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Abstract.—Rapid increase in abundance and expanded distribution of introduced blue catfish *Ictalurus furcatus* populations in the Chesapeake Bay watershed have raised regional management concerns. This study uses information from multiple surveys to examine expansion of blue catfish populations and document their role in tidal river communities. Originally stocked in the James, York, and Rappahannock River systems for development of commercial and recreational fisheries, blue catfish have now been documented in adjacent rivers and have expanded their within-river distribution to oligo- and mesohaline environments. Range expansions coincided with periods of peak abundance in 1996 and 2003 and with the concurrent decline in abundance of native white catfish *I. catus*. Blue catfish in these systems use a diverse prey base; various amphipod species typically dominate the diet of smaller individuals (<300 mm fork length [FL]), and fishes are common prey for larger blue catfish (>300 mm FL). Recent studies based on stable isotope analyses suggest that adult blue catfish in these systems are apex predators that feed extensively on important fishery resources, including anadromous shads and herrings Alosa spp. and juvenile Atlantic menhaden *Brevoortia tyrannus*. Minimizing effects on Chesapeake Bay communities by controlling high densities of blue catfish populations is a primary goal of management, but conflicting demands of the commercial and recreational sectors must be resolved. Further, low market demand and human consumption concerns associated with purported accumulation of contaminants in blue catfish pose additional complications for regulating these fisheries.

Introduction

The blue catfish *Ictalurus furcatus* is native to the Mississippi, Missouri, and Ohio River basins of the central and southern United States (Glodek 1980), where it supports both recreational and commercial fisheries (Michaletz and Dillard 1999). Success of blue catfish fisheries within its native range prompted development of fisheries elsewhere. Stocking programs and unauthorized introductions have established blue catfish populations in reservoirs and

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rivers of several states, including tributaries of the Chesapeake Bay in Maryland and Virginia. Such introductions may affect natural communities through direct and indirect biotic interactions, including competition, predation, and habitat alteration (Sakai et al. 2001). In the Chesapeake Bay region, the ecological role of blue catfish is not well understood. However, the ability of this species to exceed 165 cm in length, 45 kg in weight, and 20 years of age (Graham 1999), coupled with its omnivorous feeding strategy, has raised concerns about the effect of this large predator on fish communities in Chesapeake Bay tributaries.

Although blue catfish were reported as introduced in the Chesapeake Bay region between 1898 and 1905 in the Potomac River, this purported introduction has been attributed to a misidentified channel catfish *I. punctatus* (Burkhead et al. 1980). Beginning in 1974, more than 300,000 juvenile blue catfish were introduced into coastal rivers of Virginia to establish self-sustaining fisheries, starting with the James and Rappahannock rivers, and ending in 1985 with introductions into the York River system (Mattaponi, Pamunkey, and York rivers; Virginia Department of Game and Inland Fisheries; Higgins 2006). Following a 10- to 15-year lag, these populations expanded rapidly from tidal freshwater regions (average annual salinity <0.5 practical salinity units [psu]) into oligohaline (0.5–5 psu) and mesohaline (5–18 psu) waters of Chesapeake Bay tributaries (Dennison et al. 1993). Although blue catfish is typically a freshwater species, it does occupy estuarine waters of southern Louisiana (Perry 1969), suggesting that a range expansion into the saline waters of Chesapeake Bay may be possible.

Currently, blue catfish are common in all Atlantic slope rivers of Virginia; occupy several rivers in Maryland, including the Potomac, Patuxent, Elk, and Nanticoke rivers; and are found in Chesapeake Bay as far up-estuary as the mouth of the Susquehanna River. Blue catfish frequently dominate the ichthyofauna in portions of these coastal rivers, representing up to 75% of total fish biomass from recent boat electrofishing collections in the tidal James and Rappahannock rivers (Virginia Commonwealth University and Virginia Department of Game and Inland Fisheries, unpublished data).

Introduced blue catfish populations in tidal rivers of Virginia and Maryland support modest commercial fisheries. In recent years, commercial landings of blue catfish from tidal rivers in both states increased from about 9.5–17 metric tons in 2003–2005 to more than 72.5 metric tons in 2008 (VMRC 2010; A. C. Carpenter, Potomac River Fisheries Commission, personal communication). Additionally, hundreds of metric tons of unclassified catfishes are landed each year in Virginia and Maryland. For example, since 2000, an estimated 680–860 metric tons of "catfishes" were harvested annually in Virginia, with a market value averaging more than $1 million since 2006 (VMRC 2010). However, accurate economic data are lacking because market prices are reported voluntarily. Blue catfish is likely to be the dominant species in the undifferentiated catch in Virginia due to relative abundance of blue catfish in tidal rivers of this state.

Blue catfish also support important recreational fisheries, including a nationally recognized trophy fishery in the James River, Virginia. In Virginia, one-third of total recreational fishing effort for freshwater species is directed at catfish (Greenlee 2004); this fishery is primarily a catch-and-release fishery targeting trophy fish at night. Although a large proportion of the recreational catch from the Chesapeake Bay region is harvested, consumption advisories may potentially limit removals.

Spread of blue catfish populations is suspected to have influenced resident fish assemblages; in particular, declines in abundance of white catfish *I. catus*, a native species traditionally utilized by commercial fishers, were observed after blue catfish populations became established in the mid-1990s (Tuckey and Fabrizio 2010). Here, we examine putative effects of blue catfish on tidal river communities of Chesapeake Bay. Because current understanding of blue catfish population dynamics from these systems is fairly limited, we assembled available data for this region and provide a synthesis of comparable results when possible. Population biology of blue catfish was investigated by examining changes in distribution and abundance of this species through time. Community-level effects of introduction and expansion of blue catfish were also evaluated, including examination of predator–prey interactions and elucidation of the trophic status of blue catfish. Implications of these findings are used to explore societal and economic issues affecting management of this species in the Chesapeake Bay region.

Methods

Sampling Area Description

Tributaries of the Chesapeake Bay provide permanent and temporary habitats for a diverse array of species that use these waters as nursery grounds or for foraging. Due to presence of a salinity gradient and influence of tides, inhabitants of estuaries include species from both marine and freshwater faunas. Salinity generally increases from headwaters to the mouth of tidal rivers, as well as from north to south in the bay main stem. Salinity at the mouths of tributaries in Chesapeake Bay varies annually. Between 1999 and 2008, summer (July–September) salinities averaged 16.5 psu (±1.9 SD) in the Rappahannock River, 20.4 ± 1.5 psu in the York River, and 21.4 ± 1.6 psu in the James River (T. D. Tuckey and M. C. Fabrizio, Virginia Institute of Marine Science, unpublished data).

Field Collections

Data from numerous fishery-independent surveys were used to examine the ecological role of blue catfish in Chesapeake Bay tributaries (Table 1); for the most part, these state-based surveys are pursued independently. The juvenile fish trawl survey (hereafter "trawl survey"; Tuckey and Fabrizio 2010) conducted by the Virginia Institute of Marine Science (VIMS) has sampled blue and white catfish populations since 1989 using a 9.1-m semi-balloon otter trawl towed for 5 min along the bottom. Blue catfish ranging from 70 to 300 mm fork length (FL) were vulnerable to this gear, although larger fish (up to 600 mm) were sometimes captured. Monthly collections occurred at both fixed and random stratified sampling sites between river kilometer (rkm) 64.4 and the mouth of the river (rkm 0) in the James, York, and Rappahannock rivers. Sampling domain of the survey was stratified along the river axis (strata were differentiated every 10 longitudinal minutes) and by depth (1.2–3.7 m, 3.7–9.1 m, 9.1–12.8 m, and >12.8 m). Additionally, blue catfish were collected in the VIMS seine survey for striped bass *Morone saxatilis* using a 30.5-m beach seine at fixed sampling sites in the James (rkm 19.3–123.9), York (rkm 24.1–64.0), Pamunkey (rkm 0–43.5), Mattaponi (rkm 0–38.6), and Rappahannock (rkm 16.1–120.7) rivers (Machut and Fabrizio 2010; Table 1). Shallow (<1.2 m) mud and sandy-bottom habitats were sampled during five biweekly sampling periods from July through mid-September since 1985.

Since the early 1990s, Virginia Commonwealth University (VCU) and Virginia Department of Game and Inland Fisheries have sampled blue catfish using low-frequency pulsed direct-current electrofishing (15 pulses/s, 340 or 680 V), as well as high-frequency electrofishing (60–120 pulses/s, 340 or 680 V), from various rivers in Virginia (Table 1). Most collections were made with a Smith-Root 9.0 GPP electrofishing unit mounted on a 5.5-m aluminum boat. These surveys were conducted over several days during summer (July–August) or fall (October–November) in the Rappahannock (rkm 67–151), James (rkm 79–150), Mattaponi (rkm 52–99), Pamunkey (rkm 52–124), and Piankatank (rkm 15–36.7) rivers, as well as in several smaller tributaries. These survey data were used previously to describe distribution and abundance of blue catfish in freshwater and tidal freshwater regions of the rivers (Edmonds 2006). A subsample of the fish captured provided pectoral spines and otoliths for aging, stomach contents for diet analysis, and various tissues for stable isotope analysis of trophic ecology (MacAvoy et al. 2009).

Electrofishing surveys conducted by the Maryland Department of Natural Resources (MDDNR) in the Patuxent River (rkm 99.8) and tidal Potomac River (rkm 105–173.5) recently began targeting blue catfish and documenting basic life history information for this species (Table 1). These exploratory surveys were first conducted in September 2001 using a low-frequency Smith-Root SR18 electrofishing boat (7.5 or 15 pulses/s, 680 V) and were repeated in November 2007, in October 2008, and during spring (April–June) and fall (September) 2009.

Distribution and Relative Abundance

To create a synoptic distribution map describing expansion of blue catfish since their introduction in the Chesapeake Bay region, we integrated georeferenced presence–absence data from the aforementioned trawl, seine, and electrofishing surveys. We used verified angler catches (1997–present), along with information from other MDDNR surveys (2007–present) and the Potomac River Fisheries Commission (Carpenter, personal communication) to confirm occurrence and establishment of blue catfish in Maryland waters. Distribution maps were created for three periods—pre-1996, 1996 to 2002, and 2002 to 2008—that corresponded with periods of key changes in blue catfish relative abundance.

Relative abundance indices (fish/tow) for young-of-the-year (YOY) and adult blue catfish were calculated for the James, York, and Rappahannock rivers based on trawl survey catches taken between December and March of each year. Adult and YOY fish were differentiated on the basis of

TABLE 1. Gear type, time period, and system sampled for blue catfish from fishery-independent sources.

Survey	Gear type	Years	Months	Rivers sampled	River kilometer
Juvenile fish trawl	Otter trawl	1975–present	Jan–Dec	James, Rappahannock, York	0–64.4
Striped bass seine	Comon seine	1985–present	Jul–Sep	James	19.3–123.9
				Mattaponi	0–38.6
				Pamunkey	0–43.5
				Rappahannock	16.1–120.7
				York	24.1–64.0
Low-frequency (7.5 or 15 pulses/s) electrofishing	SR18 electrofishing boat	2009	Jun	Patuxent	99.8
		2001, 2007–present	Apr–Nov	Potomac	105–173.5
Low-frequency (15 pulses/s)	Boat-mounted 9.0 GPP unit	1994–2002, 2004, 2006, 2008	Jul–Aug	James	79–150
		1999, 2000, 2002–2004, 2006, 2008	Jul–Aug	Mattaponi	52–99
		1999–2006, 2008	Jul–Aug	Pamunkey	52–124
		2000, 2002–2007	Jul–Aug	Piankatank	15–36.7
		2000–2002, 2004, 2005, 2007	Jul–Aug	Rappahannock	67–151
High-frequency (60–120 pulses/s) electrofishing	Boat-mounted 9.0 GPP unit	1998–1999, 2001–2008	Oct–Nov	James	79–150
		2001–2002, 2004, 2005, 2007	Jul–Aug	Rappahannock	67–151

fork length (≤30 mm for young of the year and >130 mm for adult). Due to the large number of zero catches, indices were calculated using a delta distribution (Aitchison and Brown 1957). Stratum-specific mean catch was calculated using the estimator of the mean for the delta-lognormal distribution (e.g., see Pennington 1983; Lo et al. 1992; Ortiz et al. 2000), and overall stratified estimate of mean catch was calculated by weighting stratum-specific means by stratum area (Cochran 1977). In the same manner, white catfish relative abundances were determined using a length threshold of 100 mm FL to differentiate YOY and adult life stages from samples collected between December and March.

Trophic Interactions

Stomach contents of blue catfish ranging in size from 48 to 590 mm FL (N = 1,030) were subsampled from the trawl survey and analyzed to describe diet composition. These fish were collected from 324 sites in the James, York, and Rappahannock rivers between spring 2004 and fall 2007; during this period, we collected monthly samples of up to five (random) specimens per stratum. Percent weight index (Hyslop 1980) was used to identify the main prey in diet of small (<300 mm FL) and medium (300–600 mm FL) blue catfish in each of the three rivers; we selected the 300-mm threshold because others had reported increased piscivory at this size (Perry 1969; Edds et al. 2002). Prey types that represented only minor components of the diet were grouped at higher taxonomic levels. Because fish in a tow are likely to have been feeding in the same prey field, each trawl tow represents a cluster sample (or multiple cluster samples if several size-groups were present) from each sampling site; therefore, the aforementioned index was calculated using the cluster sampling estimator (Bogstad et al. 1995; Buckel et al. 1999). A chi-square test with Yates' correction (Fleiss 1981) was used to compare size-group differences in the proportion of blue catfish consuming either fish or macroinvertebrates; all tests were conducted with an alpha value of 0.05.

We also characterized diet composition of blue catfish from the tidal Potomac River (N = 139; 101–1100 mm FL) by examining frequency of occurrence of prey items among three length-groups of fish: small (<300 mm FL), medium (300–600 mm FL), and large (>600 mm FL). Stomach contents were obtained by gastric lavage or from fish that were sacrificed for other studies. As described previously, size-group differences in the proportion of blue catfish consuming either fish or macroinvertebrates were examined using Yates' chi-square test (α = 0.05); we also examined seasonal differences for Potomac River fish.

Results

Distribution and Relative Abundance

Trawl survey sampling indicated that relative abundance of YOY and adult blue catfish in the tidally influenced regions of the James, York, and Rappahannock rivers has increased in recent years (Figure 1). Adult blue catfish abundance peaked subsequent to high recruitment events, a pattern that is most notable in the James River. Along with growth of blue catfish populations, concurrent declines in native white catfish abundance and recruitment were observed in all rivers except the Rappahannock River, for which too few YOY specimens were collected to calculate a relative abundance index (Figure 1). Electrofishing surveys in the nontidal regions of the James and Pamunkey rivers also documented the increase in blue catfish relative abundance and the decline in relative abundance of white catfish (Table 2); trends are not apparent in the Rappahannock River because blue catfish had become well established prior to onset of sampling in 1999.

Periods of highest YOY relative abundance coincided with high freshwater flow rates and the expansion of blue catfish populations into higher salinity waters. Blue catfish dispersed downstream from initial stocking locations at an average rate of 3.5 km/year since 1975 and now occupy estuarine habitats with salinities as high as 14.7 psu (Rappahannock River 2008). Specifically, blue catfish are found between rkm 9.4 and 138.7 in the James River, rkm 23.1 and 146.7 in the Rappahannock River, rkm 37.1 and 64.4 in the York River, rkm 0 and 118.8 in the Pamunkey River, and rkm 0 and 63.4 in the Mattaponi River. Furthermore, blue catfish are now established in the Potomac (rkm 53.6–181.0), Patuxent (rkm 99.8), Nanticoke (rkm 30.4), Elk (rkm 0–13.1), and Susquehanna (rkm 0) rivers in Maryland, as well as the Piankatank (rkm 28.5–34.2) River in Virginia (Figure 2; data in part from Edmonds (2006)). Currently, the northern-most point in the Chesapeake Bay region from which this species has been collected is near the mouth of the Susquehanna River at Perryville, Maryland.

Trophic Interactions

In Virginia tributaries, blue catfish consume a broad array of prey, with contributions of major diet con-

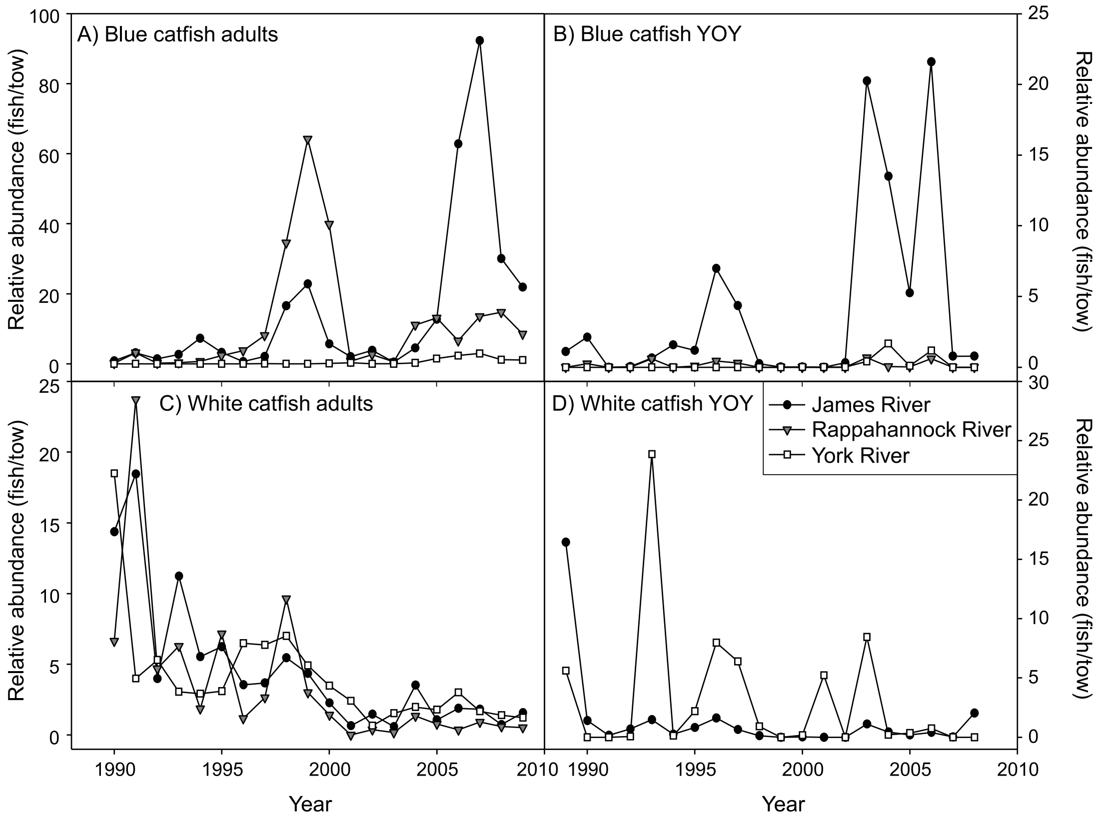

FIGURE 1. Relative abundance (fish/tow) of (A) blue catfish adults, (B) blue catfish young of the year, (C) white catfish adults, and (D) white catfish young of the year in the James (●), Rappahannock (▼), and York (□) rivers based on Virginia Institute of Marine Science trawl survey catches. Note differences in scale of the y-axis in these panels.

stituents differing among size ranges investigated. Amphipods (four identified species) comprised the largest component of the diet by weight (42.1%) for small (<300 mm) blue catfish but represented only 13.4% of the diet of medium (300–600 mm) blue catfish. Bony fishes (10 identified species) constituted the major portion of medium blue catfish diets by weight (26.9%), but they were less important for smaller blue catfish (9.9%). Proportion of blue catfish consuming bony fishes was significantly greater for medium-sized blue catfish than for small blue catfish ($\chi^2 = 47.9$, df = 1, $P < 0.05$), an observation consistent with piscivorous habits reported in previous studies from this region (Chandler 1998; Garman and Macko 1998; MacAvoy et al. 2009). Other crustaceans (i.e., crabs, shrimp, isopods, etc.; 20 identified species) and mollusks (15 identified species) were also important for small and medium blue catfish, representing 15.0% and 7.8% of small blue catfish diets by weight and 17.5% and 15.8% of medium blue catfish diets by weight, respectively. A considerably greater proportion (56.3%) of medium-sized blue catfish consumed macroinvertebrates (all crabs and mollusks), compared with only 40.1% of the small blue catfish ($\chi^2 = 20.4$, df = 1, $P < 0.05$). Unidentified material and mud comprised appreciable portions of stomach contents of blue catfish in all three river systems.

Within each size-group, spatial variability in blue catfish diet was observed among the James, York, and Rappahannock rivers (Figure 3A–C). In the Rappahannock and James rivers, the common burrower amphipod *Leptocheirus plumulosus* was the dominant prey of small blue catfish by weight (52.8% in the Rappahannock River and 29.1% in the James River). In the York River, dominant prey by weight were gammarid amphipods *Gammarus* spp. (25.2%); common burrower amphipods were less

TABLE 2. Percent catch relative to all catfish species collected (including channel catfish and flathead catfish *Pylodictis olivaris*) and catch per unit effort (fish/h) for blue catfish and white catfish from Virginia Department of Game and Inland Fisheries low-frequency electrofishing surveys in the Pamunkey and James rivers.

	Pamunkey River				James River			
	% catch		Catch per unit effort (fish/hour)		% catch		Catch per unit effort (fish/hour)	
Year	Blue catfish	White catfish	Blue catfish	White catfish	Blue catfish	White catfish	Blue catfish	White catfish
1994	–	–	–	–	64.1	23.6	139	51
1995	–	–	–	–	–	–	–	–
1996	–	–	–	–	71.2	18.6	261	68
1997	–	–	–	–	–	–	–	–
1998	–	–	–	–	94.6	2.7	1,963	57
1999	33	23	107	75	–	–	–	–
2000	46	35	92	71	–	–	–	–
2001	–	–	–	–	–	–	–	–
2002	84	11	607	80	96.2	3.2	1,316	44
2003	93	5	398	21	–	–	–	–
2004	97	3	687	18	98.4	1	1,399	15
2005	99.8	0.1	1245	1	–	–	–	–
2006	99.7	0.3	1484	4	99	0.9	2,556	23
2007	–	–	–	–	–	–	–	–
2008	–	–	–	–	99.5	0.1	4,785	7

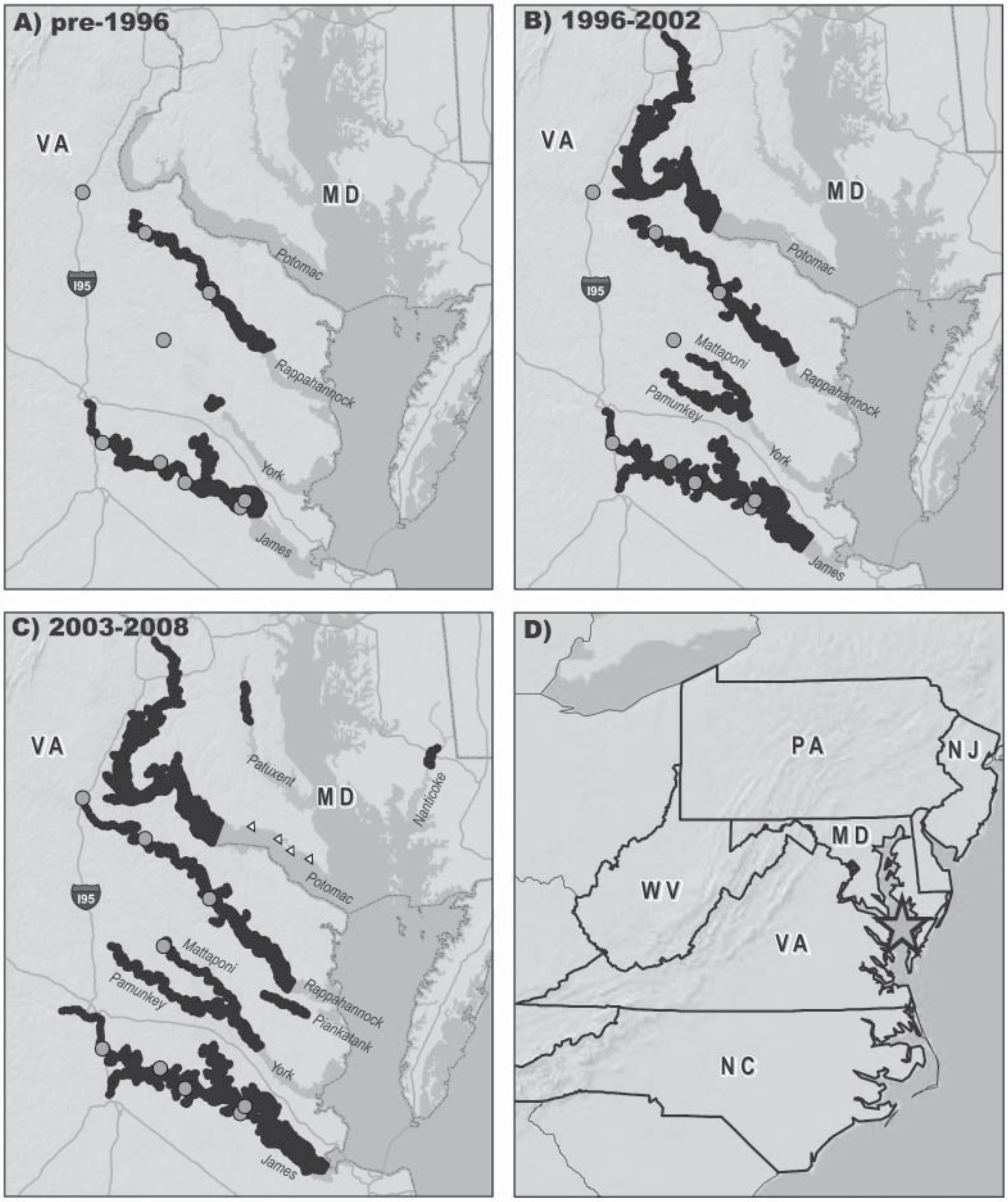

FIGURE 2. Distribution of blue catfish in major Chesapeake Bay tributaries (A) prior to 1996, (B) 1996–2002, and (C) 2003–2008. Panel (D) shows location of Chesapeake Bay along the Atlantic coast of the U.S. Presence–absence georeferenced data were obtained by bottom trawl, gill net, seine net, and low-frequency boat electrofishing. Gray circles indicate stocking locations in Virginia (Edmonds 2006). Open triangles indicate reported commercial catches from the Potomac River Fisheries Commission (Carpenter, personal communication). Reported catches in the Elk River and in the Susquehanna River, near Perryville, Maryland are not shown. Occurrence and distribution of blue catfish in the Potomac River before 1996 is difficult to ascertain, but it has been discussed in other reports (Sauls et al. 1998).

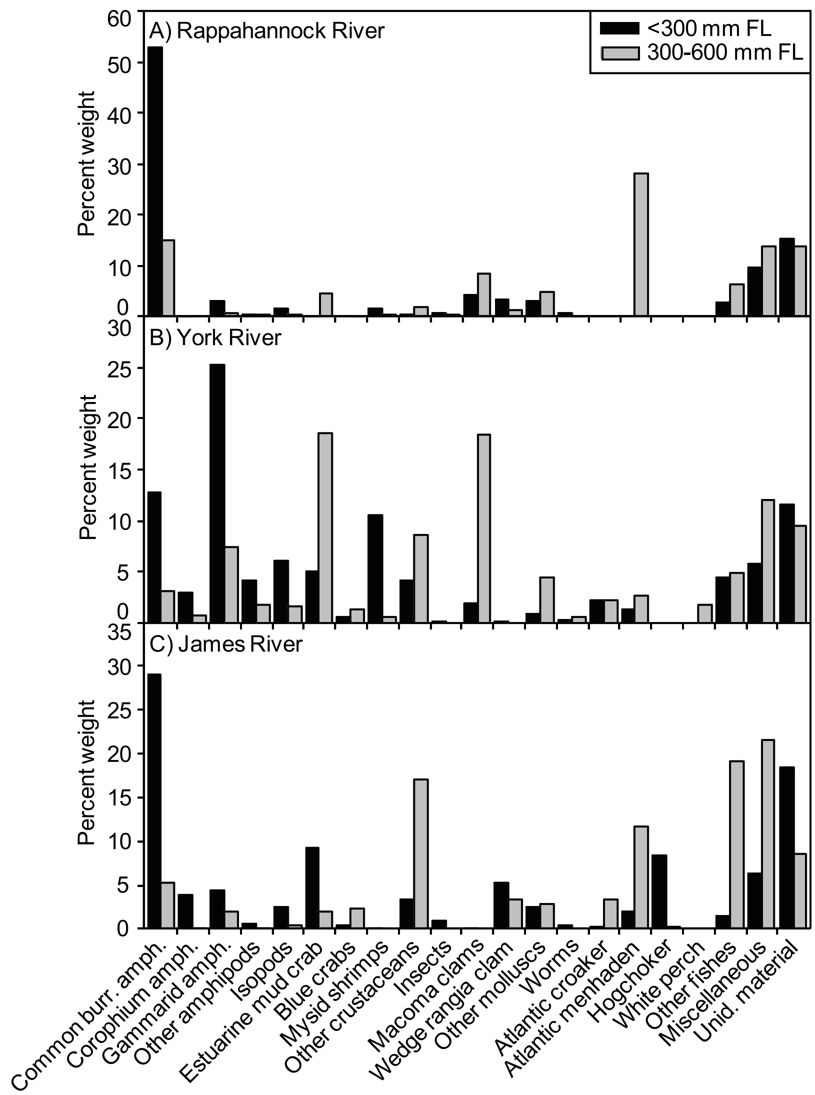

FIGURE 3. Blue catfish diet composition by percent weight in the (A) Rappahannock, (B) York, and (C) James rivers from 2004 to 2007. FL = fork length, unid = unidentified, burr = burrower, and amph = amphipod.

important prey for small blue catfish in the York River (12.8%). Small blue catfish also consumed estuarine mud crabs *Rhithropanopeus harrisii* (9.3% by weight) and hogchokers *Trinectes maculatus* (8.4% by weight) in the James River, as well as mysid shrimp (Family Mysidae, 10.5% by weight) in the York River. All other prey types contributed little to the overall diet of small blue catfish in the Rappahannock River.

Medium blue catfish showed a similar degree of spatial variability in major diet components (Figure 3A–C). Atlantic menhaden *Brevoortia tyrannus* was the main prey by weight in the Rappahannock River (28.1%) and an important component in the James River (11.6%) but contributed little to diet of medium blue catfish in the York River (2.6%). Clams *Macoma* spp. were important in the diet of fish from the Rappahannock (8.5%) and York (18.6%) rivers but comprised less than 0.1% of the diet by weight in the James River. Other main prey types consumed by medium blue catfish included estuarine mud crabs (18.6%) and other crustaceans (8.5%) in the York River and the common burrower amphipod in the Rappahannock River (14.9%). The diet of medium blue catfish in the James River exhibited the greatest diversity of the systems investigated, with various other fishes and crustaceans comprising more than 19.2% and 17.1%, respectively, of the diet by weight.

In the Potomac River, submerged aquatic vegetation, unidentified fish remains, and empty stomachs were most commonly encountered, but decapods and other fish were important food items for medium and large blue catfish (Figure 4). Although small sample sizes for blue catfish less than 300 mm FL restricted analysis, we found a significant difference in the proportion of medium versus large blue catfish that consumed fish ($\chi^2 = 4.76$, df = 1, $P < 0.05$): 41% of blue catfish greater than 600 mm FL had fish prey in their stomachs compared with 21% of individuals between 300 and 600 mm FL. No significant differences between seasons ($\chi^2 = 0.44$, df = 1, $P > 0.05$) or the proportion of fish consuming macroinvertebrates ($\chi^2 = 2.76$, df = 1, $P > 0.05$) were detected, but macroinvertebrates were identified in 10.3% of fish collected in the fall compared with only 1.9% for fish collected in the spring. Our inability to detect this apparent seasonal difference was likely due to small sample sizes.

Discussion

Introductions of blue catfish in the Chesapeake Bay watershed have resulted in establishment of populations with few physical barriers to restrict further range expansion or population growth. Rivers that were stocked between 1974 and 1985 now support thriving populations, although relative abundance of blue catfish in the York River is not as great as that in the James and Rappahannock rivers. The difference in relative abundance most likely reflects the 10-year deferral of stocking efforts in the York River system. Peaks in relative abundance of YOY blue catfish in 1996 and 2003 were followed by an increase in adult abundances in subsequent years, and this was particularly notable in the James River. Since 1996, spatial distribution of blue catfish has expanded upstream into freshwater reaches and downstream into oligo- and mesohaline portions of the rivers; in addition, blue catfish now occupy portions of the Piankatank River, Virginia and the Potomac, Patuxent, Nanticoke, Elk, and Susquehanna rivers in Maryland. The pattern of establishment followed by a lag phase and then rapid dispersal of blue catfish in Chesapeake Bay tributaries is consistent with population dynamics of an invasive species (Sakai et al. 2001).

The concomitant increase in relative abundance and expansion of spatial distribution of populations suggests that two mechanisms may be operating to facilitate expansion of blue catfish into novel habitats. During years of high recruitment, YOY blue catfish may be driven into more saline habitats as a result of resource competition. In this scenario, salinity is not the sole factor influencing movement of blue catfish into estuarine waters, a supposition supported by observations on other freshwater species (Peterson and Meador 1994). Edmonds (2006) suggested that freshwater discharge events, coupled with the species' salinity tolerance, are primary mechanisms for expansion beyond areas originally stocked. This mechanism seems plausible because major flood events occurred in 1996 and 2003. Genetic variation of DNA microsatellite loci among populations from various Chesapeake Bay tributaries also suggests that dispersal into new habitats during periods of high freshwater flows was more likely than intentional introductions by anglers (Higgins 2006). Flooding events may provide opportunities to reduce competition among conspecifics in tidal freshwater reaches that support high blue catfish abundance, and as such, freshwater regions may represent a "reservoir" from which other habitats are colonized.

Movements of blue catfish among tidal riverine and upstream freshwater habitats are not well known. After 1999, blue catfish began dispersing upriver into the nontidal (i.e., Piedmont) reaches of the James River through a vertical slot fishway installed at Bosher's Dam in Richmond, Virginia (Fisher 2007). In contrast, the removal of Embrey Dam from the main-stem Rappahannock River in 2004 has not yet resulted in expansion of blue catfish populations into the nontidal habitats above the fallzone in this river (J. Odenkirk, Virginia Department of Game and Inland Fisheries, personal communication).

Expansion of blue catfish into previously unoccupied habitats, coupled with rapid increase in abundance within the tidal tributaries of Chesapeake Bay in recent years has heightened concerns about potential effects of this top predator on estuarine fish communities. Although few studies have documented the effect of "freshwater" species that move into, and become established in, estuarine waters, evidence from studies of largemouth bass *Micropterus salmoides* suggests that freshwater species can utilize marine food resources (Norris et al. 2010). Furthermore, contrary to expectations, largemouth bass living in estuarine conditions do not experience negative changes in vital rates (e.g., reduced growth

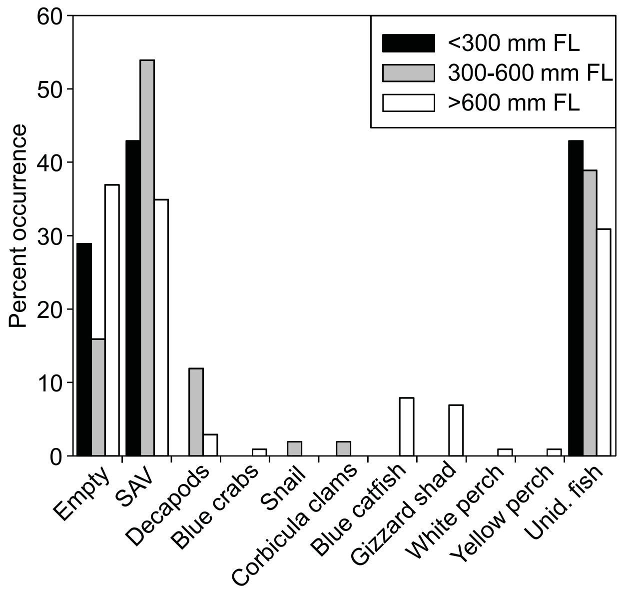

FIGURE 4. Frequency of occurrence of blue catfish prey in the tidal Potomac River from 2008 to 2009. Potomac River values represent the proportion of fish within each length-group containing listed prey items. FL = fork length, unid = unidentified, and SAV = submerged aquatic vegetation.

or increased mortality) due to physiological stress (Norris et al. 2010). This appears to be the case for blue catfish in the Chesapeake Bay region. Blue catfish are known to consume marine food resources (Lousiana estuaries: Perry 1969; Chesapeake Bay tributaries: Garman and Macko 1998), and the wide variety of consumed items is not unique to the Chesapeake Bay region. Crustaceans, insects, fishes, and vegetation were reported in the diets of blue catfish collected from Louisiana estuaries (Perry 1969). The spatial and temporal variability we observed in diet of blue catfish among Chesapeake Bay tributaries is similar to that reported for the lower Mississippi River (Eggleton and Schramm 2004). Compared with other resident predators from the James and Rappahannock rivers, blue catfish (>450 mm FL) included a greater proportion of marine-derived organic matter in their diets (Garman and Macko 1998; MacAvoy et al. 2009). As such, blue catfish may represent a relatively new, and potentially significant, source of mortality for economically and ecologically important estuarine fishes such as juvenile American shad *Alosa sapidissima*, Atlantic menhaden, and river herring *Alosa* spp. (Chandler 1998).

Considering the diverse prey base of blue catfish in the rivers examined, we postulate that competition for prey resources between blue and white catfishes may have contributed to observed declines in white catfish abundance. Although the nature of the interaction between blue and white catfishes is unknown, we observed a decline in white catfish abundance coincident with an increase in blue catfish abundance in the James and Rappahannock rivers. In the upper Piankatank River, blue catfish replaced white catfish as the numerically dominant ictalurid within 5 years of its introduction (G. Garman, Virginia Commonwealth University, unpublished data). Further research is necessary to elucidate the ecological interaction of these two congeners.

Although they are characterized as voracious consumers, blue catfish are an important prey of riverine-dependent avian predators in Virginia and Maryland. Blue catfish are postulated to have facilitated the relatively recent expansion of osprey and bald eagle populations into tidal freshwater habitats throughout the region (Viverette et al. 2007). However, in the James River, and possibly other tidal rivers, high concentrations of polychlorinated biphenyls (PCBs) and other contaminants in blue catfish tissues (Garman et al. 1998) may represent a long-term, but poorly understood health threat to avian predators.

Management Implications

Blue catfish play a complicated role in the ecology of estuarine communities in tributaries of the Chesapeake Bay, and concerns about potential negative effects on native species have arisen because of high abundance of blue catfish and their ability to consume a broad prey base. Yet, growing fisheries bring socioeconomic benefits to the region, and management actions will need to balance needs of fisheries with concerns for conservation of native communities.

Resource managers seeking to apply an ecosystem-based approach to management are considering measures to help control density and spread of blue catfish in tidal tributaries. Eradication is not an option because it has been shown to be ineffective for established populations (B. Greenlee, personal observation). Harvest levels that could result in an overfished population are difficult to determine because a scientific assessment of blue catfish populations from tidal tributaries is lacking. Even if overfishing can be attained, current market demand is limited, and significant shifts in market conditions will be required to achieve sufficiently high harvest levels to mitigate the continued expansion and growth of blue catfish populations. If blue catfish population size cannot be contained in tidal tributaries, we foresee negative effects on other aquatic resources through predation or through competition and shifts in food web dynamics. Population-level effects on other resources have not been thoroughly documented, although we present some evidence for such outcomes, particularly for native white catfish.

Management of blue catfish fisheries in tidal tributaries must also address conflicting objectives of the recreational and commercial fishery components. Specifically, commercial fishery objectives to maximize harvest may be incompatible with the desire to sustain a recreational trophy fishery (Arterburn et al. 2002). Both recreational and commercial fisheries have been sustainable to date because of the high productivity of these tidal systems and relatively high abundance of blue catfish; however, in recent years, an emerging commercial market for large blue catfish has resulted in additional user-group conflicts.

Blue catfish populations in Virginia support a nationally recognized trophy fishery targeting trophy blue catfish (≥96.5 cm FL or ≥13.6 kg), which comprise less than 2% of the population. Several hundred anglers are recognized annually for trophy fish captured from the tidal James River alone. Maryland recognizes anglers that capture blue catfish ≥101.6 cm FL. Anecdotal evidence suggests that anglers target trophy fish year round, except for the late spring when blue catfish are spawning; the summer trophy fishery occurs predominantly at night. Virginia anglers that target blue catfish as food do so year round, throughout the day; furthermore, these anglers are diverse, representing multiple cultures (Greenlee 2004). Multicultural aspects of this fishery bring additional challenges for management in terms of effective communication of fishery regulations.

Attempts to increase harvest by developing markets for this nonnative species are hampered by consumption advisories (VDH 2010). Blue catfish from the tidal James River exhibit high concentrations of PCBs, organotin compounds (i.e., tri-butyl tin), and DDE (dichlorodiphenyl-dichloroethane; Garman et al. 1998). Concentrations of PCBs in muscle tissue correlate positively with fish size, and the majority of fish greater than 540 mm FL exceeded the Food and Drug Administration's PCB action level (2 ppm), posing a significant risk to recreational anglers (Harris and Jones 2008). Although Bullene (2008) demonstrated that patterns of blue catfish consumption by recreational anglers in the James and York River systems did not result in significantly increased health risks from mercury exposure, further studies may be needed before expansion of the blue catfish fishery is pursued.

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