Progress Report to the Academic Advisory Committee, Virginia Department of Environmental Quality

# Development of Freshwater Nutrient Criteria for Non-wadeable Streams in Virginia: Fish Community Assessment, Phase II

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## Introduction

The complex ecological and biological relationships among nutrient concentrations and fishes in freshwater systems, including streams, lakes, and reservoirs, are documented by a large and diverse literature. Many such studies focus on the role of nutrients in determining rates of secondary production (and, therefore, potential yields) of higher trophic levels, including fishes (e.g. Dodds, et al. 2002), nutrient cycling and spiraling (e.g. Griffiths 2006), and the effects of nutrient releases from aquaculture facilities (e.g. Dalsgaard and Krause-Jensen 2006). The impact of nutrient enrichment (eutrophication) from anthropogenic sources on aquatic systems has also been widely-studied and is considered a serious threat to aquatic ecosystem health and function (EPA 1998). In response, many U.S. jurisdictions have moved to develop and implement regional nutrient criteria, with the goal of protecting aquatic living resources, including fishes. Frequently, measures (indices) of biotic assemblages (fish and macroinvertebrates) are used to assess stream health, integrity, and, indirectly, water quality. However, only a limited number of published studies (e.g. Wang, et al. 2006) have examined *directly* the putative effects of cultural eutrophication on fish community structure and function in streams, and only a few of these reports (e.g. Morgan, et al. 2007) have focused on the mid-Atlantic region.

At a 2006 meeting of an Academic Advisory Committee working group focused on establishing numeric nutrient criteria for Virginia's streams, participants discussed several potential approaches for linking nutrient concentrations and criteria to aquatic life use standards in larger (i.e., non-wadeable) streams and rivers. Specifically, the subcommittee reasoned that fish community structure may be a useful diagnostic of nutrient-related effects in such systems, which are typically too large for standard benthic macroinvertebrate sampling protocols. The subcommittee proposed a preliminary analysis, using existing data, to determine whether statistically significant relationship(s) exist among a limited suite of variables representing nutrient conditions and fish community structure, and at broad geospatial scales. If such a relationship can be demonstrated, based on analyses with archival data alone, additional future analyses and targeted database development may support the establishment and/or validation of ecologically-based, and scientifically defensible, numeric nutrient criteria for larger lotic ecosystems.

A previous study for the AAC (Garman, et al. 2007) completed broad and preliminary analyses of fish community and nutrient data for streams and rivers in the Virginia Coastal Zone. These analyses were based on an extensive database of fish community metrics for Chesapeake Bay freshwater systems and DEQ's nutrient concentration data (TP, Chl a) from that agency's ambient monitoring program. This 2007 pilot study had the following objectives: 1.) create a working database by combining and distilling large amounts of archival data representing nutrient concentrations and fish community structure from multiple sources, and 2.) conduct simple correlation analyses to test the hypothesis that derived measures of nutrient conditions and stream health (fish communities) may be related statistically and could, therefore, be the basis for future predictive models and nutrient criteria thresholds. This study successfully demonstrated that statistical relationships among fish community indices (modified Index of Biotic Integrity, mIBI) and nutrient concentrations (DEQ ambient monitoring) could be used to develop nutrient criteria related to both localized and downstream effects. Unfortunately, these

preliminary analyses were constrained limited by several factors, including the lack of temporally and spatially synoptic data (nutrients and fish), representation of a single geographic region, and the inability to separate wadeable and non-wadeable ambient monitoring stations within the DEQ/STORET database. The current study, described below, attempts to expand and improve the initial analysis.

## Approach and Methods

DEQ monitoring data representing ambient nutrient concentrations and algal primary production at georeferenced stream locations were downloaded to a VCU server for post-processing. Approximately 600K records were provided to VCU by Roger Stewart at DEQ headquarters. Data were filtered based on specific criteria (e.g. stream characteristics, date, parameter, Chesapeake Bay basin) and joined to a subset of the fish community database maintained by VCU's INSTAR stream assessment program, which generates stream health (i.e., biotic integrity) scores based on empirical data and established models (described below). In addition, model outputs representing NPS nutrient loadings were provided by Karl Huber, DCR Division of Soil and Water and subjected to similar preparation and analysis. Analyses were limited to the Shenandoah basin, the Virginia Coastal Zone, and the Virginia portion of the Eastern Shore. Data representing streams and rivers in other Chesapeake Bay regions (i.e., Piedmont) were deemed insufficient and eliminated from further analyses. Because no objective criteria exist to identify streams as non-wadeable and quantitative and large-river data for fish communities in Virginia are limited, we did not restrict the database to large (non-wadeable) streams and rivers. Individual data records were combined to generate descriptive statistics (means, percentiles and ranges) for 6$^{th}$-order hydrologic units (HUCs) in each region and for each selected parameter/metric. Hence, the fundamental spatial unit for all subsequent analyses and data presentations was the HUC; some HUCs did not have sufficient data and were eliminated from further analysis. Geospatial analyses were conducted using ESRI's ArcGIS application. More detailed methods and data descriptions are provided below:

*Stream Nutrient Concentrations*: The following nutrient parameters were selected from the DEQ ambient monitoring database and developed for further analysis: total nitrogen concentration (TN, mg/l; Figure 1), total phosphorus concentration (TP, mg/l; Figure 2) and chlorophyll-*a* concentration (Chl-a, ug/l; Figure 3). Chlorophyll-a concentration is indicative of the trophic status of a water body and high Chl-a values generally indicate eutrophication. A detailed description of DEQ's ambient monitoring program for nutrients is provided at: http://www.deq.virginia.gov/watermonitoring/aqm.html.

*Stream Nutrient Loadings*: The non-point source (NPS) assessment program coordinated by DCR Division of Soil and Water provided 2008 loading values for total nitrogen (TN) and total phosphorous (TP) based on a modeling effort that calibrates to CBWM monitoring stations and data. The loadings outputs are edge-of-stream, do not include delivery downstream, and represent 6$^{th}$-order HUCs. A detailed description of DCR's NPS Assessment Program is provided at: http://www.dcr.virginia.gov/soil_&_water/nps.shtml.

*Stream Fish Community Assessment*: The ***INSTAR*** application (http://instar.vcu.edu and http://128.172.160.131/instarlite/) and the extensive aquatic resource database on which it runs, were developed to support a variety of stream assessment, management and planning activities aimed at restoring and protecting water quality and aquatic living resources throughout the Commonwealth. In addition, regional reference stream models (i.e., *virtual* streams) for both

non-tidal and small to medium-sized tidal tributaries are developed as criteria for prioritization of candidate streams and watersheds for protection and restoration, objective and quantitative performance measures, and as a decision support tool for environmental planning and implementation. Currently, *INSTAR* has compiled information on approximately 2,000 Virginia streams and *INSTAR* databases comprise over 225,000 records (Figure 1). Probabilistic study reaches for *INSTAR* sampling were selected through a statistically powerful, stratified (by stream order) random design. Within each geo-referenced reach (150-200 m), fishes are sampled quantitatively using electrofishing equipment (backpacks, tote barge units, boats) and standard methods. Backpack and tote barge sampling is performed throughout the entire reach in a single pass. Boat electrofishing may include additional sampling effort depending on stream width and habitat variability. Data are compiled in Access® databases and application macros within INSTAR calculate over 50 separate metrics and ecological variables, including those typically generated for the Index of Biotic Integrity (IBI), Rapid Bioassessment Protocol (RBP), and Rapid Habitat Assessment (RHA). Variables and metrics are then subjected to ordination and cluster analysis using unimodal models (e.g. correspondence analysis (CA), detrended correspondence analysis (DCA), and canonical correspondence analysis (CCA)) and linear response models (e.g. principal components analysis (PCA), multiple regression techniques). The site scores (i.e., coefficients from the final response model) are entered as the response variable and significant ($P<0.05$) biotic and abiotic variables and metrics are entered as explanatory variables, and used to develop a series of reference stream models (i.e., *virtual* streams). We used Gower's similarity index to compare empirical scores obtained from sampled stream reaches to the appropriate virtual reference stream, generating an index of stream health (VSA score) as a measure of percent comparability to the appropriate (*virtual*) reference condition model (Figure 4). Fish assemblages with high percent comparability scores (VSA scores > 71%) are assumed to represent streams with high ecological integrity (i.e., healthy).

<u>Findings</u>

Stream nutrient concentrations (TN and TP) were generally negatively correlated with stream health categories, based on an analysis of fish community metrics and this pattern was observed for all geographic regions included in the analysis (Figures 5-7). The relationships were most pronounced for the maximum nutrient concentrations associated with each stream health category. Specifically, streams classified as 'compromised' or 'restoration potential' were characterized by a wide range of nutrient values, suggesting that although many degraded streams had low nutrient values, only degraded streams had high TN and TP values. In contrast, streams classified as 'exceptional' or 'healthy' and which likely support a full suite of uses, were consistently associated with relatively low nutrient values. Specifically, no HUC characterized by healthy streams (mean VSA percent comparability > 70) exhibited ambient nutrient concentrations above 3.5 mg/l (TN) or 0.8 mg/l (TP). These relationships were also observed between NPS stream nutrient loadings and stream health categories (Figures 8 & 9). No HUCs with streams classified as healthy (mean VSA percent comparability score >70) were associated with nutrient loadings above 6.2 (TN) or 0.8 (TP). The upper limits of stream nutrient concentrations and NPS nutrient loadings, based on a visual fit of the data, for streams classified as 'healthy' could be considered as very crude, numeric criteria necessary to maintain stream health and derived ecosystem services. With better data and more extensive statistical analyses, the development of defensible criteria based on fish community data may be feasible.

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Conclusions

The current project, together with an earlier report (Garman, et al. 2007), should be viewed as a proof-of-concept study and not a comprehensive or rigorous statistical analysis. The relatively course geospatial scale of analysis ($6^{th}$-order HUCs) and the lack of true synoptic data, while demonstrating consistent patterns and relationships, limit the accuracy of these analyses. Furthermore, we have not been able to sort the ambient monitoring data for nutrients as a function of stream size or order. Hence, these conclusions cannot yet address the question of non-wadeable streams, specifically. However, findings to-date generally support the hypothesis that ecological relationships can be demonstrated among selected fish community health metrics and selected measures of nutrient concentration for non-wadeable streams and rivers. These results appear to support further analyses (e.g. multiple regression) of existing datasets and the development of new databases (i.e., DEQ ProbMon) that could develop statistically valid, predictive relationships among selected nutrient measures and fish community metrics for the streams and rivers of the Commonwealth. Our findings are generally similar to the few comparable studies in the literature (e.g. Wang et al. 2006), which employed analogous datasets to demonstrate similar relationships, and from those relationships developed numeric nutrient criteria for streams based on fish community data. It would appear that the same approach, based in part on available data sources, may work in Virginia to establish nutrient criteria for non-wadeable streams.

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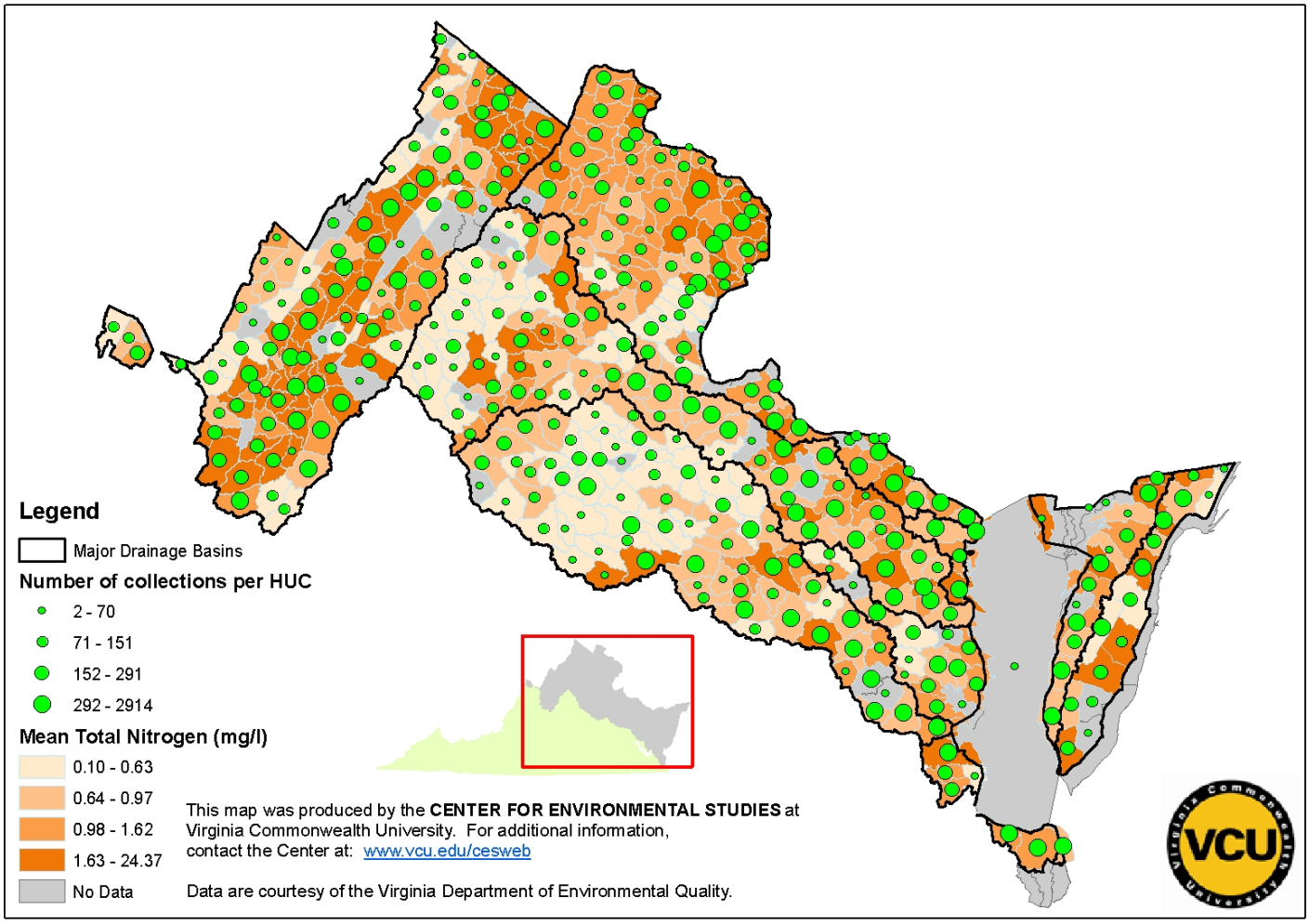



Figure 1. Distribution of total nitrogen concentrations (TN, mg/l) and data density for streams in 6th-order hydrological units in the Chesapeake Bay basin, Virginia. Data provided by DEQ ambient monitoring program.

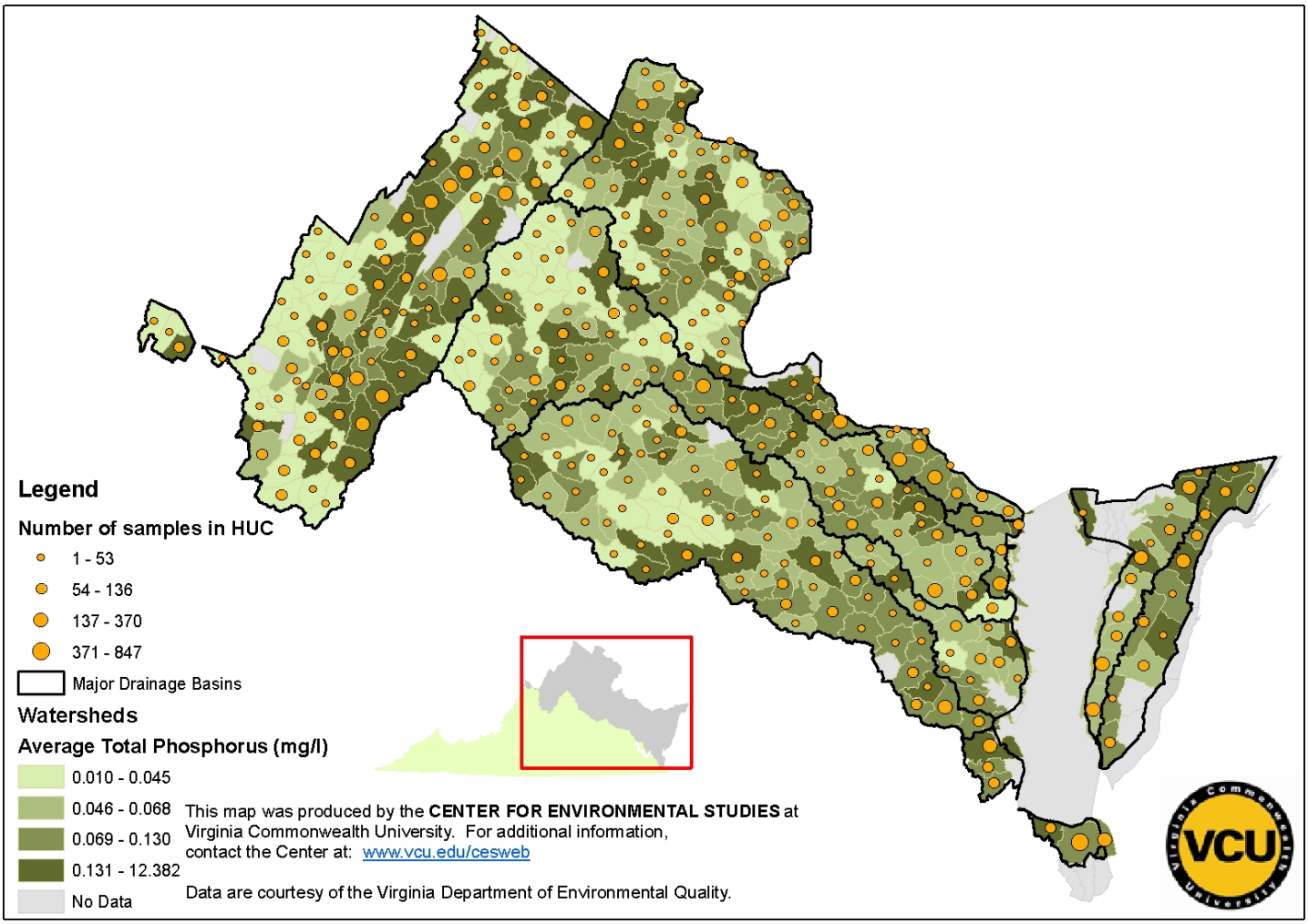



Figure 2. Distribution of total phosphorous concentrations (TP, mg/l) and data density for streams in 6th-order hydrological units in the Chesapeake Bay basin, Virginia. Data provided by DEQ ambient monitoring program.

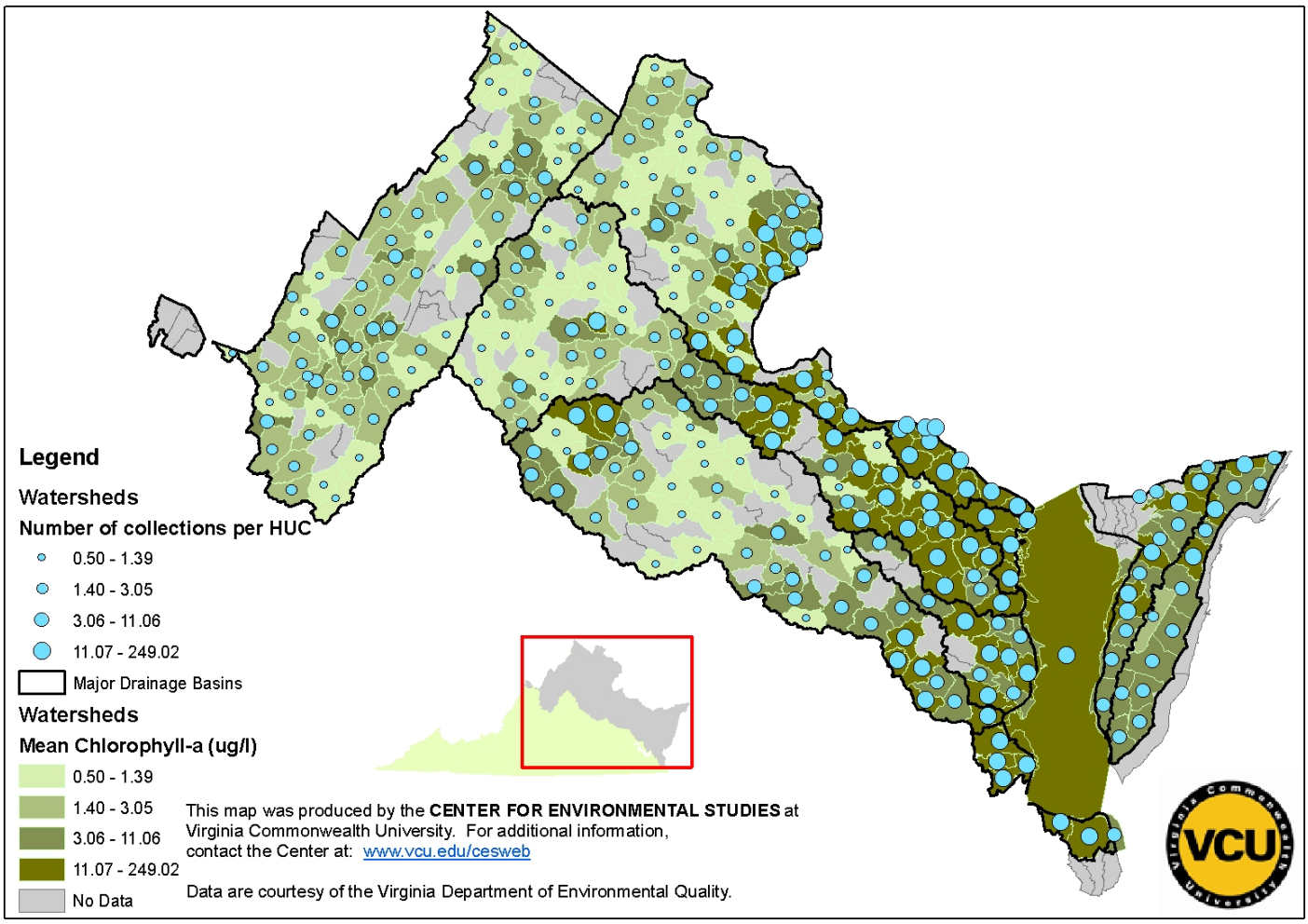



Figure 3. Distribution of Chlorophyll-*a* concentrations (Chl-*a*, ug/l) and data density for streams in 6th-order hydrological units in the Chesapeake Bay basin, Virginia. Data provided by DEQ ambient monitoring program.

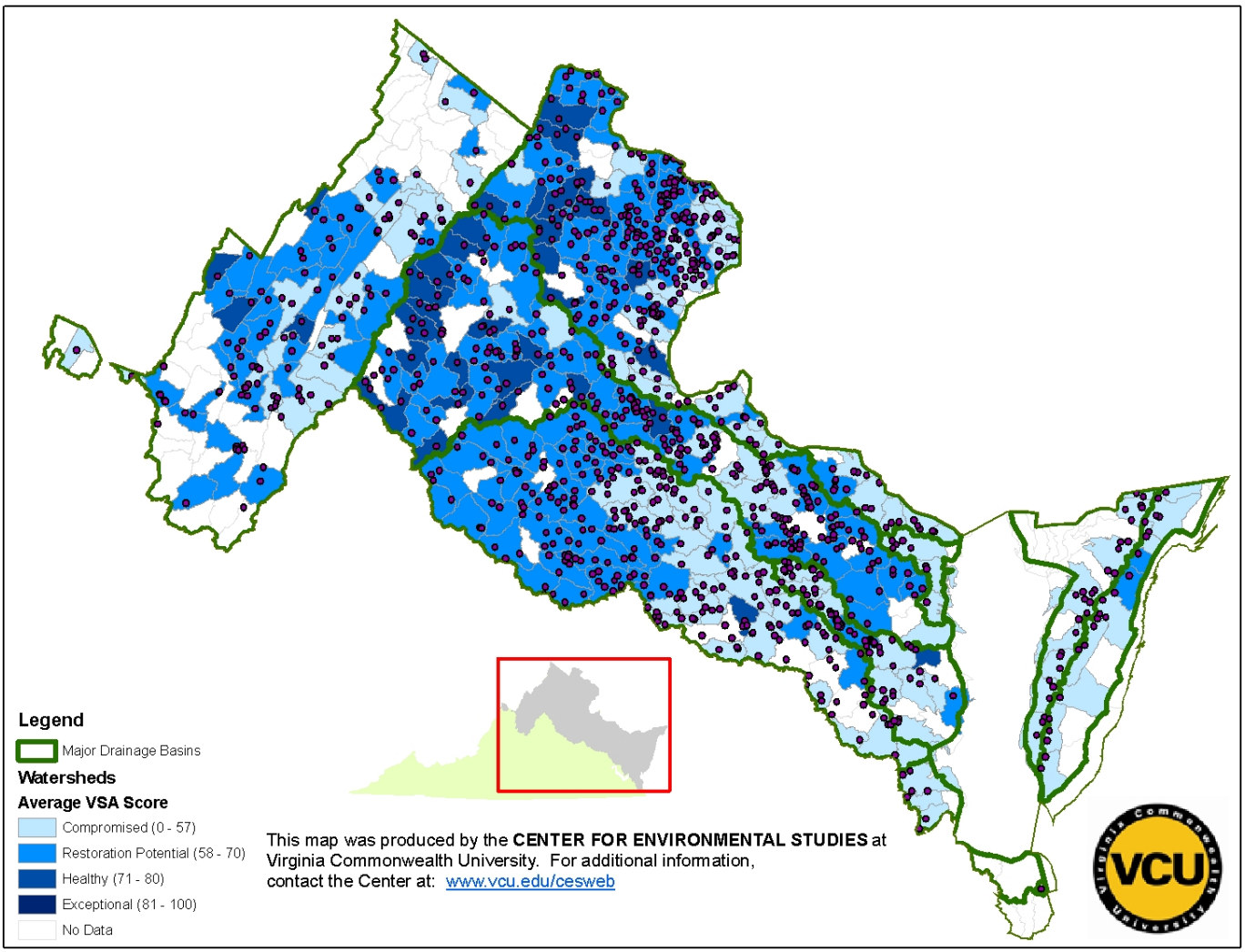
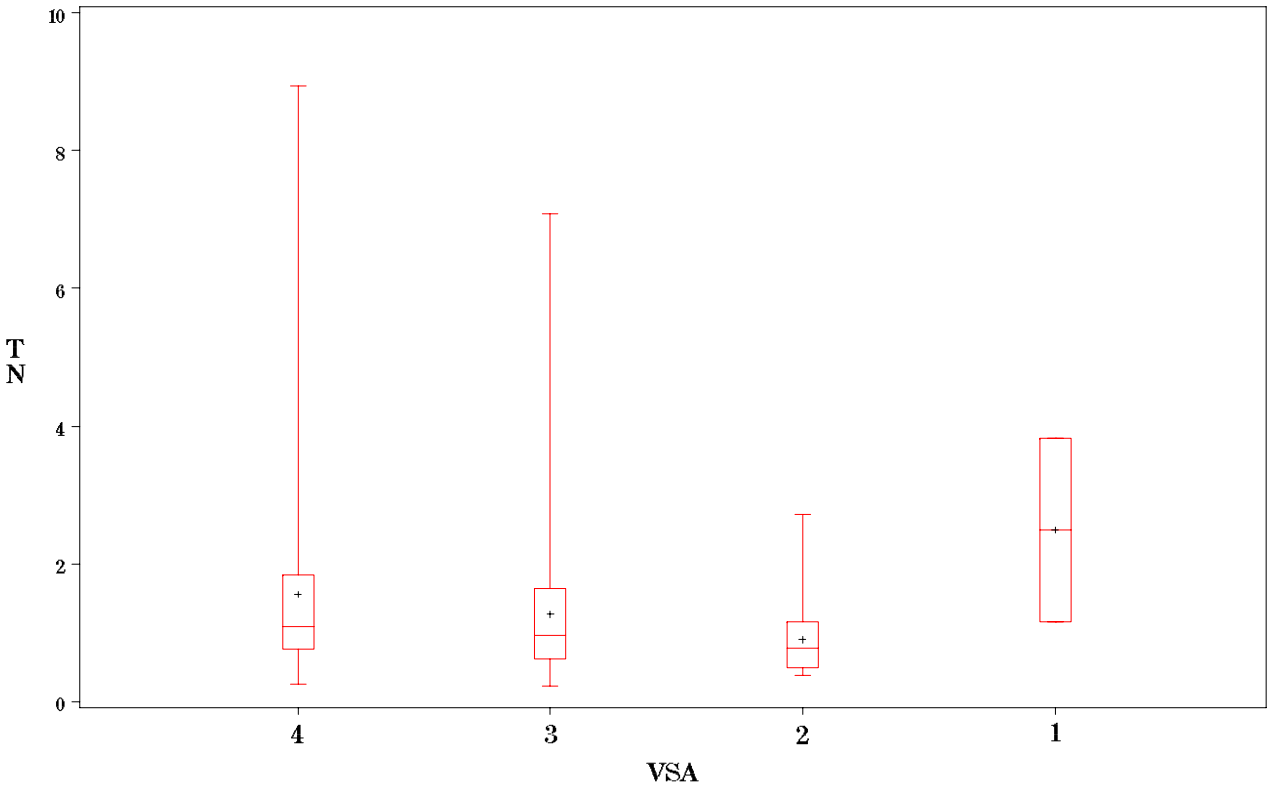
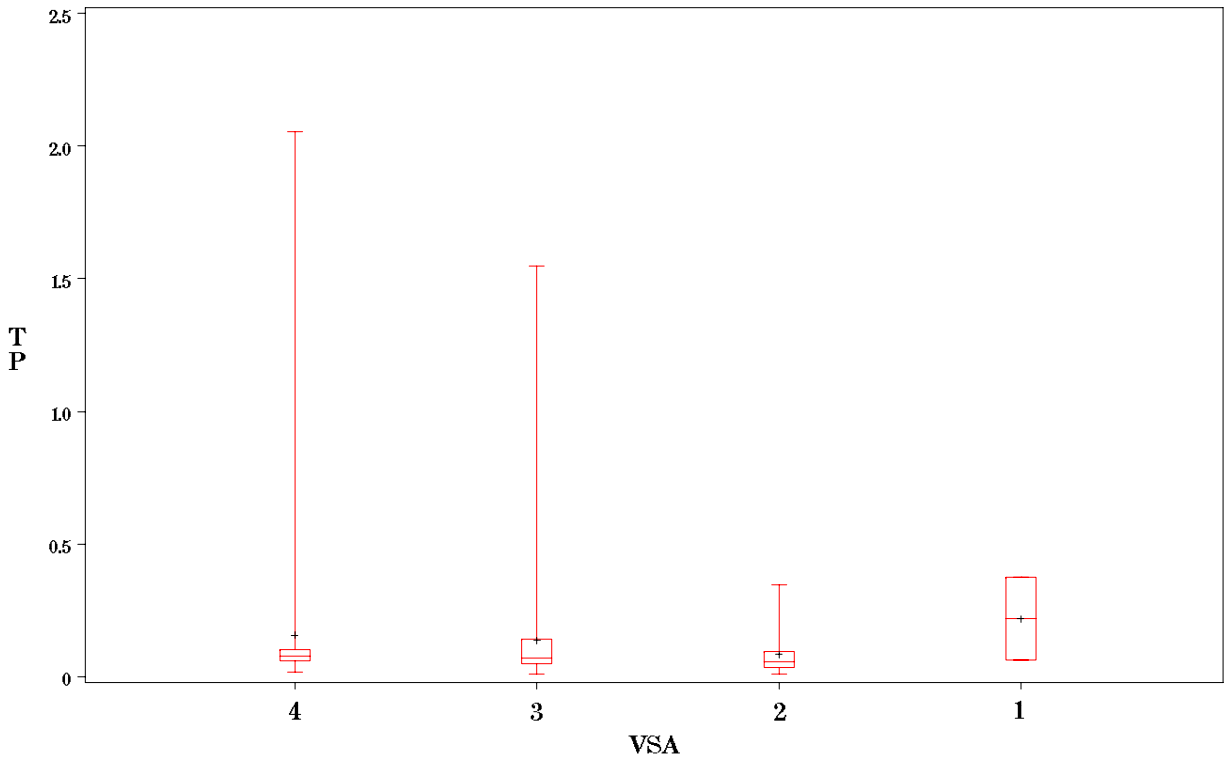



Figure 4. Stream health classification (INSTAR fish assemblage models) for streams in 6th-order hydrologic units in the Chesapeake Bay basin, Virginia. Categories are based on the mean VSA score (percent comparability to appropriate virtual reference condition. Breakpoints for stream health categories are based on the mean, +/-1 standard error, and + 2 standard errors of the distribution of n=1,033 randomly selected VSA scores for INSTAR stream reaches. HUCs in the 'exceptional' and 'healthy' categories are dominated by streams exhibiting high ecological integrity. Points represent individual quantitative (electrofishing) collections for selected HUCs.

Figure 5 a-c. Graphical relationships between stream nutrient **concentrations** (TN, TP; mg/l) and a eutrophication surrogate (Chl-*a*) and stream health categories (INSTAR fish assemblage VSA models) for the **Chesapeake Bay basin**, Virginia. Data are mean values calculated for 6th-order HUCS. VSA stream health categories on the x-axis correspond to 1=exceptional, 2=healthy, 3=restoration potential, 4=compromised. Box plots represent the mean, 25th and 75th percentiles, and ranges for the distribution of nutrient values.

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TP
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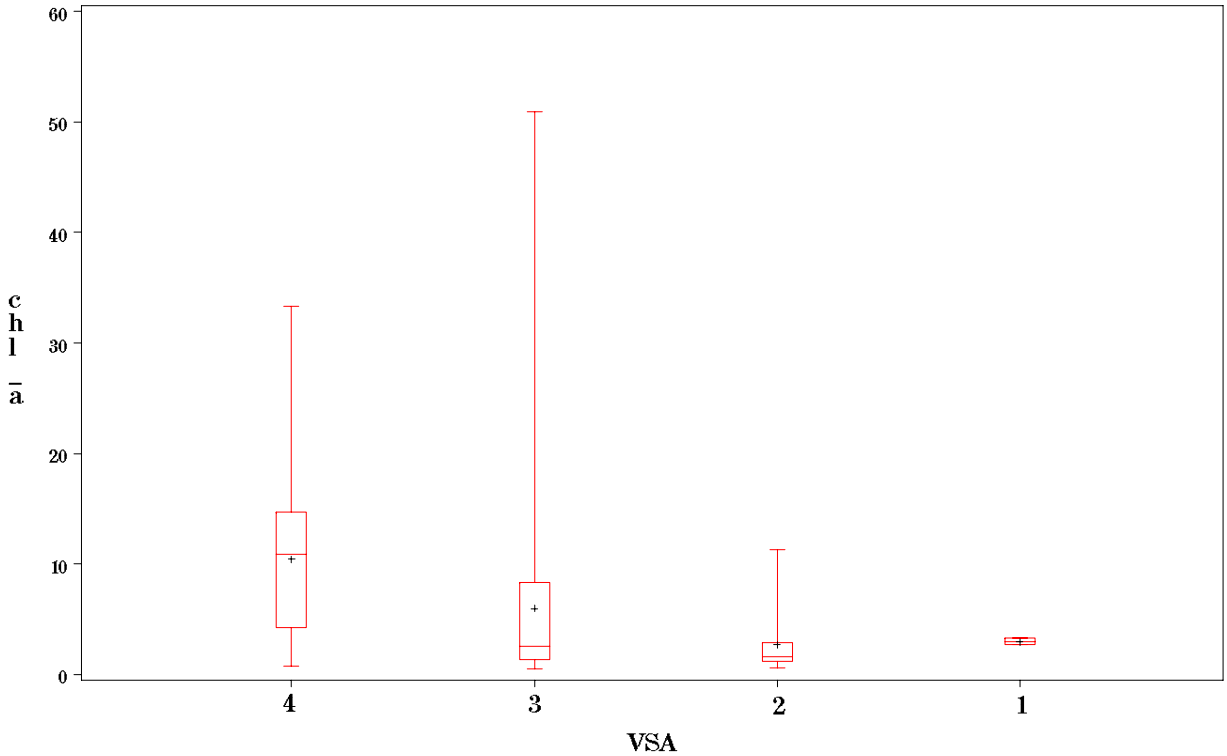
2
1
VSA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chl_a
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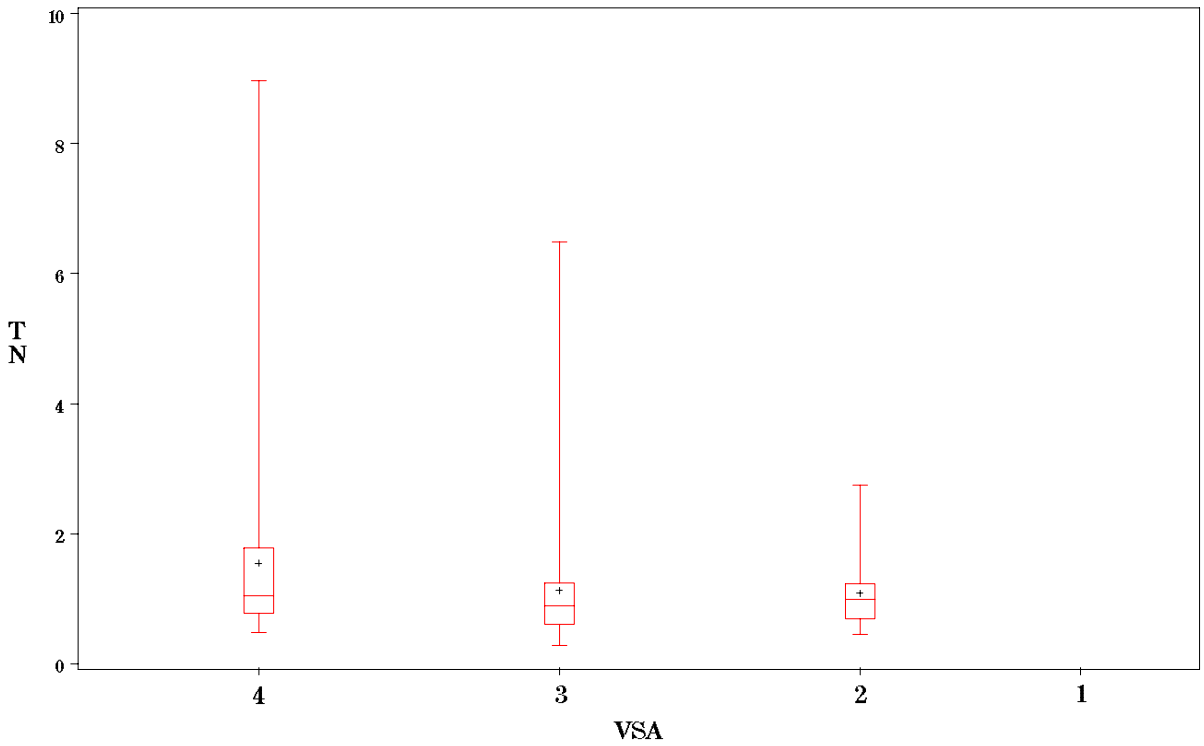
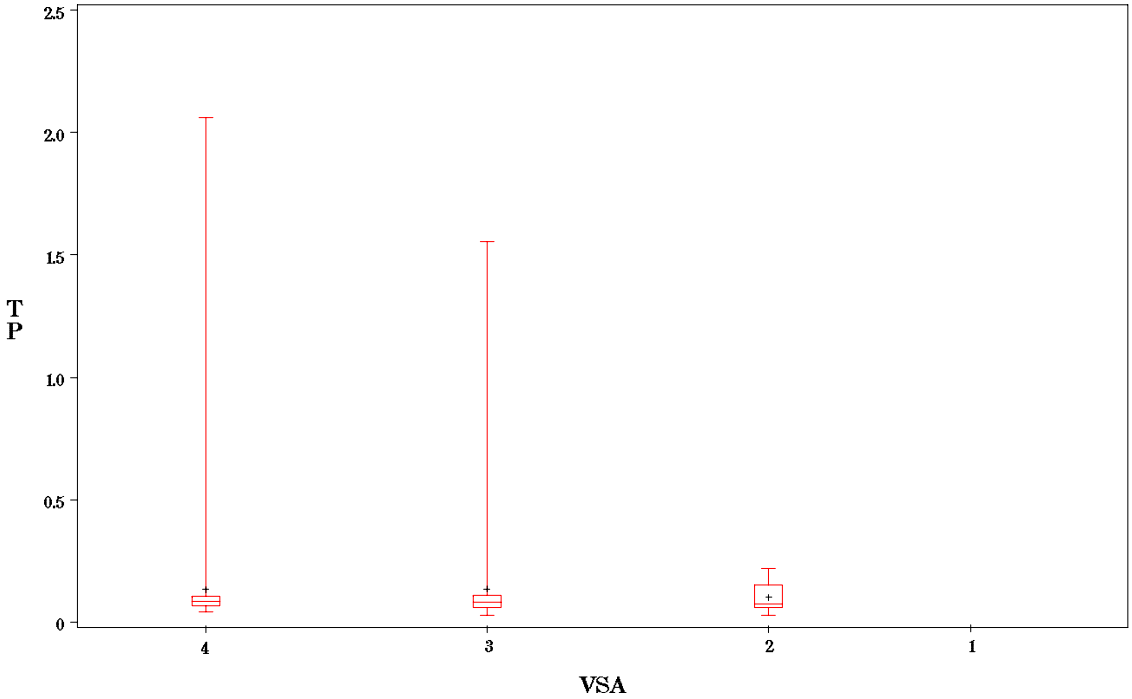
Figure 6 a-c. Graphical relationships between stream nutrient **concentrations** (TN, TP; mg/l) and a eutrophication surrogate (Chl-*a*) and stream health categories (INSTAR fish assemblage VSA models) for the **Coastal Zone and Eastern Shore**, Virginia. Data are mean values calculated for 6th-order HUCS. VSA stream health categories on the x-axis correspond to 1=exceptional, 2=healthy, 3=restoration potential, 4=compromised. Box plots represent the mean, 25th and 75th percentiles, and ranges for the distribution of nutrient values.

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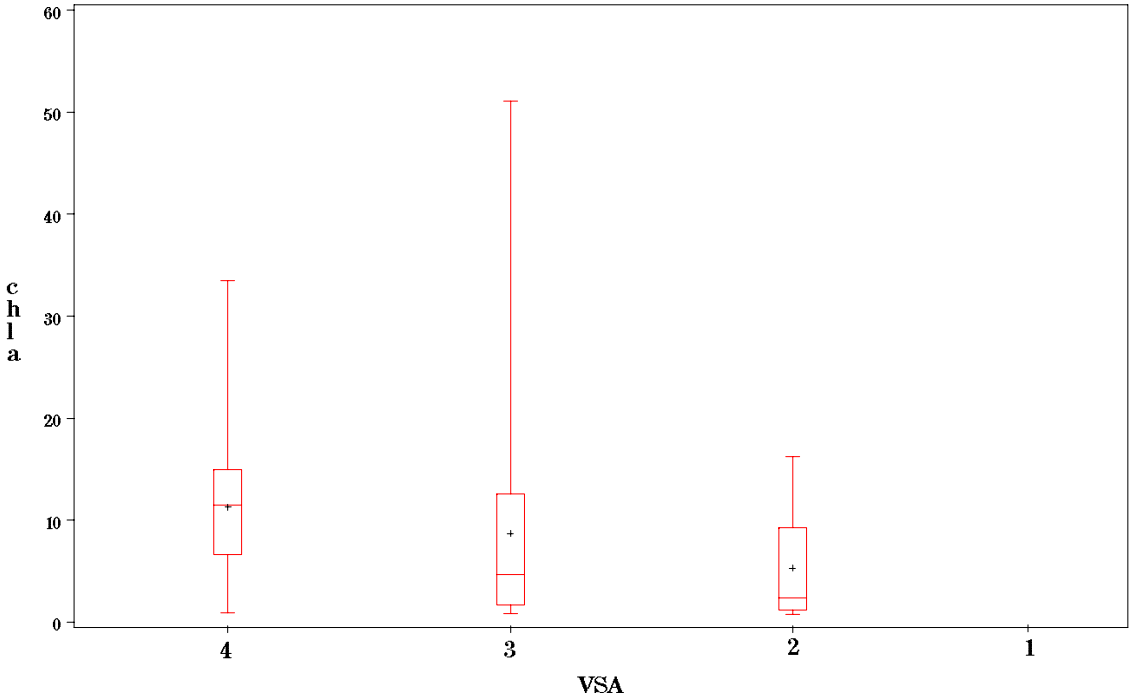
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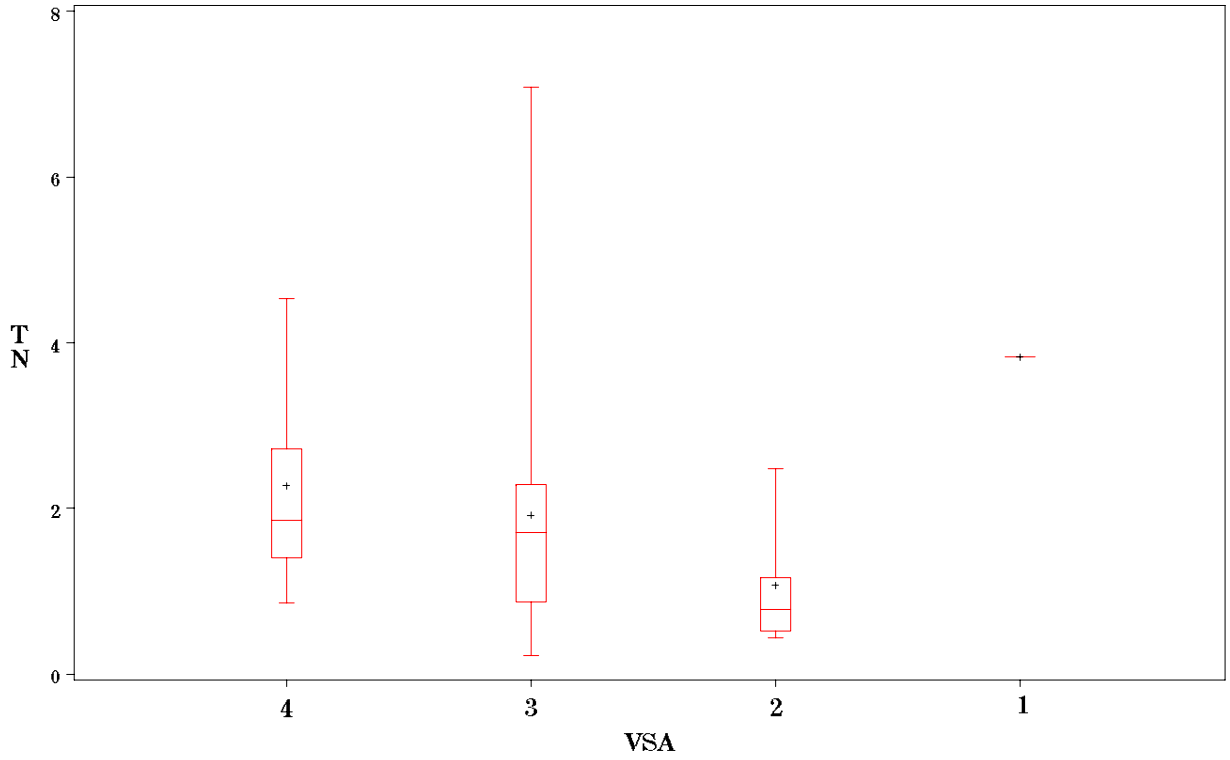
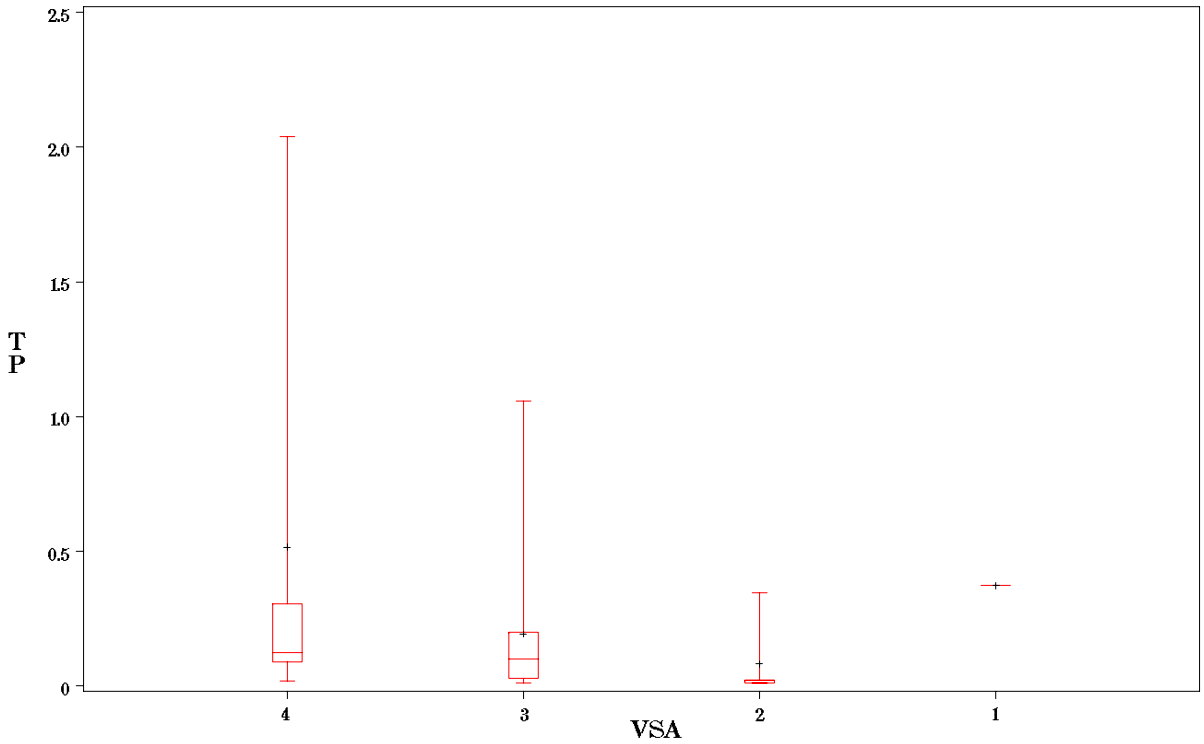
VSA

Figure 7 a-c. Graphical relationships between stream nutrient **concentrations** (TN, TP; mg/l) and a eutrophication surrogate (Chl-*a*) and stream health categories (INSTAR fish assemblage VSA models) for the **Shenandoah Basin**, Virginia. Data are mean values calculated for 6th-order HUCS. VSA stream health categories on the x-axis correspond to 1=exceptional, 2=healthy, 3=restoration potential, 4=compromised. Box plots represent the mean, 25th and 75th percentiles, and ranges for the distribution of nutrient values.

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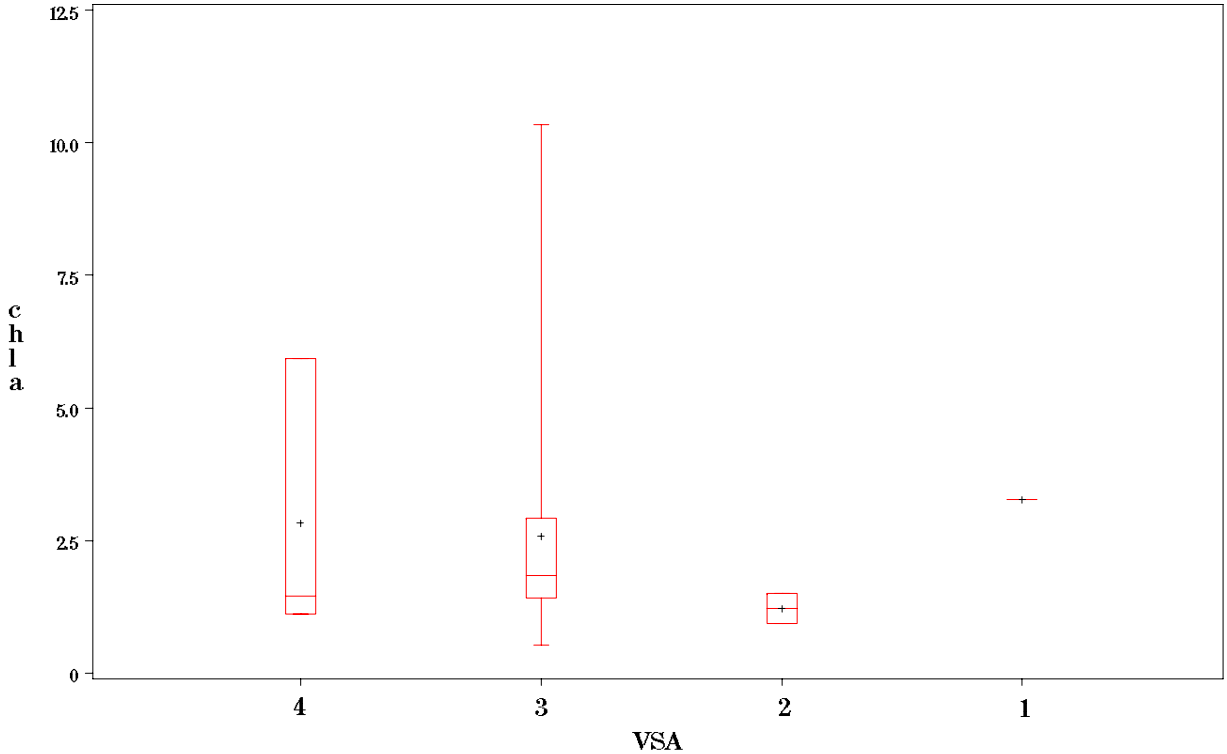
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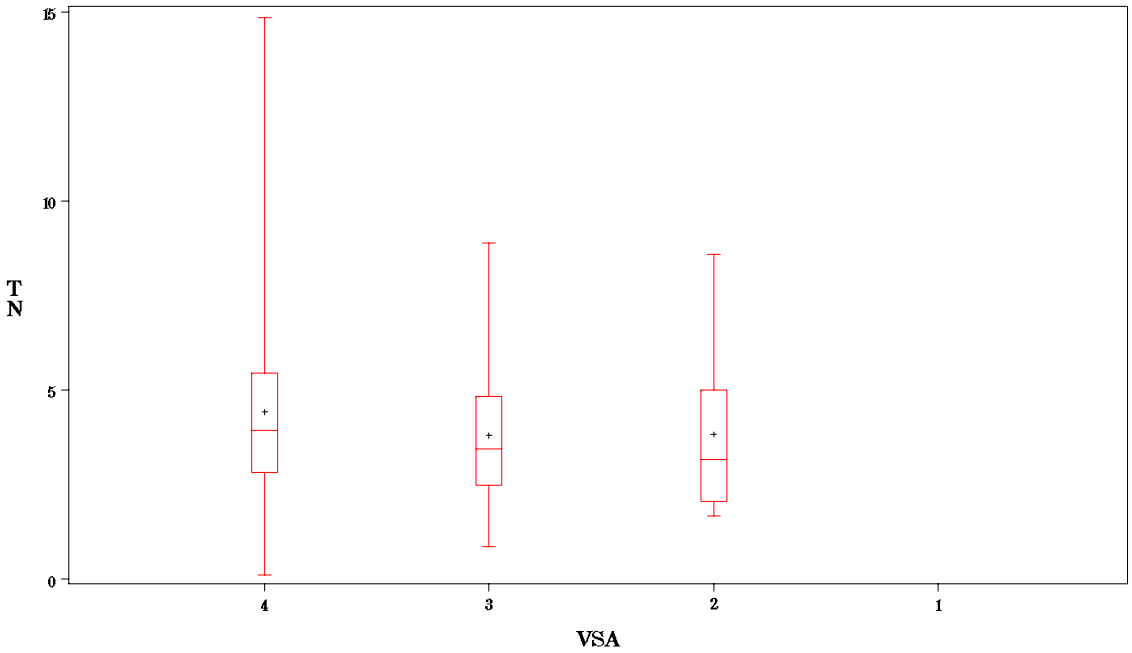
Figure 8 a-b. Graphical relationships between stream nutrient **loadings** (TN, TP; mg/l) and stream health categories (INSTAR fish assemblage VSA models) for the **Coastal Zone and Eastern Shore**, Virginia. Data are mean values calculated for 6th-order HUCS. VSA stream health categories on the x-axis correspond to 1=exceptional, 2=healthy, 3=restoration potential, 4=compromised. Box plots represent the mean, 25th and 75th percentiles, and ranges for the distribution of nutrient values.



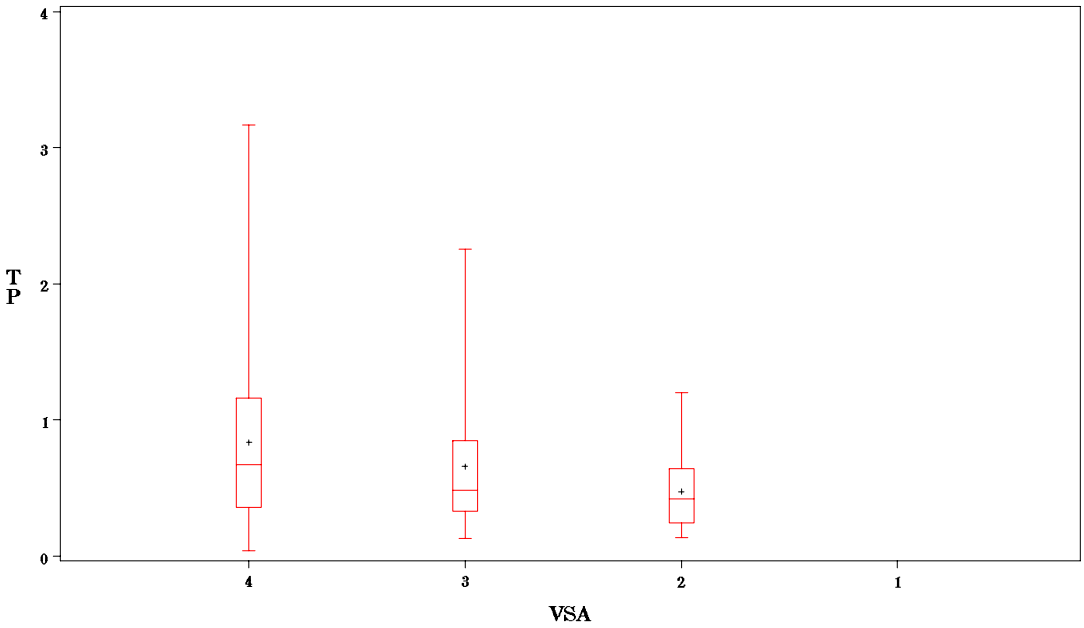
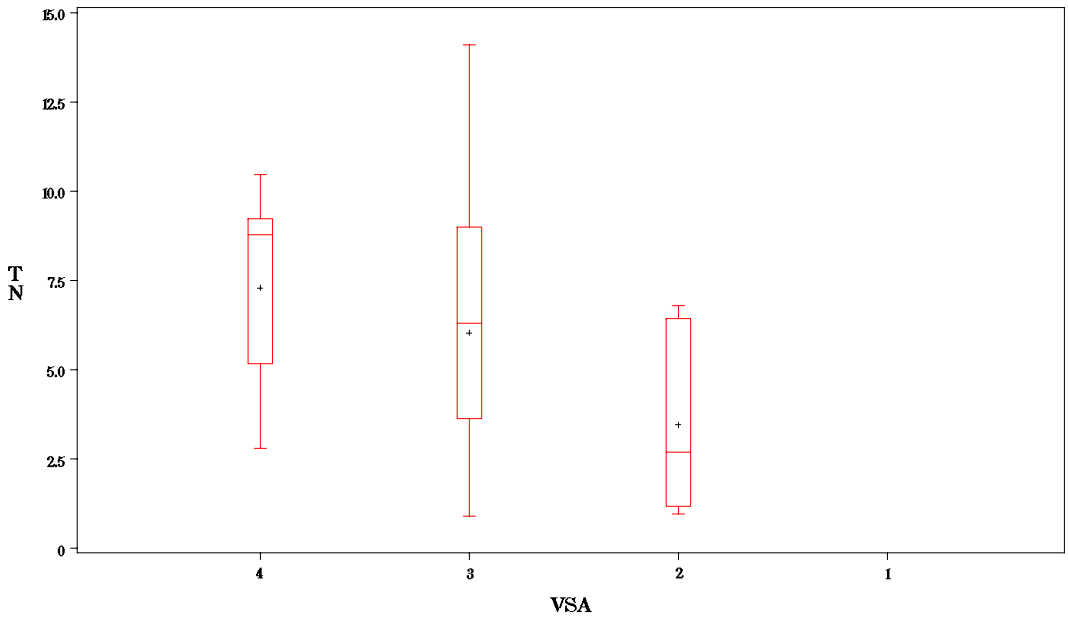
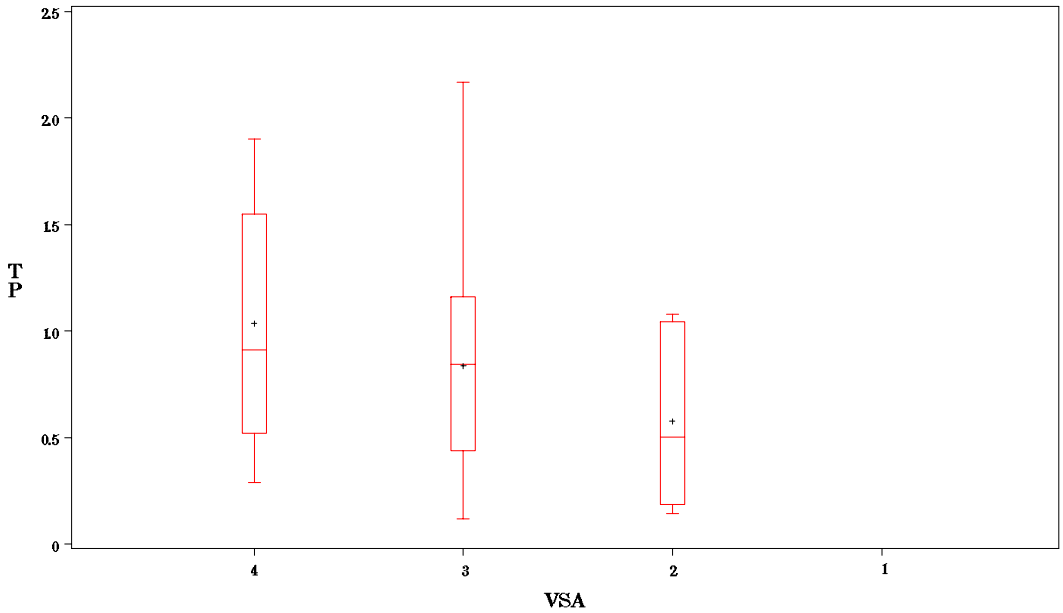



Figure 9 a-b. Graphical relationships between stream nutrient **loadings** (TN, TP; mg/l) and stream health categories (INSTAR fish assemblage VSA models) for the **Shenandoah Basin**, Virginia. Data are mean values calculated for 6th-order HUCS. VSA stream health categories on the x-axis correspond to 1=exceptional, 2=healthy, 3=restoration potential, 4=compromised. Box plots represent the mean, 25th and 75th percentiles, and ranges for the distribution of nutrient values.



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