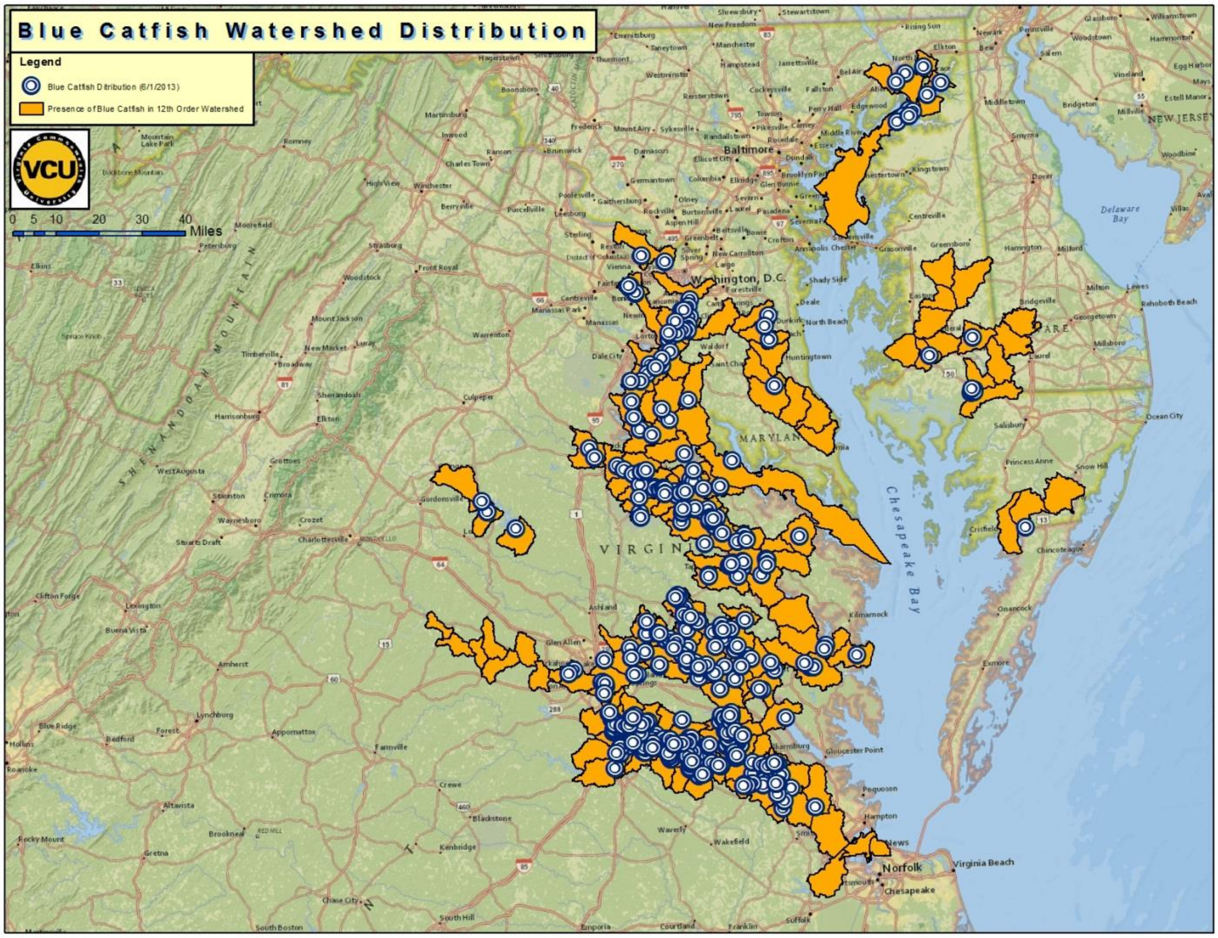
Predation by introduced catfishes on selected fishery resources in Chesapeake Bay tributaries



Greg Garman, Stephen McIninch, David Hopler, Matthew Balazik, and William Shuart

Center for Environmental Studies and VCU Rice Rivers Center

Virginia Commonwealth University

Richmond, Virginia

ggarman@vcu.edu

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Cover

Distribution of introduced blue catfish in the Chesapeake Bay basin, based on documented and verified records (fishery independent) from agency or academic sources, including Maryland Department of Natural Resources, Virginia Department of Game and Inland Fisheries, Virginia Institute of Marine Science, and Virginia Commonwealth University. Data are current as of September 2013. Inclusion of anecdotal (unverified) records would extend the range to Lynchburg on the James, above the former Embrey Dam on the Rappahannock, into coastal waters of the Virginia Eastern Shore (bayside), and into the bay mainstem at several additional locations. Data presented are point occurrences and catchments (6^{th} order HUCs).

FINAL REPORT to the NOAA Chesapeake Bay Office

Co-Principal Investigators: Dr. Greg Garman and Dr. Steve McIninch, Center for Environmental Studies, Virginia Commonwealth University, PO Box 843050, Richmond, VA 23284-3050, (804) 828-1574, ggarman@vcu.edu

Cooperators: Dr. Mary Fabrizio and Dr. Rob Latour, Department of Fishery Science, Virginia Institute of Marine Science, Gloucester Point, Virginia; Mary Groves, Fishery Scientist, Maryland Department of Natural Resources, Annapolis, Maryland

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Project Duration: January 1 – December 31, 2012

Project Title: Predation by invasive catfishes as a potentially important and novel source of mortality for selected fishery resources in Chesapeake Bay waters

Objectives:

- **I.** Quantify seasonal and spatial occurrence of selected prey types, representing ecologically and economically important species such as American shad, blueback herring, and Atlantic menhaden, in blue catfish and flathead catfish diets for major riverine and estuarine habitats of Chesapeake Bay.
- **II.** Generate expanded estimates of predation mortality by blue catfish populations on anadromous clupeid fishes, including American shad and blueback herring, for specific river systems in Virginia and Maryland.
- **III.** Design and implement an experimental catfish control/containment study focused on reducing predation mortality on one or more populations of migratory alosine fishes in the Chesapeake Bay region.
- **IV.** Develop specific management recommendations regarding the current and future impact of invasive catfish predation on restoration programs for anadromous fishes in Virginia and Maryland, including tactics to mitigate those impacts where feasible.

Executive Summary:

The VCU research team conducted targeted dietary analyses of nonindigenous blue catfish (*Ictalurus furcatus*) and flathead catfish (*Pylodictis olivaris*) in selected riverine and estuarine habitats in Virginia and Maryland waters to evaluate the hypothesis that predation by introduced catfishes is a potentially significant and novel source of mortality for some populations of native anadromous fishes (e.g. *Alosa* spp.) and other fishery resources. This hypothesis was supported by several lines of quantitative and anecdotal evidence but this study is the first targeted assessment of current and future predation impacts from potentially invasive catfishes on Chesapeake Bay fishery resources.

A total of 1,002 blue catfish and 125 flathead catfish were collected for dietary analysis in 2011 and 2012; both tidal freshwater and lower estuarine habitats were sampled. Blue catfish ranged between 390 and 1120 mm (TL) and flathead catfish ranged between 380 and 1080 mm (TL). Blue catfish predators in tidal freshwater habitats of the James and Rappahannock rivers preyed on several migratory or otherwise important species, including adult and young of the year blueback herring, juvenile American shad, adult white perch, and blue crabs. Frequency of occurrence of alosine and white perch prey in blue catfish diets was higher in the Rappahannock than in the James, possibly based on greater availability of these taxa in the former basin, where > 20 percent of blue catfish examined contained *Alosa* prey.

Blue catfish predators in the lower (mesohaline) James River at Burwell Bay consumed six economically important taxa, including Atlantic menhaden (juveniles), white perch, American eel, spot, blue crab, and softshell clam, based on the examination of 596 fish collected in the Spring of 2012. Only Atlantic menhaden, blue crab, and softshell clam represented a substantial portion of the diet in this estuarine habitat, however.

Findings support several potentially important conclusions. First, introduced catfish predators may contribute to substantial losses of key fishery resources, even though large (> 400 mm TL) flathead and blue catfish represent a relatively small proportion of most established populations within the Chesapeake basin. Second, these losses may be ecologically significant for migratory species like blueback herring that continue to decline across the region and are concentrated spatially during spawning runs. Third, the potential impacts of blue catfish predation on estuarine fishery resources, including Atlantic menhaden and blue crabs, may be more important than previously assumed. Although a freshwater species in its native range, blue catfish introduced here have demonstrated a marked ability to colonize or temporarily occupy estuarine habitats with salinities up to 17 ppt. Finally, GIS-based risk assessment models developed suggest that the current range of both blue catfish and flathead catfish in Chesapeake Bay and its tributaries is likely to double in the near future.

Five specific management recommendations, including the establishment of Freshwater Protected Areas (FPAs) in the region and the experimental use of electrofishing to increase commercial harvest of potentially invasive catfishes, are included in this report. Complementary, GIS-based analyses of risk from catfish expansion are presented.

Background and Problem Statement:

The establishment and expansion of non-native, predatory catfishes—specifically blue catfish and flathead catfish that are long-lived, grow to large size, and represent a novel apex trophic level in Chesapeake Bay waters—has been well-document by biologists and commercial and recreational fishers in recent decades (MacAvoy, et al. 2009). Introduced to Virginia waters in the mid-1970s, blue catfish may eventually occupy the upper Bay and many of its tributaries, based on a relatively high salinity tolerance (Figure 1) and other biological traits that favor dispersal and establishment (Schloesser, et al. 2012). Flathead catfish may have a comparatively lower potential to become established in estuarine habitats but are capable of dispersal into tidal and nontidal freshwater and oligohaline habitats (Bringolf, et al. 2005). The potential ecological effects and economic costs associated with further expansion of these invasive species in Chesapeake Bay could be considerable (Schloesser, et al. 2012). These non-native catfish populations support important commercial and recreational fisheries, particularly in Virginia waters, but also represent a potentially significant—and novel—source of predation mortality on, and competitive interactions with, native fish and fisheries throughout the Chesapeake Bay region.

Blue catfish occur at highest densities in tidal freshwater reaches of Virginia's and Maryland's coastal rivers. For example, 50-70% of total fish biomass in the vicinity of Hopewell, Virginia (James River) is represented by blue catfish (VDGIF and VCU, unpublished data). These upper tidal and nontidal regions may represent a population 'reservoir' from which downstream (i.e., estuarine) habitats are colonized (Edmonds 2003). Patterns of longitudinal movements by individuals among estuarine, tidal riverine and upland habitats are not well understood. A GIS-based study comparing "predicted" and "observed" distributions of blue catfish in Chesapeake Bay tributaries (Edmonds 2003) suggested that downstream dispersal during high-discharge (i.e., storm) events, coupled with the species' relatively high salinity tolerance, was the primary mechanism for expansion beyond the initial stocking locations in Virginia. This study, coupled with observations by the VIMS trawl survey that larger (300-500 mm FL) individuals first occupy a higher salinity habitat, followed by an influx of smaller conspecifics, suggests that blue catfish will likely continue to expand into all but the highest-salinity waters of Chesapeake Bay and its tributaries in coming decades. The Edmonds (2003) study also implicated unauthorized transport and

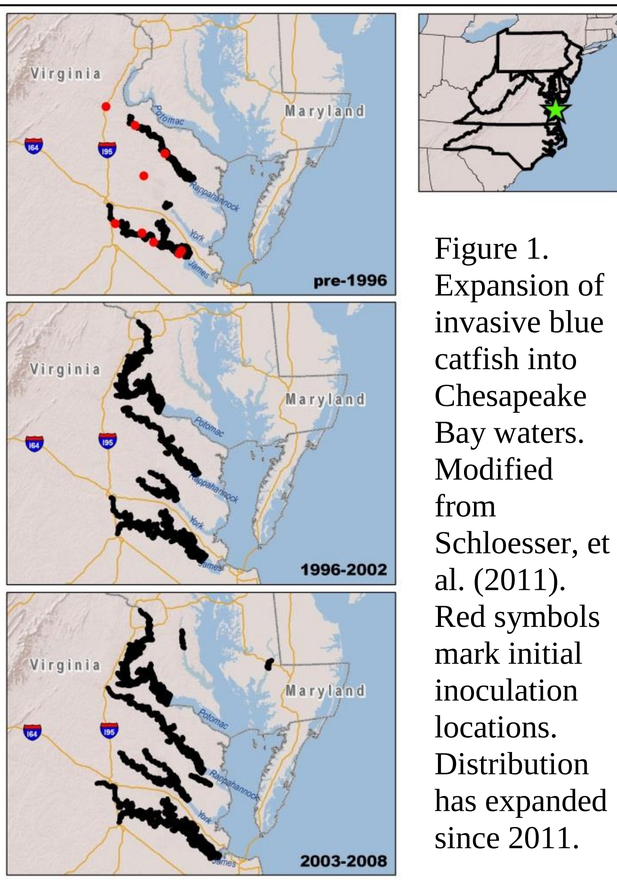

Figure 1. Expansion of invasive blue catfish into Chesapeake Bay waters. Modified from Schloesser, et al. (2011). Red symbols mark initial inoculation locations. Distribution has expanded since 2011.

introductions by recreational fishers as a mechanism for expansion of potentially invasive catfish. Finally, removal of mainstem dams for anadromous fish passage (e.g. Embrey dam on the Rappahannock River) and the construction of fish passage structures (e.g. Bosher's dam on the James River) will continue to create opportunities for the expansion of non-native fishes into nontidal waters. For example, during a single year (2005) of operation, the denil fishway at Bosher's dam passed an estimated 7,400 blue catfish (and several thousand flathead catfish) into the non-tidal James River (Fisher 2007). It's something of a paradox that intact dams—generally considered ecosystem stressors—may be effective barriers to range expansion by some invasive predatory fishes (Freeman 2002).

Blue catfish are generalist predators with a diverse diet composed of benthic, pelagic, and terrestrial prey including fish, crustaceans, worms, clams, freshwater mussels, and crabs. Scientists at VIMS examined the guts of 907 blue catfish (39-595 mm FL) from the James, York, and Rappahannock rivers during 2004 to 2007. Amphipods were the primary prey consumed by smaller blue catfish foraging in low salinity areas; miscellaneous material and bivalves were also found in abundance in the diet of these fish. At higher salinity range (6-17 ppt), miscellaneous material was found to be slightly more important in the diet than amphipods, and Atlantic menhaden (*Brevoortia tyrannus*) were also consumed (Schloesser et al., 2012). In a collaborative study between VCU and VDGIF, Chandler (1998) found that blue catfish >300 mm TL in the tidal James and Rappahannock rivers switched to a largely piscivorous diet. In the same study, flathead catfish >200 mm TL were almost exclusively piscivorous. In 2002, VDGIF biologists examined stomach contents of blue catfish collected in 0 to 6 ppt waters from the James, Pamunkey, Mattaponi, and Rappahannock rivers. Fish prey dominated the diets of catfish > 600 mm TL. Other prey items included Asiatic clam (*Corbicula*), crustaceans, and native freshwater mussels (R. Greenlee, VDGIF, unpubl. data).

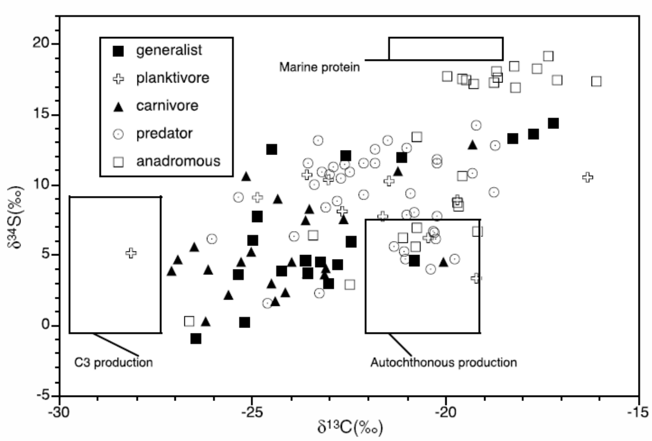

Figure 2

$\delta^{34}S$ vs. $\delta^{13}C$ values for the four guilds and anadromous *Alosa* species, with boxes to indicate the isotope signature of C3 terrestrial plant primary production, freshwater autochthonous production, and marine primary production. *Alosa* spp. are highly ^{34}S-enriched relative to most freshwater residents, reflecting marine sulfate (which becomes incorporated into primary producers and *Alosa* spp. while they grow in the Atlantic Ocean). Predators are the only guild showing elevated $\delta^{34}S$, indicating the incorporation of marine protein derived from *Alosa* spp.

Stable isotope analyses of fish tissues from coastal rivers in Virginia demonstrate that introduced blue catfish and flathead catfish represent a novel trophic level that is significantly higher (based on $\delta^{15}N$ values) compared to native predatory fishes and that nonnative catfishes prey on adult anadromous clupeid fishes (Figs. 2 & 3; MacAvoy et al. 2009, MacAvoy et al. 2001, MacAvoy et al. 2000, Garman and Macko 1998). Similar stable isotope analyses have been used elsewhere to document the effects of non-native fishes (Cucherousset, et al. 2011). Other potential ecological effects associated with blue catfish and flathead catfish include the near-extirpation of native white catfish (*Ameiurus catus*) and brown bullhead (*A. nebulosus*) from most Virginia rivers. Studies by

MacAvoy et al. (1998, 2009) documented marine Carbon and Sulfur isotopic signatures in ictalurid predators that were most likely associated with consumption of adult anadromous fishes such as American shad, blueback herring, and alewife during Spring spawning migrations into freshwater habitats (Table 1). Likewise, Chandler (1998) found that blue catfish >300 mm TL in the tidal James and Rappahannock rivers switched to a largely piscivorous diet, including adult and juvenile *Alosa* spp. Maryland DNR and VIMS biologists also report predation by blue catfish on anadromous clupeid fishes (M. Groves, MdDNR, unpubl. data) , but the relative importance of predation by introduced predators on depressed populations of native migratory and semi-migratory fishes, although potentially significant, is unclear.

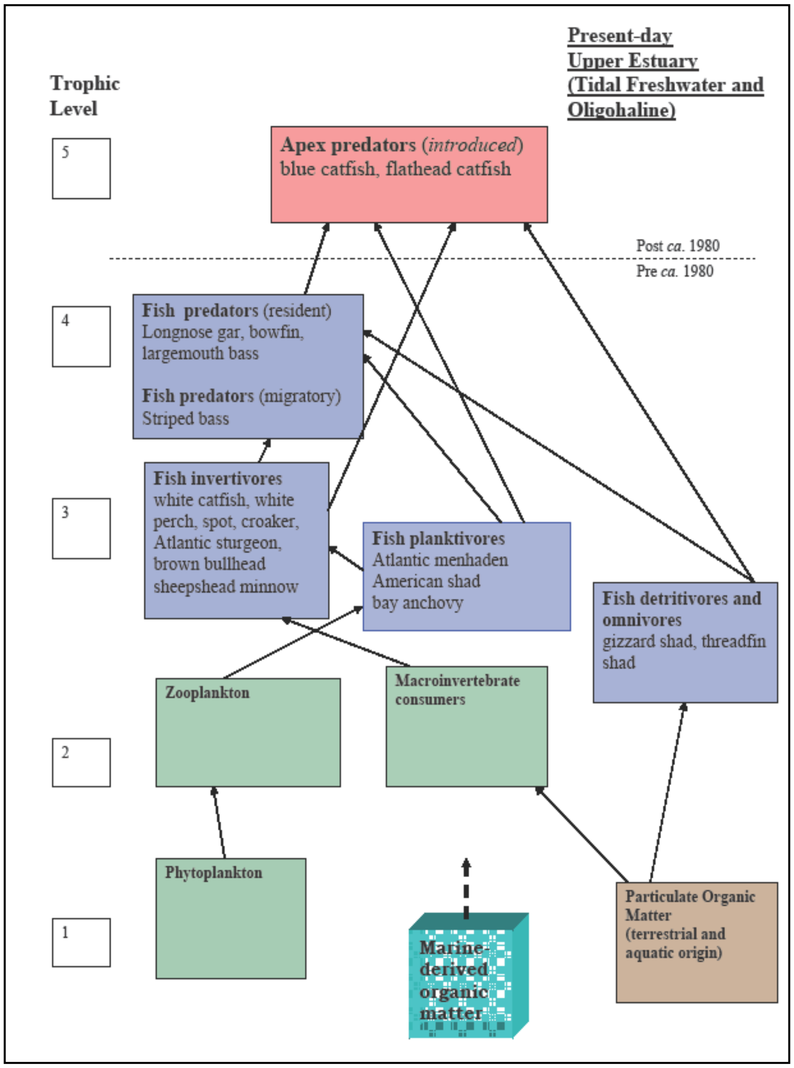

Figure 3. Conceptual model of James River trophic structure following establishment of blue catfish, circa 1980. Based in part on data from Garman and Macko (1998) and MacAvoy, et al. (2001 & 2009). Boxes are not scaled to production, biomass, or abundance.

Since the early 1990s, state and federal natural resources agencies have invested heavily (e.g. stocking programs, fish passage structures, commercial harvest moratoria) in attempts to restore declining stocks of American shad and other native anadromous fishes in Chesapeake Bay waters. Unfortunately, recovery efforts during the past two decades—a period that overlaps with expansion of invasive catfish populations in the region—have met with very limited success for reasons that are not fully understood (Aunins et al. 2013). Clearly, novel predation by introduced predators such as large blue catfish and flathead catfish—that are not gape-limited for adult alosines—has the potential to compromise restoration and recovery efforts for these and other species. Other economically and ecologically important taxa consumed by blue catfish and flathead catfish in coastal rivers included blue crab and juvenile Atlantic menhaden (Chandler

1998, VIMS unpubl. data). However, the ecological effects of catfish predation on native fishery resources, although inferred from stable isotope analyses and anecdotal accounts, are neither well-documented nor quantified.

Table 1

Fatty acid (FA) $\delta^{13}C$ values for Rappahannock River fish. Means ± 1 Standard Deviation. (n=3). Values are corrected for $CH4OH$ derevitization. FAs show that carbon from anadromous fish has been incorporated by *Ictalarus furcatus* but not by other resident fishes. Bulk isotope values show trends similar to the FAs and are as follows: alewife *A. pseudoharengus*, $\delta^{13}C$ −19.3‰, $\delta^{15}N$ 11.9‰, $\delta^{34}S$ 17.1‰; blue catfish *Ictalarus furcatus* (A) $\delta^{13}C$ −26.0‰, $\delta^{15}N$ 13.3‰, $\delta^{34}S$ 6.1‰; *I. furcatus* (B) $\delta^{13}C$ −19.3‰, $\delta^{15}N$ 16.6‰, $\delta^{34}S$ 10.8‰; gizzard shad *Dorosoma cepedianum* $\delta^{13}C$ −21.5‰, $\delta^{15}N$ 14.5‰, $\delta^{34}S$ 10.2‰.

Fatty acid	*Alosa pseudoharengus* alewife (‰)	*Ictalurus furcatus* blue catfish (‰)	*A Ictalurus furcatus* blue catfish (‰)	*B Dorosoma cepedianum* gizzard shad (‰)
12:0	−22.4 (0.4)	−28.5 (0.5)	−22.5 (0.9)	−27.4 (1.0)
14:0	−27.4 (1.8)	−33.6 (0.9)	−26.9 (0.6)	−25.5 (1.4)
16:1	−26.8 (0.8)	−35.4 (0.6)	−25.6 (0.7)	−27.4 (0.6)
16:0	−22.1 (0.1)	−30.3 (0.2)	−23.3 (0.3)	−25.7 (0.6)
18:1	−23.3 (0.6)	−30.5 (0.6)	−24.5 (0.7)	−28.7 (0.4)
18:0	−19.9 (1.8)	−28.8 (0.7)	−20.4 (1.1)	−23.5

Modified from MacAvoy, et al. (2009)

Approach and Methods:

The research team conducted targeted dietary analyses of adult blue catfish and flathead catfish in selected riverine and estuarine habitats in Virginia and Maryland waters (Figure 4) to evaluate the hypothesis that predation by introduced catfishes is a significant and novel source of mortality for some populations of native anadromous fishes (*Alosa* spp.) and other fishery resources. Specifically, activities under Objective 1 developed a more comprehensive picture of the relative importance of economically and ecologically significant fishery resources (e.g. blue crab, Atlantic menhaden, American shad, blueback herring) in blue catfish and flathead catfish diets than previously existed for the region. A second objective attempted to estimate daily consumption rates (C_{24}) for blue catfish and flathead catfish predators on selected fishery resources in two seasons (Spring 2011and Fall 2012) in several estuarine habitats known to support nonindigenous catfishes. Where feasible, we expanded these date- and site-specific consumption rate estimates temporally and spatially to estimate total prey losses to predation in sections of the James and Rappahannock river systems. Objective 3 designed and tested experimental invasive catfish control/containment methods aimed at reducing predation mortality for one or more populations of alosine fishes in the region. Finally, we used data developed under Objectives 1-3 to make specific management recommendations regarding the probable current and future ecological impacts of blue catfish and flathead catfish predation in Chesapeake Bay waters and how those impacts might be controlled or mitigated for critical fishery resources, including anadromous clupeid fishes.

Objective 1 Stomachs from stratified (by length class) random samples of blue catfish and flathead catfish > 400 mm TL collected by low and high frequency boat electrofishing and horizontal gill nets (6-10" monofilament) during two seasons (Fall 2011 and Spring 2012) were excised and placed immediately on wet ice or in a 10% solution of formalin to retard postmortem digestion of prey. Collection locations (Figure 4) represented three river systems (James, Potomac, Rappahannock) and a continuum of riverine habitats from tidal fall-zone to

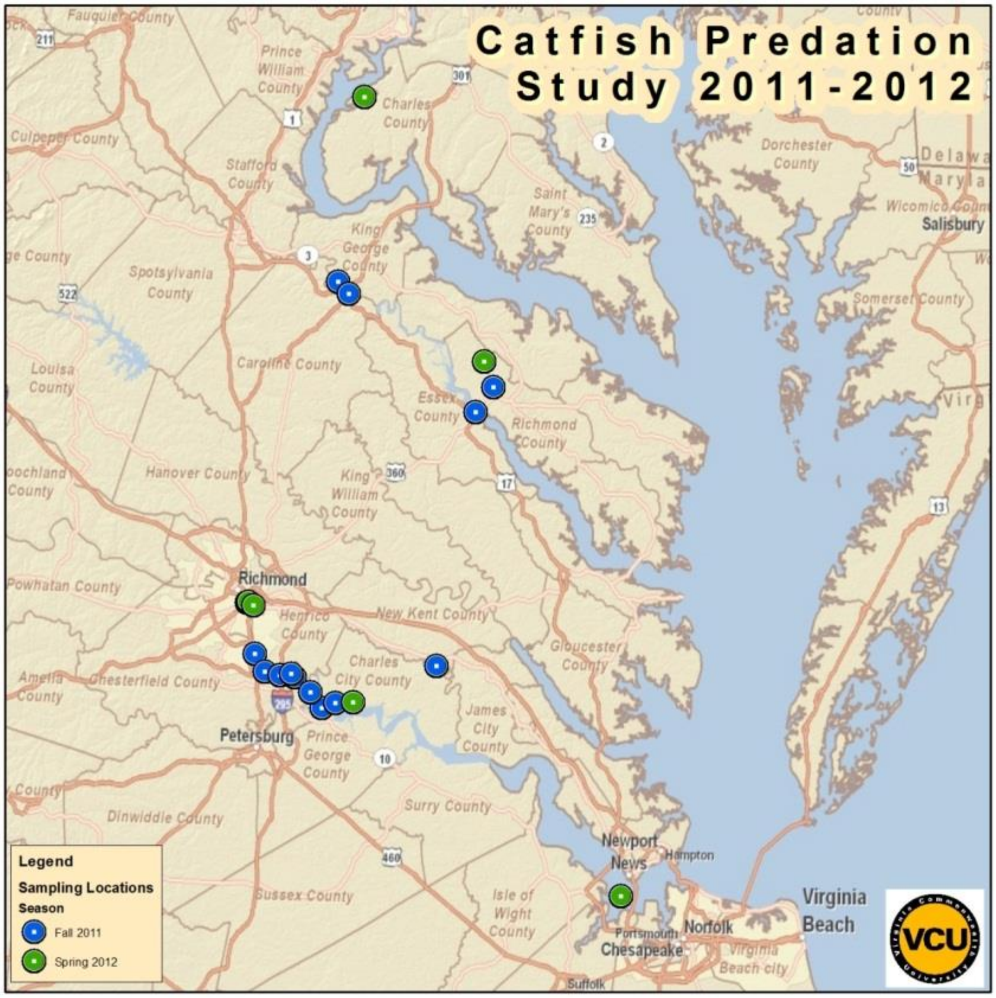

Figure 4. Catfish sampling locations for this study in the James, Rappahannock, and Potomac River basins, 2011-2012.

lower estuary. A limited number of night-time collections were also conducted. Where feasible, prey items representing a pre-determined list of economically or ecologically significant taxa (e.g. blue crab, Atlantic menhaden, American shad, blueback herring) were identified to species (or the lowest possible taxon) *in the field* by experienced fish biologists, enumerated, and dietary importance expressed as frequency of occurrence (FO). Non-targeted prey were not identified or enumerated as part of this project in order to focus limited resources on the stated objective. Where immediate field processing is not feasible, preserved stomachs were returned to the laboratory and processed using the same protocol. The purpose of this approach is to develop a temporally and spatially broad picture of predation by blue catfish and flathead catfish on *specific* fishery resources across seasons and major habitat types in the Chesapeake Bay region. A minimum of three days of intensive field effort, using the appropriate sampling gears, in up to three major habitat types (fallzone, tidal freshwater, polyhaline) and at least two seasons (total of 30+ sampling days) generated a sufficient number of large blue catfish and flathead catfish for rapid diet assessment.

Objective 2 As a complement to the targeted dietary analyses described above, and in order to evaluate the presumptive ecological effect of blue catfish and flathead catfish predation on selected fishery resources, we estimated total daily consumption (C_{24}) of prey by blue catfish and flathead catfish based on *diel* (24-h) field sampling of predators and a simple daily ration model modified from Garman and Nielsen (1982) and Boisclair and Leggett (1988). Whenever possible, predators were sampled at regular intervals over 24 hours so that expressions of diet represented all foraging periods (i.e., crepuscular, daytime, nighttime). Input variables for the model included: mean number of prey taxa per predator, estimates of catfish gastric evacuation times at ambient temperatures (MacAvoy 2000), and Schnabel estimates of larger (>300 mm TL) blue catfish density (218 fish/ha +/- 33 fish, 95% C.I.) in Powell Creek, a tributary of the tidal James River (R. Greenlee, VDGIF, unpubl. data). To the best of our knowledge, the Powell Creek values are the only quantitative estimate of blue catfish density for the region. Although more complicated approaches (e.g. bioenergetics) for estimating daily consumption of prey are available, the current approach is both robust and appropriate for our objectives (Boisclair and Leggett 1988). Based on archival databases (e.g. www.instar.vcu.edu) and extensive prior experience in the region, the research team identified locations in Virginia and Maryland where temporal and spatial co-occurrence among adult blue catfish, flathead catfish, and adult or juvenile *Alosa* spp. in both Virginia and Maryland waters has been documented in prior years. Sampling locations for diel sampling included: Catpoint Creek (Rappahannock), Kimages Creek, James River head-of-tide (James), Burwell Bay (James River), and Mattawoman Creek (Potomac River). Mean daily consumption of selected prey by blue catfish and flathead catfish was estimated for Spring and Fall seasons at selected sampling locations. Where data supported such an analysis, site- and date-specific estimates of mean daily consumption for specific taxa were expanded over the sampling period, the areal extent of the adjacent and comparable habitat (ESRI ArcGIS), and the estimated number of catfish predators. In this way we attempted to estimate total consumptive losses of selected fishery resources for larger areas and over longer periods (*sensu* Beamesderfer, et al. 1996).

Objective 3 Two locations from Objective 2 were used to test experimental control/exclusion measures for limiting catfish predation mortality on pre-reproductive adults and out-migrating juveniles of *Alosa* spp. We were unable to secure the necessary permits from VDGIF for our preferred location (Catpoint Creek, Rapphannock basin) and were limited to Kimages Creek in the lower James River basin for these studies. Catfish predators were removed by electrofishing or other appropriate gears during critical periods (e.g. spawning run) and immediately excluded from key habitats for these periods by strategic (downstream channel constrictions) placement of 'semi-permeable' barriers (panels of 6", 8", or 10" mesh, horizontal gill nets, both monofilament and braided twine) that allowed passage of adult river herring species and other smaller fishes but prevented upstream movement by larger (piscivorous) invasive catfishes. The gill net barriers were maintained regularly during deployment periods and replaced, as needed. At intervals, electrofishing was used to sample above, below, and between exclusion panels and potential predators were counted. In Kimages Creek, we conducted three, two-week deployments of barriers during the period April-June, 2012.

Objective 4 Explicit fishery management recommendations regarding the current and future risk represented by catfish predation on critical (e.g. Atlantic menhaden) and collapsed (e.g. American shad) stocks will be based on the findings from Objectives 1-3.

Data Management:

Drs. Garman and McIninch (co-PIs) supervised the project data manager, Mr. William Shuart, who is the full-time information manager for the VCU Rice Center, which maintains data using industry standard Microsoft SQL for the biological databases and enterprise geodatabases for storage of spatial data. Field data were collected according to established milestones and staff were responsible for QC/QA of data collected and recorded in tabular form in Access or Excel files; Spatial locations of all study sites were entered into spatial datasets.

Sample of flathead catfish and blue catfish from the upper tidal James River near Ancarrow Landing, September 24, 2012.

Accomplishments:

Objective 1:

A total of 1,002 blue catfish and 125 flathead catfish were sampled for dietary analysis during the study (Table 2). Blue catfish ranged between 390 and 1120 mm (TL) and flathead catfish ranged between 380 and 1080 mm (TL). Catfish below these minimum thresholds were not likely to be piscivorous (Chandler 1998) and were excluded from analysis. Fish above our threshold were uncommon or even rare in some electrofishing collections, requiring extensive effort for a limited number of catfish predators. In contrast, blue catfish < 200 mm TL were extremely abundant at most freshwater locations. Sampling at Potomac River locations (e.g. Mattwoman Creek) produced only 10 blue catfish within the target size range and these were not included in further analyses. Flathead catfish were only collected in James River freshwater habitats with structure (e.g. large woody debris) and were not abundant at any location. We compared results of our boat electrofishing in 2012 to comparable results (same location, season, gear, and methods) in 2007 and blue catfish > 400 mm TL appeared to be much less common in 2012, compared to 2007 (Figure 5). These observations are consistent with anecdotal declines in the relative abundance of large blue catfish in the tidal freshwater reaches of the James and Rappahannock rivers in recent years. In contrast, blue catfish above this size threshold were relatively common in gill nets during Spring, 2012 in lower reaches of the James River (e.g. Burwell Bay). We do not know if these findings represent episodic (seasonal) movements within the James River estuary or a permanent expansion of larger blue catfish into higher-salinity habitats within the basin.

We conducted a total of 32 successful collections during the period September, 2011 to June, 2012 at 19 locations, representing three rivers and a range of riverine and estuarine habitats (Figure 4, Table 3). Electrofishing collections were based on a minimum effort of 1,000 seconds but frequently exceeded 3,000 seconds of effort and included both low and/or high frequency settings (Smith-Root GPP), as water conditions allowed. Boat electrofishing was limited to tidal freshwaters (salinities < 1 ppt). Ten gill net collections for predator-sized blue catfish (n=596) were conducted with the cooperation of commercial fishers during March-May, 2012 in Burwell Bay (James River at Newport News). Surface salinities during Burwell Bay collections ranged between 5 and 7 ppt.

Table 2. Characteristics and sample sizes of catfish included in dietary analysis; values represent fish from all locations and sampling periods.

	Minimum TL	Maximum TL	Mean TL	Number
Blue catfish (tidal fresh)	390	1120	582	406
Blue catfish (oligohaline)	402	740	532	596
Flathead catfish	380	1080	670	125

Table 3. Sampling dates, rivers, and locations for successful catfish predator collections conducted by VCU under project objective 1.

Date	River	Location
16-Sep-11	James	Drewry's Bluff
16-Sep-11	James	Dutch Gap
29-Sep-11	James	Presquile Reef
29-Sep-11	James	Jones Reef
29-Sep-11	James	Henricus
4-Oct-11	James	Kimages Cove
4-Oct-11	James	Harrison Bridge-Hopewell
5-Oct-11	Rappahannock	Catpoint Creek
5-Oct-11	Rappahannock	Rt. 360 Bridge
14-Oct-11	Rappahannock	Rt. 301 Bridge
14-Oct-11	Rappahannock	Buoy 79
17-Oct-11	James	Chickahominy River below Walker's Dam
18-Oct-11	James	Harrison Bridge-Hopewell
26-Mar-12	Rappahannock	Catpoint Creek @ County Bridge
Mar-May, 2012[a]	James	Burwell Bay @ Newport News
2-Apr-12	Rappahannock	Catpoint Creek @ County Bridge
4-Apr-12	Potomac	Mattawoman Creek
16-Apr-12	James	Herring Creek
20-Apr-12	James	Herring Creek
24-Apr-12	Potomac	Mattawoman Creek
30-Apr-12	James	Manchester
7-May-12	James	Ancarrows
10-Jun-12	James	Ancarrows

[a]10 separate collections (commercial gillnet) during this period

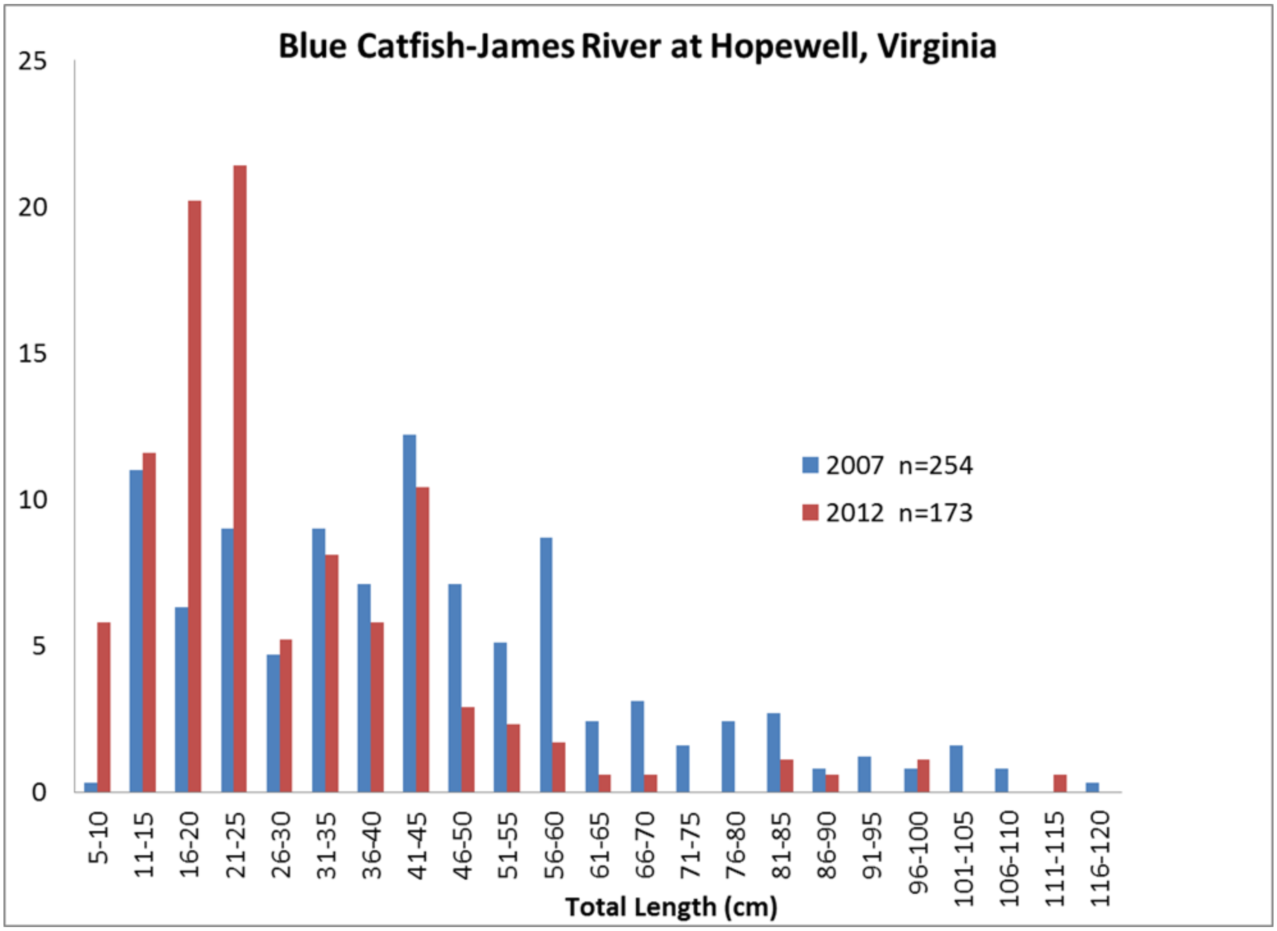

Figure 5. Length-frequency distribution of blue catfish sampled by boat electrofishing in the James River at Hopewell, Virginia in 2007 and again in 2012. Data from 2007 were provided courtesy of R. Greenlee (VDGIF).

Blue catfish predators (>400 mm TL) in tidal freshwater habitats of the James and Rappahannock rivers preyed on several migratory or otherwise important species, including adult (Spring) and young of the year (YOY; Fall) blueback herring, YOY American shad (Fall), adult white perch, and blue crabs. Frequency of occurrence (FO) of alosine and white perch prey in blue catfish diets was higher in the Rappahannock than in the James (Table 4), possibly based on greater availability of these taxa in the former basin, where > 20 percent of blue catfish examined contained *Alosa* prey. In a comparable study by Chandler (1998), predation (as FO) by large blue catfish in the upper tidal James and Rappahannock rivers ranged between 5-17 percent for *Alosa* spp. and up to 28 percent for white perch. In contrast to the present study, which found blue crabs in 36 percent of blue catfish guts, Chandler (1998) observed no predation on blue crabs. Blue catfish exhibited cannibalism (6-12 percent) and consumed other fish prey, including gizzard shad, native brown bullhead, and introduced grass carp (Table 4). A high proportion of blue catfish stomachs examined were empty (up to 45 percent) or contained non-fish items (up to 34 percent). This observation may suggest limited food availability in some habitats. Because predator collections represented most diel periods and the types of prey recovered digest slowly, the high percentage of empty guts is unlikely to be a sampling artifact.

Blue catfish predators (> 400 mm TL) in the lower (oligohaline) James River at Burwell Bay consumed six economically important taxa, including Atlantic menhaden (juveniles), white perch, American eel, spot, blue crab, and softshell clam (Table 5), based on the examination of 596 fish collected in the Spring of 2012. Only Atlantic menhaden, blue crab, and softshell clam represented a substantial portion of the diet, however. On some dates, predation on these taxa was high—up to 71 percent (FO, March 22) for Atlantic menhaden, up to 40 percent (FO, May 1), and up to 21 percent (FO, May 4) for softshell clam. No cannibalism was observed in these samples, suggesting that juvenile blue catfish were not common in associated habitats. As with the upper tidal collections, the percentage of empty guts was significant (mean 34 percent, range 13-50 percent) in the Burwell Bay samples. Because predator collections represented most diel periods and the types of prey recovered digest slowly, the high percentage of empty guts is unlikely to be a sampling artifact.

Table 4. Summary of rapid stomach content analysis for blue catfish > 400 mm TL (n=396) in the tidal freshwater James and Rappahannock river basins. For this table, data were pooled across most of the locations and dates described in Table 3, with the exception of Potomac River sites and Burwell Bay on the James. Values are frequency of occurrence (FO); calculations of FO included empty guts.

Prey Taxon	James[a]	Rappahannock	Combined (pooled)
Blue crab	36	0	22
Blueback herring	12	19	15
American shad	0	13	5
White perch	24	63	39
Blue catfish	12	6	10
Dorosoma spp.	16	0	10
Grass carp	4	0	2
Tessellated darter	0	6	2
Brown bullhead	0	13	5
Non-target items	34	24	30
Empty	33	45	39

Table 5. Summary of rapid stomach content analysis for blue catfish > 400 mm TL (n=596) in the lower tidal James River at Burwell Bay (Newport News, Virginia) during the period March-May, 2012. All fish were collected by gill net; surface salinities for this period ranged between 5 – 7 ppt. Values are frequency of occurrence (FO); calculations of FO included empty guts.

Prey Taxon	March	April	May
Atlantic menhaden	57	33	24
Blue crab	9	22	23
Softshell clam	2	13	21
American eel	2	0	1
White perch	2	0	0
Spot/croaker	1	1	0
Butterfish	0	0	1

Table 6. Summary of rapid stomach content analysis for flathead catfish > 400 mm TL (n=125) in the tidal freshwater James River. For this table, data were pooled across locations and dates described in Table 3. Values are frequency of occurrence (FO); calculations of FO included empty guts.

Prey Taxon	James River
Blueback herring	11
White perch	49
Dorosoma spp.	5
Flathead catfish	10
Centrarchid sp.	20
Hogchoker	5
tessellated darter	5
Empty	47
Non-fish prey	2

Approximately 11 percent of flathead catfish examined consumed alosine prey, including YOY and adult blueback herring (Table 6), while almost half contained white perch (mostly age 1-2). Other fish prey included centrarchids (20 percent FO) and gizzard or threadfin shad (5 percent FO). Flathead catfish were also cannibalistic (10 percent FO) and were almost exclusively piscivorous within this size range. Similar to blue catfish, a high percentage of flathead catfish guts were empty. Because predator collections represented most diel periods and the types of prey recovered digest slowly, the high percentage of empty guts is unlikely to be a sampling artifact. Large flathead catfish collected from 13 locations in the tidal freshwater James during 1996-1997 (Chandler 1998) had very similar diets, consuming adult alosines (Spring), gizzard shad, ictalurids, and white perch (up to 47 percent FO). Flathead catfish examined by Chandler (1998) were also exclusively piscivorous over a threshold of 200 mm TL.

Top photo: Two blue crabs and a juvenile white perch recovered from a blue catfish (578 mm TL), James River near Hopewell.

Middle photo: adult blueback herring recovered from a flathead catfish (610 mm TL), James River near Ancarrow.

Bottom photo: white perch recovered from a flathead catfish (790 mm TL), James River near Hopewell.

The current findings corroborate the conclusions of other relevant and published studies (referenced above), including dietary and stable isotope analyses, of introduced catfishes in the region. It is important to point out that although these data document predation—sometimes substantial—on Chesapeake Bay migratory fishes, including blueback herring, and other fishery resources by introduced catfishes, there is no evidence that catfish predators are selectively targeting any specific prey type(s). Rather, these predators are feeding opportunistically on the most available prey resources. During some seasons and in some locations, the most abundant prey will be anadromous clupieds, Atlantic menhaden, or other commercially important taxa. Both predator species are, however, primarily (blue catfish) or exclusively (flathead catfish) piscivorous above 300 mm TL and may not be gape-limited for even relatively large fish prey.

Objective 2:

Stomach content data for blue catfish and flathead catfish from only two locations (James River near Manchester and James River, Burwell Bay) supported estimation of predator daily consumption rates (C_{24}) for selected fishery resources. Specifically, data from these locations were unique in that they were represented by multiple, diel collections each with minimum sample sizes of n=25 to allow estimation of mean daily consumption for a 24-h period (Garman and Neilsen 1982). Daily consumption estimation was attempted at two other locations (Mattawoman Creek, Potomac River; Catpoint Creek, Rapphannock River) but predator samples sizes were not sufficient for any 24-h sampling period to warrant further analysis. Other information (described in more detail above), including estimates of predatory density, temperature- and prey-specific gastric evacuation times for blue catfish, and surface area of contiguous habitat at each sampling location was used to expand daily consumption estimates to estimate consumptive losses over broader temporal and spatial scales (Table 7).

Table 7. Summary of expanded estimates of predation losses for five selected taxa at two James River locations, based on estimates of daily consumption by catfish predators during Spring, 2012. Estimates of total losses within the expanded area (measured by GIS) and time period for which expansion was deemed appropriate are provided as <u>thousands</u> (i.e., x 1,000), *except* for softshell clam (*Mya*), where values represent <u>millions</u>. Values are the 95% confidence interval (range) of the mean; this error term is derived from the predator density estimate. A more detailed description of expansion methods and assumptions is provided above.

Location	Predator	Expanded area (ha)	Expanded time (d)	White perch	Blueback herring	Atlantic menhaden	Blue crab	*Mya*
James River at Manchester (tidal fresh)	Flathead catfish (>400 mm TL)	26	30	14-18	8-10			
James River at Burwell Bay (meso-haline)	Blue catfish (>400 mm TL)	5,160	60			670-820	560-720	1.9-3.1

This analysis suggests that predation by large introduced catfishes may result in substantial losses to key fishery resources, when the results of the current study—which, like most diet studies was limited to relatively small sampling areas and specific dates—are expanded to reflect all days within a range of sampling dates and a broader area of similar habitat. For example, we took diet data from predator collections (including one diel (24 h) set of samples) during April, 2012 in the James River near Richmond and expanded daily consumption estimates to reflect total predation losses during that month and over similar adjacent habitat (Table 7). This approach makes significant assumptions, including: 1.) predator foraging behavior and prey availability were relatively consistent throughout April, 2012 and within roughly 26 ha of sampled habitat and 2.) predator activity is represented accurately by a necessarily limited analysis of predator stomach contents during that period. The accuracy of the estimates of total consumption of selected fishery resources presented in Table 7 will be influenced by the validity of these and other assumptions. It would be inappropriate to further expand these estimates of consumptive losses to reflect other periods or locations. These values should, therefore, be viewed as broad estimates that represent the *potential* for losses to catfish predation in certain seasons and in some locations.

However, the finding of objectives 1 and 2 support several potentially important conclusions. First, introduced catfish predators may contribute to substantial losses of key fishery resources, even though large (> 400 mm TL) flathead and blue catfish represent a relatively small proportion of most established populations within the Chesapeake basin. Second, these losses may be ecologically significant for migratory species like blueback herring that continue to decline across the region. Some reasons for declines in anadromous fishes are obvious (e.g. habitat loss) but other factors, including past and future predation by introduced catfish, should also be considered and incorporated into recovery plans. Third, the potential impacts of blue catfish predation on estuarine fishery resources, including Atlantic menhaden and blue crabs, may be more important than previously assumed. Although a freshwater species in its native range, blue catfish introduced here have demonstrated a marked ability to colonize or temporarily occupy estuarine habitats and have been observed here in salinities up to 17 ppt. Finally, GIS-based risk assessment models developed by VCU (W. Shuart, unpubl. data) suggest that the current range of both blue catfish and flathead catfish in Chesapeake Bay and its tributaries is likely to expand significantly in the near future.

Objective 3:

Two Virginia locations—tidal creeks with known runs of alosine fishes and catfish populations—were selected to test experimental control/exclusion measures for limiting catfish predation mortality on pre-reproductive adults of *Alosa* spp. In spite of several attempts, VCU was unable to secure the necessary permits from VDGIF for our preferred location (Catpoint Creek, Rapphannock basin) and we were, therefore, limited to Kimages Creek in the lower James River basin for studies related to Objective 3. At Kimages Creek, we excluded large predators, including catfishes, from potential alosine spawning habitats by strategic placement (at downstream channel constrictions) of ‘semi-permeable’ barriers (panels of 6”, 8”, or 10” mesh, horizontal gill nets, both monofilament and braided twine; Figure 6) that allowed passage of adult river herring species and other smaller fishes but prevented upstream movement by larger (potentially piscivorous) fish. Panels of gill net were chosen because they were relatively inexpensive, easy to deploy, and were available in a wide range of mesh sizes, materials, and configurations. Immediately prior (within 12h) to each deployment of experimental barriers, blue catfish predators (>300 mm TL) were removed from Kimages Creek by electrofishing (Smith-Root tote boat). During three, two-week experiments during the period April-June, 2012, barriers were maintained regularly and replaced, as needed, during each experiment. Between each experiment, all barriers were removed from Kimages Creek. At regular intervals during each barrier deployment, electrofishing was used to sample above, below, and between exclusion panels; potential blue catfish predators were counted to determine the exclusion efficiency of each panel (barrier) configuration. Although generally supporting the conclusion of effective exclusion by 6” and 8” panels, the estimates of predator exclusion efficiency ranged widely across experiments and among panel-types. Because the gillnets ‘fished’ during deployment, the activity of fish entrained in nets (as well as occasional, tide-borne trash) altered the placement of float- and lead-lines and this provided unintended opportunities for ingress by large catfish. In summary, any future exclusion attempts to conduct predator exclusion studies should employ more rigid materials that do not ‘fish’ and are exclusively barriers to fish movement.

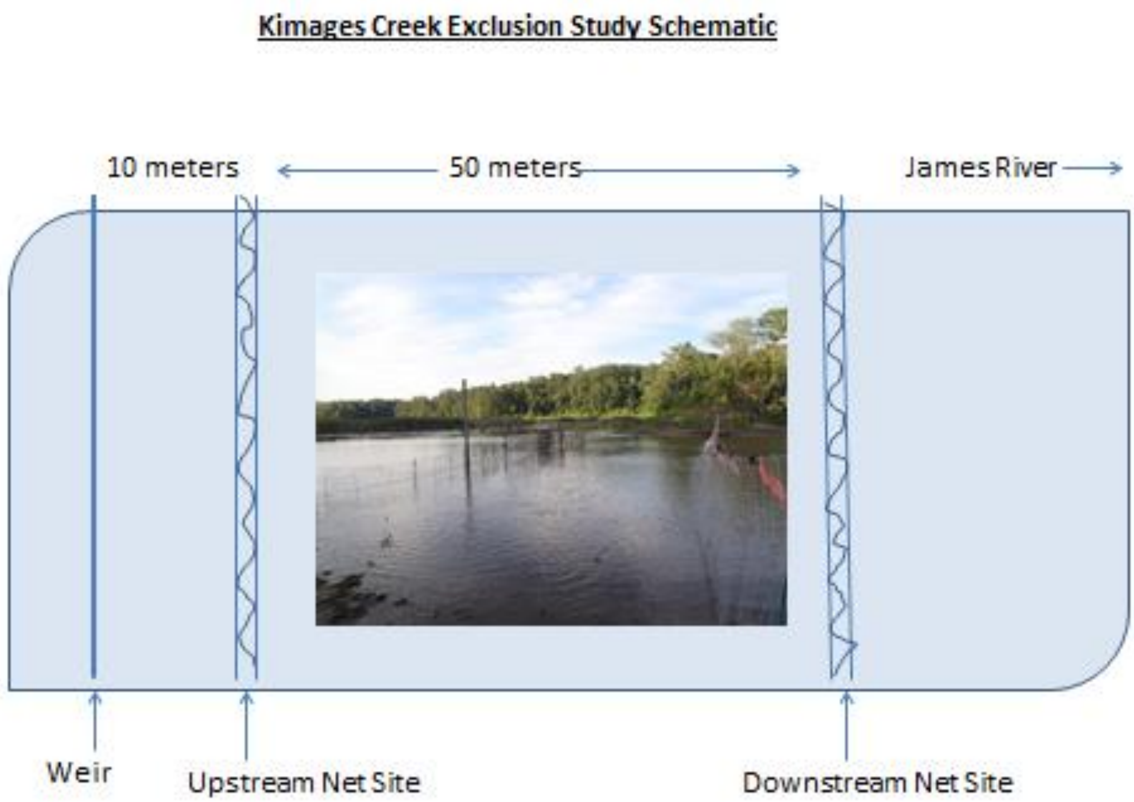

Figure 6. Schematic showing the placement of net panels (barriers) in Kimages Creek, Virginia during the period April-June, 2012.

Management Recommendations:

The timing, sources, and possible implications of introduced catfishes (Ictaluridae) in Chesapeake Bay waters have been described recently by Schlosser et al. (2012) and the topic has generated considerable discussion among regional fishers and fishery managers. Typically, debates concerning the appropriate management of potentially invasive species focus on documenting economic and ecological impacts of the introduced taxa and (if warranted) identifying feasible eradication or control measures (Sakai et al. 2001). In the case of introduced blue catfish and flathead catfish in Chesapeake Bay, negative economic consequences may be mitigated—at least in part—by revenues generated from recreational and commercial fisheries for these species (Shogren & Tschirhart 2005). Ecological impacts from predation by, or competition with, invasive catfishes in Atlantic coastal and estuarine habitats, including Chesapeake Bay, may include declines in native resident (Bonvechio et al. 2011) and anadromous (McAvoy et al. 2009) fishes. This study by VCU documented predation by large (>400 mm TL) catfish on estuarine-dependent fauna (e.g. Atlantic menhaden, blue crab, softshell clams) that support important fisheries or are the focus of conservation efforts (e.g. blueback herring, American shad). A geospatial model developed by VCU with ASMFC support (Figure 7) suggests that blue catfish distribution has the potential to nearly double, from 136 watersheds (12-digit HUCs) to 242 watersheds, in the Chesapeake basin and that flathead catfish are also expanding their distribution in the region (Figure 8).

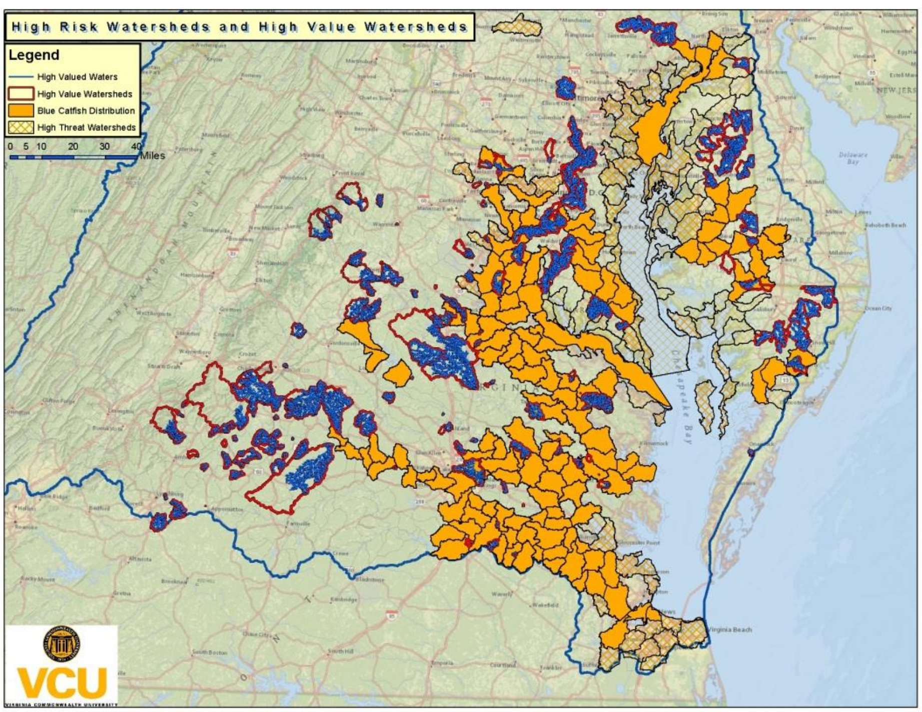

Figure 7. Current (solid polygons) and forecasted (cross-hatched polygons) distribution of blue catfish in Chesapeake Bay waters below Conowingo Dam. Geospatial units are 12-digit watersheds (HUCs). Data are compiled from several sources, including VCU, VIMS, VDGIF, and MdDNR; data were current as of 1 April, 2013.

Not all introduced fishes are problematic (Gozlan 2008) and testing the hypothesis of major impacts by blue catfish and flathead catfish in Chesapeake Bay will require additional objective research and evidence. However, nonindigenous ictalurids are associated strongly with ecological impacts elsewhere (several sources reviewed by Kwak et al. 2011, Kwak 2012, and Gozlan 2008) and negative effects on native fishes and fisheries in our region are likely. If that premise is true, management agencies should be encouraged to develop and implement 'aggressive' tactics designed to mitigate impacts and —where possible— to protect potentially vulnerable estuarine resources, habitats, and fisheries. Given the lack of *conclusive* evidence for impacts from catfishes in the Chesapeake at the present time, application of the precautionary principle (Lauck et al. 1998) would be consistent with ecosystem based management (Cucherousset and Olden 2011) of Chesapeake Bay fisheries.

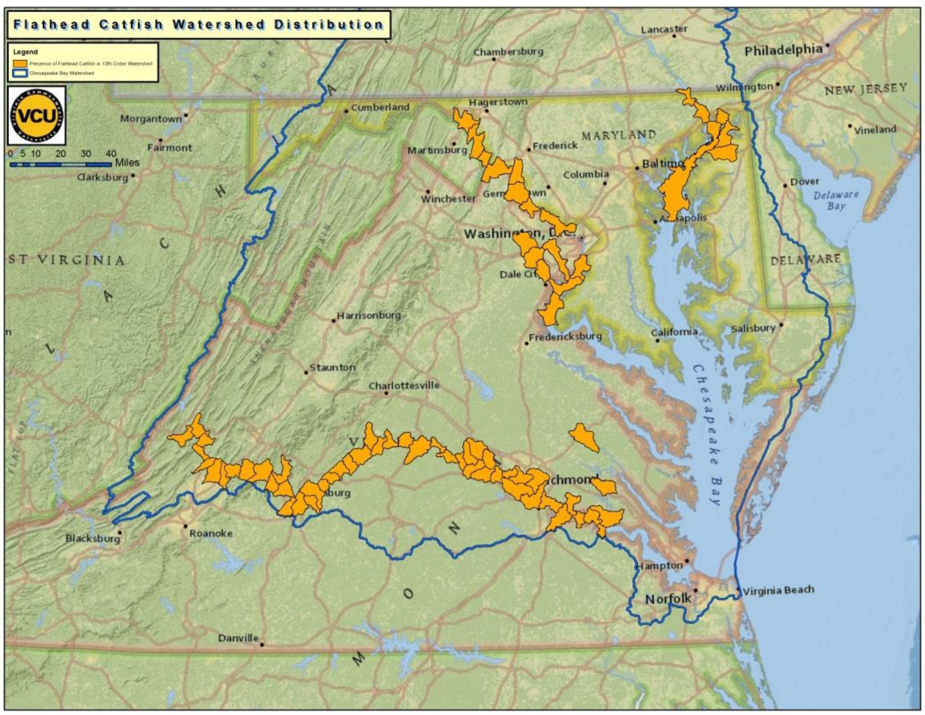

Figure 8. Current distribution of flathead catfish in Chesapeake Bay waters below Conowingo Dam. Geospatial units are 12-digit watersheds (HUCs). Data are compiled from several sources, including VCU, VIMS, VDGIF, and MdDNR; data were current as of 1 April, 2013.

The selection of appropriate management actions (e.g. prevention, eradication, control) in response to invasive fish species depends on an understanding of the steps in the invasion process and of the ecology of the host community (Kolar & Lodge 2001). For example, eradication is rarely feasible or cost-effective once a species has become widely dispersed in an open aquatic system like Chesapeake Bay (Sakai et al. 2001). In such situations, prevention (of further expansion) and control (of established invasive populations) are more likely to be effective strategies (Britton et al. 2010) and these will be the focus of the actions and recommendations outlined below. Each of the recommendations will require extensive discussion prior to implementation, broad cooperation among agencies, and a willingness to adapt strategies to new information as it becomes available. Some of the recommendations will also be controversial and—in some quarters—quite unpopular. Finally, many of the recommendations below could synoptically address concerns involving other invasive species (e.g. northern snakehead) in the region.

Specific Recommendations:

1.) Establish and Maintain Freshwater Protected Areas (FPAs) in High-Risk, High-Value Locations

Marine protected areas (MPAs; Pomeroy et al. 2005) are widely-applied tools in fisheries management and conservation that may be adapted to freshwater systems (Saunders et al. 2002). When applied to mitigate the effects of invasive species, the most effective freshwater protected areas (FPAs) should target high-risk locations with high ecological value. A recent GIS-based analysis by VCU (Figure 9) identified 64 high-value Chesapeake watersheds in Virginia and Maryland (i.e., below Conowingo Dam) that were at risk for establishment of blue catfish populations (n=9) or that already have established blue catfish populations (n=55). These watersheds are candidates for FPA status and should be evaluated in more detail; FPAs focused on other invasive taxa (e.g. northern snakehead) should also be considered. Even a handful of FPAs scattered among several basins would establish important regional refugia for native species, including fishes and mussels, and support 'heritage' recreational fishing experiences based on native resident and migratory assemblages.

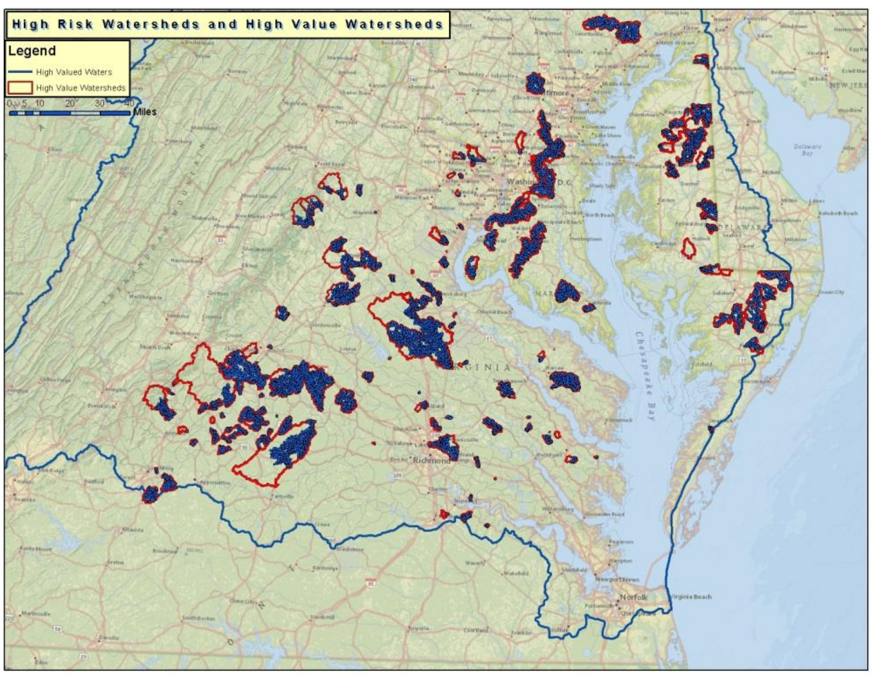

Figure 9. Ecologically significant watersheds (red polygons) and streams (blue lines) in the Chesapeake Bay that occur within high-risk watersheds for invasive catfishes. Geospatial units are 12-digit watersheds (HUCs). Data were compiled by VCU from various sources.

Some highly-ranked candidate FPAs may support recently-established populations of invasives and require renovation and long-term control. In these cases, the goal is not to eradicate the invasive, but rather to limit its abundance and, presumably, its ecological impact. The use of electrofishing or piscicides as a control measure for invasive fishes may have the potential to reduce ecological impacts in some aquatic habitats, especially smaller systems with limited connectance to source populations (Britton et al. 2010). For example, electrofishing removal (monthly for 33 months) reduced the abundance of adult invasive tilapia by 87% in an impoundment (Thuesen et al. 2011), with a concomitant reduction in ecological impacts. Low-frequency electrofishing as a catfish removal method has the advantage of limited effects on non-ictalurids. Control projects of this type require a long term commitment of resources, including effective surveillance, to maintain. Following renovation, carefully-designed, constructed or non-physical barriers (Noatch & Suski 2012) might be deployed temporarily in smaller creeks to exclude adult invasive species. For example, excluding predatory catfish from tidal spawning habitats for *Alosa* spp. during Spring months might increase spawning success in those systems.

Over a decade ago, VDGIF regional biologists used boat electrofishing in an attempt to eradicate invading blue catfish from the Piankatank River, Virginia. That effort, which had limited departmental support, failed but we still think that the upper Piankatank system (Dragon Run) would be an ideal FPA candidate in Virginia, even more so now that northern snakehead have also been confirmed in the same system (R. Greenlee, VDGIF, pers. comm.).

2.) Support Experimental Use of Electrofishing for Commercial Harvest

The idea of electrofishing as a commercial fishing gear has been around for a long time (Fitz 1970) but for many reasons, including cost, safety, and effects on non-target species, it has not been widely applied. However, in tidal freshwater or even oligohaline reaches of larger Chesapeake Bay tributaries, the use of low-frequency (≤ 15 pps), pulsed D.C. electrofishing by commercial catfishers could harvest large numbers of non-trophy blue catfish. Whether or not commercial harvest based on low frequency electrofishing (LFEF) could be an effective (i.e., ecologically relevant) control measure for blue or flathead catfish is, of course, unknown but the LFEF gear does have the advantage of limited by-catch (cp. gillnets) or habitat impacts (cp. bottom trawls). On the other hand, LFEF would be restricted to specific seasons (water temperatures between 18° and 25° C), locations (≤ 2 ppt salinity), and would be subject to variable market demand and contaminant issues (like any other fishery). Experimental electrofishing for commercial applications would require a significant financial investment ($20K per vessel) and strict oversight by agencies but might be fundable through fishery resource grant (FRG) or similar programs. We are aware of at least one commercial catfisher who works the James River and has expressed interest in experimental LFEF. North Carolina currently allows recreational (but not commercial) catfish harvest with electrofishing, with specific restrictions (T. Kwak, NCSU, pers. comm.).

3.) Strategically Retain Existing Barriers to Limit Further Expansion of Invasive Catfishes

Over 3,800 constructed impediments (mostly lowhead dams) on Chesapeake Bay tributaries are documented (E. Martin, TNC, unpubl. data) and many have been prioritized by wildlife resource agencies for removal/passage to support regional anadromous fish restoration goals. Approximately 10 percent of these structures are identified as high priority (Tier 1 & 2) for removal in the near future. In most circumstances, removal of a dam will increase significantly the ecological health of a river by restoring its hydrologic connectivity to the watershed (Holmquist et al. 1998). However, some have argued (Freeman 2002) that the benefits gained from successful fish passage projects may be offset by opening corridors to invasive species ('Trojan Fish') that had previously been blocked from upstream reaches. For example, the Bosher's Dam fishway on the James River mainstem passed at least 8,000 blue catfish between 2002 and 2005 (Fisher 2007) and the species is now well-established upstream as far as Columbia, Virginia. Ironically, the primary expected benefit of the fishway—successful spawning by American shad in the nontidal James River—has not been demonstrated. However, other fish passage projects in the region (e.g. Embry Dam on the Rappahannock) have not resulted in obvious upstream expansion by invasive catfishes.

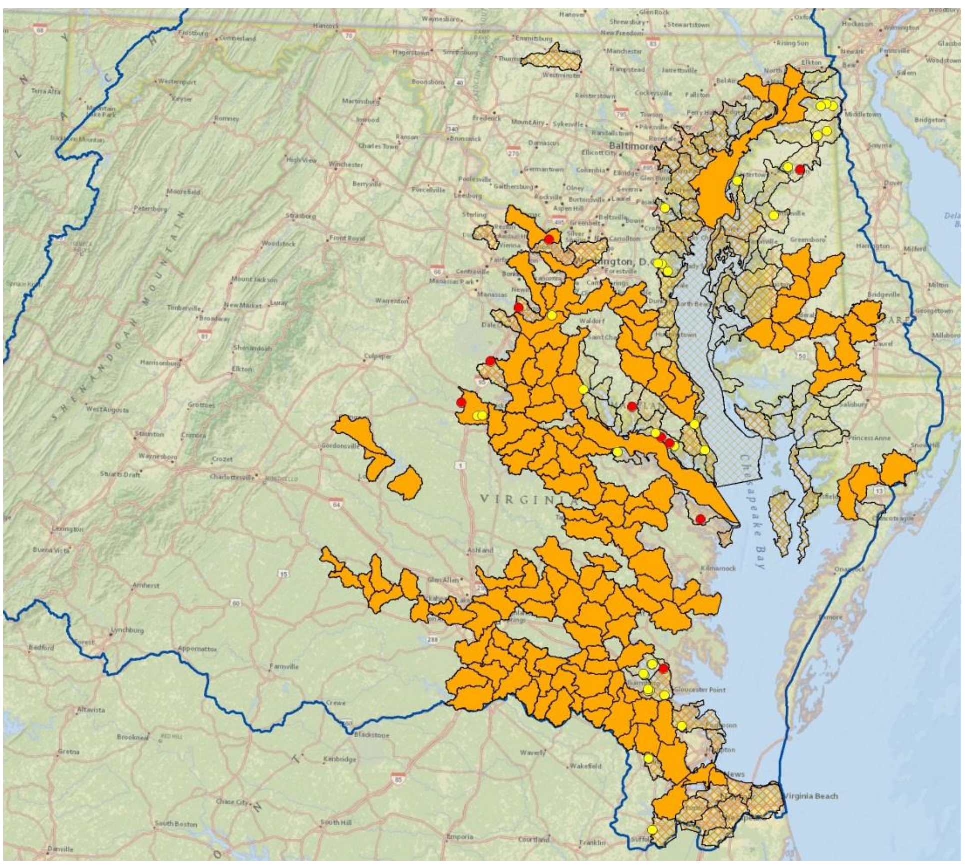

Figure 10. Tier 1 (red) and tier 2 (yellow) dams prioritized for fish passage in watersheds that currently support blue catfish (solid polygons) or at risk to support blue catfish (cross-hatched polygons); analysis limited to Chesapeake Bay waters below Conowingo Dam. Geospatial units are 12-digit watersheds (HUCs). Data are compiled from several sources, including VCU, TNC, VIMS, VDGIF, and MdDNR; data were current as of 1 April, 2013.

We recommend that an assessment of the unintended consequences, including creation of expansion corridors for invasive species, of removing or modifying Tier 1 & 2 dams should be formalized as part of the fish passage prioritization process by the relevant working groups (e.g. Habitat GIT). This is especially true for those Tier 1 or 2 dams within high-risk catfish watersheds identified by VCU's spatial model (Figure 10).

4.) Continue to Support Applied Fisheries Research on Invasive Fishes in the Region

We believe that important gaps in our understanding of the role of novel ictalurid predators in the Chesapeake Bay region remain, in spite of recently-completed and ongoing studies supported by NCBO, ASMFC, and others. Opportunities to leverage existing resources (e.g. acoustic telemetry arrays) or new technologies (e.g. molecular genetics) should be identified and pursued as part of an overall strategy for aggressively managing blue catfish and flathead catfish in the region. For example, effective and coordinated surveillance efforts for invasives are essential but such programs are very expensive to maintain, especially across large areas. The recent development of environmental DNA (eDNA) analyses as a relatively cheap and accurate way to detect Asian carp and other biological invaders (Darling and Mahon 2011) should be applied to Chesapeake Bay surveillance programs for catfish and other species. The potential effect of climate change, including sea-level rise, on Chesapeake Bay invasive species should also be considered (see Hellmann et al. 2008).

5.) Aggressively Enforce Current Regulations That Prohibit Possession and Transport of Invasive or Potentially Invasive Fishes and Expand Outreach and Education Efforts Focused on Invasive Fishes, Including Blue Catfish and Flathead Catfish

Chesapeake Bay jurisdictions have regulations intended to limit human-assisted dispersal of nonindigenous species by anglers, the aquarium trade, or other pathways. However, enforcement of current regulations may not be aggressive enough, or the rules comprehensive enough, to effectively limit the unintentional and intentional spread of invasive fishes in the region. As an example, the Maine Department of Inland Fisheries and Wildlife maintains and enforces very clear and stringent rules concerning legal baitfish species and prohibitions against the possession of live, non-natives species by anglers under any circumstances. The GIT is also encouraged to support a coordinated and regional outreach and education effort for invasive fishes, including blue catfish and flathead catfish, specifically targeting recreational anglers.

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