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 I

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July 18, 2007

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 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, nutrient criteria for larger lotic ecosystems.

The objectives, therefore, of this pilot study were: 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.

Approach

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 170K records were provided to VCU by Roger Stewart at DEQ headquarters. Data were filtered based on specific criteria (e.g. stream characteristics, date, parameter) and joined to a subset of the fish community database maintained by VCU's INSTAR program. The INSTAR database (http://instar.vcu.edu) currently represents over 1,600 stream locations throughout the Commonwealth and includes quantitative data (fish, macroinvertebrates, habitat) from multiple sources, including VDGIF, EPA, and DEQ (ProbMon) databases. In addition, approximately half of the sampling locations, particularly within the eastern third of the state, are represented by relatively new (*ca*. 2001-2006), community-level electrofishing collections by VCU biologists. For this reason, this study was limited to coastal zone and piedmont watersheds within the Chesapeake Bay drainage. In addition, because no objective criteria exist to identify streams as non-wadeable and quantitative, large-river data for fish communities in Virginia are limited, we did not restrict the database to large streams and rivers. Geospatial analyses were conducted using ESRI's ArcGIS application.

Following extensive preliminary analyses, the following metrics were selected and developed for further analysis: total phosphorus concentration (TP, mg/l), chlorophyll-*a* concentration (Chl-a, ug/l), Modified Index of Biotic Integrity (mIBI), and native fish biodiversity (species richness). Chlorophyll-a concentration is indicative of the trophic status of a water body and high Chl-a values generally indicate eutrophication. The mIBI is an integrative, multimetric index of fish community health developed by VCU that employs six derived metrics (e.g. percent tolerant species, percent non-native species) and is based on the widely-used Index of Biotic Integrity (IBI, Barbour et al. 1999). mIBI scores range between 6 and 30, with values > 18 representing high biotic integrity and, presumably, healthy streams (Figure 1); mIBI scoring criteria accommodate zoogeographic differences . mIBI scores are used by several Virginia agencies (e.g. DOF, DCR) for stream assessment and water quality modeling. Native fish species richness (Figure 2) is also used widely as a biocriterion, but one that is influenced as much by zoogeography as it is by environmental stressors.

Initially, we attempted to buffer, using ArcGIS, all existing INSTAR (fish community data) locations within the coastal zone, extract relevant nutrient data within a defined radius (1 km), and pair these data with spatially concordant fish community data. However, several subsequent attempts to conduct site-specific (fine spatial scale) analyses failed, due to the relatively few locations within the region that had adequate representation of paired (spatially and temporally) datasets. Data were later pooled by small catchments (12-digit, 6^{th}-order hydrologic unit codes, HUCs) to support analyses at a slightly broader geospatial scale, but one that retained sufficient resolution and was based on watershed boundaries. Each coastal zone catchment or HUC (n=436) was represented by derived values for mean TP, mean Chl-a, mIBI score, and native fish species richness. Some HUCs did not have sufficient data and were eliminated from further analysis. Final analyses (Figures 1-4) used the 12-digit HUC as the spatial unit of analysis and represent approximately 275K records for nutrient and pigment concentrations and fish species occurrences.

This approach complements an earlier analysis (Zipper and Ney 2005) in support of fish-based nutrient criteria for impoundments, described in Addendum 1 to the January 2005 ACC Report, but the current findings are based on quantitative data and objective criteria.

Findings

Empirical scores for mIBI ranged widely among HUCs (Figure 1) and indicated relatively low stream and river biotic integrity (based on fish community structure and function) for the northern coastal zone and Piedmont regions (e.g. Potomac, upper Rappahannock river basins) and some lower coastal zone catchments. In contrast, several coastal basins (e.g. Piankatank, Pamunkey, and Mattaponi) were characterized by relatively high mIBI scores (> 18), which imply high biotic integrity of surface waters. Native fish species richness (Figure 2) also was highly variable among catchments (HUCs) and ranged between 1 and 45. This measure of aquatic biodiversity tended to be higher in middle and upper coastal zone HUCs, and lower elsewhere. The observed pattern in fish species richness may result, in part, from sampling/data limitations in some estuarine locations (e.g. tidal reaches) but in other regions (e.g. Eastern Shore) accurately reflects low biotic integrity (i.e., compromised stream health).

Productivity of coastal streams and rivers, as inferred from mean Chl-a concentrations, ranged widely among those HUCs with sufficient data (Figure 3), with eutrophication (mean Chl-a > 3.5 u/l) possibly associated with catchments near major urban centers (e.g. Richmond, Fredricksburg), intensive agriculture (e.g. Eastern Shore), and the lower Potomac basin. Mean total phosphorous concentrations in streams and rivers (Table 4) also varied widely across the study area but did not appear to exhibit geospatial patterns or be related to specific land uses (e.g. urbanization).

Both measures of fish assemblage health (mIBI, taxonomic richness) for HUCs were related inversely to mean Chl-a values for HUCs (Figure 3). The relationship for native species richness appeared to be very strong—only one catchment with a richness value above 25 species occurred at mean Chl-a concentrations greater than 13.0 u/l. The negative association between mIBI score and mean Chl-a was also strong, especially for mIBI values >= 14 (Figure 3). However, very low mIBI scores (< 14) were not associated with the highest pigment concentrations. The empirical relationships among TP, mIBI, and native fish richness (Figure 4) were less obvious. TP concentrations (in contrast to Chl-a) ranged across at least two orders of magnitude, making graphical display of the data difficult. Results suggest a unimodal relationship with native species richness (i.e., highest TP values at intermediate richness scores) and hint at a negative relationship with mIBI. More sophisticated data analyses may elucidate these patterns, if they exist.

Conclusions

The current project, which the authors view as a proof-of-concept study and not a complete analysis, supports the hypothesis that ecological relationships can be demonstrated among selected fish community health metrics and selected measures of nutrient concentration and trophic status for streams and rivers. These findings, although limited in geographic scope and the range of potential variables evaluated, represent the integration of two extensive databases and over 300K records and appear to support further analyses (e.g. multiple regression) that could develop statistically valid, predictive relationships among selected nutrient measures and fish community metrics. These findings are 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 specific 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.

Literature Cited

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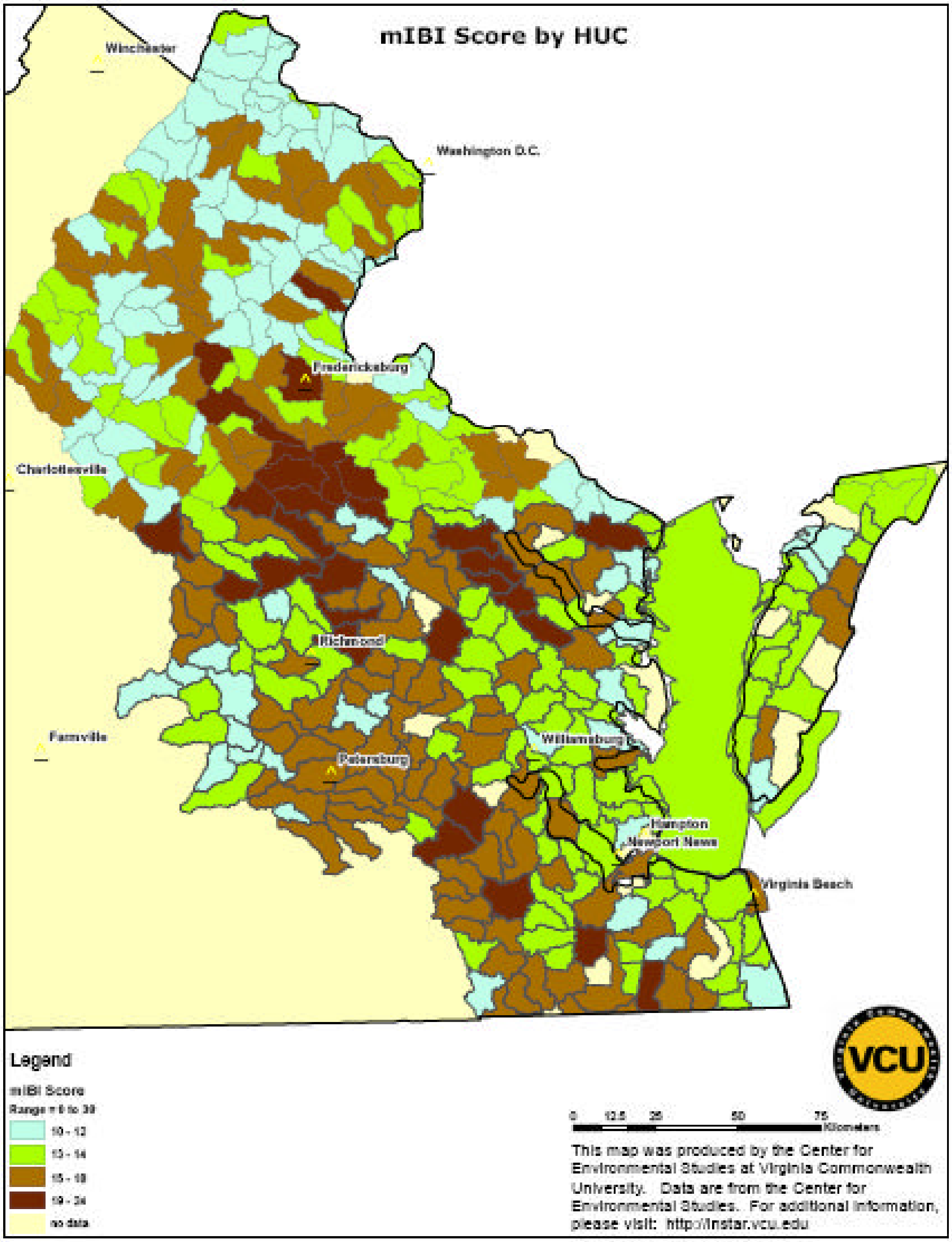
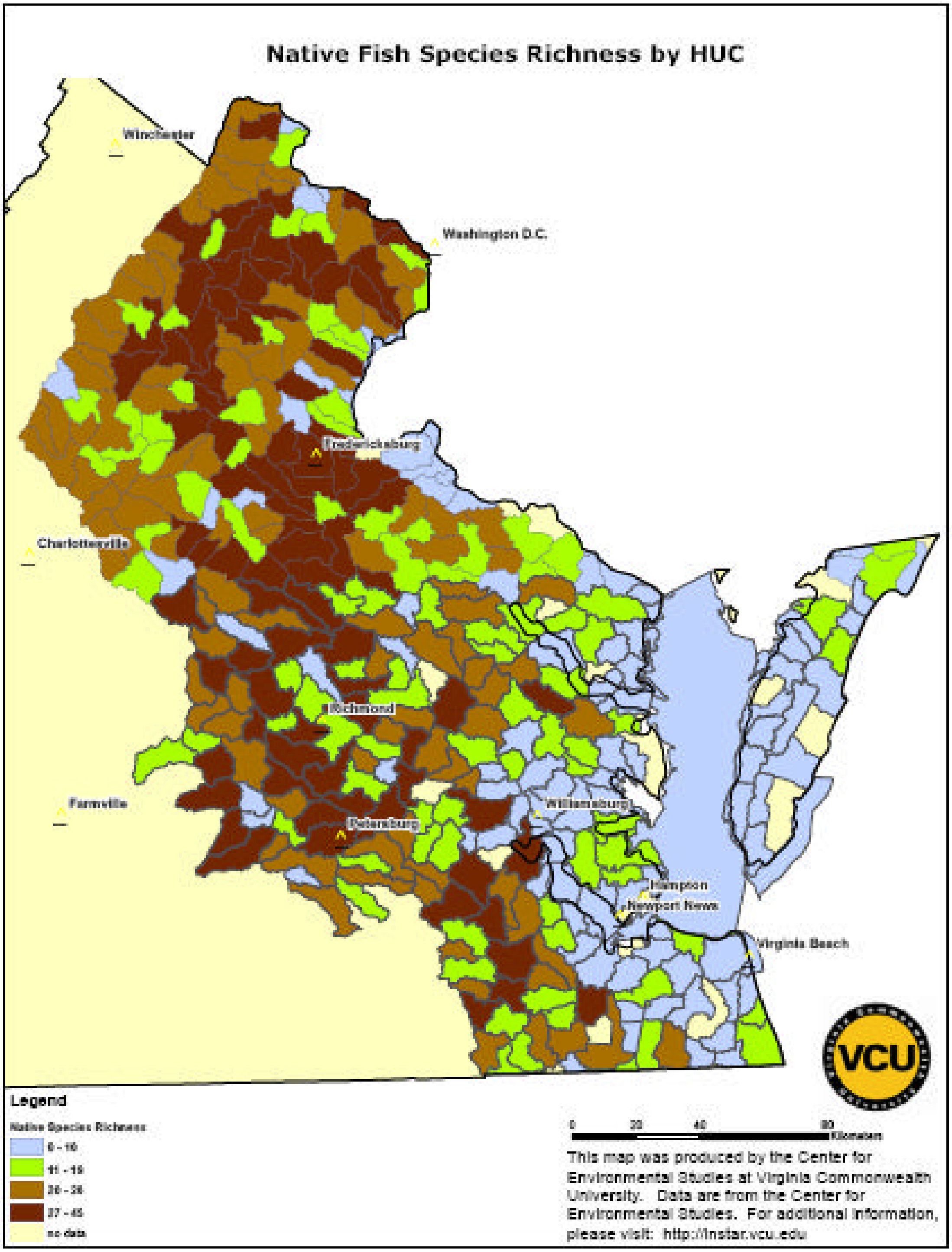
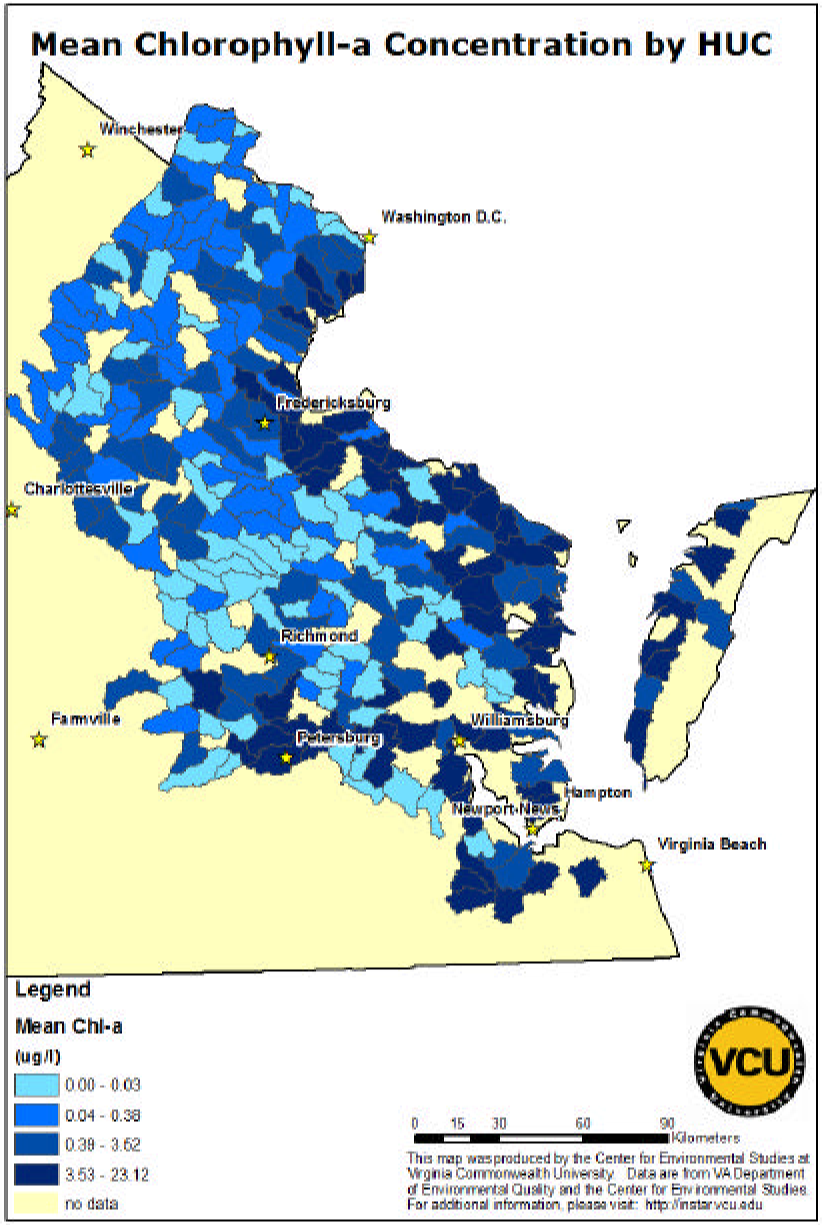
Wang, L., D. Robertson and P. Garrison. 2006. Linkages between nutrients and assemblages of macroinvertebrates and fish in wadeable streams: implications to nutrient criteria development. Environ. Management online 10.1007.


mIBI Score by HUC
Winchester
Washington D.C.
Fredericksburg
Charlottesville
Richmond
Farmville
Williamsburg
Petersburg
Hampton
Newport News
Virginia Beach
Legend
mIBI Score
Range = 0 to 39
10 - 12
13 - 14
15 - 18
19 - 34
no data
0
12.5
25
50
75
Kilometers
VCU
This map was produced by the Center for Environmental Studies at Virginia Commonwealth University. Data are from the Center for Environmental Studies. For additional information, please visit: http://instar.vcu.edu



Native Fish Species Richness by HUC
Winchester
Washington D.C.
Fredericksburg
Charlottesville
Richmond
Farmville
Petersburg
Williamsburg
Hampton
Newport News
Virginia Beach
VCU
Legend
Native Species Richness
0 - 10
11 - 19
20 - 26
27 - 45
no data
0
20
40
80
Kilometers
This map was produced by the Center for Environmental Studies at Virginia Commonwealth University. Data are from the Center for Environmental Studies. For additional information, please visit: http://instar.vcu.edu


Mean Chlorophyll-a Concentration by HUC
Winchester
Washington D.C.
Fredericksburg
Charlottesville
Richmond
Farmville
Petersburg
Williamsburg
Hampton
Newport News
Virginia Beach
Legend
Mean Chl-a
(ug/l)
0.00 - 0.03
0.04 - 0.38
0.39 - 3.52
3.53 - 23.12
no data
0 15 30 60 90
Kilometers
VCU
This map was produced by the Center for Environmental Studies at Virginia Commonwealth University. Data are from VA Department of Environmental Quality and the Center for Environmental Studies.
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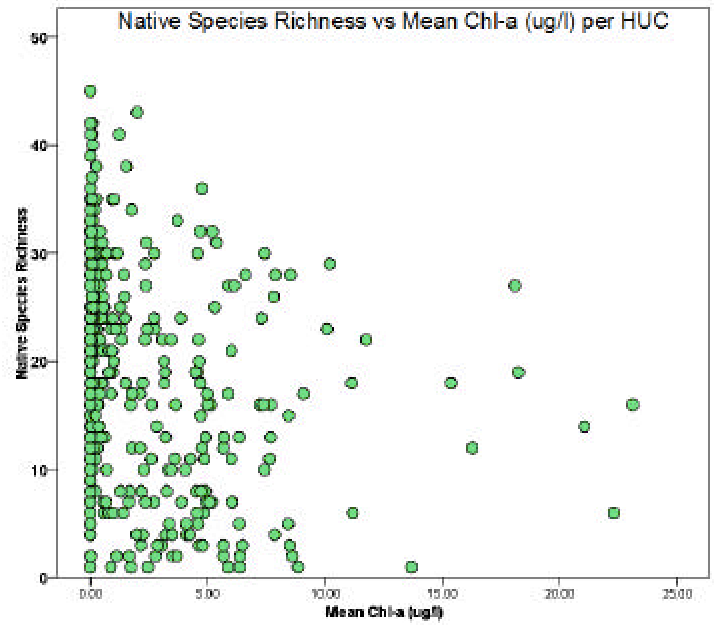
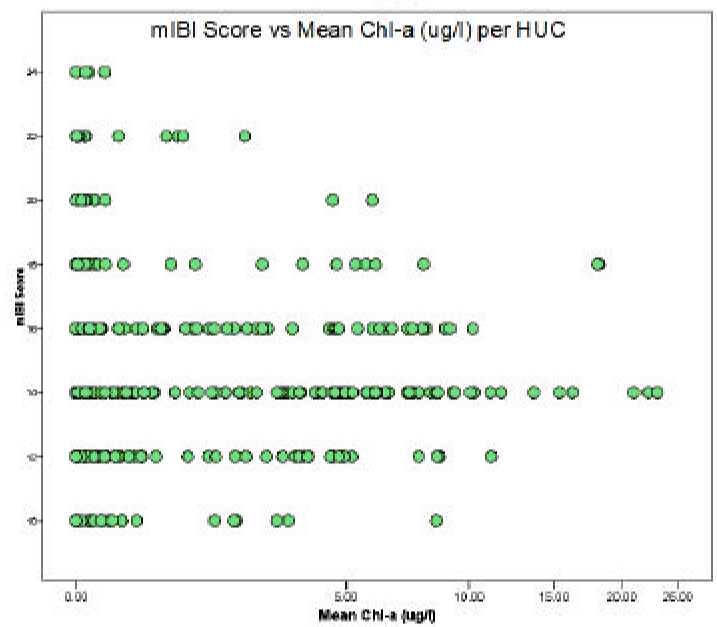
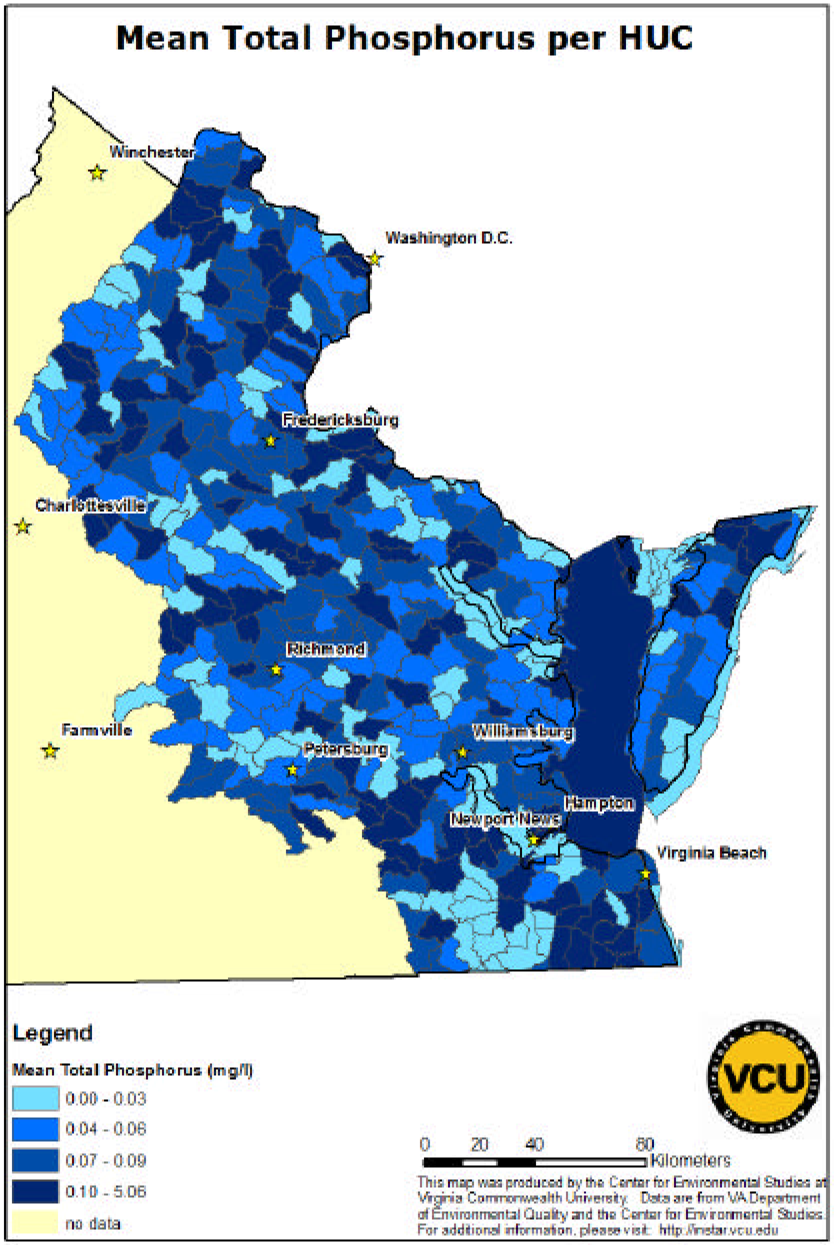
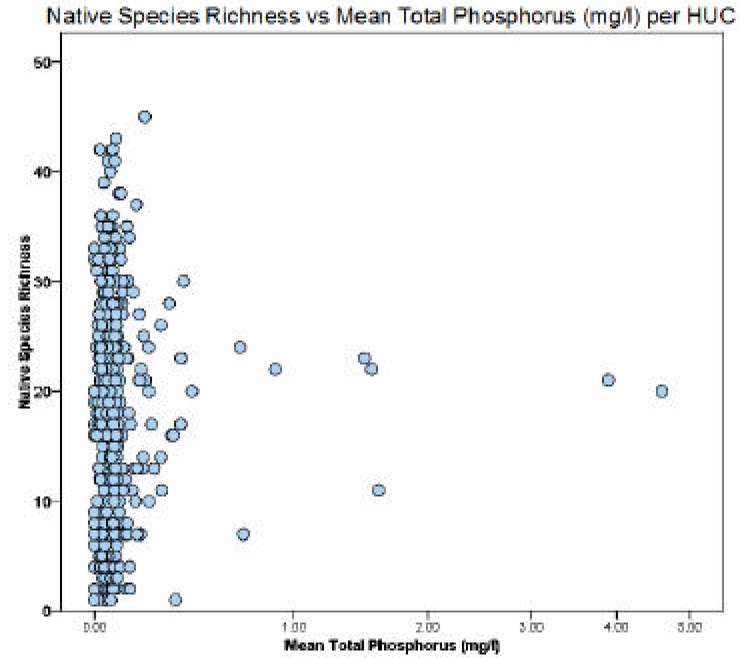
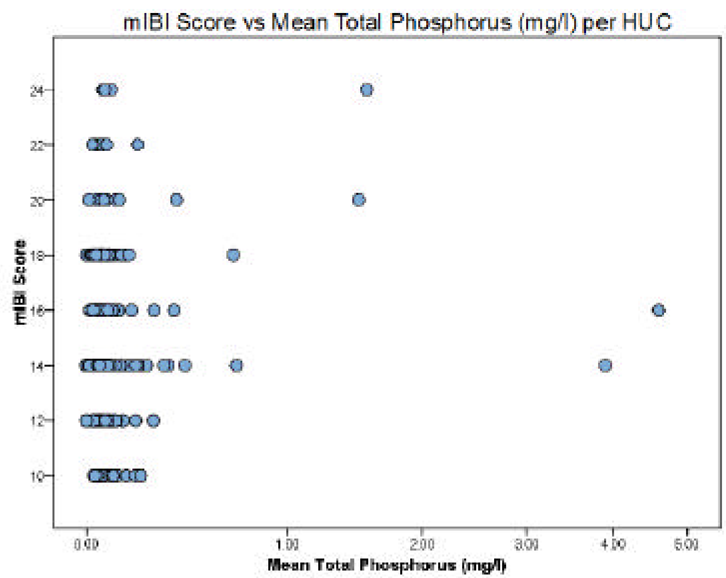

Native Species Richness vs Mean Chl-a (ug/l) per HUC
Native Species Richness
50
40
30
20
10
0
0.00
5.00
10.00
15.00
20.00
25.00
Mean Chl-a (ug/l)


mIBI Score vs Mean Chl-a (ug/l) per HUC
mIBI Score
0.00
5.00
10.00
15.00
20.00
25.00
Mean Chl-a (ug/l)


Mean Total Phosphorus per HUC
Winchester
Washington D.C.
Fredericksburg
Charlottesville
Richmond
Farmville
Petersburg
Williamsburg
Hampton
Newport News
Virginia Beach
Legend
Mean Total Phosphorus (mg/l)
0.00 - 0.03
0.04 - 0.06
0.07 - 0.09
0.10 - 5.06
no data
0 20 40 80
Kilometers
This map was produced by the Center for Environmental Studies at Virginia Commonwealth University. Data are from VA Department of Environmental Quality and the Center for Environmental Studies. For additional information, please visit: http://instar.vcu.edu


Native Species Richness vs Mean Total Phosphorus (mg/l) per HUC
Native Species Richness
0
10
20
30
40
50
0.00
1.00
2.00
3.00
4.00
5.00
Mean Total Phosphorus (mg/l)


mIBI Score vs Mean Total Phosphorus (mg/l) per HUC
mIBI Score
10
12
14
16
18
20
22
24
0.00
1.00
2.00
3.00
4.00
5.00
Mean Total Phosphorus (mg/l)