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TECHNICAL REPORT

Introduced Flathead Catfish Pilot Study

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Introduced Flathead Catfish Pilot Study

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Executive Summary

The Introduced Flathead Catfish Pilot Study was a collaborative effort of the Pennsylvania Flathead Catfish Consortium, comprised of Pennsylvania Sea Grant (PASG, Sea Grant), the Philadelphia Water Department (PWD, the Water Department), the Monell Chemical Senses Center (MCSC, the Monell Center), the Academy of Natural Sciences of Philadelphia (ANS, the Academy) in cooperation with the Pennsylvania Fish and Boat Commission (PFBC). This three-part study collected baseline information that will enable fisheries managers to make better informed decisions to protect the Delaware Estuary Coastal Zone's native fish and shellfish resources, and help prevent the spread of introduced flathead catfish (FCF) to new waterways including those of New York, New Jersey and Delaware.

The primary accomplishments of this pilot study were:

1. Preliminary assessment of FCF distribution and abundance in the Delaware River watershed
2. Preliminary analysis of FCF diet, feeding habits and prey items
3. Behavior studies that investigated potential FCF biological control techniques

This project augments Pennsylvania CZM's fisheries management policy by improving scientific knowledge about flathead catfish and identifying potential biological controls that will help protect popular recreational species of the Delaware Estuary Coastal Zone, including American shad, herring, striped bass and blue crab. It also promoted intergovernmental coordination between agencies (i.e., PWD and PFBC) and local academic research institutions (i.e., PASG, MCSC and ANS).

Throughout the project period, members of the Consortium planned and carried-out lab and field studies and tested field collection and stomach content analysis methods. The PWD and the ANS used dip-net and electrofishing techniques to perform targeted sampling for FCF in the Schuylkill River drainage and other sites in the Delaware Basin. Schuylkill River sampling sites included the Fairmount Fish Ladder in Philadelphia, Black Rock Dam in Mont Clare, Flat Rock Dam in Gladwyne, Plymouth Dam in Conshohocken, Vincent Dam in Linfield and the area upstream and downstream of Manatawny Creek in Pottstown. A number of sites were sampled along the main stem of the Delaware River, but no FCF were collected.

The stomachs of a number of the flathead stomachs were dissected and examined to gain a better understanding of diet, feeding habits and prey preferences. The ANS also examined the stomach contents of potential juvenile FCF predators, such as smallmouth bass, to determine the feasibility of increasing predation pressure to control FCF; however, these findings were inconclusive.

Finally, the MCSC conducted laboratory behavioral studies of FCF to investigate potential biological control methods. Tests of sensitivity to several possible chemical attractants were evaluated as potential lures for trapping flatheads. FCF response to electrical stimulation was also assessed to explore the possible use of commercially available electrical barriers to prevent flathead infestation of new tributaries.

A total of 101 flatheads were captured by the Consortium in 2003 and removed from the Schuylkill River drainage. Eleven FCF were preserved by the ANS for future study and possible stable isotope analysis, and the PWD has frozen tissue from a few specimens. This sampling generated data regarding the current distribution, size structure and abundance of FCF, which was compiled into a common database. Distribution maps were then generated by the PWD using ArcView software.

Many more flatheads were collected in the Fairmount Fish Ladder in 2003 than in previous years, and this may be the result of frequent flooding during the spring and summer season (that might have flushed flatheads downstream). However, size ranges of fish from the Schuylkill River indicate that reproduction is occurring and suggests that abundance is increasing, although removal during sampling may be locally decreasing the abundance of large individuals. On a more positive note, there were no confirmed reports of FCF on the mainstem of the Delaware River in 2003 that would indicate successful range expansion outside the Schuylkill drainage.

The Monell Center's basic finding was that FCF had different chemical sensitivities than the better researched channel catfish, however, more work is needed to confirm chemical sensitivity. The Monell Center also found that FCF, like other catfish, were highly sensitive to electrical stimulation, which indicates that commercially available electrical barriers may be a promising way to block the movement of FCF.

This project lays the foundation for future research to further assess FCF abundance and distribution, as well as FCF impacts on fisheries resources in the Delaware Estuary Coastal Zone. To this end, our findings will help agencies such as CZM and PFBC to better inform their fisheries management efforts. This project also provided an example for other aquatic invasive species (AIS) research and management initiatives. By facilitating cooperative, coordinated efforts among agencies and research institutions in the Delaware Estuary Coastal Zone, our findings serves as a model for future AIS management initiatives, such as monitoring and rapid response planning. Further field and lab study is underway and the 2004 findings will add to those presented in this report.

Introduction

The flathead catfish (*Pylodictes olivaris*) is native to the Mississippi River drainage and some other Gulf of Mexico watersheds, however, introduced populations have become established in a number of drainages in the Southeastern United States (Kwak et al. 2004, Jackson 2000, Moser and Roberts 1999, Dobbins et al. 1999) reaching relatively high densities for a predatory fish. Major effects on sunfishes (*Lepomis* and related species), catfishes and bullheads (*Ictalurus* and *Amieurus*), minnows, and herrings populations (Ashley and Buff 1987, Thomas 1995, Odenkirk et al. 1999, Moser and Roberts 1999) have been observed. As a result, rigorous control programs have been instituted in a number of areas. For example, intensive electrofishing in the Satilla River, GA, aimed at keeping the flathead catfish (FCF) population from gaining community dominance, has reduced the average size of FCF, although abundance remains high (Harrison 2004).

Flathead catfish were first documented in the Delaware River drainage in 1997, when a pair was caught in Blue Marsh Reservoir (Mike Kaufmann, Pennsylvania Fish and Boat Commission, personal communication). FCF were first observed in the Schuylkill River Fishway in 1999 (at the Fairmount Dam) during a routine cleaning. Since this discovery of flatheads in the Philadelphia area, they have been reported in several additional Schuylkill River locations. Only a few reports have been confirmed in the main stem of the Delaware River. Anglers now report catching FCF below the Holtwood and Safe Harbor dams on the Susquehanna River.

The abundance of flathead catfish is often difficult to estimate because of low capture efficiencies using many standard large fish collection techniques, such as, high frequency boat electrofishing (e.g., Stauffer and Koenen 1999). Flathead catfish are also not as frequently caught in traps with scented baits as channel catfish (*Ictalurus punctatus*), presumably because of their preference for live food. Similarly, FCF are not typically caught on scent baits and other hook-and-line baits commonly used by anglers to catch channel catfish and bullheads. A number of targeted sampling techniques have been employed with limited success including low frequency electrofishing (Stauffer and Koenen 1999, Gilliland 1987, Harrison 2004), unbaited hoop nets, and rod-and-reel using live fish bait; resulting catch rates were often low and some of these techniques show size selectivity. The effectiveness of these techniques also seems to vary with environmental conditions (e.g., temperature and water conductivity), season, and biological status of the fish.

In 2002, the Introduced Flathead Catfish Pilot Study was initiated out of a desire to better understand the impact populations of introduced FCF might have on Delaware Estuary fisheries. This study represents a cooperative effort of the Pennsylvania Flathead Catfish Consortium, comprised of Pennsylvania Sea Grant (PASG, Sea Grant), the Philadelphia Water Department (PWD, the Water Department), the Monell Chemical Senses Center (MCSC, Monell Center) and the Academy of Natural Sciences of Philadelphia (ANS, the Academy), in cooperation with the Pennsylvania Fish and Boat Commission. Because of the negative impacts introduced FCF have had on native fish communities in other areas of the country, the consortium felt it was important to investigate possible population control strategies.

Since limiting the spread of FCF into new habitats and reducing their reproductive success in drainages where they have been introduced will require several complimentary strategies (i.e., education, selective barriers, targeted removal and disruption of spawning), it is important that fisheries managers have a thorough understanding of their natural history, reproductive and feeding biology, and sensory ecology. Accordingly, the primary goals of this pilot study were:

4. Assessment of FCF distribution and abundance in the Delaware River watershed
5. Analysis of FCF diet, feeding habits and prey items
6. Behavior studies that investigated potential FCF biological control techniques

This report represents a summary of the Pennsylvania Flathead Catfish Consortium activities to date.

Methods

During the project period the Water Department and the Academy planned and carried-out lab and field studies and tested field collection and stomach content analysis methods. The Monell Center conducted lab studies of FCF sensory biology.

<u>Study Sites</u>
The Academy and Water Department used electrofishing and dip-net techniques to perform targeted sampling for FCF in the Schuylkill River Drainage and other sites in the Delaware Basin (figure 1). Schuylkill River sampling sites included the Fairmount Fish Ladder in Philadelphia, Black Rock Dam in Mont Clare, Flat Rock Dam in Gladwyne, Plymouth Dam in Conshohocken, Vincent Dam in Linfield and the area upstream and downstream of Manatawny Creek in Pottstown. Table 1 further describes the Schuylkill River habitats where the Academy sampled.

A number of sites along the main stem of the Delaware River were sampled by the Academy, but no FCF were collected. In addition, data from other sampling programs by ANS were compiled to provide additional information on the presence of flathead catfish. No flathead catfish were caught in these samples.

<u>Academy Fish Collection Techniques</u>
The Academy compared the effectiveness of a variety of electrofishing protocols for sampling FCF. Most electrofishing was conducted from boats during daylight hours using DC pulse output voltages. Protocols that were compared included:

1. High current, high voltage boat electrofishing (HCHV). Sampling was done with the electrofishing boat, using currents of 10-12 amps, pulse width of 30-40 %, frequency of 80-100 pulses/sec and voltages of 150-200 V.

2. Moderate current, moderate voltage boat electrofishing (MCMV). This was done using identical gear as HCHV, but with different electrical settings. For MCMV, moderate currents (7-10 amps), pulse width of 20-30 %, frequency of 40-80 pulses/sec and voltages of 100-150 V were used. This technique is the standard technique for collecting most species by ANS.

3. Low current, low voltage boat electrofishing (LCLV). Sampling was done using identical gear as HCHV, but with different electrical settings. For LCLV, currents of 3-6 amps, pulse width of 20 %, frequency of 20-40 pulses/sec and voltages of 50-80 were used.

4. Low current generator electrofishing (LCEg). Sampling was done with a Smith-Root Model 15-D backpack electrofisher operated from a boat. This shocker uses a Honda EX350 gas engine to produce various output currents. The anode electrode is an 11-in diameter aluminum ring with a cathode trailing wire. LCEg was done with about 0.5-1 amps, and 200 to 600 volts in a fixed position from an anchored boat, and moving along the shoreline.

5. Low current, low voltage micro-electronic electrofishing (LCEb). Sampling was done with a micro-electronic "pacemaker" device designed specifically for catfish collection in a fixed position from an anchored boat. It is powered by a 6-volt battery.

6. Low current, low voltage, magneto generators (LCEm). Sampling was done with a hand-cranked "telephone" magneto with dropped wire electrodes in a fixed position from an anchored boat.

HCHV, MCMV, and LCLV electrofishing techniques were tested in a variety of habitats. Typical habitats included eddies at the base of dams, lateral eddies downstream of dam walls (i.e., portions of dams with no overflowing water), riffles, runs, log and snag cover along shores, and creek and canal mouths. Sampling was done in an upstream, downstream and/or lateral direction (typically upstream and then downstream in riffles and runs, upstream or downstream in areas of low current, and lateral at the base of dams). The duration of electrofishing was recorded to calculating catch per unit of effort.

The Academy also conducted limited sampling using trotlines at one station. Two 50-ft trotlines, each with 25 hooks baited with live fish (sunfish and bullheads), were set and left overnight. One channel catfish and one yellow bullhead (*Amieurus natalis*) and no flathead catfish were caught using this technique.

All FCF that were captured were removed from the river. Most other species that the Academy captured along with flatheads were weighed, measured, enumerated and released. When large numbers of some species (e.g., common carp, white sucker, some minnows) were encountered, numbers of shocked fish were visually estimated and recorded without netting and handling, in order to maximize search time and efficiency for FCF. All FCF were measured, most were weighed and most were preserved on ice in the field and subsequently frozen. Two specimens were held alive by the Academy and 10 live catfish were used by Monell Center for lab investigations.

<u>Water Department Fish Collection Techniques</u>
The Water Department used two strategies to assess the abundance of FCF in the lower Schuylkill drainage. The first method collected fish that occupied the Fairmount Fish Ladder. Draining was accomplished by closing the sluice gate at the upstream portion of the ladder, while

a fabricated steel grate at the lower chamber blocked fish passage. After the water drained, all fish species were collected from the bottom of the ladder using a 6'-1/4" mesh dip net.

The second method incorporated boat-based electrofishing techniques in the tidal Schuylkill River and non-tidal portion of the Fairmount pool between Flatrock and Fairmount Dams. Umbrella rigs were lowered approximately one meter into the water column and an electrical current was distributed around the marine vessel. The electrical current was operated at approximately 4-6 amps at the low voltage range (0-500 volts). Stunned fish were collected using 8'-1/4" mesh nets and placed in an aerated holding tank. Duration time for electrofishing was ten minutes. All specimens collected by Water Department were observed for DELTA and total length and weights were recorded. All species, excluding FCF, were returned alive to the river.

Stomach Content Analysis

The stomachs of a number of FCF were dissected and examined to gain a better understanding of diet, feeding habits and prey preferences. Most FCF collected by the Water Department were sacrificed, dissected and the heads were frozen for future study. The stomach contents of freshly dissected FCF were examined under a dissecting microscope to determine prey items. The Academy also examined the stomach contents of potential juvenile FCF predators, such as smallmouth bass, to determine the feasibility of increasing predation pressure to control FCF; however, these findings were inconclusive.

To analyze stomach contents, the Academy thawed the stomachs of frozen specimens and opened them to determine the contents. Stomach material was removed and examined in the lab using a dissecting microscope for prey identification. In addition, stomachs were dissected and contents noted on archived specimens collected in 2000-2002 (before the study period began). Stomach contents of specimens that were held alive were obtained by pumping at the time of capture. The fish was held over a tray, the tip of a wash bottle was inserted into the esophagus, and water was pumped into the esophagus until liquid and food items were washed out into the tray. Food items were then preserved and examined in the laboratory using a dissecting microscope. Similarly, the Water Department used a siphon to pump river water into the mouths of collected FCF, resulting in the evacuation of stomach contents into a white 9"x12" pan. Stomach contents were then examined for the presence of fish, invertebrate or plant remnants and observations were recorded.

Sensory Biology Methods

The Monell Center conducted various laboratory behavioral studies of FCF to investigate potential biological control methods. For example, tests of FCF sensitivity to several possible chemical attractants were evaluated as potential lures for trapping. FCF response to electrical stimulation was assessed to explore the possible use of commercially available electrical barriers to prevent flathead infestation of new tributaries.

Sensitivity to Amino Acids

Since catfish can detect a variety of compounds that are associated with food, including amino acids, the Monell Center assessed the general sensitivity of FCF olfactory systems to amino acids using electroolfactogram (EOG) recordings from the olfactory sensory epithelium. Preliminary estimates of taste bud density were made using several large (> 40 cm TL) fish. Estimates of taste bud and ampullary electroreceptor densities were made from freshly killed fish. Small (~1 cm^2) pieces of skin from different regions of the body and fin surfaces were removed and pinned to the sylgard-covered bottom of a Petri dish containing fish Ringer solution (figure 4). For counting the external pores of the canals of ampullary organs (small pit organs), the external surface was treated for 5-10 minutes with black ink. When subsequently washed, the ink tended to stay in the pores, making them easier to visualize. Taste buds appeared as small bumps, sitting on top of pigmented dermal papillae carrying the nerve fibers and blood vessel to each bud. Brief staining of the skin with a 1% solution of methylene blue often used to further enhanced contrast.

The number of pores or taste buds in a 2 mm^2 field (inside the photo reticule of the dissecting microscope) was counted for 3-4 grids on each piece of skin. Taste bud density was estimated on the maxillary barbels by removing a small section from the middle of a barbel, measuring the diameter at each end and counting over a 2 mm length. The surface area of the piece was estimated by approximating the section as a cylinder. Counts were made all the way around the section since the taste buds tend to be concentrated on the anterior (leading) edge of the barbel.

Results

Comparison of Collection Techniques

Table 2 summarizes the sampling efficiency of different electrofishing protocols tested by the Academy. While all FCF were collected in moderate-current, moderate-voltage or high current, high-voltage electrofishing (MCMV and HCHV), a variety of other species, including channel catfish, were caught using moderate and high current (MCMV and HCHV) boat electrofishing protocols (Table 3). A variety of fish were caught using the LCLV protocol while moving along the shore and in the mouth of a lock at Mont Clare. One sunfish surfaced using the LCLV protocol in a fixed mode. The LCLV protocol was less effective than the MCMV and HCHV protocols, so collection efficiencies by the LCLV were not presented.

FCF Distribution, Abundance and Size Structure

A total of 101 flatheads were captured by the Consortium in 2003 and removed from the Schuylkill River drainage. Eleven FCF were preserved by the Academy for future study and stable isotope analysis, and the Water Department has frozen tissue from a number of specimens. Our collection generated data regarding the current distribution, size structure and abundance of FCF, which was compiled into a common database. ArcView distribution maps were then generated by the Water Department.

Eleven flathead catfish were caught by the Academy in July, one from Conshohocken, 3 from Vincent, and 7 from Mont Clare (Table 3). The specimen at Conshohocken was caught in a small eddy next to a chute at the base of Plymouth Dam in water less than a meter in depth at a temperature of 27° C and conductivity of 419 μmos. The specimens from Vincent were caught in shoreline snag piles at depths ranging from 0.7-1.3 m at a water temperature of 25° C and a conductivity of 440 μmos. The specimens at Mont Clare were also collected in relatively shallow water (about 0.7-1.3 m depth) at a temperature of 27° C and conductivity of 468 μmos around fallen trees along a portion of shore located about 300 m below Black Rock Dam. Catch rates are compared in Table 2.

Flathead catfish ranged from 6.2 to 90 cm in field total length. Fishes 40-75 cm in length predominated captures throughout the study period. Catfish smaller than 40 cm were only recorded in 2002 and 2003, likely a result of increased sampling effort and not indicative of a shift in population size structure. Other fish captured during targeted flathead electrofishing are summarized in table 4.

<u>Stomach Contents and Diet</u>
Crayfish were the most common prey item in larger catfish (4 of 6 individuals) caught by the Academy in the upper Schuylkill River (Table 5). One white perch was consumed as well. Two smaller specimens contained small macroinvertebrates (chironomids and amphipods). One fish had no prey items in the stomach. Table 6 presents the Water Department stomach contents observations. Eighty-five of the FCF were caught in the Fairmount Fish Ladder (26% of guts containing food items) and 3 caught in the Fairmount Pool (all containing food). Of the 3 specimens from the Fairmount Pool, 2 contained crayfish and 1 contained fish remains. Of the 22 fishway specimens with food, 16 (73%) contained fish, 7 (32%) contained plant material, one (5%) contained mollusks, and one (5%) contained worms (the sum of these is greater than 100%, since some specimens contained more than one food type). It is uncertain whether the plant material was ingested as food or incidentally.

<u>Sensory Biology</u>
EOG recordings from 6 FCF were made and a comparison of the most stimulatory amino acids at 100 µM concentrations for flatheads and channel catfish are shown in figure 5. Although some differences in sensitivity are apparent (e.g., high sensitivity of FCF to glutamine), these need to be confirmed by additional experiments. The availability of suitable sized fish for this work has been problematic.

The relatively unreliable availability of FCF made it difficult to justify using the few fish available for acute electrophysiological experiments. Consequently, preliminary efforts to assess the sensitivity of FCF to electrical fields have relied on behavioral measures. Initial experiments were attempted with small (< 20 cm) fish in 10-50 gallon aquaria using hand-held electrodes producing a local dipole field. Although initial reactions (body squirming) occurred at about the expected intensities (50-100 µV/cm), clear approach responses were not observed and avoidance responses were not obtained until very high intensities were reached. These results suggest that the fish were too stressed under these experimental conditions to respond reliably. Subsequent experiments were attempted with much larger fish (>50 cm) captured in the Fairmount Fish Ladder. These fish were held in 200-gallon tanks at 10-12^{o} C. Again, local dipoles did not elicit clear responses until intensities considerably higher than expected were reached. These experiments are currently being repeated at warmer temperatures

Discussion

Collection Techniques
Our study found the most effective technique for collecting FCF in mid-summer was boat electrofishing with moderate to high frequencies and voltages. Low frequency techniques, which are effective in some areas, were found to be ineffective in our study area. Low frequency electrofishing has been found to be most effective at higher temperatures (e.g., above 24°C, Vokoun and Rabeni 2000) in high conductivity waters. Flathead catfish were not caught in boat electrofishing samples collected by the Water Department and Academy in the tidal Delaware River or farther upstream, possibly due to the moderate temperatures and conductivities of this waterway.

In addition to electrofishing, FCF are often trapped by anglers. Although FCF are not as vulnerable to baited traps as other catfishes, they may enter unbaited traps or hoop nets seeking cover or nesting sites. Traps were not used in this study because of the difficulty of sampling multiple sites with traps, which require more than one visit for setting and retrieval, and the greater spatial coverage within stations by electrofishing. Local anglers noted capture of FCF in the Schuylkill River, although no angler-caught specimens were reported through the activities of this study.

FCF Distribution and Abundance
The 2003 field findings collectively indicate that the FCF is widespread in the middle and lower Schuylkill River. In addition, a specimen was reported in the Schuylkill River in 2000 or 2001 near the mouth of Monocacy Creek, upstream of the 2003 Academy sampling sites (Ann Faulds, personal communication).

Many more FCF were collected in the Fairmount Fish Ladder than in previous years, possibly as a result of frequent flooding during the spring and summer season (that might have flushed flatheads downstream). The size range of fish from the Schuylkill River indicates that reproduction is occurring and that abundance is increasing, although removal during sampling may have locally decreased the abundance of large individuals.

The three sites where the Academy collected FCF were very near the base of 3 dams and in snags along the shore several hundred meters downstream of Black Rock Dam and Vincent Dam. The Water Department caught FCF near the Flat Rock Dam (at the upper end of the pool), at Manayunk and the mouth of Wissahickon Creek (in the middle of the pool) and at the lower end of the Fairmount pool, just upstream of the fishway. The two stations at which FCF were not caught by Academy were the lower end of the Flat Rock Pool (i.e., above Flat Rock Dam), and near Pottstown. Given the low capture rate of FCF, it is difficult to determine their abundance at the different stations and additional sampling may be needed to confirm the absence of flatheads from any given site.

Flathead catfish have also been reported in the Delaware River. Three specimens have been caught in large-mesh gill nets in the vicinity of Bordentown (John O'Herron, personal communications). Specimens have also been reported in Springton Reservoir (Crum Creek drainage), but no FCF were found in several Academy backpack electrofishing samples downstream of Springton Reservoir. Moreover, there were no confirmed reports of FCF on the main stem of the Delaware River in 2003 that would indicate successful range expansion outside the Schuylkill drainage.

In the Cape Fear River, fall and winter movements of FCF into brackish water (up to 6 ppt salinity) have been documented by radiotelemetry (Kwak et al. 2004). If FCF show similar tolerance in the Delaware Estuary, they could potentially range downstream and into the C & D Canal during seasons of low salinity. Factors controlling the potential upstream limit of FCF are not known. Given the general southerly distribution of the species, reproduction may be limited by low summer water temperatures in the north. In its native range in the Allegheny River, Pennsylvania, it extends to about 42° N latitude (Argent 1997, Cooper 1983). There was a population in southern Lake Erie in Ohio (Trautman 1981), also at about 42°N latitude. There are at least two recent records from southwestern Ontario, the northernmost at about 42°20' N latitude (Goodchild 1993). In the Mississippi Drainage, the FCF ranges north to North Dakota, Minnesota and Wisconsin (Lee et al. 1980), reaching about 48° N latitude. The Pennsylvania-New York border is located at 42° N latitude, so FCF could potentially spread through most of the Delaware Drainage (and southern New England as well, if interbasin transfers occur).

The size range of FCF captured indicates the presence of multiple age classes, including young fish. Jackson (2000) summarized growth rates from a number of studies, and Mayo and Schramm (2000) reported growth rates in the Mississippi River. Over the range of systems studied, 40-cm FCF are typically 3 to 4 years old, and 70-cm catfish were typically 5 to 7 years old. Munger et al. (1994) reported ages of 2 to 11 years for FCF 29 to 100 cm in total length from Texas reservoirs. In that study, some fish were mature at 30 cm, about half the fish were mature at 40 cm, and about 80% were mature at 80 cm. Munger et al. 1994 also presented limited data that suggested that flatheads grow more slowly in rivers than in reservoirs.

Stomach Content Analysis

Food habit studies of FCF indicate feeding on a range of fishes, including minnows, clupeids (shad and herrings), catfish and bullheads, and sunfishes (Lee and Terrell 1987, Ashley and Buff 1987, Thomas 1995). Crayfish and clams are also moderately frequent in FCF diets, although fish have been found to be the predominant foods in larger catfish.

Summarizing published studies, Jackson (2000) noted that FCF typically switched from invertebrates to a fish or fish and crayfish diet by the time they reach 25-36 cm total length. While sample sizes in the present study are too small to make quantitative comparisons, a similar range of food types was seen. The presence of invertebrates in 21-cm and 28-cm catfish and fish or crayfish in 40-60 cm catfish is consistent with the transition noted in other studies. However, larger fish collected in the middle Schuylkill River (i.e., at Vincent and Mont Clare stations) had relatively few fish (only one of five fish with food had fish remains). Since catfish often feed at night, partial or complete digestion of food may have occurred by the time we sampled. As a result, catfish collected during the day may underestimate the proportion of soft-bodied prey and overall feeding rates. In this study, FCF were collected around 11:50 at Conshohocken, from 12:30-13:30 at Mont Clare and 16:45-18:15 at Vincent. Crayfish exoskeletons were nearly intact; the one fish specimen in the gut was largely dissolved, but an otolith was present.

Similarly, fish remains were evident in many catfish collected in daytime from the fish ladder by bones or scales.

Sensory Biology
Preliminary results of laboratory studies on response to electrical fields show promise as a method to control the spread of FCF into new tributaries. It may be possible to set the electrical fields of a commercially available barrier to an extremely low level to prevent catfish passage while allowing other fish to pass uninterrupted. Juvenile FCF of optimum size for behavior research (12-18 inches) are hard to obtain in the field or from hatcheries. Locating research FCF for lab experiments needs to be a major priority for next season's experiments.

Research Recommendations
This project lays the foundation for future research to further assess FCF abundance and distribution, and impacts FCF on fisheries resources in the Delaware Estuary Coastal Zone. Based on the implications of the consortium's work to date, below is an outline of work proposed in the second phase of the project, funding period October 2003 to March 2005.

The Academy will continue to assess FCF current distribution and abundance throughout the Schuylkill River and at sites on the mainstem of the Delaware River. The Academy will also continue to assess FCF diet and potential impacts to local fisheries including additional gut analysis and a new stable isotope experiment to quantify the component of the diet that is freshwater of marine derived. The Water Department plans to augment the field activities of the Academy by reporting flathead catfish captures in their routine fish sampling, but does not plan any targeting sampling.

The Monell Center will continue its investigation of FCF sensory biology to evaluate promising biological and physical control methods. Continue research investigating chemical sensitivity would be directed at the development of possible FCF attractants. The feasibility of investigations of chemical and electrical sensitivity in a more realistic flume situation is currently being evaluated.

Pennsylvania Sea Grant will head-up work to inform anglers and boaters about the ecological health risks associated with flatheads. Public outreach work includes the development of a brochure about FCF, a portable educational exhibit, and a Delaware Estuary Introduced Flathead Catfish Internet Clearinghouse.

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Tables and Figures

Table 1. Site descriptions of locations of targeted flathead catfish sampling by ANS during 2003.

Site	River Mile	Habitat Description
Pottstown	54-55	Runs, cover along the banks and along islands, riffles and the mouth of Manatawny Creek and the mouth of an abandoned mill race.
Vincent	44-45	The base of Vincent Dam, which is partly breached, large eddies downstream of remaining portions of the dam on either side, runs, riffles, and cover along shorelines.
Mont Clare	35-36	The base of Black Rock Dam (approaching to about 25m of the dam), runs, riffles, cover along shorelines, the mouth of a canal/lock, and the mouth of a small creek.
Conshohocken	18-21	The base of Plymouth Dam, riffles, runs and pools, lateral eddies downstream of the sides of the dam, bridge abutments and the mouth of a small creek. The top of Plymouth Dam has been damaged in several places, so the base of the dam consists of a series of chutes with eddies along either side. Shocking was done in these eddies and along the sides of the chutes.
Gladwyne	16	Part of the pool above Flat Rock Dam. The area contains pools, runs, cover along shorelines, and the mouth of Mill Creek.

Table 2. A comparison of ANS 2003 sampling effort (minutes of actual sampling time) and catch rates (catch is calculated as total catch divided by total effort at the station) for various flathead catfish collection techniques.

Site & Date	Boat electrofishing		Low current, low voltage devices				Other	Effort (min.)
	HCHV	MCMV	LCLV	LCEg Generator	LCEb Battery	LCEm Magneto	Trot Line	
Pottstown								
30-Jul-03	30	105	3					138
Flathead cpue (number/hr)	0	0	0					
Vincent							2 line nights, 25 hooks each	
10-Jul-03	17	60	30					107
17-Jul-03	53	37	15					105
Flathead cpue (number/hr)	2.57	0	0					
Flathead cpue (number/hr) HCHV and MCMV	2.00							
Mont Clare								
7-May-03	153	20		124	132			429
Flathead cpue (number/hr)	0	0		0	0			
18-Jul-03	70							70
Flathead cpue (number/hr)	6.00	0						
Conshohocken								
9-Jul-03		150	30	15		15		210
Flathead cpue (number/hr)		0.4	0	0		0		
Gladwyne								
9-Jul-03	7.5		7.5			15		30
Flathead cpue (number/hr)	0		0			0		
Total Effort (min.)								**1089**

Table 3. ANS collection of flathead catfish (*Pylodictis olivaris*) in the 2003 study period. FTL (cm) is the total length measured in the field, LTL is the total length measured in the laboratory (after thawing) and TW is the total weight.

Station	Date	Sample	Protocol	FTL (cm)	LTL (cm)	TW (g)
Mont Clare	7/18/2003	BS8	HCHV			
				77.5	75.5	5750
				50.5	50.0	1400
				44.4	45.5	865
Mont Clare	7/18/2003	BS9	HCHV			
				60.5	59.1	2500
				55.5	55.1	1500
				46.4	46.0	1060
				21.2	20.9	nw
Vincent	7/17/2003	BS8	HCHV			
				14.2	nm	nw
Vincent	7/17/2003	BS9	HCHV			
				27.8	27.5	195
				a. 45	na	na
Conshohocken	7/9/2003	BS6	MCMV			
				19.0	nm	nw

Table 4. Catch per 15 minutes electrofishing time by moderate and high current boat electrofishing at Pottstown (POT), Vincent (VIN), Mont Clare (MC) and Conshohocken (CON) sites. Catch is calculated as total catch divided by total catch at the station.

	Station	**POT**	**VIN**	**MC**	**MC**	**CON**
	Month	7	7	5	7	7
	Effort (min)	135	167	173	70	150
Species	**Scientific Name**					
American shad	*Alosa sapidissima*	0.22	0	0	0	0
American eel	*Anguilla rostrata*	0.11	0.09	0	0	0.70
Rainbow trout	*Oncorhyncus mykiss*	0	0	0.35	0	0
Brown trout	*Salmo trutta*	0	0	0.26	0	0
Tiger muskie	*Esox lucius x masquinongy*	0	0	0.09	0	0
Common carp	*Cprinus carpio*	9.56	1.08	1.73	12.21	0
Goldfish	*Carassius auratus*	0.33	0.36	0.26	0.43	0
Golden shiner	*Notemigonus crysoleucas*	1.67	0.54	0	0	0
Spotfin shiner	*Cyprinella spiloptera*	7.11	8.62	4.08	0	0.10
Common shiner	*Luxilus cornutus*	0.11	0.27	0.09	0	0
Spottail shiner	*Notropis hudsonius*	0.11	1.44	0.43	0	0
Swallowtail shiner	*Notropis procne*	0	0.18	0	0	0
White sucker	*Catostomus commersoni*	1.44	2.51	5.64	0.21	1.10
Quillback	*Carpiodes cyprinus*	0	0	4.60	0	0
Northern hog sucker	*Hypentelium nigricans*	0	0	0.09	0	0
Yellow bullhead	*Amieurus natalis*	2.44	3.77	0	0	0.10
Brown bullhead	*Amieurus nebulosus*	0.11	0.63	0	0	0
Channel catfish	*Ictalurus punctatus*	0.89	3.41	1.47	1.71	0
Flatfhead catfish	*Pylodictus olivaris*	0	0.27	0	1.50	0.10
Banded killifish	*Fundulus diaphanus*	0.22	0	0	0	0
Rock bass	*Ambloplites rupestris*	3.33	0.90	0.43	0.21	0.40
Bluegill	*Lepomis macrochirus*	0.89	5.48	1.21	2.57	0.60
Redbreast sunfish	*Lepomis auritus*	4.67	2.87	0	0	
Green sunfish	*Lepomis cyanellus*	0.22	1.35	0.35	0.43	0.50
Pumpkinseed	*Lepomis gibbosus*	0.56	0.90	0.35	0.21	0.40
Hybrid sunfish	*Lepomis*	0	0.09	0.09	0	0
Sunfish species	*Lepomis*	0	0	0.09	0	0
Smallmouth bass	*Micropterus dolomieu*	2.33	3.59	4.16	0.86	3.00
Largemouth bass	*Micropterus salmoides*	0.33	0.54	0.35	0.43	0.10
Black crappie	*Pomoxis nigromaculatus*	0.67	0.63	0.78	1.29	0
White perch	*Morone americana*	2.44	0.09	0	1.07	0
Tesselated darter	*Etheostoma olmstedi*	0	0	0.09	0	0
Yellow perch	*Perca flavescens*	0	0	0.09	0.21	0
Walleye	*Stizostedion vitreum*	0	0	0.09	0	0

Table 5. Stomach contents of flathead catfish collected by ANS in 2003 along with specimens collected and archived from 2001.

Station	Date	Field Total Length (cm)	Total Weight (g)	Contents
Mont Clare	July, 2003	77.5	5750	Gravel
	July, 2003	60.5	2500	White perch otolith
	July, 2003	55.5	1500	Crayfish
	July, 2003	50.5	1400	Crayfish
	July, 2003	46.4	1060	Crayfish
	July, 2003	44.4	865	Crayfish
	July, 2003	21.2		Amphipods
Vincent	July, 2003	27.8	195	Chironomids
Fairmount Fishway	May, 2001	54.2	2120	Empty
	May, 2001	52.6	1933	Empty
	May, 2001	39.6	736	Empty

Table 6. Stomach contents of flathead catfish collected by PWD (2002-2003).

Station	Date	Field Total Length (cm)	Total Weight (g)	Contents
Fairmount Fishway	11/6/2003	6.2	0	empty*
	6/26/2003	40.7	700	empty
	6/26/2003	42.1	950	empty
	9/18/2003	42.1	950	empty
Fairmount Pool (Green Lane Bridge)	5/1/2003	43.3	720	Fish (minnow)
Fairmount Fishway	6/26/2003	46.0	1100	empty
	6/26/2003	46.8	1150	empty
	9/18/2003	46.9	1200	Fish remains
	6/26/2003	47.2	1350	empty
	9/18/2003	47.3	1150	empty
	6/26/2003	48.3	1500	Fish scales
	9/18/2003	48.4	1350	empty
	9/18/2003	48.5	1450	empty
	6/26/2003	48.7	1500	empty
	9/18/2003	49.0	1500	Fish bones, leaf
	9/18/2003	49.0	1400	empty
	9/18/2003	49.1	1300	Fish remains
	9/18/2003	49.5	1500	empty
	6/26/2003	50.1	1400	empty
	9/18/2003	50.5	1550	empty
	6/26/2003	50.7	1500	empty
	9/18/2003	51.0	1550	empty
	11/6/2003	51.0	1600	empty*
	9/18/2003	51.5	1600	empty
	9/18/2003	51.5	1800	empty
	9/18/2003	52.1	1600	Fish remains
	6/26/2003	52.3	1650	empty
	6/26/2003	52.4	1650	leaf debris
	9/18/2003	52.7	1900	Fish bones, otolith
	6/26/2003	53.0	1750	Fish scale (carp)
	9/18/2003	53.0	1700	empty
	9/18/2003	53.2	2100	empty
	11/6/2003	53.3	1950	empty*
	9/18/2003	53.5	1950	empty
	9/18/2003	53.9	1950	plant material
	11/6/2003	54.0	1750	worms and leaves
	9/18/2003	54.1	2000	empty
	9/18/2003	54.5	2000	empty
	6/26/2003	54.6	2200	empty
	9/18/2003	54.6	1900	leaf debris

Table 6 (cont.). Stomach contents of flathead catfish collected by PWD (2002-2003).

Station	Date	Field Total Length (cm)	Total Weight (g)	Contents
Fairmount Fishway	9/18/2003	54.8	1700	empty
	6/26/2003	55.5	2100	empty
	11/6/2003	55.7	1850	leaves
	6/26/2003	56.0	2050	Fish scale (sunfish)
	6/26/2003	56.1	2000	empty
Fairmount Pool (above Fishway)	9/13/2002	58.0	2000	Crayfish
Fairmount Fishway	9/18/2003	58.1	2300	empty
	6/26/2003	58.5	2400	empty
	6/26/2003	58.8	2750	empty
Manayunk Canal at Lock Street	8/14/2003	59.0	2200	crayfish
Fairmount Fishway	6/26/2003	59.0	2400	empty
	9/18/2003	59.5	2700	Fish bones and otoliths; Mollusc (*Corbicula* and unidentified)
	6/26/2003	59.7	2700	empty
	9/18/2003	60.0	2850	empty
	11/6/2003	60.0	2600	Fish scales and leaves
	9/18/2003	60.9	2550	empty
	9/18/2003	61.0	2800	Fish bones and flesh
	9/18/2003	61.3	2600	empty
	9/18/2003	61.5	2900	empty
	6/26/2003	61.6	3400	empty
	6/26/2003	62.0	2550	empty
	9/18/2003	62.0	2900	empty
	9/18/2003	62.1	3250	empty
	11/6/2003	62.4	3050	empty*
	9/18/2003	63.0	3300	empty
	6/26/2003	63.5	3600	empty
	9/18/2003	63.8	3300	empty
	6/26/2003	66.6	3850	empty
	9/18/2003	66.9	4100	plant material
	11/6/2003	66.9	3550	empty*
	6/26/2003	67.5	3400	Fish scale (carp)
	9/18/2003	67.5	3900	Fish bones
	9/18/2003	67.7	4000	empty
	9/18/2003	68.0	4200	empty
	11/6/2003	68.1	4000	empty*
	9/18/2003	68.5	4450	empty
	9/18/2003	68.5	4400	empty
	5/17/2003	70.0	5000	empty
	6/26/2003	70.0	5100	empty
	9/18/2003	70.0	4100	Fish bones

Table 6 (cont.). Stomach contents of flathead catfish collected by PWD (2002-2003).

Station	Date	Field Total Length (cm)	Total Weight (g)	Contents
Fairmount Fishway	6/26/2003	71.0	5500	empty
	11/6/2003	72.0	4700	empty*
	9/18/2003	72.5	5200	empty
	9/18/2003	73.2	5150	Fish ribs
	9/18/2003	74.1	5100	empty
	6/26/2003	79.5	6500	empty
	6/26/2003	81.0	7100	empty
	6/26/2003	90.0	12500	Fish (sunfish)
* Stomach contents from pumping				

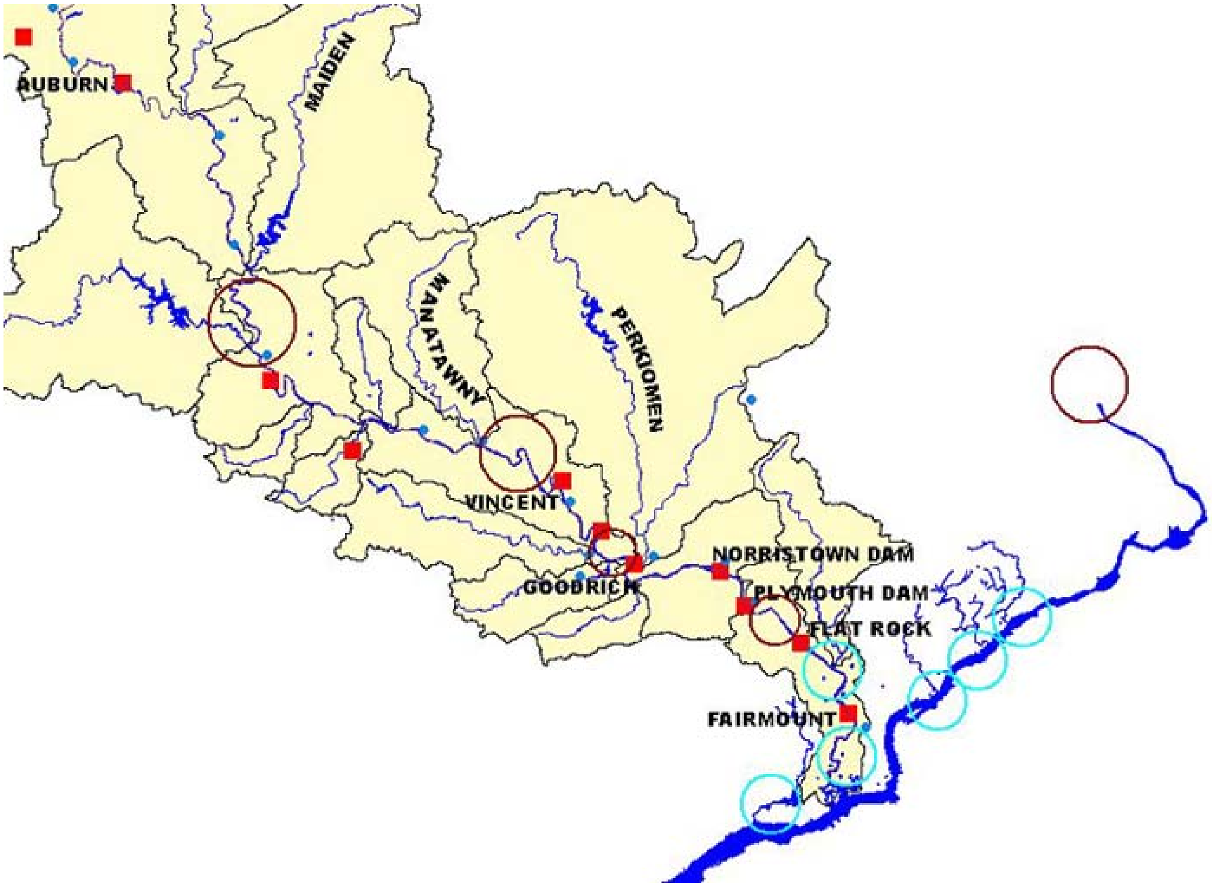

Figure 1. Areas sampled for the presence of Flathead Catfish in 2003. Brown circles represent areas where the Philadelphia Water Department sampled in 2003 while blue circles represent areas where ANS sampled. Squares indicate confirmed sightings as of 2002.

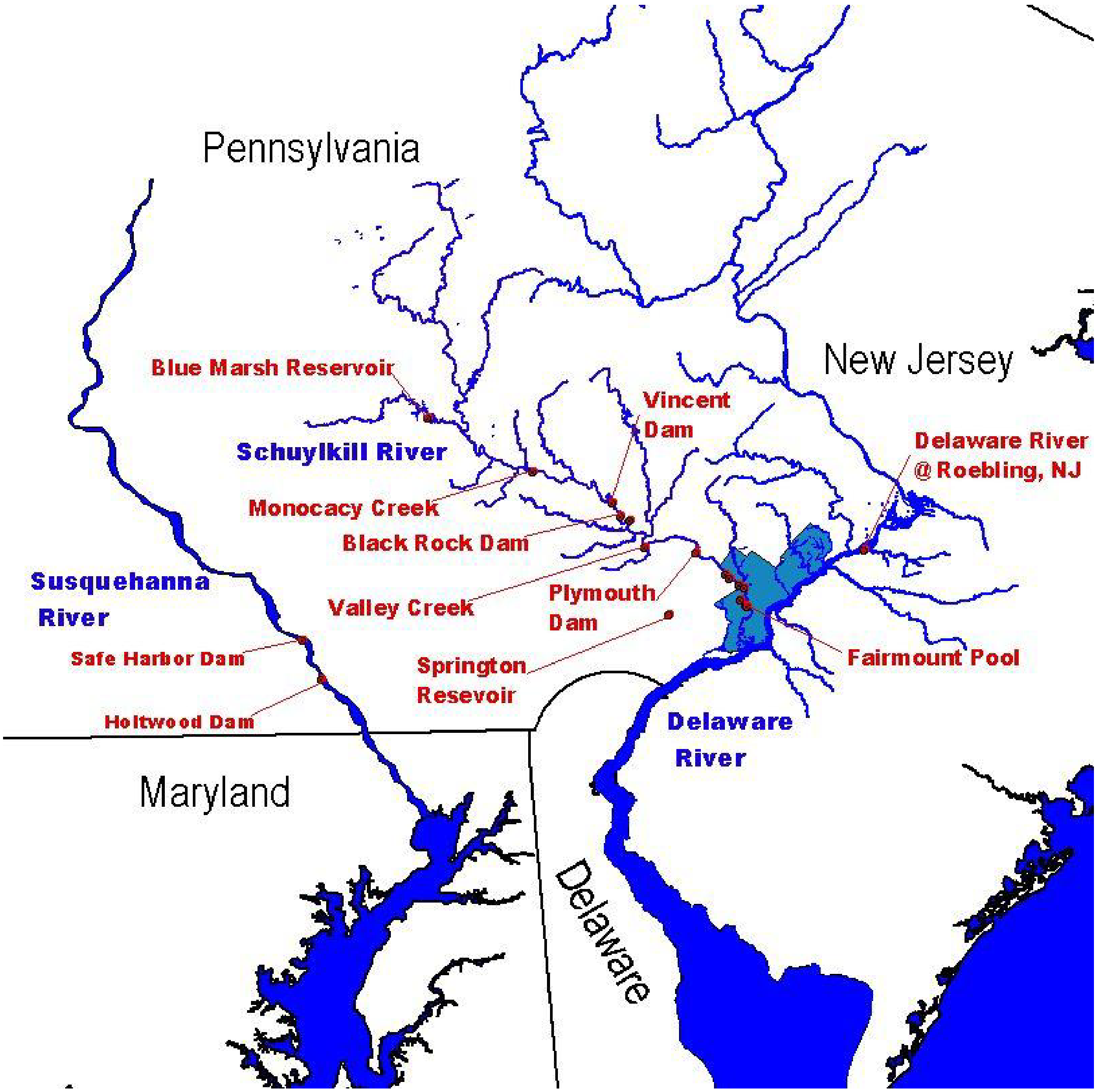

Figure 2. Areas in the Delaware and Susquehanna drainage with confirmed Flathead Catfish reports as of March 2004.

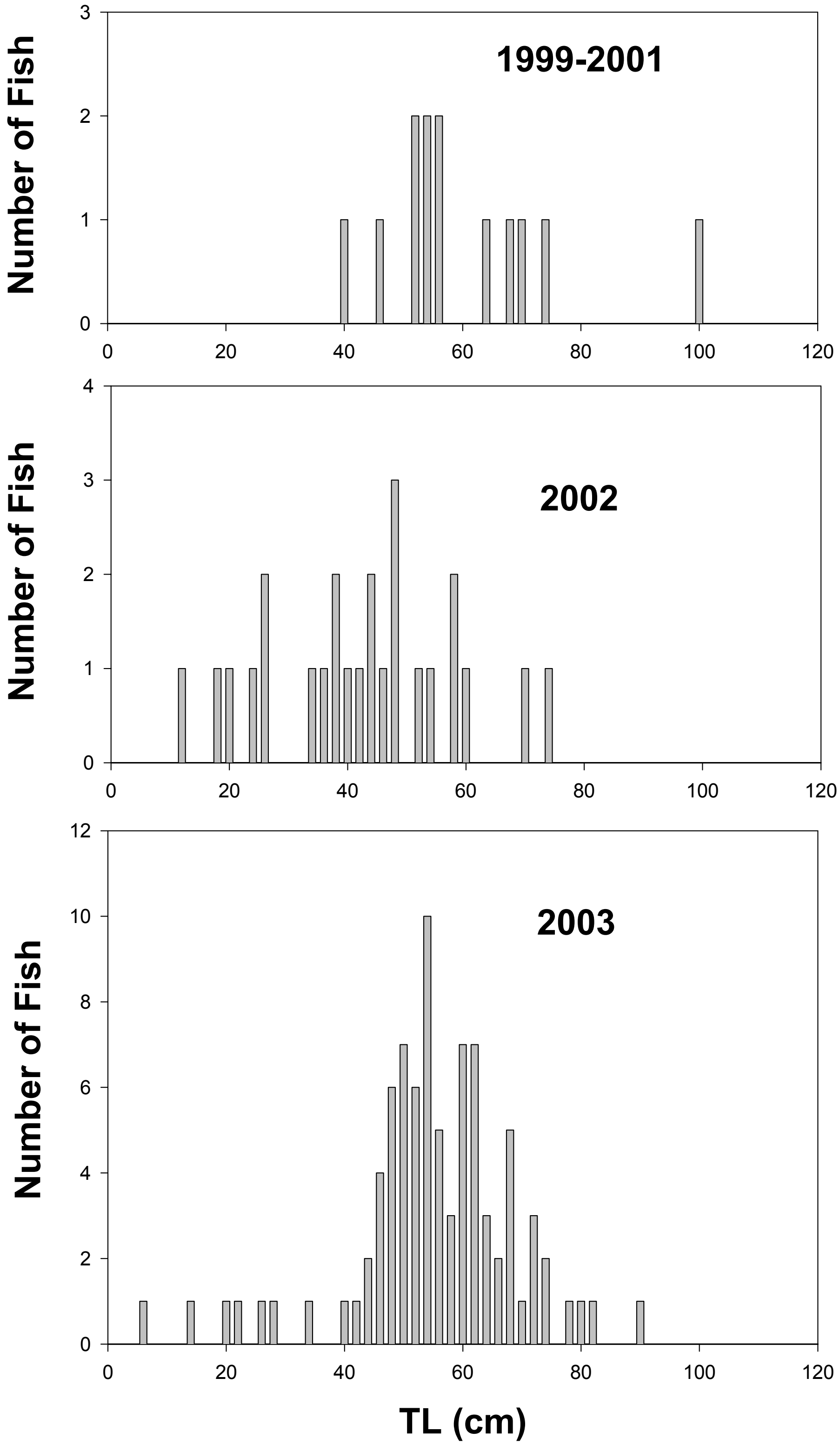

Figure 3. Frequency of total lengths (in 2-cm groups) of flathead catfish collected in the Schuylkill River, 1999-2003. Specimens are from 2003 collections by AND, PWD, and 1999-2002 observations and collections in the Schuylkill Fishway by PWD and others.

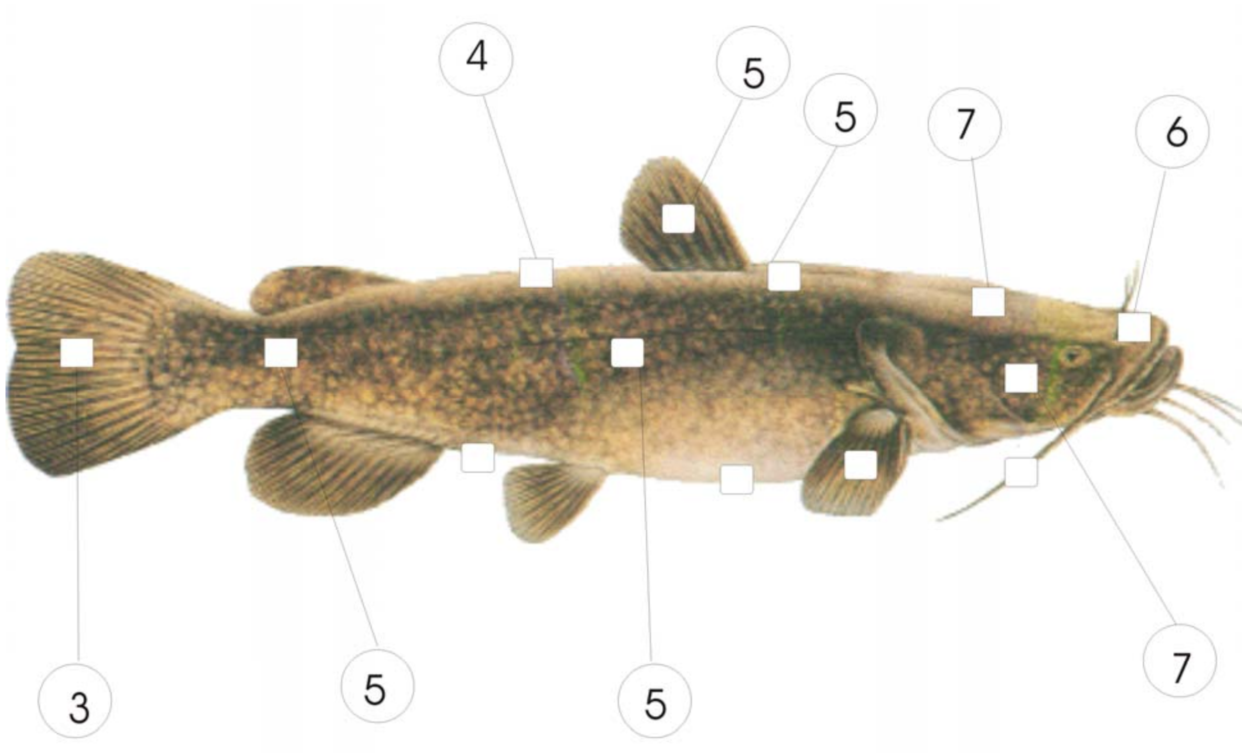

Figure 4. Taste bud densities at selected regions. Mean number of taste buds per mm^2 (3 counts per region) for a flathead catfish 47 cm total length, 41 cm standard length.

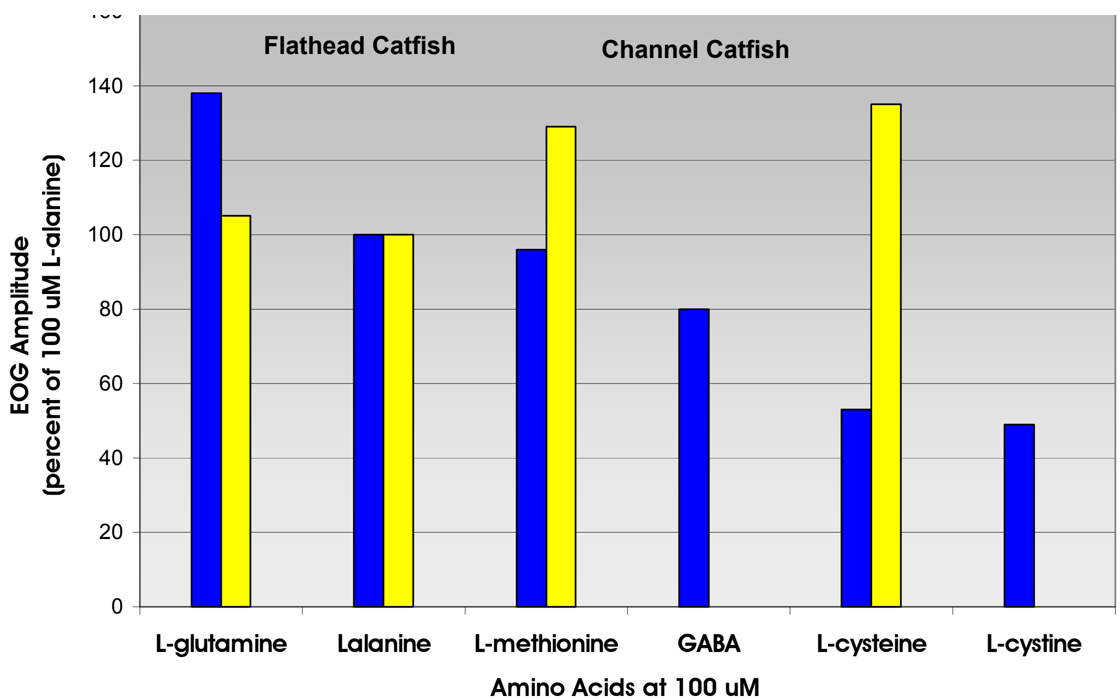

Figure 5. Relative olfactory stimulatory effectiveness of 6 amino acids. Charted is a comparison of the most stimulatory L-amino acids for flathead catfish (blue) and channel catfish (yellow). Channel catfish data from Caprio (1982).