

## Diet Selectivity of Introduced Flathead Catfish in Coastal Rivers

WILLIAM E. PINE, III\*<sup>1</sup>

North Carolina Cooperative Fish and Wildlife Research Unit,<sup>2</sup> Campus Box 7617,  
North Carolina State University, Raleigh, North Carolina 27695, USA

THOMAS J. KWAK

U.S. Geological Survey, North Carolina Cooperative Fish and Wildlife Research Unit,  
Campus Box 7617, North Carolina State University,  
Raleigh, North Carolina 27695, USA

D. SCOTT WATERS<sup>3</sup>

North Carolina Cooperative Fish and Wildlife Research Unit, Campus Box 7617,  
North Carolina State University, Raleigh, North Carolina 27695, USA

JAMES A. RICE

Department of Zoology, Campus Box 7617, North Carolina State University,  
Raleigh, North Carolina 27695, USA

**Abstract.**—In two coastal North Carolina rivers (Contentnea Creek and the Northeast Cape Fear River), we found the food habits of introduced flathead catfish *Pylodictis olivaris* to be primarily piscivorous, which could restructure or suppress native fish communities through direct predation. Fish or crayfish contributed more than 50% of the stomach contents by percent occurrence, percent by number, and percent by weight in both rivers during each of 2 years. Significant differences in diet composition (percent by number) were found between rivers and between years in the Northeast Cape Fear River but not between years within Contentnea Creek. Chesson's selectivity index values and trends in relative abundances of fish availability relative to those occurring in the diet suggest that flathead catfish feeding is generally random, indicating that these introduced flathead catfish do not selectively feed on prey species with which they did not coevolve. Our research represents the first assessment of prey selectivity by an introduced ictalurid population and provides evidence of the potential impact on native fish communities through their piscivorous food habits.

The flathead catfish *Pylodictis olivaris* is a large piscivorous catfish native to drainages of the Rio Grande, Mississippi, and Mobile rivers (Smith-Vaniz 1968; Jenkins and Burkhead 1994) that has been introduced by legal and illegal means into at least 13 states and one Canadian province (Jackson 1999). Fuller et al. (1999) considered the introduction of flathead catfish as probably the most

biologically harmful of all fish introductions in North America. The first known flathead catfish introduction into North Carolina waters occurred in 1966 when 11 adults (total weight, 107 kg) were released into the Cape Fear River near Fayetteville, North Carolina (Guier et al. 1984). Within 15 years, the flathead catfish distribution had expanded to cover a 200-km section of the river, and it had emerged as the dominant predator fish within the Cape Fear River system (Guier et al. 1984).

Here we examine diet patterns in introduced populations of flathead catfish from two coastal river systems in North Carolina and compare these results with published foraging information for both native and other introduced flathead catfish populations. Invasive species are widely thought to, at least initially, exploit an abundance of prey types that did not coevolve with the invading predator and their mode of predation (Moyle and Light 1996; White and Harvey 2001). Unlike most other catfishes, flathead catfish are obligate carnivores

\* Corresponding author: bill-pine@mote.org

<sup>1</sup> Present address: Department of Fisheries and Aquatic Sciences, University of Florida, 7922 NW 71st Street, Gainesville, Florida 32653, USA.

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<sup>3</sup> Present address: Kansas Department of Wildlife and Parks, Glen Elder Area Office, Rural Route 1, Post Office Box 162A, Glen Elder, Kansas 67446, USA.

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and primarily piscivorous. Concern has been widespread in many areas where flathead catfish have been introduced in relation to declining populations of native fishes after flathead catfish introduction (Guier et al. 1984; Ashley and Buff 1988; Quinn 1988; Marsh and Brooks 1989; Thomas 1995). These studies generally have documented a decline in native fish populations (presumed to be via predation) after the introduction of flathead catfish. The species affected are usually native centrarchids, ictalurids, and catostomids, some of which did not coevolve with flathead catfish (Marsh and Brooks 1989; Thomas 1995). Here we attempt to determine whether foraging patterns exist that address this question: Do introduced flathead catfish selectively feed on prey types that are not present in their native range? We examine this question through selectivity analysis of flathead catfish prey items for our study rivers and from published diet studies of flathead catfish from other areas where they have been introduced.

The food habits of flathead catfish have been described for native and introduced populations in an attempt to discern their interactions with native fish communities, but no study of introduced or native populations has incorporated prey availability to assess diet selectivity. Selectivity information is particularly important in assessing the potential impact of an invasive species on native fish communities. This knowledge gap probably stems from the logistic difficulty of quantifying fish populations in medium to large rivers, where flathead catfish often are found. Information on the composition of the native fish community before invasion is usually limited for any given area, and species introductions often occur simultaneously with other anthropogenic impacts that may alter the abundance of native fish (Townsend and Crowl 1991; White and Harvey 2001). In such cases, declines in native species are often assumed to be the result of species introduction, when it is also possible that a suite of biotic (e.g., poor recruitment) or anthropogenic abiotic changes could be altering fish assemblage composition. Our approach to this topic extends beyond such previous research on introduced or native flathead catfish populations by examining diet selectivity patterns to improve inference from this and previous diet studies of this piscivore.

### Methods

*Study sites.*—We selected two study rivers of similar size (mean width about 50 m each)—Northeast Cape Fear River, Cape Fear River drain-

age; Contentnea Creek, Neuse River drainage—located in the coastal plain region of eastern North Carolina. Flathead catfish presence in each of these rivers had been previously documented by the North Carolina Wildlife Resources Commission (NCWRC). We conducted intensive sampling in fixed sample reaches spanning long-term NCWRC sampling locations. Two 1-km reaches were sampled in Contentnea Creek and three 1-km reaches were sampled in the Northeast Cape Fear River during 2001–2002.

*Field and laboratory procedures.*—Flathead catfish were collected by using low-frequency electrofishing (Smith-Root Inc.; Mark VI GPP unit pulsed-DC; 1.5–2.0 A, 15 pulses/s), a nonlethal capture technique that has been shown to be an effective collection technique for flathead catfish (Justus 1996; Stauffer and Koenen 1999). Fish were collected when water temperatures exceeded 18°C (generally May–September), the minimum temperature threshold for efficient capture of flathead catfish in North Carolina (Grussing et al. 2001; Kwak et al. 2004). All flathead catfish collected were weighed (g) and measured (total length [TL]; mm) and stomach contents were collected by using pulsed gastric lavage (>95% effective in removing stomach contents from flathead catfish; Waters et al. 2004). Stomach contents were placed on wet ice, returned to the laboratory, and frozen. Before analysis, samples were thawed and the extracted stomach contents were identified to the lowest possible taxon, blotted, and weighed wet ( $\pm 0.01$  g), after which they were measured along the longest axis ( $\pm 0.5$  mm). Items that were not identifiable to family (e.g., bones, scales, or pieces of tissue) were grouped as either unknown fish or unknown invertebrates.

The frequency of occurrence of prey items was quantified by compiling a cumulative list of all the fish families or invertebrate taxa found in the diet and recording the presence or absence of each stomach item from the list for each fish (Bowen 1996). We also examined the percent composition by number of stomach contents for individual fish by calculating the percent composition of each prey group in flathead catfish stomachs, and then calculating a mean percent composition value for each group in each year and river (Bowen 1996). We then used a repeated-measures multivariate analysis of variance (MANOVA) to compare diet composition by number between rivers (years combined) and between years within each river. In this comparison, the treatment was river or year, the repeatedly measured response variable was

percent by number of each prey group in the diet, and replicates were individual fish within each river. Stomach fullness was calculated  $[(\text{total stomach contents wet weight}/\text{fish wet body weight}) \times 100]$  and reported as a percent of the flathead catfish weight. Weight of individual stomach content items was summed across all flathead catfish prey items in each year and river and was presented as the mean weight of each prey group by year and river.

As an approximate index of fish availability as prey for flathead catfish, we used density estimates of fish populations calculated during spring and summer in each river (Kwak et al. 2004). Fish population densities (number/km) and associated variance (SE) were estimated with a three-pass removal method (Seber 1982). Fish density estimates for individual species were combined with others within each fish family to estimate density according to family. Rank abundance of fish families (prey availability) was compared as to occurrence by number of the same fish families in the flathead catfish diet (prey consumed) to generally indicate patterns in feeding selectivity of flathead catfish. Chesson's alpha ( $\alpha$ ) values (Chesson 1978) and associated 95% confidence intervals were calculated from the percent composition of each family in the diet samples of each individual fish and the river environment to assess prey selectivity.

## Results

Many stomach items were highly digested and often difficult to identify. Identification to the family level was common, and each family or other taxon was considered a group for analysis. Flathead catfish have well-developed pharyngeal teeth, which masticated many of the food items when eaten. Unidentifiable material in the stomach contents was classified as unknown fish or unknown invertebrates (we could identify it at least to this gross level), and each was included as a group (similar to taxa) for analysis. Typical unknown contents included pieces of flesh, scales, bones, or spine fragments for fish and wings, thorax, or legs for invertebrates. Although some invertebrate taxa may digest rapidly relative to other invertebrates or fishes (Bowen 1996), we found no evidence of differential digestion rates among fish species; given this, unidentifiable fish material was assumed to come from the same species and in the same proportions as for the identifiable groups.

### *Contentnea Creek*

Flathead catfish in Contentnea Creek were primarily piscivorous, fish contributing the majority of stomach contents by frequency of occurrence, percent by number, and weight each year (Tables 1, 2). In 2001, stomach contents from 176 fish were examined, of which 80 contained food items (45%) from seven identified fish groups and four invertebrate groups. In 2002, contents from 158 stomachs were examined, and 84 contained food items (53%) from six fish groups and five invertebrate groups. Unknown fish material was the most common prey item by occurrence (57.5%) and number (49.0%) in 2001 (Table 1), but the family Centrarchidae (mostly sunfish, *Lepomis* spp.) was the most common group by weight (48.2%; Table 1). On average, individual prey items from the family Percidae (perch and darters) were the largest by weight (mean = 28.8 g), although this average was strongly skewed by one large yellow perch *Perca flavescens* (168 g). If this yellow perch was not included, Centrarchidae would be the largest group by weight. Similar results were found in 2002 for frequency of occurrence (Table 1; unknown fish = 61.9%), percent by number (unknown fish = 51.5%), and percent total weight (Table 1; Centrarchidae = 65.0%). Sunfish were the heaviest individual prey item (mean = 14.5 g). Cambaridae (crayfish) was also a common prey item by occurrence, number, and total weight (Table 1). In 2001, crayfish ranked second in both occurrence (Table 1; 26.3%) and number (18.7%) and were fourth in weight (Table 1; 4.0%). In 2002, crayfish were again the second most commonly occurring stomach item (Table 1; 27.4%), the third most common item by number (19.3%) and by total weight (Table 1; 10.1%). Diet percent composition did not differ significantly between years (Wilk's lambda:  $F_{14,149} = 1.16, P = 0.32$ ). Stomach fullness was low (<1.0% of flathead catfish body weight) and variable during 2001 and 2002 in Contentnea Creek (Table 2).

### *Northeast Cape Fear River*

Flathead catfish from the Northeast Cape Fear River consumed primarily crayfish and fish material from unknown families. In 2001, stomach contents from 100 flathead catfish were examined, of which 29 contained food items (29.0%) from three identified fish families and four invertebrate taxa (Table 1). In 2002, contents from 115 stomachs were examined, and 58 contained food items (50.4%) from three identifiable fish and two in-

TABLE 1.—Percent frequency of occurrence, mean number and total weight of prey items in the stomachs of flathead catfish, by year and river. A zero value indicates a group that was not identified in the stomach contents for that year and river. See Table 2 for more details on flathead catfish.

Prey group	2001					
	Contentnea Creek			Northeast Cape Fear River		
	Occurrence	Mean number	Weight	Occurrence	Mean number	Weight
Anisoptera	0	0		3.5	1.2	0.02
Baetidae	0	0		10.3	5.9	0.03
Cambaridae	26.3	18.7	4.0	27.6	24.1	27.7
Catostomidae	2.5	1.7	1.0		0	0
Centrarchidae	18.8	9.5	48.2	20.7	9.0	45.9
Clupeidae	3.8	2.9	2.8	0	0	
Corbiculidae	2.5	1.3	0.1	0	0	
Corydalidae	3.8	2.2	0.1	0	0	
Cyprinidae	7.5	5.5	0.4	0	0	
Ictaluridae	1.3	1.3	0.9	6.9	6.9	10.8
Penaidae	7.5	2.8	0.1	0	0	
Percidae	3.8	2.8	28.8	0	0	
Soleidae	2.5	1.7	1.2	17.2	11.7	5.5
Trichoptera	0	0		3.5	1.7	
Unknown invertebrates	1.3	0.6		3.5	0.7	0.01
Unknown fish	57.5	49.0	12.5	55.2	38.8	10.0
Stomachs with contents		80			29	
Empty stomachs		96			71	

vertebrate families. In 2001, unknown fish material was the most common prey item by occurrence (Table 1; 55.2%) and number (38.8%), but centrarchids were the most common item by total weight (Table 1; 45.9%). Sunfish were the largest prey item by weight (mean = 9.49 g). In 2002, crayfish were the leading stomach item by frequency of occurrence (60.3%; Table 1), number (53.4%), and percent total weight (52.4%). Sunfish were the largest prey group by average weight (mean = 8.08 g). Overall in 2001, all fish material contributed about 50% of the stomach contents by occurrence, number, and total weight, whereas invertebrates (primarily crayfish) were the dominant items in 2002. Diet percent composition differed significantly between years (MANOVA, Wilk’s lambda:  $F_{9,77} = 2.68, P = 0.009$ ). Stomach fullness in the Northeast Cape Fear River was also low (stomach fullness range 0.2–3.8%) and variable during 2001 and 2002 (Table 2).

*Diet Comparisons and Selectivity*

Percent composition of flathead catfish diet was significantly different between Contentnea Creek and the Northeast Cape Fear River (MANOVA, Wilk’s lambda:  $F_{15,245} = 4.71, P < 0.0001$ ). The percent by number data identified the two most common food types as unknown fish material (three of four estimates) or crayfish (one of four estimates), which corresponded well with the find-

ings by frequency of occurrence; most flathead catfish consumed other fishes, and the most commonly occurring prey items were fish material. Fish material contributed over 50% of all stomach items in three of four estimates. The MANOVA results between years within each river are supported by examining the frequency by number data. In Contentnea Creek, the ranked composition of the diet material by number did not change between 2001 and 2002 and the MANOVA test for differences in percent by number of each group was not significant ( $P = 0.32$ ). However, in the Northeast Cape Fear River, rankings of the diet composition changed fairly dramatically between years from unknown fish as the leading group in 2001, with about 39% of the total diet, to crayfish as most common in 2002, with about 53% of the diet, resulting in a significant between-year MANOVA result ( $P = 0.009$ ).

Examining trends in relative abundances of fish availability and those occurring in the flathead catfish diet suggests that flathead catfish feeding is generally random for most prey fish families (Figure 1; Table 3). The following findings—qualitative rank comparisons of fish abundance and occurrence, Chesson’s  $\alpha$  for prey selection, and qualitative rank comparisons of fish abundance and occurrence—for flathead catfish diets from Contentnea Creek fish are generally consistent with random feeding for most families (i.e., prey fam-

TABLE 1.—Extended.

Prey group	2002					
	Contentnea Creek			Northeast Cape Fear River		
	Occurrence	Mean number	Weight	Occurrence	Mean number	Weight
Anisoptera	1.2	0.4	0.1	0		
Baetidae	1.2		0.1	0	0	
Cambaridae	27.4	19.3	10.1	60.3	53.4	52.4
Catostomidae	2.4	2.5	3.6	0	0	
Centrarchidae	14.3	7.0	65.0	6.9	4.8	18.5
Clupeidae	0			0	0	
Corbiculidae	0			1.7	0.4	2.4
Corydalidae	1.2	0.6	0.0	0	0	
Cyprinidae	1.2	1.2	0.3	0	0	
Ictaluridae	6.0	3.4	2.3	1.7	0.9	3.0
Penaidae	6.0	3.1	0.3	0	0	
Percidae	15.5	9.1	3.4	0	0	
Soleidae	2.4	0.7	0.7	8.6	4.6	1.6
Trichoptera	0			0	0	
Unknown invertebrates	1.2	1.2	0.2	8.6	7.5	0.5
Unknown fish	61.9	51.5	14.1	32.8	28.5	21.5
Stomachs with contents		84			58	
Empty stomachs		74			57	

ilies were consumed in proportion to their availability). Positive selection was not detected for any families in Contentnea Creek (95% confidence intervals overlapped with the  $1/m$  value; Figure 1). Chesson's index values for other fish families were generally below the  $1/m$  value and considered to be slightly negative to neutral selectivity (Figure 1; Table 3).

Only three fish families were found in the diet of flathead catfish from the Northeast Cape Fear River, and selectivity for them appeared to be random (Table 3). Centrarchidae and Soleidae were the first and second most abundant fish families, respectively, during both spring and summer sampling events, and those families were tied for the most prevalent in the flathead catfish diet from that

TABLE 2.—Sampling times, number ( $N$ ), mean length and weight, and stomach fullness values for flathead catfish collected in each study river. Values are shown  $\pm$  SEs.

Year	Month	$N$	TL (mm)	Weight (g)	Fullness (% body weight)
<b>Contentnea Creek</b>					
2001	Jul	15	492 $\pm$ 45	1,827 $\pm$ 432	0.67 $\pm$ 0.33
	Aug	52	455 $\pm$ 25	1,636 $\pm$ 305	0.33 $\pm$ 0.08
	Sep	13	428 $\pm$ 61	1,785 $\pm$ 960	0.73 $\pm$ 0.35
2002	May	19	498 $\pm$ 27	1,688 $\pm$ 295	0.20 $\pm$ 0.05
	Jun	22	512 $\pm$ 38	2,164 $\pm$ 446	0.44 $\pm$ 0.17
	Jul	21	438 $\pm$ 35	1,390 $\pm$ 366	0.27 $\pm$ 0.60
	Aug	11	301 $\pm$ 72	1,504 $\pm$ 621	0.30 $\pm$ 0.09
<b>Northeast Cape Fear River</b>					
2001	Jul	10	407 $\pm$ 53	1,205 $\pm$ 547	2.40 $\pm$ 0.76
	Aug	12	409 $\pm$ 46	1,237 $\pm$ 476	3.00 $\pm$ 1.32
	Sep	2	413 $\pm$ 139	1,083 $\pm$ 867	3.70 $\pm$ 3.10
	Oct	5	420 $\pm$ 76	1,029 $\pm$ 647	0.47 $\pm$ 0.40
2002	Apr	8	555 $\pm$ 88	4,681 $\pm$ 3,344	1.50 $\pm$ 0.53
	May	14	381 $\pm$ 46	1,096 $\pm$ 390	3.80 $\pm$ 1.40
	Jun	8	298 $\pm$ 40	444 $\pm$ 265	1.50 $\pm$ 1.00
	Jul	5	449 $\pm$ 58	1,216 $\pm$ 473	0.28 $\pm$ 0.10
	Aug	18	379 $\pm$ 40	989 $\pm$ 295	0.41 $\pm$ 0.13
	Sep	5	239 $\pm$ 79	1,043 $\pm$ 88	0.18 $\pm$ 5.00

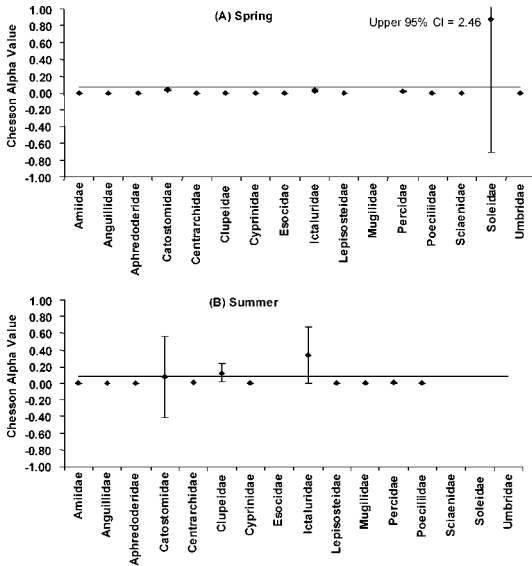


FIGURE 1.—Chesson’s alpha index of selectivity ( $\pm$  95% confidence intervals for selected families) for each prey family in Contentnea Creek during (A) spring and (B) summer. The horizontal dashed lines represent neutral selectivity ( $1/m$ , where  $m$  is the total number of prey categories). A value above this line indicates positive selectivity for a particular prey family, a value below this line indicates negative selectivity. Families without values were not available as prey items during that season.

river (Table 3). Ictalurids were relatively rare in the river, and although they were the third most abundant fish family in the flathead catfish diet, they occurred in the diet only twice; thus feeding selectivity for ictalurids was generally random. However, nine other fish families that occur in this river were not found in the flathead catfish diet; these may be considered negatively selected prey taxa (Table 3). Chesson’s index values were not calculated for the Northeast Cape Fear River because of small sample sizes.

**Discussion**

Our results demonstrate that flathead catfish consume both species that coevolved with them and those that did not. The prediction that introduced predators selectively prey on species unfamiliar with a particular predation style cannot be resolved with certainty for introduced flathead catfish from our diet and selectivity information alone, or by other published accounts of flathead catfish diets. Indirect evidence demonstrating a correlation in declines of specific prey species with the introduction of flathead catfish found in other

TABLE 3.—Ranks by number of fish prey identified in the flathead catfish diet and number of fish prey available in the two study rivers during spring and summer, by family (see Kwak et al. 2004 for individual population density estimates).

Family	Spring		Summer	
	Prey rank	Availability rank	Prey rank	Availability rank
<b>Contentnea Creek</b>				
Amiidae		5		11
Anguillidae		3		10
Aphredoderidae		9		9
Catostomidae	4	7	5	4
Centrarchidae	2	2	1	3
Clupeidae		12	4	5
Cyprinidae	6	1	2	1
Esocidae		11		
Ictaluridae	3	6	7	8
Lepisosteidae		8		7
Mugilidae				12
Percidae	1	4	3	2
Poeciliidae		10		6
Sciaenidae		14		
Soleidae	5	13		5
Umbridae		14		
<b>Northeast Cape Fear River</b>				
Amiidae		3		3
Anguillidae		12		
Bothidae		10		
Catostomidae		6		8
Centrarchidae	1	1	1	1
Cyprinidae		4		4
Esocidae		5		8
Gerreidae				5
Ictaluridae	3		3	6
Lepisosteidae		7		8
Mugilidae		11		
Percidae		9		6
Poeciliidae		8		11
Soleidae	1	2	1	2

studies may support the hypothesis that flathead catfish disproportionately affect certain species or families, but our rankings of prey items and selectivity results suggest that flathead catfish feeding is generally nonselective with regard to available prey fishes. However, the impact of the predation pressure from introduced flathead catfish, even at low levels, in addition to that from native predators may exceed the sustainable mortality level for a particular prey species population; a modeling exercise may further resolve this hypothesis (Pine 2003).

In Contentnea Creek and the Northeast Cape Fear River, flathead catfish coexist with a broad range of available forage items, including anadromous and estuarine species. These species may serve as a predation buffer to resident native freshwater fishes by diffusing flathead catfish predation

pressure across a larger prey base. This finding supports the suggestion by Ashley and Rachels (2000) that declines in native redbreast sunfish populations (which did not coevolve with flathead catfish) observed in the Black and Lumber rivers of North Carolina may result from direct predation by flathead catfish, because a lack of marine organisms in these rivers presents fewer potential prey types available compared with the prey base in the rivers we studied. In our study, flathead catfish stomachs from Contentnea Creek contained twice as many identified fish families as did those from the Northeast Cape Fear River. Of the 14 identifiable prey groups considered here, only 4 were common to both the Northeast Cape Fear River and Contentnea Creek in 2001 and 2002. The MANOVA result also serves as supporting evidence for the ecological conclusion that flathead catfish in Contentnea Creek fed on a wider range of prey types than in the Northeast Cape Fear River.

Juvenile anadromous shad were found in flathead catfish stomachs in Contentnea Creek, and Chesson's index values suggest positive selection for this family. Juvenile American shad *Alosa sapidissima* and Hickory shad *A. mediocris* occupied Contentnea Creek in moderate densities during our summer sampling (30 fish/km; Kwak et al. 2004). Also, as part of other sampling efforts during early spring within the Neuse River basin, flathead catfish were incidentally collected and found to be feeding on adult hickory shad (J. Hightower, North Carolina Cooperative Fish and Wildlife Research Unit, unpublished data). Neither of these shad species coevolved with flathead catfish or any other similar freshwater predator. Ashley and Buff (1988) also found adult anadromous shad in stomachs of flathead catfish from the Cape Fear River, North Carolina. Adult shad were not present in the rivers we sampled during the periods when we could effectively collect flathead catfish. Within their native and introduced range, flathead catfish have been documented to forage intensively on juvenile and adult gizzard shad *Dorosoma cepedianum* (Layher and Boles 1980; Quinn 1988). This further indicates that adult clupeids do not pose gape limitations to adult flathead catfish. The predation impacts of introduced flathead catfish on juvenile and adult anadromous shad should be important to managers concerned with anadromous shad restoration efforts along the Atlantic slope.

We examined published diet studies for introduced flathead catfish to determine whether prey species that did not coevolve with flathead catfish,

and that thus were more vulnerable to the predation style of a newly introduced predator (Moyle and Light 1996; Williamson 1996), were more common in the flathead catfish diet. We did not find evidence for preferential feeding; however, several important examples should be highlighted. Guier et al. (1984) reported large abundance changes in the native fish community in the Cape Fear River, North Carolina, after flathead catfish introduction primarily in the native ictalurids, brown bullheads *Ameiurus nebulosus* and flat bullheads *A. platycephalus*, neither of which coevolved with flathead catfish, nor were they collected in either of our two study rivers. The most frequently occurring stomach items reported by Guier et al. (1984) were from the families Centrarchidae and Ictaluridae, both of which were available and found in stomach samples in our study. Additionally, all native ictalurids were absent in sampling by Moser and Roberts (1999) on the lower Cape Fear River; these investigators suggested that flathead catfish and blue catfish extirpated native ictalurids in their study reaches.

Several corollary declines in native fish populations have been documented after flathead catfish introduction. Ashley and Rachels (2000) noted a decline in electrofishing catch rates for native redbreast sunfish *Lepomis auritus* in the Black and Lumber rivers, North Carolina, and considered predation by flathead catfish to be a reason for this decline. Thomas (1995) documented an 80% decline in redbreast sunfish abundance in the Altamaha River, Georgia, and near elimination of native bullheads after the introduction of flathead catfish. Over the same period, electrofishing catch rates for flathead catfish in that area increased nearly 400%, implicating flathead catfish as the cause for changes in the river's fish assemblage. In other lotic systems with introduced flathead catfish populations such as the Ocmulgee River, Georgia, the abundances of silver redhorse *Moxostoma anisurum*, robust redhorse *M. robustum*, snail bullhead *Ameiurus brunneus*, flat bullhead, and redbreast sunfish were all negatively correlated with flathead catfish presence and abundance, which was attributed to direct predation by flathead catfish (Bart et al. 1994). Redbreast sunfish did not coevolve with flathead catfish and presumably would be a candidate species to be selectively preyed upon by flathead catfish because the sunfish would be naïve to the predation style of flathead catfish. Redbreast sunfish were present in both of our rivers, although their abundance was low compared with that of other congeneric species such as bluegill *L. ma-*

*crochirus* (Kwak et al. 2004). However, additional predation pressure by flathead catfish may have altered the *Lepomis* spp. component of the community before we undertook our study. We found a prevalence of sunfish in the flathead catfish diet but neutral selectivity for them, suggesting that they are impacted by predation but are no more vulnerable to it than other fish families.

Our results on flathead catfish diet selectivity among prey fishes are not unequivocal, but they are the first such data on selectivity in either native or introduced flathead catfish populations and offer insight on the predator–prey relations of this species in riverine habitats. Flathead catfish appear to feed most prevalently on species that are abundant in their river surroundings. Overall, the trends we observed between prey fish occurrence and flathead catfish diet suggest that among fish families, flathead catfish may feed nonselectively with respect to prey abundance and opportunistically within microhabitats they occupy. For example, the generally positive feeding selectivity for hogchokers *Trinectes maculatus* (Soleidae) that we detected may be related to similar microhabitat selection between this family (demersal) and the flathead catfish (also demersal; Kwak et al. 2004).

Our diet and selectivity analyses have shown that introduced flathead catfish in coastal river systems are primarily piscivorous and feed on a wide variety of fish families, generally in a nonselective fashion. Flathead catfish also frequently consume crayfish, a secondary component of their diet. Many of the fish families we found in the flathead catfish diet include species that represent important recreational fisheries in coastal rivers—bluegill, largemouth bass *Micropterus salmoides*, redbreast sunfish, and anadromous shad. Other families represented in the diet contain species of special concern because of their imperiled population status (e.g., robust redbreast and Cape Fear shiner *Notropis mekistocholas*). Although our results suggest nonselective feeding as the predominant mode at the fish family level, we are not able to ultimately resolve the hypothesis that flathead catfish selectively feed on certain prey species, including recreationally important sport fishes or species that did not coevolve with flathead catfish. However, the flathead catfish populations examined here are established, reproducing populations, and if highly selective feeding by flathead catfish occurred in the past, the impact would likely be greatest initially after introduction, such that the assemblages we studied now suffer from the “ghost of predation past.” Restoration and management efforts for

native fish communities should consider the presence of invasive species, such as flathead catfish, in coastal and inland rivers. The ecological impact of a voracious predator such as flathead catfish could hamper the success of these efforts (e.g., restoration efforts for anadromous shad species along the Atlantic slope) by direct predation on species of interest to river managers and the public.

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