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OBJECTIVES

Blue catfish, *Ictalurus furcatus*, were introduced to Virginia tributaries of Chesapeake Bay beginning in the 1970's. In recent decades, they have spread throughout most tributaries of the Bay including many Maryland tributaries which are often characterized by shallow water (relative to large Virginia rivers) and low salinities. The primary objective of the present study was to quantify the diet of blue catfish in nearshore, shallow water areas of Maryland's tributaries. Specific objectives were to investigate how diet varies (1) spatial among four Maryland tributaries report to support blue catfish populations (Patuxent, Nanticoke, Susquehanna and Sassafras Rivers), (2) across seasons, and (3) ontogenetically with size. Catch per unit effort data were also recorded to enable comparisons of catfish relative abundance among study rivers. The project specifically focused on freshwater tidal regions of the rivers.

MATERIALS AND METHODS

Field Sampling

Blue catfish trophic dynamics were examined in three main systems in Chesapeake Bay during 2012-2013: Patuxent River, Nanticoke River (Marshyhope Creek) and upper Chesapeake Bay (Northeast River [NER], Sassafras River [SAS] and Swan Creek [SWC]; Figure 1). Patuxent River and Nanticoke River were sampled in both years, whereas Northeast River and Sassafras River were only sampled in 2012 and Swan Creek was only sampled in 2013. These sites were

only sampled in a single year because no blue catfish were encountered in random sampling. Patuxent River was subdivided into 3 sampling areas (APX, UPX and MPX) and Nanticoke River was subdivided into 2 sampling areas, both in Marshyhope Creek (UNK and MNK; Figure 1). Each sampling area was sampled seasonally during summer (June-July) and autumn (September-October), with the exception of MPX, which was not sampled in autumn because seasonal increases of water conductivity (salinity) restricted electrofishing to upstream sites. Each sampling area was apportioned into 400 m^2 cells (Figure 1). During each sampling event, 6-7 randomly chosen cells were sampled with 600 s of low frequency (15 Hz) boat electrofishing (Smith-Root 5.0 GPP; Smith-Root, Vancouver, Washington). Catfish - blue catfish in particular - are acutely responsive to lower electrofishing frequencies, while most other fish species are not greatly affected. All captured blue catfish were retained for gut content analyses. At the end of each seasonal sampling period, additional non-random boat electrofishing was performed when sample size from random sampling was small. Water temperature, salinity, ambient conductivity, dissolved oxygen and general habitat type were recorded for each electrofishing sample.

On return to the laboratory, total length (TL), fork length (FL) and weight of each blue catfish were recorded. Whole stomachs were dissected and weighed. Gut fullness was visually assessed with each stomach scored: 0) empty; 1) Slightly distended, >0-20% full; 2) Partially distended, >20-40% full; 3) Moderately distended, >40-60% full; 4) Mostly distended, >60-80% full; 5) Completely distended, 100% full. The stomach contents were removed, washed through a 500 µm sieve and then frozen. The empty stomach linings were patted dry with paper towels and weighed. Otoliths were removed and flank muscle tissue was taken for stable isotope analysis from all blue catfish.

We assessed the relationship between blue catfish length and weight using liner regression of the $\log_{10}$ transformed data. ANCOVA (analysis of co-variance) was used to test for differences in the length-weight regression slopes of blue catfish caught in Patuxent River and Nanticoke River. If a significant difference was not found, ANCOVA using an equal slope dummy variable was used to test for significant differences between regression intercepts (Pope and Kruse 2007).

Gut Content Analysis

Frozen gut content samples were thawed and microscopically examined. Each prey item was identified to the lowest possible taxonomic group based on morphology and animal prey items were enumerated. The relative volumes of similar prey item groups were estimated using a sampling grid containing 1.5 mm^2 cells. Prey items (in taxonomic groups) were then patted dry on paper towels to remove excess water and weighed to the nearest 0.00001 g (wet weight).

Differences in the stomach contents of blue catfish were examined with non-Metric Multidimensional Scaling (nMDS) based on triangular matrix of Bray-Curtis dissimilarities using log (x+1) transformed biomass (wet weight) data. Differences between years were evaluated using an ANOSIM test. ANOSIM (Analysis of Similarities) is a nonparametric analog of ANOVA comparing *a priori* defined groups within a dissimilarity matrix (Bray-Curtis in our case). All multivariate stomach content data were analyzed with Primer v7 (Primer-e, Plymouth, UK).

Fish Prey Genetic Barcoding

Following morphological gut content identifications, fish prey items were either processed immediately for genetic barcoding or were re-frozen for later processing. Prior to genetic sampling, fish prey items containing tissue were rinsed with RO water to remove any debris or residual chime. We did not process any scales or bones. Prey items varied in their state of digestion, from nearly pristine whole fish to loose fragments of tissue. A pilot study indicated that genetic barcode sequencing could be conducted on all but the most degraded fish tissue with >80% success (R Aguilar, unpublished, data). Thus, to achieve the highest probability of successful sequencing, muscle tissue was preferentially selected when available. Furthermore, muscle tissue segments that were not directly exposed to the predator's stomach (i.e., decreased exposure to the effects of digestion) were preferentially selected. Using sanitized forceps, scalpel and work surface for each prey item, 10-25 mg of tissue was placed in a 0.75 ml sterile centrifuge tube containing 150 ml of digester solution and sent to Smithsonian Laboratory of Analytical Biology (LAB) for sequencing. Edited sequences were identified to species using BOLD (Barcode of Life Data Systems) based on high (>98%) matching percentages. In a project funded separately, SERC has added genetic barcode sequences of >200 of the ~315 species of fish in Chesapeake Bay to the BOLD database. Nearly all freshwater and tidal fish of the Chesapeake Bay are in the database, such that all fish prey items were highly likely to be accurately identified using genetic barcoding.

Stable Isotope Analysis

Fish flank muscle samples were frozen, freeze dried and then ground into a fine powder. Small amounts of powered tissue (0.6-0.8mg) were packed into tin capsules for $\delta^{15}N$ and $\delta^{13}C$ analysis. Stable isotope analyses were performed by the Smithsonian OUSS/MCI Stable Isotope Mass Spectrometry Laboratory (Suitland, MD) using a Thermo Delta V Advantage mass spectrometer in continuous flow mode coupled to a Costech 4010 Elemental Analyzer (EA) via a Thermo Conflo IV. Samples are introduced to the EA via a Costech Zero Blank Autosampler. EA run parameters were as follows: Combustion column temperature, 1050 °C; Reduction column temperature, 650 °C; Gas chromatography column temperature, 60 °C; Helium flow rate, 85mL/min. All calculations of raw isotope values were performed with Isodat 2.8 software.

All runs included a set of standards for every 10-12 samples. Standards included Costech Acetanilide and a urea (Urea-UIN3[1]) standard, both of which were calibrated to USGS40 (L-glutamic acid) and USGS41 (L-glutamic acid). Raw isotope values were corrected using a 2-point linear correction on the calibrated Costech Acetanilide and urea standards. The weight %N and weight %C values were calculated using a peak area calibration based on the homogeneous Costech Acetanilide standard. Reproducibility of standards is ≤0.2‰ (1σ) for both $\delta^{13}C$ and $\delta^{15}N$.

The isotopic niches of blue catfish caught in Patuxent River and Nanticoke River during 2012-2013 were examined by generating standard ellipse areas (SEAs) and convex hulls of the $\delta^{13}C$ and $\delta^{15}N$ data. The SEA is a bivariate equivalent of the standard deviation in a univariate analysis and can be used to compare different populations (Barnum et al. 2013). A parametric

Hotelling's T^2 test (a multivariate equivalent to a univariate t-test) was used to determine whether the Euclidean distance between the centroids was significantly greater than zero. All isotopic analyses were handled in the R package SIAR (Parnell et al. 2008, 2010) using methodologies described in Jackson et al. (2013) and Turner et al. (2010).

Fish Prey Assemblage Sampling

To characterize fish prey assemblages, each low-frequency electrofishing event was paired with high frequency electrofishing separated by 2-4 d. Similar to low-frequency sampling, 6-7 randomly chosen cells were sampled with 600 s of boat electrofishing. All captured fish were identified, counted and a subset of 30 individuals was measured for each species if more than 30 individuals were collected. Water temperature, salinity, ambient conductivity, dissolved oxygen and general habitat type were recorded for each sample.

Differences in the fish community composition were examined with an nMDS ordination plot based on a triangular matrix of Bray-Curtis dissimilarities using log (x+1) transformed mean site abundances. Differences in the fish community between years were evaluated using an ANOSIM test. The SIMPER procedure was used to identity the fish species that contributed to the differences in fish community among systems (Patuxent, Nanticoke and Upper Bay). SIMPER assesses the average percent contribution of individual variables to the dissimilarity among *a priori* defined groups. All multivariate community data were analyzed with Primer v7.

RESULTS

Field Sampling

During two years of sampling in Chesapeake Bay, a total of 319 blue catfish were collected. Although blue catfish had been reported in the upper Chesapeake Bay, no blue catfish were encountered in our Upper Bay sites (Northeast River, Sassafras River and Swan Creek) or in APX during 2013 (Figure 2, 3). In general, blue catfish were more abundant in the Patuxent River sites in comparison with Nanticoke River sites and in 2012 in comparison with 2013. Blue catfish were often found in association with structured areas (e.g., tree falls/woody debris, pilings, etc.) and deep holes (>5 m). Within the Nanticoke River (i.e., Marshyhope Creek) blue catfish were often caught near the two bridge crossings (Route 392 and Route 14) as well as in the more upstream wooded portion of the system (i.e., upstream half of UNK) and in deeper holes near the confluence with the mainstem Nanticoke River (most downstream portion of MNK). Within the Patuxent River, blue catfish were most abundant from about Jug Bay to the downriver extent of our study area and were often associated with deep holes, which were generally located in bends of the river channel. UPX and MPX sites possessed a wide margin of emergent vegetation (*Nuphar sp.*, *Peltandra virginica*, etc.), which fronted taller marsh species (*Phragmites australis, Typha spp., Zizania aquatica,* etc.) and did not contain much obvious in-stream woody debris. APX was mostly wooded and fairly shallow with a deep hole at a narrowing of the river channel at Spyglass Island. This hole was the only APX location where blue catfish were captured during low-frequency sampling. However, one large blue catfish was

caught along a degrading bulwark further downstream in APX during high-frequency sampling in 2012.

In a study funded separately, we used acoustic telemetry to track the movements of blue catfish in the Patuxent and Nanticoke Rivers. Preliminary data indicate that most blue catfish spend the majority of their time near deeper holes and generally remain within a range of several km for most of the year. However, blue catfish are known to be highly migratory and individual catfish tracked in our study have been observed to move throughout the 2-3 regions sampled in the present diet study and to distances of >20km further downriver. None of the catfish we have tracked have been documented moving outside of the river system in which they were tagged. These results are relevant to the present study because they indicate that catfish caught within any of the study areas (e.g. UPX) are mostly likely to have obtained prey items from within that study area, but could also have moved into that area from a neighboring study area just prior to capture. They are highly unlikely to have obtained any prey items from outside the study river.

In general, Patuxent River blue catfish were slightly larger than fish from Nanticoke River. With the exception of MPX, mean sizes of blue catfish were similar between 2012 and 2013 (Figure 4). Length-weight relationships were similar for Patuxent River and Nanticoke River blue catfish based on slope comparisons (ANCOVA: $F_{(3,315)} = 0.555$, P=0.457; Table 1; Figure 5). However, subsequent ANCOVA testing indicated the intercepts were significantly different (ANCOVA: $F_{(2,316)} = 7.812$, P=0.006), with Patuxent River blue catfish weighing more than Nanticoke River blue catfish, but adding body weight to length at a similar rate.

There was a seasonal difference in the size structure of the blue catfish captured in Nanticoke and Patuxent River. In both river systems, there were proportionally more smaller fish in the autumn than summer (Figure 6). This reflects the recruitment of the same year's YOY in sizes large enough to be adequately sampled via boat electrofishing. Blue catfish spawn during the spring; thus, YOY fish are not available to our electrofishing gear in the summer because of their small size and/or habitat preferences.

Gut Contents

A varied array of prey items were found in the stomach contents of blue catfish caught in the Patuxent and Nanticoke River during 2012-2013 (Table 2). By weight, fish were the most important prey item (Figure 7) even though fish prey was only found in ~20% of all samples (Figure 8). The identification of digested fish prey to species is found in the section entitled Genetic Barcoding of Fish Prey. The contribution of fish to the diet of blue catfish increased with size (Figure 9). While fish prey remains were found in blue catfish as small as 102mm TL, this may reflect scavenging, as most the fish prey items in smaller individuals consisted of scales from larger fish. The smallest size blue catfish that contained a whole fish (bay anchovy) had a length of 196 mm TL.

Four species of bivalve were reported in the stomachs of the blue catfish, *Corbicula fluminea, Mulinia lateralis, Rangia cuneata Mytilopsis leucophaeata* (Table 2), with *C. fluminea* being the most abundant. *C. fluminea* is non-native in Chesapeake Bay and since its introduction in the 1970s it has rapidly spread to most freshwater tributaries, where it may compete with native

freshwater mussels. Several workers have reported that *C. fluminea* can comprise a significant portion of blue catfish diets (Bonvechio et al. 2011; Grist 2002; Mary Groves, Maryland Department of Natural Resources, unpublished data). In the present study, bivalves were most important by weight in the diet of blue catfish ranging in size from 150-349 mm TL (Figure 9).

Insects were an important component of blue catfish diets, particularly for smaller fish (Figure 9). The majority of insect prey were aquatic larval forms associated with the benthos. However, a number of intact terrestrial species (Hymenoptera, Diptera, Cicadomorpha, etc.) and a few adult aquatic Coleoptera were found (Table 2). Plant material consisted of blades of aquatic plants, algae, and also seeds of *Nuphar sp.***,** *Peltandra virginica and Zizania aquatic*.

The most common and 2nd most important prey item by weight was invertebrate tube material (ITM; Figure 7, 8). ITM consisted of obvious tube remnants and constituent silk fibers associated with trichopterans and dipterans, tubes produced by tube-dwelling amphipods and a whitish, tacky substance that appeared to be the partly digested invertebrate silk. However, some portion of this whitish, tacky substance may have been amalgam of other partly digested complex molecules. Due to its inherent sticky nature, other small bits of stomach contents were occasionally adhered to it. We removed as much of this material as possible. However, this may have artificially inflated the weights of some ITM samples. ITM was found to be an important component of blue catfish stomach contents across all size classes, even in the largest size class, which consumed proportionally less benthic inverts by weight (Figure 9). However, this largest size class consumed the most fish prey, generally the individual heaviest prey item, which lessened mean within-stomach contribution of lighter prey items. Benthic invertebrates were still found with regularity in the stomachs of larger blue catfish. Thus, it did not appear that blue catfish were eating less benthic invertebrates by weight (that produce the tube materials) *per se*, but eating greater amounts of fish prey that tended to be heavy.

A large part of blue catfish diets were derived from benthic sources, including bivalves, benthic invertebrates and associated tube materials, a few soft blue crabs, detritus, sediment, aquatic plants/algae, invertebrate epifauna, tessellated darter, etc. A portion of this material may be secondary to the intended prey choice (detritus, sediment, etc.), but this suggests that blue catfish are often feeding directly from the river bottom or channel sides. However, blue catfish also appear to feeding from the water column as evidenced by a high percentage of pelagic fish species and several vagile insects, as well as from the surface, evidenced by floating plant matter and by several intact terrestrial insects. This strategy most likely increases with size as pelagic fish become a more important prey item.

In total, 7% of blue catfish stomachs were empty. If the percentage of stomachs that only included ITM (11.7%) is included, roughly 18.7% of blue catfish stomachs were "functionally empty." This is well within range reported for other catfish species (Arrington 2002; Bonvechio et al. 2011). Fish captured in Nanticoke River appeared to have fuller stomachs compared to Patuxent River (prior to rinsing and sieving) based on visual inspection (Figure 10).

The major difference among Sampling Site-Year groupings was between groups that possessed more overall stomach contents and heavier prey items, such as fish (MPX-2012, MPX-2013, UPX-2013, UNK-2012 and UNK-2012) than those that possessed less overall stomach contents

(UPX-2012, UNK-2013, MNK-2013; Figure 11). The few samples captured in APX-2012 contained low overall diversity, but a proportionally large amount of plant material. Differences in the stomach contents between blue catfish caught in Patuxent River and Nanticoke River were driven by higher amounts of ITM, bivalves, amphipods, mysids and detritus in Patuxent River compared with higher amounts of fish, plant/algae, chironomid larvae, dipteran pupae, trichopterans and sediment in Nanticoke River (Figure 11). There did not appear to be a significant year effect (ANOSIM, R =0.13, P = 0.405). However, except for UPX, all sites had more stomach contents in 2012 compared with 2013.

Stable Isotope

Although the range of stable isotope values was similar among river, small but statistically significant differences were observed that may reflect differences in prey availability. The total area of the standard ellipse represents the isotopic niche of a particular organism in both space and time (Barnum et al. 2009). While there were some overlap between the Patuxent River and Nanticoke River SAEs (Figure 12), the mean centroid distance between Patuxent River and Nanticoke River was significantly different (Distance = 1.73, Hotelling's $T^2 = 10.7$, $P = 0.008$). This indicates there were likely differences in blue catfish prey resources between the Patuxent and Nanticoke River, which resulted in generally higher ^{13}C and ^{15}N values in Patuxent River compared with Nanticoke River.

As predators consume prey, ^{15}N isotopes are transferred to predators and the concentration of ^{15}N increases in tissues. Thus, predators will have a higher ^{15}N values relative to prey species, which can be useful in indicating trophic level position. In both Patuxent River and Nanticoke there was a positive relationship between ^{15}N values and total length (Figure 13). Gut content analysis indicated that larger blue catfish were feeding at higher trophic levels, ingesting proportionally more fish prey and less small benthic organisms (Figure 9).

In contrast to ^{15}N, ^{13}C is only slightly enriched in upper trophic levels and will generally reflect the primary production source responsible for energy flow through the ecosystem. Thus, differences in ^{13}C values can indicate shifts in prey resources and/or shifts in primary energy sources (e.g., phytoplankton assemblages, marsh grasses, terrestrial sources, etc.). There appears to be an overall positive relationship between ^{13}C values and TL in Patuxent River, but not in Nanticoke River (Figure 14).

In both systems, there appeared to be a marked shift in ^{13}C and ^{15}N values at around 100-200 mm TL (Figure 13, 14), which most likely reflects an ontogenetic shift in diet. Afterwards there appeared to be a steady rate of enrichment in relation to growth, with the exception of ^{13}C in Nanticoke River.

Genetic Barcoding of Fish Prey

The overwhelming majority (98%) of fish prey items were digested beyond recognition based on standard morphological examinations. Most samples consisted of chunks of tissue around spinal remnants, often without a head or tail. In some instances there were small amounts of loose tissue or pieces of bone/scales without any tissue present. We were only able to identify one prey

item to species with certainty based on visual examination alone – a banded killifish that possessed a small amount of scales with coloration intact. Several prey items were assigned to Family, but a full species identification was not possible. We found a total of 60 catfish yolk-sac larvae in 13 blue catfish stomach samples. However, were not able to identify these catfish to a specific species microscopically.

Genetic barcoding was highly successful (91.6%) in identifying digested fish prey to species. Most stomachs contained a single fish prey item, but we were able to identify multiple individuals even when they were separate species from the same stomach. A large number of prey items were heavily digested. Moreover, several identified prey species were closely related and morphologically similar, causing the identification of their partially digested remains to species inherently difficult (e.g., Clupeidae, Moronidae). Without genetic barcoding the overwhelming majority of fish prey items would have been categorized as partially-digested unidentified fish (PDUF) and information regarding fish prey preferences/identifications would have been lost.

We identified a total of 13 fish prey species from the stomach contents of blue catfish with genetic barcoding - 10 from Nanticoke River and 6 from Patuxent River (Table 3). All the identified fish species were also caught during high-frequency electrofishing sampling. Excluding the large number of channel catfish yolk-sac larvae, white perch was the most numerous fish prey item found in the stomach contents of blue catfish, as well as the most abundant species captured during high-frequency sampling (Table 4). Given our relatively small sample size, it is difficult to fully examine fish prey preferences of blue catfish. However, there was a noticeable lack of centrarchids found in the stomach contents of blue catfish relative to the surrounding fish assemblage (detailed below). Pumpkinseed and bluegill comprised a sizable portion of the fish community in both systems (Table 4). Moreover, centrarchids have been reported from the stomachs of Chesapeake Bay blue catfish and channel catfish (R. Aguilar, unpublished data). With the exception of the moronids and congeners, the fish prey found in blue catfish stomachs were soft-bodied. At the sizes of blue catfish we captured, there may be a preference for less spinous fish prey.

Fish captured with high-frequency electrofishing represented several different life-history guilds as well as habitat guilds, including pelagic species and marsh/shallow water associated species (including tessellated darter). This indicates that blue catfish are likely feeding at multiple habitats including shallow areas. These species also included a number of commercially important species (e.g., white perch, striped bass, menhaden, channel catfish, etc.) and species of management concern (e.g., alewife, blueback herring, and other forage species).

Fish Assemblage Sampling

We caught a diverse array of fish species during high-frequency electrofishing during 2012-2013, which included 27 freshwater species, 9 estuary-resident species, 8 diadromous (including semi-anadromous) species and 5 species whose juveniles use estuaries as nursery grounds (Table 5). In all systems, white perch was the most abundant species captured, with bluegill, gizzard shad, pumpkinseed, spottail shiner, and yellow perch being fairly abundant across all sites (Table 5). In general, Nanticoke River sites were the more dissimilar to Patuxent River sites and Upper Bay

sites than those sites were to each other (Figure 15.). This difference was characterized by Nanticoke River sites having higher abundances of white perch, bluegill and longnose gar, as well as a number of unique species and lower abundances of pumpkinseed, yellow perch and banded killifish (Table 5). Patuxent River sites possessed higher abundances of white perch, spottail shiner and eastern silvery minnow and lower abundances of pumpkinseed, gizzard shad, yellow perch, banded killifish and bluegill in comparison with Upper Bay sites. It should be noted that the fish prey communities also include other non-native species (e.g. goldfish, common carp, channel catfish, largemouth bass, etc.) that likely have important food web interactions.

Nanticoke River sites possessed a number of fish species not caught in other systems, including longnose gar (which is generally not reported north of Potomac River/Tangier Sound), redbreast sunfish, naked goby, spotted seatrout, red drum and threadfin shad. Upper Bay sites possessed three unique species that are not common on the coastal plain: Chesapeake logperch and rock bass, and to a lesser extent smallmouth bass, as well as Atlantic needlefish. Patuxent River sites possessed three unique species, Atlantic croaker, Atlantic silverside and green sunfish, which were all fairly uncommon. There was no difference in the fish assemblages between years (ANOSIM, R = 0.007, P=0.249).

IMPLICATIONS FOR MANAGEMENT

Distribution and abundance

Blue catfish were commonly encountered in the freshwater tidal portions of the Patuxent and Nanticoke Rivers, but were not encountered during fishery-independent sampling in the Sassafras River or Lower Susquehanna River/Susquehanna flats area. Catch per unit effort (CPUE) was greatest in the Patuxent River, suggesting that blue catfish are most established there and less abundant in tributaries on the Eastern Shore and Upper Chesapeake Bay. CPUE was at least an order of magnitude less than has been reported for Virginia rivers (e.g. Garman et al. 2013). Blue catfish were encountered most often in deep holes with woody debris along bends in the rivers or near bridge pilings or other man-made structures. These observations are consistent with preliminary results of an acoustic telemetry study of blue catfish in the Patuxent and Nanticoke Rivers (using other funds).

Size distribution

The size range of blue catfish encountered in the Patuxent and Nanticoke Rivers was small relative to the Potomac River and Virginia rivers. In the present study, catfish ranged from ~60-700 mm total length (TL) and nearly all fish were <550 mm TL. Small fish (<200 mm TL) were much more common in fall, reflecting recruitment of young fish to the sampling gear. In Virginia, Garman et al. (2013) documented the diets of blue catfish as large as 1120 mm TL, and larger individuals are known to occur there. Thus, the populations of blue catfish encountered in the present study are comprised of smaller (likely younger) fish than those in the Potomac River and Virginia rivers. It is likely that these populations will increasingly include larger fish with time as the initial cohorts living in Maryland tributaries approach their maximum age and size. It

does not appear that blue catfish have reached a stable age distribution in Maryland tributaries north of the Potomac. Thus, it is likely that populations will continue to increase as numbers of reproductive fish increase.

Diet

Blue catfish in the Patuxent and Nanticoke Rivers were largely omnivorous with a shift from benthic resources at smaller sizes to increased piscivory above ~300 mm TL. The diet of the smallest fish (<150 mm TL) was composed primarily of small benthic invertebrates (especially insects), mysids, and plant matter. From 150-349 mm TL, bivalves (mostly small clams) were added as an important component of the diet. Above 350 mm TL, fish became the dominant prey item but the diet remained diverse. There were minor differences in diet between the Patuxent and Nanticoke Rivers that appeared to be due to differences in the available prey communities. These results were supported by stable isotope analyses indicating enrichment in $\delta^{15}N$ with increasing size. Preliminary analysis (not included in the report) was suggestive of minor seasonal differences in diet, but the sample sizes were too small for robust comparisons among seasons, sites and years. It is likely that diets do shift seasonally, reflecting seasonal changes in prey abundance. The most notable difference between the present study and other blue catfish diet studies in Chesapeake Bay is the high proportion of insects and insect tube material in the diet as compared to amphipods and other small crustaceans (Chandler 1998, Schloesser et al. 2011, Garman et al. 2013). This difference was likely due to the focus of the present study in freshwater tidal areas adjacent to extensive freshwater marshes and associated differences in benthic prey species rather than a difference in prey preference among catfish populations.

Sustainable fisheries

The impacts of blue catfish trophic interactions (predation) on the sustainability of fishery resources likely shifts as catfish increase in size. At sizes <300 mm TL, blue catfish likely compete with fishery species (e.g. juvenile striped bass, white perch, blue crabs, other catfish, etc.) for benthic forage species including small benthic invertebrates and bivalves. Above ~300 mm TL, trophic interactions likely broaden to include both competition for a broad base of forage species including forage fish and direct predation on fishery species. Genetic barcoding of partially digested fish was a powerful way to identify fish prey in catfish guts, revealing 13 different species including commercially and recreationally important striped bass, white perch, menhaden, alewife, blueback herring, and American eel and other forage fish including bay anchovy and gizzard shad. Soft shell blue crabs were also observed in the stomachs of a few blue catfish. The relatively low abundance of blue crabs in the diet relative to other diet studies (Chandler 1998, Schloesser et al. 2011, Garman et al. 2013) is most likely due to the location of the present study in freshwater tidal sections of rivers where blue crabs are at low abundance compared to more saline areas sampled in other studies. Taken together, these diet studies consistently suggest that blue catfish likely have substantial impacts of Chesapeake Bay food webs, especially in areas with high blue catfish densities.

Commercial and recreational fisheries for blue catfish are rapidly expanding in Chesapeake Bay. If fishery managers pursue sustainable blue catfish fisheries, the present study is applicable to management of those fisheries. The results of the present study indicate that blue catfish stocks

are supported by a broad base of forage species (fish and invertebrates) that changes with ontogeny. Tidal freshwater areas, especially those with deep structured habitats, are important habitats for blue catfish. Preliminary results from telemetry studies (funded separately) indicate that the freshwater tidal reaches sampled in the present study are the primary blue catfish habitats in the Patuxent and Nanticoke Rivers. However, individual fish have been observed moving downstream of these areas for periods of up to several months, especially during early spring and fall. Recent efforts to conserve sufficient forage resources to support sustainable fisheries in Chesapeake Bay are also likely to benefit blue catfish stocks due to their broad diet.

Invasive fish in freshwater tidal areas

Although the introduction of blue catfish is likely impacting food webs and ecosystems in Chesapeake Bay, it is by no means the only non-native or invasive species in freshwater tidal habitats. Although not encountered in the present study, flathead catfish and snakeheads are two additional invasive predatory fish in freshwater tidal areas about which there are many concerns about potential impacts on fishery or other resources. A number of other non-native fish were encountered in the present study as well including goldfish, common carp, channel catfish and largemouth bass. The presence of multiple large non-native and invasive fish species in our sampling highlights the substantial changes that introductions of non-native fish on fish communities, food webs, and ecosystems in freshwater tidal zones of Chesapeake Bay and other estuaries.

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Table 1. Parameters of $\log_{10}$ transformed length-weight linear regressions of blue catfish caught in Patuxent River and Nanticoke River during 2012-2013.

System	Slope ± 95% CI	Intercept ± 95% CI	r^2
Patuxent River	3.181 ± 0.045	-8.487 ± 0.107	0.991
Nanticoke River	3.155 ± 0.054	-8.443 ± 0.124	0.990

Table 2. Proportional weight and occurrence of prey items contained in the stomach contents of blue catfish caught by river system (Patuxent River and Nanticoke River), during 2012-2013.

		Patuxent		Nanticoke	
Prey Group	Prey Item	P. Weight	P. Occurrence	P. Weight	P. Occurrence
Fish	Fish*	0.206	0.234	0.372	0.163
	Egg	0.001	0.034	<0.001	0.021
	Dorosoma cepedianum				
	UID fish egg				
Mollusk	Bivalve	0.246	0.217	0.131	0.255
	Corbicula fluminea				
	Mulinia lateralis				
	Mytilopsis leucophaeata				
	Rangia cuneata				
	Snail	<0.001	0.011	0.001	0.021
	Hydrobiidae				
	Valvatidae				
Crustacean	Amphipoda	0.048	0.457	0.008	0.312
	Apocorophium lacustre				
	Gammurus sp.				
	Leptocheirus plumosus				
	UID amphipod				
	Argulus sp.	<0.001	0.006	<0.001	0.007
	Balanidae	<0.001	0.017	<0.001	0.007
	Callinectes sapidus	0.004	0.006	0.033	0.014
	Copepoda	<0.001	0.011	<0.001	0.007
	Crab Megalops	0	0	<0.001	0.007
	Crayfish	<0.001	0.006	0	0
	Cumacea	<0.001	0.006	0	0
	Mysidae	0.013	0.177	0.005	0.135
	Isopoda	0	0	<0.001	0.014
	Cyathura polita				
	Edotia triloba				
	Ostracoda	<0.001	0.006	0	0
	Rhithropanopeus harrisii	0.001	0.011	0.005	0.014
	UID crustacean	<0.001	0.006	<0.001	0.021
Insect	Chironomid larvae	0.001	0.200	0.009	0.433
	Cicadomorpha	0.003	0.011	0	0
	Coleoptera	<0.001	0.006	<0.001	0.007
	Diptera larvae	<0.001	0.006	0	0
	Diptera adult	<0.001	0.006	0	0
	Diptera pupae	0.001	0.086	0.001	0.142
	Ephemeroptera	<0.001	0.006	0	0

	Hymenoptera	<0.001	0.011	<0.001	0.014
	Odonata	0.003	0.011	<0.001	0.014
	Trichoptera	<0.001	0.023	0.005	0.135
	UID Insect	<0.001	0.057	<0.001	0.057
Misc. Inverts	Hydroid	0	0	0.005	0.007
	UID Worm	<0.001	0.006	0.001	0.050
	Freshwater Sponge	<0.001	0.011	0.002	0.014
Benthos	Invertebrate tube material	0.245	0.811	0.166	0.794
	Detritus	0.134	0.229	0.013	0.149
	Plant/Algae	0.059	0.126	0.156	0.220
	Sediment	0.020	0.251	0.061	0.340
UID Materials	Anthropogenic material	<0.001	0.017	<0.001	0.014
	UID arthropod	0.001	0.029	<0.001	0.014
	UID invertebrate	<0.001	0.006	<0.001	0.007
	UID animal material	0.014	0.080	0.006	0.064
	UID organic material	0.001	0.046	0.019	0.085

Table 3. List of fish species identified from digested prey remains by genetic barcoding for blue catfish caught within Patuxent River and Nanticoke River during 2012-2013. Data are the number of individual prey items identified by barcoding with the number in parentheses indicating the total number of blue catfish predators that possessed that particular prey item. *It is estimated a total of 60 channel catfish yolk-sac larvae were ingested by 13 blue catfish predators (i.e., not every yolk-sac larvae [YSL] was barcoded, but at least one YSL from each predator was processed). Failed indicates the number of samples that were processed but genetic sequencing was unsuccessful.

Scientific name	Common name	Patuxent River	Nanticoke River
Alosa aestivalis	Blueback Herring	0	1 (1)
Alosa pseudoharengus	Alewife	0	2 (2)
Anchoa mitchilli	Bay Anchovy	4 (4)	0
Anguilla rostrata	American eel	0	1 (1)
Brevoortia tyrannus	Menhaden	1 (1)	0
Dorosoma cepedianum	Gizzard Shad	1 (1)	1 (1)
Etheostoma olmstedi	Tessellated Darter	0	1 (1)
Fundulus diaphanus	Banded Killifish	0	1 (1)
Ictalurus furcatus	Blue Catfish	2 (2)	3 (2)
Ictalurus punctatus	Channel Catfish	13 (13)*	0
Morone americana	White Perch	3 (2)	6 (3)
Morone saxatilis	Striped Bass	0	1 (1)
Notropis hudsonius	Spottail Shiner	0	3 (2)
Sum	13	24 (23)*	20 (15)
Failed		1(1)	3 (3)

Table 4. Proportional abundance of fish species caught during paired fish assemblage sampling by major sampling systems, 2012-1013. Guild represents diadromous (D), estuary-resident (E), freshwater (F) and nursery-resident (N).

Scientific name	Common name	Guild	Upper Bay	Patuxent River	Nanticoke River
Alosa aestivalis	Blueback Herring	D	0.002	0	0.021
Alosa pseudoharengus	Alewife	D	0	<0.001	0.004
Alosa sapidissima	American Shad	D	<0.001	0	0.002
Ambloplites rupestris	Rock Bass	F	<0.001	0	0
Ameiurus catus	White Catfish	F	<0.001	0.001	0.002
Ameiurus nebulosus	Brown Bullhead	F	0.018	0.012	0.002
Anchoa mitchilli	Bay Anchovy	E	0.029	0.002	0.025
Anguilla rostrata	American Eel	D	0.014	0.010	0.008
Bairdiella chrysoura	Silver Perch	E	0	0	<0.001
Brevoortia tyrannus	Menhaden	N	0.011	0.014	0
Carassius auratus	Goldfish	F	0.005	0.006	0
Catostomus commersonii	White Sucker	F	0.012	0.014	0
Cynoscion nebulosus	Spotted Seatrout	N	0	0	0.001
Cyprinella analostana	Satinfin Shiner	F	0.001	0.006	0.019
Cyprinus carpio	Common Carp	F	0.013	0.006	0.008
Dorosoma cepedianum	Gizzard Shad	D	0.103	0.030	0.024
Dorosoma petenense	Threadfin Shad	D	0	0	0.001
Enneacanthus gloriosus	Bluespotted Sunfish	F	0.002	0.002	0
Erimyzon oblongus	Creek Chubsucker	F	0	0.004	<0.001
Esox niger	Chain Pickerel	F	0	0.003	<0.001
Etheostoma olmstedi	Tessellated Darter	F	0.001	<0.001	0.001
Fundulus diaphanus	Banded Killifish	E	0.057	0.059	0.034
Fundulus heteroclitus	Mummichog	E	0	0.087	0.002
Gobiosoma bosc	Naked Goby	E	0	0	<0.001
Hybognathus regius	Eastern Silvery Minnow	F	0.010	0.038	0
Ictalurus furcatus	Blue Catfish	F	0	<0.001	0.001
Ictalurus punctatus	Channel Catfish	F	0.008	0.016	0.024
Leiostomus xanthurus	Spot	N	0.003	0.002	0.003
Lepisosteus osseus	Longnose Gar	F	0	0	0.023
Lepomis auritus	Redbreast Sunfish	F	0	0	0.003
Lepomis cyanellus	Green Sunfish	F	0	0.001	0
Lepomis gibbosus	Pumpkinseed	F	0.218	0.175	0.014
Lepomis macrochirus	Bluegill	F	0.032	0.020	0.083
Menidia beryllina	Inland Silverside	E	0.015	0.011	0.005
Menidia menidia	Atlantic Silverside	E	0	<0.001	0
Micropogonias undulatus	Atlantic Croaker	N	0	0.001	0
Micropterus dolomieu	Smallmouth Bass	F	0.002	0	0

Micropterus salmoides	Largemouth Bass	F	0.017	0.009	0.020
Morone americana	White Perch	D	0.292	0.334	0.530
Morone saxatilis	Striped Bass	D	0.007	0.012	0.008
Moxostoma macrolepidotum	Shorthead Redhorse	F	0.001	0.002	<0.001
Notemigonus crysoleucas	Golden Shiner	F	0.004	0.002	0.009
Notropis hudsonius	Spottail Shiner	F	0.050	0.073	0.076
Perca flavescens	Yellow Perch	F	0.070	0.046	0.032
Percina bimaculata	Chesapeake Logperch	F	<0.001	0	0
Pomoxis nigromaculatus	Black Crappie	F	0.001	0.001	0.003
Sciaenops ocellatus	Red Drum	N	0	0	<0.001
Strongylura marina	Atlantic Needlefish	E	<0.001	0	0
Trinectes maculatus	Hogchoker	E	<0.001	<0.001	0.007
Species richness			**28**	**31**	**31**

Table 5. Data output from SIMPER procedure indicating mean log abundances by site, mean dissimilarity, percent contribution to the dissimilarity and the cumulative percentage.

Patuxent vs. Upper Bay Average dissimilarity = 58.21

Species	Patuxent Mean Abund.	Upper Bay Mean Abund.	Mean Dissimilarity	Percent Contribution	Cumulative Percentage
Pumpkinseed	1.68	2.03	5.56	9.55	9.55
White Perch	2.47	2.41	5.12	8.8	18.35
Gizzard Shad	0.62	1.55	4.91	8.43	26.78
Spottail Shiner	1.07	0.81	4.22	7.26	34.04
Yellow Perch	0.81	1.3	4.21	7.23	41.27
Banded Killifish	0.69	0.7	3.69	6.33	47.6
Bluegill	0.42	0.76	3.14	5.4	53
Eastern Silvery Minnow	0.5	0.23	2.31	3.97	56.97

Patuxent vs. Nanticoke Average dissimilarity = 64.90

Species	Patuxent Mean Abund.	Nanticoke Mean Abund.	Mean Dissimilarity	Percent Contribution	Cumulative Percentage
Pumpkinseed	1.68	0.43	5.84	9	9
White Perch	2.47	2.99	5.55	8.56	17.56
Spottail Shiner	1.07	0.96	4.9	7.55	25.11
Bluegill	0.42	1.15	4.4	6.78	31.89
Yellow Perch	0.81	0.71	3.57	5.5	37.39
Banded Killifish	0.69	0.44	3.41	5.25	42.65
Gizzard Shad	0.62	0.65	3.15	4.85	47.5
Longnose Gar	0	0.62	2.88	4.44	51.94

Upper Bay vs. Nanticoke Average dissimilarity = 62.78

Species	Upper Bay Mean Abund.	Nanticoke Mean Abund.	Mean Dissimilarity	Percent Contribution	Cumulative Percentage
Pumpkinseed	2.03	0.43	6.81	10.85	10.85
White Perch	2.41	2.99	5.15	8.21	19.06
Gizzard Shad	1.55	0.65	4.63	7.38	26.43
Spottail Shiner	0.81	0.96	4.32	6.89	33.32
Yellow Perch	1.3	0.71	4.23	6.73	40.05
Bluegill	0.76	1.15	4.11	6.55	46.6
Banded Killifish	0.7	0.44	3.22	5.13	51.73
Longnose Gar	0	0.62	2.6	4.14	55.87

Figure Captions

Fig 1**.** Map of Chesapeake Bay indicating three main sampling systems: (A) Patuxent River, (B) Nanticoke River; (C) Upper Bay. Grid cells in A-C indicate the full set of cells from which random sampling sites were chosen.

Fig 2. Maps of mean CPUE at sampling locations in the Patuxent (blue circles) and Nanticoke Rivers (red circles). The size of circles is indicative of CPUE. Sampling areas shown include Apical (APX), Upper (UPX), and Middle Patuxent River (MPX), and Upper (UNK) and Middle Nanticoke River (MNK) and are divided by black horizontal bars. Red (wooded) and green (marshy) bars at right indicate differences in the primary shoreline habitat between sampling areas. Important landmarks are labeled.

Fig. 3. Mean CPUE (fish caught per hour;±SE) of blue catfish caught by sampling site. Light bars indicate blue catfish caught in 2012 and dark bars indicate blue catfish caught in 2013. Sampling sites included Northeast River (NER), Swan Creek (SWC), Sassafras River (SAS), Apical (APX), Upper (UPX), and Middle Patuxent River (MPX), and Upper (UNK) and Middle Nanticoke River (MNK). No blue catfish were caught in Upper Bay sites (NER, SAS and SWC). These data include all fish collected from both random and additional non-random sampling.

Fig 4. Mean total length (±SE) of blue catfish caught by sampling site. Sampling sites included Northeast River (NER), Swan Creek (SWC), Sassafras River (SAS), Apical (APX), Upper (UPX), and Middle Patuxent River (MPX), and Upper (UNK) and Middle Nanticoke River (MNK). Light bars indicate blue catfish caught in 2012 and dark bars indicate blue catfish caught in 2013. No blue catfish were caught in Upper Bay sites, NER, SAS and SWC and these sites are not shown.

Fig 5. Total length-weight relationships of blue catfish caught in Patuxent River (blue circles) and Nanticoke River (red squares) during 2012-2013.

Fig 6. Seasonal size distribution of blue catfish caught in Nanticoke River and Patuxent River. Green bars represent summer captures (June-July) and brown bars represent autumn captures (September-October).

Fig 7. Percentage by weight of a subset of prey items identified from the stomach contents of blue catfish caught within Patuxent River (blue bars) and Nanticoke River (red bars) during 2012-2013

Fig 8. Percent occurrence of a subset of prey items identified from the stomach contents of blue catfish caught within Patuxent River (blue bars) and Nanticoke River (red bars) during 2012-2013.

Fig 9. Mean within stomach prey biomass percentage by category for blue catfish caught in Patuxent River and Nanticoke River, 2012-2013. ITM denotes Invertebrate Tube Material. Benthic Invertebrate category includes amphipods, juvenile dipterans and trichopterans and Plant Matter category includes both live plant/algae and detrital material.

Fig 10. Percent occurrence of Gut Fullness Scores for blue catfish caught in Nanticoke River and Patuxent River during 2012-2013. Gut fullness scores are as follows: 0) empty; 1) Slightly distended, >0-20% full; 2) Partially distended, >20-40% full; 3) Moderately distended, >40-60% full; 4) Mostly distended, >60-80% full; 5) Completely distended, 100% full.

Fig 11. Non-metric Multidimensional Scaling (nMDS) ordination plot of mean stomach content biomass obtained from blue catfish predators. Blue circles indicate sites within in Patuxent River and red squares indicate sites within Nanticoke River. Vectors for a subset of important prey items are shown in blue. Similar in interoperation to some parametric ordination techniques (PCA, CCA, etc.), the direction and length of each vector represents the contribution of a specific variable (prey item) to among-group (site-year) differences in n-dimensional space.

Fig 12. Biplot of δ^{15}N-δ^{13}C of blue catfish caught within Patuxent River (blue circles) and Nanticoke River (red squares) during 2012-2013. The dotted lines represent convex hulls as described in Layman et al. (2007) and the solid lines represent standard ellipses, the bivariate equivalent of the univariate standard deviations (Jackson et al. 2011).

Fig 13. Biplot of δ^{15}N-Total length of blue catfish caught within Patuxent River (blue circles) and Nanticoke River (red squares) during 2012-2013.

Fig 14. Biplot of δ^{13}C-Total length of blue catfish caught within Patuxent River (blue circles) and Nanticoke River (red squares) during 2012-2013.

Fig 15. Non-metric Multidimensional Scaling (nMDS) ordination plot of mean abundance data of fish obtained by high-frequency electrofishing during 2012-2013. Blue circles indicate sites within in Patuxent River and red squares indicate sites within Nanticoke River. Vectors for a subset of important fish species are shown in blue. Similar in interoperation to some parametric ordination techniques (PCA, CCA, etc.), the direction and length of each vector represents the contribution of a specific variable (fish species) to among-group (sites) differences in n-dimensional space.

Figure 1.

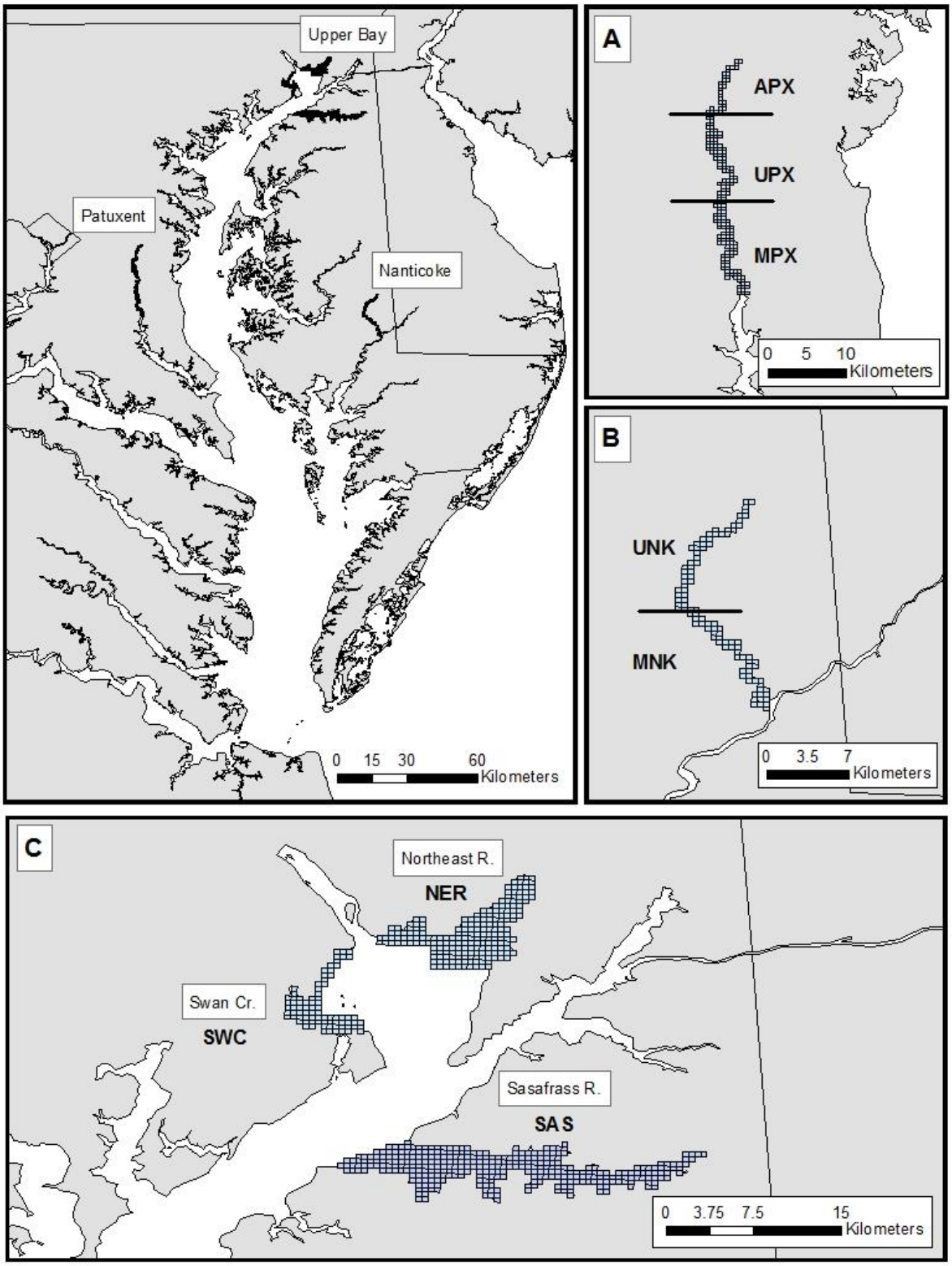

Upper Bay
Patuxent
Nanticoke
0 15 30 60
Kilometers
A
APX
UPX
MPX
0 5 10
Kilometers
B
UNK
MNK
0 3.5 7
Kilometers
C
Northeast R.
NER
Swan Cr.
SWC
Sasafrass R.
SAS
0 3.75 7.5 15
Kilometers

Figure 2.

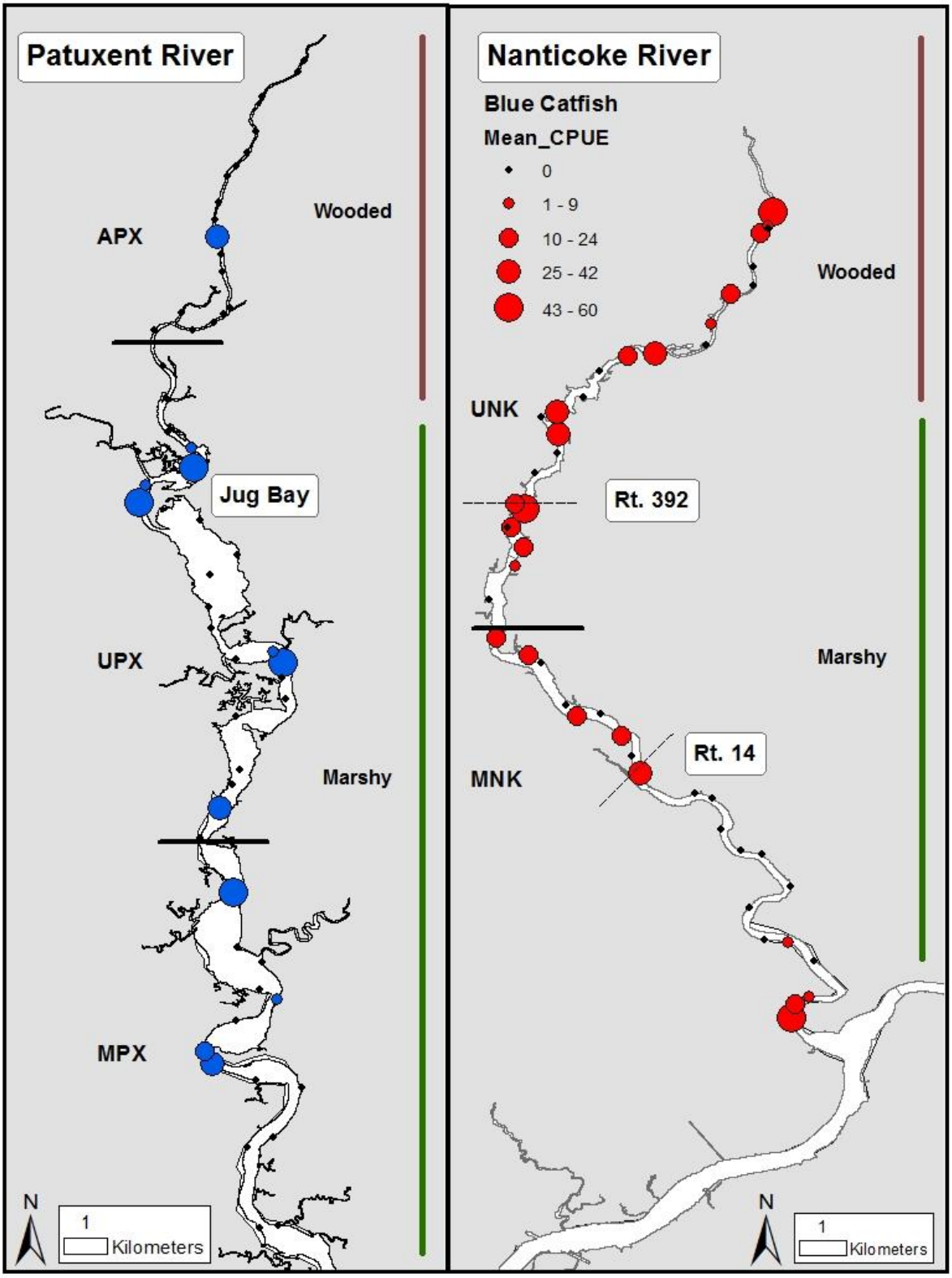

Patuxent River
APX
Wooded
Jug Bay
UPX
Marshy
MPX
N
1
Kilometers
Nanticoke River
Blue Catfish
Mean_CPUE
0
1 - 9
10 - 24
25 - 42
43 - 60
Wooded
UNK
Rt. 392
Marshy
Rt. 14
MNK
N
1
Kilometers

Figure 3.

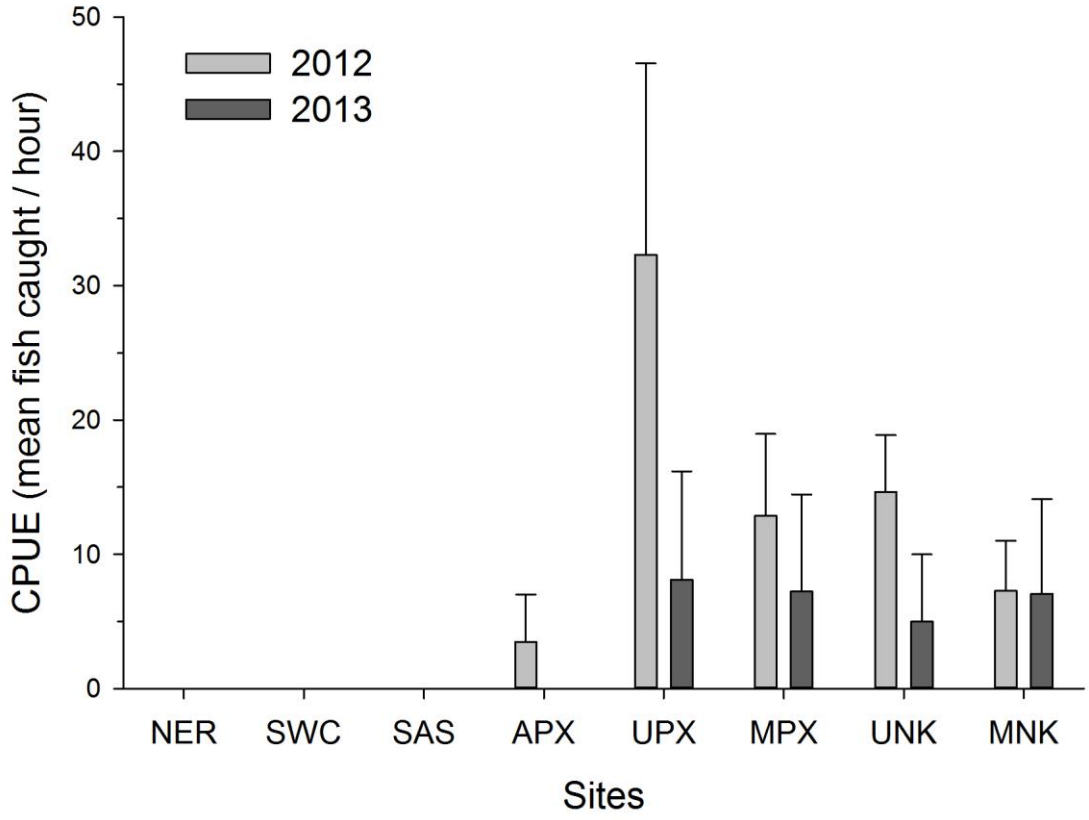

2012
2013
CPUE (mean fish caught / hour)
0
10
20
30
40
50
NER
SWC
SAS
APX
UPX
MPX
UNK
MNK
Sites

Figure 4.

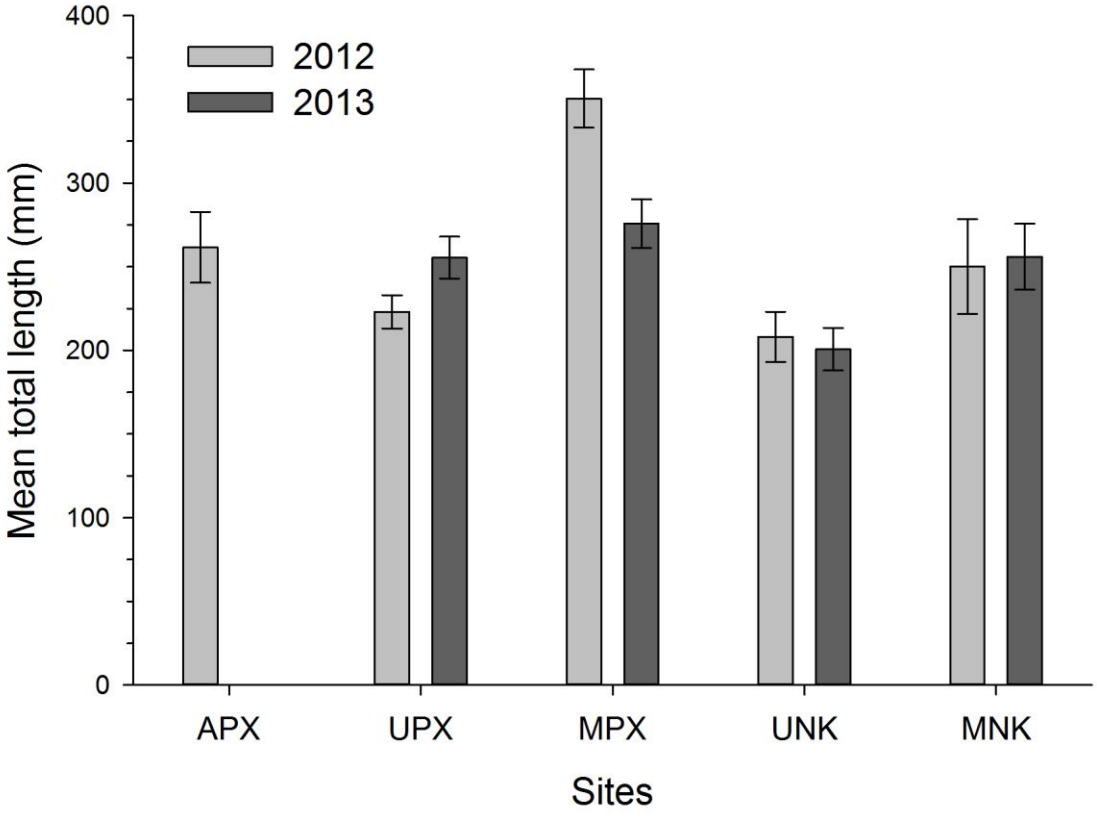

400
300
200
100
0
Mean total length (mm)
2012
2013
APX
UPX
MPX
UNK
MNK
Sites

Figure 5.

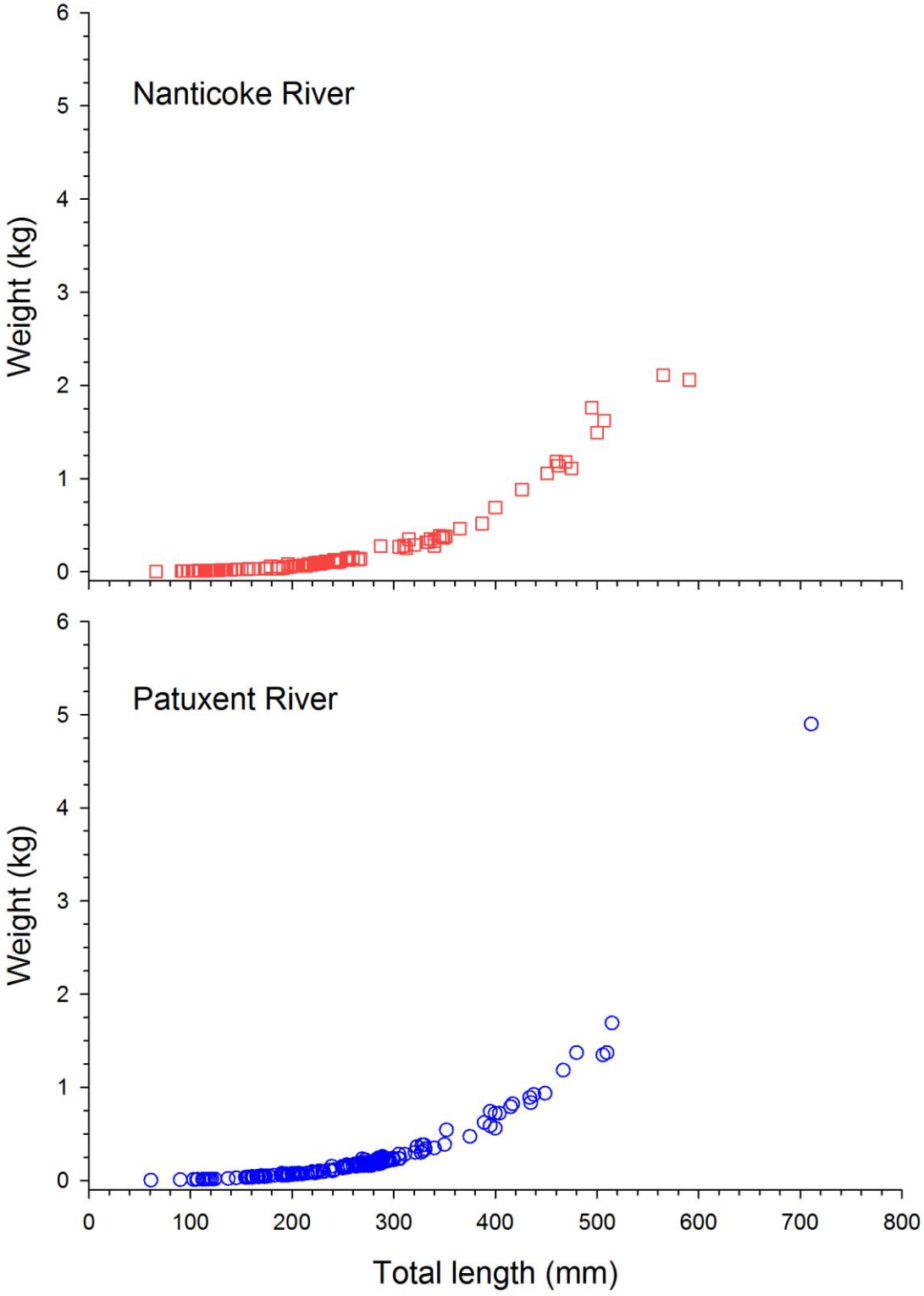

Nanticoke River
Weight (kg)
0
1
2
3
4
5
6
Patuxent River
Weight (kg)
0
1
2
3
4
5
6
0
100
200
300
400
500
600
700
800
Total length (mm)

Figure 6.

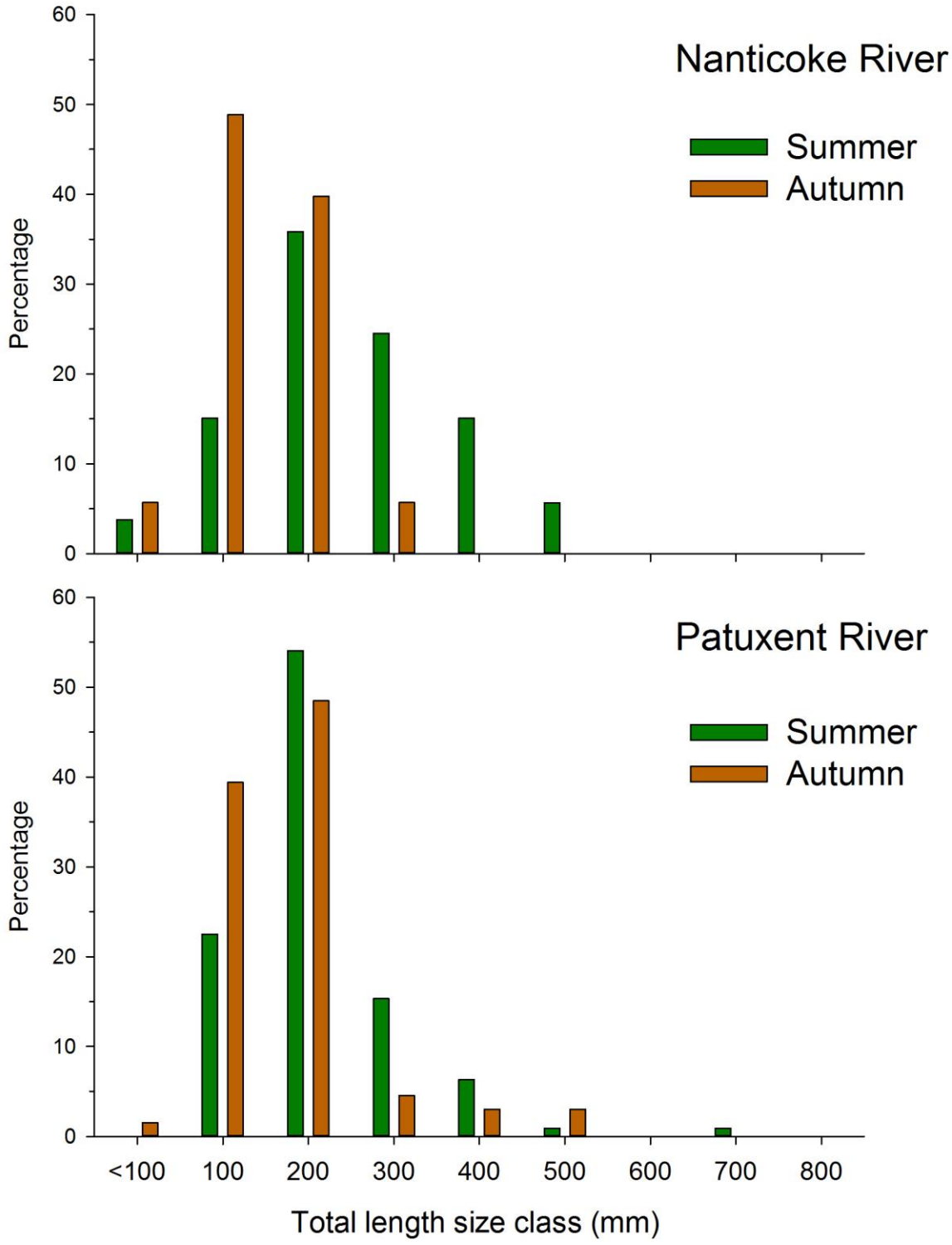

Nanticoke River
Summer
Autumn
Percentage
60
50
40
30
20
10
0
Patuxent River
Summer
Autumn
Percentage
60
50
40
30
20
10
0
<100
100
200
300
400
500
600
700
800
Total length size class (mm)

Figure 7.

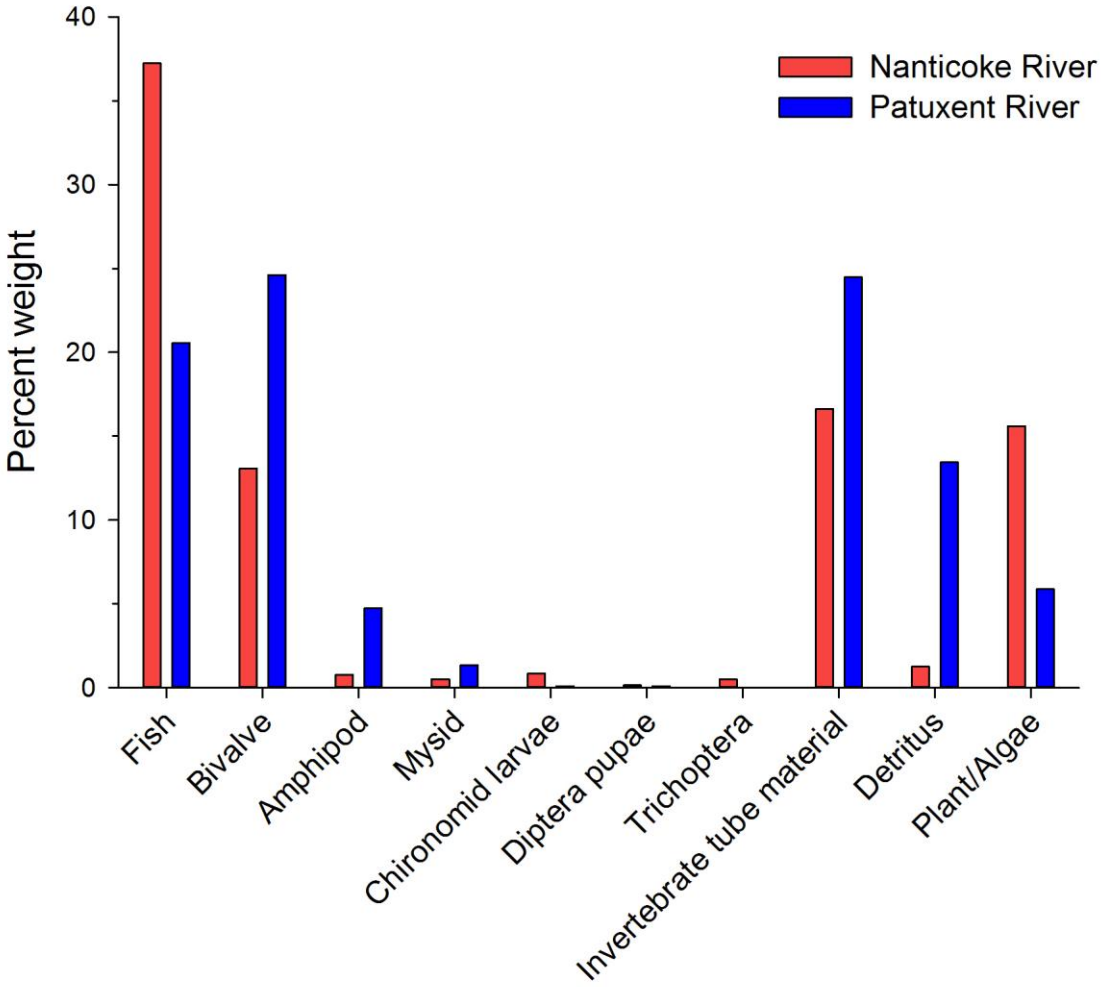

Nanticoke River
Patuxent River
Percent weight
40
30
20
10
0
Fish
Bivalve
Amphipod
Mysid
Chironomid larvae
Diptera pupae
Trichoptera
Invertebrate tube material
Detritus
Plant/Algae

Figure 8.

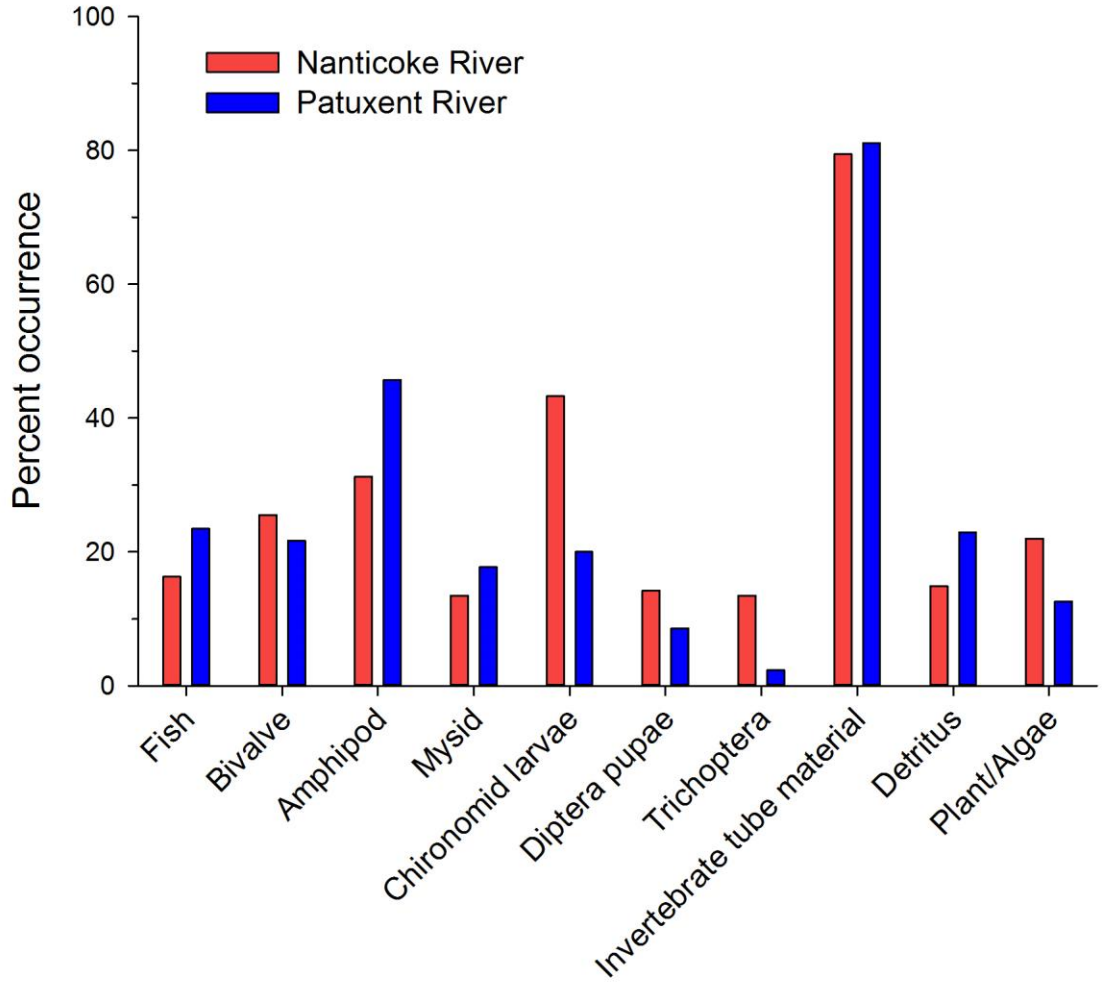

Nanticoke River
Patuxent River
Percent occurrence
100
80
60
40
20
0
Fish
Bivalve
Amphipod
Mysid
Chironomid larvae
Diptera pupae
Trichoptera
Invertebrate tube material
Detritus
Plant/Algae

Figure 9.

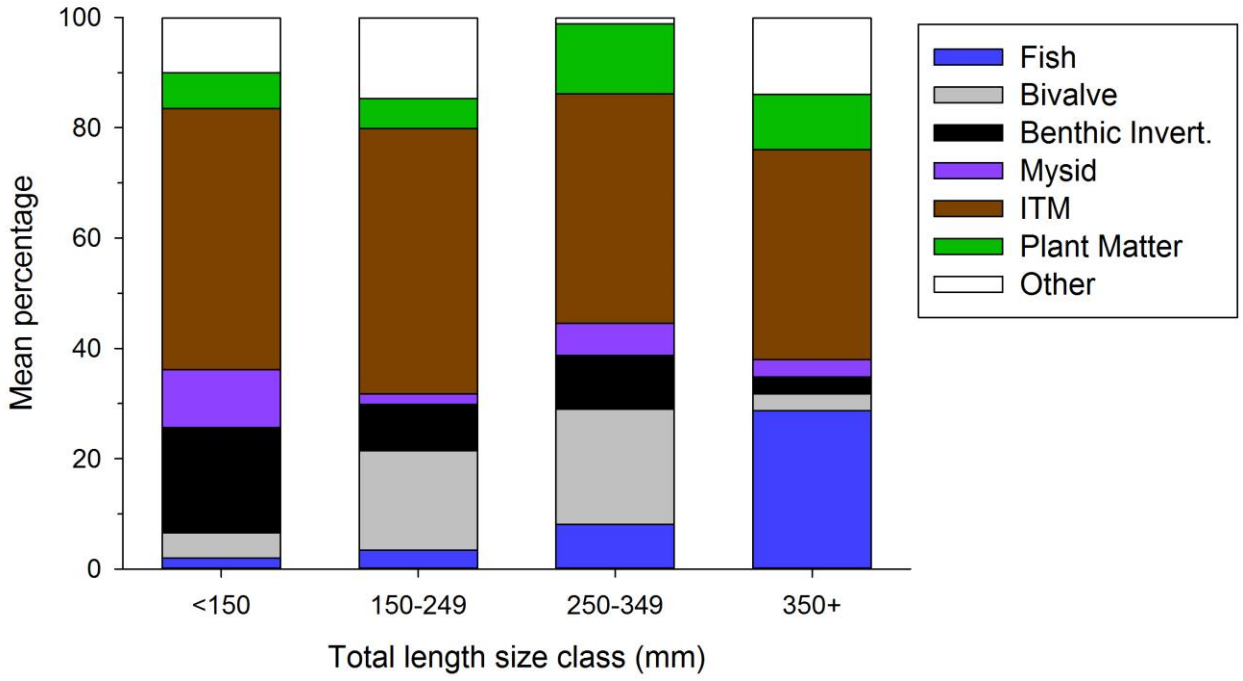

100
80
60
40
20
0
Mean percentage
<150
150-249
250-349
350+
Total length size class (mm)
Fish
Bivalve
Benthic Invert.
Mysid
ITM
Plant Matter
Other

Figure 10.

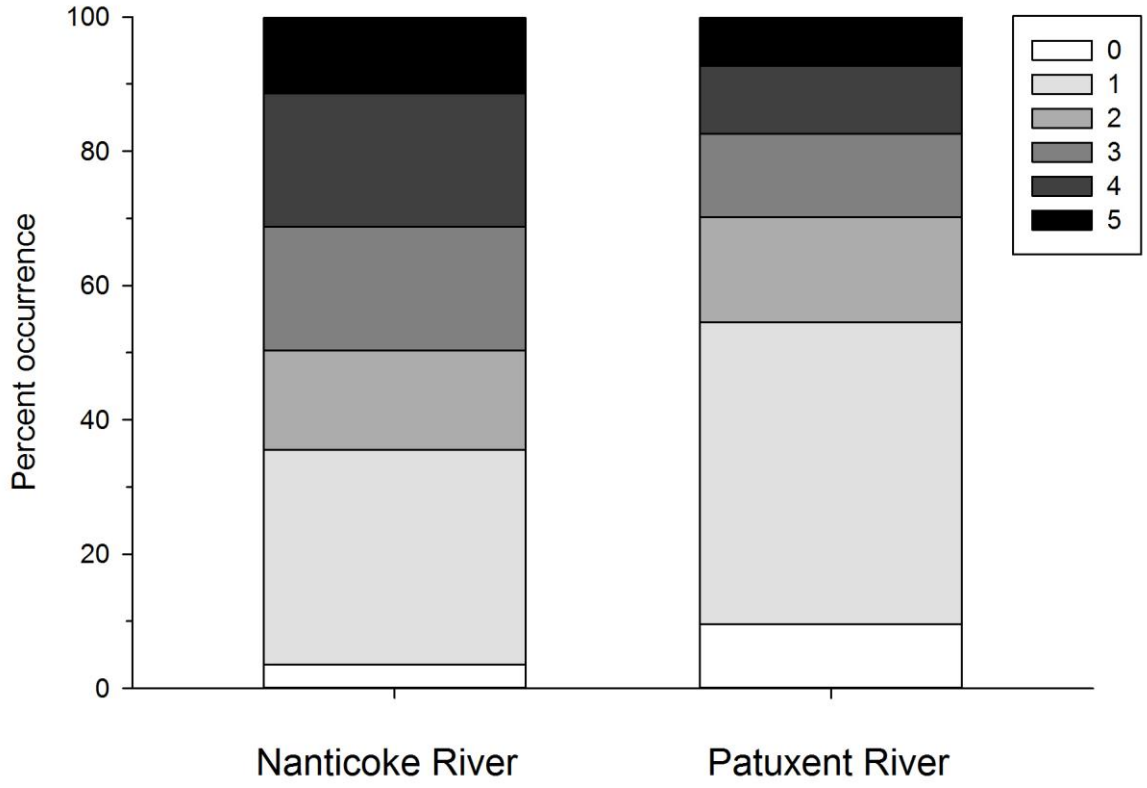

100
80
60
40
20
0
Percent occurrence
0
1
2
3
4
5
Nanticoke River
Patuxent River

Figure 11.

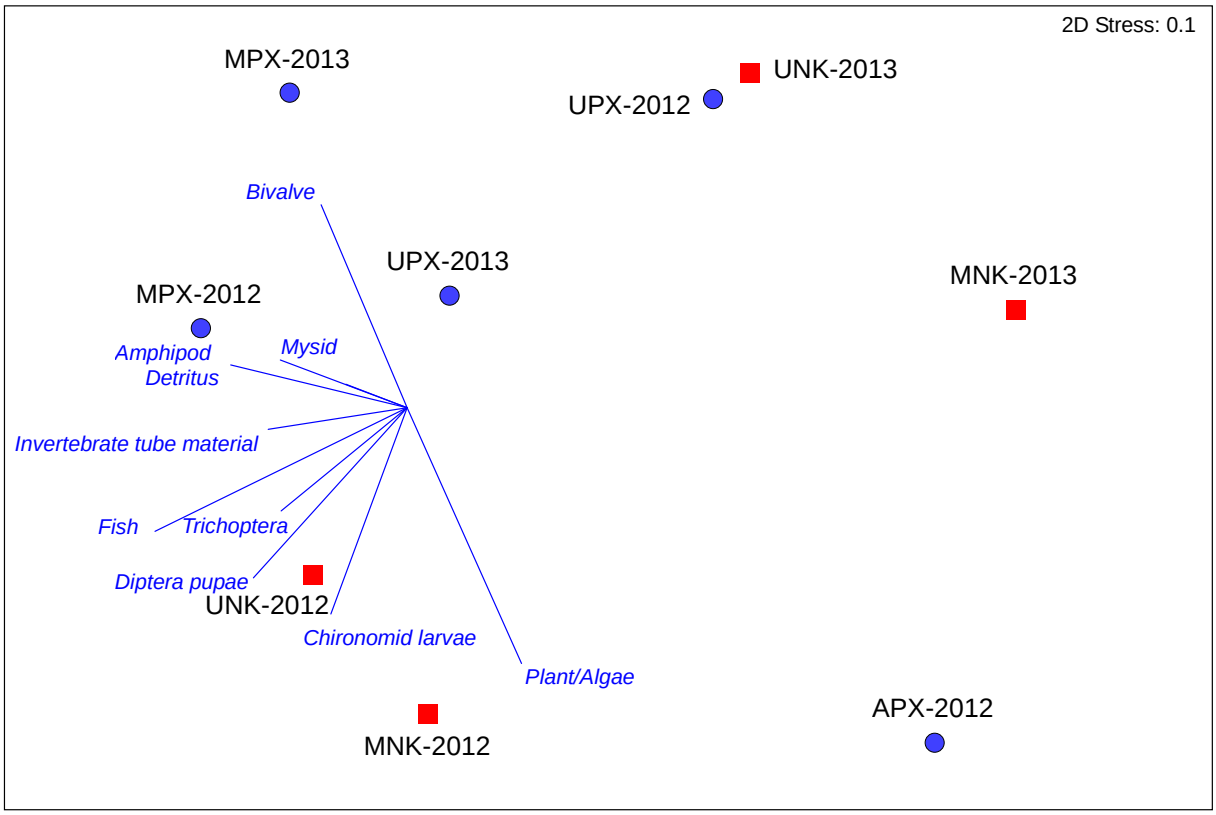

2D Stress: 0.1
MPX-2013
UNK-2013
UPX-2012
Bivalve
UPX-2013
MNK-2013
MPX-2012
Amphipod
Detritus
Mysid
Invertebrate tube material
Fish
Trichoptera
Diptera pupae
UNK-2012
Chironomid larvae
Plant/Algae
APX-2012
MNK-2012

Figure 12.

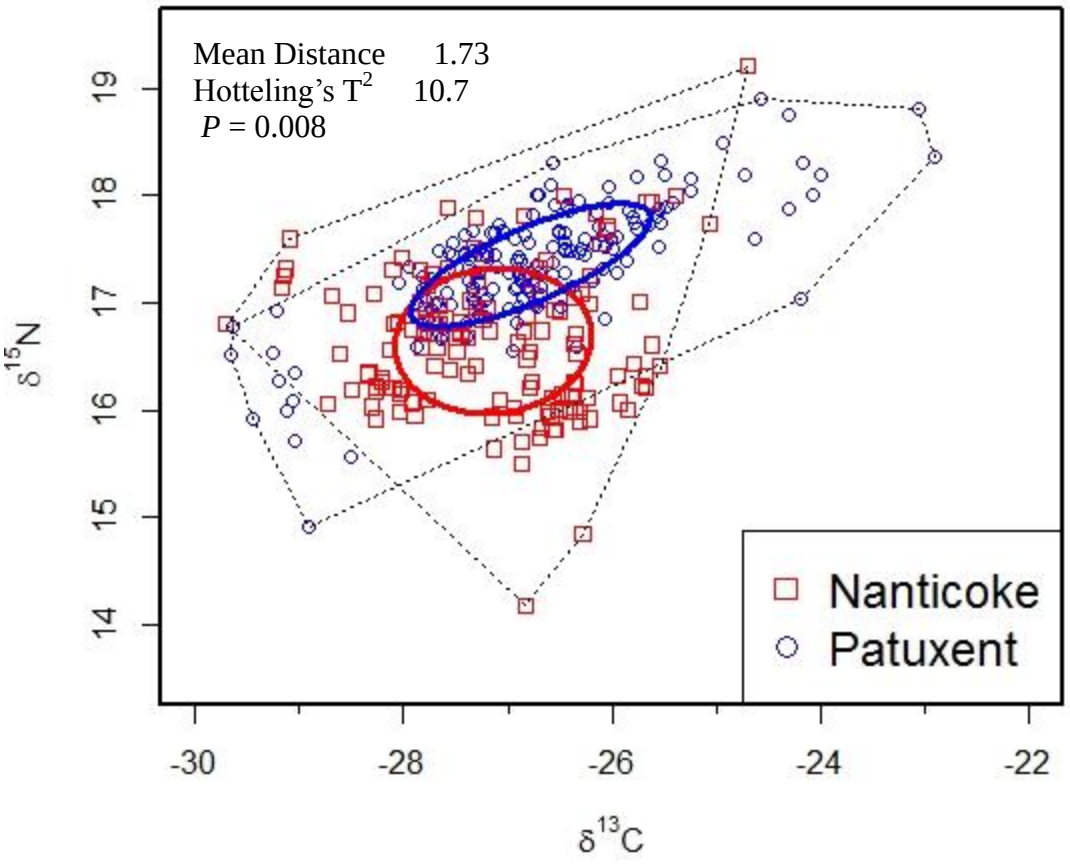

Mean Distance 1.73
Hotteling's T2 10.7
P = 0.008
Nanticoke
Patuxent
δ15N
δ13C
14
15
16
17
18
19
-30
-28
-26
-24
-22

Figure 13.

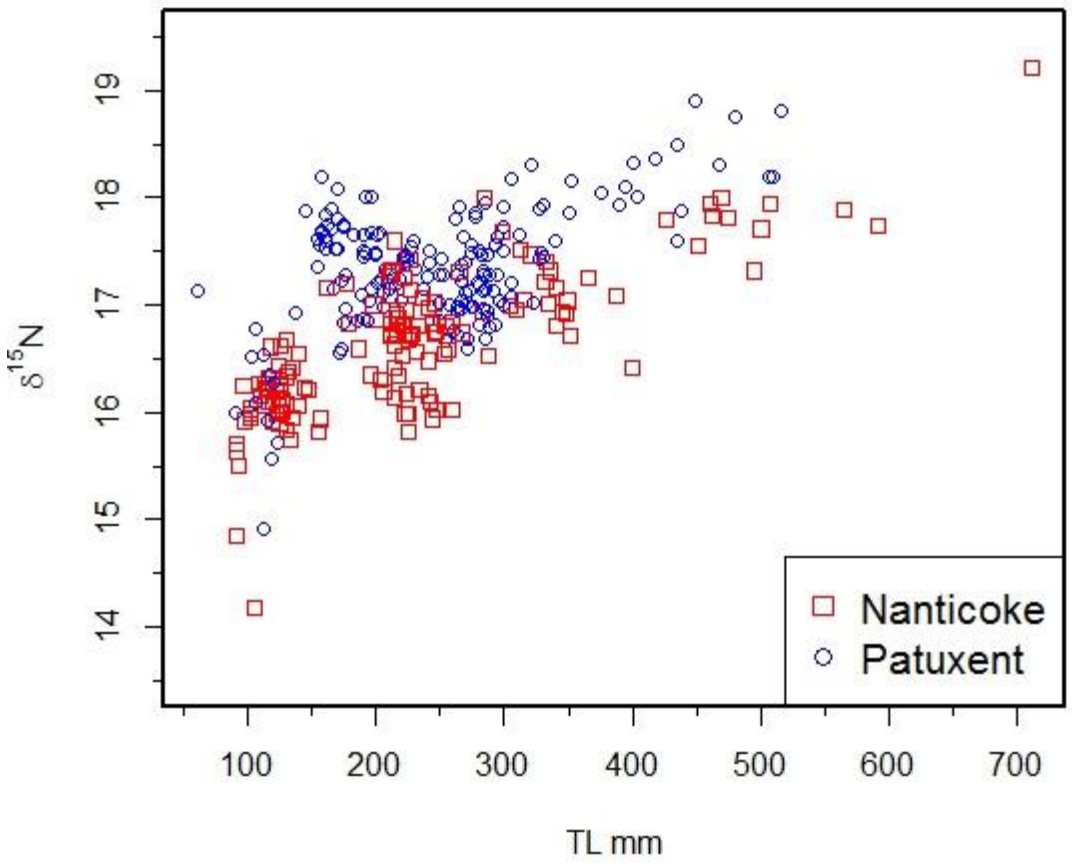

δ15N
14
15
16
17
18
19
100
200
300
400
500
600
700
TL mm
Nanticoke
Patuxent

Figure 14.

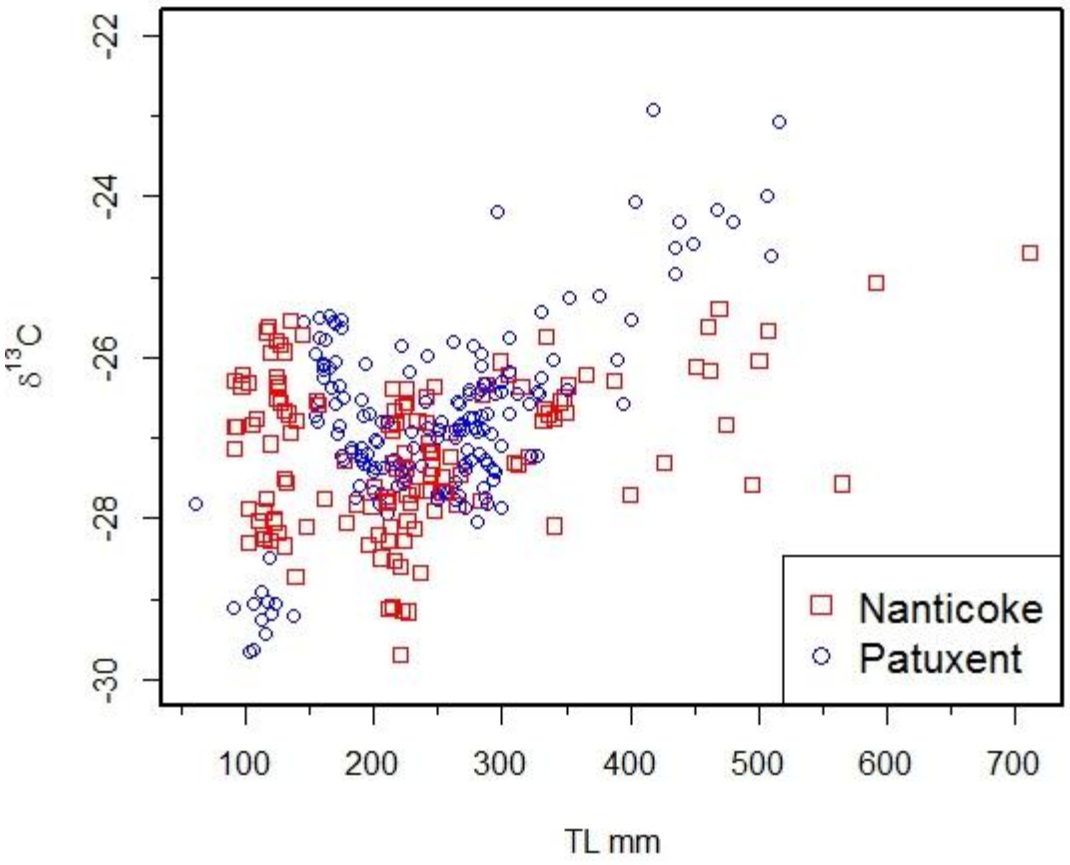
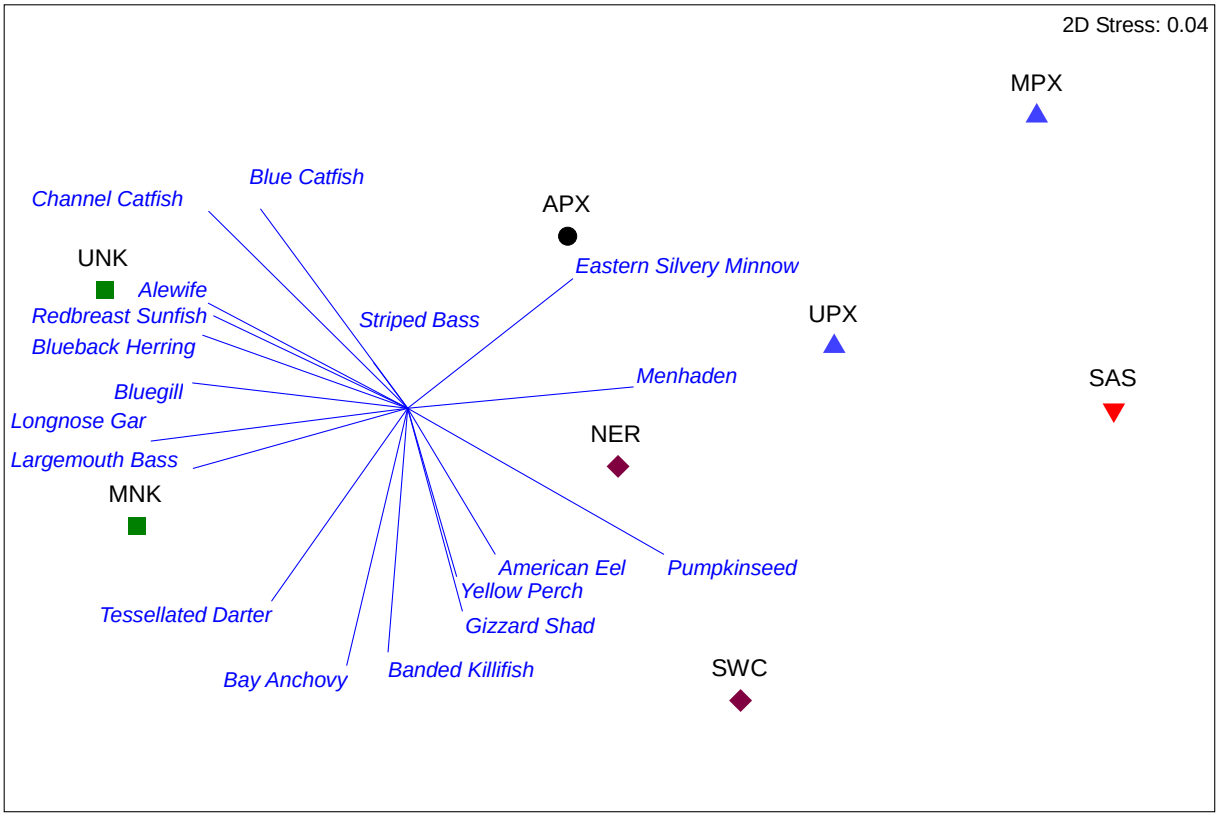

-22
-24
-26
-28
-30
δ13C
100
200
300
400
500
600
700
TL mm
Nanticoke
Patuxent

Figure 15.


2D Stress: 0.04
MPX
Blue Catfish
Channel Catfish
APX
UNK
Eastern Silvery Minnow
Alewife
Striped Bass
UPX
Redbreast Sunfish
Blueback Herring
Menhaden
SAS
Bluegill
Longnose Gar
NER
Largemouth Bass
MNK
American Eel
Pumpkinseed
Yellow Perch
Tessellated Darter
Gizzard Shad
Bay Anchovy
Banded Killifish
SWC

2. Applications:

a. Outputs

i. New fundamental or applied knowledge:

Blue catfish abundance in Maryland tributaries of Chesapeake Bay was low compared to the Potomac River and Virginia tributaries. The present study indicated that the size distribution of blue catfish in the sites surveyed were generally smaller than in more southern tributaries, likely because the invasion occurred more recently and most fish are relatively young. This is particularly true for sites in the Upper Bay, where no blue catfish were encountered in our standardized sampling despite confirmed reports of blue catfish occurrence in these areas. Blue catfish diets in Maryland are similar to those of southern tributaries and are indicative of a similar shift from omnivory to piscivory as fish grow beyond approximately 350 mm total length.

ii. Scientific publications: None Yet

iii. Patents: None yet

Workshops

A NOAA press event was organized at the Smithsonian Environmental Research Center in January 2012. We presented the goals, methods, and results of our project for managers, scientists, and reporters. This resulted in media stories in Annapolis Capital and Tom Pelton's blog.

This project was also presented at several workshops/ meetings of the Sustainable Fisheries Goal Implementation Team (GIT) of the Chesapeake Bay Program 2012-2014. We presented goals, methods and initial results to the committee of Chesapeake Bay state and federal fishery managers and reporters. This resulted in stories in the Bay Journal and a NPR news story.

Presentations

Robert Aguilar, Matthew B. Ogburn , Mike R. Goodison, Paige M. Roberts, Kimberly D Richie, Kierra E. Heggie, Midge A. Kramer, Brooke Weigel, T Flock, Anson H. Hines. Movement of Non-native Blue Catfish, *Ictalurus furcatus*, in Two Upper Chesapeake Bay Tidal Tributaries. American Fisheries Society Tidewater Chapter Annual Meeting, 05-07 March 2015. Pine Knoll Shores, NC.

Matthew B. Ogburn, Blue Catfish Diet in Maryland. Sustainable Fisheries Goal Implementation Team, 3 December 2014. Edgewater, MD.

Travis Flock, Matthew B. Ogburn, Robert Aguilar, Anson H. Hines. Tracking Blue Catfish Movement in Chesapeake Bay using Ultrasonic Telemetry. Wabash College, Biology Department, Poster Presentation, 2014.

Matthew B. Ogburn, Rob Aguilar, Lee A. Weigt, Amy Driskell, Anson H. Hines. Genetic barcoding of gut contents: From partially digested tissue to species identity. American Fisheries Society Annual Meeting, 17-21 August 2014, Quebec City, Quebec, Canada.

Matthew B. Ogburn. Chesapeake catch: science supporting sustainable fisheries. Smithsonian Environmental Research Center Evening Lecture Series, 20 May 2014, Edgewater, MD.

Robert Aguilar, Brooke Weigel, Eric G. Johnson, Matthew B. Ogburn, Anson H. Hines, Mike R. Goodison, Paige M. Roberts, Midge A. Kramer. Trophic Dynamics and Movement of Non-native Blue Catfish, *Ictalurus furcatus*, in Maryland. American Fisheries Society Tidewater Chapter Annual Meeting, 21-23 March 2014. Newport News, VA.

Matthew B. Ogburn. Ecology of the Invasive Blue Catfish in Chesapeake Bay. Jug Bay Wetlands Sanctuary, 10 January 2014. Lothian, MD.

Matthew B. Ogburn, Catfish Distribution, Diet, and Movement in Maryland. Sustainable Fisheries Goal Implementation Team, 3-4 December 2013. Solomons, MD.

Brooke Weigel. Determining the Impacts of Invasive Blue Catfish in Maryland Using Diet Studies and Acoustic Telemetry. Smithsonian Environmental Research Center, 14 November 2013. Edgewater, MD.

Angela Trenkle. Potential Impacts of Invasive Blue Catfish on Native White Catfish. Internship Final Presentation. Smithsonian Environmental Research Center, 8 May 2013. Edgewater, MD.

Robert Aguilar, Miranda M. Marvel, Eric G. Johnson, Mattew B. Ogburn, Anson H. Hines, Michael R Goodison, Paige M. Roberts. Trophic Dynamics of Non-native Catfish, *Ictalurus furcatus*, in Maryland. American Fisheries Society Tidewater Chapter Annual Meeting, 21-23 March 2013. Solomons, MD.

Robert Aguilar, Lee A. Weigt, Amy C. Driskell, Anson H. Hines, Eric G. Johnson, Matt B. Ogburn. Barcoding the Bay: Enhancing the Study of Chesapeake Bay Communities, Foodwebs and Invasions through DNA Barcoding. American Fisheries Society Tidewater Chapter Annual Meeting, 21-23 March 2013. Solomons, MD.

Miranda Marvel. Trophic Dynamics of Non-native Catfish, *Ictalurus furcatus*, in Maryland. Internship Final Presentation. Smithsonian Environmental Research Center, 16 November 2012. Edgewater, MD.

Outreach activities/products (e.g. website, newsletter articles):

- Website: http://www.serc.si.edu/labs/fish_invert_ecology/invasives/overview.aspx
- SERC Science and the Media program featuring invasive species (http://www.mediaandscience.org/2014/09/16/science-and-the-media-and-smithsonian-environmental-research-center-co-host-program-on-marine-invaders/). The event was featured in an article by Louise Lief in the Wilson Quarterly, a product of the Woodrow

Wilson International Center for Scholars, "Science, meet journalism. You two should talk." (http://wilsonquarterly.com/stories/science-and-innovation-in-changing-newsroom/).

- Associated Press video interview featured in "Taking a bite out of Chesapeake invasive species" (https://www.youtube.com/watch?v=hqXI2MhRzeI).
- Family Science Day on the Bay, open house at the Smithsonian Environmental Research Center, Sept 20, 2014.
- Intern training: 4 undergraduate interns for ecology and management of invasive species.

b. Management outcomes - I. Management application or adoption of:

i. New fundamental or applied knowledge:

ii. Two presentations of preliminary results have been made to the Sustainable Fisheries Goal Implementation Team (GIT) of the Chesapeake Bay Program. Diet information from the present study has been incorporated into the Invasive Catfish Task Force Report submitted to the GIT Executive Committee in Feb 2014 and will be updated during the ongoing revision of the report.

iii.

iv. New or improved skills: SERC technicians were trained in and have become proficient in boat electrofishing

v. Information from publications, workshops, presentations, outreach products: None yet

vi. New or improved methods or technology: None yet

vii. New or advanced tools: Developed a DNA barcode library of prey fish (with funding from other sources) and conducted DNA barcode analysis of blue catfish gut contents. We have also collaborated with Maryland DNR to analyze some of their gut content samples using DNA barcoding and have assisted Dr. Don Orth at Virginia Tech in incorporated DNA barcoding into gut content sampling in Virigina rivers.

c. Management outcomes - II. Societal condition improved due to management action resulting from output; examples:

i. Improved water quality: None yet

ii. Lower frequency of harmful algal blooms: None yet

iii. Reduced hypoxic zone area: None yet

iv. Improved sustainability of fisheries: Sustainable Fisheries Goal Implementation Team (GIT) of the Chesapeake Bay Program has considered potential management strategies to reduce negative impacts of invasive blue catfish in Chesapeake Bay. Results from the present study have been incorporated into a report to the GIT produced in 2014 by the Invasive Catfish Task Force and which is currently under revision. The present study, as well as other recent blue catfish diet studies in other regions of Chesapeake Bay, provide evidence that invasive catfish are likely impacting food webs through direct predation of managed species and through competitive for prey or other resources. Reducing these impacts is likely to improve the sustainability of fisheries for native species. Understanding abundance, distribution and diet is also likely to

inform sustainable management of the rapidly-expanding commercial and recreational fisheries for blue catfish in Chesapeake Bay.

d. Partnerships established with other federal, state, or local agencies, or other research institutions (other than those already described in the original proposal):
Collaborative work with Maryland Department of Natural Resources and Virginia Tech.

3. Expenditures:

b. Describe actual expenditures this period.

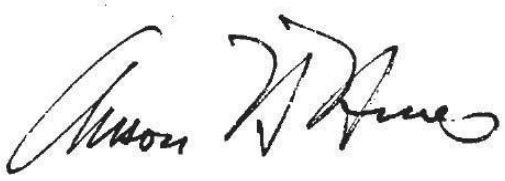
To date (April 2015) the project has spent $165,067 of the $165,097 total for the project.

c. Explain special problems that led to differences between scheduled and actual expenditures, etc.

The rate of spending was initially low until the construction of the electrofishing equipment was completed. The majority of spending was for personnel. We received supplemental funds for supplies and travel expense for this project from another source.

Prepared By: Signature of Principal Investigator; Date: 04/30/2015

Anson H. Hines



NOAA COP Annual Progress Report Form

7/16/2007