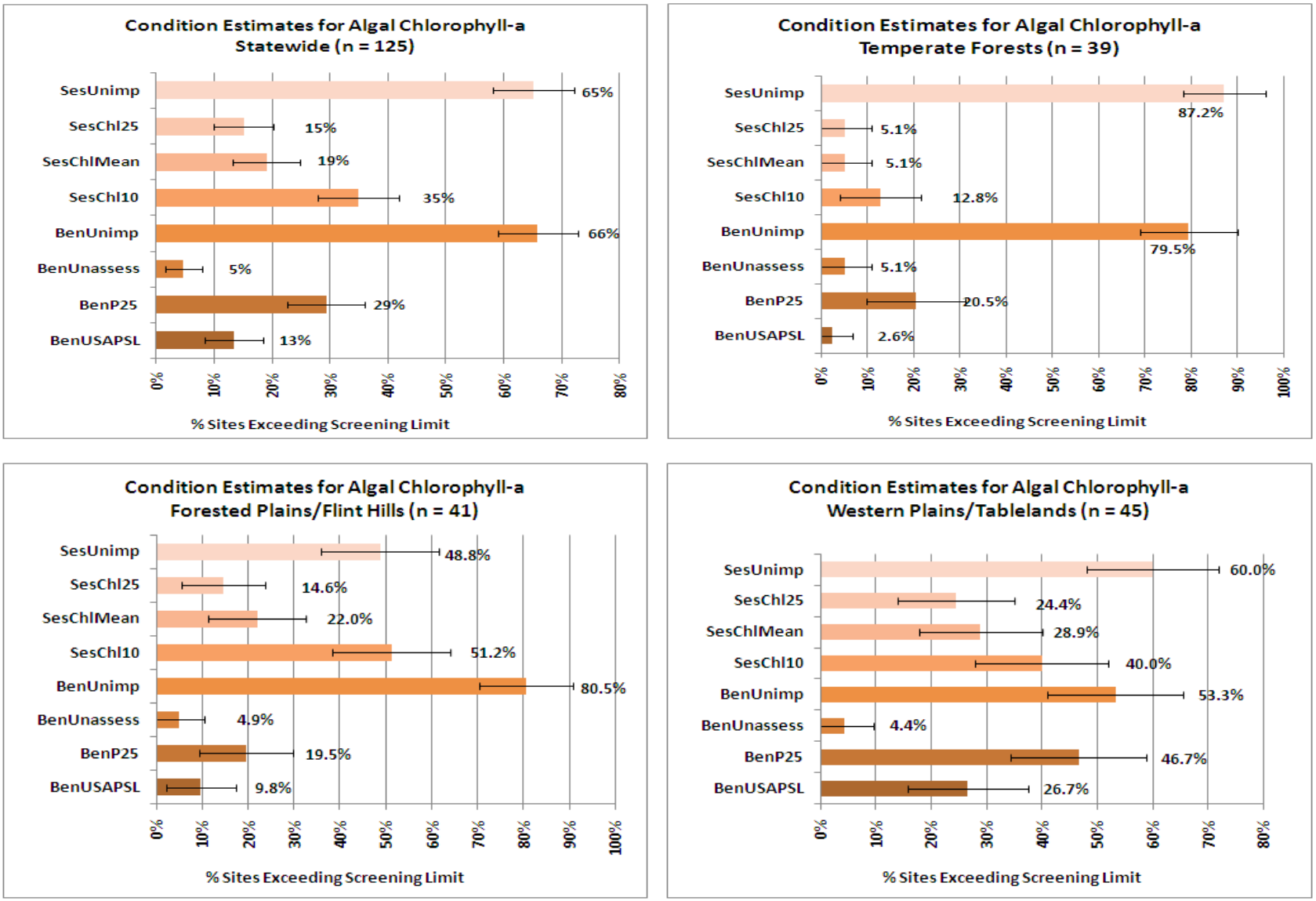

Figure 6. Algal chlorophyll-a condition estimated for all geographic scales. Upper and lower bounds represent a 90% confidence interval. (Refer to Table 10 for stressor descriptions.)

Conclusions

This report marks Oklahoma's first attempt at making a statistically based assessment of the condition of Oklahoma's waters. The study benefits this report in several ways. First, this study marks Oklahoma's first attempt at making a statistically based assessment of the condition of Oklahoma's waters. The OWRB recommends that the study and conclusions be adopted into the 305(b) section of Oklahoma's Integrated Water Quality Report. Included graphics and tables can be used to show overall statewide and regional condition. Second, individual waterbodies not yet included in Oklahoma's Integrated Water Quality Report now have some level of assessment.

The concept of using relative risk to develop a relationship between biological condition and stressor extent was developed initially for the USEPA's National Wadeable Streams Assessment (USEPA, 2006) by Van Sickle et al. (2006). The method calculates a ratio between the number of streams with poor biological condition/high stressor concentration and those with poor biological condition/low stressor concentration. A variety of stressors were used to determine stressor extent and calculate relative risk. Nutrient stressors include measures total phosphorus, total nitrogen (nitrate + nitrite + total Kjeldahl nitrogen), and available nitrogen (nitrate + nitrite + ammonia). General water quality stressors represent a diverse group of parameters—*in situ* and salinity-related parameters *In situ* parameters include pH, dissolved oxygen, turbidity, and water temperature. Salinity-related parameters include conductivity, chloride, sulfate, and total dissolved solids (TDS). Metals were used in stressor studies to provide insight into stressors related to biological condition as well as those related human health beneficial uses—public/private water supply and fish consumption. Habitat stressors include total habitat score, several individual habitat metrics, and an index for sedimentation Relative risk was determined for fish, macroinvertebrate, and algal condition. The relative risk analysis produced widely variable results depending upon both condition and stressor and has implications for criteria development, not only at the stressor level, but for biological condition as well.

Conclusions based on analysis are: 1) regional reference condition needs to be refined across all Omernik Level III ecoregions to include many Omernik Level IV ecoregions, 2) effective nutrient criteria will lie somewhere between regional screening levels and those in Oklahoma rule, 3) macroinvertebrates tend to respond in a more predictable fashion to water quality stressors than do fish, 4) sestonic algal condition is more easily predicted by nutrient concentrations than benthic algal condition, 5) application of naturally occurring condition protocols can benefit from relative risk analysis, 6) Oklahoma should explore the use of relative bed stability (RBS) as a measure of sedimentation, and 7) regional nuisance benthic algal screening levels are needed. Additionally, other recommendations can be made from the varied analysis, including: 1) all metals listed in the OWQS (OWRB, 2007a) but not occurring above criteria in ambient monitoring programs should not be monitored further, 2) since most metals occur regionally, a table specifying regional metals of concern should be created, 3) the contact recreation use should be a tiered use much like the aquatic life uses, and 4) refine agriculture criteria to include conductivity as a surrogate for TDS or create a regional criteria for conductivity to use in place of TDS.

In Oklahoma, probabilistic monitoring is an ongoing process. In terms of monitoring, probabilistic design has been completely integrated into both the OWRB and OCC monitoring programs (OWRB, 2009b). The OWRB is currently participating in the National Rivers and Streams Assessment (NRSA) and will use data from it to provide an update to the current report. Also, the third two-year statewide study will begin in winter or summer 2009 and include 50 sites. Substantive changes to the program will include: 1) use of the NRSA protocols for large wadeable and non-wadeable waterbodies, 2) use of NRSA habitat protocols for wadeable streams in concert with the current rapid bioassessment habitat protocol, 3) inclusion of a second winter macroinvertebrate index period, 4) inclusion of dissolved metals for some analytes, and 5) exclusion of bacteria from

program. The OCC initiated a probabilistic program during 2008 that will provide estimates for planning basins throughout the state. Fifty random sites are being monitored per basin over the five-year rotating basin cycle. Lastly, the OWRB will conclude the Illinois River Probabilistic Monitoring Survey in 2009-2010. It is the first regionally based probabilistic study in Oklahoma, and is centered on setting a baseline biological condition to assist in implementation of nutrient criteria in Oklahoma's scenic rivers. Additional plans are in the works for future regionally based studies.

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