The Virginia Coastal Plain Macroinvertebrate Index

Water Quality Monitoring, Biological Monitoring and
Water Quality Assessment Programs

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Table of Contents

Acknowledgements

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List of Tables

List of Figures

1.0 EXECUTIVE SUMMARY

The challenges associated with evaluating the biological integrity of Virginia's coastal plain streams stem from flat terrain, low-gradient swamp-like conditions and over 200 years of anthropogenic influence. The current assessment tool, the Coastal Plain Macroinvertebrate Index (CPMI, Maxted et al. 2000), was developed during a multi-state effort that included only 15 Virginia biomonitoring sites. In 2009, the Virginia Department of Environmental Quality (VDEQ) Biologists completed a self-assessment of the Biological Monitoring Program and found that the Maxted CPMI lacks in its discrimination power between unimpaired and impaired low gradient coastal streams in Virginia (VDEQ 2009). As a result, VDEQ Biologists determined that an improved assessment tool for the coastal plain ecological regions was needed for the following reasons: (1.) to offer necessary support for low gradient coastal stream assessment decisions; (2.) to prevent some waters from being inappropriately listed as impaired (and subsequently subjected to the costly TMDL process); and (3.) to increase the number of stream miles which can be confidently assessed. The process presented here is based on family-level data, increases the number of reference and stress sites and utilizes new filters yielding improved metrics and more accurate identification of stress. This process began as an effort to validate the existing Maxted CPMI and its use in Virginia, but resulted in new sets of metrics for each of the two coastal plain ecological regions: the Mid-Atlantic Coastal Plain (MACP) and Southeastern Plain (SEP). The Chowan Basin streams exhibited closer similarity to MACP streams than SEP streams and are recommended for assessments using MACP metrics. The resulting Virginia CPMI (VCPMI) is applicable as the MACP (plus Chowan basin) VCPMI and the SEP (minus Chowan basin) VCPMI. The new metrics respond slightly better to stress and improve the probability of correctly evaluating MACP (plus Chowan basin) sites as unimpaired from 48% to 74%. In the SEP (minus Chowan basin), the appropriate classification of stress sites increased from 66% to 82%, while the classification as unimpaired remained unchanged.

The following 7 metrics are recommended for use in Virginia's MACP (plus Chowan basin sites):

- Total Taxa (Richness)
- EPT Taxa (Richness)
- % Ephemeroptera (Composition)
- % PT-Hydropsychid (Composition)
- HBI (Tolerance/Dominance)
- % 5 Dominant Taxa (Tolerance/Dominance)
- % Clingers minus Hydropsychidae+Simuliidae (Habit)

The following 8 metrics are recommended for use in Virginia's SEP (minus Chowan basin sites):

- Total Taxa (Richness)
- EPT Taxa (Richness)
- % Ephemeroptera (Composition)
- % PT minus Hydropsychidae (Composition)
- HBI (Tolerance/Dominance)
- % Intolerant Taxa (Tolerance/Dominance)

- % Clingers minus Hydropsychidae+Simuliidae (Habit)
- % Scrapers (Trophic Group Composition)

The methods employed in developing the VCPMI began with identification of reference and stressed sites using VDEQ and Virginia Commonwealth University's Interactive Stream Assessment Resource (INSTAR) data. Reference and stress filters were applied followed by VDEQ Regional Biologist review to select appropriate reference and stress stations. Reference sites were examined by Multivariate Analysis and 21 metrics were evaluated for best discriminatory efficiency.

Best Standard Values were calculated for each of the selected metrics to establish scoring thresholds. Index performance was evaluated by plotting the VCPMI and Maxted CPMI against stressor gradients using Principal Components Analysis (PCA). Precision analysis was conducted by evaluating same-day replicates. The VCPMI and Maxted CPMI were applied to the reference and stress dataset to compare the discrimination efficiency of each index. Metric scoring was established on a zero to 100 scale by incorporating the 5th and 95th percentiles as the floor and ceiling values. This scoring approach allows for unitless comparison of different types of metrics. A total VCPMI score of 40 (25th percentile of reference) was selected as an appropriate assessment threshold for determining biological impairment in both the MACP (plus Chowan basin) and SEP (minus Chowan basin).

2.0 INTRODUCTION

Biological monitoring, or biomonitoring, is an important component of the Virginia Department of Environmental Quality's (VDEQ) Water Quality Monitoring and Assessment Program. The biomonitoring program is implemented to evaluate the ecological quality of Virginia's streams in support of the agency's mission "to protect and improve the environment for the well-being of all Virginians" and the aquatic life use Water Quality Standard: "State waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life" (9VAC25-260-20). Appropriate tools for assessing the diverse biological communities found in the Commonwealth are critical for a successful and credible biomonitoring program. The concept of ecological regions, or ecoregions, is integral to understanding and interpreting biomonitoring data. Ecoregions offer a spatial structure for monitoring and assessing ecosystems by grouping regions with similar types, quality and quantity of environmental resources (Woods et al. 2012).

The coastal plain region located in the eastern part of the Commonwealth consists of the Mid-Atlantic Coastal Plain (MACP) and Southeastern Plain (SEP) ecoregions and hosts very different aquatic habitats (and consequently, distinct communities) from the central and western regions. Tools for the assessment of coastal plain aquatic communities must be specifically calibrated to account for differences in those communities. In order to illustrate the need for appropriate tools, Non-metric Multidimensional Scaling (NMS) was used to compare upland and coastal sites (Figure 1). Figure 1 shows noticeable separation between upland and coastal sites. Given the pattern shown in Figure 1, the analysis suggests that different assessment tools (or at the very least a recalibration) are warranted in the two areas. Note that all coastal sites and a significant number of upland sites were collected using multi-habitat protocols and as such, the separation between the groups cannot be explained by sampling technique.

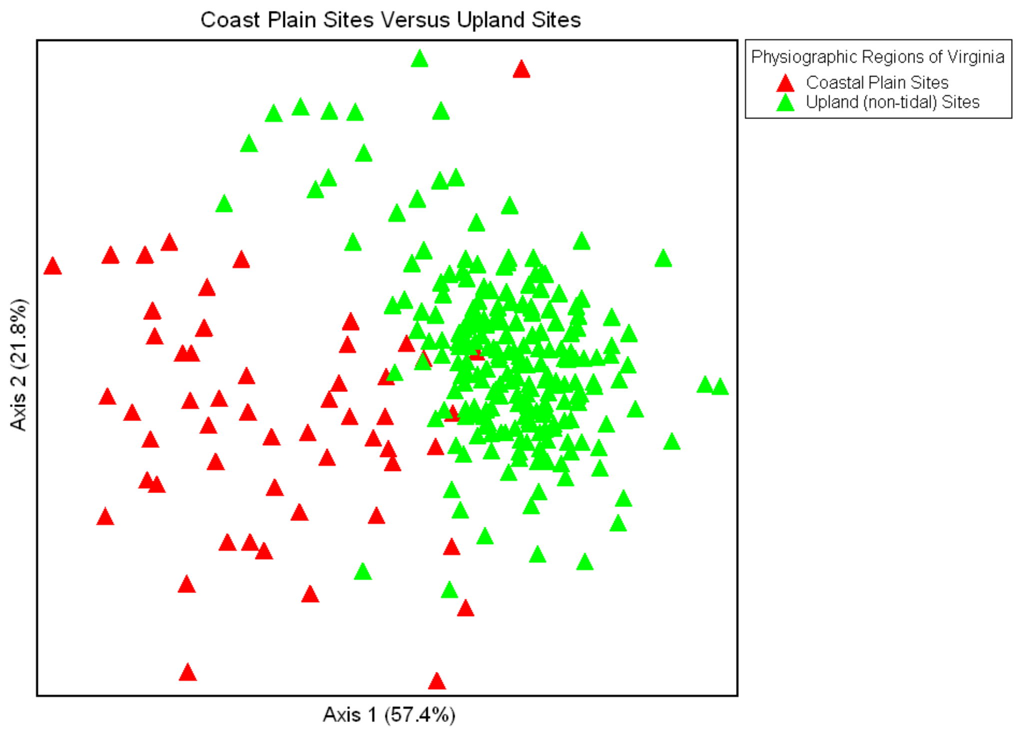

Figure 1. NMS of reference coastal plain vs. reference upland (non-tidal) sites (n=56 coastal and n=213 upland).

In 2009, VDEQ's Biologists initiated a Self-Assessment of the Biomonitoring Program (VDEQ, 2009) in order to gage the future needs of the program. One of the workgroups that formed as a result of the Self-Assessment process was tasked with evaluating and revising the Coastal Plain Macroinvertebrate Index (CPMI), which is the tool utilized to assess MACP and SEP aquatic communities. The Workgroup concluded that certain metrics in the CPMI do not discriminate well between unimpacted and impacted coastal streams and recommended that the CPMI be revised for Virginia (VDEQ 2009). An improved assessment tool for the coastal plain areas was needed for the following reasons: (1.) to offer necessary support for low gradient coastal stream assessment decisions; (2.) to prevent some waters from being inappropriately listed as impaired (and subsequently subjected to the costly TMDL process); and (3.) to increase the number of stream miles which can be confidently assessed.

The original CPMI was developed by Maxted et al. (2000) following a multi-state effort to review the methods and metrics applied to freshwater streams in the mid-Atlantic coastal region. The total number of Virginia stations included in the original CPMI development was 15 (7 reference and 8 stressed stations) (Maxted et al. 2000), which was only 15% of the total stations used. VDEQ conducts biological assessments using family-level taxonomic data and as such the CPMI was adapted for use with family-level benthic macroinvertebrate data. The CPMI incorporates the following core metrics: Total Taxa; Ephemeroptera, Plecoptera and Trichoptera (EPT) Taxa; % Ephemeroptera Taxa; Modified Hilsenhoff Biotic Index (MHBI); and % Clingers.

The approach of this study incorporates data from different programs within VDEQ and from the Virginia Commonwealth University's Interactive Stream Assessment Resource (INSTAR) (VCU 2009). The dataset utilizes data from the Southeastern Plain (SEP) and Middle Atlantic Coastal Plain (MACP) Ecological Regions (Figure 2).

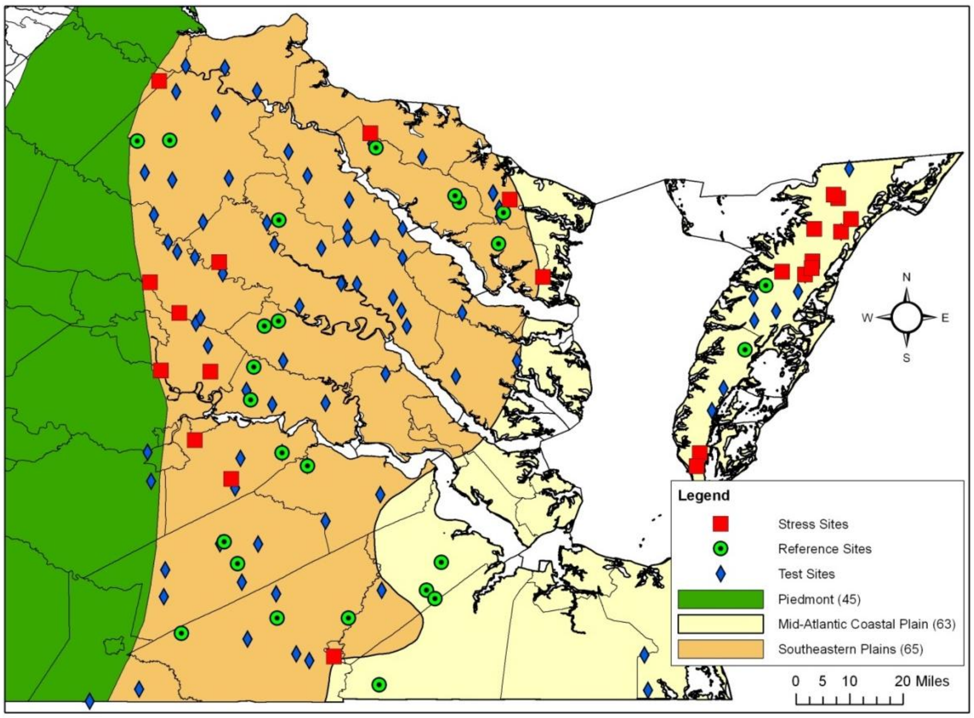

Figure 2. Map of Stations (n=25 reference sites; n=30 stress sites).

The intent of this report is to present methodology used to develop a new multi-metric index called the Virginia Coastal Plain Macroinvertebrate Index (VCPMI). The VCPMI is based on a comprehensive Virginia dataset and recommended for use in assessing Virginia's MACP and SEP streams. The majority of VDEQ's biomonitoring data to date is identified to the family taxonomic level; the amount of family-level data made this study possible. Miller (2012) evaluated available genus-level data in order to establish a foundation for development of a genus-level multi-metric index. Due to the limited size of the dataset, Miller (2012) recommended that additional genus-level data be collected before a genus-level index can be developed. The discussion of the VCPMI presented in the sections that follow support the implementation of the VCPMI as a critical interim step between Virginia's current application of the CPMI and the future development and adoption of a genus-level coastal plain multi-metric index.

3.0 METHODS

3.1 Study Sites

The data used in this technical document originated from several sources: VDEQ Biological Monitoring Program, Ambient Water Quality Monitoring, and Probabilistic Monitoring programs and the Virginia Commonwealth University's Interactive Stream Assessment Resource (INSTAR) (VCU 2009). Data were collected using VDEQ standard operating procedures for Ambient Water Quality Monitoring (VDEQ 2010) and VDEQ Biological Monitoring Program Quality Assurance Project Plan for Wadeable Streams and Rivers (VDEQ 2008). VCU data were collected using modified EPA Rapid Bioassessment Protocols (RBP III) for multi-habitat collections (Barbour et al. 1999, Plafkin et al. 1989, VCU 2008). Methodology was evaluated for quality assurance and quality control by the VDEQ Biomonitoring Coordinator to ensure comparability with VDEQ's methods.

Throughout the duration of this study, data was stored and managed using Microsoft Excel and Access. INSTAR data is stored in an online database available through VCU's website. VDEQ's Biological Monitoring and Probabilistic Monitoring data is stored in a Microsoft Access database (VDEQ's Ecological Data Application System [EDAS]) whereas Ambient Water Quality Monitoring data is found in the Oracle-based Comprehensive Environmental Database System (CEDS). Genus-level data was rarified to the family taxonomic level. Since INSTAR does not collect water chemistry data, GIS was used to apply a two kilometer buffer and then select the nearest VDEQ Ambient Water Quality monitoring (AWQM) station. The INSTAR sites and the VDEQ AWQM stations were projected in order to confirm that they were comparable (i.e. in the same body of water, not influenced by major tributaries/land use, etc.). VDEQ sites were also matched with the nearest AWQM station data in order to fill in data gaps. Land cover data was generated using GIS and Analytical Tools Interface for Landscape Assessments (ATtILA) (Ebert and Wade 2004).

3.2 Reference Benthic Community Characterization

Identification of regional reference sites that represent the least anthropogenically disturbed condition is critical to evaluating a multimetric index. Reference sites are supposed to describe good ecological condition through their biotic and abiotic characteristics (Stoddard et al. 2006; Whittier et al. 2007). In an effort to select reference sites that represent the least disturbed conditions, reference and stress filters (Miltner 1998, Barbour et al. 1999, USEPA 2000, Dodds 2000, Ohio EPA 1999, Boward 1999, Carle 2005, Tetra Tech 2003, VDEQ 2005 and 2009, Wang 2003) were applied to the dataset and evaluated by the VDEQ Regional Biologists (Table 1). Best Professional Judgment (BPJ) was incorporated to adjust the reference and stressed sites. The final reference and stress sites were imported into Microsoft Access and eventually into PC-ORD Version 4 (McCune and Medford 1999), MeanSim (Van Sickle 1997), and ArcView 3.2. The final counts of individual reference and stress stations evaluated in this report are n=25 and n=30, respectively.

Table 1. Reference and stress filters.

Parameter	Reference	Stress
pH	<7.5	>7.5
Specific Conductance (µS/cm)	<200	>500
Epifaunal Substrate/Cover *	>13	<7
Riparian Vegetation *	>13	<7
Total Habitat Score *	>140	<120
Dissolved Oxygen (mg/L)	>4	<4
Total Suspended Solids (mg/L)	<10	>30
% Urban Landcover	<4	>15
% Forested Landcover	>67.5	<30
Total Nitrogen (mg/L)	<1.5	>3.0
Total Phosphorus (mg/L)	<0.05	>0.1

*Rapid Bioassessment Protocols habitat parameter (Barbour et al. 1999)

Classification parameters that explain biological properties are of particular importance when the goal is to evaluate biological condition of a sample site (Hawkins and Norris 2000). The Reference dataset (n=56, APPENDIX B) includes multiple visits over several years to the reference stations and was initially analyzed by classification grouping: basin, basin size, VDEQ Region, Level III Ecoregion, season, stream order, and ecoseason (ecoregion+season). Reference data was Log (x+1) transformed and then visually assessed using ordinations generated by PC-ORD Nonmetric Multidimensional Scaling (NMS) ('slow and thorough' setting on Autopilot). NMS was used to look for patterns in the reference benthic macroinvertebrate community and to help identify the best possible reference condition. Chironomidae organisms and "rare taxa" (i.e. taxa that appeared at only one site in the data set) were removed and NMS was re-evaluated (reference site n=56). McCune and Grace (2002) noted that the exclusion of rare taxa led to a more robust multivariate analysis and reveal more obvious patterns. NMS ordinations were generated for the dataset with Chironomidae taxa and without rare taxa and without Chironomidae taxa and with rare taxa but these analyses are not presented here. In brief, these iterations did not improve the variability explained.

Mean similarity analysis was applied using MeanSim in order to evaluate the classification strength, or the extent to which reference sites within the same group are more similar to one another than they are to those in other groups. MeanSim incorporates a matrix of pairwise similarities and a statistical test comparing average within-group similarities and between-group similarities (Van Sickle 1997). VDEQ utilized a Bray-Curtis input matrix and executed MeanSim analysis by basin, basin size, VDEQ Region, Ecoregion, season, stream order, and Ecoseason (Ecoregion+season). Classification strength (CS) is represented by the difference between Within Group similarity (W) and Between Group similarity (B); thus, CS = W – B. If the classification strength is strong, W is high and B is low. The observed ratio, M, is expressed as the product of dividing B by W (M = B/W). In order to test the null hypothesis of 'no class structure', 10,000 randomly chosen samples were reassigned to groups of the same size as the tested classification (Van Sickle and Hughes 2000; Jackson and Somers 1989). If the null hypothesis is true, then the observed ratio should be close to one.

Table 2. Basin size categories.

Initial Basin Size Categorization	
Size (mi^2)	**Category**
< 1	1
1 – 10	2
10 – 200	3
200 – 500	4
> 500	5

3.3 Metric Evaluation

Twenty-one candidate metrics were evaluated in this study. The metrics vary in purpose and include species richness, species composition, pollution tolerance and functional feeding groups (Table 3). The approach to assessing the candidate metrics was accomplished by evaluating: (1.) discriminatory power, (2.) redundancy and (3.) relationship with stressors. Classification differences were further explored by creating box-and-whisker plots for each of the 21 candidate metrics in SYSTAT®11 and visually inspecting degrees of discrimination and overlap. Pearson correlation analysis was performed using SYSTAT®11 in order to evaluate metric redundancy. Spearman Rank correlations were generated to evaluate the relationship between candidate metrics and environmental stressors.

Table 3. Definitions, abbreviations and expected response under stress for candidate metrics.

Metric Type	Metric	Abbreviation	Metric Definition	Response type to stress
Richness measures	Total number of taxa	TOTTAXA	Number of distinct taxa in sample	Decrease
	No. of Ephemeroptera, Plecoptera, Trichoptera taxa	EPTTAX	Number of organisms from Ephemeroptera (mayfly), Plecoptera (stonefly), Trichoptera (caddisfly) orders	Decrease
Tolerance measures	HBI (Family)	HBI	Uses tolerance values to weight abundance in an estimate of overall pollution	Increase
	% Intolerant taxa	%INTOL	Percentage of taxa with PTV < 4	Decrease
	% Tolerant taxa	%TOLER	Percentage of taxa with PTV > 6	Increase
	% 1 Dominant family	%1DOM	Percentage of individuals in the single most dominant family	Increase
	% 2 Dominant families	%2DOM	Percentage of individuals in the two most dominant families	Increase
	% 5 Dominant families	%5DOM	Percentage of individuals in the five most dominant families	Increase
Composition measures	% Ephemeroptera	%EPHEM	Percentage of taxa in Ephemeroptera	Decrease
	% Diptera individuals	%DIPTERA	Percentage of taxa in Diptera	Increase
	% Chironomid individuals	%CHIRO	Percentage of individuals in Chironomidae	Increase
	% Plecoptera, Trichoptera less Hydropsychidae taxa	%PT-HYDROP	Percentage of taxa in Plecoptera, Trichoptera less Hydropsychidae	Decrease
	% Ephemeroptera, Plecoptera, Trichoptera less Hydropsychidae	%EPT-HYDROP	Percentage of taxa in Ephemeroptera, Plecoptera, Trichoptera less Hydropsychidae	Decrease
	% Non-insects	%NONINSECT	Percentage of individuals in non-insect taxa	Increase
	% Trichoptera taxa	%TRICH	Percentage of taxa in Trichoptera	Decrease
	% Trichoptera less Hydropsychidae taxa	%T-HYDROP	Percentage of taxa in Trichoptera less Hydropsychidae	Decrease
	% Non-collector gatherers	%NONCOLGAT	Percentage of individuals not in collector-gatherer taxa	Increase
Trophic/Feeding measures	% Scrapers	%SCRAPERS	Percentage of taxa that are scrapers	Decrease
	% Clingers less Hydropsychidae	%CLING-HYDRO/SIMULIIDS	Percentage of taxa that are clingers less Hydropsychidae	Decrease
	% Clingers	%CLING	Percentage of taxa that are clingers	Decrease

(Blocksom et al. 2001; Pond et al. 2012)

Classification differences were further explored by creating box-and-whisker plots for each of 21 candidate metrics in SYSTAT®11. A bioregion was created by moving the Chowan basin sites to the Mid-Atlantic Coastal Plain Ecoregion. New box-and-whisker plots and MeanSim analysis were generated for the Bioregion category. In addition, the basin size categories were re-allocated in order to more evenly distribute the data across all size categories (Table 4). Box-and-whisker plot analyses for the 21 candidate metrics by ecoregion revealed the need for additional Southeastern Plains stress sites. Regional Biologists recommended additional sites and EDAS database was queried for additional sites. Final Southeastern Plains ecoregion sites used in box-and-whisker plot analyses included n=10 stress sites and n=27 reference sites. Mid-Atlantic Coastal plain sites (including Chowan sites from Southeastern plain ecoregion) were n= 41 and n=22 for stress and reference, respectively.

Table 4. Basin size re-categorization.

First Basin Size Categorization		**Second Basin Size Categorization**	
Size (mi^2)	**Category**	**Size (mi^2)**	**Category**
< 5	1	< 1	1
5 - 20	2	1 – 10	2
20 – 200	3	10 – 200	3
> 200	4	> 200	4

Box-and-whisker plots were used to evaluate metric discriminatory power, or the ability of a metric to separate reference and stress sites. Utilizing the system developed by Barbour et al. (1996) and applied by Blocksom et al. (2001), the interquartile (IQ) ranges were assigned scores based on the degree of overlap observed between reference and stress site boxes. Metrics with no IQ range overlap scored a '3', metrics where both medians were outside the other's IQ range scored a '2', metrics with only one median outside the other's IQ range scored a '1', and those where each median overlapped the other's IQ range receive a score of '0'. Metrics that scored a 2 or 3 exhibited the ability to discriminate well between reference and stress sites.

Pearson correlation analysis was performed using SYSTAT11 in order to evaluate metric redundancy. Pearson correlation coefficients were generated on the entire dataset (n=428) including the initials sites that were not filtered into the reference or stress category. Redundancy analysis is important in order to highlight metrics that provide similar information. Pseudo replicated sites were removed and Pearson correlation coefficients were generated on the revised dataset (n=242). Metrics with correlation coefficients (r) $\geq$ 0.8 were considered redundant. Pond et al. (2012), Maxted et al. (2000) and Blocksom and Johnson (2009) used an r-value of greater than 0.75 to screen for metric redundancy and Gerritsen et al. (2000a) utilized 0.85. This study used 0.80 to screen metrics for redundancy.

Spearman Rank correlations were generated to evaluate the relationship between candidate metrics and environmental stressors. A preliminary review of the scatterplots showed skewed total nitrogen and specific conductance plots based on several outliers. The dataset was evaluated and the sites with excessively high total nitrogen and specific conductance measurements were removed. The data ranges for total nitrogen and specific conductance at the removed sites were 41-86 mg/L and 1036-2024 uS/cm, respectively. The final dataset was comprised of n=124 sites.

4.0 METRIC EVALUATION RESULTS AND SUMMARY

4.1 Reference Benthic Community Characterization

NMS ordination results include a final stress of 17.5 (Table 5) and accounted for 73.1% of the variation (Table 6). The stress is a measure of confidence in the ordination and in general, a value less than 20 is considered acceptable (McCune and Grace 2002). For graphical evaluation, two-dimensional plots using axes 2 and 3 were used (these accounted for the most variance).

Table 5. Stress in relation to dimensionality (number of axes).

	Stress in real data 40 run(s)			Stress in randomized data Monte Carlo test, 50 runs			
Axes	Min	Mean	Max	Min	Mean	Max	p
1	41.230	53.067	56.731	50.231	54.725	56.695	0.0196
2	24.770	26.744	40.378	30.247	32.580	40.364	0.0196
3	17.576	18.536	31.241	22.016	23.630	31.179	0.0196
4	13.031	14.107	25.702	17.320	18.409	19.398	0.0196
5	10.213	10.546	22.236	14.098	15.102	21.606	0.0196
6	8.270	8.837	19.778	11.662	12.466	13.420	0.0196

p = proportion of randomized runs with stress < or = observed stress
i.e., p = (1 + no. permutations <= observed)/(1 + no. permutations)

Table 6. Variation explained by axis (r-squared) with rare taxa and Chironomids removed.

	R-Squared	
Axis	**Increment**	**Cumulative**
1	.166	.166
2	.292	.458
3	.273	.731

The following figures display the NMS ordination results: basin (Figure 3), basin size (Figure 4), basin size first re-categorization (Figure 5), basin size second re-categorization (Figure 6), ecoregion (Figure 7), ecoseason (ecoregion + season, Figure 8), DEQ region (Figure 9), stream order (Figure 10). As shown in Table 6, axes 2 and 3 explain the greatest amount of variation. The shapes represent individual reference sites. Basin size (Figure 4), ecoregion (Figure 7) and DEQ region (Figure 9) exhibit the greatest clustering potential.

Each basin is shown as a different shape in Figure 3: James River basin sites are triangles, Rappahannock River sites are squares, Chowan sites are circles, Chesapeake Bay sites are diamonds and York River basin sites are stars. The majority of the Chesapeake Bay sites cluster in the upper right area of the graph. The one site that separated away from the Chesapeake Bay cluster is a different stream order and is in the SEP, whereas the others are all first order and in the MACP.

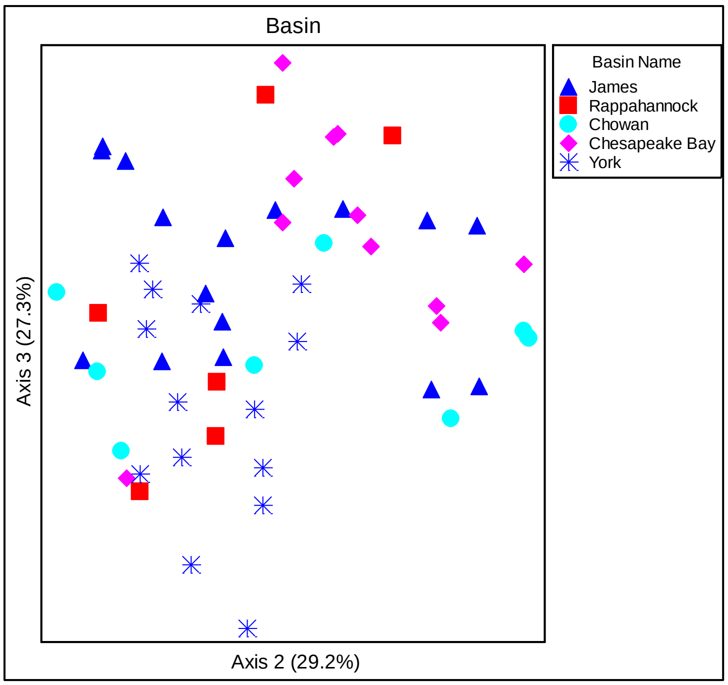

Figure 3. NMS by basin (n=56).

Figures 4, 5 and 6 show the ordinations of different basin size categorization schemes. The triangles in Figure 4 represent reference sites with drainage areas less than 1 square mile. The squares are reference sites with drainages between 1 and 10 square miles. Circles, diamonds, and stars represent reference sites with drainages of between 10 and 200 square miles, between 200 and 500 square miles, and greater than 500 square miles, respectively. Figures 5 and 6 depict the smallest basin size with red triangles (<5 mi^2 and <1 mi^2, respectively). Figure 5 uses green triangles for the 5-20 mi^2, turquoise for 20-200 mi^2 and purple for >200 mi^2. Figure 5 displays 1-10 mi^2 as green triangles, 10-200 mi^2 as turquoise triangles and >100 mi^2 as purple triangles.

Figure 4 shows the reference sites with drainage areas less than 1 square mile clustered together in the middle upper area of the graph. The less than 1 square mile drainage area datapoints are all from the same site but with different sample dates. The datapoints with drainages between 200 and 500 square miles generally clustered together near the middle center of the graph area and are all from the same Mattaponi River site. There were only 3 sites (all Nottoway River) with very large drainages (>500 mi^2) and they loosely clustered on the left side of the graph. It appears that the benthic communities in the < 1 mi^2 sites are most different from those in the two largest basin size categories. Given the lack of diversity with respect to sites in three of the basin size categories, ordinations were generated for two re-categorizations of basin size (Figure 5 and Figure 6). Figure 5 shows the majority of sites in the 5-20 mi^2 size range clustering in the middle right of the graph area. The second basin re-categorization (Figure 6) shows the same cluster of <1 mi^2 sites. Overall, it does not appear that re-categorization improved the clustering of the reference sites.

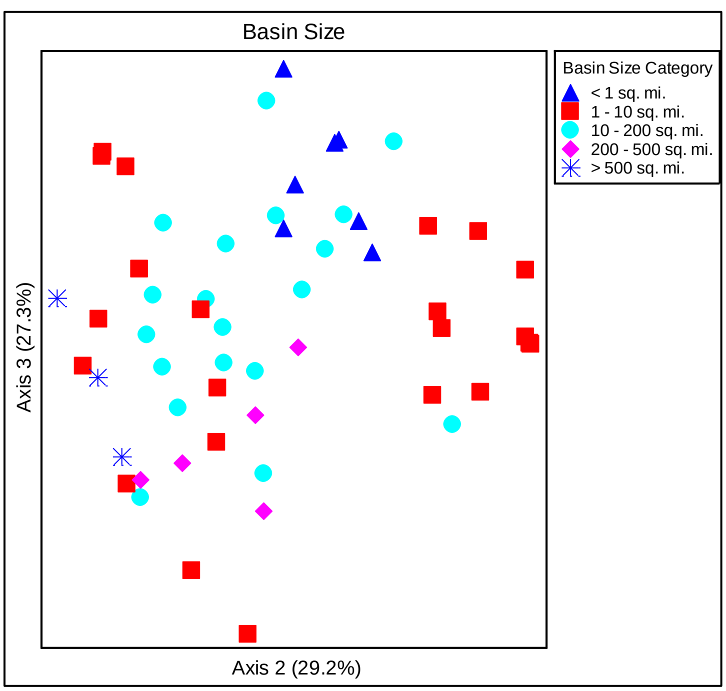

Figure 4. NMS by basin size (n=56).

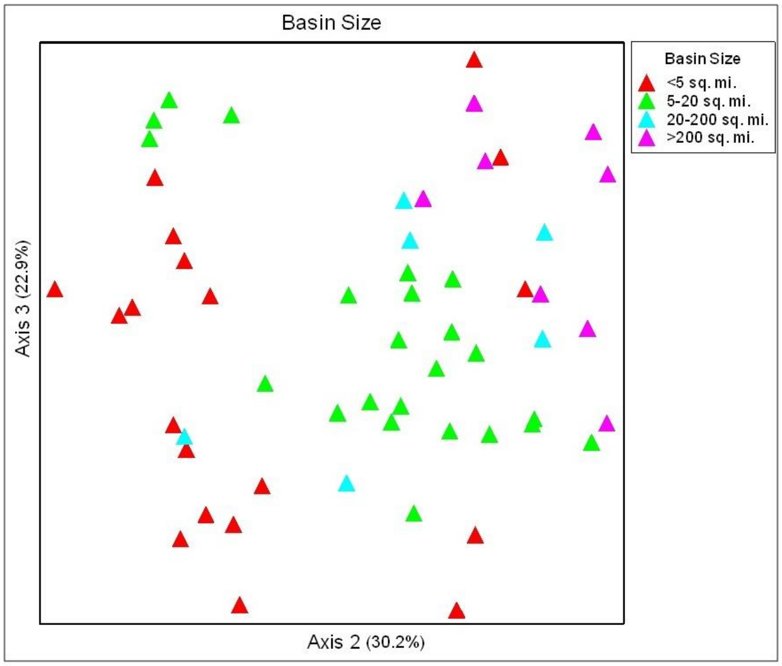

Figure 5. NMS by first basin size re-categorization (n=56).

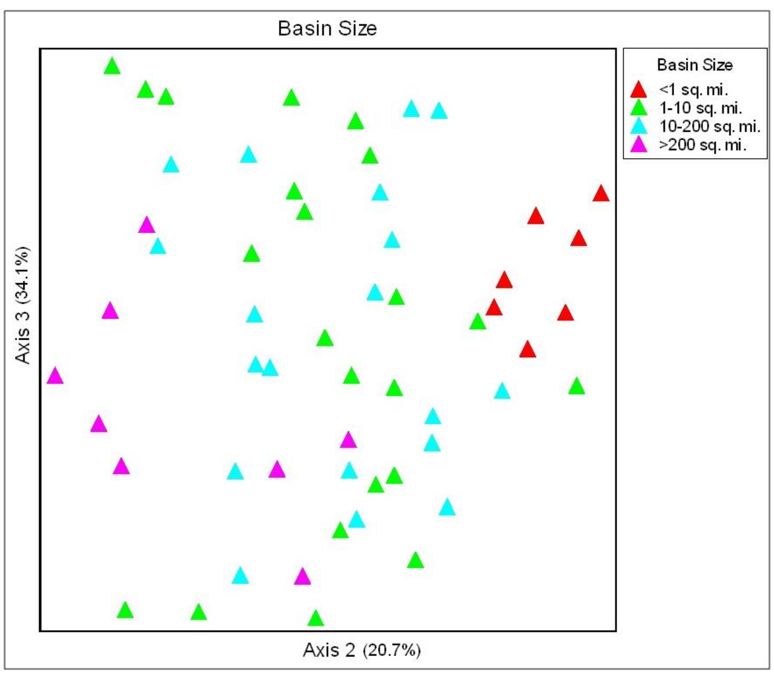

Figure 6. NMS by second basin size re-categorization (n=56).

MACP is represented by the squares in Figure 7 and SEP is represented by the triangles. In general, the MACP sites clustered together on the right side of the graph area. The SEP sites grouped into one large cluster with a few separate sites intermingled in the MACP cloud. Further examination of the sites revealed that three of the SEP sites that grouped with the MACP are in the Chowan basin. The reference sites in the Chowan basin may be more similar to the MACP than the SEP. This relationship will be explored in subsequent sections.

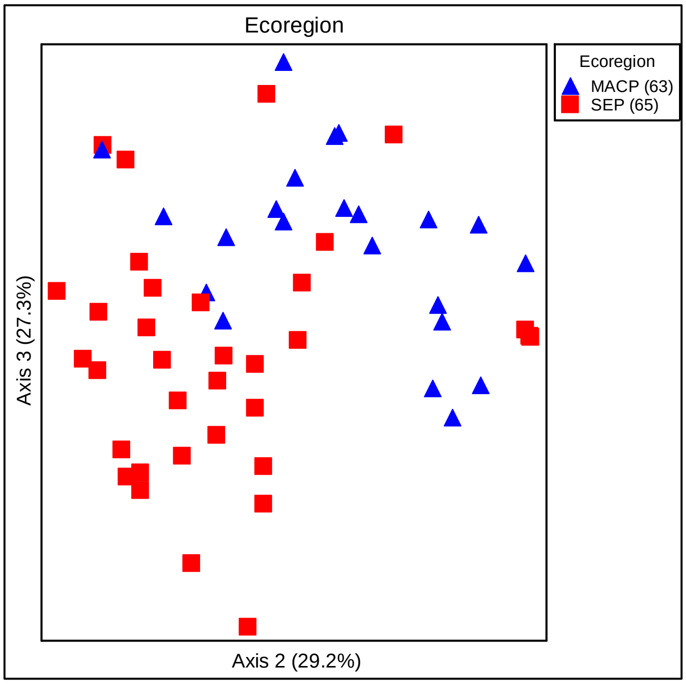

Figure 7. NMS by ecoregion (n=56).

Spring and fall SEP sites are labeled using triangles and squares, respectively (Figure 8). Circles represent spring MACP and diamonds are fall MACP. Spring SEP forms a cluster on the lower left of the graph area. The majority of the spring MACP form an elongate cluster in the upper right of the graph area. In general, the ecoregions separate from one another but the seasons do not.

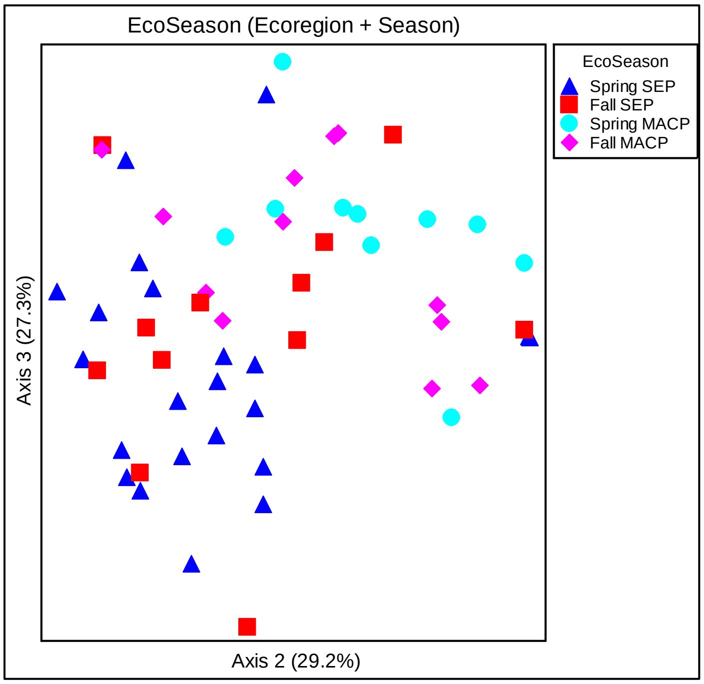

Figure 8. NMS by EcoSeason (n=56).

Figure 9 shows reference sites in DEQ's Northern Region (NRO) as triangles, Piedmont Region (PRO) as squares, and Tidewater Region (TRO) as circles. The majority of the PRO sites cluster together on the left side of the graph area. The TRO sites occupy the upper right area and the NRO sites loosely cluster in the center left area with some PRO overlap. The 4 PRO sites at the top of the graph area are all SEP, James basin sites. All of the NRO sites are in the SEP, York basin sites. The patterns shown here may be explained by ecoregion.

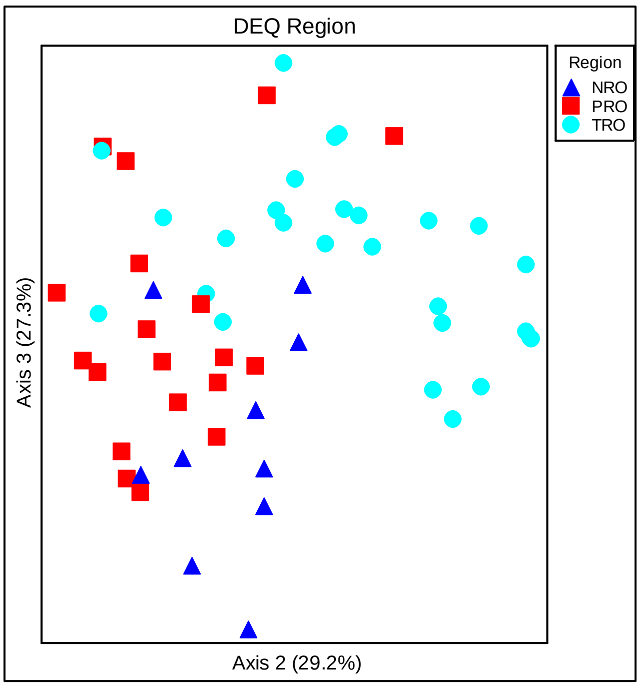

Figure 9. NMS by DEQ Region (n=56).

Figure 10 displays first order streams as triangles, second order streams as squares, third order streams as circles, fourth order streams as dark diamonds, fifth order streams as stars and sixth order streams as light diamonds. The majority of first order sites cluster in the upper right of the graph area. Fourth order sites form a loose cloud on the left of the graph area. Third order sites overlap with the first and fourth order sites. Benthic communities collected in smaller headwater streams (first order) appear to differ most from fourth order streams and higher.

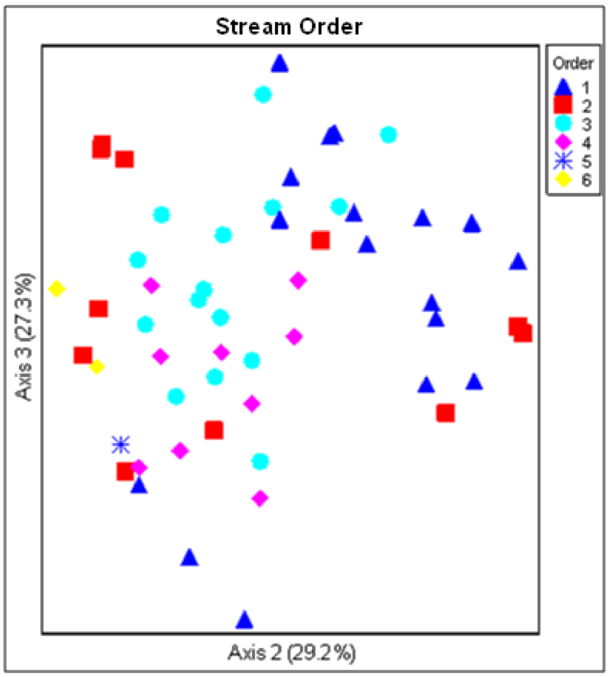

Figure 10. NMS by Stream Order (n=56).

4.2 Metric Evaluation Results

The following sections (4.2.1-4.2.4) present the findings of mean similarity analysis, box-and-whisker plots, redundancy analyses, and relationship with stressors analyses using Spearman Rank correlations. As discussed in section 3, these steps establish the foundation for selecting appropriate metrics from the candidate metric list. Mean similarity analysis was used to further explore the results of NMS, specifically to evaluate the strength of a classification of reference sites into a small number of groups. The Mean Similarity Analyses results are presented in Section 4.2.1. Section 4.2.2 presents box-and-whisker plot analyses utilized to identify aspects of natural variability that warrant benchmarking. Metric discriminatory power evaluation involved box-and-whisker plots of reference verses stress sites by metric and the results are summarized in Section 4.2.3. Section 4.2.4 shows results of the Redundancy analyses using Pearson correlation. Section 4.2.5 summarizes results of Spearman Rank correlations generated to show how well the metrics correlate to stressors.

4.2.1 Classification Strength

NMS ordination resulted in clustering of reference sites by the following classification variables: basin size (see Figure 4), ecoregion (Figure 7), DEQ Region (Figure 9), and stream order (Figure 10). In order to further explore these relationships, mean similarity analysis was performed using MeanSim. None of the classification strength (CS) values for the classification variables were considered high. As evident in Table 7, the highest CS calculated was 4.63%. Given the tendency for some of the SEP Chowan sites to group with the MACP in the NMS analyses, a bioregion was created that included the SEP Chowan sites with the MACP. The bioregion CS was 2.70%, which is considered low. The M ratios were very close to 1 in all classification variables offering further support for weak classifications (Van Sickle and Hughes 2000). The basin size re-categorization (Table 4) mixed more sites into each size category and resulted in a decrease in CS from 4.41% to 4.01% (Table 7).

Table 7. Mean Similarity Analysis results for Family-Level Sites (Chironomidae taxa and rare taxa removed).

	N (Reference sites)	N (Groups)	Within Group (W)	Between Group (B)	Classification Strength (W-B)	M (B/W)	p-value
Basin	56	5	66.6%	66.2%	0.4%	0.947	<0.0010
Basin Size	56	5	66.6%	66.2%	0.4%	0.934	<0.0010
Basin Size – 1st re-categorization	56	4	65.1%	61.9%	3.2%	0.950	<0.0010
Basin Size – 2nd re-categorization	56	4	66.2%	62.1%	4.1%	0.939	<0.0010
Ecoregion	56	2	64.6%	61.3%	3.3%	0.950	<0.0010
Bioregion (MACP+Chowan)	56	2	64.3%	61.6%	2.7%	0.958	<0.0010
VDEQ Regional Office	56	3	65.9%	61.3%	4.6%	0.930	<0.0010
Season	56	2	63.2%	62.5%	0.7%	0.989	0.0330
Ecoregion and Season	56	4	65.0%	62.2%	2.8%	0.957	<0.0010
Stream Order	55*	5	64.9%	62.1%	2.8%	0.957	<0.0010

*5th order site removed as it was the only one in its category.

4.2.2. Environmental Significance

Box-and-whisker plots were generated for each of the 21 metrics (Table 3) by the following classification variables using the reference site dataset (n=56): basin, basin size, ecoregion, bioregion, eco-season, VDEQ region, and stream order (APPENDIX A). All box-and-whisker plots are presented in Appendix A; however, select plots are also presented in this section to accompany significant findings described in the text.

Figure A-1 shows the metrics by basin. The Chowan and Chesapeake Bay sites exhibit the lowest median % Clingers, % Ephemeroptera, and % Clingers – Hydropsychid/Simuliids (also Figure 11b). Further, the Chowan reference sites exhibit low EPT Taxa (also Figure 11a), % Scraper, % PT-Hydropsychid, % Intolerant Taxa, and % Trichoptera scores and the highest median HBI scores. The reference sites ideally represent the best of what is available and the performance by the Chowan reference sites indicated that they may be better suited for grouping with the MACP sites. Basin box-and-whisker plots were not evaluated for discriminatory power using the Barbour et al. (1996) method.

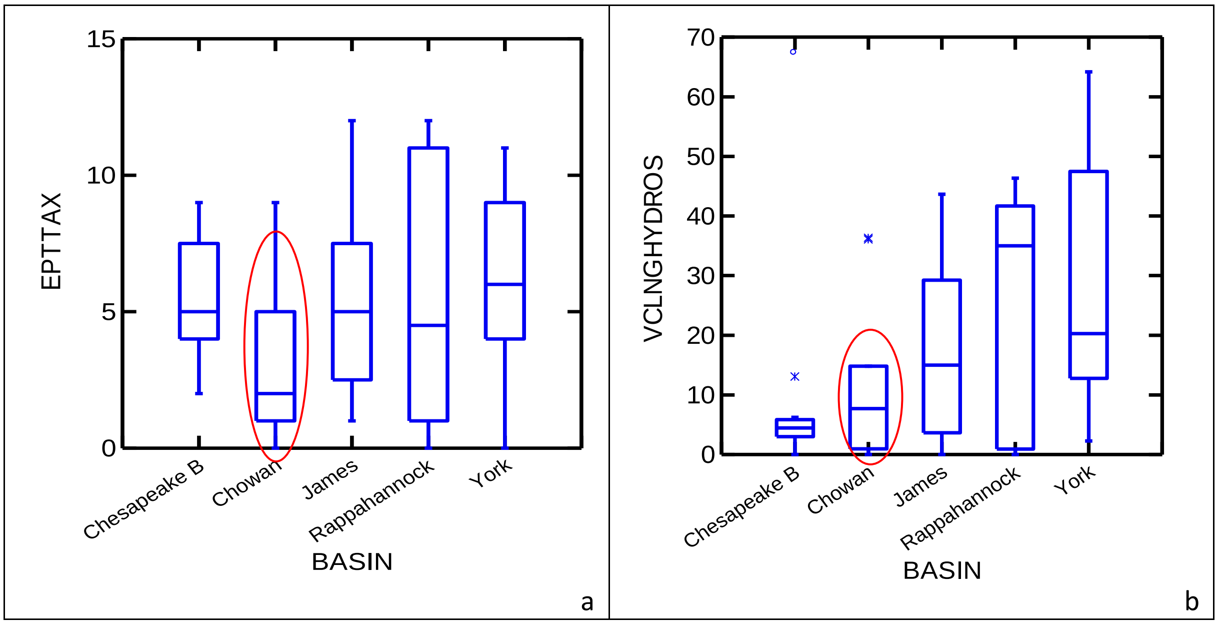

Figure 11. Box-and-whisker plots of EPT Taxa by basin (a) and % Clingers-Hydropsychidae and Simuliidae by basin (b) (n=56).

Box-and-whisker plots for metrics verses basin size are shown in Figure A-2. Box-and-whisker plots of metrics by basin size. Reference sites with drainages of less than 1 mi^2 exhibited the highest median HBI, % Trichoptera, % Hyropsychid scores and the lowest median scores for the following metrics: % Ephemeroptera, % Clingers, and % Clingers-Hydropsychid/Simuliids. However, given that the less than 1 mi^2 datapoints were all from the same station, these patterns are not considered valid but warrant additional investigation. The same concern applies to both the 200-500 mi^2 and > 500 mi^2 categories, having few independent sites. Box-and-whisker plots were generated for the second basin re-categorization (Figure A-3) for comparison because the second re-categorization had the higher CS of the two re-categorization attempts (Table 7). The trends were similar to those of the initial basin size categorization.

Figure A-4 shows box-and-whisker plots by ecoregion. Using the discriminatory power scoring technique (Barbour et al., 1996), HBI and % Clingers both scored 3's; therefore those metrics demonstrated the highest discriminatory power. Percent Ephemeroptera, % Scrapers, % EPT-Hydropsychid, % EPT, %

Clingers-Hydropsychid (also Figure 12), and % Tolerant Taxa scored 2's. Percent 5 Dominant Taxa was on the border between a 2 and 1. Metrics were also compared using the bioregion (MACP + Chowan sites from the SEP and SEP). The bioregion box-and-whisker plots are presented in Figure A-5. The Chowan reference sites decreased overall EPT Taxa richness in the SEP, but this metric demonstrated higher discriminatory power (2) after the Chowan sites were moved to the MACP (compare Figure A-2 and Figure A-5). Similarly, Percent Clingers-Hydropsychid also demonstrated higher discriminatory power once the Chowan sites were moved to the MACP (Figure 12. Box-and-whisker plots showing % Clingers less Hydropsychidae by ecoregion (a) and % Clingers less Hydropsychidae by bioregion (Chowan sites included with MACP) (n=56).a and 12b). In addition to HBI and % Clingers, % Clingers – Hydropsychid scored a 3 in the bioregion box-and-whisker plot analysis.

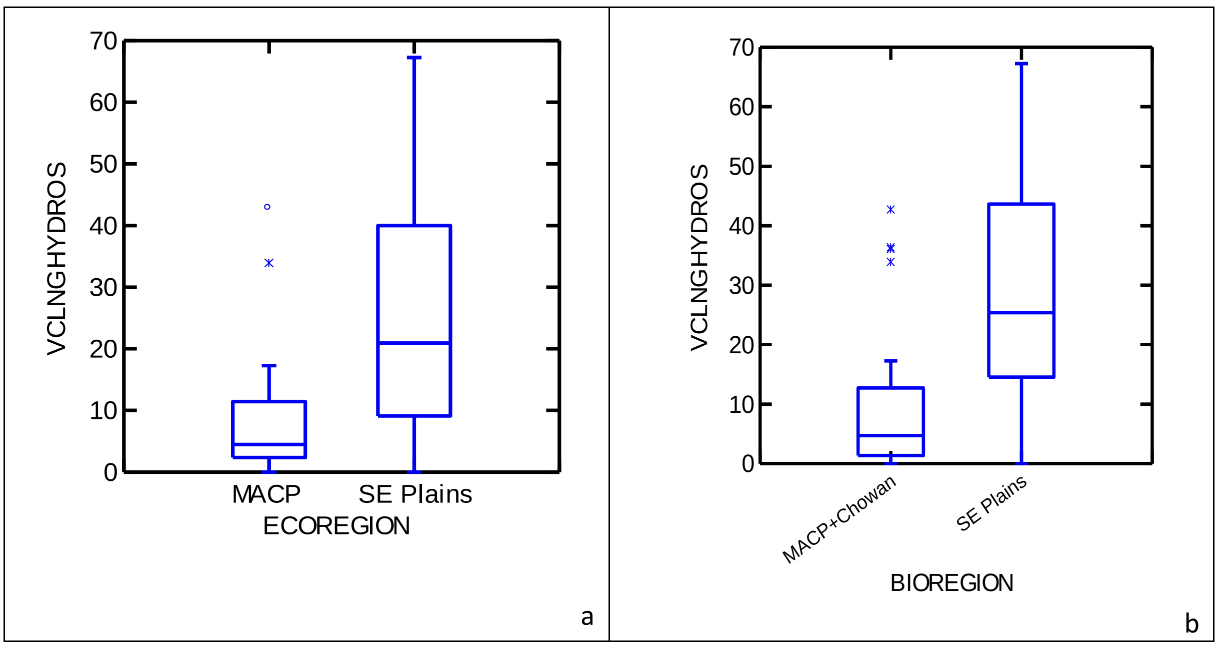

Figure 12. Box-and-whisker plots showing % Clingers less Hydropsychidae by ecoregion (a) and % Clingers less Hydropsychidae by bioregion (Chowan sites included with MACP) (n=56).

Metric box-and-whisker plots by ecoseason are displayed in Figure A-6. Spring MACP reference sites have a substantially higher HBI than that of Fall MACP, Spring SEP or Fall SEP. Percent Scrapers and % Clingers both showed lower median values for both seasons in the MACP. The Spring MACP displayed lower values for % Clingers – Hydropsychid with only slight, if any, overlap of quartiles. The Spring and Fall MACP box-and-whisker plots separated with no quartile overlap in the following metrics: HBI, % EPT, % EPT – Hydropsychid, and % Intolerant taxa.

VDEQ region box-and-whisker plots are shown in Figure A-7. TRO separated from NRO and PRO with no overlap of quartiles in % Clingers, HBI, and % Clingers – Hydopsychids. Interestingly, NRO separated from TRO and PRO with no quartile overlap in the following metrics: % Chironomids, % 2 Dominant taxa, % 1

Dominant taxa, % Non-Collector Gatherer and % Diptera. Percent Chironomids, % 1 Dominant taxa, % 2 Dominant taxa, and % Diptera taxa showed NRO having the lowest scores suggesting that low numbers of Chironomids were observed at NRO reference sites. It is important to note that NRO had the least number of sites overall (total n=10).

Stream order box-and-whisker plots are displayed in Figure A-8. Percent Chironomids, % 2 Dominant taxa, %1 Dominant taxa, % 5 Dominant taxa, and % Diptera showed 4^{th} order stream median values well below the median values for the other stream orders. The 4^{th} order reference sites are dominated by NRO sites; thus, the low numbers of Chironomids in the NRO sites may be drawing the 4^{th} order site box-and-whisker plot down. Percent Clingers and % Scrapers appear to increase as stream order increases from 1 to 5.

4.2.3. Discriminatory Power

Box-and-whisker plots were generated for five different scenarios and are presented in Appendix A: reference vs. stress (Figure A-9), SEP reference vs. stress (Figure A-10), MACP reference vs. stress (Figure A-11), SEP reference vs. stress less Chowan sites (Figure A-12), MACP reference vs. stress sites including SEP Chowan sites (Figure A-13). Figure A-9 displays the all of the SEP (n=35) and MACP (n=69) reference and stress sites by metric. Eleven metrics scored a 3 in discriminatory power and 4 metrics scored a 2 (Table 8). Over half of the metrics performed well at discriminating between reference and stress sites using the combined dataset. Discriminatory power is presented in Table 8. Removal of the Chowan sites from the SEP improved the discriminatory power of several metrics and did not appear to affect the majority of the MACP metrics (Table 8, Figure A-12 and Figure A-13). Metrics that exhibited strong discriminatory power in both the SEP and MACP are Total Taxa, HBI, EPT Taxa, %Ephemeroptera, %EPT-Hydropsychid, %Clingers-Hydropsychid/Simuliids, and %T-Hydropsychid (Table 8).

Table 8. Metric discriminatory power (n=124): All reference vs. stress sites, reference vs. stress sites by ecoregion, and reference vs. stress sites by ecoregion with Chowan sites included with MACP. Shading corresponds to metrics with improved discriminatory power in SEP with Chowan sites excluded.

	Reference vs. Stress Sites	**Reference vs. Stress by Ecoregion**		**Reference vs. Stress by Ecoregion *Chowan sites included with MACP***	
Metric Name*	All Ref vs. Stress n=104	SEP Ref vs. Stress n=37	MACP Ref vs. Stress n=59	**SEP ref vs. stress less Chowan sites n=35**	**MACP ref vs. stress incl. Chowan sites n=69**
TOTTAXA	3	0	3	3	3
HBI	3	1	2	3	2
EPTTAX	3	1	3	3	3
%EPHEM	3	1	3	3	3
%CLING	3	0	3	0	3
%PT-HYDROP	3	0	3	2	3
%SCRAPAE	0	2	2	3	1
%CHIRO	0	0	0	0	0
%NONINSECT	1	1	0	1	0
%EPT	3	0	3	2	3
%EPT-HYDROP	3	1	3	3	3
%1DOM	2	0	3	0	3
%2DOM	2	0	3	1	3
%5DOM	3	0	3	1	3
%NONCOLGAT	1	0	1	0	1
%CLING-HYDRO/SIMULIIDS	3	1	3	3	3
%DIPTERA	0	0	0	1	0
%TOLER	0	0	1	0	1
%INTOL	2	0	2	2	2
%TRICH	2	0	3	1	2
%T-HYDROPS	3	0	3	3	3

* See Table **3** for abbreviation definitions.

Table 9. Summary statistics for SEP and MACP reference sites.

	SEP reference sites				MACP reference sites			
	Min	Max	Mean	Median	Min	Max	Mean	Median
TotTaxa	9.0	26.0	17.1	17.0	16.9	17.0	8.0	23.0
HBI	3.2	6.7	5.2	5.4	5.7	5.9	4.1	6.9
EPTTax	0.0	12.0	5.7	5.0	4.5	4.0	1.0	10.0
%Ephem	0.0	49.1	17.9	15.9	12.3	5.2	0.0	62.5
%Cling	0.9	74.1	31.4	26.2	10.6	7.3	0.0	44.6
%PT-Hydrop	0.0	38.2	9.4	5.5	6.2	5.0	0.0	20.0
%Scraper	0.0	42.7	17.1	14.7	9.7	6.8	0.0	39.1
%Chiro	0.8	62.0	27.7	23.6	24.7	19.3	6.0	60.0
%NonInsect	0.0	16.1	1.9	0.9	2.0	0.9	0.0	10.9
%EPT	0.0	86.3	29.5	30.8	19.1	13.4	1.0	67.0
%EPT-Hydrop	0.0	81.4	27.4	27.8	18.5	11.0	0.9	67.0
%1Dom	13.6	62.0	36.9	36.4	33.6	31.8	16.0	60.0
%2Dom	24.2	80.0	53.4	54.6	52.8	51.0	30.0	90.0
%5Dom	57.0	94.6	79.2	83.5	78.7	78.2	64.0	97.3
%NonColGat	5.5	99.0	49.7	47.4	41.7	43.1	3.6	76.0
%Cling-Hydro/Simuliids	0.0	67.3	26.0	20.9	8.3	4.5	0.0	42.7
%Diptera	0.8	68.5	32.3	31.8	29.5	26.2	6.0	60.9
%Toler	0.0	49.0	13.3	10.8	22.6	23.7	1.8	48.2
%Intol	0.0	68.6	12.9	8.8	11.5	8.4	0.0	34.6
%Trich	0.0	40.2	8.0	6.4	6.4	4.0	0.0	20.9
%T - Hydrop	0.0	35.3	5.9	2.7	5.7	4.0	0.0	20.0

Box-and-whisker plots of the final SEP reference/stress dataset are displayed in Figure A-12. Removal of Chowan sites significantly improved the discriminatory ability of the metrics. Total Taxa, HBI, EPT Taxa, %Ephemeroptera, %Scrapers, %PT-Hydropsychid, %Clingers-Hydropsychid/Simulids and %T-Hyrdopsychid scored 3s (Table 8). SEP data responds well to the aforementioned metrics.

The addition of the Chowan sites to the MACP (n=69; reference n=27, stress n=42) resulted in a change in discriminatory power in two metrics: %Trichoptera and % Scrapers. Metrics that performed well (discriminatory power = 3) include the following: Total Taxa, EPT Taxa, % Ephemeroptera, %Clingers, %PT-Hydropsychid, %EPT, %EPT-Hyrdopsychid, %1, %2, and %5 Dominant taxa, %Clingers-Hydropsychid/Simuliids, and %T-Hydropsychid (Figure A-13, Table 8). HBI scored a 2 due to a slight overlap in the box-and-whisker interquartile ranges (Figure A-13).

4.2.4 Redundancy Analysis Results

This study uses 0.80 to screen metrics for redundancy. Six metrics exhibited redundancy above the screening value (Table 10).

Table 10. Pearson correlation results (n=242).

	Redundancy (r-value > 0.80)		
Metric	Metric (r-value)	Metric (r-value)	Metric (r-value)
%EPT	%Ephem (0.82)		
%EPT-Hydrop	%Ephem (0.88)	%EPT (0.95)	
%1Dom	%2Dom (0.91)		
%5Dom	%2Dom (0.85)		
%Cling-Hydro/Simuliids	%Cling (0.84)	%EPT (0.83)	%EPT-Hydrop (0.81)
%Diptera	%Chiro (0.92)		

4.2.5 Relationships to Stressors

Table 11 shows the results of the Spearman Rank correlations generated with the non-pseudoreplicated dataset (n=124). The highest correlations occurred between %Scrapers and pH (r=0.454) and %Clingers and DO (r=0.454). Percent Chironomids exhibited the lowest correlations to stressors overall. Percent 2Dominant taxa, %Non-insect, %EPT Taxa, and %EPT-Hyrdropsychids correlated well to % Forest. The former two metrics correlated negatively to % Forest and the latter two metrics positively. Total taxa, EPT taxa, and % Ephemeroptera negatively correlated with total nitrogen (TN).

Table 11. Spearman correlation results (n=124).

Metric	Highest Correlations n=124 (r)				
Total Taxa	TN (-0.435)	% Forest (0.391)	Natural Index (0.366)	Human Land Use (-0.366)	% Agriculture (-0.297)
HBI	DO (-0.352)	% Forest (-0.347)	PH (-0.333)	Natural Land Use (-0.283)	Human Land Use (0.283)
EPT Taxa	TN (-0.427)	DO (0.420)	% Forest (0.410)	Natural Land Use (0.334)	Human Land Use (-0.334)
% Ephemeroptera	TN (-0.440)	% Forest (0.408)	Natural Land Use (0.360)	Human Land Use (-0.360)	% Agriculture (-0.302)
% Clingers	DO (0.454)	% Forest (0.400)	TN (-0.314)	Bank Stability (-0.313)	Natural Land Use (0.300)
% PT-Hydros	DO (0.351)	TN (-0.341)	% Forest (0.311)	Channel Alteration (0.291)	% Agriculture Cropland (-0.253)
% Scrapers	PH (0.454)	Bank Stability (-0.243)	Sediment Deposition (-0.200)	Specific Conductance (0.199)	TN (-0.148)
% Chironomids	% Agriculture (0.179)	Human Land Use (0.170)	Natural Land Use (-0.170)	Epifaunal Substrate (0.163)	% Wetland (-0.162)
% 2 Dominant Taxa	% Forest (-0.344)	Human Land Use (-0.322)	Natural Land Use (0.322)	TN (-0.299)	Channel Alteration (-0.265)
% Non-Insect	% Forest (-0.320)	Human Land Use (0.231)	Natural Land Use (-0.231)	% Wetland (0.224)	Specific Conductance (0.185)
% EPT Taxa	% Forest (0.421)	TN (-0.382)	DO (0.346)	Natural Land Use (0.346)	Human Land Use (-0.346)
% EPT-Hydros	% Forest (0.435)	TN (-0.428)	Natural Land Use (0.367)	Human Land Use (-0.367)	DO (0.327)
% 1 Dominant Taxa	% Forest (-0.280)	Human Land Use (0.271)	Natural Land Use (-0.272)	Channel Alteration (-0.236)	TN (0.235)
% 5 Dominant Taxa	TN (0.393)	% Forest (-0.369)	Natural Land Use (-0.325)	Human Land Use (0.325)	Channel Alteration (-0.279)
% Non-Collector Gatherer	% Forest (0.270)	Natural Land Use (0.239)	Human Land Use (-0.239)	Sediment Deposition (-0.236)	Epifaunal Substrate (-0.208)
% Clingers-Hydros Simuliids	TN (-0.368)	DO (0.356)	% Forest (0.347)	Bank Stability (-0.321)	Sediment Deposition (-0.264)
% Diptera Taxa	DO (0.233)	Riparian Vegetation (-0.210)	Channel Alteration (-0.182)	% Wetland (-0.155)	Epifaunal Substrate (0.129)
% Tolerant Taxa	DO (-0.396)	% Wetland (0.246)	PH (-0.226)	% Agriculture Cropland (0.206)	Bank Stability (0.175)
% Intolerant Taxa	PH (0.337)	TN (-0.301)	% Forest (0.295)	Natural Land Use (0.251)	Human Land Use (-0.251)
% Trichoptera Taxa	DO (0.298)	Channel Alteration (0.296)	% Wetlands (-0.274)	% Forest (0.256)	TP (-0.225)
% Trichoptera-Hydros	TN (-0.259)	DO (0.237)	Channel Alteration (0.222)	% Forest (0.222)	TP (-0.220)

4.3 Discussion of Metric Evaluation and Selection

NMS and MeanSim aided in the selection of the best classification scheme to explain biological properties in the dataset. From the NMS results, it appeared that basin size, ecoregion, and region exhibited potential patterns. MeanSim CS results were low suggesting that the classification variable patterns warrant further investigation. Basin size resulted in the highest CS with the original size categorization. The fact that 3 of the categories (<1 mi^2, 200-500 mi^2, >500 mi^2) were comprised of data from one stream may explain the clustering and CS. Further evidence was exhibited by the two re-classification attempts that applied heterogeneity within the size groupings and the resulting lower CSs. It is important to note that NMS by stream order resulted in a cluster of first order streams (which have smaller basin sizes). The stream order and basin size findings support the need for further investigation and the general rule that it is best to use caution with data from extremely small watersheds and extremely large watersheds. It is likely that the VDEQ region clustering patterns and CS results may be related to ecoregion. The NRO occupies the north western most areas of the SEP and that area tends to have more topographic relief and floodplains that are more evident (Maxted et al. 2000, White 1997). Based on the results of this study, recalibration by basin size or DEQ region is not recommended however; further exploration of data from headwater streams and rivers with large drainage areas is warranted.

CS was low for bioregion; however, other analyses (Appendix A) performed in this study suggested that grouping the Chowan basin sites with the MACP may be appropriate for the CPMI as the Chowan tends to be swamp-like and thus, more like MACP streams. Removal of the Chowan basin sites from the SEP resulted in significant discriminatory power improvements in all but 5 metrics. Including Chowan basin sites in the MACP resulted in no change to the majority of the metrics.

5.0 RECOMMENDED METRICS AND INDEX EVALUATION

5.1 Recommended metrics

Five metrics performed well in both the MACP (including Chowan basin sites) and SEP: Total Taxa, EPT Taxa, % Ephemeroptera, HBI and % Clingers-Hydropsychid/Simuliids. The aforementioned 5 metrics all exhibited discriminatory power of 3; however, % Intolerant taxa in the SEP and HBI and %PT-Hydropsychid in the MACP had somewhat lower discriminatory ability. In addition, the selected metrics were not redundant and they correlated to both chemical and land use stressors.

The following 7 metrics are recommended for further analysis in the MACP (plus Chowan basin sites):

- Total Taxa (Richness)
- EPT Taxa (Richness)
- % Ephemeroptera (Composition)
- % PT-Hydropsychid (Composition)
- HBI (Tolerance/Dominance)
- % 5 Dominant Taxa (Tolerance/Dominance)
- % Clingers minus Hydropsychid+Simuliid (Habit)

The following 8 metrics are recommended for further analysis in the SEP (minus Chowan basin sites):

- Total Taxa (Richness)
- EPT Taxa (Richness)
- % Ephemeroptera (Composition)
- % PT – Hydropsychid (Composition
- HBI (Tolerance/Dominance)
- % Intolerant Taxa (Tolerance/Dominance)
- % Clingers minus Hydropsychid+Simuliid (Habit)
- % Scrapers (Trophic Group Composition)

The MACP metrics were selected based on their strong discriminatory power and sensitivity to stressors. Of the 12 metrics that successfully discriminated between reference and stress, %EPT, %EPT-Hydropsychid, %Clingers, %1 Dominant taxa and %2 Dominant taxa did not add any additional information. Percent 5 Dominant taxa was selected because it correlated better to stress than did %2 Dominant taxa. Percent PT-Hydropsychid was selected over %T-Hydropsychid based on the Spearman Rank correlation results. HBI had slightly lower discriminatory power but was selected in order to add another Dominance/Tolerance metric to the MACP metric list. The final selected metric list consists of 2 Richness, 2 Composition, 2 Dominance/Tolerance metrics and one Habit metric.

The SEP metric selection process resulted in 2 Richness and 2 Tolerance/Dominance metrics, and one metric each from Composition, Habit and Trophic/Feeding Group Composition. The metrics chosen were successful at discriminating between reference and stress sites and correlated well to stressors. For the next sections in this report, we will refer to the new CPMI metrics presented above as VCPMI MACP+C and VCPMI SEP-C.

5.2 Index and Metric Scoring

In order to establish scoring thresholds, the 95th percentiles (or 5th percentiles for negative responding metrics) were calculated for each of the selected metrics (Table 12 and Table 13, respectively). Ceiling and floor values (95th and 5th percentile, respectively) were calculated for each metric (Pond et al. 2012, Blocksom 2003, Blocksom and Johnson 2009, and Whittier et al. 2007) and are presented in Table 14 and Table 15. This approach allows for comparison of different types of metrics (i.e. those based on counts, percentages, and logarithmic functions) by weighting them into unitless comparison of different types of metrics. Metrics that score greater than 100, and as such are greater than the 95th percentile value, were set at 100. Metrics that scored below the 5th percentile were set to zero. It is noteworthy that the MACP+C VCPMI %Ephem Best Standard Value was just over half of the 95th percentile from the Maxted CPMI. The former was 25.4 (Table 12) and the latter was 48.1 (Maxted et al. 2000).

Table 12. Best Standard Values for VCPMI MACP plus Chowan sites.

Percentile	TotTaxa	mHBI	EPTTax	%Ephem	%PT - H	%5Dom	%Clingers minus Hydropsychid +Simuliid
95th Percentile (Ceiling)	21.0	7.4	8.0	25.4	8.2	100.0	18.7
5th Percentile (Floor)	6.1	4.9	0.0	0.0	0.0	69.2	0.0

Table 13. Best Standard Values for VCPMI SEP minus Chowan sites.

Percentile	TotTaxa	mHBI	EPTTax	%Ephem	%PT - H	%Scrap	%Clingers minus Hydropsychid +Simuliid	%Intol
95th Percentile (Ceiling)	22.0	7.2	9.1	34.6	27.8	35.5	46.6	31.3
5th Percentile (Floor)	7.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0

The floor and ceiling values were incorporated into the metric scoring calculations as shown in Table 14 and Table 15. The CPMI Score is the sum of all of the metrics.

Table 14. Index Calculations for MACP (plus Chowan sites) VCPMI Metrics.

Metric	Ceiling	Floor	Equation
TotTaxa	21	6.1	$\frac{\#TotTaxa - Floor}{Ceiling - Floor} \times 100$
mHBI	7.4	4.9	$\frac{Ceiling - mHBI}{Ceiling - Floor} \times 100$
EPTTaxa	8	0	$\frac{\#EPTTaxa - Floor}{Ceiling - Floor} \times 100$
%Ephem	25.4	0	$\frac{\%Ephem - Floor}{Ceiling - Floor} \times 100$
%PT - H	8.2	0	$\frac{\%PT\text{-}H - Floor}{Ceiling - Floor} \times 100$
%5Dom	100	69.2	$\frac{Ceiling - \%5Dom}{Ceiling - Floor} \times 100$
%Clingers-H&S	18.7	0	$\frac{\%Clinger\text{-}H\&S - Floor}{Ceiling - Floor} \times 100$

Table 15. Index Calculation for SEP (minus Chowan sites) VCPMI Metrics.

Metric	Ceiling	Floor	Equation
TotTaxa	22	7	$\frac{\#TotTaxa - Floor}{Ceiling - Floor} \times 100$
mHBI	7.2	4.2	$\frac{Ceiling - mHBI}{Ceiling - Floor} \times 100$
EPTTaxa	9.1	0	$\frac{\#EPTTaxa - Floor}{Ceiling - Floor} \times 100$
%Ephem	34.6	0	$\frac{\%Ephem - Floor}{Ceiling - Floor} \times 100$
%PT - H	27.8	0	$\frac{\%PT\text{-}H - Floor}{Ceiling - Floor} \times 100$
%Scrapers	35.5	0	$\frac{\%Scrapers - Floor}{Ceiling - Floor} \times 100$
%Clingers-H&S	46.6	0	$\frac{\%Clinger\text{-}H\&S - Floor}{Ceiling - Floor} \times 100$
%Intol	31.3	0	$\frac{\%Intol - Floor}{Ceiling - Floor} \times 100$

5.3 Index Performance

5.3.1. Discrimination Efficiency

All sites (reference, stress and test sites; n=122) were analyzed with Principal Component Analysis (PCA) and compared to a stressor gradient (inferred from Axis 1). The PCA (Figure 13) shows that CPMI scores increase along a stressor gradient with lower scores correlating to high nutrients, specific conductance and agricultural land uses and higher scores correlating with forested and more natural landcovers.

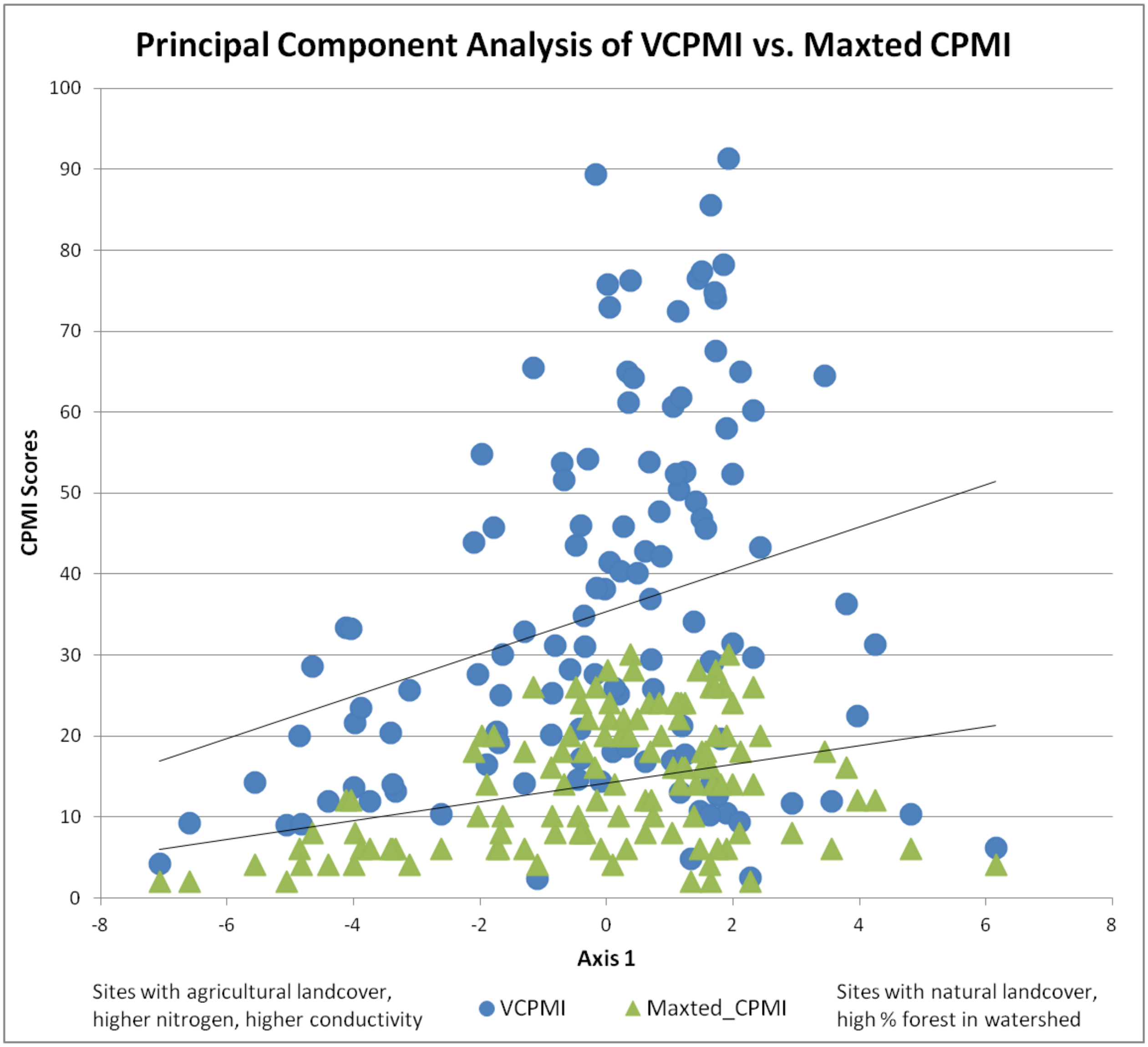

Figure 13. Scatterplot of Maxted CPMI vs. VCPMI Scores (all sites, n=122) along a stressor gradient (Principal Component Analysis Axis 1).

Table 16 displays eigenvalues and percent variance represented by each axis. Axis 1 explained 28% of the variance and had an eigenvalue of 5.6. Table 17 shows each variable's factor coefficient by axis number of the first three components. Natural landcover (-0.40), % Forest (0.38) and % Agriculture (0.38) had the highest correlations.

Table 16. Principal Component Analysis (PCA) Results.

Axis	Eigenvalue	Percentage	Cum. Variance
1	5.6	28.1	28.1
2	2.8	14.0	42.1
3	2.0	9.7	51.8

Table 17. Principal Component Analysis (PCA) coefficients of the first three components with moderately correlated parameters (>0.3) bolded and italicized. Habitat parameters based on Rapid Bioassessment Protocols methods (Barbour et al. 1999).

Parameters	Axis 1	Axis 2	Axis 3
Epifaunal Sub	0.05	0.22	-0.08
Channel Alt	-0.16	***0.39***	0.24
Sediment	-0.10	***0.42***	0.09
Bank Stab	-0.03	***0.39***	0.00
Riparian Veg	-0.07	***0.46***	0.25
pH	0.16	-0.19	***0.33***
DO	-0.01	-0.12	***0.52***
Spec Cond	***0.31***	-0.10	0.05
TSS	0.04	0.10	***-0.41***
Total N	***0.32***	0.12	-0.10
Total P	0.20	-0.08	-0.27
Natural Landcover	***-0.40***	-0.07	-0.02
% Forest	***-0.38***	-0.10	0.07
% Wetland	-0.16	0.13	***-0.38***
% Urban	0.14	-0.22	0.08
% Barren	-0.03	0.01	-0.24
% Agriculture	***0.38***	0.19	0.04
% Pasture	***0.32***	0.09	0.10
% Row Crop	***0.30***	0.21	-0.01

5.3.1. Precision

Same-day replicate samples were used to estimate precision of the metrics and the MACP+C VCPMI and SEP-C VCPMI. The approach utilized was based on methodology described by Stribling (2008) and Pond et al. (2012). Analysis of Variance (ANOVA) was used to calculate within-samples mean square. Each group is made up of the same-day replicate samples for a station. The ANOVA resulted in variance values for each group and the within groups mean square (i.e. the average variance). The root mean square error (RMSE; i.e. the square root of the within-group mean square) represents the best estimate of the metric standard deviation. The RMSE was then used to calculate 90% Confidence Intervals. The coefficient of variance (%CV) was calculated as the standard deviation divided by the mean VCPMI score for all samples within each stratum (i.e. all seasons, fall, and spring or score ranges). The relative percent difference (RPD) is the difference between the two same-day replicate VCPMI scores divided by the average of the two same-day replicate scores. According to Pond et al. (2012), lower RPD values are indicative of better precision but the actual RPD can be susceptible to low mean values. Table 18 shows the MACP+C VCPMI precision estimates and Table 19 depicts the SEP-C VCPMI precision estimates and statistics.

Table 18. MACP+Chowan VCPMI precision estimates and statistics (includes % coefficient of variance [CV %] and relative percent difference [RPD]).

VCPMI by Stratum	N	MEAN	ST DEV	ONE-TAIL 90% C.I.	CV (%)	RPD
ALL SCORES (BOTH SEASONS)	51	36.4	4.1	9.6	11.3	19.9
ALL SCORES (FALL)	21	45.8	4.1	9.6	8.9	14.3
ALL SCORES (SPRING)	30	29.6	4.2	9.5	13.9	23.9
VCPMI by Score Ranges						
POOR SCORES (0 to 30)	23	18.8	3.1	7.2	16.6	25.2
FAIR SCORES (30 to 55)	16	39.3	4.3	10.2	11.1	18
GOOD SCORES (55 to 100)	12	66.4	5.7	12.2	8.6	12.5

Table 19. SEP-Chowan VCPMI precision estimates and statistics (includes % coefficient of variance [CV %] and relative percent difference [RPD]).

VCPMI by Stratum	N	MEAN	ST DEV	ONE-TAIL 90% C.I.	CV (%)	RPD
ALL SCORES (BOTH SEASONS)	21	52.8	3.9	7.7	7.4	11.6
ALL SCORES (FALL)	13	55.2	4.4	8.6	8.0	12.7
ALL SCORES (SPRING)	8	50.4	3.1	6.1	6.3	9.8
VCPMI by Score Ranges						
FAIR/POOR SCORES (0 to 55)	11	35.5	3.5	7.4	9.7	14.2
GOOD SCORES (55 to 100)	10	71.9	4.4	8.1	6.1	8.8

5.4 Discussion of Index Evaluation

From the discrimination efficiency analysis using PCA (Figure 13), it is evident that both the Maxted CPMI and the VCPMI respond to stressors in the appropriate direction; however the VCPMI exhibits a slightly stronger relationship. In effect, the VCPMI has a slightly stronger relationship to human disturbance. The precision analysis resulted in low RPDs indicating that the index is precise. The indices are more precise when the scores are in the "good" ranges (Tables 18 and 19).

6.0 RECOMMENDATIONS

Based on the conclusions of the VDEQ Biologists' Self-Assessment that the existing CPMI needs improvement in its discriminatory power, in combination with the analyses presented in the previous sections, it is recommended that the new VCPMI be used to assess sites in the SEP and MACP for future 305(b)/303(d) Integrated Reports. The inclusion of 100% Virginia sites in this study when compared to 15% in the Maxted CPMI provides further support for the VCPMI being an improvement over the existing application of the Maxted CPMI in Virginia. It is also important to note that the VCPMI showed a slightly better response to human disturbance (Figure 13) and good precision.

In order to establish an appropriate impairment threshold for Virginia, reference percentiles were calculated for the MACP (plus Chowan sites) VCPMI and SEP (minus Chowan sites) VCPMI. Table 20 depicts the 5th, 10th, 25th, 50th, 75th and 95th reference percentiles for the VCPMIs. The 25th percentile was determined to be the most appropriate threshold for the MACP+C VCPMI and the SEP-C VCPMI. The 25th percentile was selected because the SEP and MACP ecoregions are influenced by a substantial amount of natural variability and anthropogenic stressors.

Table 20. Percent of Reference for VCPMI. Impairment threshold for Virginia is recommended at the 25th percentile.

MACP VCPMI (plus Chowan sites) n=27		SEP VCPMI (minus Chowan sites) n=22	
95th Percentile	88.3	**95th Percentile**	88.5
75th Percentile	72.8	**75th Percentile**	76.3
50th Percentile	58.0	**50th Percentile**	56.0
25th Percentile	***40.0***	***25th Percentile***	***40.8***
10th Percentile	25.5	**10th Percentile**	35.1
5th Percentile	19.8	**5th Percentile**	31.4

7.0 COMPARISON OF MAXTED et al. CPMI (2000) AND VCPMI

There are noticeable differences between the Maxted CPMI and VCPMI. The VCPMI was developed using a more extensive and robust Virginia dataset. During the analysis, ecoregional differences were evident and a different set of metrics were selected for SEP and MACP. In addition, the Chowan basin sites are more similar to the MACP making the addition of the Chowan a distinct difference between the Maxted CPMI and the VCPMI. The recommended VCPMI scoring approach (a 0 to 100 scale) differs from how the Commonwealth utilized the Maxted CPMI. This section explores additional data analyses to compare the Maxted CPMI and VCPMI using available Virginia reference and stress sites.

Figure 14 shows box-and-whisker plots of reference and stress sites by MACP+C VCPMI scores. Figure 15 incorporates the Maxted CPMI scoring and shows that 57% (12 out of 21) MACP reference sites were considered impaired using the Maxted CPMI with the original impairment threshold (CPMI=16). A similar trend was observed using the Maxted CPMI where 31% (11 out of 35) of SEP reference sites were considered impaired (Figure 17). In general, the VCPMI discriminates well between reference and stress sites (Figure 16); whereas the Maxted CPMI tends to misclassify some reference sites as impaired. This relationship is explored further in Figure 18, Figure 19, Tables 20 and 21.

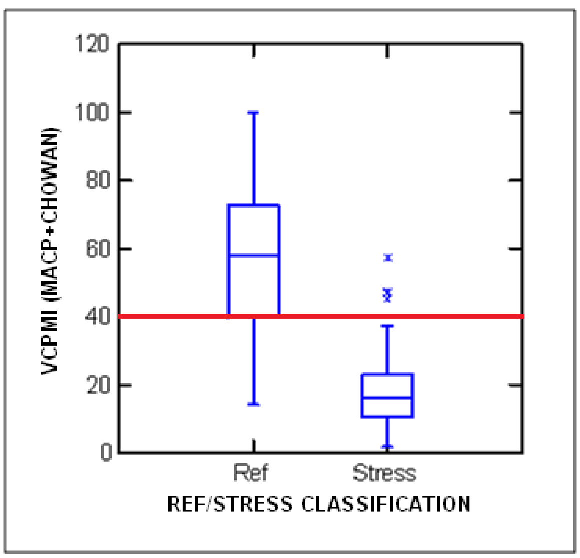

Figure 14. Box-and-whisker plots showing reference (n=27) and stress (n=42) sites using MACP+Chowan VCPMI scoring.

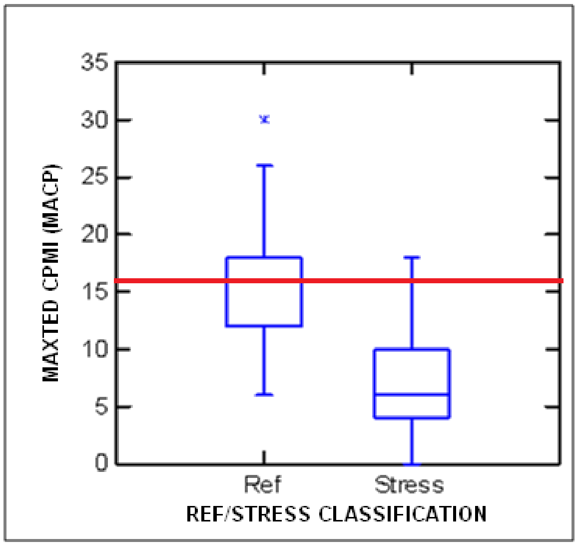

Figure 15. Box-and-whisker plots showing reference (n=21) and stress (n=35) sites using Maxted MACP CPMI scoring. The red line depicts the current impairment threshold (CPMI=16).

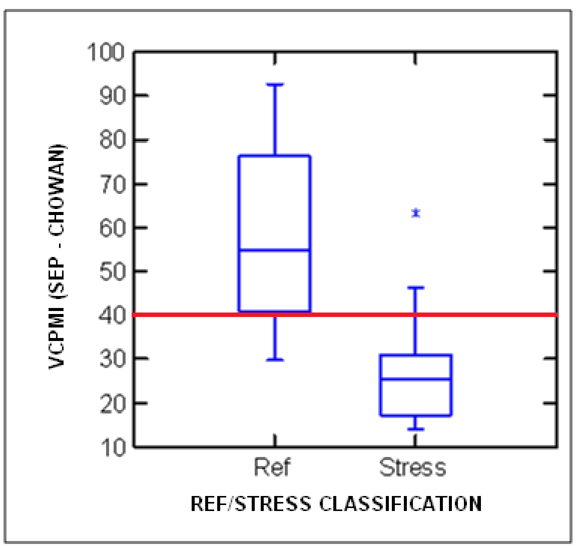

Figure 16. Box-and-whisker plots showing reference (n=22) and stress (n=11) sites using SEP-Chowan VCPMI scoring.

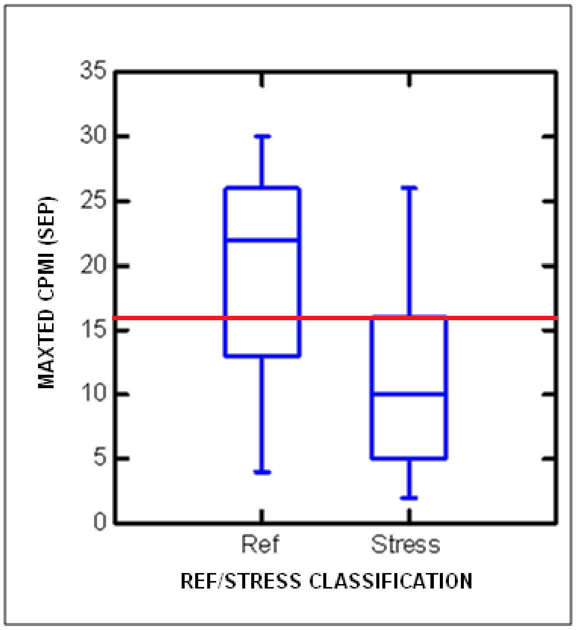

Figure 17. Box-and-whisker plots showing reference (n=31) and stress (n=15) sites using Maxted SEP CPMI scoring.

Scatterplots of all available MACP and SEP sites between 2002 and 2012 were utilized to depict discrepancies between the Maxted CPMI and the VCPMI (Figure 18 and Figure 19). The upper left corner of both plots the sites considered unimpaired by the Maxted CPMI and impaired using the VCPMI. The upper right quartile represents Maxted CPMI and VCPMI unimpaired sites. The lower left quartile contains sites that are considered impaired by both indices. The lower right area shows sites that are Maxted CPMI impaired and VCPMI unimpaired. Both figures utilize large datasets for the MACP+C and SEP-C ecoregions (n=472 and n=309, respectively).

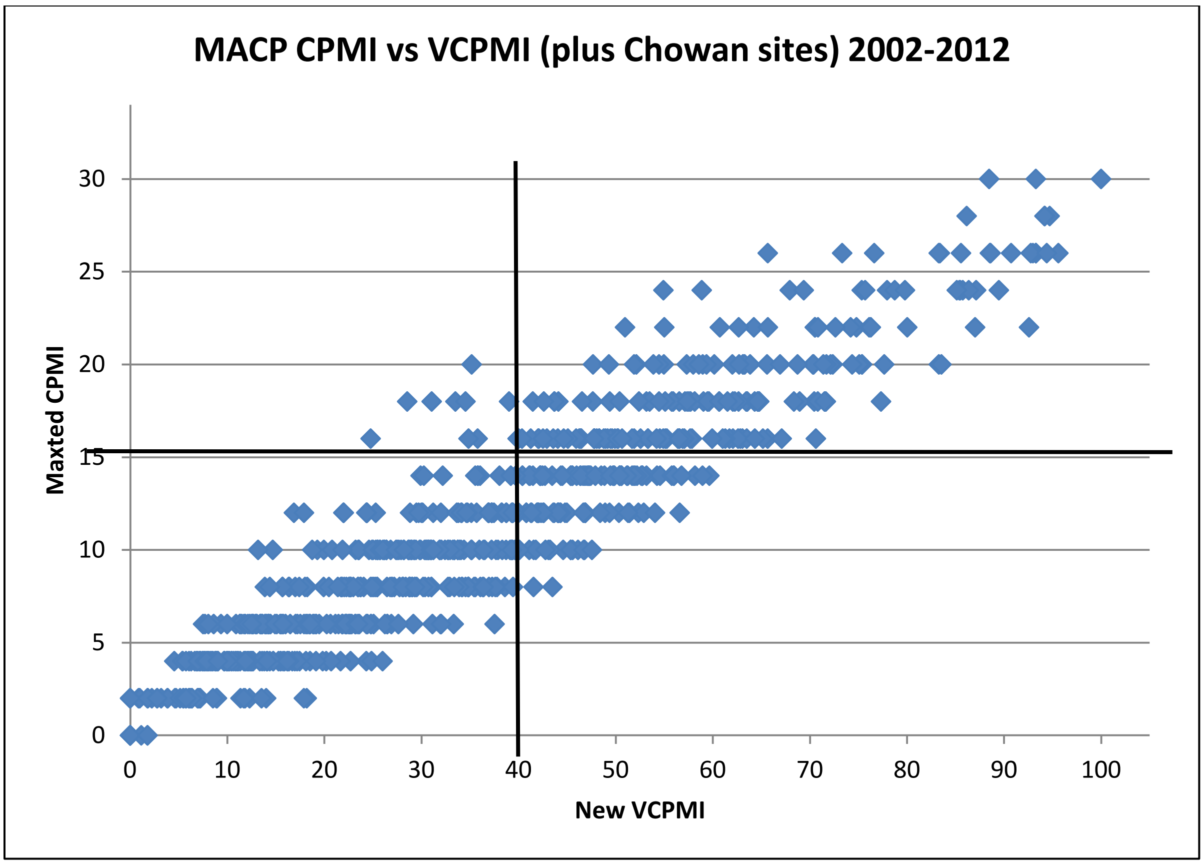

Figure 18. Scatterplot comparison of MACP Maxted CPMI vs. VCPMI (plus Chowan sites) (n=472, r^2=0.87).

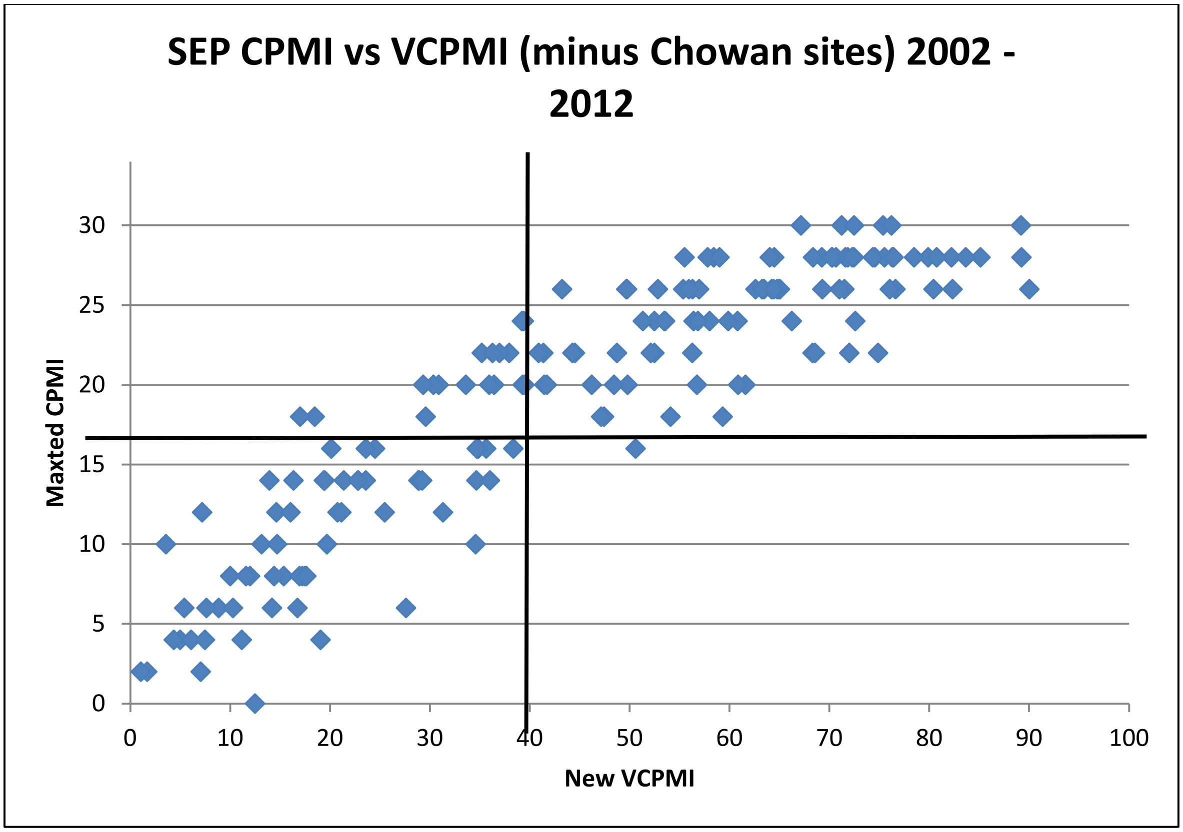

Figure 19. Scatterplot comparison of SEP Maxted CPMI vs. VCPMI (minus Chowan sites) (n=309, r^2=0.82).

Tables 21 and 22 present the probability each index was correct in classifying a site as reference or stress. In the MACP+C, the VCPMI classifies sites as reference 74% of the time as compared to Maxted CPMI at 48%. The VCPMI resulted in 91% correct for stress, which is slightly less than the Maxted CPMI.

Table 21. Probability of MACP (plus Chowan sites) reference and stress sites being appropriately classified using CPMI = 16 and VCPMI = 40 (reference n=27, stress n=42).

MACP + Chowan	# Sites	% Correct
Maxted CPMI Classifies Reference	13 out of 27	48%
Maxted CPMI Classifies Stress	41 out of 42	98%
New VCPMI Classifies Reference	20 out of 27	74%
New VCPMI Classifies Stress	38 out of 42	91%

The VCPMI more accurately identifies reference sites and the two indices are very close when it comes to classifying stress sites. SEP-C sites were more accurately classified as stress using the VCPMI. Both indices accurately classified SEP-C reference sites 77% of the time.

Table 22. Probability of SEP (minus Chowan sites) reference and stress sites being appropriately classified using CPMI = 16 and VCPMI = 40 (reference n=22, stress n=11).

SEP - Chowan	# Sites	% Correct
Maxted CPMI Classifies Reference	17 out of 22	77%
Maxted CPMI Classifies Stress	8 out 11	66%
VCPMI Classifies Reference	17 out of 22	77%
VCPMI Classifies Stress	9 out 11	82%

8.0 CONCLUSIONS

The original CPMI developed by Maxted et al. (2000) lacked a comprehensive Virginia dataset. Maxted et al. (2000) found that few suitable reference sites existed in the MACP and SEP ecoregions. Since that time, through various DEQ programs and VCU's INSTAR program, a more robust dataset became available and yielded the opportunity to revise the CPMI. This effort began as a validation study but ended up with the development of the MACP+C VCPMI and SEP-C VCPMI.

Possible basin size, ecoregion and VDEQ region patterns were noted in the NMS ordinations. MeanSim Classification Strengths were low. The analyses presented did not support recalibration by any of these classification approaches because it would result in fewer reference sites and thus less confidence in the assessment screening value. Based on the first order stream clustering in the stream order NMS ordination and the observation that smaller basin size reference sites tended to cluster, it is appropriate to use caution with sites that represent very small watersheds. Further evaluation of basin size is recommended as additional data becomes available. Even though bioregion CS was low, it became evident during other analyses in the VCPMI study that the two coastal plain ecoregions needed to be assessed using two different sets of metrics. In addition, the Chowan basin sites more closely resemble assemblages within the MACP ecoregion. Removal of the Chowan basin sites from the SEP resulted in significant discriminatory power improvements in all but 5 metrics. It was determined that the VDEQ region NMS patterns were related to ecoregion.

By significantly increasing the number of reference and stress sites when compared to the original CPMI study, the VCPMI is a more robust index specific to the coastal plain ecoregions of Virginia. The VCPMI replaces metrics that did not perform well in Virginia's coastal plain and has correctly calibrated each metric's best standard values. The VCPMI study has confirmed that the VCPMI works better than the old CPMI to discriminate between sites with acceptable water quality and habitat versus sites with degraded water quality and habitat. The VCPMI classifies stress slightly better than the Maxted CPMI. VDEQ's assessment threshold for the Maxted CPMI in the MACP tends to result in the listing of more streams as impaired. The VCPMI shows a clear improvement in SEP-C stress classification.

Overall, the VCPMI is an improvement over the Maxted CPMI and provides a reasonable interim step between the existing application of the Maxted CPMI and the development of a genus-level CPMI in Virginia. Even with the limited dataset, Miller's 2012 genus-level study observations support the key findings of this study (recalibration by ecoregion) and offer further support for recalibration by basin size and ecoseason. The ultimate goal is to develop a genus-level multi-metric index, which will likely further refine the enhancements made by the VCPMI over the Maxted et al. (2000) CPMI. Data collection is ongoing and revisiting the VCPMI and incorporating additional data will allow for further refinement of the indices.

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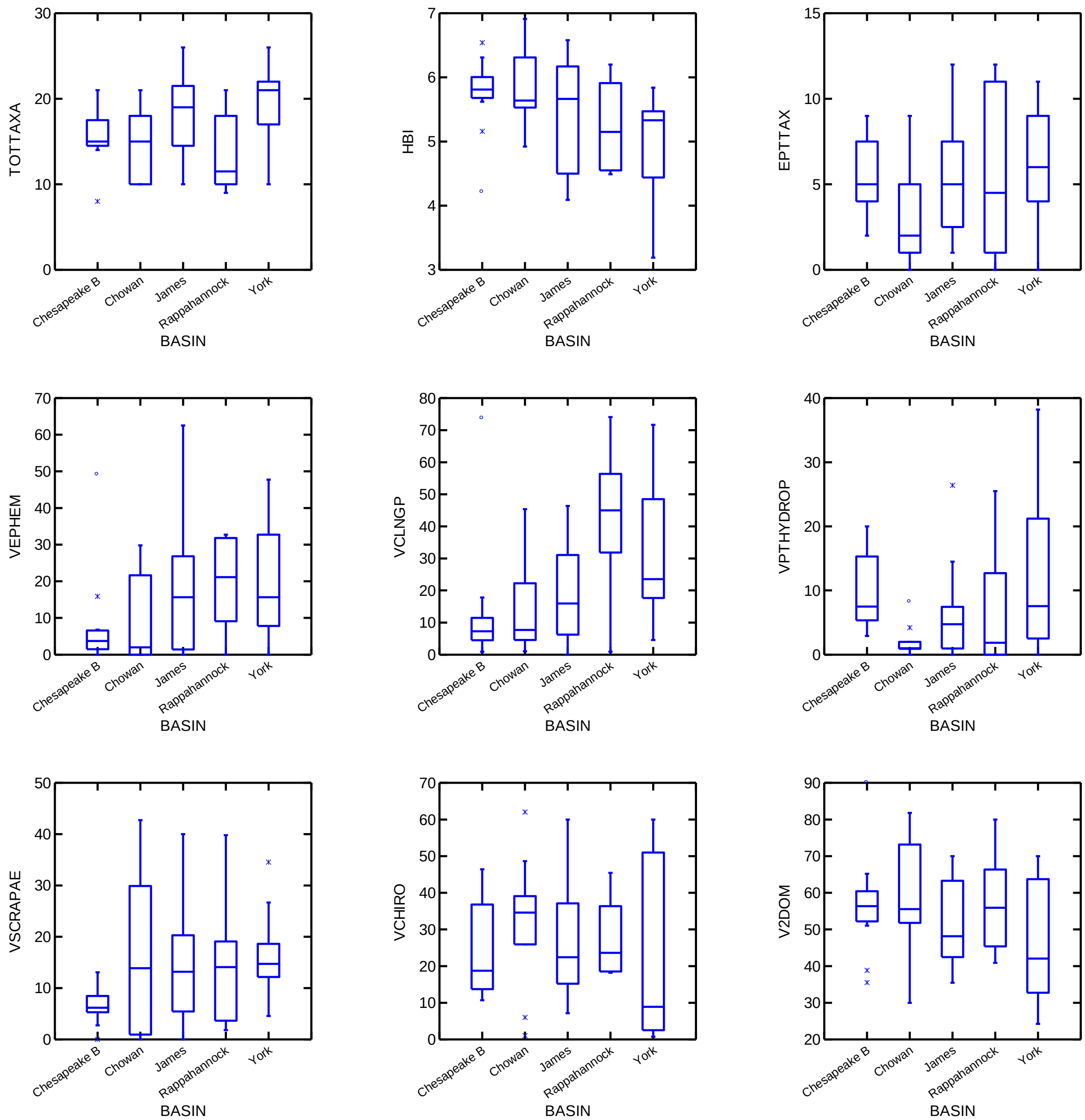
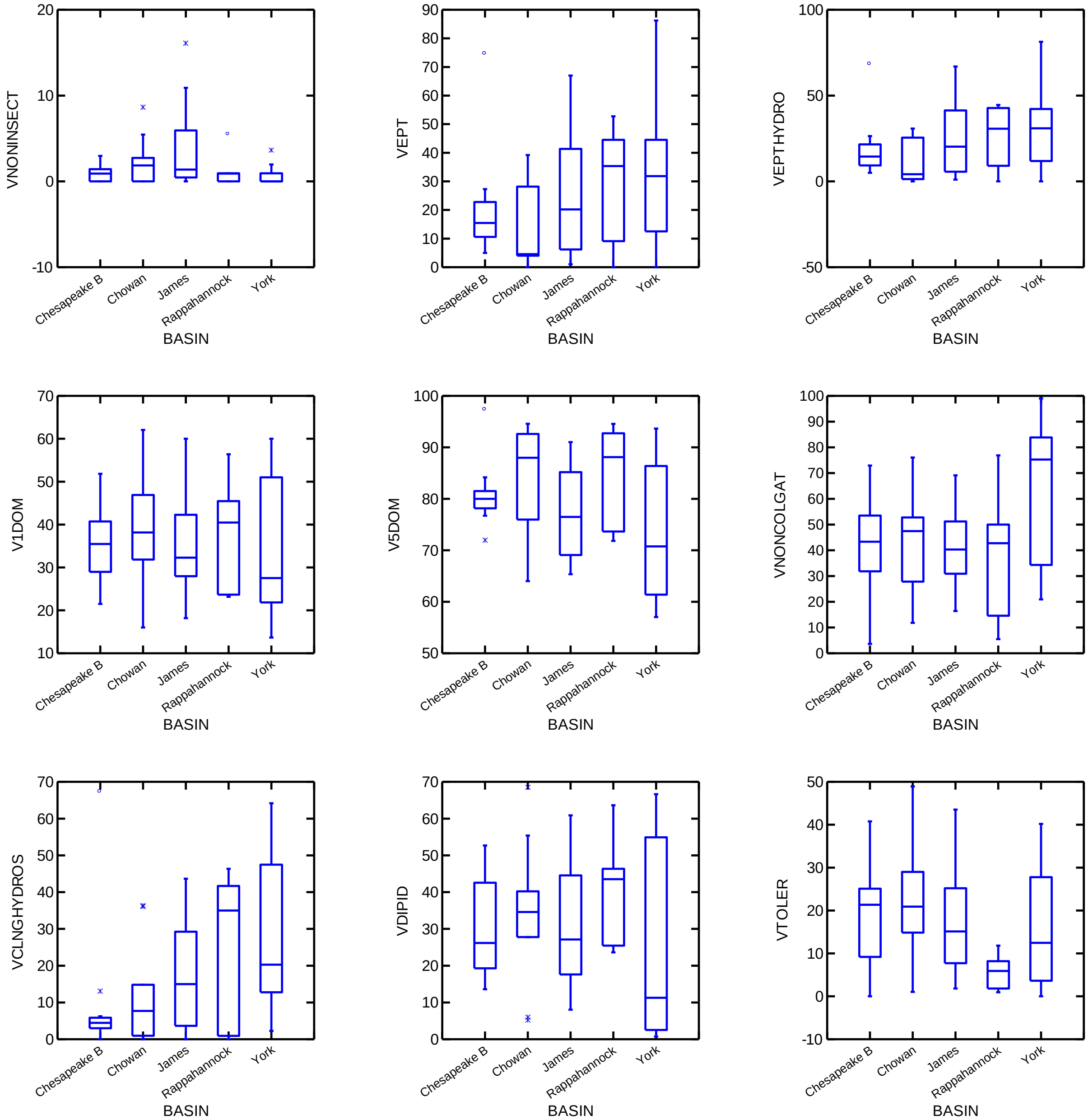
APPENDIX A

Figure A-1. Box-and-whisker plots of metrics by basin (n=56).




VNONINSECT
VEPT
VEPTHYDRO
V1DOM
V5DOM
VNONCOLGAT
VCLNGHYDROS
VDIPID
VTOLER
Chesapeake B
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James
Rappahannock
York
BASIN

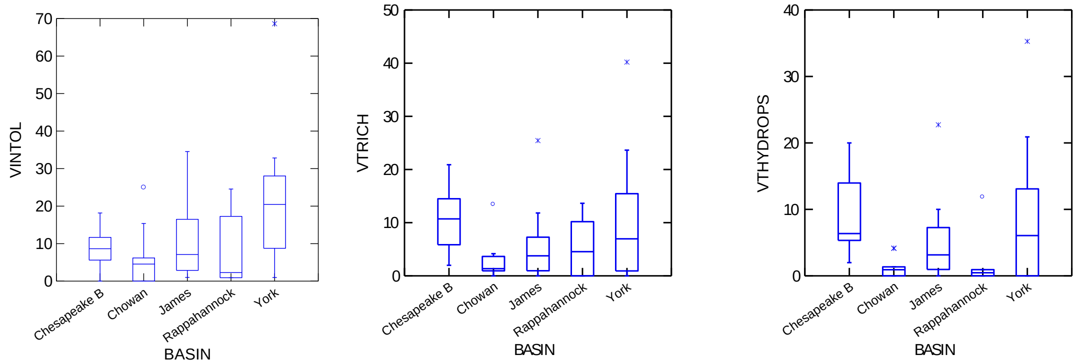
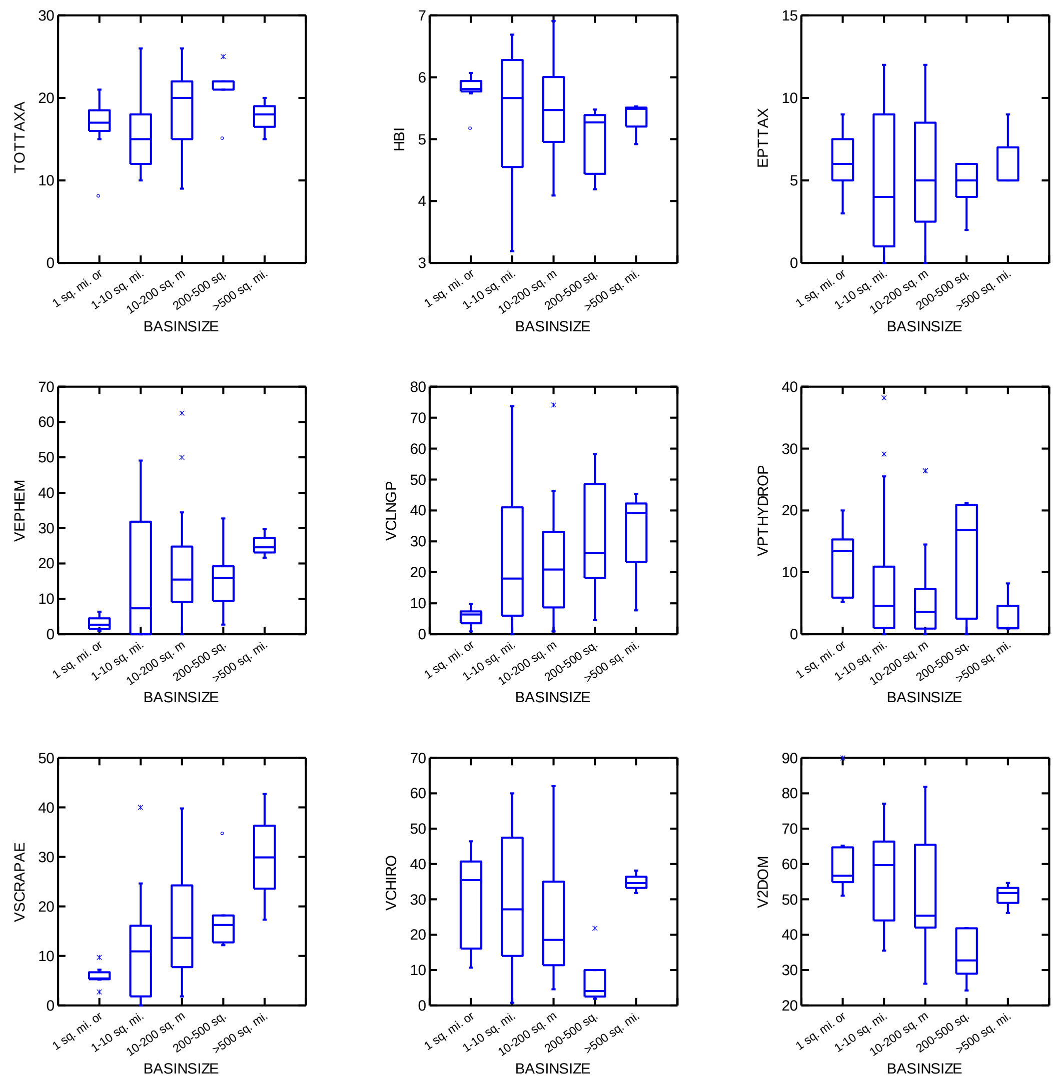


Figure A-2. Box-and-whisker plots of metrics by basin size.



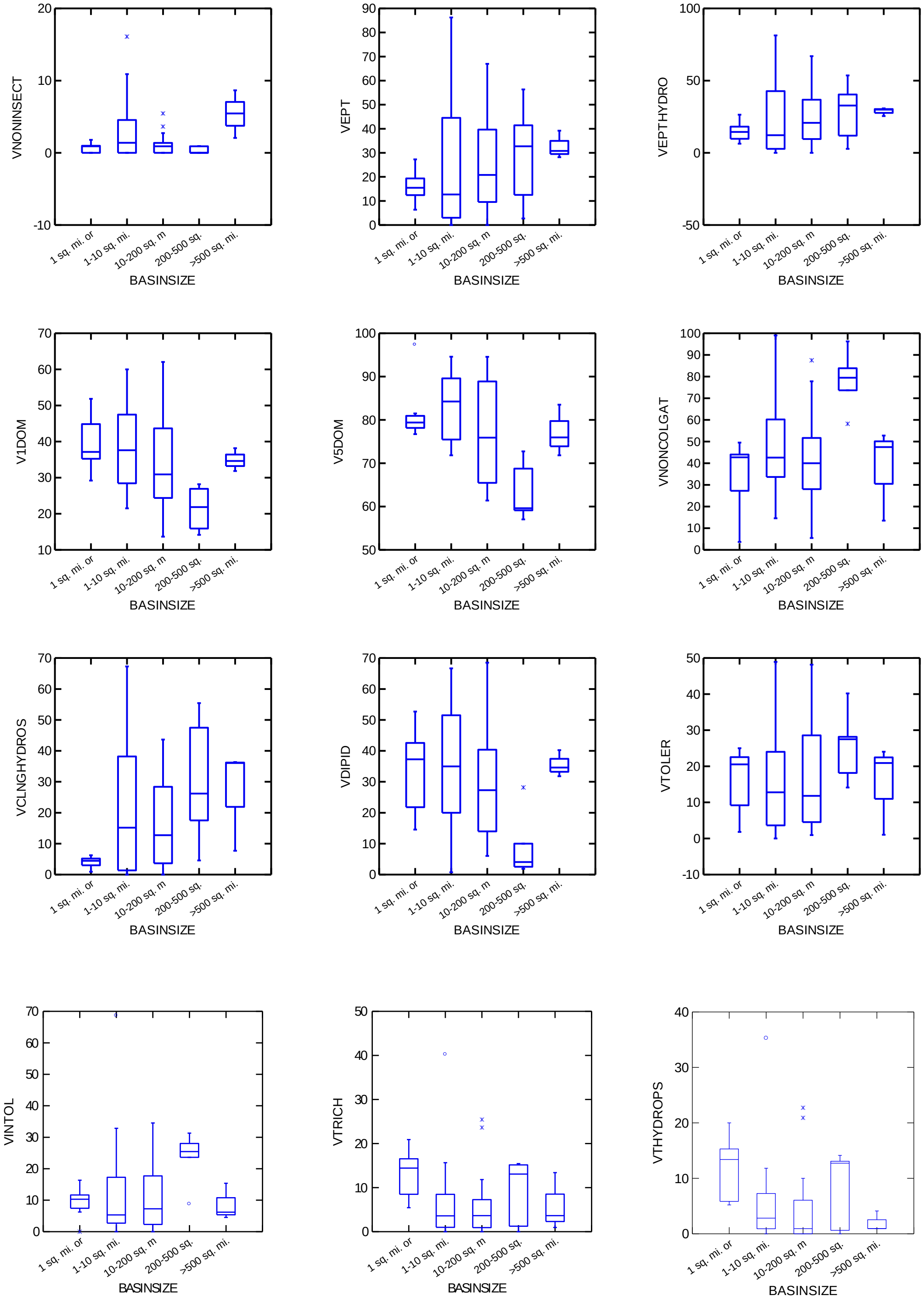
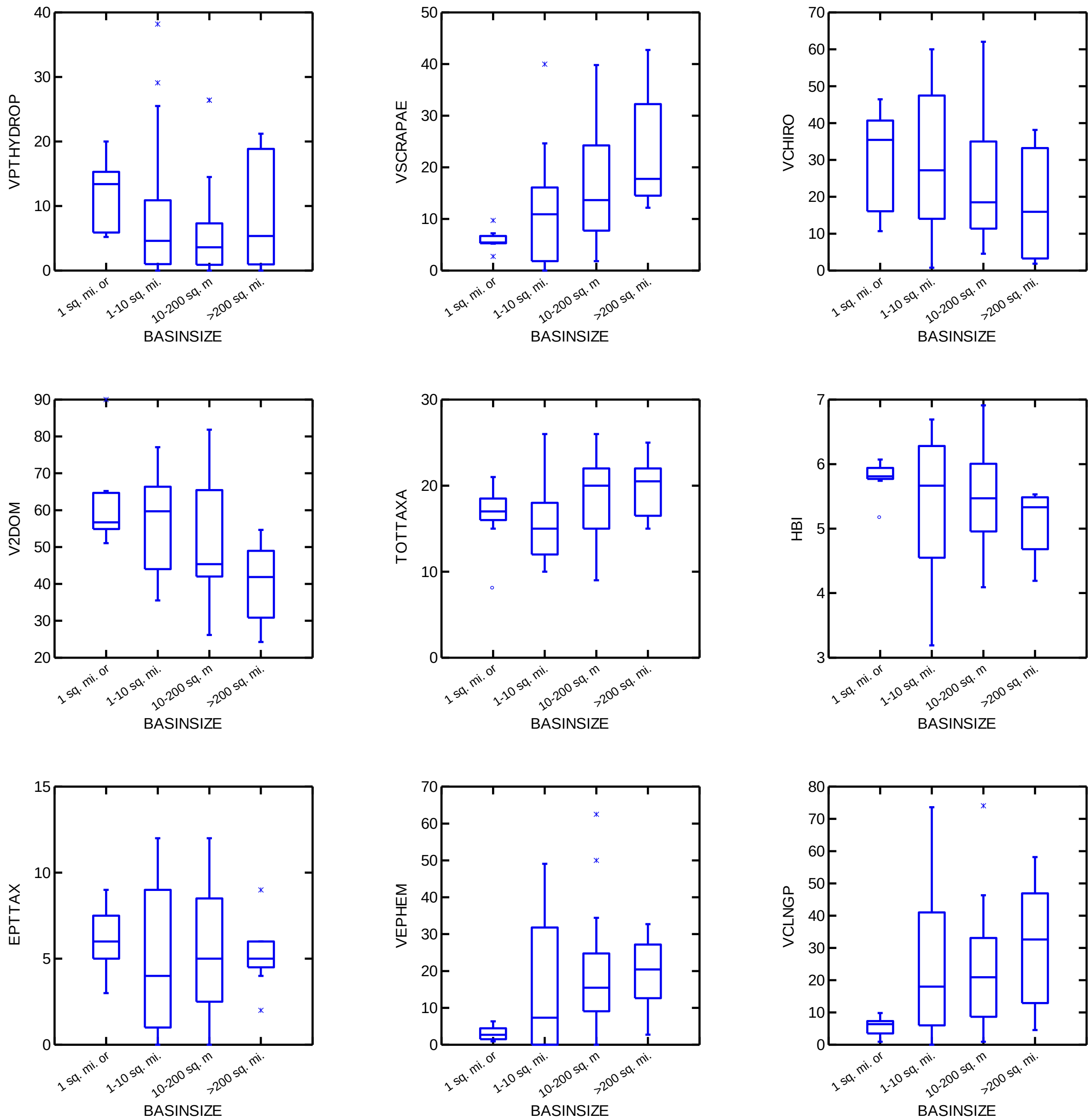
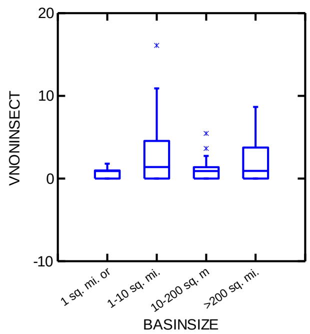
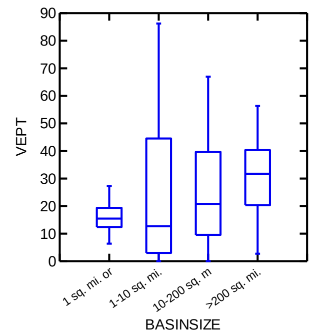
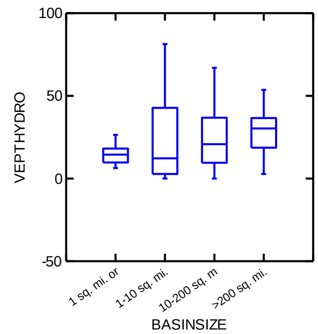

VNONINSECT
VEPT
VEPTHYDRO
V1DOM
V5DOM
VNONCOLGAT
VCLNGHYDROS
VDIPID
VTOLER
VINTOL
VTRICH
VTHYDROPS
BASINSIZE
1 sq. mi. or
1-10 sq. mi.
10-200 sq. m
200-500 sq.
>500 sq. mi.

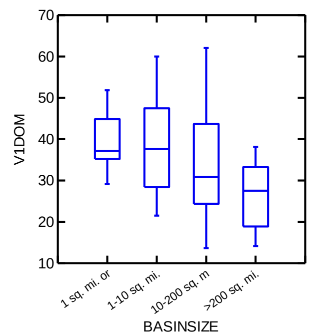
Figure A-3. Box-and-whisker plots of metrics by basin size (second re-categorization).

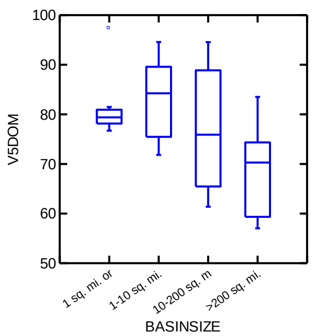


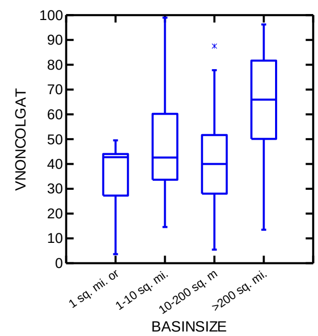

VNONINSECT
1 sq. mi. or
1-10 sq. mi.
10-200 sq. m
>200 sq. mi.
BASINSIZE

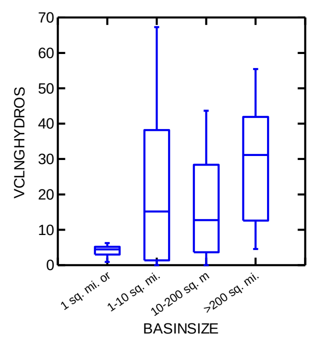

VEPT
1 sq. mi. or
1-10 sq. mi.
10-200 sq. m
>200 sq. mi.
BASINSIZE

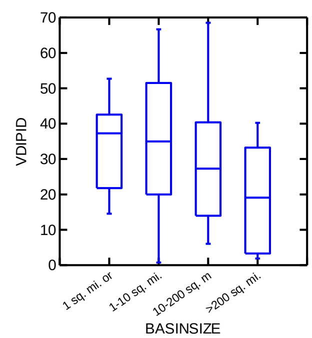

VEPTHYDRO
1 sq. mi. or
1-10 sq. mi.
10-200 sq. m
>200 sq. mi.
BASINSIZE

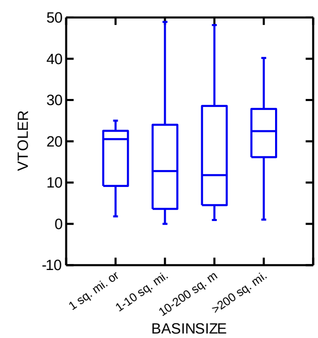

V1DOM
1 sq. mi. or
1-10 sq. mi.
10-200 sq. m
>200 sq. mi.
BASINSIZE

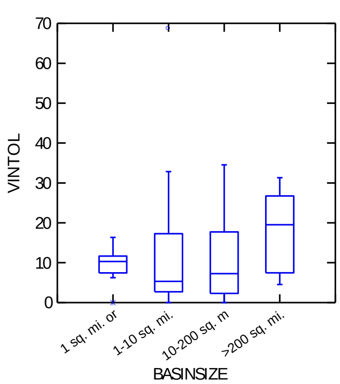

V5DOM
1 sq. mi. or
1-10 sq. mi.
10-200 sq. m
>200 sq. mi.
BASINSIZE

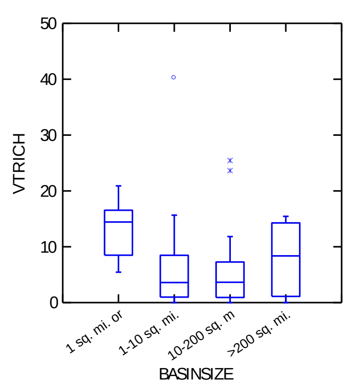

VNONCOLGAT
1 sq. mi. or
1-10 sq. mi.
10-200 sq. m
>200 sq. mi.
BASINSIZE


VCLNGHYDROS
1 sq. mi. or
1-10 sq. mi.
10-200 sq. m
>200 sq. mi.
BASINSIZE


VDIPID
1 sq. mi. or
1-10 sq. mi.
10-200 sq. m
>200 sq. mi.
BASINSIZE


VTOLER
1 sq. mi. or
1-10 sq. mi.
10-200 sq. m
>200 sq. mi.
BASINSIZE


VINTOL
1 sq. mi. or
1-10 sq. mi.
10-200 sq. m
>200 sq. mi.
BASINSIZE


VTRICH
1 sq. mi. or
1-10 sq. mi.
10-200 sq. m
>200 sq. mi.
BASINSIZE

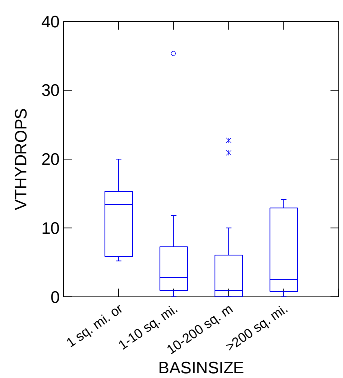
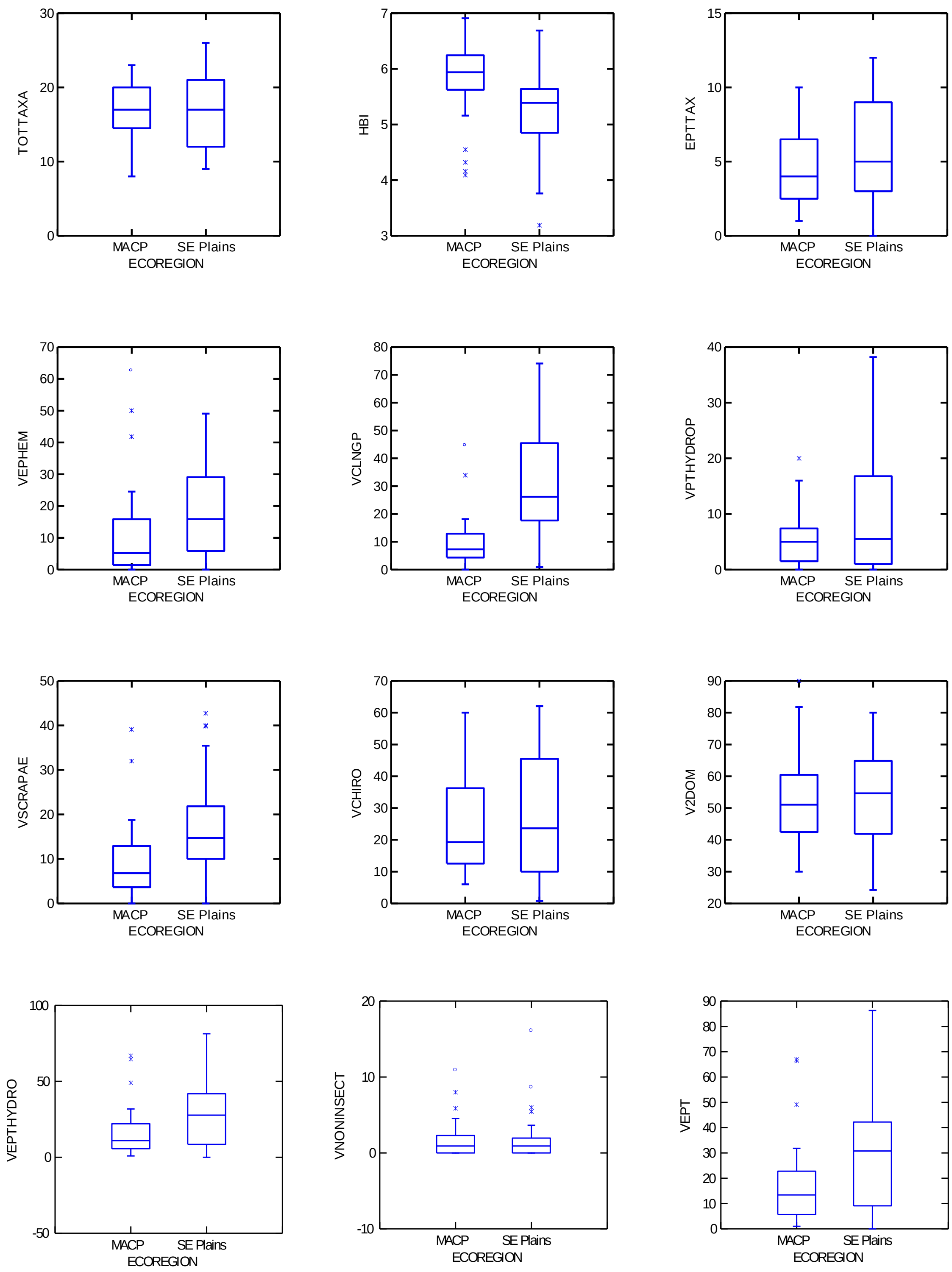

VTHYDROPS
1 sq. mi. or
1-10 sq. mi.
10-200 sq. m
>200 sq. mi.
BASINSIZE

Figure A-4. Box-and-whisker plots of metrics by ecoregion.



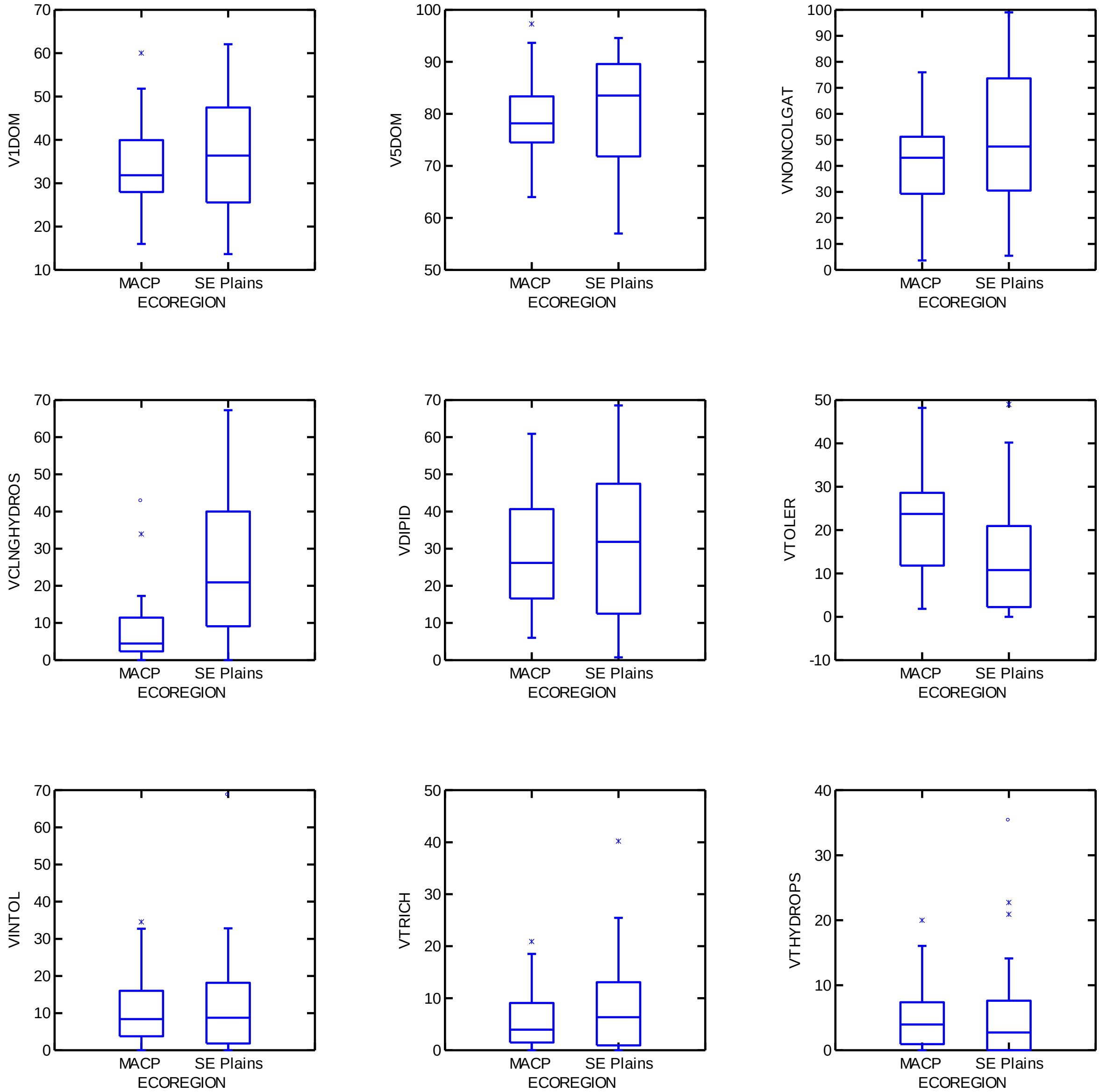
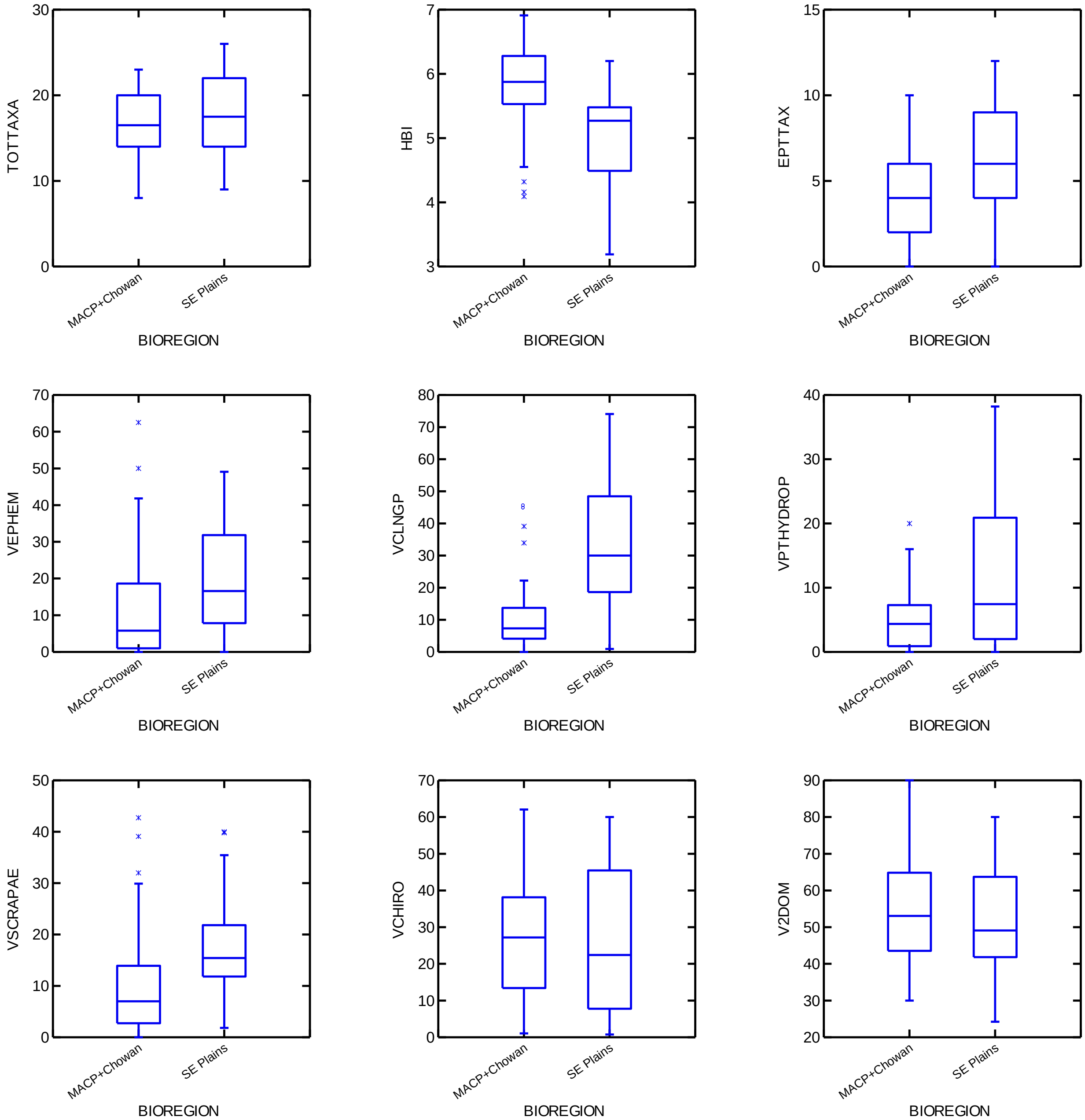
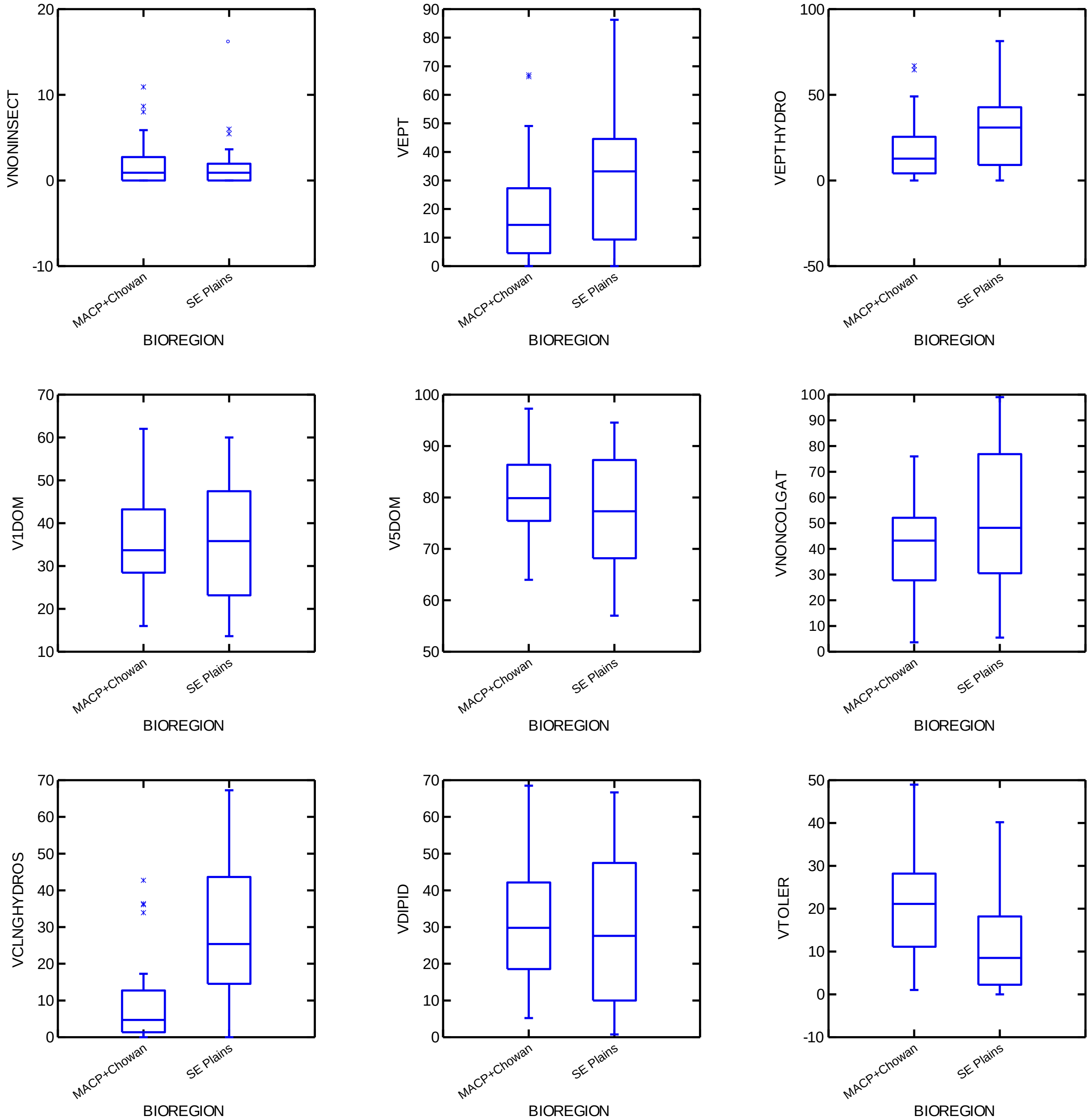

V1DOM
V5DOM
VNONCOLGAT
VCLNGHYDROS
VDIPID
VTOLER
VINTOL
VTRICH
VTHYDROPS
MACP
SE Plains
ECOREGION

Figure A-5. Box-and-whisker plots of metrics by bioregion.




VNONINSECT
VEPT
VEPTHYDRO
V1DOM
V5DOM
VNONCOLGAT
VCLNGHYDROS
VDIPID
VTOLER
MACP+Chowan
SE Plains
BIOREGION

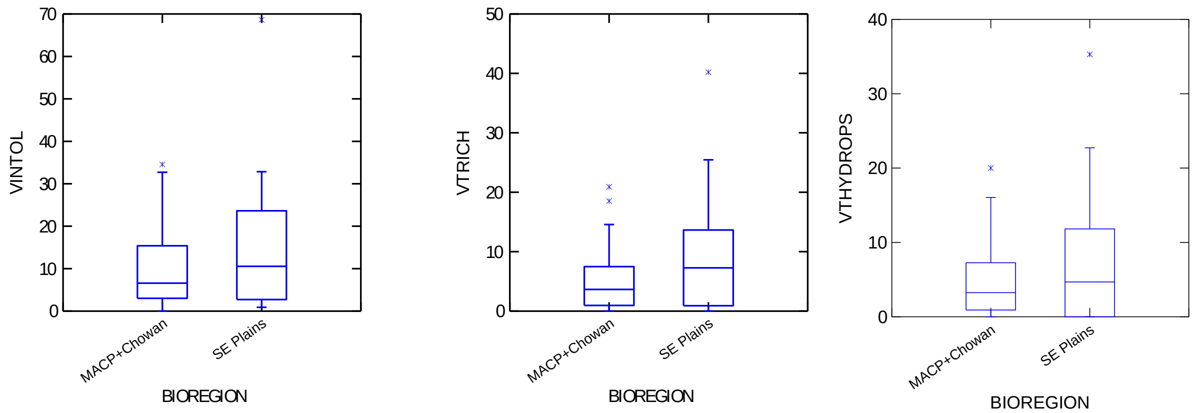
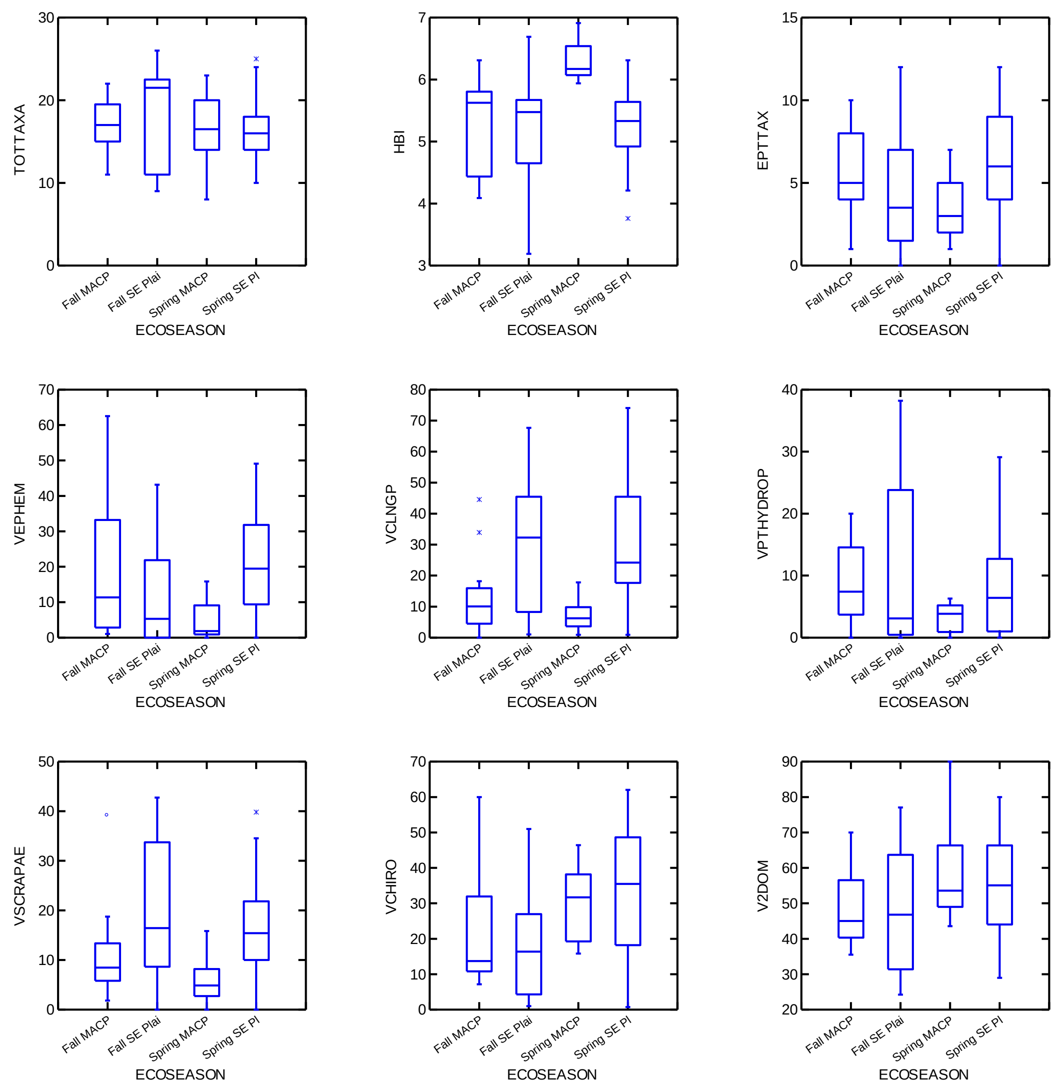
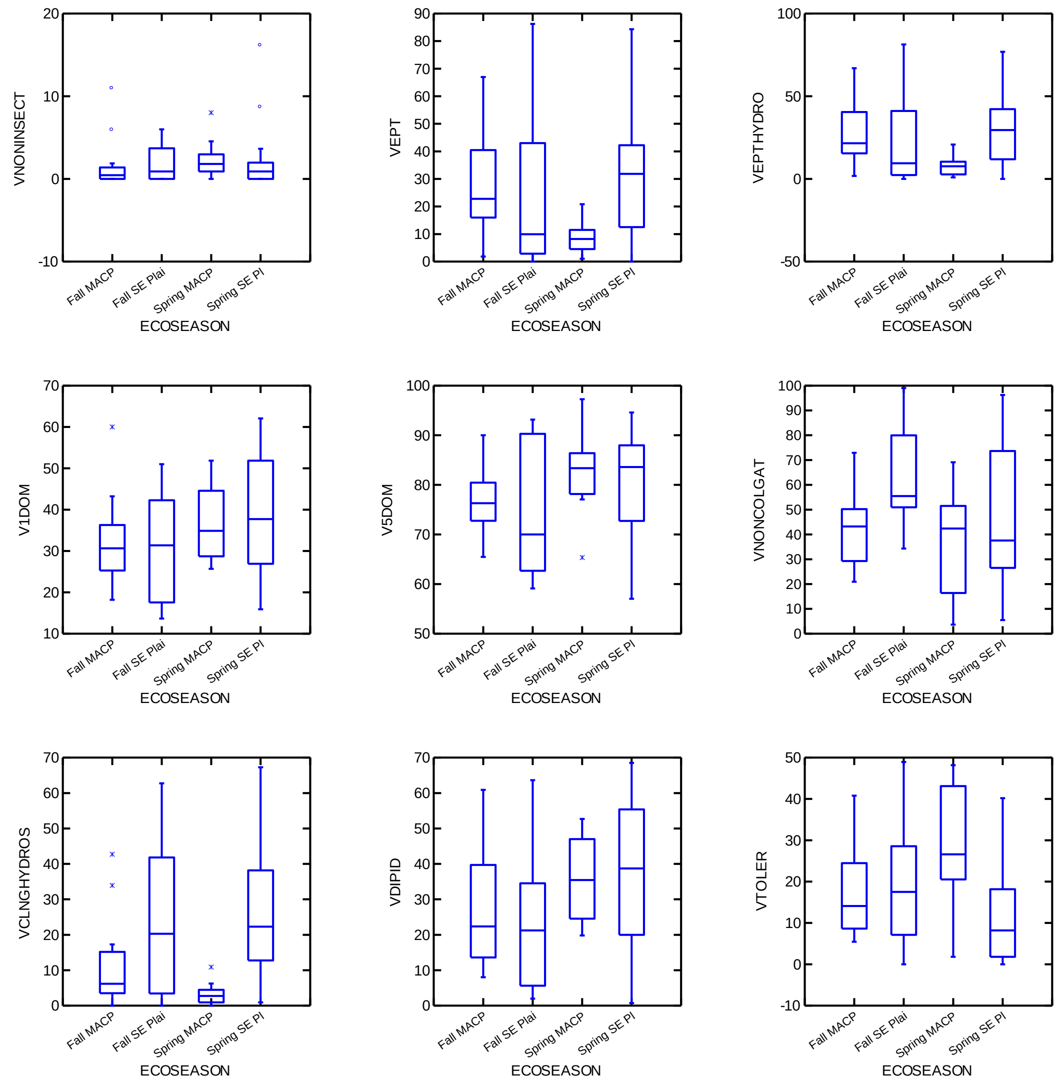


Figure A-6. Box-and-whisker plots of metrics by ecoseason.




VNONINSECT
VEPT
VEPTHYDRO
V1DOM
V5DOM
VNONCOLGAT
VCLNGHYDROS
VDIPID
VTOLER
Fall MACP
Fall SE Plai
Spring MACP
Spring SE Pl
ECOSEASON

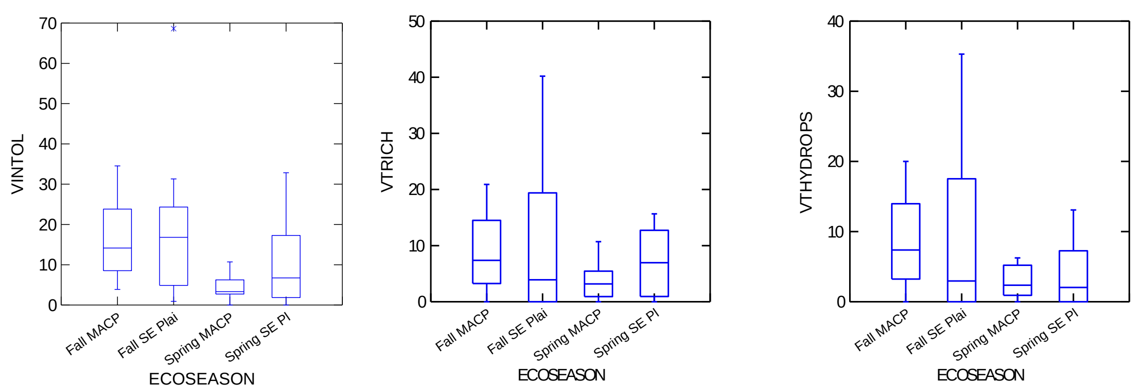
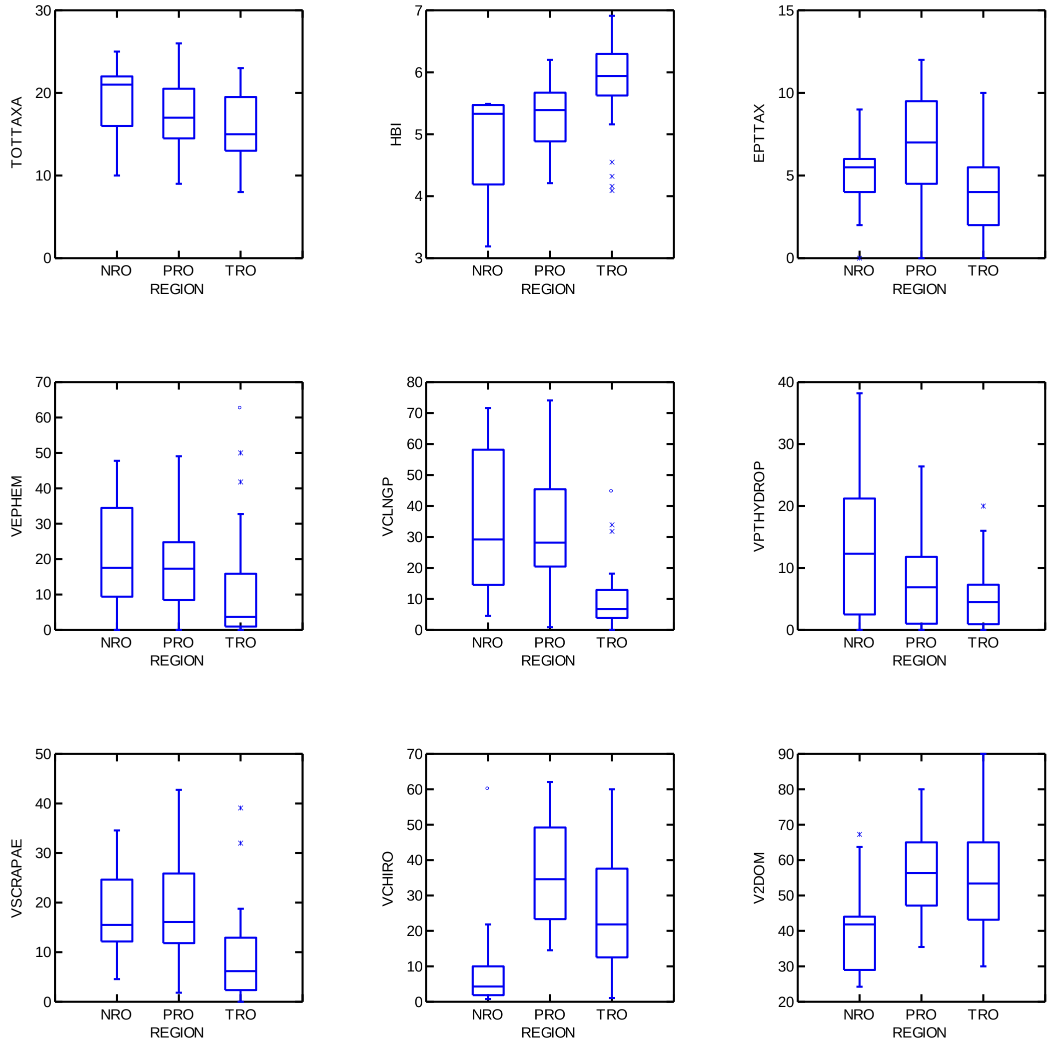

VINTOL
VTRICH
VTHYDROPS
Fall MACP
Fall SE Plai
Spring MACP
Spring SE Pl
ECOSEASON

Figure A-7. Box-and-whisker plots of metrics by VDEQ region.



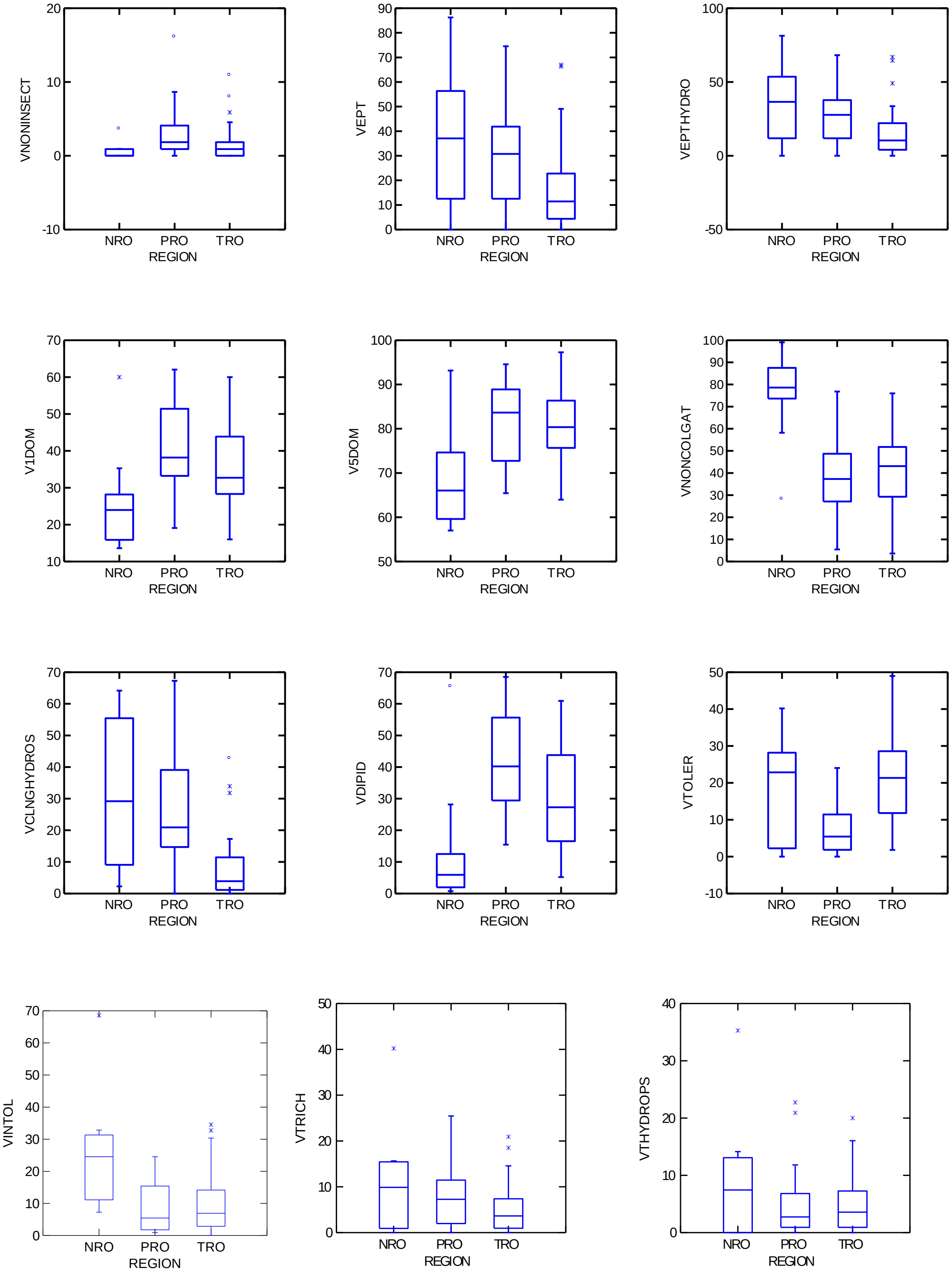
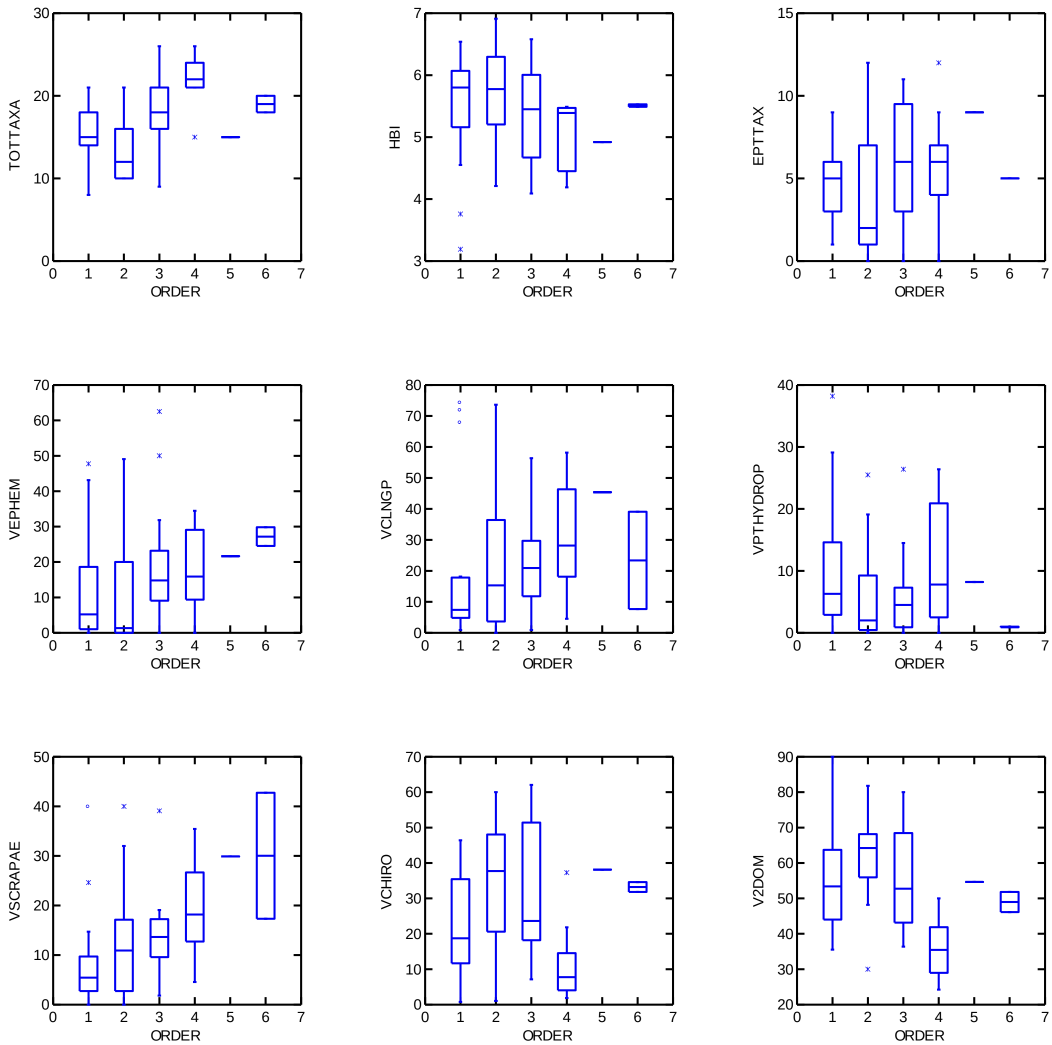

VNONINSECT
VEPT
VEPTHYDRO
V1DOM
V5DOM
VNONCOLGAT
VCLNGHYDROS
VDIPID
VTOLER
VINTOL
VTRICH
VTHYDROPS
NRO
PRO
TRO
REGION

Figure A-8. Box-and-whisker plots of metrics by stream order.



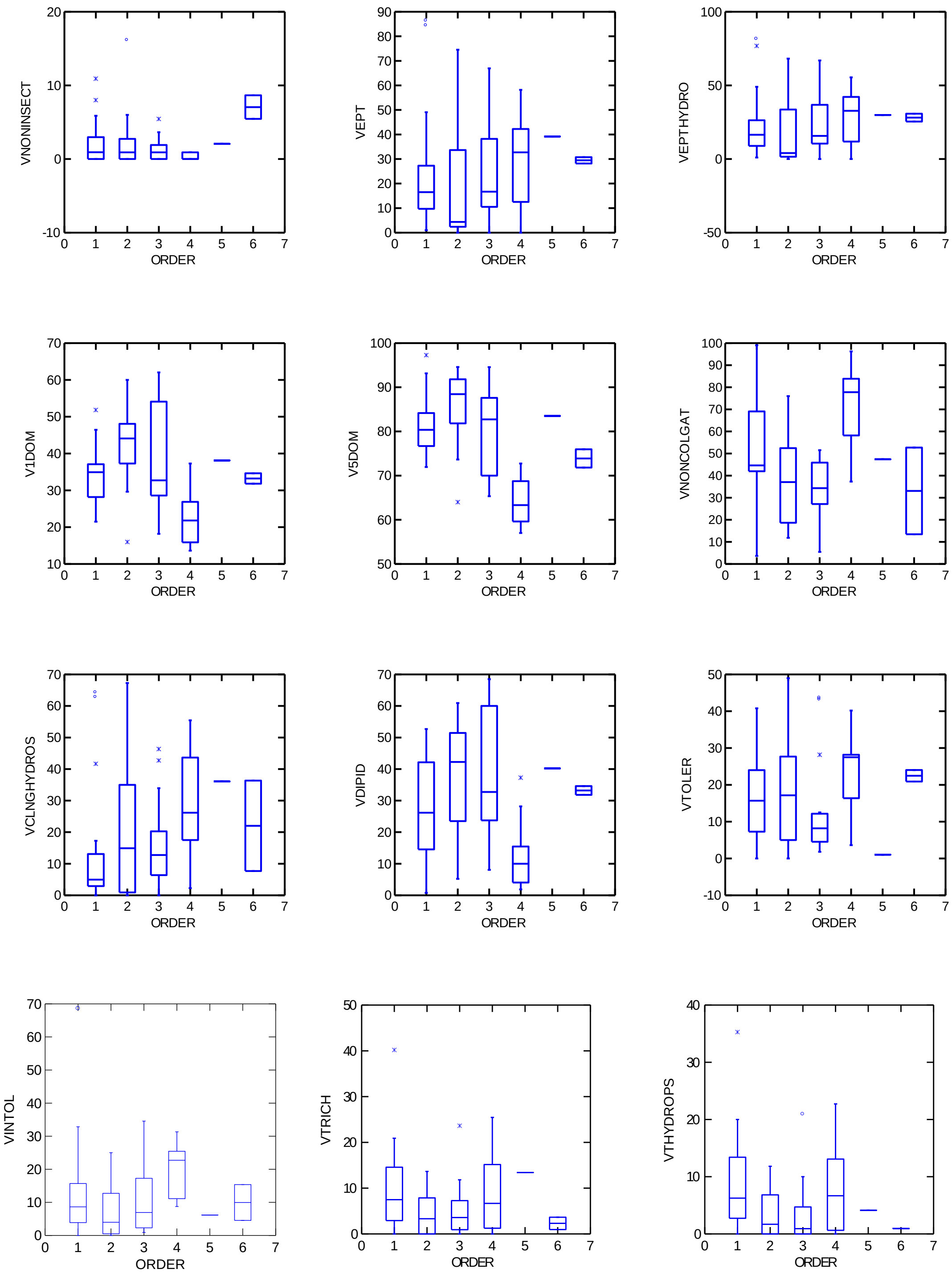
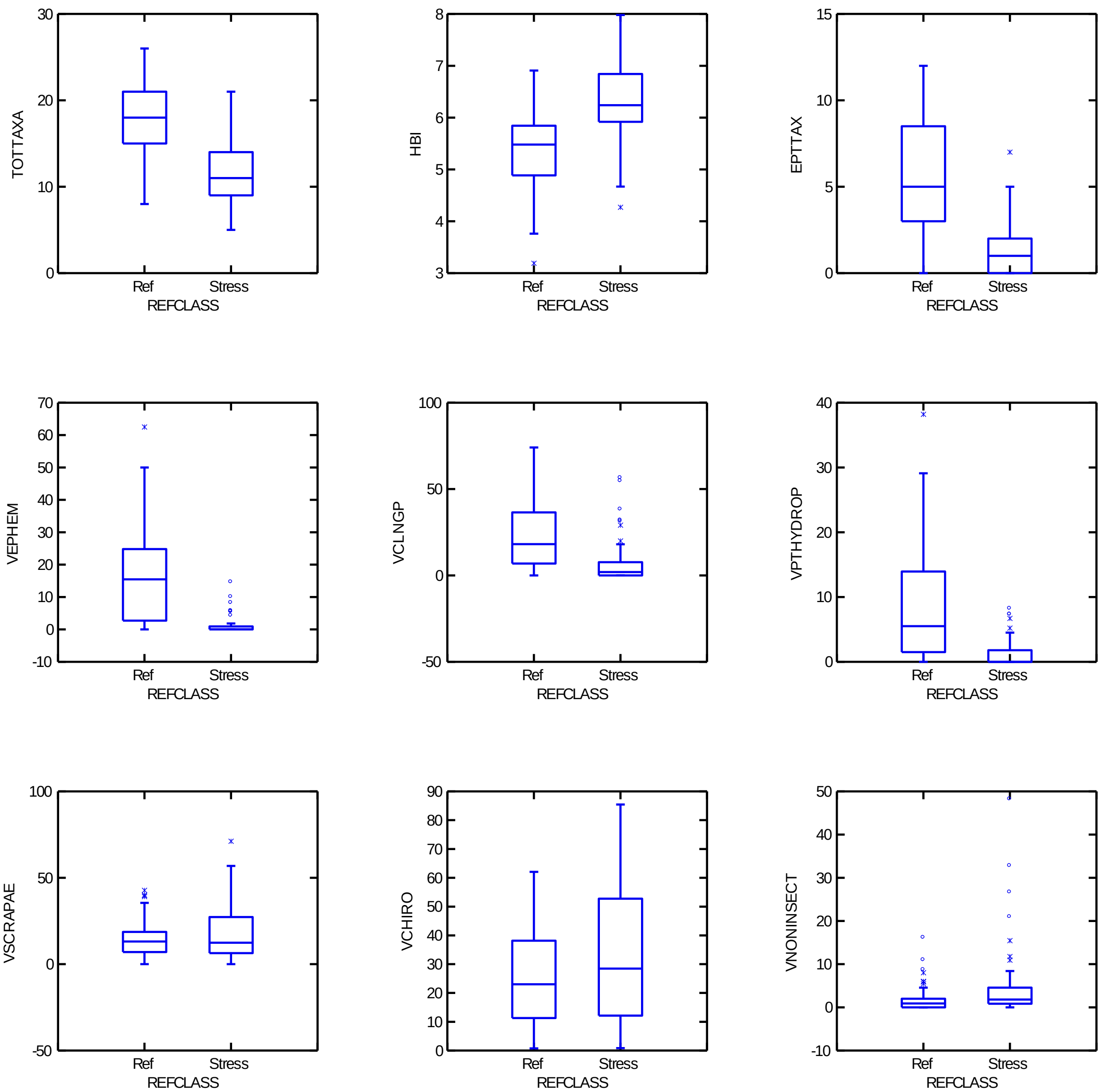

VNONINSECT
ORDER
VEPT
ORDER
VEPTHYDRO
ORDER
V1DOM
ORDER
V5DOM
ORDER
VNONCOLGAT
ORDER
VCLNGHYDROS
ORDER
VDIPID
ORDER
VTOLER
ORDER
VINTOL
ORDER
VTRICH
ORDER
VTHYDROPS
ORDER

Figure A-9. Box-and-whisker plots of metrics by reference and stress sites.

Family Reference vs. Stress Sites (including 2-BLY005.73, 7-DYM003.52, 7-FOX002.55, 3-GIN002.64, 2-RHC000.58, 3-RUN000.13 as stressed; 5AAPW001.04 and VCU_2-WER001.93 removed from reference sites; see notes below)



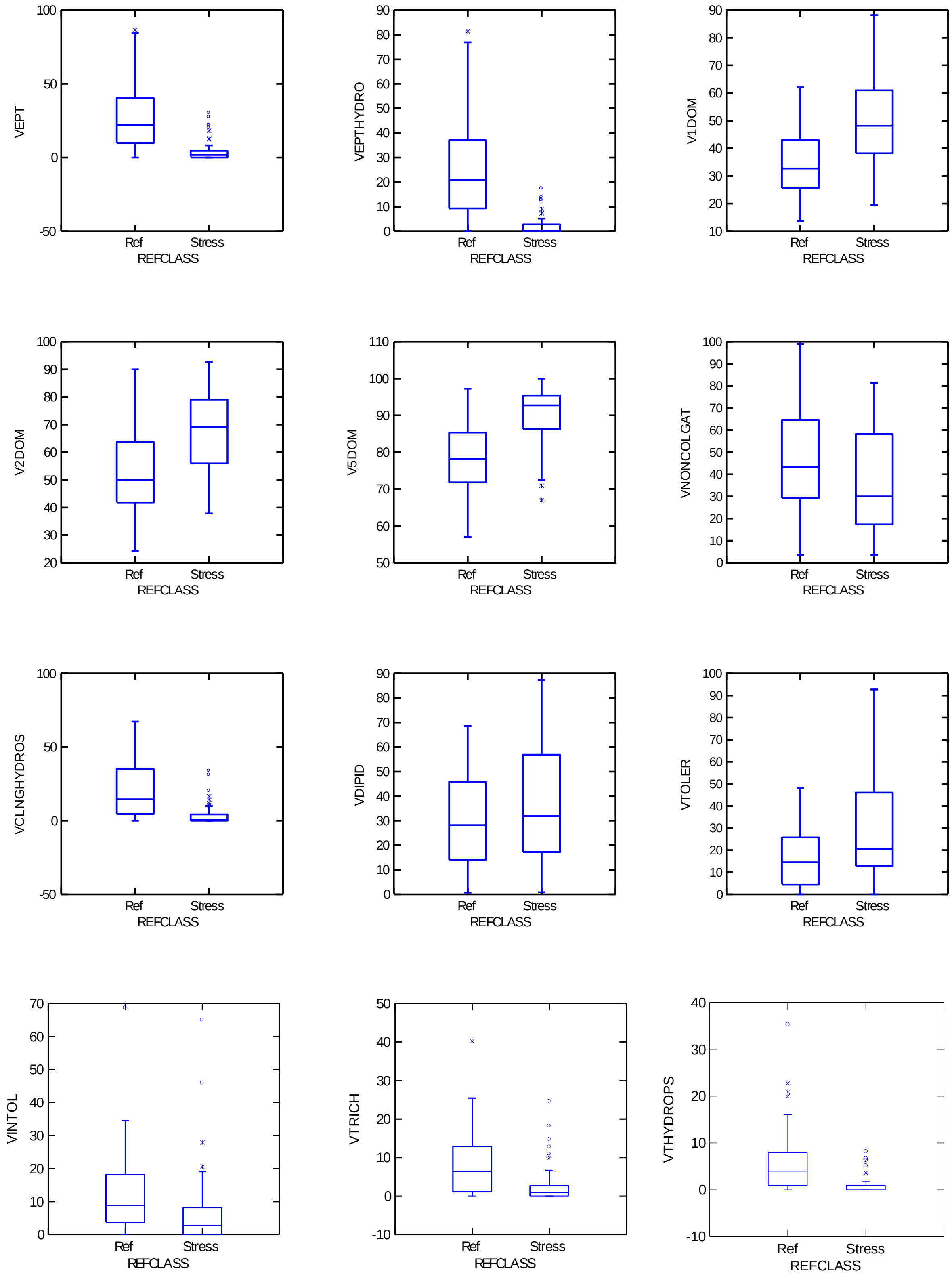
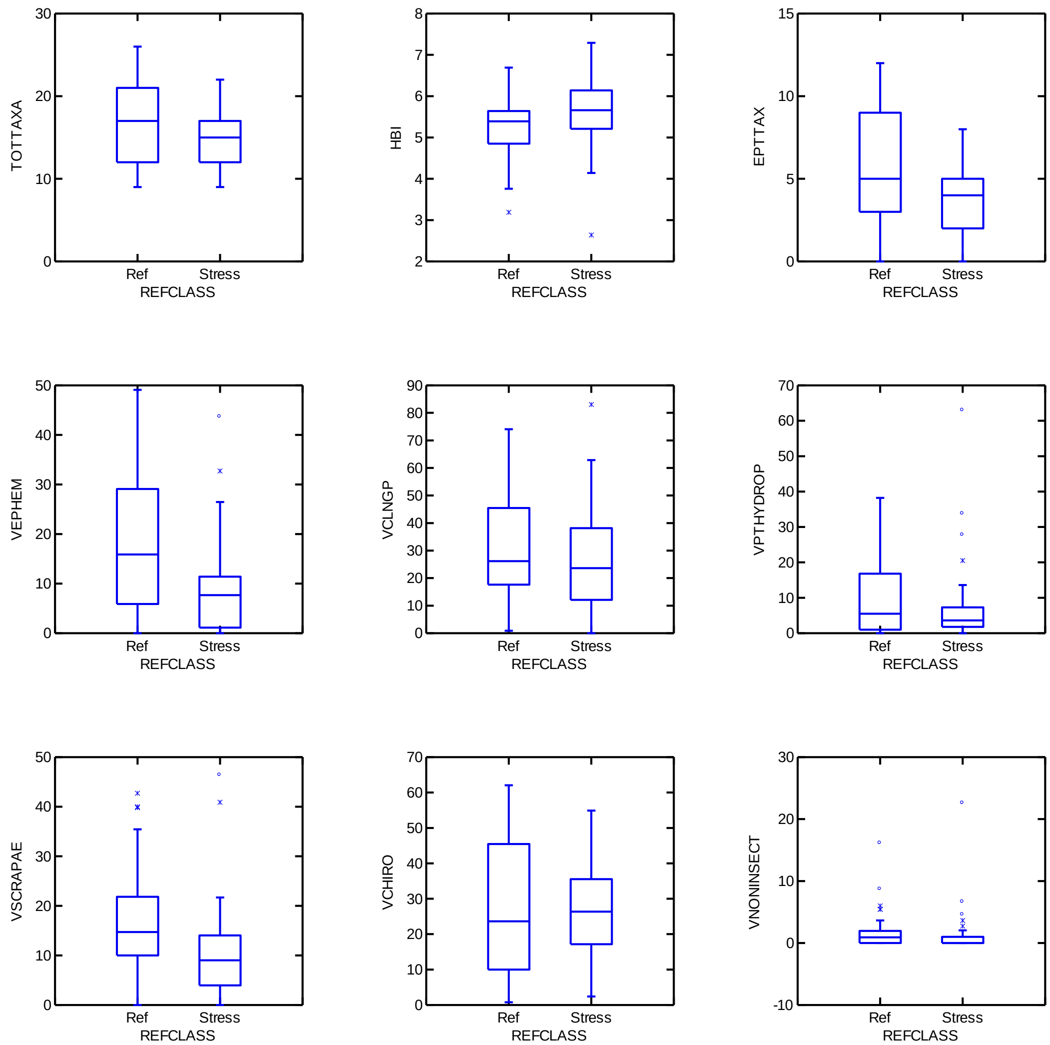
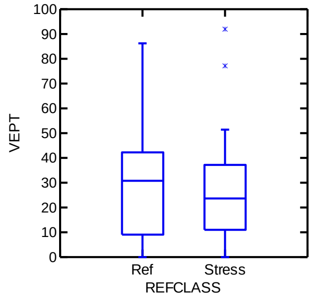
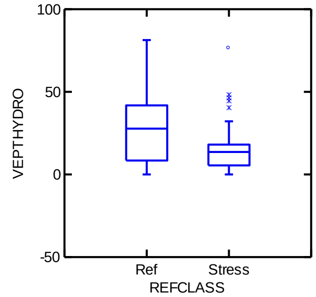
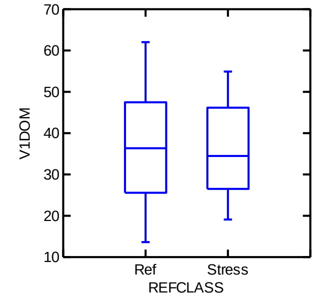

VEPT
VEPTHYDRO
V1DOM
V2DOM
V5DOM
VNONCOLGAT
VCLNGHYDROS
VDIPID
VTOLER
VINTOL
VTRICH
VTHYDROPS
Ref
Stress
REFCLASS

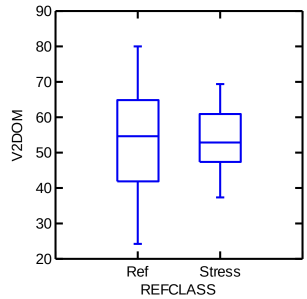
Figure A-10. Box-and-whisker plots of metrics by SEP reference and stress sites.

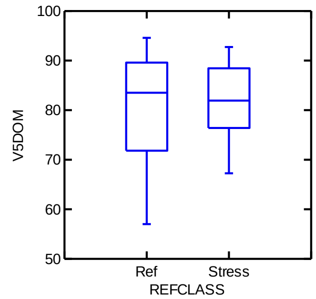


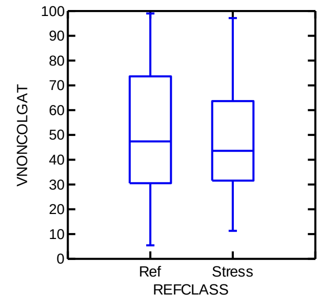

VEPT
Ref
Stress
REFCLASS

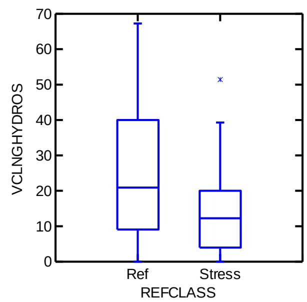

VEPTHYDRO
Ref
Stress
REFCLASS

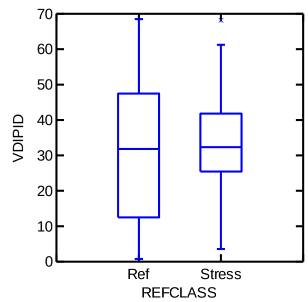

V1DOM
Ref
Stress
REFCLASS

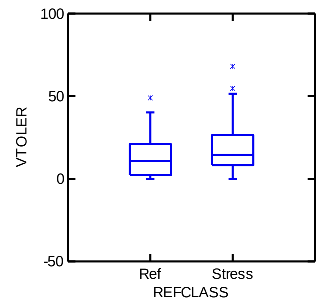

V2DOM
Ref
Stress
REFCLASS

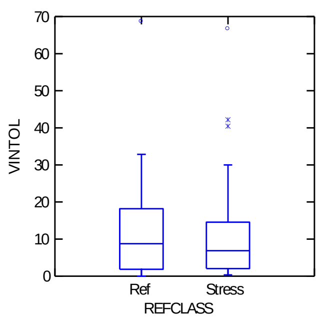

V5DOM
Ref
Stress
REFCLASS

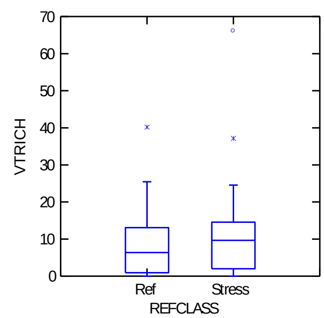

VNONCOLGAT
Ref
Stress
REFCLASS


VCLNGHYDROS
Ref
Stress
REFCLASS


VDIPID
Ref
Stress
REFCLASS


VTOLER
Ref
Stress
REFCLASS


VINTOL
Ref
Stress
REFCLASS


VTRICH
Ref
Stress
REFCLASS

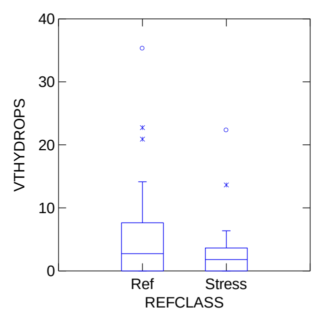
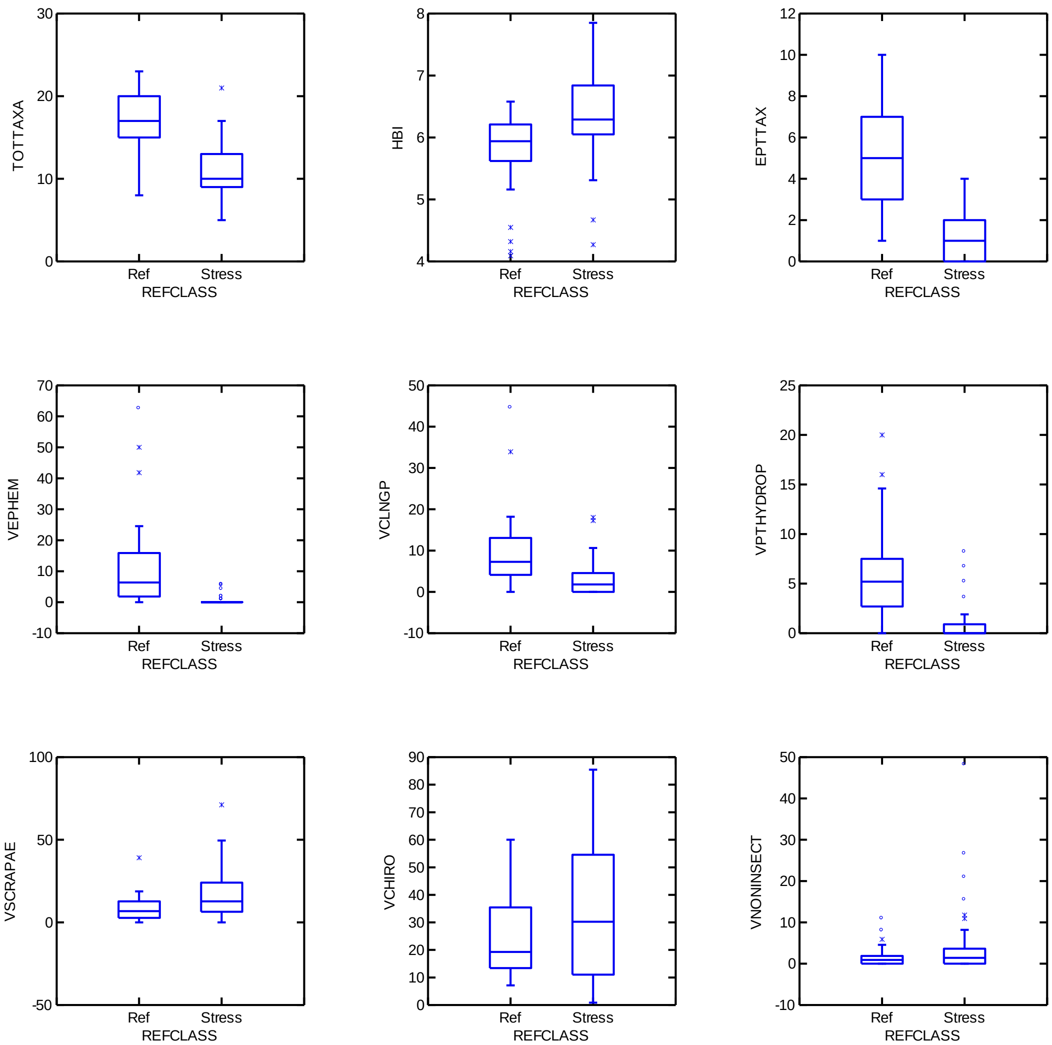

VTHYDROPS
Ref
Stress
REFCLASS

Figure A-11. Box-and-whisker plots of metrics by MACP reference and stress sites.



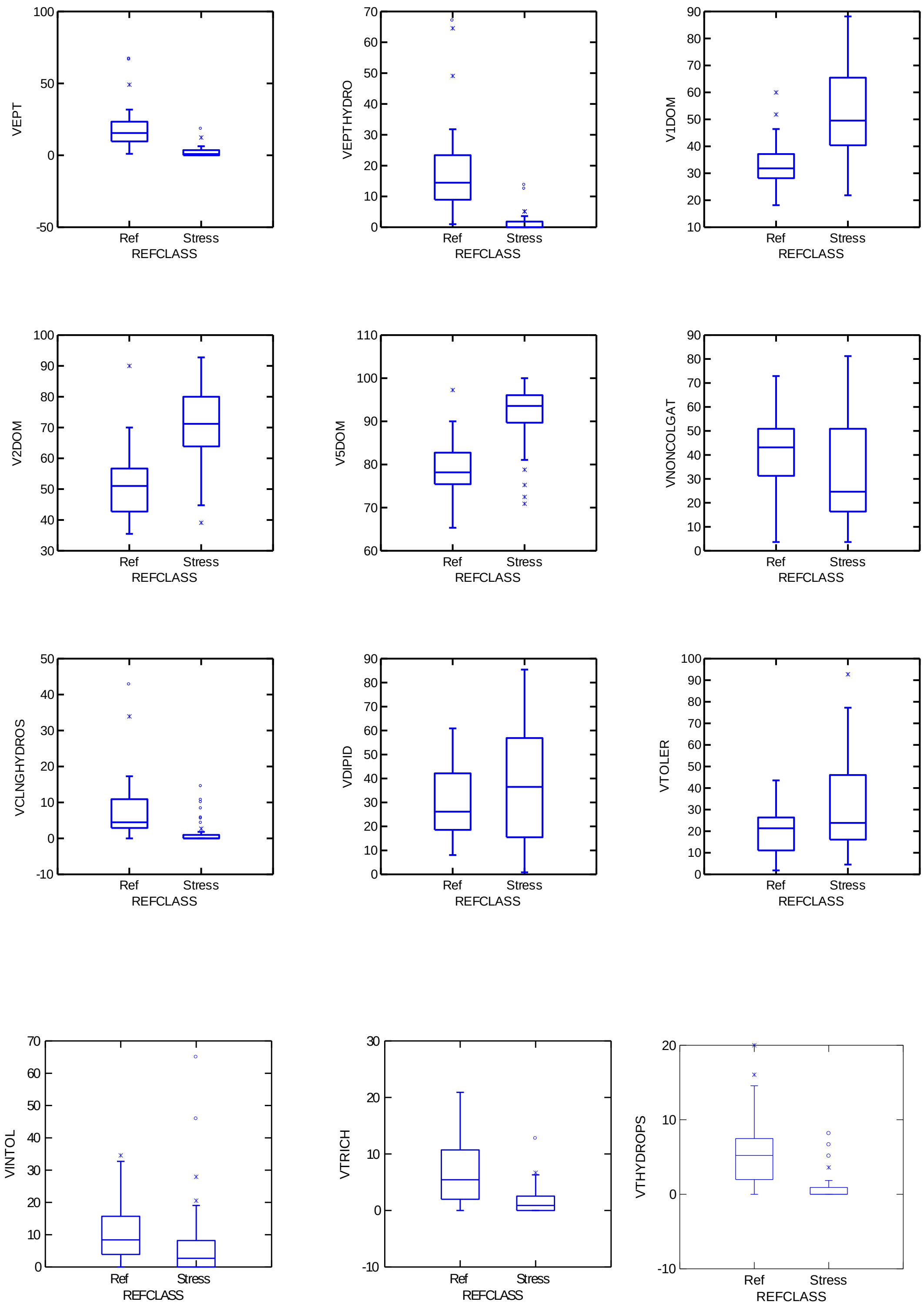
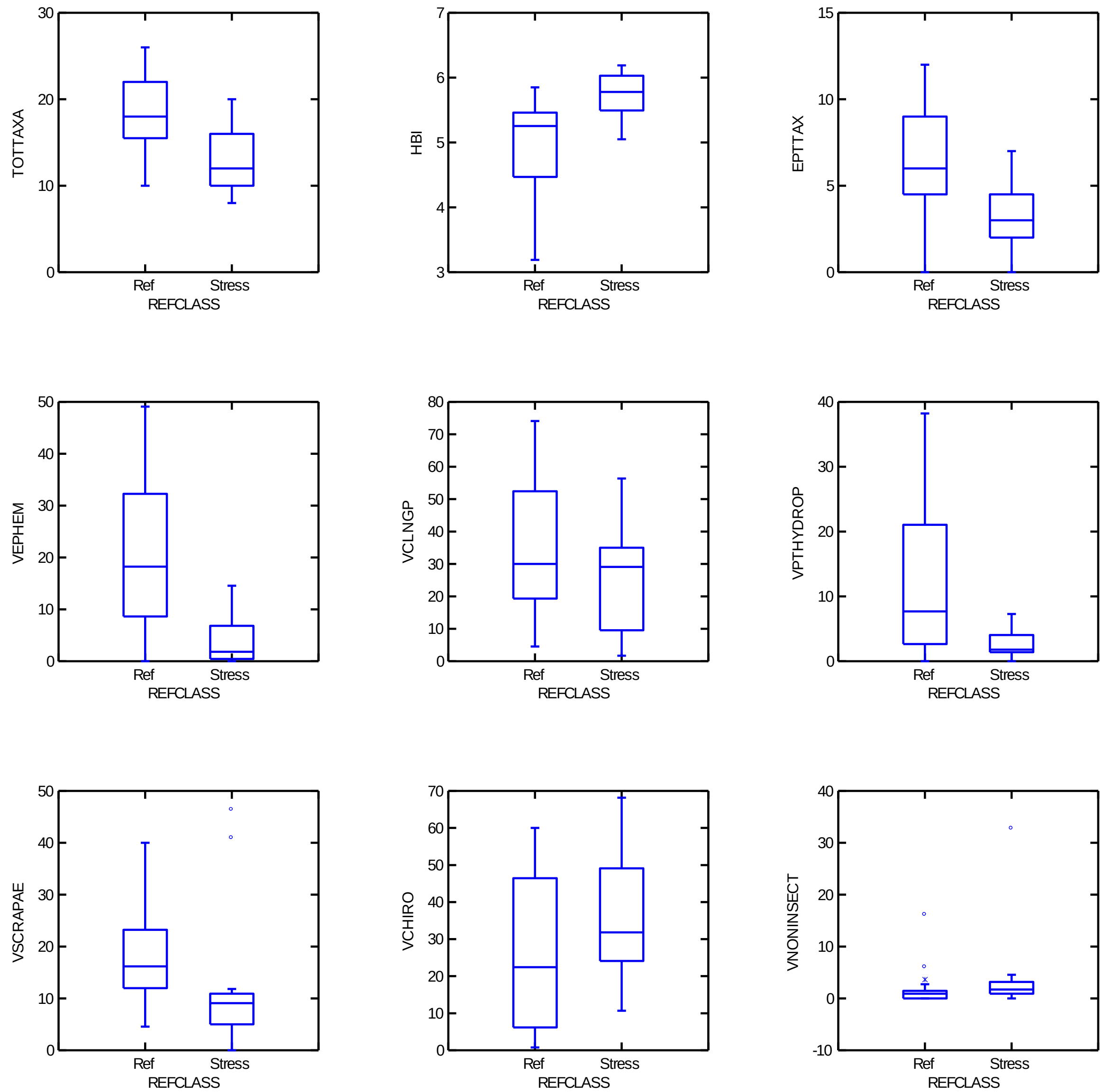

VEPT
VEPTHYDRO
V1DOM
V2DOM
V5DOM
VNONCOLGAT
VCLNGHYDROS
VDIPID
VTOLER
VINTOL
VTRICH
VTHYDROPS
Ref
Stress
REFCLASS

Figure A-12. Box-and-whisker plots of metrics by SEP reference and stress sites less Chowan sites.

SEP Reference vs. Stress Sites (including 2-BLY005.73, 7-DYM003.52, 7-FOX002.55, 3-GIN002.64, 2-RHC000.58, 3-RUN000.13 as stressed; VCU_2-WER001.93 removed from reference sites). Note: A re-evaluation of the SEP sites revealed a very low number of stress sites (n=4) and two reference sites with several questionable individual metric scores. In order to address the low number of stress sites, the VDEQ Biologists and the EDAS database were re-queried for additional stressed sites. That effort resulted in 7 new stress sites (n=11). East Run (VCU_2-WER001.93) was also removed from the database due to a CPMI assessment of 'moderately impaired', HBI above 6, relatively low Total Taxa (mean 9.5) and EPT Taxa (mean 0.5) scores. Remaining SEP sites are n=35 (reference n=24, stress n=11).



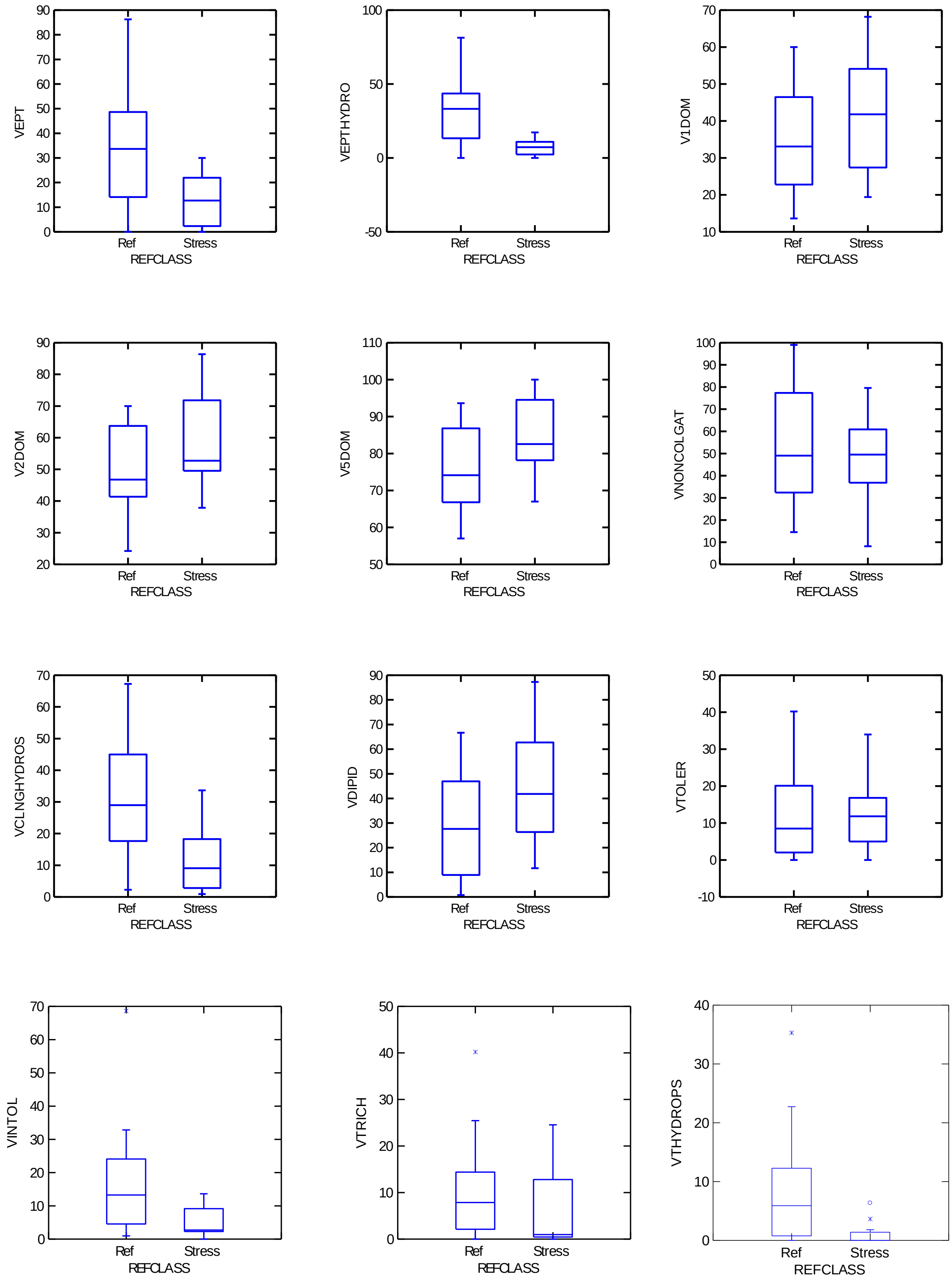
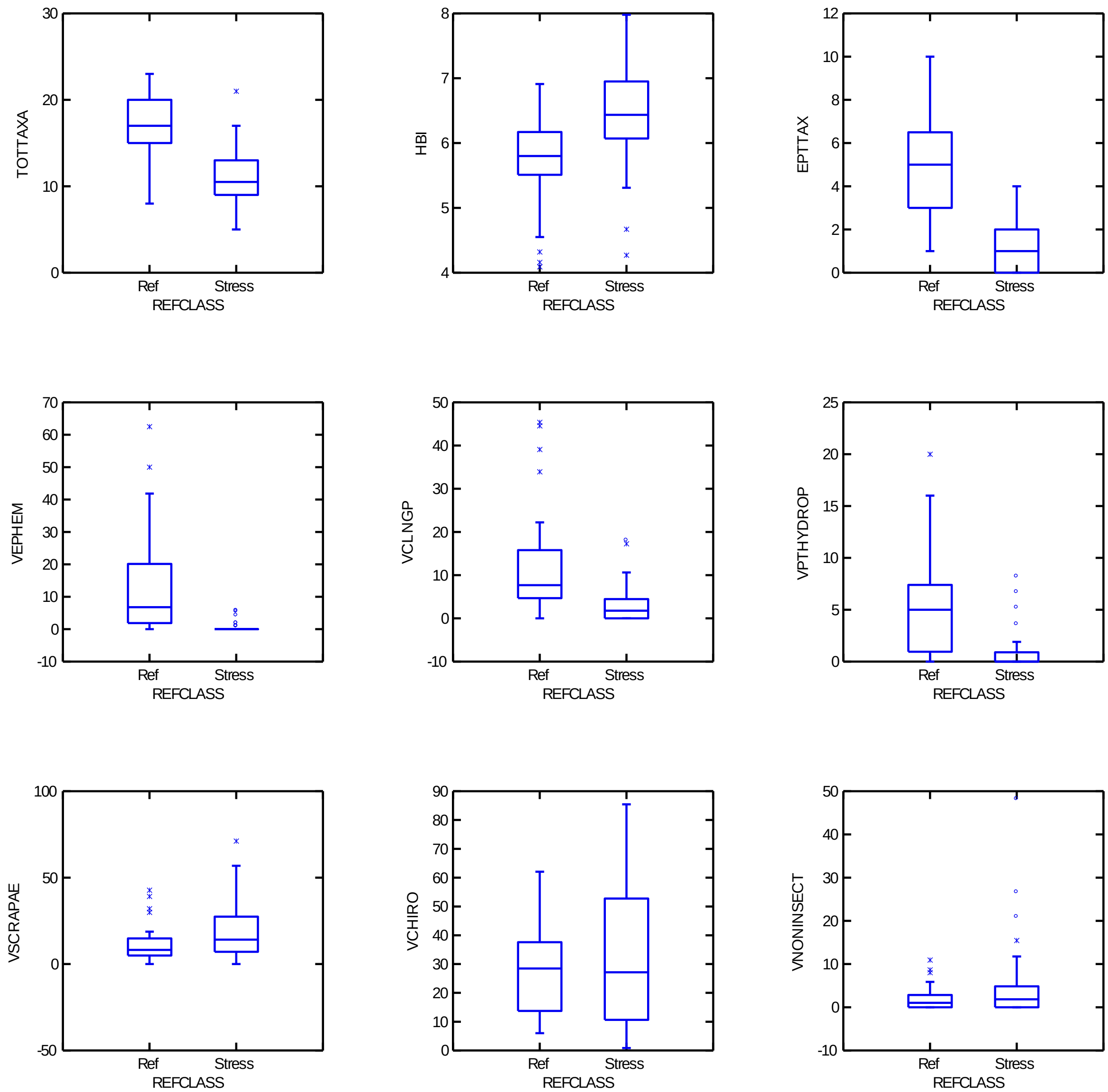
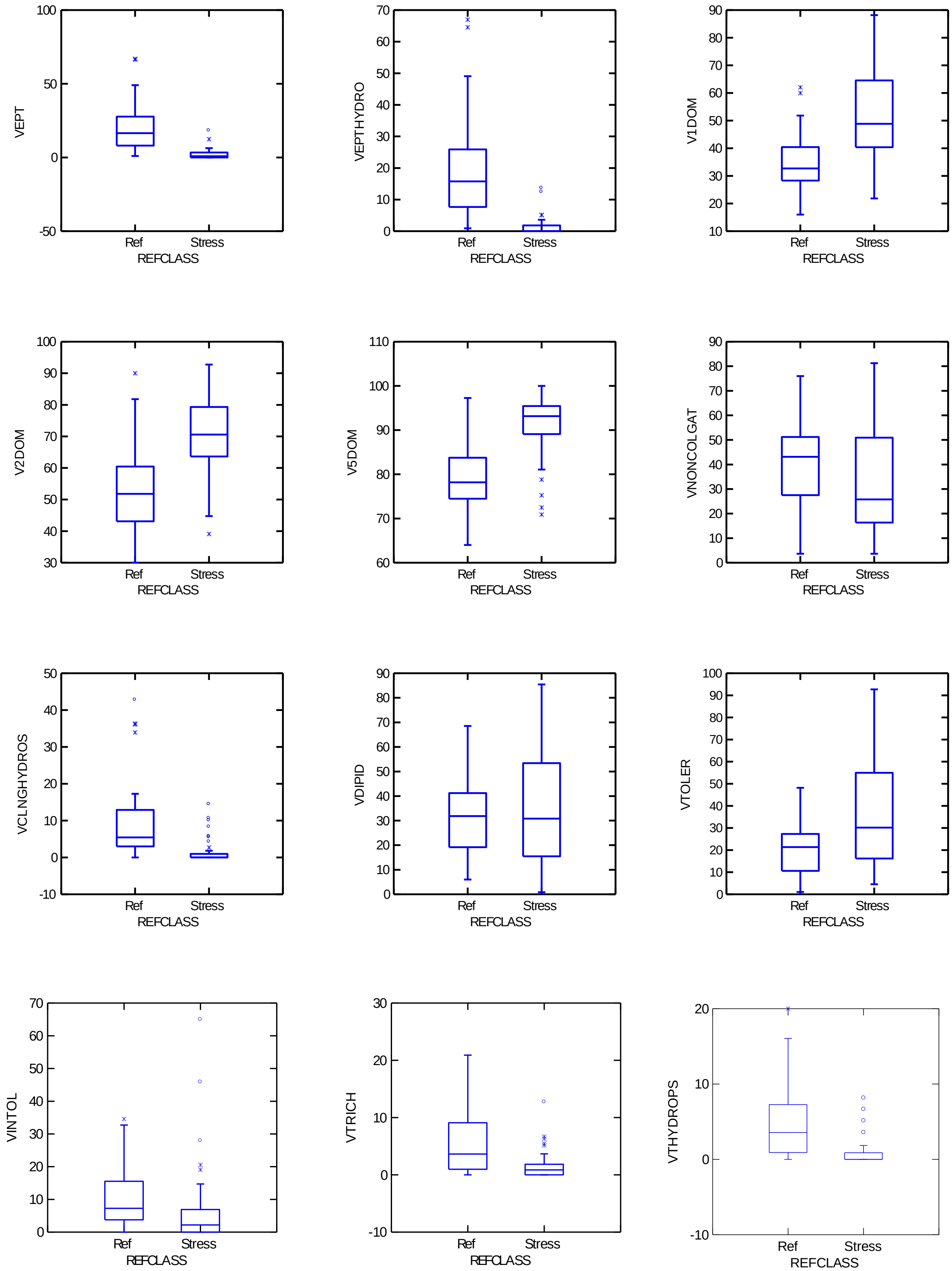

VEPT
Ref
Stress
REFCLASS
VEPTHYDRO
Ref
Stress
REFCLASS
V1DOM
Ref
Stress
REFCLASS
V2DOM
Ref
Stress
REFCLASS
V5DOM
Ref
Stress
REFCLASS
VNONCOLGAT
Ref
Stress
REFCLASS
VCLNGHYDROS
Ref
Stress
REFCLASS
VDIPID
Ref
Stress
REFCLASS
VTOLER
Ref
Stress
REFCLASS
VINTOL
Ref
Stress
REFCLASS
VTRICH
Ref
Stress
REFCLASS
VTHYDROPS
Ref
Stress
REFCLASS

Figure A-13. Box-and-whisker plots of metrics by MACP reference and stress sites including Chowan sites.

MACP Reference vs. Stress (including all Chowan sites except 5AAPW001.04 removed from reference sites). Note: Applewhite Swamp (5AAPW001.04) was removed from the database due to being assessed as 'moderately impaired' using the Maxted CPMI. In addition, 5AAPW001.04 had HBIs above 6.2, relatively low Total Taxa (mean = 10.67) and EPT Taxa (mean = 0.5) as well as zero Ephemeroptera (Table 8).




VEPT
VEPTHYDRO
V1DOM
V2DOM
V5DOM
VNONCOLGAT
VCLNGHYDROS
VDIPID
VTOLER
VINTOL
VTRICH
VTHYDROPS
Ref
Stress
REFCLASS

APPENDIX B

Table B- 1. Table of Reference Samples (n=56). Bolded and italicized were later removed.

Station ID	Basin	Stream Order	DEQ Region	Latitude	Longitude	Ecoregion	Square Miles
2-BLB002.23	James River	2	PRO	37.18014	-77.01234	SEPLAIN (65)	5.11
2-CPN004.81	James River	3	TRO	36.92027778	-76.65138889	MACP (63)	10.89
2-CPN004.81	James River	3	TRO	36.92027778	-76.65138889	MACP (63)	10.89
2-CPN004.81	James River	3	TRO	36.92027778	-76.65138889	MACP (63)	10.89
2-CPN004.81	James River	3	TRO	36.92027778	-76.65138889	MACP (63)	10.89
2-CPN004.81	James River	3	TRO	36.92027778	-76.65138889	MACP (63)	10.89
2-CPN004.81	James River	3	TRO	36.92027778	-76.65138889	MACP (63)	10.89
2-CRL004.04	James River	1	TRO	36.84444444	-76.69111111	MACP (63)	1.7
2-CRL004.04	James River	1	TRO	36.84444444	-76.69111111	MACP (63)	1.7
2-CRL004.04	James River	1	TRO	36.84444444	-76.69111111	MACP (63)	1.7
2-CRL004.04	James River	1	TRO	36.84444444	-76.69111111	MACP (63)	1.7
2-POS002.62	James River	2	PRO	37.447544	-77.157703	SEPLAIN (65)	2.03
2-POS002.62	James River	2	PRO	37.447544	-77.157703	SEPLAIN (65)	2.03
2-WRD005.40	James River	4	PRO	37.216389	-77.081667	SEPLAIN (65)	16.42
2-WRD005.40	James River	4	PRO	37.216389	-77.081667	SEPLAIN (65)	16.42
3-BMS002.00	Rappahannock River	2	PRO	37.89172	-76.60282	SEPLAIN (65)	7.13
3-CAT011.62	Rappahannock River	1	PRO	38.03992	-76.82734	SEPLAIN (65)	45.62
3-TOT012.53	Rappahannock River	3	PRO	37.9099	-76.61436	SEPLAIN (65)	9.98
5AAPW001.04	***Chowan River***	***2***	***TRO***	***36.728809***	***-77.353027***	***SEPLAIN (65)***	***5.96***
5AAPW001.04	***Chowan River***	***2***	***TRO***	***36.728809***	***-77.353027***	***SEPLAIN (65)***	***5.96***
5AAPW001.04	***Chowan River***	***2***	***TRO***	***36.728809***	***-77.353027***	***SEPLAIN (65)***	***5.96***
5ABLC000.88	Chowan River	2	TRO	36.769463	-76.901773	SEPLAIN (65)	16.33
5AMRN000.38	Chowan River	3	PRO	36.76992	-77.09432	SEPLAIN (65)	13.48
5ANTW051.60	Chowan River	5	PRO	36.916641	-77.201527	SEPLAIN (65)	1088
5ANTW058.88	Chowan River	6	PRO	36.975123	-77.237588	SEPLAIN (65)	984.69
5ANTW058.88	Chowan River	6	PRO	36.975123	-77.237588	SEPLAIN (65)	984.69
7-BBR001.31	Chesapeake Bay	1	TRO	37.668002	-75.774664	MACP (63)	1.07
7-BBR001.31	Chesapeake Bay	1	TRO	37.668002	-75.774664	MACP (63)	1.07
7-BBR001.31	Chesapeake Bay	1	TRO	37.668002	-75.774664	MACP (63)	1.07
7-GRS002.29	Chesapeake Bay	1	TRO	37.49416667	-75.83083333	MACP (63)	0.97
7-GRS002.29	Chesapeake Bay	1	TRO	37.49416667	-75.83083333	MACP (63)	0.97
7-GRS002.29	Chesapeake Bay	1	TRO	37.49416667	-75.83083333	MACP (63)	0.97
7-GRS002.29	Chesapeake Bay	1	TRO	37.49416667	-75.83083333	MACP (63)	0.97
7-GRS002.29	Chesapeake Bay	1	TRO	37.49416667	-75.83083333	MACP (63)	0.97
7-GRS002.29	Chesapeake Bay	1	TRO	37.49416667	-75.83083333	MACP (63)	0.97
7-GRS002.29	Chesapeake Bay	1	TRO	37.49416667	-75.83083333	MACP (63)	0.97
7-XCY000.46	Chesapeake Bay	2	PRO	37.86443	-76.48325	SEPLAIN (65)	3.35
8-BLC005.54	York River	3	PRO	37.558346	-77.129362	SEPLAIN (65)	15.81
8-BLC005.54	York River	3	PRO	37.558346	-77.129362	SEPLAIN (65)	15.81
8-BRC002.70	***York River***	***1***	***NRO***	***38.166022***	***-78.048833***	***SEPLAIN (65)***	***1.38***
8-BRC002.70	***York River***	***1***	***NRO***	***38.166022***	***-78.048833***	***SEPLAIN (65)***	***1.38***
8-MPN094.79	York River	4	NRO	38.06	-77.38472222	SEPLAIN (65)	255.76
8-MPN094.79	York River	4	NRO	38.06	-77.38472222	SEPLAIN (65)	255.76
8-MPN094.79	York River	4	NRO	38.06	-77.38472222	SEPLAIN (65)	255.76
8-MPN094.79	York River	4	NRO	38.06	-77.38472222	SEPLAIN (65)	255.76
8-MPN094.79	York River	4	NRO	38.06	-77.38472222	SEPLAIN (65)	255.76
8-SOB000.15	York River	3	PRO	37.571512	-77.090879	SEPLAIN (65)	7.31
8-SOB000.15	York River	3	PRO	37.571512	-77.090879	SEPLAIN (65)	7.31
8-STH006.43	York River	4	NRO	38.057595	-77.472289	SEPLAIN (65)	39.09
8-STH006.43	York River	4	NRO	38.057595	-77.472289	SEPLAIN (65)	39.09
2-CRL001.83	James River	2	TRO	36.8218	-76.66877	MACP (63)	5.39
2-WER001.93	***James River***	***3***	***PRO***	***37.358611***	***-77.165833***	***SEPLAIN (65)***	***21.25***
2-WER001.93	***James River***	***3***	***PRO***	***37.358611***	***-77.165833***	***SEPLAIN (65)***	***21.25***
3-BLD001.54	Rappahannock River	2	PRO	37.78	-76.496388	SEPLAIN (65)	7.27
5ACHP002.03	Chowan River	2	TRO	36.58914	-76.81864	MACP (63)	17.42
8-CPL004.15	York River	3	NRO	37.84389	-77.0897	SEPLAIN (65)	33.83

Table B- 2. SEP sites used to generate Figure A-10 (n=42).

StationID	StreamName	RefClass	Total Taxa	HBI	EPTTax	%Ephem	%ClngP	%PT - Hydros	%Scrap	%Chiro	%Non-Insect	%EPT	%EPT - Hydro	%1Dom	%2Dom	%5Dom	%NonColGat	%Clng-HydroSimulid	%Dip	%Toler	%Intol	%Trich	%T - Hydros
2-BEV002.00	Beaverdam Creek	Stress	20	5.05	7	10	38.18	7.3	46.36	25.45	3.64	21.82	17.27	25.45	47.27	78.18	63.64	33.64	27.27	8.18	13.64	10.91	6.36
2-BEV002.00	Beaverdam Creek	Stress	15	5.47	5	5.45	54.55	3.6	40.91	22.73	2.73	30	9.09	26.36	49.09	81.82	55.45	30.91	25.45	11.82	2.73	24.55	3.64
2-BLB002.23	Bailey Branch	Ref	16	5.17	9	22.73	20	10.9	10	57.27	2.73	33.64	33.64	57.27	66.36	83.64	16.36	20	57.27	1.82	5.45	7.27	7.27
8-BLC005.54	Black Creek	Ref	23	4.85	11	15.45	25.45	26.4	13.64	30.91	0.91	44.55	41.82	30.91	41.82	68.18	40	20.91	37.27	5.45	18.18	23.64	20.91
8-BLC005.54	Black Creek	Ref	17	5.27	10	21.82	20.91	7.3	11.82	51.82	0	30.91	29.09	51.82	70	93.64	20.91	14.55	56.36	3.64	3.64	7.27	5.45
VCU_3-BLD001.54	Bellwood Swamp	Ref	12	5.24	4	32.73	31.82	0.9	18.18	45.45	0.91	33.64	33.64	45.45	66.36	86.36	14.55	31.82	45.45	8.18	2.73	0	0
2-bly005.73	bailey creek	Stress	10	6.15	2	0.91	3.64	1.8	4.55	57.27	32.73	2.73	2.73	57.27	79.09	97.27	8.18	3.64	57.27	13.64	1.82	0	0
3-BMS002.00	Bookers Mill Stream	Ref	21	4.55	12	17.27	45.45	25.5	10	36.36	0.91	44.55	42.73	36.36	48.18	73.64	39.09	38.18	46.36	1.82	24.55	13.64	11.82
8-BRC002.70	Beaver Creek	Ref	18	3.76	9	47.76	71.64	29.1	24.63	0.75	0	84.33	76.87	22.39	44.03	74.63	76.87	64.18	0.75	2.24	32.84	15.67	8.21
8-BRC002.70	Beaver Creek	Ref	10	3.19	5	43.14	67.65	38.2	14.71	0.98	0	86.27	81.37	35.29	63.73	93.14	99.02	62.75	1.96	0	68.63	40.2	35.29
3-CAT011.62	Cat Point Creek	Ref	11	5.06	5	25	74.07	2.8	39.81	18.52	0.93	37.04	27.78	23.15	45.37	89.81	76.85	41.67	41.67	0.93	1.85	10.19	0.93
VCU_8-CPL004.15	Chapel Creek	Ref	16	5.45	6	11.82	14.55	3.6	7.27	60	3.64	16.36	15.45	60	67.27	86.36	28.18	9.09	65.45	1.82	7.27	0.91	0
7-dym003.52	dymer creek	Stress	10	5.78	1	0	15.45	0	11.82	68.18	0.91	0.91	0.00	68.18	80	96.36	30	11.82	72.73	1.82	0	0.91	0
7-FOX002.55	Fox Mill Run (Impact)	Stress	20	6.19	2	0.97	1.94	1	6.8	10.68	0.97	1.94	1.94	19.42	37.86	66.99	79.61	1.94	11.65	33.98	9.71	0.97	0.97
3-GIN002.64	Gingoteague Creek	Stress	17	6	0	0	1.72	0	0	15.52	1.72	0	0.00	34.48	50	74.14	79.31	1.72	17.24	20.69	8.62	0	0
3-GIN002.64	Gingoteague Creek	Stress	15	5.75	3	8.18	20	4.5	10	41.82	0.91	12.73	12.73	41.82	52.73	78.18	40.91	20	41.82	20	5.45	0	0
8-MHX000.27	Mehixen Creek	Stress	10	5.5	5	14.55	29.09	2.7	5.45	53.64	0	27.27	17.27	53.64	64.55	92.73	32.73	8.18	68.18	0	2.73	10	0
8-MPN094.79	Mattaponi River	Ref	22	5.48	2	2.73	4.55	0	12.73	21.82	0.91	2.73	2.73	21.82	32.73	59.09	58.18	4.55	28.18	28.18	23.64	0	0
8-MPN094.79	Mattaponi River	Ref	25	5.27	6	15.89	26.17	16.8	12.15	1.87	0.93	32.71	32.71	15.89	28.97	57.01	79.44	26.17	1.87	40.19	28.04	13.08	13.08
8-MPN094.79	Mattaponi River	Ref	21	5.39	4	9.38	18.13	2.5	16.25	2.5	0	12.5	11.88	26.88	41.88	68.75	96.25	17.5	2.5	27.5	8.75	1.25	0.63
8-MPN094.79	Mattaponi River	Ref	22	4.19	5	19.19	48.48	21.2	18.18	4.04	0	41.41	40.40	14.14	24.24	59.6	83.84	47.47	4.04	14.14	31.31	15.15	14.14
8-MPN094.79	Mattaponi River	Ref	15	4.44	6	32.73	58.18	20.9	34.55	10	0	56.36	53.64	28.18	41.82	72.73	73.64	55.45	10	18.18	25.45	15.45	12.73
2-POS002.62	Possum Run	Ref	16	5.85	5	0.85	18.64	7.6	16.1	47.46	16.1	9.32	8.47	47.46	63.56	87.29	30.51	17.8	47.46	11.02	1.69	8.47	7.63
2-POS002.62	Possum Run	Ref	10	5.7	2	0	41	2	40	23	6	3	2.00	40	63	91	69	40	27	22	1	3	2
2-RHC000.58	Rohoic Creek	Stress	8	5.78	4	5.45	56.36	1.8	0	31.82	4.55	8.18	7.27	54.55	86.36	100	58.18	0.91	87.27	0	2.73	0.91	0
3-run000.13	Ruin Branch	Stress	12	6.06	3	1.82	31.82	1.8	9.09	44.55	1.82	20	3.64	44.55	60.91	88.18	47.27	9.09	52.73	13.64	0	18.18	1.82
8-SOB000.15	Southern Branch	Ref	17	5.84	3	5.88	17.65	1	14.71	59.8	1.96	6.86	6.86	59.8	69.61	84.31	26.47	12.75	66.67	10.78	0.98	0	0
8-SOB000.15	Southern Branch	Ref	26	5.44	9	7.84	21.57	6.9	18.63	50.98	1.96	15.69	14.71	50.98	63.73	87.25	34.31	19.61	54.9	8.82	8.82	4.9	3.92
8-STH006.43	South River	Ref	21	5.49	9	34.44	32.22	7.8	26.67	7.78	0	42.22	42.22	25.56	42.22	63.33	77.78	32.22	7.78	27.78	11.11	6.67	6.67
8-STH006.43	South River	Ref	22	5.47	0	0	4.55	0	4.55	4.55	0	0	0.00	13.64	26.14	61.36	87.5	2.27	12.5	30.68	22.73	0	0
2-SWE001.50	Sweeny Creek	Stress	11	5.49	2	0	31.19	7.3	9.17	28.44	0	22.02	7.34	28.44	50.46	82.57	49.54	16.51	30.28	8.26	11.93	14.68	0
3-TOT012.53	Totuskey Creek	Ref	18	4.49	11	31.82	56.36	12.7	19.09	23.64	0	52.73	44.55	23.64	40.91	71.82	46.36	46.36	25.45	3.64	17.27	9.09	0.91
2-WRD005.40	Wards Creek	Ref	26	4.45	12	29.09	46.36	26.4	35.45	14.55	0.91	58.18	55.45	19.09	35.45	65.45	51.82	43.64	15.45	3.64	15.45	25.45	22.73
2-WRD005.40	Wards Creek	Ref	24	5.39	7	15.45	28.18	5.5	21.82	37.27	0	24.55	20.91	37.27	50	71.82	37.27	24.55	37.27	16.36	10	6.36	2.73
7-XCY000.46	X-Trib to Bushmill Stream	Ref	14	4.21	9	49.09	73.64	19.1	11.82	18.18	0.91	74.55	68.18	38.18	56.36	80	36.36	67.27	20	0	18.18	12.73	6.36
5AMRN000.38	Mill Run	Ref	16	5.64	4	14.81	22.22	0.9	13.89	62.04	1.85	16.67	15.74	62.04	73.15	87.96	27.78	14.81	68.52	1.85	1.85	0.93	0
5ANTW058.88	Nottoway River	Ref	18	5.49	5	29.81	7.69	1	17.31	34.62	8.65	30.77	30.77	34.62	46.15	75.96	13.46	7.69	34.62	24.04	15.38	0.96	0.96
5ANTW058.88	Nottoway River	Ref	20	5.53	5	24.55	39.09	0.9	42.73	31.82	5.45	28.18	25.45	31.82	51.82	71.82	52.73	36.36	31.82	20.91	4.55	3.64	0.91
5ANTW051.60	Nottoway River	Ref	15	4.92	9	21.65	45.36	8.2	29.9	38.14	2.06	39.18	29.90	38.14	54.64	83.51	47.42	36.08	40.21	1.03	6.19	13.4	4.12
5AAPW001.04	Applewhite Swamp	Ref	10	6.23	1	0	6.76	1.4	0	48.65	0	1.35	1.35	48.65	64.86	94.59	37.84	1.35	55.41	14.86	0	1.35	1.35
5AAPW001.04	Applewhite Swamp	Ref	10	6.31	0	0	2.78	0	0.93	25.93	0	0	0.00	29.63	55.56	92.59	52.78	0.93	27.78	19.44	0	0	0
5AAPW001.04	Applewhite Swamp	Ref	12	6.69	1	0	1.04	4.2	0	1.04	0	4.17	4.17	46.88	77.08	89.58	52.08	0	5.21	48.96	5.21	4.17	4.17

Note: 8-BLC005.54 was removed from the dataset.

Table B- 3. MACP sites used to generate Figure A-11 (n=59).

StationID	StreamName	RefClass	TotTaxa	HBI	EPTTax	%Ephem	%ClngP	%PT - Hydros	%Scrap	%Chiro	%Non-Insect	%EPT	%EPT - Hydro	%1Dom	%2Dom	%5Dom	%NonCol Gat	%Clng-HydroSimul	%Dip	%Toler	%Intol	%Trich	%T - Hydros
2-CPN004.81	Champion Swamp	Ref	20	6.58	3	10.09	6.42	0.9	11.01	19.27	1.83	11.01	11.01	25.69	44.95	77.06	38.53	3.67	23.85	43.12	2.75	0.92	0.92
2-CPN004.81	Champion Swamp	Ref	19	4.16	8	62.5	33.93	4.5	18.75	7.14	0	66.96	66.96	29.46	47.32	75.89	31.25	33.93	8.04	12.5	30.36	3.57	3.57
2-CPN004.81	Champion Swamp	Ref	14	6.21	3	9.09	3.64	0.9	8.18	32.73	0.91	10	10.00	32.73	52.73	82.73	16.36	3.64	32.73	28.18	3.64	0.91	0.91
2-CPN004.81	Champion Swamp	Ref	22	4.32	10	50	44.55	14.5	39.09	8.18	0.91	66.36	64.55	31.82	42.73	66.36	50.91	42.73	10	5.45	17.27	11.82	10
2-CPN004.81	Champion Swamp	Ref	23	6.1	7	15.84	10.89	5	15.84	15.84	0	20.79	20.79	27.72	43.56	65.35	51.49	10.89	19.8	43.56	6.93	3.96	3.96
2-CPN004.81	Champion Swamp	Ref	20	4.09	5	24.55	12.73	7.3	12.73	18.18	0	31.82	31.82	18.18	36.36	65.45	45.45	12.73	27.27	5.45	34.55	7.27	7.27
2-CRL004.04	Carbell Swamp	Ref	14	6.54	1	1	6	0	0	37	8	1	1.00	37	49	84	42	0	47	24	3	0	0
2-CRL004.04	Carbell Swamp	Ref	21	5.63	3	18.63	13.73	1	1.96	28.43	5.88	19.61	19.61	28.43	42.16	73.53	43.14	6.86	42.16	15.69	15.69	0.98	0.98
2-CRL004.04	Carbell Swamp	Ref	19	6.13	1	0	2.73	2.7	2.73	21.82	4.55	2.73	2.73	44.55	66.36	86.36	69.09	1.82	24.55	14.55	2.73	2.73	2.73
2-CRL004.04	Carbell Swamp	Ref	15	4.55	5	41.82	18.18	7.3	1.82	10.91	10.91	49.09	49.09	28.18	41.82	75.45	33.64	17.27	13.64	10	32.73	7.27	7.27
7-BBR001.31	Bull Branch	Ref	15	6.31	4	6.8	4.85	2.9	6.8	11.65	0	9.71	9.71	22.33	38.83	81.55	60.19	3.88	13.59	40.78	3.88	2.91	2.91
7-BBR001.31	Bull Branch	Ref	14	6.54	2	0	17.82	5	0	30.69	2.97	4.95	4.95	28.71	54.46	84.16	57.43	0	51.49	37.62	4.95	1.98	1.98
7-BBR001.31	Bull Branch	Ref	15	5.62	4	15.89	13.08	7.5	13.08	14.02	1.87	23.36	23.36	21.5	35.51	71.96	72.9	13.08	26.17	25.23	8.41	7.48	7.48
7-GRS002.29	Greens Creek	Ref	21	6.07	5	5.21	7.29	5.2	5.21	18.75	1.04	11.46	10.42	29.17	51.04	78.13	42.71	6.25	25	25	6.25	6.25	5.21
7-GRS002.29	Greens Creek	Ref	17	5.8	6	1.03	4.12	13.4	7.22	13.4	0	15.46	14.43	37.11	56.7	79.38	43.3	3.09	18.56	23.71	10.31	14.43	13.4
7-GRS002.29	Greens Creek	Ref	19	5.94	7	2.68	9.82	6.3	5.36	46.43	1.79	13.39	8.93	46.43	65.18	80.36	44.64	4.46	52.68	20.54	10.71	10.71	6.25
7-GRS002.29	Greens Creek	Ref	17	5.81	5	1.94	2.91	14.6	9.71	10.68	0	16.5	16.50	34.95	53.4	76.7	49.51	2.91	14.56	21.36	12.62	14.56	14.56
7-GRS002.29	Greens Creek	Ref	15	5.74	9	3.7	7.41	16	6.17	43.21	0	22.22	19.75	43.21	64.2	81.48	27.16	4.94	46.91	11.11	8.64	18.52	16.05
7-GRS002.29	Greens Creek	Ref	8	5.94	3	0.91	0.91	5.5	2.73	38.18	0.91	6.36	6.36	51.82	90	97.27	3.64	0.91	38.18	1.82	0	5.45	5.45
7-GRS002.29	Greens Creek	Ref	18	5.16	8	6.36	6.36	20	5.45	35.45	0.91	27.27	26.36	35.45	56.36	78.18	27.27	5.45	37.27	7.27	16.36	20.91	20
VCU_2-CRL001.83	Carbell Swamp	Ref	11	6.28	1	1.82	0	0	13.64	60	0.91	1.82	1.82	60	70	90	20.91	0	60.91	26.36	7.27	0	0
7-GAR006.01	Gargathy Creek	Stress	17	5.85	4	5.71	7.62	6.7	12.38	25.71	2.86	12.38	12.38	25.71	44.76	75.24	50.48	5.71	28.57	25.71	8.57	6.67	6.67
7-GAR006.01	Gargathy Creek	Stress	13	5.31	3	1.8	2.7	1.8	37.84	27.03	0	3.6	3.60	27.03	54.05	90.09	62.16	2.7	29.73	19.82	27.93	1.8	1.8
7-GAR006.01	Gargathy Creek	Stress	15	6.97	3	0.88	1.77	1.8	7.08	10.62	0	2.65	2.65	53.1	69.03	89.38	66.37	0.88	12.39	59.29	2.65	1.77	1.77
7-GAR006.01	Gargathy Creek	Stress	10	6.53	2	4.24	4.24	0.8	22.88	9.32	0	5.08	5.08	44.07	64.41	94.07	29.66	4.24	11.02	36.44	3.39	0.85	0.85
7-GAR006.01	Gargathy Creek	Stress	11	6.26	2	1.82	5.45	0	14.55	65.45	4.55	4.55	1.82	65.45	75.45	90.91	10	1.82	67.27	16.36	0.91	2.73	0
7-GLF003.77	Guilford Creek	Stress	10	6.45	2	0.93	0	1.9	24.07	40.74	1.85	2.78	2.78	40.74	63.89	93.52	44.44	0	40.74	41.67	13.89	1.85	1.85
7-GLF003.77	Guilford Creek	Stress	14	6.88	3	5.45	4.55	8.2	20.91	10	0	18.18	13.64	21.82	39.09	70.91	58.18	0	10	58.18	6.36	12.73	8.18
7-GLF003.77	Guilford Creek	Stress	12	6.08	3	0.85	3.39	0.8	12.71	42.37	0.85	3.39	1.69	42.37	71.19	93.22	21.19	0.85	44.07	16.1	6.78	2.54	0.85
7-GLF003.77	Guilford Creek	Stress	12	6.79	1	0	4.46	0	37.5	0.89	0.89	2.68	0.00	49.11	69.64	94.64	81.25	0	2.68	71.43	20.54	2.68	0
VCU_7-JOY000.59	Jaynes Branch	Stress	8	6.27	1	0.91	0	0	0	27.27	0.91	0.91	0.91	53.64	80.91	97.27	4.55	0	28.18	15.45	0	0	0
VCU_7-MCR002.00	Mill Creek	Stress	10	7.29	1	0	0.91	0	20	17.27	0	0.91	0.00	46.36	63.64	93.64	50.91	0	19.09	67.27	0	0.91	0
7-PAR004.35	Parker Creek (Impact)	Stress	8	6.95	0	0	0	0	8.82	56.86	11.76	0	0.00	56.86	77.45	97.06	22.55	0	56.86	42.16	0	0	0
7-PAR004.35	Parker Creek (Impact)	Stress	13	7.16	1	0	1.83	0	6.42	31.19	26.61	1.83	0.00	31.19	55.05	86.24	30.28	0	33.94	48.62	2.75	1.83	0
7-PAR004.35	Parker Creek (Impact)	Stress	5	7.85	1	0	1.82	0	0	4.55	0	1.82	0.00	88.18	92.73	100	7.27	0	4.55	92.73	0	1.82	0
7-PAR004.35	Parker Creek (Impact)	Stress	9	6.79	0	0	0	0	5.45	9.09	48.18	0	0.00	48.18	73.64	90.91	30	0	11.82	38.18	0	0	0
7-PAR004.35	Parker Creek (Impact)	Stress	8	6.25	1	0	10	0	3.64	74.55	3.64	5.45	0.00	74.55	80.91	94.55	16.36	0	79.09	12.73	0	5.45	0
7-PET000.80	Pettit Branch	Stress	13	6.24	1	0	2.48	0	10.74	68.6	0	0.83	0.00	68.6	79.34	92.56	17.36	0.83	76.86	19.01	3.31	0.83	0
7-PET000.80	Pettit Branch	Stress	12	6.45	1	0	1.77	0	1.77	24.78	0	0.88	0.00	43.36	68.14	94.69	29.2	0.88	31.86	46.02	9.73	0.88	0
7-PET000.80	Pettit Branch	Stress	11	7.01	0	0	1.94	0	29.13	48.54	6.8	0	0.00	48.54	77.67	91.26	12.62	0.97	53.4	44.66	0	0	0
7-PET000.80	Pettit Branch	Stress	17	6.93	0	0	0	0	27.27	29.29	3.03	0	0.00	29.29	54.55	78.79	23.23	0	39.39	54.55	6.06	0	0
7-PET000.80	Pettit Branch	Stress	8	6.14	0	0	0	0	0.91	85.45	0.91	0	0.00	85.45	90.91	100	7.27	0	85.45	8.18	0.91	0	0
7-RSS001.40	Ross Branch	Stress	10	6.31	1	0	2.54	0	8.47	37.29	0	0.85	0.00	37.29	71.19	94.92	23.73	0.85	38.98	21.19	2.54	0.85	0
7-RSS001.40	Ross Branch	Stress	10	7.28	0	0	0	0	10.91	13.64	3.64	0	0.00	68.18	81.82	94.55	77.27	0	15.45	77.27	8.18	0	0
7-RSS001.40	Ross Branch	Stress	9	6.42	1	0	3.67	0	2.75	71.56	2.75	3.67	0.00	71.56	88.99	96.33	22.94	0	71.56	22.02	1.83	3.67	0
7-RSS001.40	Ross Branch	Stress	6	6.05	0	0	0	0	9.48	0.86	0.86	0	0.00	79.31	88.79	100	16.38	0	0.86	12.93	6.9	0	0
7-RSS001.40	Ross Branch	Stress	9	5.98	0	0	0	0	3.64	38.18	20.91	0	0.00	38.18	70	95.45	8.18	0	40	4.55	3.64	0	0
VCU_7-SBB000.17	Sandy Bottom Branch	Stress	14	5.95	1	0	17.27	1.8	14.55	54.55	0.91	1.82	1.82	54.55	64.55	89.09	25.45	10	62.73	12.73	0.91	1.82	1.82
VCU_7-TOM001.73	Magothy Bay	Stress	5	6.67	0	0	0	0	12.73	1.82	0	0	0.00	64.55	80	100	70	0	1.82	33.64	0	0	0
7-XAZ000.30	Sandy Bottom Branch (Impact)	Stress	10	6.64	1	0	10.62	0.9	41.59	42.48	1.77	0.88	0.88	42.48	73.45	92.92	23.89	10.62	44.25	43.36	0	0.88	0.88
7-XAZ000.30	Sandy Bottom Branch (Impact)	Stress	17	6.84	3	0	18.02	3.6	49.55	14.41	2.7	6.31	3.60	34.23	51.35	81.08	40.54	14.41	22.52	54.95	0	6.31	3.6
7-XAZ000.30	Sandy Bottom Branch (Impact)	Stress	11	6.07	1	0	6.36	0	13.64	72.73	8.18	0.91	0.00	72.73	80.91	100	10	5.45	72.73	10.91	0	0.91	0
7-XAZ000.30	Sandy Bottom Branch (Impact)	Stress	21	5.91	2	0	9.17	0.9	15.6	11.01	1.83	1.83	0.92	40.37	51.38	72.48	66.06	8.26	17.43	26.61	0	1.83	0.92
7-XAZ000.30	Sandy Bottom Branch (Impact)	Stress	8	6.09	0	0	1.82	0	1.82	74.55	15.45	0	0.00	74.55	90	100	3.64	0.91	76.36	5.45	0	0	0
7-XDE000.40	X Trib to Folly Creek	Stress	11	5.75	0	0	0.95	0	21.9	60.95	0.95	0	0.00	60.95	79.05	95.24	25.71	0	62.86	16.19	19.05	0	0
7-XDE000.40	X Trib to Folly Creek	Stress	9	4.67	2	0	6.42	1.8	38.53	17.43	0	3.67	1.83	38.53	55.96	85.32	67.89	0	29.36	7.34	45.87	3.67	1.83
7-XDE000.40	X Trib to Folly Creek	Stress	9	5.92	0	0	0.98	0	27.45	50	1.96	0	0.00	50	67.65	96.08	16.67	0	51.96	16.67	14.71	0	0
7-XDE000.40	X Trib to Folly Creek	Stress	12	4.27	2	0	0	5.2	71.13	9.28	1.03	5.15	5.15	62.89	72.16	89.69	73.2	0	10.31	16.49	64.95	5.15	5.15
7-XDE000.40	X Trib to Folly Creek	Stress	9	6.16	0	0	0	0	10	52.73	10.91	0	0.00	52.73	64.55	90.91	8.18	0	52.73	16.36	5.45	0	0

Table B- 4. SEP sites used to generate Figure A-12(n=35) and Figure A-9.

StationID	Date	BensampID	StreamName	Ecoregion	RefClass	TotTaxa	HBI	EPTTax	%Ephem	%ClngP	%PT - Hydropsych	%Scrap	%Chiro	%NonInsect	%EPT	%EPT - Hydro	%1Dom	%2Dom	%5Dom	%NonColGat	%Clng-HydroSimulid	%Dip	%Toler	%Intol	%Trich	%T - Hydropsych
2-BLB002.23	3/24/2010	BLB1138R110	Bailey Branch	SE Plains	Ref	16	5.17	9	22.73	20	10.9	10	57.27	2.73	33.64	33.63636364	57.27	66.36	83.64	16.36	20	57.27	1.82	5.45	7.27	7.27
2-POS002.62	3/13/2006	POS4049	Possum Run	SE Plains	Ref	16	5.85	5	0.85	18.64	7.6	16.1	47.46	16.1	9.32	8.474576271	47.46	63.56	87.29	30.51	17.8	47.46	11.02	1.69	8.47	7.63
2-POS002.62	9/6/2006	POS4167	Possum Run	SE Plains	Ref	10	5.7	2	0	41	2	40	23	6	3	2	40	63	91	69	40	27	22	1	3	2
2-WRD005.40	6/3/2009	WRD80R110	Wards Creek	SE Plains	Ref	24	5.39	7	15.45	28.18	5.5	21.82	37.27	0	24.55	20.90909091	37.27	50	71.82	37.27	24.55	37.27	16.36	10	6.36	2.73
2-WRD005.40	10/22/2009	WRD160R110	Wards Creek	SE Plains	Ref	26	4.45	12	29.09	46.36	26.4	35.45	14.55	0.91	58.18	55.45454545	19.09	35.45	65.45	51.82	43.64	15.45	3.64	15.45	25.45	22.73
3-BMS002.00	3/16/2010	BMS1140R110	Bookers Mill Stream	SE Plains	Ref	21	4.55	12	17.27	45.45	25.5	10	36.36	0.91	44.55	42.72727273	36.36	48.18	73.64	39.09	38.18	46.36	1.82	24.55	13.64	11.82
3-CAT011.62	6/9/2009	CAT69R110	Cat Point Creek	SE Plains	Ref	11	5.06	5	25	74.07	2.8	39.81	18.52	0.93	37.04	27.77777778	23.15	45.37	89.81	76.85	41.67	41.67	0.93	1.85	10.19	0.93
3-TOT012.53	4/5/2010	TOT1141R110	Totuskey Creek	SE Plains	Ref	18	4.49	11	31.82	56.36	12.7	19.09	23.64	0	52.73	44.54545455	23.64	40.91	71.82	46.36	46.36	25.45	3.64	17.27	9.09	0.91
7-XCY000.46	3/16/2010	XCY1142R110	X-Trib to Bushmill Stream	SE Plains	Ref	14	4.21	9	49.09	73.64	19.1	11.82	18.18	0.91	74.55	68.18181818	38.18	56.36	80	36.36	67.27	20	0	18.18	12.73	6.36
8-BLC005.54	4/22/2009	BLC67R110	Black Creek	SE Plains	Ref	17	5.27	10	21.82	20.91	7.3	11.82	51.82	0	30.91	29.09090909	51.82	70	93.64	20.91	14.55	56.36	3.64	3.64	7.27	5.45
8-BLC005.54	10/15/2009	BLC158R110	Black Creek	SE Plains	Ref	23	4.85	11	15.45	25.45	26.4	13.64	30.91	0.91	44.55	41.81818182	30.91	41.82	68.18	40	20.91	37.27	5.45	18.18	23.64	20.91
8-BRC002.70	4/25/2001	BRC2989	Beaver Creek	SE Plains	Ref	18	3.76	9	47.76	71.64	29.1	24.63	0.75	0	84.33	76.86567164	22.39	44.03	74.63	76.87	64.18	0.75	2.24	32.84	15.67	8.21
8-BRC002.70	10/2/2001	BRC3002	Beaver Creek	SE Plains	Ref	10	3.19	5	43.14	67.65	38.2	14.71	0.98	0	86.27	81.37254902	35.29	63.73	93.14	99.02	62.75	1.96	0	68.63	40.2	35.29
8-MPN094.79	6/22/1999	MPN1418	Mattaponi River	SE Plains	Ref	25	5.27	6	15.89	26.17	16.8	12.15	1.87	0.93	32.71	32.71028037	15.89	28.97	57.01	79.44	26.17	1.87	40.19	28.04	13.08	13.08
8-MPN094.79	9/21/1999	MPN4793	Mattaponi River	SE Plains	Ref	22	4.19	5	19.19	48.48	21.2	18.18	4.04	0	41.41	40.4040404	14.14	24.24	59.6	83.84	47.47	4.04	14.14	31.31	15.15	14.14
8-MPN094.79	6/14/2000	MPN2764	Mattaponi River	SE Plains	Ref	21	5.39	4	9.38	18.13	2.5	16.25	2.5	0	12.5	11.875	26.88	41.88	68.75	96.25	17.5	2.5	27.5	8.75	1.25	0.63
8-MPN094.79	6/15/2010	MPN709R110	Mattaponi River	SE Plains	Ref	15	4.44	6	32.73	58.18	20.9	34.55	10	0	56.36	53.63636364	28.18	41.82	72.73	73.64	55.45	10	18.18	25.45	15.45	12.73
8-MPN094.79	10/6/2010	MPN1335R110	Mattaponi River	SE Plains	Ref	22	5.48	2	2.73	4.55	0	12.73	21.82	0.91	2.73	2.727272727	21.82	32.73	59.09	58.18	4.55	28.18	28.18	23.64	0	0
8-SOB000.15	4/25/2006	SOB4037	Southern Branch	SE Plains	Ref	17	5.84	3	5.88	17.65	1	14.71	59.8	1.96	6.86	6.862745098	59.8	69.61	84.31	26.47	12.75	66.67	10.78	0.98	0	0
8-SOB000.15	10/31/2006	SOB4178	Southern Branch	SE Plains	Ref	26	5.44	9	7.84	21.57	6.9	18.63	50.98	1.96	15.69	14.70588235	50.98	63.73	87.25	34.31	19.61	54.9	8.82	8.82	4.9	3.92
8-STH006.43	4/18/2005	STH3437	South River	SE Plains	Ref	21	5.49	9	34.44	32.22	7.8	26.67	7.78	0	42.22	42.22222222	25.56	42.22	63.33	77.78	32.22	7.78	27.78	11.11	6.67	6.67
8-STH006.43	10/20/2005	STH3661	South River	SE Plains	Ref	22	5.47	0	0	4.55	0	4.55	4.55	0	0	0	13.64	26.14	61.36	87.5	2.27	12.5	30.68	22.73	0	0
VCU_3-BLD001.54	4/6/2003	BLD1827R110	Bellwood Swamp	SE Plains	Ref	12	5.24	4	32.73	31.82	0.9	18.18	45.45	0.91	33.64	33.63636364	45.45	66.36	86.36	14.55	31.82	45.45	8.18	2.73	0	0
VCU_8-CPL004.15	4/15/2003	CPL1820R110	Chapel Creek	SE Plains	Ref	16	5.45	6	11.82	14.55	3.6	7.27	60	3.64	16.36	15.45454545	60	67.27	86.36	28.18	9.09	65.45	1.82	7.27	0.91	0
8-MHX000.27	5/25/2010	MHX1115R110	Mehixen Creek	SE Plains	Stress	10	5.5	5	14.55	29.09	2.7	5.45	53.64	0	27.27	17.27272727	53.64	64.55	92.73	32.73	8.18	68.18	0	2.73	10	0
2-BEV002.00	12/16/2009	BEV173R110	Beaverdam Creek	SE Plains	Stress	20	5.05	7	10	38.18	7.3	46.36	25.45	3.64	21.82	17.27272727	25.45	47.27	78.18	63.64	33.64	27.27	8.18	13.64	10.91	6.36
2-BEV002.00	5/27/2009	BEV78R110	Beaverdam Creek	SE Plains	Stress	15	5.47	5	5.45	54.55	3.6	40.91	22.73	2.73	30	9.090909091	26.36	49.09	81.82	55.45	30.91	25.45	11.82	2.73	24.55	3.64
2-SWE001.50	5/30/2002	SWE02556	Sweeny Creek	SE Plains	Stress	11	5.49	2	0	31.19	7.3	9.17	28.44	0	22.02	7.339449541	28.44	50.46	82.57	49.54	16.51	30.28	8.26	11.93	14.68	0
2-bly005.73	5/25/2011	BLY1873	bailey creek	SE Plains	Stress	10	6.15	2	0.91	3.64	1.8	4.55	57.27	32.73	2.73	2.727272727	57.27	79.09	97.27	8.18	3.64	57.27	13.64	1.82	0	0
7-dym003.52	5/26/2011	dmy2101	dymer creek	SE Plains	Stress	10	5.78	1	0	15.45	0	11.82	68.18	0.91	0.91	0	68.18	80	96.36	30	11.82	72.73	1.82	0	0.91	0
7-FOX002.55	10/3/1994	FOX96	Fox Mill Run (Impact)	SE Plains	Stress	20	6.19	2	0.97	1.94	1	6.8	10.68	0.97	1.94	1.941747573	19.42	37.86	66.99	79.61	1.94	11.65	33.98	9.71	0.97	0.97
3-GIN002.64	10/13/2010	GIN1326R110	Gingoteague Creek	SE Plains	Stress	17	6	0	0	1.72	0	0	15.52	1.72	0	0	34.48	50	74.14	79.31	1.72	17.24	20.69	8.62	0	0
3-GIN002.64	5/19/2010	GIN707R110	Gingoteague Creek	SE Plains	Stress	15	5.75	3	8.18	20	4.5	10	41.82	0.91	12.73	12.72727273	41.82	52.73	78.18	40.91	20	41.82	20	5.45	0	0
2-RHC000.58	4/27/2010	RHC1133R110	Rohoic Creek	SE Plains	Stress	8	5.78	4	5.45	56.36	1.8	0	31.82	4.55	8.18	7.272727273	54.55	86.36	100	58.18	0.91	87.27	0	2.73	0.91	0
3-run000.13	5/25/2011	RUN1874	Ruin Branch	SE Plains	Stress	12	6.06	3	1.82	31.82	1.8	9.09	44.55	1.82	20	3.636363636	44.55	60.91	88.18	47.27	9.09	52.73	13.64	0	18.18	1.82

Table B- 5. MACP sites used to generate Figure A-13 (n=69) and Figure A-9.

StationID	Date	StreamName	Ecoregion	RefClass	TotTaxa	HBI	EPTTax	%Ephem	%ClngP	%PT - Hydropsychidae	%Scrap	%Chiro	%NonInsect	%EPT	%EPT - Hydro	%1Dom	%2Dom	%5Dom	%NonColGat	%Clng-HydroSimulid	%Dip	%Toler	%Intol	%Trich	%T - Hydropsychidae
2-CPN004.81	4/30/2008	Champion Swamp	MACP	Ref	20	6.58	3	10.09	6.42	0.9	11.01	19.27	1.83	11.01	11.00917431	25.69	44.95	77.06	38.53	3.67	23.85	43.12	2.75	0.92	0.92
2-CPN004.81	10/14/2008	Champion Swamp	MACP	Ref	19	4.16	8	62.5	33.93	4.5	18.75	7.14	0	66.96	66.96428571	29.46	47.32	75.89	31.25	33.93	8.04	12.5	30.36	3.57	3.57
2-CPN004.81	5/14/2009	Champion Swamp	MACP	Ref	14	6.21	3	9.09	3.64	0.9	8.18	32.73	0.91	10	10	32.73	52.73	82.73	16.36	3.64	32.73	28.18	3.64	0.91	0.91
2-CPN004.81	10/22/2009	Champion Swamp	MACP	Ref	22	4.32	10	50	44.55	14.5	39.09	8.18	0.91	66.36	64.54545455	31.82	42.73	66.36	50.91	42.73	10	5.45	17.27	11.82	10
2-CPN004.81	5/17/2007	Champion Swamp	MACP	Ref	23	6.1	7	15.84	10.89	5	15.84	15.84	0	20.79	20.79207921	27.72	43.56	65.35	51.49	10.89	19.8	43.56	6.93	3.96	3.96
2-CPN004.81	10/16/2007	Champion Swamp	MACP	Ref	20	4.09	5	24.55	12.73	7.3	12.73	18.18	0	31.82	31.81818182	18.18	36.36	65.45	45.45	12.73	27.27	5.45	34.55	7.27	7.27
2-CRL004.04	4/30/2008	Carbell Swamp	MACP	Ref	14	6.54	1	1	6	0	0	37	8	1	1	37	49	84	42	0	47	24	3	0	0
2-CRL004.04	10/14/2008	Carbell Swamp	MACP	Ref	21	5.63	3	18.63	13.73	1	1.96	28.43	5.88	19.61	19.60784314	28.43	42.16	73.53	43.14	6.86	42.16	15.69	15.69	0.98	0.98
2-CRL004.04	5/14/2009	Carbell Swamp	MACP	Ref	19	6.13	1	0	2.73	2.7	2.73	21.82	4.55	2.73	2.727272727	44.55	66.36	86.36	69.09	1.82	24.55	14.55	2.73	2.73	2.73
2-CRL004.04	10/22/2009	Carbell Swamp	MACP	Ref	15	4.55	5	41.82	18.18	7.3	1.82	10.91	10.91	49.09	49.09090909	28.18	41.82	75.45	33.64	17.27	13.64	10	32.73	7.27	7.27
5ABLC000.88	11/5/2003	Black Creek	MACP	Ref	21	5.64	2	2	12	2	32	6	0	4	4	16	30	64	76	12	6	29	25	0	0
7-BBR001.31	10/30/2003	Bull Branch	MACP	Ref	15	6.31	4	6.8	4.85	2.9	6.8	11.65	0	9.71	9.708737864	22.33	38.83	81.55	60.19	3.88	13.59	40.78	3.88	2.91	2.91
7-BBR001.31	4/6/2004	Bull Branch	MACP	Ref	14	6.54	2	0	17.82	5	0	30.69	2.97	4.95	4.95049505	28.71	54.46	84.16	57.43	0	51.49	37.62	4.95	1.98	1.98
7-BBR001.31	10/27/2004	Bull Branch	MACP	Ref	15	5.62	4	15.89	13.08	7.5	13.08	14.02	1.87	23.36	23.36448598	21.5	35.51	71.96	72.9	13.08	26.17	25.23	8.41	7.48	7.48
7-GRS002.29	4/17/2001	Greens Creek	MACP	Ref	21	6.07	5	5.21	7.29	5.2	5.21	18.75	1.04	11.46	10.41666667	29.17	51.04	78.13	42.71	6.25	25	25	6.25	6.25	5.21
7-GRS002.29	9/25/2001	Greens Creek	MACP	Ref	17	5.8	6	1.03	4.12	13.4	7.22	13.4	0	15.46	14.43298969	37.11	56.7	79.38	43.3	3.09	18.56	23.71	10.31	14.43	13.4
7-GRS002.29	4/4/2002	Greens Creek	MACP	Ref	19	5.94	7	2.68	9.82	6.3	5.36	46.43	1.79	13.39	8.928571429	46.43	65.18	80.36	44.64	4.46	52.68	20.54	10.71	10.71	6.25
7-GRS002.29	10/3/2002	Greens Creek	MACP	Ref	17	5.81	5	1.94	2.91	14.6	9.71	10.68	0	16.5	16.50485437	34.95	53.4	76.7	49.51	2.91	14.56	21.36	12.62	14.56	14.56
7-GRS002.29	10/29/2008	Greens Creek	MACP	Ref	15	5.74	9	3.7	7.41	16	6.17	43.21	0	22.22	19.75308642	43.21	64.2	81.48	27.16	4.94	46.91	11.11	8.64	18.52	16.05
7-GRS002.29	5/12/2009	Greens Creek	MACP	Ref	8	5.94	3	0.91	0.91	5.5	2.73	38.18	0.91	6.36	6.363636364	51.82	90	97.27	3.64	0.91	38.18	1.82	0	5.45	5.45
7-GRS002.29	10/28/2009	Greens Creek	MACP	Ref	18	5.16	8	6.36	6.36	20	5.45	35.45	0.91	27.27	26.36363636	35.45	56.36	78.18	27.27	5.45	37.27	7.27	16.36	20.91	20
VCU_2-CRL001.83	11/6/2006	Carbell Swamp	MACP	Ref	11	6.28	1	1.82	0	0	13.64	60	0.91	1.82	1.818181818	60	70	90	20.91	0	60.91	26.36	7.27	0	0
VCU_5ACHP002.03	6/1/2005	Chapel Swamp	MACP	Ref	10	6.91	2	0.91	4.55	0	4.55	39.09	2.73	4.55	0.909090909	42.73	81.82	93.64	11.82	0.91	39.09	48.18	0	3.64	0
5AXGI001.79	4/25/2006	X-Trib to Blackwater River	MACP	Stress	13	7.37	0	0	0	0	56.9	7.76	6.9	0	0	56.03	73.28	93.1	25.86	0	25	65.52	0	0	0
5AXGI001.79	11/2/2006	X-Trib to Blackwater River	MACP	Stress	15	7.98	1	0.93	0.93	0	27.1	5.61	3.74	0.93	0.934579439	41.12	64.49	87.85	60.75	0.93	6.54	85.98	0	0	0
5AXGI001.79	5/17/2007	X-Trib to Blackwater River	MACP	Stress	14	7.25	0	0	0.97	0	35.92	22.33	4.85	0	0	33.98	56.31	84.47	35.92	0.97	28.16	65.05	0	0	0
5AXGI001.79	10/16/2007	X-Trib to Blackwater River	MACP	Stress	10	7.85	0	0	0	0	48.6	12.15	8.41	0	0	47.66	60.75	88.79	30.84	0	16.82	79.44	0	0	0
7-GAR006.01	10/27/2004	Gargathy Creek	MACP	Stress	17	5.85	4	5.71	7.62	6.7	12.38	25.71	2.86	12.38	12.38095238	25.71	44.76	75.24	50.48	5.71	28.57	25.71	8.57	6.67	6.67
7-GAR006.01	10/20/2005	Gargathy Creek	MACP	Stress	13	5.31	3	1.8	2.7	1.8	37.84	27.03	0	3.6	3.603603604	27.03	54.05	90.09	62.16	2.7	29.73	19.82	27.93	1.8	1.8
7-GAR006.01	10/19/2006	Gargathy Creek	MACP	Stress	15	6.97	3	0.88	1.77	1.8	7.08	10.62	0	2.65	2.654867257	53.1	69.03	89.38	66.37	0.88	12.39	59.29	2.65	1.77	1.77
7-GAR006.01	4/29/2008	Gargathy Creek	MACP	Stress	10	6.53	2	4.24	4.24	0.8	22.88	9.32	0	5.08	5.084745763	44.07	64.41	94.07	29.66	4.24	11.02	36.44	3.39	0.85	0.85
7-GAR006.01	5/13/2010	Gargathy Creek	MACP	Stress	11	6.26	2	1.82	5.45	0	14.55	65.45	4.55	4.55	1.818181818	65.45	75.45	90.91	10	1.82	67.27	16.36	0.91	2.73	0
7-GLF003.77	4/27/2005	Guilford Creek	MACP	Stress	10	6.45	2	0.93	0	1.9	24.07	40.74	1.85	2.78	2.777777778	40.74	63.89	93.52	44.44	0	40.74	41.67	13.89	1.85	1.85
7-GLF003.77	10/20/2005	Guilford Creek	MACP	Stress	14	6.88	3	5.45	4.55	8.2	20.91	10	0	18.18	13.63636364	21.82	39.09	70.91	58.18	0	10	58.18	6.36	12.73	8.18
7-GLF003.77	5/1/2006	Guilford Creek	MACP	Stress	12	6.08	3	0.85	3.39	0.8	12.71	42.37	0.85	3.39	1.694915254	42.37	71.19	93.22	21.19	0.85	44.07	16.1	6.78	2.54	0.85
7-GLF003.77	10/19/2006	Guilford Creek	MACP	Stress	12	6.79	1	0	4.46	0	37.5	0.89	0.89	2.68	0	49.11	69.64	94.64	81.25	0	2.68	71.43	20.54	2.68	0
VCU_7-JOY000.59	4/25/2003	Jaynes Branch	MACP	Stress	8	6.27	1	0.91	0	0	0	27.27	0.91	0.91	0.909090909	53.64	80.91	97.27	4.55	0	28.18	15.45	0	0	0
VCU_7-MCR002.00	6/6/2005	Mill Creek	MACP	Stress	10	7.29	1	0	0.91	0	20	17.27	0	0.91	0	46.36	63.64	93.64	50.91	0	19.09	67.27	0	0.91	0
7-PAR004.35	4/29/2008	Parker Creek (Impact)	MACP	Stress	8	6.95	0	0	0	0	8.82	56.86	11.76	0	0	56.86	77.45	97.06	22.55	0	56.86	42.16	0	0	0
7-PAR004.35	10/29/2008	Parker Creek (Impact)	MACP	Stress	13	7.16	1	0	1.83	0	6.42	31.19	26.61	1.83	0	31.19	55.05	86.24	30.28	0	33.94	48.62	2.75	1.83	0
7-PAR004.35	5/21/2009	Parker Creek (Impact)	MACP	Stress	5	7.85	1	0	1.82	0	0	4.55	0	1.82	0	88.18	92.73	100	7.27	0	4.55	92.73	0	1.82	0
7-PAR004.35	10/28/2009	Parker Creek (Impact)	MACP	Stress	9	6.79	0	0	0	0	5.45	9.09	48.18	0	0	48.18	73.64	90.91	30	0	11.82	38.18	0	0	0
7-PAR004.35	4/20/2010	Parker Creek (Impact)	MACP	Stress	8	6.25	1	0	10	0	3.64	74.55	3.64	5.45	0	74.55	80.91	94.55	16.36	0	79.09	12.73	0	5.45	0
7-PET000.80	5/1/2006	Pettit Branch	MACP	Stress	13	6.24	1	0	2.48	0	10.74	68.6	0	0.83	0	68.6	79.34	92.56	17.36	0.83	76.86	19.01	3.31	0.83	0
7-PET000.80	10/19/2006	Pettit Branch	MACP	Stress	12	6.45	1	0	1.77	0	1.77	24.78	0	0.88	0	43.36	68.14	94.69	29.2	0.88	31.86	46.02	9.73	0.88	0
7-PET000.80	4/29/2008	Pettit Branch	MACP	Stress	11	7.01	0	0	1.94	0	29.13	48.54	6.8	0	0	48.54	77.67	91.26	12.62	0.97	53.4	44.66	0	0	0
7-PET000.80	10/29/2008	Pettit Branch	MACP	Stress	17	6.93	0	0	0	0	27.27	29.29	3.03	0	0	29.29	54.55	78.79	23.23	0	39.39	54.55	6.06	0	0
7-PET000.80	5/13/2010	Pettit Branch	MACP	Stress	8	6.14	0	0	0	0	0.91	85.45	0.91	0	0	85.45	90.91	100	7.27	0	85.45	8.18	0.91	0	0
7-RSS001.40	4/27/2006	Ross Branch	MACP	Stress	10	6.31	1	0	2.54	0	8.47	37.29	0	0.85	0	37.29	71.19	94.92	23.73	0.85	38.98	21.19	2.54	0.85	0
7-RSS001.40	10/18/2006	Ross Branch	MACP	Stress	10	7.28	0	0	0	0	10.91	13.64	3.64	0	0	68.18	81.82	94.55	77.27	0	15.45	77.27	8.18	0	0
7-RSS001.40	5/3/2007	Ross Branch	MACP	Stress	9	6.42	1	0	3.67	0	2.75	71.56	2.75	3.67	0	71.56	88.99	96.33	22.94	0	71.56	22.02	1.83	3.67	0
7-RSS001.40	4/29/2008	Ross Branch	MACP	Stress	6	6.05	0	0	0	0	9.48	0.86	0.86	0	0	79.31	88.79	100	16.38	0	0.86	12.93	6.9	0	0
7-RSS001.40	4/20/2010	Ross Branch	MACP	Stress	9	5.98	0	0	0	0	3.64	38.18	20.91	0	0	38.18	70	95.45	8.18	0	40	4.55	3.64	0	0
VCU_7-SBB000.17	4/28/2003	Sandy Bottom Branch	MACP	Stress	14	5.95	1	0	17.27	1.8	14.55	54.55	0.91	1.82	1.818181818	54.55	64.55	89.09	25.45	10	62.73	12.73	0.91	1.82	1.82
VCU_7-TOM001.73	6/6/2005	Magothy Bay	MACP	Stress	5	6.67	0	0	0	0	12.73	1.82	0	0	0	64.55	80	100	70	0	1.82	33.64	0	0	0
7-XAZ000.30	4/29/2008	Sandy Bottom Branch (Impact)	MACP	Stress	10	6.64	1	0	10.62	0.9	41.59	42.48	1.77	0.88	0.884955752	42.48	73.45	92.92	23.89	10.62	44.25	43.36	0	0.88	0.88
7-XAZ000.30	10/29/2008	Sandy Bottom Branch (Impact)	MACP	Stress	17	6.84	3	0	18.02	3.6	49.55	14.41	2.7	6.31	3.603603604	34.23	51.35	81.08	40.54	14.41	22.52	54.95	0	6.31	3.6
7-XAZ000.30	5/21/2009	Sandy Bottom Branch (Impact)	MACP	Stress	11	6.07	1	0	6.36	0	13.64	72.73	8.18	0.91	0	72.73	80.91	100	10	5.45	72.73	10.91	0	0.91	0
7-XAZ000.30	10/28/2009	Sandy Bottom Branch (Impact)	MACP	Stress	21	5.91	2	0	9.17	0.9	15.6	11.01	1.83	1.83	0.917431193	40.37	51.38	72.48	66.06	8.26	17.43	26.61	0	1.83	0.92
7-XAZ000.30	4/20/2010	Sandy Bottom Branch (Impact)	MACP	Stress	8	6.09	0	0	1.82	0	1.82	74.55	15.45	0	0	74.55	90	100	3.64	0.91	76.36	5.45	0	0	0
7-XDE000.40	5/8/2007	X Trib to Folly Creek	MACP	Stress	11	5.75	0	0	0.95	0	21.9	60.95	0.95	0	0	60.95	79.05	95.24	25.71	0	62.86	16.19	19.05	0	0
7-XDE000.40	10/31/2007	X Trib to Folly Creek	MACP	Stress	9	4.67	2	0	6.42	1.8	38.53	17.43	0	3.67	1.834862385	38.53	55.96	85.32	67.89	0	29.36	7.34	45.87	3.67	1.83
7-XDE000.40	4/29/2008	X Trib to Folly Creek	MACP	Stress	9	5.92	0	0	0.98	0	27.45	50	1.96	0	0	50	67.65	96.08	16.67	0	51.96	16.67	14.71	0	0
7-XDE000.40	10/29/2008	X Trib to Folly Creek	MACP	Stress	12	4.27	2	0	0	5.2	71.13	9.28	1.03	5.15	5.154639175	62.89	72.16	89.69	73.2	0	10.31	16.49	64.95	5.15	5.15
7-XDE000.40	4/20/2010	X Trib to Folly Creek	MACP	Stress	9	6.16	0	0	0	0	10	52.73	10.91	0	0	52.73	64.55	90.91	8.18	0	52.73	16.36	5.45	0	0
5AMRN000.38	6/3/2009	Mill Run	SEP	Ref	16	5.64	4	14.81	22.22	0.9	13.89	62.04	1.85	16.67	15.74074074	62.04	73.15	87.96	27.78	14.81	68.52	1.85	1.85	0.93	0
5ANTW051.60	5/29/2007	Nottoway River	SEP	Ref	15	4.92	9	21.65	45.36	8.2	29.9	38.14	2.06	39.18	29.89690722	38.14	54.64	83.51	47.42	36.08	40.21	1.03	6.19	13.4	4.12
5ANTW058.88	4/12/2004	Nottoway River	SEP	Ref	18	5.49	5	29.81	7.69	1	17.31	34.62	8.65	30.77	30.76923077	34.62	46.15	75.96	13.46	7.69	34.62	24.04	15.38	0.96	0.96
5ANTW058.88	10/13/2004	Nottoway River	SEP	Ref	20	5.53	5	24.55	39.09	0.9	42.73	31.82	5.45	28.18	25.45454545	31.82	51.82	71.82	52.73	36.36	31.82	20.91	4.55	3.64	0.91