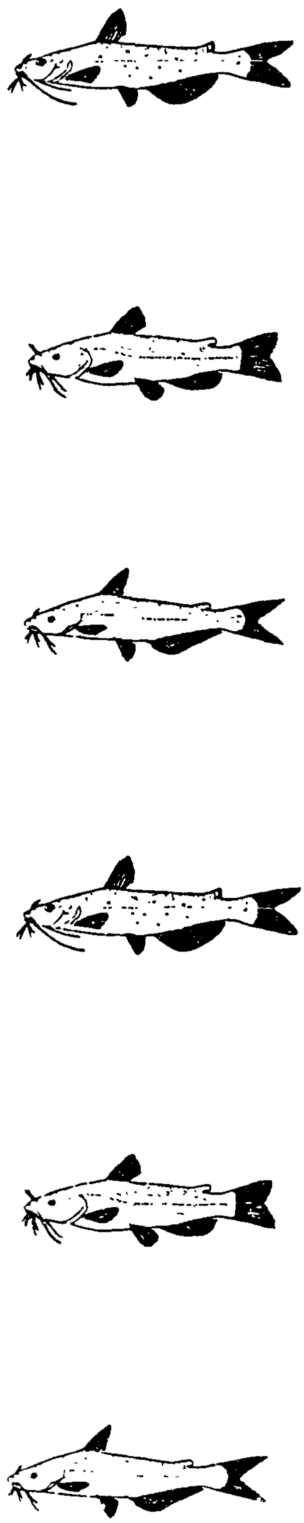


EPA 903-R-98-001
CBP/TRS 193/98

Catfish Populations in Chesapeake Bay

January 1998

Chesapeake Bay Program

Chesapeake Bay Program

The Chesapeake Bay Program is a unique regional partnership leading and directing restoration of Chesapeake Bay since 1983. The Chesapeake Bay Program partners include the states of Maryland, Pennsylvania, and Virginia; the District of Columbia; the Chesapeake Bay Commission, a tri-state legislative body; the U.S. Environmental Protection Agency (EPA), which represents the federal government; and participating citizen advisory groups.

In the *1987 Chesapeake Bay Agreement*, Chesapeake Bay Program partners set a goal to reduce the nutrients nitrogen and phosphorus entering the Bay by 40% by the year 2000. In the *1992 Amendments* to the *Chesapeake Bay Agreement*, partners agreed to maintain the 40% goal beyond the year 2000 and to attack nutrients at their source--upstream in the tributaries. The Chesapeake Executive Council, made up of the governors of Maryland, Pennsylvania, and Virginia; the mayor of Washington, D.C.; the EPA administrator; and the chair of the Chesapeake Bay Commission, guided the restoration effort in 1993 with five directives addressing key areas of the restoration, including the tributaries, toxics, underwater bay grasses, fish passages, and agricultural nonpoint source pollution. In 1994, partners outlined initiatives for habitat restoration of aquatic, riparian, and upland environments; nutrient reduction in the Bay's tributaries; and toxics reductions, with an emphasis on pollution prevention.

The 1995 *Local Government Partnership Initiative* engages the watershed's 1,650 local governments in the Bay restoration effort. The Chesapeake Executive Council followed this in 1996 by adopting the *Local Government Participation Action Plan* and the *Priorities for Action for Land, Growth and Stewardship in the Chesapeake Bay Region*, which address land use management, growth and development, stream corridor protection, and infrastructure improvements. A 1996 riparian forest buffers initiative furthers the Bay Program's commitment to improving water quality and enhancing habitat with the goal of increasing riparian buffers on 2,010 miles of stream and shoreline in the watershed by the year 2010.

Since its inception, the Chesapeake Bay Program's highest priority has been the restoration of the Bay's living resources--its finfish, shellfish, bay grasses, and other aquatic life and wildlife. Improvements include fisheries and habitat restoration, recovery of bay grasses, nutrient reductions, and significant advances in estuarine science.

U.S. Environmental Protection Agency

Libraries

OLS Record

Search | Summary | Prior | Next | Manual | Help | Display Records as Bibliography | Item Status

RECORD NUMBER: 1 OF 1

Main Title	**Catfish populations** in **Chesapeake Bay**
Author	Sauls, B.; Dowling, D.; Odenkirk, J.; Cosby, E.
CORP Author	Maryland Dept. of Natural Resources, Annapolis. ;Virginia Marine Resources Commission, Newport News. VA. ;Virginia Dept. of Game and Inland Fisheries, Richmond.;Environmental Protection Agency, Annapolis, MD. Chesapeake Bay Program.
Publisher	printed by the U.S. Environmental Protection Agency for the Chesapeake Bay Program,
Year Published	1998
Report Number	DBP/TRS 193/98 ; EPA 903-R-98-001; CBP/TRS-193/98
Stock Number	PB98-123235
OCLC Number	39102540
Subjects	Catfish, Chesapeake Bay, Estuaries, Surveys; Fish populations; Habitats; Freshwater fish; Maryland; Virginia; Ictaluridae, Ameiurus catus; Ameiurus matalis; Ictalurus punctatus, Ictalurus furcatus
Subject Added Ent	Catfishes--Chesapeake Bay (Md. and Va.) ; Fish populations--Chesapeake Bay (Md. and Va.)
Collation	58 p. : ill. ; 28 cm.
Holdings	

LIBRARY	CALL NUMBER		LOCATION
EJAD	EPA 903/R-98-001		Region 3 Library/Philadelphia, PA
EJDD	CB 00753	2 copies	OASQA Library/Fort Meade,MD
NTIS	PB98-123235	Most EPA libraries have a fiche copy filed under the call number shown. Check with individual libraries about paper copy.	NTIS

Abstract	This report is the result of a multi-jurisdictional effort to explore current knowledge of the Chesapeake Bay's catfish populations. Long-term surveys of catfish species do not exist in the Chesapeake Bay region, and basic biological data are fragmented with small, regional studies conducted over intermittent periods of time. This report represents a regional cooperative effort to bring together all available information and assimilate the best possible understanding of catfish biology, ecology and stock dynamics of native and introduced catfish species in the Chesapeake Bay system. This report also documents the evolution of social, economic, and recreational dependence as fisheries have developed following the naturalizaton of non-native catfish species. As efforts shift to exploit more abundant or less regulation resources, resilient species such as catfish should be carefully monitored. By assembling current information and identifying research and data needs, this report establishes a reference from which to gauge and direct future management.
Notes	"EPA 903-R-98-001." "CBP/TRS 193/98." "January 1998."
Supplementary Notes	Prepared in cooperation with Virginia Marine Resources Commission, Newport News. VA. and Virginia Dept. of Game and Inland Fisheries, Richmond. Sponsored by Environmental Protection Agency, Annapolis, MD. Chesapeake Bay Program.
Availability Notes	Product reproduced from digital image. Order this product from NTIS by: phone at 1-800-553-NTIS (U.S. customers); (703)605-6000 (other countries); fax at (703)321-8547; and email at orders@ntis.fedworld.gov. NTIS is located at 5285 Port Royal Road, Springfield, VA, 22161, USA.
Author Added Ent	Sauls, Beverly.
Corp Au Added Ent	United States. Environmental Protection Agency. Chesapeake Bay Program.
Place Published	Annapolis :
PUB Date Free Form	1998.
NTIS Prices	PC A05/MF A01
Holdings Modified	**LIBRARY Date Modified** EJA 19980522 EJD 19990313
Bib Level	m
OCLC Time Stamp	19990312111337
Cataloging Source	OCLC/T
Language	eng
OCLC/NTIS	OCLC
Type	MERGE
OCLC Rec Leader	01030nam 2200265Ka 45020

Catfish Populations in Chesapeake Bay

Prepared by

Beverly Sauls
Maryland Department of Natural Resources

David Dowling and John Odenkirk
Virginia Department of Game and Inland Fisheries

Ellen Cosby
Virginia Marine Resources Commission

for the
Fishery Management Plan Workgroup
Living Resources Subcommittee
Chesapeake Bay Program
Annapolis, MD

Printed by the U.S. Environmental Protection Agency
for the Chesapeake Bay Program

TABLE OF CONTENTS

TABLES AND FIGURES

PURPOSE

This report is the result of a multi-jurisdictional effort to explore current knowledge of the Chesapeake Bay's catfish populations. Long-term surveys of catfish species do not exist in the Chesapeake Bay region, and basic biological data are fragmented with small, regional studies conducted over intermittent periods of time. This report represents a regional cooperative effort to bring together all available information and assimilate the best possible understanding of catfish biology, ecology and stock dynamics of native and introduced catfish species in the Chesapeake Bay system. This report also documents the evolution of social, economic, and recreational dependence as fisheries have developed following the naturalization of non-native catfish species. As efforts shift to exploit more abundant or less regulated resources, resilient species such as catfish should be carefully monitored. By assembling current information and identifying research and data needs, this report establishes a reference from which to gauge and direct future management.

BIOLOGY

Introduction

North American catfish from the family Ictaluridae are freshwater species that commonly range into estuarine waters. Large members of the genus *Ictalurus* (forktail catfishes) are important commercial, recreational and aquacultural species. Medium-size species from the genus *Ameiurus* (bullheads) are important recreational species and are moderately exploited commercially. Madtoms, small catfish of the genus *Noturus*, are found primarily in high reaches of freshwater creeks and small rivers and are not covered in this report.

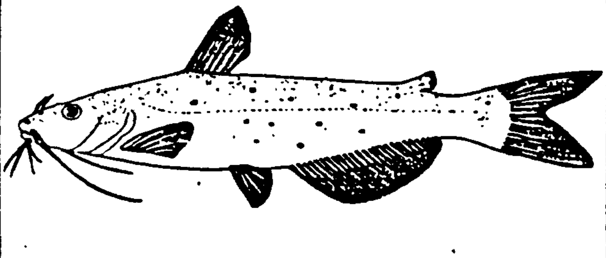
Three species of bullheads are native to the Chesapeake Bay system: white catfish (*Ameiurus catus*[1]), brown bullhead (*A. nebulosus*[2]), and yellow bullhead (*A. natalis*[3]). Two introduced species of catfish, channel catfish (*Ictalurus punctatus*) and blue catfish (*I. furcatus*), have become economically important to the region. Channel catfish are established in the upper Bay and tributaries throughout the Bay system. Blue catfish, once considered rare, are becoming increasingly abundant in several drainage systems. A third introduced species, flathead catfish (*Pylodictis olivaris*), has only a limited distribution in Chesapeake Bay at present. Habitats are not clearly partitioned between species, and overlap is common. When found together, one species usually dominates, as has been observed with white and channel catfish in the Choptank River (Bonzek and Morin 1988) and Virginia tributaries (VIMS unpublished data) and with blue and channel catfish in the upper reaches of some Virginia tributaries (VDGIF unpublished data).

---

[1] Previously known as *Ictalurus catus*.

[2] Previously known as *Ictalurus nebulosus*

[3] Previously known as *Ictalurus natalis*

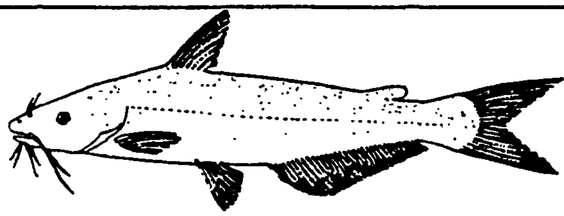


Channel Catfish

COLOR: Gray to greenish-gray or yellow-olive, sides fade to silver-gray, white belly. Juveniles have black speckles.

FINS: Caudal fin deeply forked, 24 - 29 anal rays.

OTHER: Barbels extend past head, upper jaw slightly protruded.

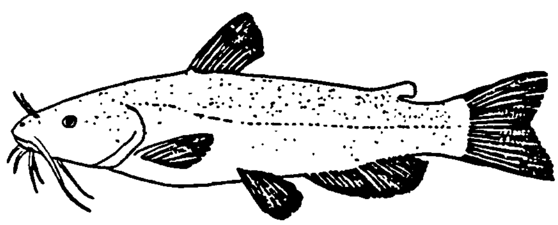


Blue Catfish

COLOR: Pale blue to white underneath.

FINS: Caudal fin deeply forked. Anal fin straight-edged with 30 - 36 anal rays.

OTHER: Steeply sloping predorsal profile, heavy bodied. Largest Bay species.

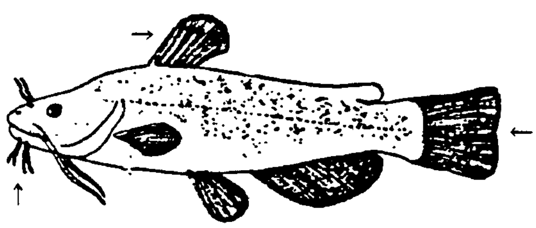


White Catfish

COLOR: Bluish-gray on back and sides, white underneath.

FINS: Caudal fin moderately forked, 19 - 23 anal rays.

OTHER: Noticeably broad head and stout body. Smaller than blue and channel cats.

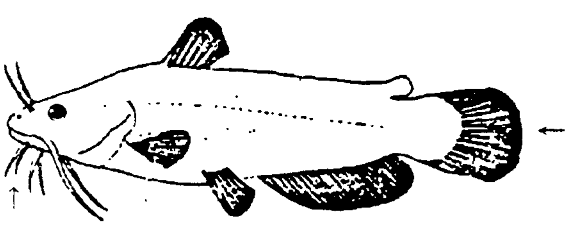


Brown Bullhead

COLOR: Brown back, sides often mottled brown, white underside.

FINS: Square, slightly notched caudal fin. 20 - 24 anal rays.

OTHER: Dark barbels, serrated pectoral spine.

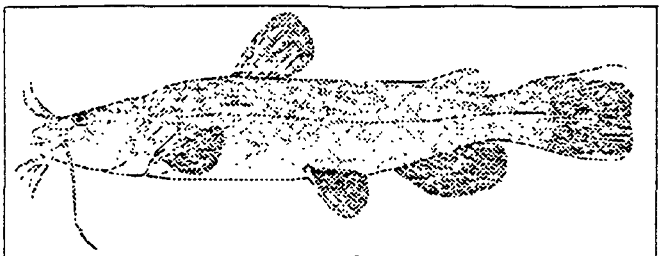


Yellow Bullhead

COLOR: Light olive to dark brown, yellow sides, white underside.

FINS: Rounded caudal fin, 24 - 27 anal rays.

OTHER: Yellow to white barbels, short bodied.



Flathead Catfish

COLOR:	Olive to dark brown with dark marbled blotches. Yellow to olive underneath.
FINS:	Squarish, white-edged tail. 14-17 anal rays (rarely 13 or 18 rays).
OTHER:	Broad, flat head. Lower jaw protrudes beyond upper jaw.

Historical Ranges, Local Distribution, and Abundance

Range

White catfish, brown bullhead, and yellow bullhead inhabit fresh and brackish water bodies of central and eastern North America. White catfish are an eastern species that occur along the Atlantic and Gulf Coast States from New York to Florida. Brown bullheads range from Maine to Florida and from the Great Lakes in the Midwest south to Texas. Yellow bullheads range from Connecticut to Florida and the Gulf States and north to Minnesota in the central United States.

The native range of channel catfish extends from southern Canada, through the Great Lakes and central United States drainage system, to Mexico including all the Gulf States and some of the Atlantic Coast. Extensive introductions have resulted in a current range that encompasses essentially all of the Pacific and Atlantic drainage systems in the 48 continental states (Lee et al. 1980; McMahon and Terrell 1982). According to Jenkins and Burkhead (1994), channel catfish from Missouri and Illinois were first stocked in the Potomac River during 1889-1905 and into the Upper James River during 1893-1894. Channel catfish have been so successful in the Chesapeake Bay drainage system that they are now believed to be the most abundant *Ictalurus* species in the upper Bay (MDNR unpublished data).

Blue catfish range north into Canada and south through eastern Mexico with large populations in the lower Mississippi and Missouri rivers. The species was indigenous to Pennsylvania in the Ohio River drainage system, but has been extirpated. The range of blue catfish in the United States has been extended from California to the east coast through stocking. Blue catfish numbers are steadily increasing in Chesapeake Bay tributaries as the result of intentional stocking, most notably in Virginia (VDGIF unpublished data). Young fish from a Texas hatchery were introduced in the mid 1970's by the Virginia Department of Game and Inland Fisheries (VDGIF) into Virginia waters. Records indicate that a total of 97,800 fish were introduced in the Rappahannock in 1974, 1975, and 1977; 64,100 in the James in 1975 (Jenkins and Burkhead 1994). The Mattaponi River (a tributary of the York River) was stocked with 1,850 blue catfish in 1985 (VDGIF unpublished data). The origin of blue catfish in the Potomac River is not well documented.

Flathead catfish are native to the southern Great Lakes and Mississippi basins and most Gulf slope drainage systems. It has been introduced on the Atlantic slope and in California. In Virginia, flathead catfish are indigenous to the New, Tennessee, and Big Sandy drainage systems, and introduced to the Chesapeake Bay system in the Potomac, James and Roanoke drainage systems (Jenkins and Burkhead 1994). The establishment of the flathead catfish on the Atlantic slope in Virginia stemmed from releases of apparently few individuals, as also reported in the Cape Fear River, North Carolina (Guier et al. 1984). Introductions to the lower James and middle Roanoke rivers, including Smith Mountain Reservoir, via accidental and intentional releases during 1965-1977, are discussed by Burkhead (1980). The flathead catfish is expected to spread throughout the James and Roanoke rivers (Jenkins and Burkhead 1994). Although it is classed as only semi-mobile by Funk (1955), it dispersed rapidly and widely in the Cape Fear River, North Carolina, following establishment (Guier et al. 1984).

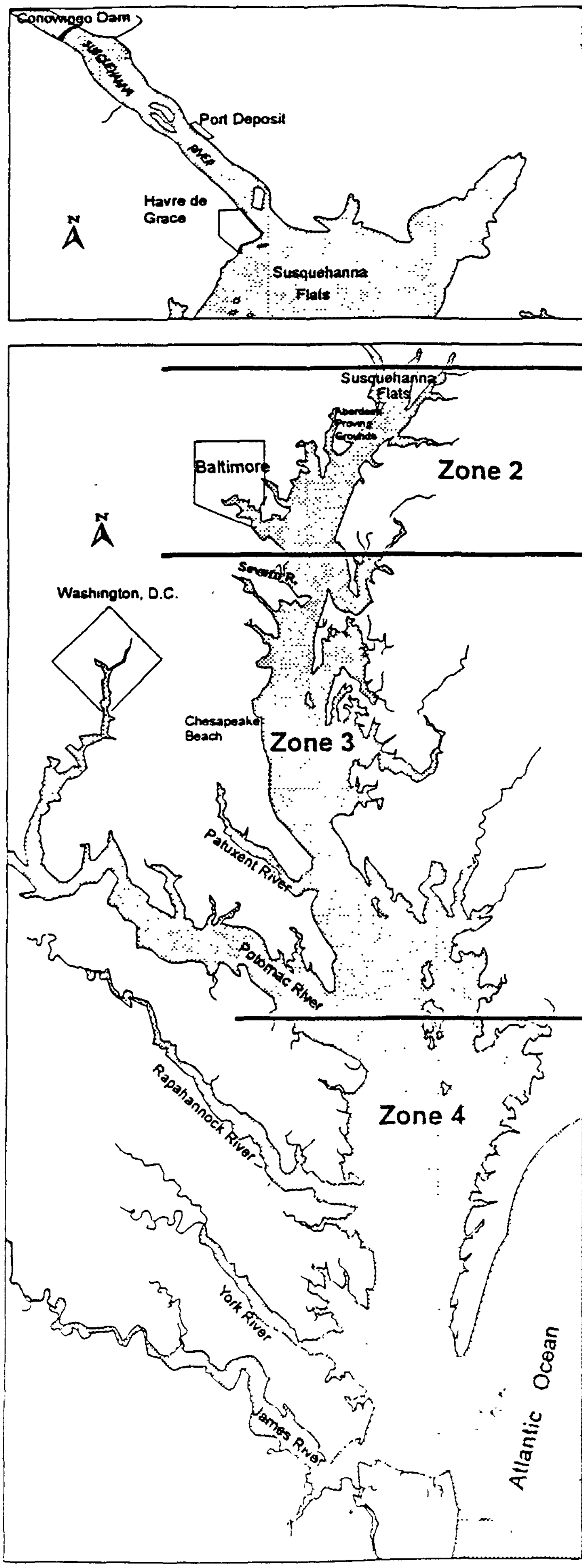
Distribution and Abundance in the Chesapeake Bay System

There are four general zones of catfish distribution in the Chesapeake Bay system (Figure 1). Zone 1, the Susquehanna River, is entirely freshwater. Zone 2, the upper Chesapeake Bay, contains low salinities that allow catfish to freely migrate between the Bay mainstem and adjacent river systems below dams. Salinity barriers to migration fluctuate seasonally and annually in Zone 3, the mid-Bay, and catfish distribution down-river and in the Bay mainstem is limited. In Zone 4, the lower Bay, catfish are restricted to rivers and tributaries and migration between adjacent rivers does not occur.

Zone 1. Susquehanna River, Pennsylvania to Conowingo Dam

Open water is defined in this document as a body of water that migratory fish can freely enter and exit. The Susquehanna River is obstructed by the Conowingo Dam, which is currently operated to provide hydroelectric power. The dam has been in place since 1928. In 1991, a fish lift operation was implemented at the Conowingo Dam to transport anadromous fish, particularly Alosa species (shad and herring), to spawning habitat upriver. Catfish species present in 1996 at the fish lift, in order of decreasing abundance, were channel catfish, white catfish, brown bullhead, and yellow bullhead (SRAFRC 1997). Blue catfish are not present in the Susquehanna River. Currently, catfish caught at the fish lift are examined and returned to waters below the Conowingo Dam; however, some catfish may pass the dam and move upriver through a partially automated system on the east shore which transports all species over the dam into Conowingo Lake. Fish passage facilities at three dams upriver from Conowingo Dam are currently under design and construction. Upon completion, all fish lift operations at Conowingo Dam will become automated and will not select for targeted species.

Data on catfish species collected at the Conowingo Dam fish lift since 1973 show a decline in channel catfish, white catfish (Figure 2) and bullheads (Figure 3). The reason for this decline is unknown, particularly in light of their high abundance in the Susquehanna Flats and Upper Bay, and no formal investigation of this decline has been conducted. One speculation is the decline may be due to the introduction of gizzard shad (*Dorosoma cepedianum*) to above-dam impoundments in 1972. Gizzard shad are plankton feeders and the transfer of energy to this non-native species following its introduction is believed to be the cause for declines in the black crappie (*Pomoxis nigromaculatus*) population noted by 1976 in Conowingo Pond. Catfish production above the dam may be similarly affected and subsequent recruitment of juvenile catfish from Conowingo Pond to tailwaters below the dam may have also declined as a result



Zone 1: Susquehanna River. Closed system above Conowingo Dam up through Pennsylvania; open system below Conowingo Dam to Zone 2.

Zone 2: Susquehanna Flats to Magothy River. Open system, no salinity barriers to migration.

Mainstem Salinity (average, 1949-1994):
Susquehanna Flats to Aberdeen Proving Grounds: 1.3 ppt
Aberdeen to Severn River: 5.9 ppt

Zone 3: Magothy River to Potomac River. Semi-open system, migration between rivers possible during periods of high rainfall and low salinity.

Mainstem Salinity (average, 1949-1994):
Severn River to Chesapeake Beach: 10.3 ppt
Chesapeake Beach to Patuxent River: 12.1 ppt
Patuxent River to Potomac River: 13.6 ppt

Zone 4: Lower Bay, Potomac Rivér to James River.
Closed river systems; migrations restricted by salinity barrier in lower portions of major rivers.

Average salinity at the Potomac River mouth can be as low as 10 ppt during years of high rainfall (1949-1994 data).

Figure 1. Catfish distribution in the Chesapeake Bay system by zone.

(Chris Frese, SRAFRC, personal communication). Other speculations may be recreational fishing pressure at the Conowingo Dam, commercial fishing pressure downstream, or some environmental alteration that has affected important catfish habitat.

Above the Conowingo Dam, catfish species present throughout the Susquehanna system in Pennsylvania include, in order of decreasing abundance: brown bullhead, channel catfish, and yellow bullhead (Richard Snyder, PFBC, personal communication). The introduced channel catfish are highly sought after by recreational anglers. Stocks are often sustained as put-and-take, with the most recent stocking of channel catfish occurring in 1993. The only known flathead catfish specimen from Pennsylvania's portion of the Chesapeake Bay system was captured from a lake in Lancaster County and returned.

Zone 2. Upper Bay, Susquehanna Flats to Magothy River

Field studies in 1927 documented only white catfish in the upper Bay (Hildebrand and Schroeder 1972 reprint). Presence of channel catfish at the Susquehanna River mouth is noted as early as 1961, though they were uncommon in other parts of the state (Schwartz 1961). Channel catfish were first introduced to the Susquehanna River system in impoundments. From there, they were stocked in impoundments across Maryland and, in some cases, directly into open waters for the purpose of providing a recreational fishery (Leon Fewlass, MDNR, personal communication). Channel catfish are highly abundant in the upper Bay and are now considered a naturalized species throughout Chesapeake Bay. Naturalized species are defined as introduced species which are established and have been self-sustaining for at least 10 years (CBP 1993).

Beach seine surveys conducted by Maryland's Department of Natural Resources (MDNR) in the Susquehanna Flats document channel catfish presence since 1958 (MDNR unpublished data, 1958-1995; Figure 4). Trawl surveys offer a better measure of juvenile abundance for catfish due to their habitat preferences. In 1968 and 1969, a trawl survey was conducted in the Susquehanna Flats and catfish densities were calculated (Table 1). The study was repeated in 1980 and 1981 and channel catfish abundance increased nearly three-fold. Channel catfish is now the dominant *Ictalurus* species in the upper Bay.

Table 1. Historic abundance of white and channel catfish and brown bullhead in the Susquehanna Flats from MDNR trawl surveys (Carter 1973; Weinrich et al. 1981, 1982).

YEAR	SAMPLE AREA	# CATFISH PER ACRE		
		CHANNEL	WHITE	BROWN BULLHEAD
1968/69	Susquehanna Flats (118.5 acres)	4.0	<1.0	
1980	Susquehanna Flats (65.6 acres)	12.6	0	0.5
1981	Susquehanna Flats (60.1 acres)	10.5	0.2	1.0

Zone 3. Mid-Bay Transition Zone and Tributaries, Magothy River to Potomac River

The upper Bay is an open system where freshwater conditions allow catfish to move freely throughout. Salinity conditions in the mid-Bay are dependent on levels of annual precipitation, which varies seasonally, and may restrict movement of catfish between adjacent tributaries. Winter snow melt and spring rainfall influence freshwater input from upper tributaries and, as precipitation tapers off during summer months, salinities generally rise. Commercial landings in the Bay mainstem from 1975 to 1993 suggest catfish are not as abundant in the Bay mainstem below the Magothy River as they are in the upper Bay. Average landings in the upper Bay mainstem are approximately 145,000 pounds annually; whereas, average landings in the mainstem south of the Magothy River to the Potomac River are only about 1,500 pounds per year (MDNR, unpublished data, 1975-1993).

Channel catfish were introduced into the Potomac River system near Hagerstown in western Maryland from 1889 to 1892 by the U.S. Fish Commission. In 1929, channel catfish were documented in the upper Potomac River system around Montgomery County, MD (Truitt et al. 1929). Beach seine surveys conducted by MDNR in the Potomac, Choptank and Nanticoke rivers since 1956 document channel catfish presence. In the tidal Potomac River, channel catfish were present in beach seines below Pomonkey Creek in 1957, though their numbers were very low. Between 1957 and 1977, their frequency in seine samples gradually increased. Channel catfish are reported to be the second most abundant species in jurisdictional waters of Washington, DC (Table 3). Channel catfish were not collected in seine surveys in the Choptank River until 1978 and in the Nanticoke River until 1979.

In addition to seine survey results, trawl surveys in the Choptank River in 1971 and 1972 found no channel catfish. In 1986 and 1987 and again in 1993 and 1994, channel catfish were not only present, but had become more abundant than the native white catfish during the intervening 15 years (Table 2).

Table 2. Abundance of white and channel catfish from MDNR trawl surveys in the Choptank River (MDNR unpublished data 1971-1987; MDNR unpublished data collected from Casey et al. 1988; Piavis et al. 1995).

		# CATFISH PER ACRE	
YEAR	AREA	CHANNEL	WHITE
1971/72	Choptank River (summer)	0	8.0
1986	Choptank River (spring)	36.0	6.4
1987	Choptank River (spring)	46.5	17.9
1993	Choptank River (spring)	14.9	4.0
1994	Choptank River (spring)	213.0	67.0

In 1988, Bonzek and Morin (1988) reported approximately a 2:1 ratio of channel catfish to white catfish from both fyke nets and trawl surveys in the Choptank River. Piavis et al. (1994), reported increased ratios during 1994, to almost 3:1 channel catfish to white catfish from fyke nets and 4.5:1 from trawl surveys. Trawl surveys from both studies collected small fish; whereas, fyke nets captured larger, mature fish.

Channel catfish and, to a lesser extent, white catfish were unusually abundant in the Bay mainstem south of the Magothy River during 1994. The years 1993 and 1994 experienced greater precipitation than normal and Susquehanna River flows were the highest since Hurricane Agnes in 1972 (Bay Journal 1994a). Salinities in the upper to mid-Bay during the spring of these years were highly diluted. Rains in 1994 persisted through the summer months and held salinity at freshwater levels through July (Bay Journal 1994b). In the Patuxent River, Kendall and Schwartz (1968) noted that downstream dispersal of white catfish was limited by salinity and suggested that this species may migrate to stay within a particular salinity regime. The influx of channel and white catfish to lower Bay stations may be the result of favorable salinities during 1993 and 1994 which allowed catfish to extend their foraging range.

Catfish in the Potomac River are most abundant above 52 miles (32 km) from the river entrance (Lippson et al. 1979). This same river mile is the approximate boundary between oligohaline (0.5-5.0 ppt salinity) and mesohaline (5.0-18.0 ppt salinity) conditions in the Potomac River mainstem. Biological surveys during 1973 and 1974 from 63 miles (39 km) upriver to 80.4 miles (26 km) upriver ranked all species encountered in order of abundance. Brown bullheads ranked fourth, white catfish were ninth, channel catfish were thirteenth, and blue catfish were not present (EAI 1974). More recent surveys in the jurisdictional waters of Washington, DC, recorded five species of catfish (Tilak and Siemien 1993; 1994; 1995; 1996; 1997). The native brown bullhead was the dominant species, followed by the non-native channel catfish (Table 3). Yellow bullhead and white catfish naturally occur in District waters, though their abundance was very low. In addition, the non-native blue catfish was reported to be present in low numbers (Table 3).

Table 3. Biological survey of anadromous and resident fishes of the Potomac and Anacostia Rivers within the District of Columbia (Tilak and Siemien 1991; 1992; 1993; 1994; 1995; 1996; 1997). Number of catfish sampled.

	1990	1991	1992	1993	1994	1995	1996	Length Range
Brown Bullhead	212	295	418	1474	876	462	281	38-387mm
Channel Catfish	217	83	120	73	121	69	133	42-700mm
Yellow Bullhead	14	2	6	1	11	2	0	12-330mm
White Catfish	6	1	8	1	6	7	8	274-856mm
Blue Catfish	0	0	5	2	2	3	2	260-700 mm

Blue catfish have been documented in the Potomac River, which is currently the most northern tributary in which this species ranges in Chesapeake Bay. Blue catfish may have been stocked in the Potomac River near Washington, DC, between 1898 and 1905, though the accuracy of records documenting their introduction has been questioned (Burkhead *et al.* 1980). Burkhead *et al.* (1980) revisited historically documented blue catfish specimens from the Potomac River and, in some instances, found them to be misidentified channel catfish. Nammack and Fulton (1987) captured a blue catfish at the mouth of the Anacostia River in 1987, and speculated on the origin of the specimen. Possible sources for introduction of blue catfish to the open waters of the Potomac River included Burke and Brittle lakes in Virginia, which were stocked with blue catfish and may have allowed for escapes during high water conditions; the adjacent Rappahannock River by recreational fishermen; or via Chesapeake Bay during a year of reduced salinity.

Since Nammack and Fulton documented their presence in 1987, records of blue catfish in the Potomac River have continued to be random and sporadic, though a few sightings have been consistently reported since 1992. Biological surveys in the Washington, DC, portion of the Potomac and Anacostia Rivers since 1990 reported no blue catfish until 1992 (Table 3; Tilak and Siemien 1993; 1994; 1995; 1996; 1997). In 1994, the juvenile striped bass seine survey in Maryland captured one blue catfish young-of-year in the Potomac River approximately 73.5 miles (45.6 km) upriver (Don Cosden, MDNR, personal communication). Otherwise, there has been no evidence of reproduction by blue catfish in the Potomac River basin. Pennsylvania reports no blue catfish in the upper portion of the Potomac River system (Richard Snyder, PFBC, personal communication).

Another introduced species to the Potomac River drainage system is the flathead catfish. Apparently, a few (<15) flathead catfish were stocked in the Occoquan Reservoir in Virginia in 1965 and are now established in open waters of the Occoquan River, a tributary of the Potomac River (Jenkins and Burkhead 1994). Flathead catfish were also reported in Potomac River and stocked in Lake Brittle, Virginia. Truitt et al. (1929) reported a large catfish species, then recorded as *Ameiurus ponderosus*, commonly called the Mississippi catfish, in the Potomac River between Chain Bridge and Georgetown. The species was reportedly introduced by the U.S. Bureau of Fisheries and was described as large, up to 32 pounds, with a long head and a caudal fin not deeply forked. Whether this was an attempt to introduce flathead catfish or another unidentified species is unknown. Since no such species has been collected in biological surveys of Washington, DC, it appears to have been unsuccessful.

The appearance of blue and flathead catfish in Potomac River may pose the threat of expansion into adjacent tributaries and the upper Bay. Salinity in the mid-Bay region adjacent to the Potomac River entrance may be low enough during abnormal events, such as a hurricane, to allow blue catfish to exit the river and expand into the Upper Bay. Larger than both white or channel catfish, blue catfish may represent serious competition to related Ictalurid species and other native species. Flathead catfish also grow to large sizes and could compete with the existing Ictalurid stocks if the species were to expand in abundance and distribution in the Chesapeake Bay system. The establishment of flathead catfish in Virginia stemmed from releases of apparently few individuals. Similar releases of a small number of individuals in the Cape Fear River in North Carolina also resulted in successful introduction (Guier et al. 1984).

Zone 4. Lower Bay, South of Potomac River to James River

Salinity in the lower portions of tributaries of the lower Bay exceeds the upper tolerance limits of catfish species and inhibits movement between adjacent rivers. Trawl surveys conducted by the Virginia Institute of Marine Science (VIMS) in the lower Chesapeake Bay and tributaries did not find catfish outside of tributaries (VIMS unpublished data, 1983-1993). In the lower 35 miles (22 km) of the James, York, and Rappahanock Rivers, the greatest overall catfish abundance occurrs at upriver stations. White catfish is the dominant species and channel catfish is the second most abundant (Figure 5). Lanier (1971) reported the greatest abundance of catfish in the James River between 40 and 70 miles (25 to 43 km) upriver during 1969 and 1970 and did not report the presence of blue catfish. In VIMS trawl surveys conducted since 1983, blue catfish have been collected primarily in the upper portions of the sample area. Increased trawl survey indices for blue catfish since 1990 are believed to be the result of an upriver, five mile expansion in survey area (Figure 5; Bonzek et al. 1995); however, increasing frequencies of blue catfish captured in lower river stations during this same time period suggest the species may be expanding its distribution as densities increase upriver (Patrick Geer, VIMS, personal communication).

Surveys conducted by VDGIF 176 miles (109 km) up the Rappahannock River documented a substantial blue catfish population in 1991. In 1993 and 1994, large numbers of blue catfish were collected adjacent to the bridge pilings of the Benjamin Harrison Memorial Bridge in the James River by VDGIF. Additionally, blue catfish were collected by VDGIF from Herring Creek in the James drainage system, from Occupacia Creek and Gingoteaque Creek in the Rappahannock drainage system, and during 1994 in the tidal portion of the Chickahominy River (James River drainage). Citations awarded to anglers for record fish in recent years show an increasing number of large fish, weighing up to 66.5 pounds (VDGIF unpublished data).

Although Ictalurids are tolerant of estuarine conditions, upstream portions of major rivers and estuaries where salinities are highly diluted or diminished appears to be the preferred habitat of channel catfish and blue catfish. This observation is based on trawl surveys in major rivers in Virginia (Patrick Geer, VIMS, personal communication) and the dominant status of channel catfish in the headwaters of Chesapeake Bay. In a Louisiana estuary with a salinity range of 0.18 ppt to 35.0 ppt, blue catfish were collected in waters up to 11.4 ppt salinity (Perry 1969). Given their tolerance for moderate salinities, blue catfish presence in lower portions of tributaries may be expected as populations become more established.

Habitat Requirements

Much of the information available on habitat requirements for catfish pertains to freshwater habitats. Little information exists on Ictalurids in estuarine environments. As a result, this section should not be considered complete for catfish populations throughout their range in the Chesapeake Bay system.

Temperature

Catfish are warm water species that tolerate cold temperatures for overwintering. Catfish are relatively heat-tolerant (Kendall and Schwartz 1968). White catfish acclimated at 20°C can tolerate temperatures between 29°C and 31°C (Kendall and Schwartz 1968). The upper heat tolerance of brown bullheads is 29.1°C to 35.3°C, and channel catfish acclimated at 20°C can tolerate up to 32.7°C (Hart 1952).

Salinity

Catfish of the family Ictaluridae, while considered freshwater species, are common downstream into the brackish waters of the Chesapeake Bay mainstem to Kent Island, Maryland, where salinities range up to 10 ppt (Lippson and Lippson 1984).

Brown bullheads suffer stress in salinities above 10 ppt (cited in Jones et al. 1978). Yellow bullheads have been observed in 15 ppt salinity (Kilby 1955); however, the species is not beleived a common estuarine inhabitant (Jenkins and Burkhead 1994). Kendall and Schwartz (1968) reported a lethal salinity for white catfish of 14 ppt (LC_{50}, 60 hours); however, the species was reported in salinities as high as 15 ppt in the Potomac River (Lippson et al. 1979).

Channel catfish were reported in salinities as high as 15 ppt in Potomac River (Lippson et al. 1979). Tagging studies by Dames et al. (1989) suggest large adult channel catfish leave backwaters and reside in river areas where they become largely piscivorous. Blue catfish, though tolerant of salinities up to 11.4 ppt (Jenkins and Burkhead 1994), have not been observed in the lower portions of Bay tributaries and it is not believed that they have ventured too far into estuarine waters. In a Louisiana estuary with a salinity range of 0.18 ppt to 35.0 ppt, blue catfish were collected in waters up to 11.4 ppt salinity (Perry 1969).

Dissolved Oxygen

Catfish are relatively resistant to low dissolved oxygen levels. Jones et al. (1988) reported habitat requirements for channel catfish, white catfish and brown bullheads. The level of dissolved oxygen required for growth and successful reproduction was 5.0 ppm, although the species can apparently tolerate dissolved oxygen levels as low as 3.0 ppm. Lethal dissolved oxygen concentrations for channel catfish at 25°C, 30°C, and 35°C were 0.76 ppm, 0.89 ppm and 0.96 ppm, respectively (Jones et al. 1978).

Physical Habitat

The yellow bullhead prefers shallow fresh water with dense vegetation and are often associated with cover (Jenkins and Burkhead 1994). Trautman (1981) cited loss of submerged vegetated habitat in two Ohio lakes as the cause for yellow bullhead decline. Trautman (1981) also cited competition from brown bullheads as a cause for depressed yellow bullhead populations. The yellow bullhead is tolerant of high acidity and is the most abundant species in the Dismal Swamp, Virginia (Jenkins and Burkhead 1994).

The brown bullhead is found over muddy bottoms, is known to burrow into soft sediments, and is sometimes associated with vegetation (Jones et al. 1978). The brown bullhead may be found in stagnant water, but is usually restricted to deep canals in sluggish rivers, sometimes in dense schools (Jones et al. 1978). Habitat preferences sometimes overlap with white catfish in shallow, silty slow-flowing tributaries as well as open, clear and deep water.

White catfish typically avoid dense vegetation and are found in slow-moving streams, river backwaters, reservoirs and ponds. White catfish prefer less current than channel or blue catfish and are more tolerant of silty bottoms (Sternberg 1987). Trautman (1981) observed that white catfish habitat preferences fall in between those of brown bullheads, which prefer quiet waters and silted bottom, and channel catfish, which prefer more current and hard bottom. In large river systems of Chesapeake Bay, white catfish more frequently occupy down-river stations; whereas, channel catfish and blue catfish abundance dominate upriver (VIMS unpublished data). White catfish are rarely found in small streams (Jenkins and Burkhead 1994).

Channel catfish prefer deep-channeled rivers, streams, and brackish estuaries with slow to moderate current. The species is frequently associated with pools and is adapted to clear and turbid waters, but is apparently not tolerant of acidic conditions (Jenkins and Burkead 1994). Channel catfish prefer sand, gravel or rubble bottoms (Sternberg 1987) and easily adapt to enclosed water bodies of lakes, reservoirs and ponds.

The blue catfish is a large-river species which typically inhabits deep, swift-flowing channels and pools (Jenkins and Burkhead 1994). They prefer clearer, swifter water than other catfish and are associated with unsilted bottoms of sand, gravel, or rock (Sternberg 1987; Etnier and Starnes 1993). Trautman (1981) stated that feeding was done in the swift-flowing chutes or rapids and over bars, or elsewhere in pools, where there was good current and solid substrates. The Ohio River population reportedly declined when the river was ponded in 1911, which reduced flow and created a deep silted bottom (Trautman 1981). When not feeding and during winter months, they apparently retreat into deeper water and enter sloughs and backwaters in spring (Jenkins and Burkhead 1994).

The flathead catfish inhabits large, warm-water streams, rivers, lakes and reservoirs and favors deep pools with little flow (Jenkins and Burkhead 1994). Flatheads are tolerant of heavy turbidity, though they are usually associated with hard or slightly silty bottoms (Trautman 1981) scoured by currents, such as those adjacent to bridge pilings, and in tailraces below dams (Manooch and Raver 1991). During daylight hours, adults are strongly associated with cover such as caves, undercut banks, brush piles, and log jams (Minckley and Deacon 1959).

Reproduction and Development[4]

Catfish species move upstream to spawn in freshwater during late spring and early summer when water temperatures reach 21-27°C. Their use of estuarine waters for spawning is unknown.

White catfish

White catfish spawn in still or flowing waters near sand or gravel banks. Large, saucer-shaped nests are formed by both male and female fanning their sides and fins on the bottom. Approximately 1,000 to 4,000 adhesive eggs are laid. Males guard the nest and undulate their

---

[4] For review and citations, see Jenkins and Burkhead 1994; Jones et al. 1978; Mansueti and Hardy 1967.

bodies to aerate eggs and disturb sediments on the egg surfaces. Both brown bullheads and white catfish were observed sucking eggs into their oral cavity and forcefully shooting them back out into the nest, which may also remove sediments and debri. Males may remain close to the nest after hatching until the fry break from schooling tendencies and disperse. Yolk-sac larvae are 9.0-9.8 mm total length (TL; 0.36-0.4 inches) at hatch and are tadpole-like juveniles at approximately 14.0 mm (0.56 inches).

Bullheads

Brown bullheads may spawn up to twice a year in late spring. Nesting sites are in shallow water of slow-moving tributaries. Nests may be excavated in sand or mud, often under logs, brush or banks or any other available cover, and in vegetation on firm substrate such as sand, gravel or stone. Eggs are adhesive. Small females lay approximately 2,000 eggs; whereas, larger females may lay up to 13,000 eggs and may reproduce several times during a season. Nests may be guarded by one or both of the parents and are aerated and kept free of sediments. Eggs hatch in five to eight days at water temperatures of 20 to 24°C. Parents may remain near the nest after hatching, and fry stay in the nest six to eight days. Juveniles prefer low salinities of 1.7 ppt or less with a maximum tolerance of 11 ppt. The optimum dissolved oxygen level for growth is 7 ppm or greater. Yellow bullheads lay between 1,650 and 7,000 eggs in shallow, saucer-shaped nests in shallow water, usually beneath a bank, log or tree root. Juveniles are 17-21 mm TL (0.68-0.84 inches).

Channel catfish

Channel catfish usually spawn once a year, in the summer, and lay approximately 2,000 to 21,000 eggs in turbid tributaries, sometimes in areas of swift current. Two spawning peaks per season is not uncommon. Spawning typically occurs between the hours of 1230 am - 0730 am and 0330 pm - 0530 pm (Jones et al. 1978). Channel catfish select nest sites in dark depressions, cavities, or undercut stream banks, or inside crevices, hollow logs, or man-made containers. Spawning success is dependent on available cover (Marzolf 1957). Spawning usually occurs in salinities of 2 ppt or less. Upon hatching, sac-fry of channel catfish are tolerant of salinities up to 8 ppt and 9-10 ppt following yolk absorption; however, growth and survival through the fingerling stage is best in fresh water up to 5 ppt (Allen 1971). Channel catfish fry sometimes aggregate in tight schools after leaving the nest until suitable cover is found. Fingerlings shelter or aggregate during daylight hours and disperse and feed at night (Brown et al. 1970). The upper lethal temperature is approximately 37°C with abnormal development at 35°C (Jones et al. 1978).

Blue catfish

Blue catfish spawning occurs in spring, beginning as early as April in Louisiana and extends into June farther north (Etnier and Starnes 1993). On 24 June, 1994, a 29.9 kg (66 pounds 8 ounces) gravid female, the Virginia state record blue catfish, was caught in the Appomattox River near its confluence with the James River. Preferred spawning temperatures range from 21° C to 24° C (Jenkins and Burkhead 1994). Manooch and Raver (1991) indicated that blue catfish eggs are deposited in nests constructed under logs, brush, or the riverbank. Because blue and channel catfish spawn at the same time and temperature, as well as select similar nest sites (Jenkins and Burkhead 1994), interspecific competition for spawning substrate may occur.

Flathead catfish

Flathead catfish spawn June through August, in shallow waters with temperatures from 22° C to 29° C. Nests are usually associated with submerged logs or protected areas along river banks. Eggs are adhesive and fecundity varies with female size. Small fish may lay 4,000 eggs; larger fish may lay up to 93,000 (Manooch 1984). Males guard the nest, and after hatching, young and juvenile flathead catfish are usually associated with riffles in streams (Jenkins and Burkhead 1994).

Growth and Maturity

The five species of catfish and bullheads grow and mature at different rates. Growth may also occur at different rates for different sexes of the same species. Blue catfish and flatheads are the largest species in Chesapeake Bay, followed by channel catfish. White catfish and brown and yellow bullheads do not grow to enormous sizes. Channel catfish and white catfish grow at the same rate during their first year. After the first year, channel catfish continue to increase in length and weight and white catfish continue to accumulate weight without increasing much in length (Menzel 1943; Lanier 1971; Bonzeck and Morin 1988). Ramsey and Graham (1991) cited several investigators who documented that blue catfish grow more rapidly and live longer than channel catfish.

White catfish

White catfish mature at three to four years of age (Manooch 1984). A study in the Patuxent River found fish from this age group to be 170-220 mm (6.8-8.8 inches) TL (Schwartz and Jackowski 1965). This is comparable to a more recent Choptank River study (Bonzek and Morin 1988) and another study in the James River (Lanier 1971). Longevity of white catfish, based on one large specimen from Higgins Millpond in Dorchester County, MD, was estimated to be 14 years (Schwartz and Jackowski 1965).

Bullheads

Brown bullheads grow up to 18 inches (450 mm) and 3-4 pounds (1.4-1.8 kg). This species is estimated to reach maturity at three years or older (Manooch 1984) and may live to ten years or more.

Channel catfish

Channel catfish size and age at maturity varies between sexes and among locations. Male channel catfish in the Susquehanna River ranged from 6 to 23 mm (0.2-0.9 inches) larger than females (Fewlass 1980). In a southwest Louisianna study, female channel catfish grew slower than males and matured at a larger size and older age (Perry and Carver 1972). In Louisiana, Perry and Carver (1972) found 100% of females 350-359 mm (14-14.4 inches) in length were mature and 100% of males 330-339 mm (13.2-13.56 inches) were mature. Female channel catfish examined in Susquehanna River matured as early as three years of age at 200 to 250 mm (8-10 inches) total length (Fewlass 1980). Fish in this study were thought to have slow growth rates due to the dense population of channel catfish in the study area; however, other studies in Choptank River (Bonzek and Morin 1988) and James River (Menzel 1942; Lanier 1971) found only slightly greater lengths at age. Studies in Potomac River (Sanderson 1958; Bonzek and Morin 1987) found substantially greater lengths at age than in the James, Susquehanna, and Choptank River studies illustrating variability in growth within the Bay. This variability may also be affected by selective fishing pressure or river-specific primary productivity, rather than interspecific competition due to overcrowding. Longevity of channel catfish was documented as 24 years in Canada (Scott and Crossman 1973).

Blue catfish

Blue catfish are reported to grow to 68 kg (150 pounds), however, the largest specimen to date from the Chesapeake Bay system was 30.2 kg (66.5 pounds; VDGIF state record). Blue catfish show no significant difference in growth rates between sexes (Brooks et al. 1982); however, females mature at a larger size and older age (Perry and Carver 1972). Limited studies were done on age and growth of blue catfish within the Chesapeake Bay drainage system. Table 4 indicates the mean length and weight at capture of blue catfish, age 0-10, in James River at Hopewell, VA, which were captured on 17 September, 1993, by VDGIF. Length at age in the James River compared favorably with values shown by Sternberg (1987) and Manooch and Raver (1991) for other aquatic systems in the United States (Table 4). Jenkins and Burkhead (1994) reported the weight at maturation of cultured fish was approximately 2.3 kg (5.1 pounds), which Carlander (1969) indicated would be about 400-600 mm (16-24 inches) TL. Age and growth were figured for blue and channel catfish in southeast Louisiana by Perry and Carver (1972). One-hundred percent of female blue catfish, estimated to be five years and older and greater than 590 mm (23.6 inches) long, were mature. Four-year-old males 490 mm (19.6 inches) and longer were also mature. These lengths were considerably larger than mature channel catfish in the same study (100% maturity: females, 350-359 mm (14-14.4 inches); males 330-339 mm (13.2-13.6 inches). Longevity of blue catfish is recorded to 21 years (Pflieger 1975).

Table 4. Comparisons of reported mean length and weight at capture of blue catfish at various ages.

		James River at Hopewell, VA[5]				Southeast, U.S.[6]	North America[7]
Age	N	Mean length mm (inches)	S.D.	Mean weight g (pounds)	S.D.	Mean length mm (inches)	Mean length mm (inches)
0	1	112.5 (4.5)	-	9.0 (0.02)	-	-	-
1	18	207.5 (8.3)	21.0	74.6 (0.16)	24.2	147.5 (5.9)	155.0 (6.2)
2	23	290.0 (11.6)	29.7	198.4 (0.44)	55.8	265.0 (10.6)	277.5 (11.1)
3	10	385.0 (15.4)	39.2	552.4 (1.22)	188.0	360.0 (14.4)	367.5 (14.7)
4	22	455.0 (18.2)	66.6	1044.2 (2.30)	599.0	452.5 (18.1)	457.5 (18.3)
5	6	555.0 (22.2)	40.8	2333.3 (5.14)	906.0	537.5 (21.5)	552.5 (22.1)
6	2	680.0 (27.2)	72.0	4625.0 (10.20)	1675.0	620.0 (24.8)	637.5 (25.5)
7	0	-	-	-	-	650.0 (26.0)	720.0 (28.8)
8	1	632.5 (25.3)	-	3130.0 (6.9)	-	682.5 (27.3)	765.0 (30.6)
9	0	-	-	-	-	807.5 (32.3)	807.5 (32.3)
10	2	832.5 (33.3)	8.0	8390.0 (18.50)	240.0	872.5 (34.9)	852.5 (34.1)
11	0	-	-	-	-	947.5 (37.9)	-
12	0	-	-	-	-	970.0 (38.8)	-
13	0	-	-	-	-	1025.0 (41.0)	-
14	0	-	-	-	-	1050.0 (42.0)	-

[5] Data collected on September 17, 1993, by VDGIF. Data from Virginia Commonwealth University, 1994.

[6] Reported by Manooch and Raver (1991).

[7] Reported by Sternberg (1987).

Flathead catfish

Flathead catfish mature at about three years of age and as small as 380 mm (15.2 inches; Etnier and Starnes 1993). They are known to grow to 1400 mm (56 inches) and 45.4 kg (100 pounds). Age and growth data are given in Table 5.

Table 5. Mean length at age or length range at age for Flathead Catfish.

	Sternberg 1987		Manooch and Raver 1991	Etnier and Starnes 1993
AGE	North, U.S. mm (inches)	South, U.S. mm (inches)	Southeast, U.S. mm (inches)	Tennessee mm (inches)
1	187.5 (7.5)	-	60.0 (2.4)	62.5 - 235.0 (2.5 - 9.4)
2	272.5 (10.9)	407.5 (16.3)	115.0 (4.6)	125.0 - 352.5 (5.0 - 14.1)
3	370.0 (14.8)	607.5 (24.3)	195.0 (7.8)	182.5 - 467.5 (7.3 - 18.7)
4	-	-	305.0 (12.2)	255.0 - 570.0 (10.2 - 22.8)
5	482.5 (19.3)	692.5 (27.7)	442.5 (17.7)	315.0 - 637.5 (12.6 - 25.5)
6	-	-	542.5 (21.7)	370.0 - 767.5 (14.8 - 30.7)
7	597.5 (23.9)	867.5 (34.7)	605.0 (24.2)	415.0 - 892.5 (16.6 - 35.7)
8	-	-	647.5 (25.9)	457.5 - 970.0 (18.3 - 38 8)
9	700.0 (28.0)	907.5 (36.3)	682.5 (27.3)	-
11	887.5 (35.5)	1010.0 (40.4)	757.5 (30.3)	-
13	925.0 (37.0)	1105.0 (44.2)	807.5 (32.3)	-
15	1000.0 (40.0)	1157.5 (46.3)	-	-

Maryland Stock Assessment Data

Rothschild et al. (1992) estimated mortality rates for white catfish and channel catfish in Maryland's Chesapeake Bay. White catfish mortality was based on a small sample of 44 fish; total instantaneous mortality (Z) was 0.51; Z for channel catfish was 0.67. More accurate estimates of mortality from larger sample sizes are currently being generated from data collected by the Maryland Department of Natural Resources (Jim Uphoff, MDNR, personal communication).

In 1993, Maryland initiated a comprehensive sampling of resident and migrant Chesapeake Bay recreational finfish (COMPFISH). The COMPFISH project is a multispecies survey which monitors adult resident and ocean migrant species during the spring, summer and fall. Spring sampling targets catfish populations. Length frequency and age data are collected for both channel catfish and white catfish in the Upper Bay and Choptank, Chester, and Nanticoke Rivers. The following results are summarized from Piavis et al. (1994; 1995), Markham and Piavis (1996), and Markham et al. (1997).

Choptank River

Catfish were collected from five experimental fyke nets set in the Choptank River between 65 and 78 km (40-48 miles) upriver from the mouth. The nets were fished March through May. Experimental trawls, which sampled age 0 catfish more adequately, were discontinued in 1995. Trawl data from 1993 and 1994 are presented in Table 2. The mean length for channel catfish between 1993 and 1996 did not show a significant trend and ranged between 389 mm ±113 (15.6 inches ±4.5) and 451 mm ±132 (18.0 inches ±5.28). In 1996, nine year classes of channel catfish were observed between the ages of two and ten years old. In 1995, only seven year classes were observed (two to eight years old). The presence of age two channel catfish increased between 1995 and 1996. Instantaneous mortality (Z) was estimated in 1996 to equal 0.15. The relationship of Z and growth rate (K) for channel catfish in Choptank River was estimated. Relative mortality (Z/K; Z = instantaneous mortality rate; K = Brody growth coefficient) was 0.24 in 1995 and 0.60 in 1996. The appearance of a strong 1994 year class during 1996 indicated that recruitment has not been impacted by harvest pressure in the near term.

White catfish are not a highly targeted species for exploitation and competitive interaction among channel catfish may have more of an impact on this species than the recreational and commercial harvest. Relative mortality rates for white catfish were 2.6 in 1995 and 0.6 in 1996. The mean length for white catfish from 1993 to 1996 ranged between 269 mm ±89 (10.8 inches ±3.6) and 327 mm ±83 (13.1 inches ±3.3) and did not show a significant trend.

Nanticoke River

Nanticoke River catfish were sampled during 1995 and 1996 from four commercial pound nets between 23 and 37 km (14 to 23 miles) upriver from the mouth. The nets were sampled from late February to early May. The mean length of channel catfish from Nanticoke River was 399 mm ±90 (16.0 inches ±3.6) in 1995 and 427 mm ±72 (17.1 inches ±2.9) in 1996. The age structure of catfish from the Nanticoke River was compared with the Choptank River. Overall, channel catfish from the Nanticoke River were younger. However, the percentage of young channel catfish between the ages of two and four years declined from 1995 to 1996 in the Nanticoke River (46% to 15%) while age two fish increased in the Choptank River (1% to 13%). Estimates of relative mortality in the Nanticoke River were similar during 1995 and 1996 (numbers not reported) and total mortality for 1996 was estimated to be 0.3.

The mean length of white catfish in the Nanticoke River was 264 mm ±103 (10.6 inches ±4.1) in 1995 and 267 mm ±89 (10.7 inches ±3.6) in 1996. Relative mortality rates for white catfish were 1.3 in 1995 and 4.4 in 1996.

Chester River

Catfish were collected from five commercial pound nets in the Chester River between 30 and 32 km (19-20 miles) upriver from the mouth. The nets were sampled April through May. The mean length for channel catfish has been increasing every year since 1993; however, confidence intervals overlap between years and between the lowest and highest values and the increase is not significant (range 423 mm ±86 to 485 mm ±72; 16.9 inches ±3.4 to 19.4 inches ±2.9). Total mortality for channel catfish was 0.2 in 1996, and relative mortality rates declined from 1.1 in 1995 to 0.78 in 1996.

White catfish mean lengths were between 303 mm ±58 (12.1 inches ±2.3) and 383 ±55 (15.3 inches ±2.2) from 1993 to 1996 and showed no significant trend. The relative mortality rate increased from 0.6 in 1995 to 0.8 in 1996.

Upper Bay

Commercial pound nets in the upper Chesapeake Bay mainstem were sampled for catfish during October. Mean lengths for channel catfish in the upper Bay were between 416 mm ±74 (16.6 inches ±3.0) and 493 mm ±47 (19.7 inches ±1.9) between 1993 and 1996. Relative mortality estimates were 0.31 in 1995 and 0.82 in 1996. Total mortality for channel catfish during 1996 was estimated to be 0.2. White catfish are rarely encountered in the upper Bay and no data was given for the species.

Feeding Strategies

Catfish are opportunistic feeders with highly varied diets. Common food categories are aquatic plants and seeds, fish, molluscs, insects and their larvae and crustaceans. Brown bullheads and white catfish examined from the Potomac River were found to be full of herring eggs (Weiser 1969). A study of stomach contents of channel catfish from the Susquehanna River found small amounts of bryozoans, arachnids, gastropods and nematodes (Fewlass 1980). Channel catfish typically seek cover during the day and move from deep, sheltered areas to shallow areas at night to feed (Pflieger 1971; Brown et al. 1970). Flathead catfish exhibit the same diurnal behavior (Trautman 1981).

Habitat partitioning occurs between adults and young due to food preference. Subadults and adults leave backwaters and shift from invertebrates to a mainly piscivorous diet (Jones et al. 1978). Fewlass (1980) found evidence of food partitioning between different aged channel catfish in the Susquehanna River. Young-of-year fed mainly on crustaceans and insects. Fish age one and older consumed significantly less crustaceans and more insects, and catfish 250 mm and greater (≥10 inches) fed more frequently on small fish. Perry (1969) found similar partitioning of food between size classes for channel and blue catfish in brackish waters in Louisiana. Blue catfish 95-187 mm long (3.8-7.5 inches) fed mainly on small invertebrates, with fish appearing in catfish 100-240 mm (4.0-9.6 inches). Catfish greater than 200 mm (8.0 inches) fed primarily on fish and macroinvertebrates including blue crab (*Callinectes sapidus*). Flathead catfish are more piscivorous than blue and channel catfishes and are known to eat gizzard shad, freshwater drum, carp, channel catfish, bullheads, bluegill, and crayfish (Manooch 1984). Juvenile flatheads feed more on insects and crustaceans.

Although catfish and bullheads have poor eyesight, their barbels are well-equipped with taste buds which help them find food at night and in muddy waters (Sternberg 1987). According to Atema et al. (1969) and Todd (1971), the olfactory apparatus is responsible for recognizing other individuals and their social status, while barbels and other dermal taste buds are the structures used for locating food.

Nonindigenous Aquatic Species

Ecological Role

No studies exist that qualify possible factors which led to the success of nonindigenous introductions of Ictalurid species in Chesapeake Bay. Such success is dependent on the physiological, behavioral, and ecological potential of the new species, as well as the physical and biological properties of the ecosystem receiving the introduction (Taylor et al. 1984). Successful introductions, as reviewed by Taylor et al. (1984), are often species which posess physiological tolerances, feeding habits, or reproductive capabilities that differ from native species and function as a selective advantage. Catfish are nocturnal, opportunistic feeders, and their ability to find food in dark, murky waters through chemosensory detection may offer some advantage over local species. Physiological aspects, such as tolerance for polluted and degraded conditions and wide salinity ranges, may also be selective advantages.

Habitat alterations prior to introductions also increase the chances for survival of non-native species (Courtenay and Williams 1992). Native species that are stressed due to habitat alteration, fishing pressure, or a combination of both often experience population decline. Courtenay et al. (1986) suggested that introduced species probably act synergistically with anthropgenic changes and are able to fill niches previously occupied by native species. For example, brown bullheads were introduced into Europe in the 1880s to stock heavily industrialized rivers that contained few fish. Kendall (1902) recognized the ablility of catfish to fill vacant niches when he saw little objection to the introduction of bullheads into waters unsuited to other fishes or in which fishes did not live.

Declines in sensitive native fish species, which may compete with introduced species for food or habitat, may have contributed to the successful introduction of non-native catfish species in the Chesapeake Bay system. Sensitive species are those with vulnerable life history stages that are not highly tolerant of natural or anthropogenic changes in environmental conditions. Jordan et al. (1990) compared Chesapeake Bay species with sensitive early life stages (i.e. anadromous and semi-anadromous fish that spawn in freshwater reaches), with more tolerant and persistent species. Persistent species such as mummichog (*Fundulus heteroclitus*) and Atlantic menhaden (*Brevoortia tyrannus*) functioned as opportunistic species, and the authors suggested they may fill niches vacated by sensitive species due to degraded water quality and/or overfishing. Anthropogenic sources for sensitive species declines include loss of spawning habitat, deteriorating water quality (particularly in spawning reaches), and fishing pressure (Vaas and Jordan 1990).

The increasing range and abundance of catfish in the upper Bay may be temporary and the result of unusually wet years during 1993 and 1994 (Figure 6). Catfish may be exploiting new foraging areas during wet seasons and retreating to more suitable habitat during dry seasons. However, changes in the Chesapeake Bay system may be contributing to a more permanent expansion of catfish in the upper Bay mainstem. Forest cover in the Chesapeake Bay watershed has been reduced from 95% to less than 60% since colonial settlement; wetlands have been reduced by about 50% (27% of original wetlands remain in Maryland, 58% in Virginia, 44% in Pennsylvania). Vegetative cover is important for regulating stream flow and moderating salinity after storms and during wet seasons. In devegetated areas or that have been covered with impervious surface, rain washes over land and directly drains into waterways over a short period of time and in greater quantities, causing salinities downstream to rapidly fluctuate. The result is greatly reduced salinities after storms and during wet seasons. It has been estimated that peak freshwater flows to the Bay before development and agriculture in the watershed were 25 to 30% less than they are today (Biggs 1981). As growth in the watershed continues and forest cover is lost, the ability of the watershed to moderate salinity during wet seasons is expected to decrease. As a result, reduced salinities during spring and early summer may provide greater opportunity for catfish to forage over an expanded area and possibly invade new tributaries. The effects of increased catfish distribution in Chesapeake Bay is largely undocumented and the effects of their presence on community structure are unknown.

Ecological and Economic Impacts

Known and potential impacts from the introduction of non-native fishes in U.S waters were reviewed by Taylor et al. (1984) and include habitat and trophic alterations by the introduced species, hybridization with native species, and spatial alterations. The escape or introduction of aquaculture species to open waters have had negative effects on native fauna, habitat and regional economies in the past, as reviewed by Courtenay and Williams (1992). For example, Mozambique tilapia was introduced on an international scale and is now considered a pest species due to its high fecundity and ability to displace native fishes (Bardach et al. 1972; Ling 1977; Shelton and Smitherman 1984). Courtenay and Williams (1992) reported that in nearly every case where an exotic aquatic species has been the subject of culture, escape into open waters occurred. Shelton and Smitherman (1984) noted the escape of exotic species is virtually inevitable and such eventuality should not be overlooked. Welcomme (1988) went further to say any introduction for aquaculture should be considered as a potential addition to the wild fauna.

Blue catfish are a highly prized recreational fish in Virginia with trophy potential. A commercial market has also evolved around the emerging resource. However, expansion and establishment of blue catfish and flathead catfish north of the Potomac River could have negative economic impacts. Maryland's commercial fishery caters primarily to the live catfish market and targets channel catfish because they adapt well to confinement. Conversations with commercial harvesters reveal blue catfish do not adapt as easily to confinement, are difficult to bring to market live and in good condition, and may also damage other marketable fish contained within fishing gear (Appendix B).

Policy and Recommendations

Maryland law prohibits the introduction of nonindigenous fish species[8] without first obtaining a permit that certifies the specific fish to be imported is free of disease and will not be harmful to native flora and fauna. Permits may be obtained for aquaculture of nonindigenous fish in Maryland, as long as the activity does not adversely affect wild stocks of fish; result in the release of non-native species into Maryland waters, except in confined water such as ponds where there are safeguards to prevent escape; or result in the contamination of native or naturalized species of fish or their ecosystem.

The *Chesapeake Bay Policy for Non-Indigenous Aquatic Species* (CBP 1993) requires that each jurisdiction list species that are considered native or naturalized within their waters. Species not listed will be subject to management as laid out in the *Policy*. The *Introduction of Non-Indigenous Aquatic Species Implementation Plan* (CBP 1996) addresses five issues: aquaculture (private and public), research, monitoring, education, and control. It focused on the following aspects of unintentional introduction of nonindigenous aquatic species: 1) identification of introduction pathways; 2) risk assessment for the respective pathways; 3) development of appropriate protocols to minimize the risks associated with unintentional introduction; and 4) education as a means of preventing unintentional introduction.

With the exception of one juvenile blue catfish collected in 1994, there is no evidence that blue catfish are potentially reproducing in the Potomac River system. It is recommended that blue catfish not be considered as native or naturalized in the Potomac River system or within Maryland, Pennsylvania or Washington, DC, jurisdictional waters and subject to management as laid out in the *Chesapeake Bay Policy for Non-Indigenous Aquatic Species*. Flathead catfish should also be excluded from the list of native or naturalized species in Maryland; Pennsylvannia; Washington, DC; and isolated river systems of Virginia where they have not been introduced or become established.

Habitat Alterations

Obstructions to Fish Migration

More than 1,000 miles of migratory fish spawning habitat are currently blocked by dams and other obstructions in the Chesapeake Bay system (Chesapeake Executive Council 1993). The effects of habitat alteration above and below stream and river blockages have been documented for catfish species. Trautman (1981) indicated that the ponding of the Ohio River and the subsequent rapid and deep silting above the dams destroyed preferred blue catfish habitat.

Catfish are commonly concentrated below dams, possibly due to migratory blockage during spawning (Trautman 1957; Pflieger 1975; Richards et al. 1986). Walburg (1971) proposed a combination of food availability, suitable temperatures and currents, activities related to spawning and the presence of a dam that prevented further upstream movement as the cause for channel catfish concentrations below the Lewis and Clark Lake in South Dakota. Below Conowingo Dam, injured gizzard shad that pass through the turbines attract a number of species

[8] Nonindigenous fish pertains to species not native and species not self-sustaining, or naturalized, in Maryland waters for at least ten years.

to feed. Tailwaters below impoundments with hypolimnal (bottom water) release are characterized by reduced water temperatures, hard substrate and reduced biodiversity; such environments are unsuitable catfish habitat (Hagen and Roberts 1973). Epilimnetic (surface water) releases are less disruptive; tailwaters are of moderate temperatures, well oxygenated, and heavy metals are generally not present.

Catfish in impoundments are self-sustaining, but stocking is common to supplement recreational fishing. For management purposes, catfish above migratory obstructions are treated as closed populations, though there is some passage over dams or through intakes. Mortality associated with catfish entrained in turbines or passed over dams is unquantified in Chesapeake Bay. Although catfish are not target species for fish passage programs, they may benefit from the removal of stream blockages and the construction of fish passages. Use of fish ladders by catfish has been documented in Maryland. A channel catfish was found by the Maryland Fish Passage Program in the Bloede Dam Fishway of the Patapsco River (Larry Leasner, MDNR, personal communication). The Bloede Dam Fishway is a Denil design and measures 293 linear feet (89 m) with a vertical height of 25 feet (7.6 m). Brown bullhead were also documented using a smaller Denil fishway (87 feet linear length, 4.7 feet vertical height; 26.5 m linear length, 1.4 m vertical height) in Tuckahoe Creek, a tributary of the Choptank River (Larry Leasner, MDNR, personal communication). Migratory fish passages may facilitate the expansion of blue catfish, particularly in the upper Bay where reduced salinity allows for exploration of adjacent tributaries.

Flow and Hydrographic Alterations

High velocity water flows below impoundments scour soft and fine-grained bottom sediments and expose hard substrate. Spawning habitat is reduced, and nests are frequently washed out during high flow events in these areas. Channel catfish populations have been eliminated below dams with cold bottom-water (hypolimnal) discharge, but concentrate in tailwaters with warm surface-water (epilimnetic) discharges. Catfish may also be attracted to tailwaters where food-fish spil over dams.

Loss of vegetation over large portions of a watershed may increase streamflow and hinder reproductive success of native Ictalurids. Vegetated riparian buffers moderate streamflow after storms and moderate variance in flow between wet and dry seasons (CBP 1995). White catfish prefer still or flowing waters, and brown bullheads prefer slow moving tributaries. Channel catfish are known to spawn in swift current and may not be affected by increased streamflow.

Water Quality

Freshwater Withdrawal

Catfish populations in Chesapeake Bay are concentrated in fresh and low salinity portions of rivers and the upper Bay mainstem. Salinity barriers which restrict catfish distribution fluctuate yearly, based on precipitation patterns in the watershed. Freshwater withdrawals above the fall line for present and future human use could move salinity barriers upstream and restrict catfish distribution to a smaller area.

Toxic Contaminants

Catfish are bottom feeders and are resident species of Chesapeake Bay throughout their entire life history; these factors cause catfish to be susceptible to bioaccumulation of contaminants. Some studies conclude Ictalurid species are tolerant of various contaminants (Bauman et al. 1987; Roberts and Bendl 1982). Brown bullheads taken from an industrialized Lake Erie tributary exhibited high frequencies of liver tumors and external tumors (Bauman et al. 1987). Toxins accumulated in brown bullhead tissue included organic contaminants and carcinogenic polyaromatic hydrocarbons (PAHs). High levels of tissue contamination in areas of Back River (Baltimore Harbor), Elizabeth River (Norfolk, VA), and a section of the Potomac River near Washington, D.C., have resulted in closure to catfish harvest. During 1990-1993, Virginia issued warnings for channel and flathead catfish in the upper James River due to contamination by dioxin, a byproduct of the bleaching of paper pulp.

The accumulation of kepone is related to residence time and distance from the source of contamination (Bender et al. 1977). Channel catfish and white catfish retain relatively low levels of kepone, compared with largemouth bass (Bender et al. 1977), eel, and bluegill (Roberts and Bendl 1982). Channel catfish fingerlings exposed to kepone under laboratory conditions experienced highest accumulations in blood and brain tissue (Van Veld 1980). White catfish in the same experiment experienced highest accumulations in blood and liver tissue. When kepone was removed from the diet, channel catfish were able to begin eliminating the pesticide from their bodies, and the half life was 8.7 days (Van Veld 1980). Roberts and Bendl (1982) calculated an 96-hour LC_{50} for channel catfish exposed to kepone equal to 514 micrograms per liter.

Kaumeyer and Setzler-Hamilton (1982) summarized toxicity of selected pollutants to white catfish, brown bullheads, and channel catfish including metals, pesticides, polychlorinated biphenyls (PCBs), halogenated compounds and monocyclic aromatic hydrocarbons. Results and parameters of laboratory studies on tolerance limits of catfish to various chemical compounds were summarized and include acute toxicity and chronic or sublethal toxicity.

Suspended Sediments

See Riparian Forest Buffers, below.

Dissolved Oxygen

See Habitat Requirements section titled Dissolved Oxygen on page 11.

Riparian Forest Buffers

Riparian areas with forest cover provide logs, branches and other submerged cover for protected nest sites, as well as overhead cover during spawning and egg development. Nest sites of brown bullheads, channel catfish, blue catfish, and flathead catfish are often associated with cover, and woody debris may be an important habitat for nesting and hatching success.

Loss of vegetative cover, particularly riparian buffers, in a surrounding watershed increases turbidity in connected water bodies. Survival of young catfish during their first year is greatest in turbid water (Lawler 1960; Pflieger 1975). However, Marzolf (1957) reported an absence of reproduction by channel catfish in turbid waters where overhead cover was lacking.

This suggests that loss of riparian buffers may reduce the area available for channel catfish reproduction.

Chesapeake Bay Program Habitat Restoration and Protection Efforts

Water Quality

In the *1987 Chesapeake Bay Agreement* (Chesapeake Executive Council 1987), Chesapeake Bay Program partners set a goal to reduce the nutrients nitrogen and phosphorus entering the Bay by 40% by the year 2000. In the *1992 Amendments* to the *Chesapeake Bay Agreement* (Chesapeake Executive Council 1992), partners agreed to maintain the 40% goal beyond the year 2000 and to attack nutrients at their source--upstream in the tributaries. Nutrient reduction will increase the survival of benthic species, stimulate species diversity and reduce anoxia in bottom waters.

In 1994, the Executive Council of the Chesapeake Bay Program adopted the *Chesapeake Bay Basinwide Toxics Reduction and Prevention Strategy* (CBP 1994). The goal of the toxics strategy is, "a Chesapeake Bay free of toxics by reducing or eliminating the input of chemical contaminants from all controllable sources to levels that result in no toxic or bioaccumulative impact on the living resources that inhabit the Bay or on human health." The strategy commitments go beyond point-source control and begin to address the more difficult tasks of controlling stormwater runoff and atmospheric deposition. Implementation of efforts to identify the origin of nonpoint source toxics will be used to develop strategies to reduce contaminants from those sources in the future.

Fish Passage

The Bay Program is committed to opening blockages in the tributaries for passage of anadromous fish to freshwater spawning grounds. Fish passage goals established in 1993 direct Bay Program signatories to open 582 stream miles by 1998 and over 1,356 miles by 2003 (Chesapeake Executive Council 1993). As of September 30, 1997, a total of 392 miles have been opened.

The Conowingo Dam on the Susquehanna River was fitted with a new fish lift in 1991. In 1997, Maryland opened the last remaining barrier on Patapsco River's mainstem, Simpkins Dam. Pennsylvania completed fish lifts at Safe Harbor and Holtwood Dams on the Susquehanna River (the largest lifts of this kind in the nation) and a fish passage at Rock Hill Dam, on the Conestoga River. Virginia began construction on a fish passage at Boshers Dam in Richmond, a project that will open 138 miles on the mainstem of the upper James River. Catfish are not a target species for fish passage programs in Chesapeake Bay and it is not known if they will benefit as a result. There is some concern that fish passages may be utilized by blue or flathead catfish should they expand their range into the upper Bay.

FISHERIES

Commercial Fisheries

Species of current commercial importance include channel catfish in Maryland, Virginia, and Potomac River, and blue catfish in Virginia river systems where they are most abundant. Brown bullheads support a small specialized market and yellow bullheads are not commercially targeted but may be mixed in as by-catch with other catfish species.

Several gears are employed for commercial catfish harvest in Chesapeake Bay. Traditional pound nets catch large quantities of catfish in the upper Bay region and tributaries are characterized by different combinations of gears used by local harvesters in each region. Gears used to commercially harvest catfish include baited fish pots, fyke nets, haul seines, and pound nets. Trotlines with baited hooks are set in Virginia and were commonly used in Maryland before multiple-hooked lines were prohibited.

Maryland

Hildebrand and Schroeder (1972 reprint) investigated Maryland's catfish fishery in 1929, prior to channel catfish introductions. During that period, primarily white catfish were commercially harvested with hook and line, pound nets, and fyke nets, and the species was an important market fish in Baltimore and Washington, D.C. Today, the major portion of the market is for channel catfish (Sauls 1997 and Appendix B). Total Maryland landings in 1996 were 1.99 million pounds. Landings were reported by species for the first time in 1996: channel catfish comprised 1,116,586 pounds, white catfish comprised 85,413 pounds, and 740,752 pounds were reported as unknown (MDNR unpublished data 1996). Records since 1975 indicate an increasing trend in commercial catfish harvest (Figure 7), probably due to the increasing availability as channel catfish have become more abundant and markets have developed. Since 1986, landings have averaged 1.55 million pounds and, more recently, landings from 1994 to 1996 averaged close to 2 million pounds (MDNR unpublished data 1996). Next to menhaden, catfish landings rank second in weight of all commercial finfish species harvested in the state.

The principal market for wild catfish harvested from Maryland is for live fish, which are purchased to stock private ponds for paid sportfishing (Sauls 1997 and Appendix B). Trautman (1981) reported the shipment of "many tons" of white catfish from Maryland and Virginia, over a 15 year span prior to the early 1980s, to stock sportfishing ponds. White catfish were said to be desirable because of their size and easy catchability. As the channel catfish population increased to a size that could support commercial harvest, live fisheries have evolved since the 1980s to target the more desirable channel catfish. Live harvest from Chesapeake Bay supplies catfish buyers in several midwest states (IL, IN) and eastern mountain states (OH, WV, PA; Sauls 1997 and Appendix B). Market demand is for fish which exceed the minimum size limit of 10". Harvesters report approximately 90% of the market is for fish 15" and greater with the exception of 10-12" for the fingerling market (Appendix B). The threatened presence of blue catfish in Maryland could have negative economic impacts on commercial harvesters that sell to the live market. Commercial harvesters from Chesapeake Bay report that blue catfish do not adapt well to confinement, are easily damaged when contained in gear and live wells, and large blue catfish damage other marketable fish held in nets and traps (Appendix B).

Virginia

Menzel (1943) investigated the early commercial catfish fishery in the James and Potomac Rivers. In general, the average fisherman and fishery biologist were relatively unfamiliar with this "small but locally important" catfish industry. Catfish landings in 1940 ranked only 13th in quantity from harvest in Virginia. Menzel reported catch composition, which included channel catfish and white catfish with an average weight of 1 pound, and brown and yellow bullheads which averaged ½ pound. Six Virginia fishermen from the Potomac, James, and Rappahannock Rivers interviewed in 1994 reported the optimum desired weight for catfish was eight pounds and was regulated by market demands. Fish less than or greater than approximately eight pounds were not desirable and were reportedly thrown back.

Since Menzel's (1943) early investigation, blue catfish have become a significant species in the commercial harvest and channel catfish continue to be in high demand. The principal market for blue catfish is for food and the live markets for channel catfish do not seem to be as established in Virginia as they are in Maryland. Harvest of white catfish may no longer be significant due to changes in market preference (Appendix B).

Table 6. Bullhead landings and dockside value in Virginia from voluntary reports (VMRC unpublished data 1993-1996).

Year	Pounds	Dockside Value
1993	43,750	$ 7,333
1994	103,550	$15,972
1995	23,614	$ 4,488
1996	98,290	$18,676

Since 1975, commercial catfish landings in Virginia averaged 916,000 pounds per year (Figure 8). More recently, landings from 1994 to 1996 averaged 758,000 pounds. Bullhead harvest in Virginia may be voluntarily reported as such or included in catfish landings. Bullheads support only local markets or are taken as bycatch and are believed to make up only a small portion of the commercial harvest. Reported landings for bullheads in Virginia are given in Table 6 and are also included in totals for Figure 8.

Potomac River

Fisheries in the Potomac River below the District of Columbia, and not including tributaries in Maryland or Virginia jurisdictions, are regulated by the Potomac River Fisheries Commission (PRFC). Species-specific size limits are in effect in PRFC jurisdictional waters. Size limits for channel catfish and white catfish take into account the different growth rates and are 8" and 10" respectively. Bullheads must be a minimum size of 6".

Catfish landings since 1964 in the Potomac River ranged from 400,141 pounds to only 6,252 pounds (Figure 9). Average landings from 1964 to 1995 were approximately 190,000 pounds per year (PRFC unpublished data, 1964-1995). Bullhead landings are reported separate from catfish in the Potomac River and ranged from 0 to 104,880 pounds since 1982 (PRFC unpublished data, 1982-1995). Blue catfish are not abundant enough to support a commercial fishery and channel catfish comprise the majority of commercial harvest. Brown bullheads support a small portion of commercial harvest, with yellow bullheads taken as bycatch. Commercial fishing is not permitted in the District of Columbia.

Commercial landings were analyzed in four zones of the Potomac River by Lippson et al. (1979). In the 26.4 river miles (16.4 km) of the upper-most zone, beginning 76 miles (47.1 km) from the river entrance to the jurisdictional boundary of Washington, DC, catfish landings were the highest of all species harvested during the years 1964-1971. During that same time period, nearly 90% of catfish harvest in the Potomac River was from that zone (Lippson et al. 1979).

Market Considerations

Of the five Ictalurid species available in the Chesapeake Bay region, only two support significant markets. Channel catfish are harvested for the food market and also sold live to stock fishing ponds. Blue catfish are desirable in the food market for their white filets that are attractive for display and are preferred by some buyers because they are easily skinned by machine. White catfish yield less meat per fish and are not as marketable; however, a local market in Maryland reports that once customers try white catfish they prefer the flavor over channel catfish. Brown bullheads yield red filets and support a small, specialized market. Yellow bullheads are not commercially targeted but may be mixed in catfish harvest as bycatch.

Commercial harvesters in the Chesapeake Bay region are concerned that the market for wild catfish for human consumption has suffered from competition with farm raised catfish. The largest aquaculture operations for catfish occur in southeastern states, most notably Louisianna and Alabama. The aquaculture industry provides a product of consistent quality and availability, and wild catfish often cannot compete with farm-raised catfish in the food market. Channel catfish are the primary species for farming and can be raised in outdoor ponds to market size in about 18 to 24 months. Indoors, in controlled conditions, catfish feed consistently and grow faster.

Aquaculture is a relatively new industry in Maryland. Eight catfish growout operations and nine fee fishing ponds were registered in the state in 1995. In 1991, 161,820 pounds of catfish were cultured in Maryland, and increased to 236,853 pounds in 1992. Extreme winter temperatures in 1993 are suspected of causing the 74% decline in Maryland catfish production which was only 61,800 pounds. The 1994 estimate increased to 197,350 pounds (MDA 1995).

Brachyplatysoma vaillanti, a wild catfish from Brazil, are also imported to the United States. The imported product is less expensive than domestic farm raised products and is a competitive product in the food market.

Recreational Fishery

The acceptance of catfish as a sportfish is documented in the 1991 U.S. Fish and Wildlife Service Fishing and Hunting Survey (U. S. Department of Interior 1993). Nationally, catfish rank third in angler preference (U. S. Department of Interior 1989). Recreational catfish harvest in Chesapeake Bay is estimated by an angler survey, the Marine Recreational Finfish Sportfishing Survey (MRFSS), conducted by the National Marine Fisheries Service (NMFS). Catfish harvest may be underestimated for Chesapeake Bay as a result of survey design, which does not sample the upper tidal freshwater portions of rivers where a high level of recreational catfish angling occurs (Piavis et al. 1994). Catfish anglers in the Chesapeake Bay region are diverse and range from charter boat participants in the upper Bay and tournament participants in Virginia tributaries, to shore fishermen throughout the tidal and nontidal portions of the system. It is not known to what extent catfish are taken for subsistence in the Chesapeake Bay region, however, the large percentage of small fish taken by anglers surveyed is evidence that catfish are targeted by more than just pure sport anglers. Catfish are resident species that may experience high levels of fishing pressure during their spawning seasons (Piavis et al. 1994).

Maryland

In 1993, Maryland issued 218,755 tidal sportfishing licenses and charter boats logged 100,300 trips. Of 12 finfish species kept by anglers in Maryland's portion of Chesapeake Bay, channel catfish ranks fifth (Feldler and Jacobson 1988). The estimated recreational catfish landings in Maryland during 1993 was 288,254 pounds (MRFSS data).

Recreational angler surveys in Choptank River during 1993 found less discrimination of size in the recreational fishery and verifies the 10 inch (250 mm) size limit as a useful conservation measure (Piavis et al., 1994). However, based on an estimated length of 12" to 14" (300-350 mm) at first maturity (Fewlass 1980), 49% of the recreational harvest of channel and white catfish surveyed by MRFSS in Maryland during 1993 were immature fish (Piavis et al. 1994). A creel survey in Choptank River in 1996 found a disproportionatly low percentage of channel catfish harvested between 10" and 13" (250-325 mm) and revealed an angler preference for fish in the 16" to 21" (400-525 mm) range (Sadzinski 1997).

Virginia

In 1994, Virginia issued nearly one-half million freshwater fishing licenses and approximately 80,000 saltwater fishing licenses. Virginia anglers spent an estimated 6.2 million days pursuing catfish in 1985 (U. S. Department of Interior 1989). Catfish are prized by anglers for both their culinary value and trophy size potential. Specific creel statistics (e.g., harvest, catch rates) are unknown for tidal systems; however, a survey by VDGIF underway on the Chickahominy River (a James River tributary) should yield some insights in this regard.

Potomac River

Elser (1954) conducted a creel survey of the Potomac River in 1954. From Oldtown to Little Falls (170 river miles, 105 km) recreational harvest of catfish ranked third in importance (26% of total finfish harvest). During that year, anglers made 89,000 trips (520 trips per mile of river) and harvested 68,000 catfish (29,000 catfish were released). The most frequent species harvested was channel catfish. Catfish harvest in creel surveys further downriver in 1960 and 1961 did not rank as high (Frisbie and Ritchie 1963) and was probably due to the lesser abundance of catfish in the lower portion of the estuary and the greater abundance of other popular sportfish such as striped bass, bluefish and other summer migrants. White catfish, which are typically found downstream from channel catfish concentrations, was the principal species reported in the 1960-61 survey.

Washington, D.C.

Washington, D.C., cites significant angler activity for brown bullheads and channel catfish, the two most abundant Ictalurid species. White catfish and blue catfish are desirable, however, their occurance is rare. In the Anacostia River, a tributary of the Potomac, human consumption of bottom-feeding fish (including catfish) is prohibited through a health advisory. Catfish from the Anacostia have high levels of PCBs and pesticides accumulated in the flesh and exceed U.S. Environmental Protection Agency (EPA) limits for consumption. In spite of the health advisory, catfish are frequently taken by anglers within the watershed (Raj Tilak, D.C. Fisheries Management Branch, personal communication).

Management

Laws and Regulations

The management strategy for catfish mainly consists of size limits for the commercial and recreational fisheries. White and channel catfish in Maryland must be at least 10" (250 mm) long, and no size limits exist for bullheads. In the Potomac River, channel catfish must be 8 inches (200 mm), white catfish must be 10 inches (250 mm), and bullheads must be 6 inches (150 mm). Virginia currently has no size limits for catfish or bullheads. The three jurisdictions regulate commercial gear with restrictions on size, design, seasons, and placement. For a summary of all regulations affecting catfish and bullhead harvest in Maryland, Virginia and the Potomac River, see Appendix A.

Fishery Management Plan Development

Development of a Fishery Management Plan (FMP) for catfish in Chesapeake Bay was explored by the Chesapeake Bay Program in 1995. The Fishery Management Plan Workgroup of the Chesapeake Bay Program's Living Resources Subcommittee recommended that adoption of a FMP for catfish be delayed for the following reasons: 1) commercially and recreationally exploited stocks appear healthy; and 2) without a stock assessment, target levels of harvest are unknown and no management recommendations can be made. Because catfish are heavily exploited, a stock assessment would be beneficial while the stocks are thought to be healthy. A stock assessment would allow the fishery to be monitored and future management strategies to be implemented before harvest grows beyond sustainable levels.

Because migration across jurisdictional lines is naturally restricted due to intolerance of high salinities, it may be determined that catfish do not need a Baywide, interjurisdictional FMP. For example, a stock assessment in the upper Bay would not be applicable to catfish stocks in the Rappahanock or James Rivers, since catfish in Virginia's river systems are isolated populations. Likewise, management strategies which benefit a population in one area may not be necessary Baywide. Regional FMPs, applicable to respective regions within the Chesapeake Bay and each supporting a different species complex, may be more appropriate to address management needs. It may be possible for catfish to pass between Maryland's portion of Chesapeake Bay and the Potomac River during years of low salinity and this should also be explored before an interjurisdictional FMP is developed.

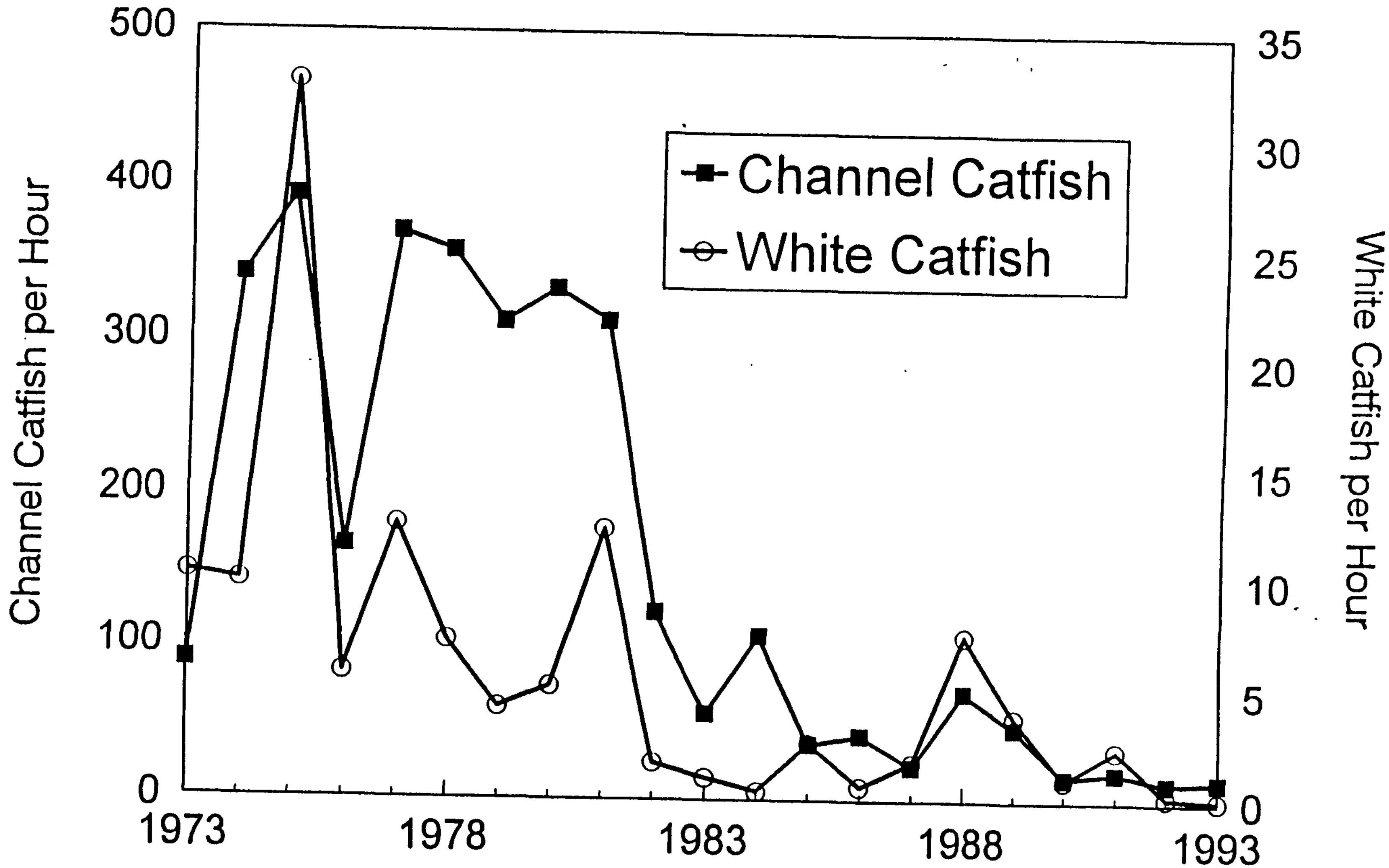


Figure 2. Channel catfish and white catfish captured at the Conowingo Dam fish lift facility, measured in fish per hour.
Data source: Susquehanna River Anadromous Fish Restoration Cooperative

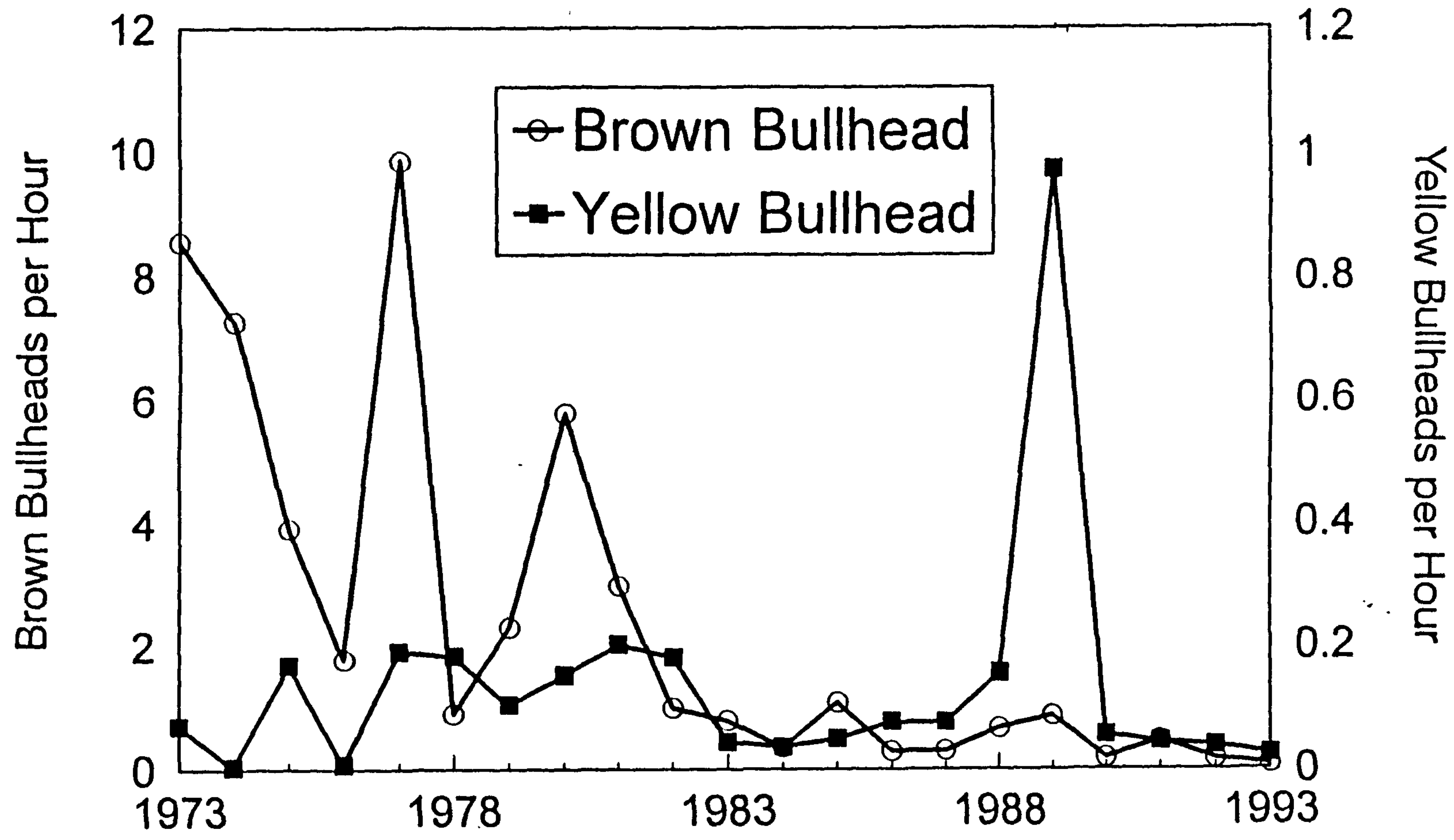


Figure 3. Brown bullheads and yellow bullheads captured at the Conowingo Dam fish lift facility, measured as fish per hour.

Data source: Susquehanna River Anadromous Fish Restoration Cooperative

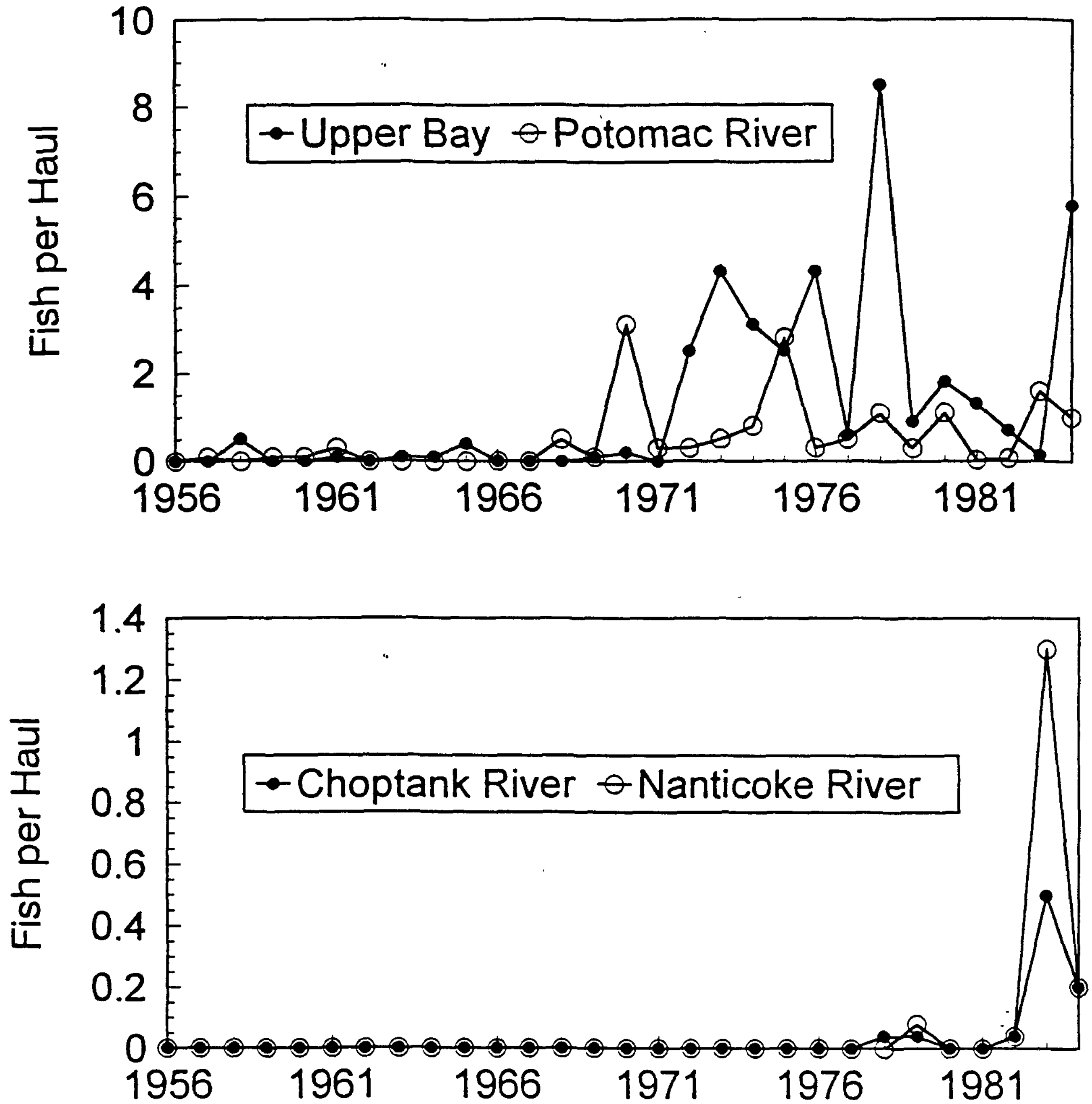


Figure 4. Catfish indices from Maryland Chesapeake Bay juvenile striped bass seine survey.

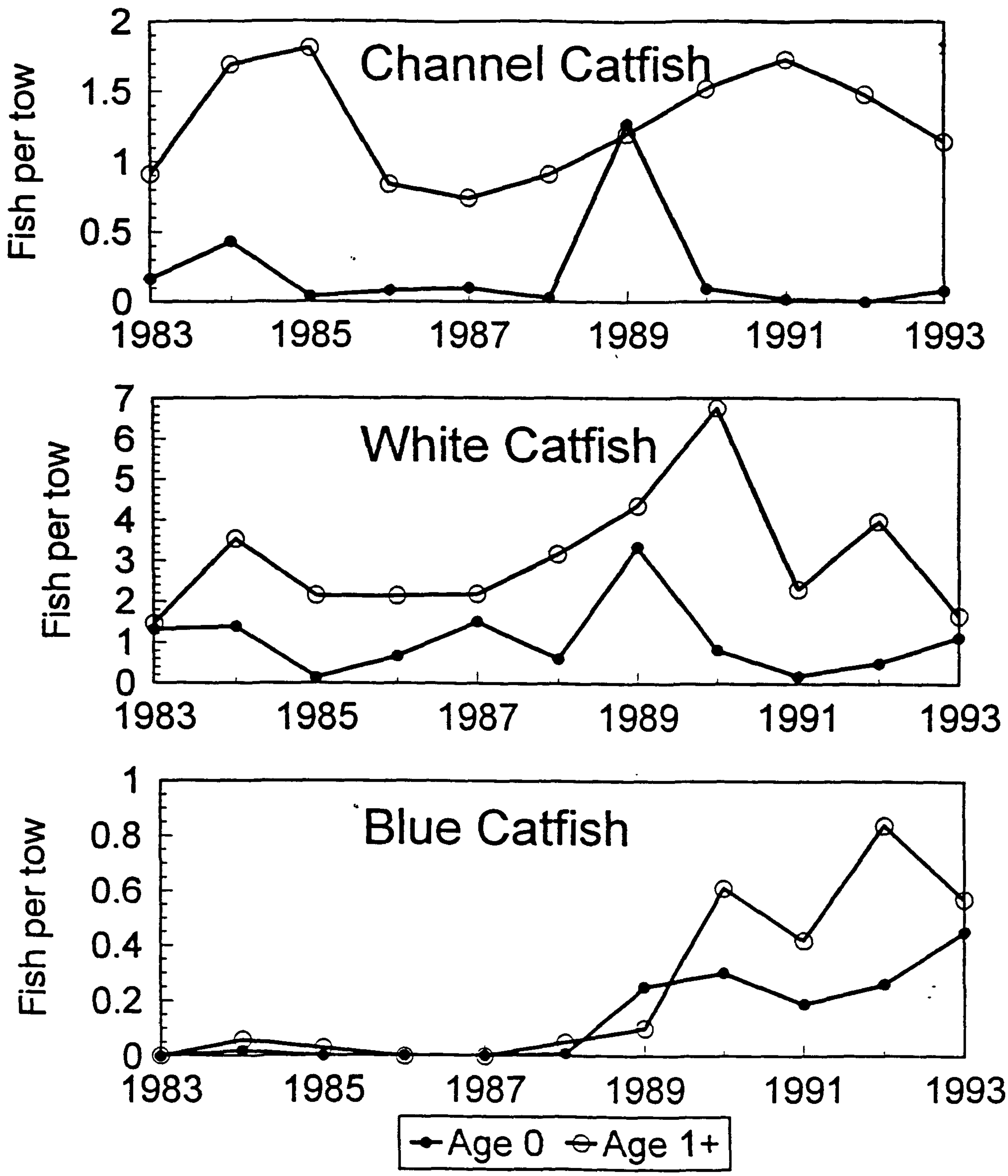


Figure 5. Virginia Trawl Survey Catfish Indices

Source: VIMS trawl survey data (Bonzek *et al.* 1995)

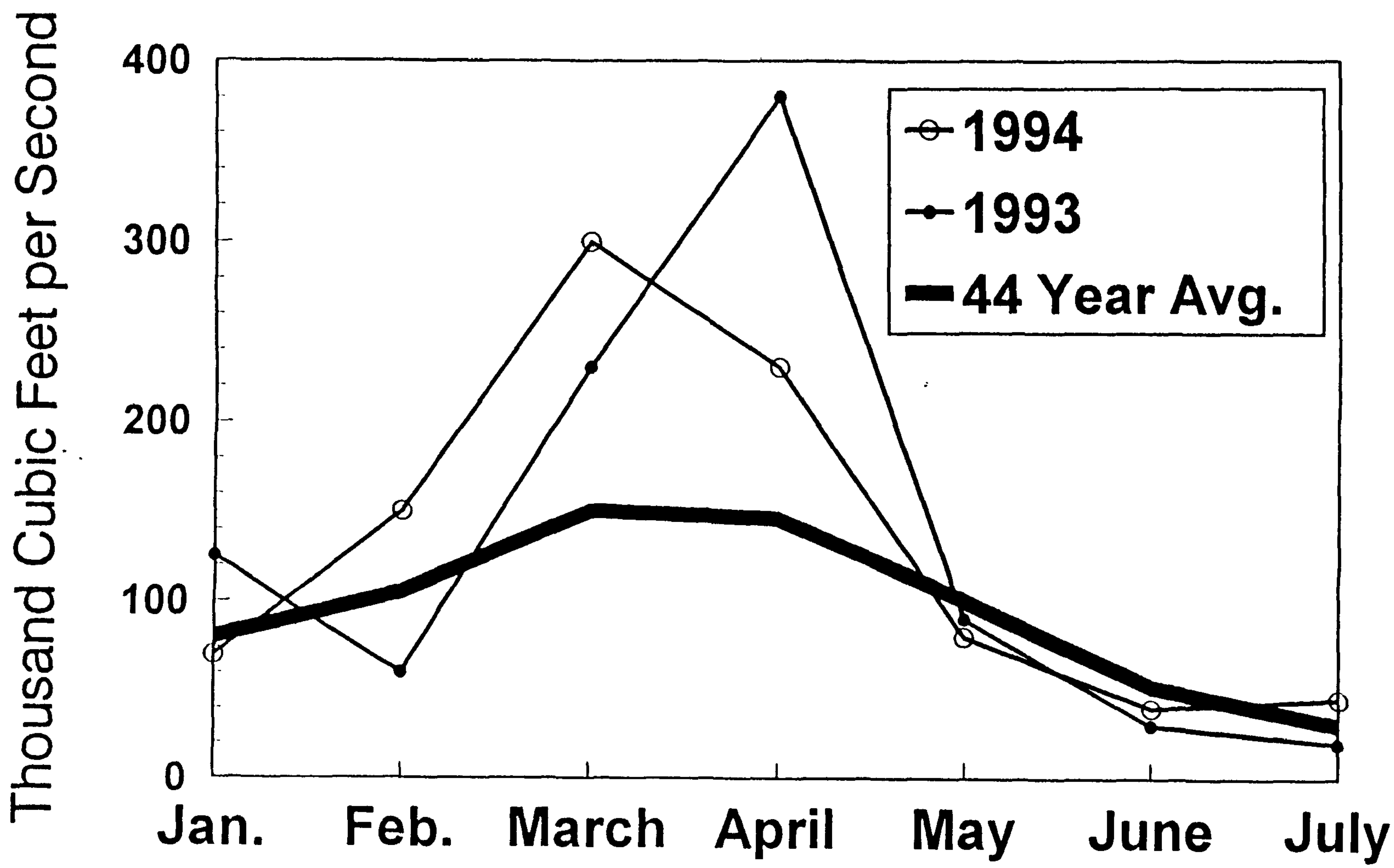


Figure 6. Estimated average daily streamflow into Chesapeake Bay.

Source: U.S. Geological Survey (Bay Journal 1994)

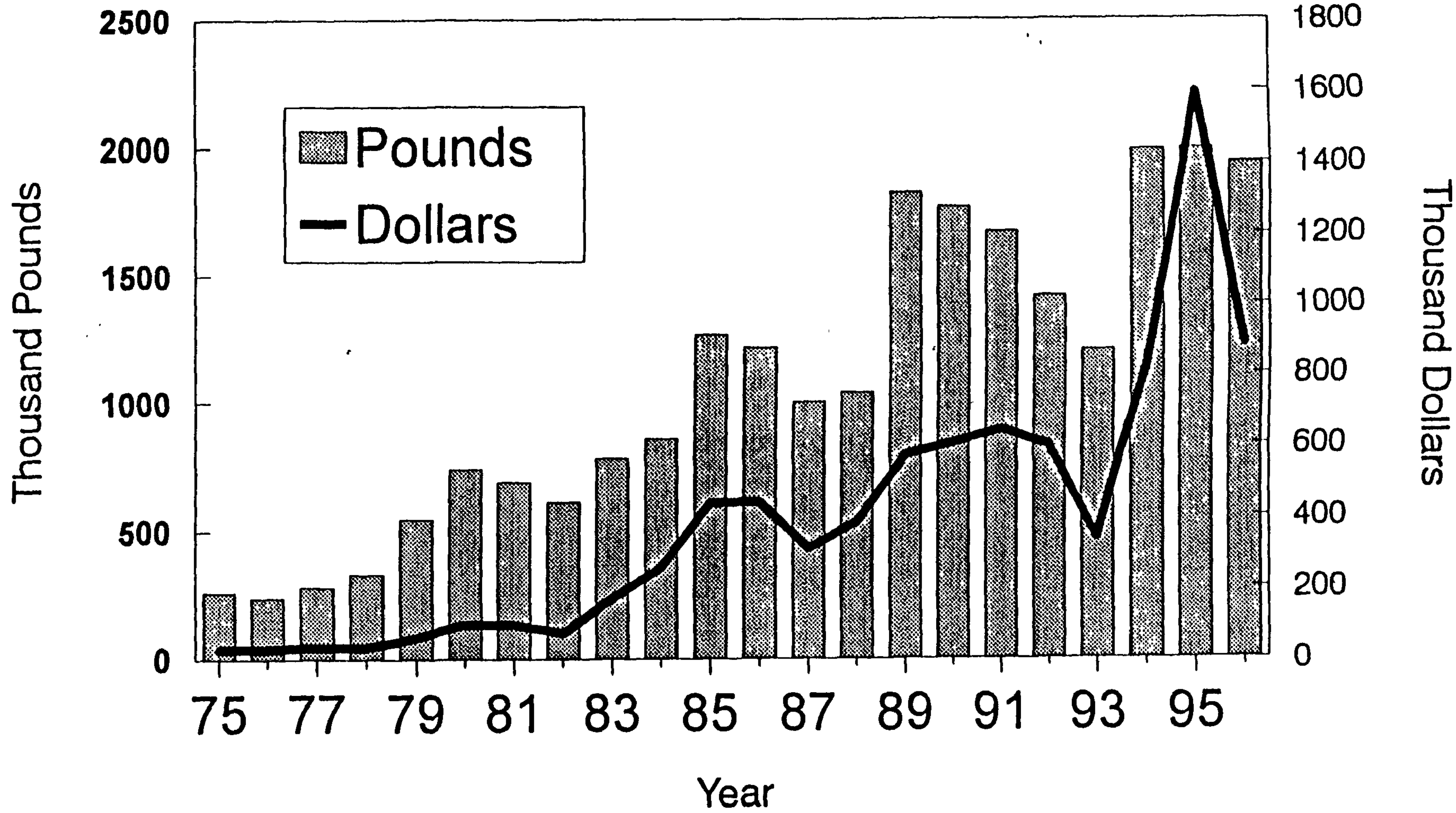


Figure 7. Maryland commercial catfish and bullhead landings and dockside value, 1975 to 1996. Landings reported by species in 1996: channel catfish, 1.1 mill. lbs.; white catfish, 85,413 lbs.; unknown, 740,752 lbs.

Source: NMFS and MDNR data

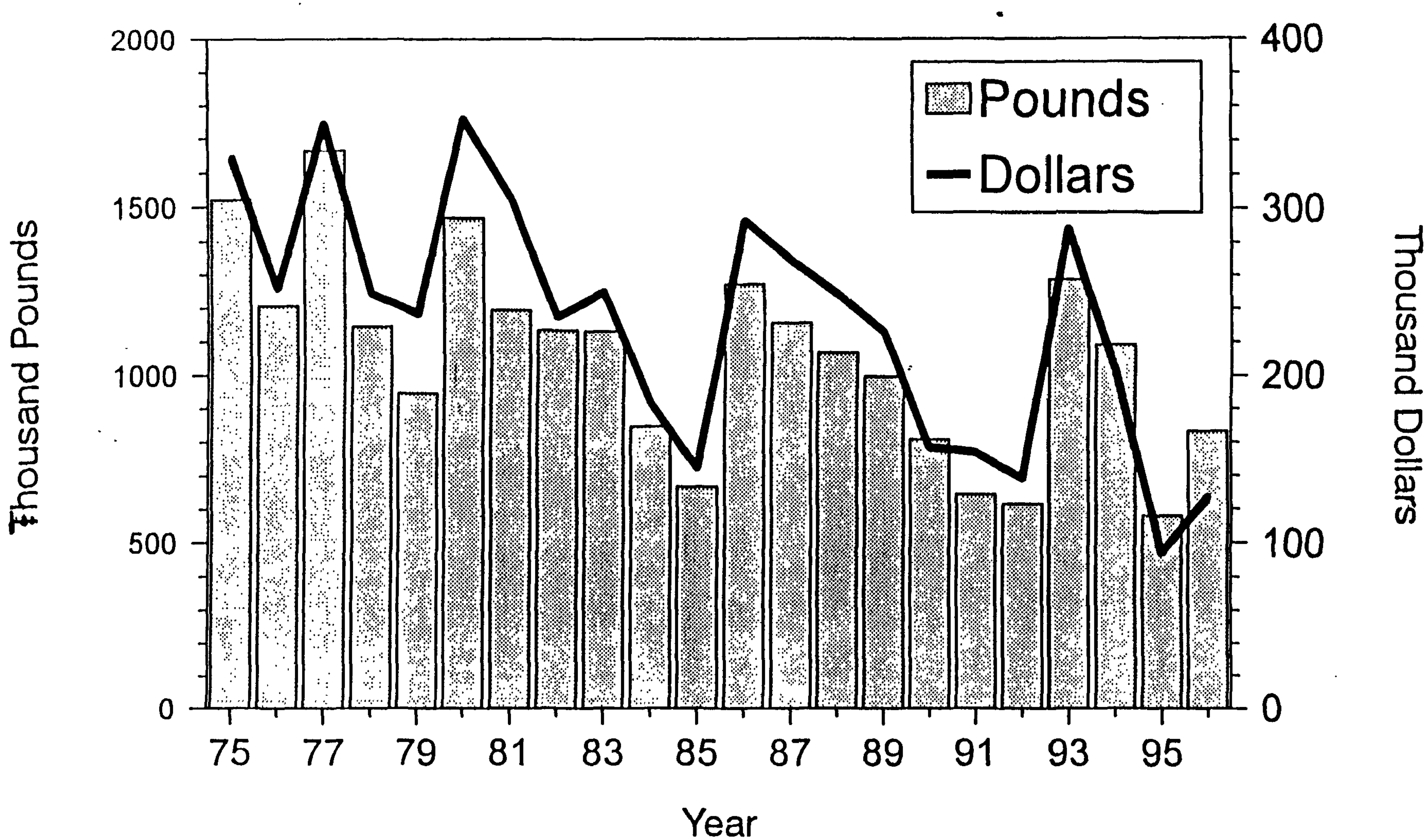


Figure 8. Virginia commercial catfish landings (including bullheads) and dockside value, 1975 to 1996.

Source: NMFS and VMRC data

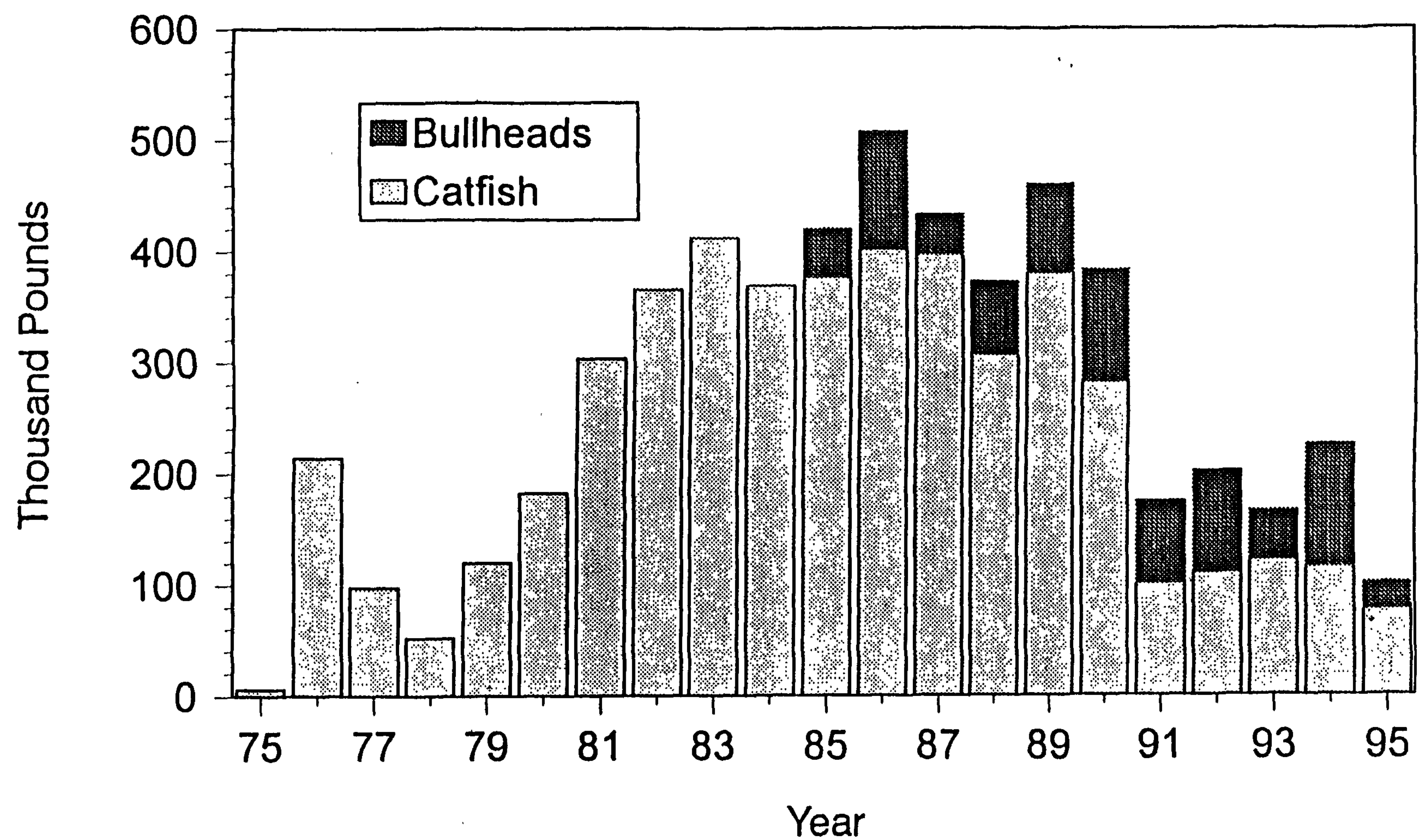


Figure 9. Potomac River commercial catfish harvest landed in Maryland and Virginia. Data since 1985 reported as catfish or bullhead species.

Source: Potomac River Fisheries Commission

RESEARCH AND DATA NEEDS

Commercial Data Needs

Commercial Reporting Deficiencies

Knowledge of species preference, fishing pressure and relative harvest of each species is required for effective conservation measures, should they be necessary. Maryland landings were reported by species for the first time in 1996; however, 38% of catfish landings were "unknown species" and reporting could continue to be improved. Studies to investigate the size composition of landed harvest are also needed.

Optimum Harvest

The maximum harvest of catfish species sustainable on a long-term basis is unknown for the Chesapeake Bay. While commercially and recreationally exploited catfish stocks are believed to be healthy, it would be most useful to determine the optimum and sustainable level of harvest prior to any increase in exploitation.

Socioeconomic Effects of Blue Catfish Introduction or Expansion

The presence of blue catfish in Virginia is supported by recreational anglers due to their large size and aggressive sporting potential. They are a commercially valuable species where populations are established. However, establishment of blue catfish in areas where commercial harvesters cater to the live market, which is predominately supplied with channel catfish, could have negative economic impacts. There is a need to identify potential economic impacts of blue catfish, should their distribution expand to other states, and create strategies to prevent their expansion.

Recreational Data Needs

Recreational Data

Catfish are an important recreational species in the Bay. Angler surveys conducted by NMFS (MRFSS data) in tidal estuarine waters do not adequately represent the recreational importance of catfish in the Bay. In Virginia, catfish are becoming a popular species for recreational tournaments. With the lack of adequate recreational data, it is difficult to evaluate the need for conservation measures. Additional data are needed on species preference, fishing pressure and harvest. Isolated tributaries with high levels of recreational effort may need more intense management than other less-fished tributaries.

Catch and Release Mortality

Catch and release techniques are widely practiced as a conservation tool by recreational fishermen. The amount of fish released by anglers and the rate of success associated with such practices is unknown for catfish. There is some current investigation of this problem in Virginia.

Research Needs

Biology

Few studies exist on catfish biology in estuaries. Growth and age-at-maturity are influenced by environmental conditions, such as temperature, and studies from differing climatic regions may not be applicable to Chesapeake Bay. Biological characteristics can vary from one tributary to the next. More information is needed on sex ratios, fecundity, age composition, standing stock biomass, stock distribution, feeding, and habitat requirements in each region of the Bay.

Habitat Requirements

Catfish are found in a variety of habitats from fresh to estuarine waters. Some species are expanding their range and distribution is changing. Habitat requirements and limits of tolerance in Chesapeake Bay are either changing or unknown. Spawning areas are largely unknown. Further research is necessary to adequately define habitat requirements for catfish in Chesapeake Bay.

Impacts of Non-Native Catfish Introductions

Effects of Predation by Catfish on Alosid Restoration Efforts.

The annual spawning migrations of alosid species at one time extended far into Bay rivers, extending into Pennsylvania and New York via the Susquehanna River, and beyond Charlottesville, Virginia, via the James River. Shad once supported a large commercial industry, with baywide landings averaging 20 million pounds annually. By the 1980's landings had fallen to less than one-twentieth of what they once were. Since the alosid decline, millions of dollars have been allocated to re-open spawning habitat blocked by dams and other obstructions and harvest of American shad has been prohibited in Chesapeake Bay since 1980 in Maryland and 1994 in Virginia. Currently, the Chesapeake Bay Program is developing restoration targets for shad populations in Chesapeake Bay and stocking programs are ongoing in Pennsylvania, Maryland and Virginia. Little is known about the impacts of non-native species, such as channel catfish and blue catfish, which have become established in areas historically utilized as spawning and juvenile habitat by alosids. Virginia is currently investigating the effects of catfish predation on alosids in river systems where shad stocking efforts are targeted.

Channel Catfish Range Expansion and Population Growth in the Upper Bay

Channel catfish are established in the upper Bay mainstem, however, during years of high freshwater flow, catfish may expand their range southward to areas not historically utilized to any great extent. Effects of catfish in newly invaded areas on local species are unknown. There is a need to investigate natural or anthropogenic causes for increases in channel catfish abundance and distribution, such as increased freshwater flow due to loss of vegetative buffering systems (mainly forests and wetlands) and increased impervious surface in the upper Bay watershed and identify the potential biological, ecological and economic impacts.

Blue and Flathead Catfish Range Expansion and Population Growth

In Virginia, species distribution is in flux due to competition between native species and growing populations of naturalized catfish. Blue catfish are an introduced species presently confined to Virginia tributaries and the Potomac River. Their numbers have been increasing rapidly in Virginia, and larger fish have been reported annually in recent years (VDGIF unpublished data). They are an aggressive fish that can reach large sizes and are tolerant of salinities to 11.4 ppt. Blue catfish are present in low numbers in the Potomac River and the potential for range expansion into the upper Chesapeake Bay and tributaries has not been investigated. The effects of blue catfish on native community structure are unknown. In addition, channel catfish may be experiencing displacement in some tributaries by blue catfish. There is a need to monitor the distribution of blue catfish in Virginia and the Potomac River, investigate the ecological effects of blue catfish introduction, and evaluate the potential for blue catfish expansion into the upper Bay.

Flathead catfish populations are present in the James River and the Occoquan River and reservoir in the Potomac River system. Flatheads are large, aggressive catfish that may compete with other catfish species, as well as other finfish. Populations are small, but indications are that the James River population is increasing and should be monitored.

Habitat Alteration

Riparian Buffers

Catfish are known to spawn in freshwater portions of tributaries in dark, sheltered areas. Loss of riparian forest buffers reduce overhead cover and wood debris utilized as nesting sites. Juveniles also need cover for protection. The relative importance of riparian vegetation to catfish species should be examined.

Water Quality

Freshwaters of tidal rivers and creeks are in close proximity to sources of toxic contaminants and nutrient inputs. Catfish remain in fresh to slightly brackish water throughout their developmental stages and may be susceptible to concentrated contaminants. Catfish are bottom dwellers and are susceptible to toxic accumulation in sediments. Catfish that are not highly migratory may be exposed to contaminants throughout their life cycle. Accumulations of contaminants in catfish tissue has resulted in the closure of certain areas to catfish fishing for consumption. Current water quality strategies should be evaluated for their benefits to the catfish resource.

LITERATURE CITED

Allen, K.O. 1971. Effects of salinity on growth and survival of channel catfish, *Ictalurus punctatus* (Rafinesque), eggs through yearlings. Disertation, Louisiana State University and Agricultural and Mechanical College, Department of Marine Science.

Atema, J., J. H. Todd, and J. E. Bardach. 1969. Olfaction and behavioral sophistication in fish. in: C. Pfaffman, editor. Olfaction and taste: Proceedings of the third international symposium. Rockefeller Univ. Press, New York, NY.

Bardach, J.E., J.H. Ryther and W.O. McLarney. 1972. Aquaculture, the farming and husbandry of freshwater and marine organisms. Weley-Interscience, New York.

Baumann, P., W. Smith, and W. Parland. 1987. Tumor frequencies and contaminant concentrations in brown bullheads from an industrialized river and a recreational lake. Trans. Amer. Fish. Soc. 116:79-86.

Bay Journal. 1994a. Freshet hits bay for second straight year. Editor: K. Blankenship. 4(4):11. Seven Valleys, PA.

Bay Journal. 1994b. 1994 freshet brings wave of ills to the Bay. Editor: K. Blankenship. 4(6):1, 10-11. Seven Valleys, PA.

Bender, M., R. Huggett, and W. Hargis. 1977. Kepone residues in Chesapeake Bay biota. Pages 14-37 in Proc. of the Kepone Seminar II, US EPA Region III, Philadelphia, PA.

Biggs, R. 1981. Freshwater inflow to estuaries: short and long-term perspectives. Proc. Natl. Sym. on Freshwater Inflow to Estuaries. USFWS: FWS/OBS-81-04.

Bonzek, C., P.J. Geer, and H. Austin. 1995. VIMS Juvenile Fish Trawl Survey, Juvenile Indices 1979-1994. Virginia Sea Grant Marine Resource Advisory No. 57. Virginia Sea Grant Marine Advisory Program. Virginia Institute of Marine Science. Gloucester Point, VA.

Bonzek, C., and R. Morin. 1988. Completion report for Maryland fisheries statistics project 3-413-D-1. Unpubl. rep.

Bonzek, C., and R. Morin. 1987. Stock description of several commercially important finfish species. Md. Dep. Nat. Resour., Fish. Div. Final Rep. to the Chesapeake Bay Stock Assessment Comm.

Brooks, M.J., R.O. Smitherman, J.A. Chappell, and R.A. Dunham. 1982. Sex-weight relations in blue, channel, and white catfishes: implications for brood stock selection. Prog. Fish-Cult. 44(2):105-107.

Brown, B., I. Inman, and A. Jearld, Jr. 1970. Schooling and shelter seeking tendencies in fingerling catfish behavior. Trans. Am. Fish. Soc. 99(3):5400-545.

Burkhead, N. M. 1980. The life history of the stoneroller minnow, *Campostoma a. anomalum* (Rafinesque) in five streams in east Tennessee. Tennessee Wildlife Resources Agency Technical Report 80-50, Nashville, TN.

Burkhead, N., R. Jenkins and E. Maurakis. 1980. New records, distribution and diagnostic characters of Virginia Ictalurid catfishes with an adnexed adipose fin. Brimleyana. (4):75-93.

Carlander, K.D. 1969. Handbook of freshwater fishery biology. Vol. 1. Iowa State University Press, Ames.

CBP (Chesapeake Bay Program). 1996. Introduction of Non-Indigenous Aquatic Species Implementation Plan. Chesapeake Bay Program Office, Annapolis, MD.

CBP (Chesapeake Bay Program). 1995. Water Quality Functions of Riparian Forest Buffer Systems in the Chesapeake Bay Watershed. Chesapeake Bay Program Offices, Annapolis, MD.

CBP (Chesapeake Bay Program). 1994. Chesapeake Bay Basinwide Toxics Reduction Strategy. Chesapeake Bay Program Office, Annapolis, MD.

CBP (Chesapeake Bay Program). 1993. Chesapeake Bay Policy for the Introduction of Non-Indigenous Aquatic Species. Chesapeake Bay Program Office, Annapolis, MD.

Chesapeake Executive Council. 1993. Directive No. 93-4. Fish Passage Goals. Chesapeake Bay Program Office, Annapolis, MD.

Chesapeake Executive Council. 1992. Chesapeake Bay Agreement 1992 Amendments. Chesapeake Bay Program Office, Annapolis, MD.

Chesapeake Executive Council. 1987. 1987 Chesapeake Bay Agreement. Chesapeake Bay Program Office, Annapolis, MD.

Carter, W.R. 1973. Ecological Study of Susquehanna River and Tributaries Below the Conowingo Dam. Submitted to National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Project AFSC-1.

Casey, J., S. Minkkinen and J. Soldo. 1988. Characterization of Choptank River Populations of White (*Morone americana*) and Yellow (*Perca flavescens*) Perch. Cooperative Agreement between NOAA and the State of Maryland. Fisheries Division, Maryland Department of Natural Resources, Tawes State Office Bldg., Annapolis, MD.

Cosden, D. 1996. Personal communication. Fisheries Service, Maryland Department of Natural Resources. Annapolis, MD.

Courtenay, W.R., Jr., D.A. Hensley, J.N. Taylor, and J.A. McCann. 1986. Distribution of exotic fishes in North America. pp. 675-698. in C.H. Hocutt and E.O. Wiley, editors. Zoogeography of North American Freshwater Fishes. John Wiley & Sons, New York.

Courtenay, W.R. and J.D. Williams. 1992. Dispersal of exotic species form aquaculture sources, with emphasis on freshwater fishes. in A. Rosenfield and R. editors. Dispersal of Living Organisms into Aquatic Ecosystems. Maryland Sea Grant, College Park, MD.

Dames, H., T. Coon, and J. Robinson. 1989. Movements of channel and flathead catfish between the Missouri River and a tributary, Perch Creek. Trans. Am. Fish. Soc. 118:670-679.

EAI (Ecological Analysts, Inc.). 1974. Douglas Point site, power plant site evaluation, aquatic biology, final report, Vol. II. Prepared for Power Plant Siting Program, Maryland Dept. of Natural Resources. EAI, Baltimore, MD. PPSE 4-2.

Elser, H.J. 1954. Fishing Pressure and the Harvest of Sport-Fishes on the Potomac River. Maryland Dept. of Research and Education, Chesapeake Biological Lab. Solomons, MD.

Etnier, D. A. and W. C. Starnes. 1993. The Fishes of Tennessee. The University of Tennessee Press, Knoxville, TN. 681 p.

Feldler, A.J. and M.P. Jacobsen. 1988. 1985 Maryland marine recreational fishing study. Department of Recreation. University of Maryland. College Park.

Fewlass, L. 1995. Personal communication. Fisheries Service. Maryland Department of Natural Resources. Earleville, MD.

Fewlass, L. 1980. Life history and management of the channel catfish in the Susquehanna River. Unpubl. Rep. of Md. Dep. of Nat. Resour. Comm., Wildl. Adm.

Frese, C. 1995. Personal communication. Muddy Run Ecology Lab. Dreumore, PA.

Frisbie, C. And D. Ritchie. 1963. Sport fishery survey of the lower Potomac estuary, 1959-1961. Chesapeake Sci. 4(4):175-191.

Funk, J.L. 1955. Movement of stream fishes in Missouri. Trans. of the Amer. Fish. Soc. 85:39-56.

Geer, P. Personal communication. Virginia Institute of Marine Science. Gloucester Pt., VA.

Guier, C. R., L. E. Nichols, and R. T. Rachels. 1984. Biological investigations of flathead catfish in the Cape Fear River. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies. 35(1981):607-621.

Hagen, R.M. and E.B. Roberts. 1973. Ecological impacts of water storage and diversion projects. in C.R. Goldman, J. McEvoy, and P.J. Richardson, editors. Environmental quality and water development. W.H. Freeman, San Francisco.

Hart, J.S. 1952. Geographic variation of some physiological and morphological characters in certain freshwater fish. Univ. of Toronto Biol. Ser. 60:1-79.

Hildebrand, S.F. and W.C. Schroeder. 1972. Fishes of Chesapeake Bay. T.F.H. Publications, Inc., Neptune, NJ. Reprint of 1928 ed., issued as vol. 53, pt. 1 of U.S. Bureau of Fisheries bulletin, and as Document 1024 of the Bureau of Fisheries.

Horton, T., and W.M. Eichbaum. 1991. Turning the Tide, Saving the Chesapeake Bay. Island Press, Washington, D.C.

Jenkins, R. E., and N. M. Burkhead. 1994. Freshwater Fishes of Virginia. American Fisheries Society, Bethesda, Maryland. 1079 p.

Jones, P.W., F.D. Martin, and J.D. Hardy. 1978. An atlas of egg, larval and juvenile stages. VI, Acitenseridae-Ictaluridae. U.S. Dept. of Interior, Fish and Wildlife Service. Fort Collins, CO. 311-333.

Jones, P., H. Speir, N. Butowski, R. O'Reilly, L. Gillingham and E. Smoller. 1988. Chesapeake Bay Fisheries: Status, Trends, Priorities and Data Needs. Maryland Department of Natural Resources, Annapolis, MD and Virginia Marine Resources Commission, Newport News, VA. 226 pp. plus appendices.

Jordan, S.J., P.A. Vaas, and J. Uphoff. 1990. Fish assemblages as indicators of environmental quality in Chesapeake Bay. Biological Criteria: Research and Regulation. U.S. Environmental Protection Agency-440/5-91-005.

Kaumeyer, K. and E. Setzler-Hamilton. 1982. Effects of Pollutants and Water Quality on Selected Estuarine Fish and Invertebrates: A Review of the Literature. Reference No. UMCEES 82-130 CBL. Chesapeake Biological Laboratory, Center for Environmental and Estuarine Studies, University of Maryland. Final report submitted to U.S. EPA, Chesapeake Bay Program, Annapolis, MD.

Kendall, W.C. 1902. Habits of some of the commercial catfishes. Bull. U.S. Fish Comm. 22:401-409.

Kendall, A.W. and F.J. Schwartz. 1968. Lethal temperature and salinity tolerances of the white catfish, *Ictalurus catus*, from the Patuxent River, Maryland. Chesapeake Science. 9(2):103-108.

Kilby, J.D. 1955. The fishes of two Gulf coastal marsh areas of Florida. Tulane Stud. Zool. 2:175-248.

Lanier, J. 1971. Catfish management in the James River, Virginia. Master's Thesis. The Coll. of William and Mary, Gloucester Pt., VA. 28 p.

Lawler, R.E. 1960. Observation on the life history of channel catfish, *Ictalurus punctatus* (Rafinesque), in Utah Lake, Utah. Master's Thesis, Utah State University, Logan.

Leasner, L. 1997. Personal communication. Fisheries Service, Maryland Department of Natural Resources. Annapolis, MD.

Lee, D. S., E. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Staffer, Jr. 1980. Atlas of North American Freshwater Fish. N.C. State Mus. of Nat. Hist. 854 pp.

Ling, S. 1977. Aquaculture in southeast Asia, a historical overview. Washington Sea Grant Publication. University of Washington Press, Seattle, Wasington.

Lippson, A. J., M. S. Haire, A. F. Holland, F. Jacobs, J. Jensen, R. L. Moran-Johnson, T. T. Polgar, and W. A. Richkus. 1979. Environmental Atlas of the Potomac Estuary. Martin Maretta Corporation for MD Dep. Nat. Res. 279 pp.

Lippson, A. J. and R. L. Lippson. 1984. Life in the Chesapeake Bay. The Johns Hopkins Univ. Press, Baltimore, Md. 229 pp.

Manooch, C. 1984. Fishes of the Southeast United States. N. C. State Mus. of Nat. Hist. 362 p.

Manooch, C.S., III and D. Raver, Jr. 1991. Fishermen's Guide; Fishes of the Southeastern United States. North Carolina State Museum of Natural History, Raliegh, NC. 362 p.

Markham, C.A. and P.G. Piavis. 1996. Project 1: Stock Assessment of Selected Adult Resident and Migratory Finfish in Maryland's Chesapeake Bay. In: Stock Assessment of Selected Migratory Recreational Finfish Species within Maryland's Chesapeake Bay. Maryland Department of Natural Resource for United States Department of Interior Fish and Wildlife Service. Project F-54-R.

Markham, C.A., P.G. Piavis and A. Jarzynski. 1997. Project 1: Stock Assessment of Selected Adult Resident and Migratory Finfish in Maryland's Chesapeake Bay. In: Stock Assessment of Selected Migratory Recreational Finfish Species within Maryland's Chesapeake Bay.

Maryland Department of Natural Resource for United States Department of Interior Fish and Wildlife Service. Project F-54-R.

Marzolf, R. 1957. The reproduction of channel catfish in Missouri ponds. J. Wildl. Management. 21(1):22-28.

McMahon, T. E. and J. W. Terrell. 1982. Habitat suitability index models = channel catfish. U.S.D.I. Fish and Wildl. Serv. FWS/OBS-82/10.2. 29 pp.

MDA (Maryland Department of Agriculture). 1995. Aquaculture Release. Annapolis, MD.

MDNR (Maryland Department of Natural Resources). 1958 to 1997. Unpublished data. Fisheries Division. Annapolis, MD.

Menzel, R.W. 1943. Notes on the Biology and Commercial Fishery of the Catfish of the James River, Virginia. Master's Thesis, College of William and Mary, Virginia Institute of Marine Science, Gloucester Pt., VA.

Menzel, R. 1943. The catfish fishery of Virginia. Trans. Am. Fish. Soc. V.73:364-

Minckley, W.L. and J.E. Deacon. 1959. Biology of the flathead catfish in Kansas. Transactions of the American Fisheries Society. 88:344-355.

MRFSS (Marine Recreational Fishery Statistic Survey). http://remora.ssp.nmfs.gov

Nammack, F. and J.M. Fulton. 1987. A blue catfish, *Ictalurus furcatus*, from the Potomac River. The Maryland Naturalist 31(2):58.

Perry, W. 1969. Food habits of blue and channel catfish collected from a brackish-water habitat. The Prog. Fish-Culturist. 31:47-50.

Perry, W.G. and D.C. Carver. 1972. Length at maturity and total length-collarbone length conversions for channel catfish, *Ictalurus punctatus*, and blue catfish, *Ictalurus furcatus*, collected from the marshes of southwest Louisiana. Proc. Of the Ann. Conf. Southeastern Assoc. of Game and Fish Commissioners. 26:541-553.

Pflieger, W. 1971. A distributional study of Missouri fishes. Univ. Kan. Mus. Nat. Hist. Publ. 20(3):225-570.

Pflieger, W. 1975. The Fishes of Missouri. Missouri Department of Conservation, Jefferson City.

Piavis, P.G., E.J. Webb, B.H. Pyle, and D.R. Weinrich. 1994. Comprehensive sampling of resident and migrant Chesapeake Bay recreational finfish. Maryland Department of Natural Resources, prepared for U.S. Department of Interior Fish and Wildlife Service, Project F-51-R-1.

Piavis, P.G., E.J. Webb, R. Sadzinski, B.H. Pyle and D.R. Weinrich. 1995. Comprehensive sampling of resident and migrant Chesapeake Bay recreational finfish. Maryland Department of Natural Resources, prepared for U.S. Department of Interior Fish and Wildlife Service, Project F-51-R-2.

PRFC (Potomac River Fisheries Commission). 1964 to 1995. Unpublished data. Colonial Beach, VA.

Ramsey, D. and L. K. Graham. 1991. A review of literature on blue catfish and channel catfish in streams. Final Rep. DJ Proj. F-1-R-40, Study S-38, Job 1. Missouri Dep. of Conserv. 46 pp.

Richards, K.R., R.J. Dent, and W.H. Dieffenbach. 1986. Fisheries problems associated with the Truman Dam pumped storage hydroelectric project in west central Missouri. Pages 247-254 in G.E. Hall and M.J. Van Den Avyle, editors. Reservoir fisheries management: strategies for the 80's. Reservoir Committee, Southern Division American Fisheries Soc., Bethesda, MD.

Roberts, M. and R. Bendl. 1982. Acute toxicity of Kepone to selected freshwater fishes. Estuaries. 5(3):158-164.

Rothschild, B.J., J. Ault, B. Huang, A. Holmes, and L. Baylis. 1992. Program development for efficient finfish sampling and stock assessment of northern Chesapeake Bay multi-species complexes. Maryland Department of Natural Resources. Annapolis, MD.

SRAFRC (Susquehanna River Anadromous Fish Restoration Cooperative). 1997. Restoration of American Shad to the Susquehanna River. Annual Progress Report, 1996. Harrisburg, PA.

Sadzinski, R. 1997. Project 2: Assessment of the Spring Recreational Finfish Harvest in Choptank River. In: Stock Assessment of Selected Migratory Recreational Finfish Species within Maryland's Chesapeake Bay. Maryland Department of Natural Resource for United States Department of Interior Fish and Wildlife Service. Project F-54-R.

Sanderson, A. 1958. Smallmouth bass management in the Potomac River basin. Trans. 23rd North Am. Wildl. Conf. 248-262.

Sauls, B. 1997. Results of a Commercial Catfish Harvester Survey: 1994 and 1995. Maryland Department of Natural Resources, Fisheries Service. Technical Memo No. 11, August, 1997.

Scott, W. B. and E. J. Crossman. 1973. Freshwater Fishes of Canada. Bulletin 184. Fisheries Research Board of Canada, Ottawa, Canada. 966 p.

Schwartz, F. 1961. Untitled. Maryland Conservationist Vol. XXXVIII 5:21-26.

Schwartz, F. and R. Jackowski. 1965. The age, growth, and length-weight relationship of the Patuxent River, Maryland, Ictalurid white catfish, *Ictalurus catus*. Chesapeake Sci. 6(4):226-237.

Shelton, W.L. and R.O. Smitherman. 1984. Exotic fishes in warmwater aquaculture, p262-301. in W.R. Courtenay, Jr. and J.R. Stauffer, Jr., editors. Distribution, biology, and management of exotic fishes. Johns Hopkins University Press, Baltimore, MD.

Snyder, R. 1995. Personal communication. Pennsylvania Fish and Boat Commission.

Sternberg, D. 1987. Freshwater Gamefish of North America. Prentice Hall Press, New York, NY. 160 p.

Taylor, J.N., W.R. Courtenay, Jr., and J.A. McCann. 1984. Known impacts of exotic fishes in the continental United States. in Courtenay, W.R., and J.R. Stauffer, editors. Distribution, Biology, and Management of Exotic Fishes. John Hopkins University Press, Baltimore, MD.

Tilak, R. And M.J. Siemien. 1991. Biological survey of the anadromous and resident fishes of the Potomac and Anacostia Rivers within the District of Columbia, 1990. Annual report submitted to the U.S. Fish and Wildlife Service.

Tilak, R. And M.J. Siemien. 1992. Biological survey of the anadromous and resident fishes of the Potomac and Anacostia Rivers within the District of Columbia, 1991. Annual report submitted to the U.S. Fish and Wildlife Service.

Tilak, R. And M.J. Siemien. 1993. Biological survey of the anadromous and resident fishes of the Potomac and Anacostia Rivers within the District of Columbia, 1992. Annual report submitted to the U.S. Fish and Wildlife Service.

Tilak, R. And M.J. Siemien. 1994. Biological survey of the anadromous and resident fishes of the Potomac and Anacostia Rivers within the District of Columbia, 1993. Annual report submitted to the U.S. Fish and Wildlife Service.

Tilak, R. And M.J. Siemien. 1995. Biological survey of the anadromous and resident fishes of the Potomac and Anacostia Rivers within the District of Columbia, 1994. Annual report submitted to the U.S. Fish and Wildlife Service.

Tilak, R. And M.J. Siemien. 1996. Biological survey of the anadromous and resident fishes of the Potomac and Anacostia Rivers within the District of Columbia, 1994. Annual report submitted to the U.S. Fish and Wildlife Service.

Tilak, R. And M.J. Siemien. 1997. Biological survey of the anadromous and resident fishes of the Potomac and Anacostia Rivers within the District of Columbia, 1994. Annual report submitted to the U.S. Fish and Wildlife Service.

Tilak, R. 1997. Personal communication. District of Columbia, Department of Consumer and Regulatory Affairs, Fisheries Management Branch.

Todd, J. H. 1971. The chemical language of fishes. Sci. Amer. 224:3-11.

Trautman, M.B. 1957. The Fishes of Ohio. University of Ohio Press, Columbus.

Trautman, M. B. 1981. The Fishes of Ohio. 2nd Ed., Ohio St. Univ. Press, Columbus, OH. 782 p.

Truitt, R., B. Bean and H. Fowler. 1929. The Fishes of Maryland. State of Maryland Conservation Department. 120 pp.

U. S. Department of the Interior, Fish and Wildlife Service and U. S. Department of Commerce, Bureau of Census. 1989. 1985 National Survey of Fishing, Hunting and Wildlife-Associated Recreation. Virginia. U. S. Government Printing Office, Washington, D.C.

U. S. Department of the Interior, Fish and Wildlife Service and U. S. Department of Commerce, Bureau of Census. 1993. 1991 National Survey of Fishing, Hunting and Wildlife-Associated Recreation. Virginia. U. S. Government Printing Office, Washington, D.C.

USGS (United States Geological Survey). Data cited in Bay Journal (1994b).

Uphoff, J. 1997. Personal communication. Fisheries Service, Maryland Department of Natural Resources. Annapolis, MD.

Vaas, P.A. and S.J. Jordan. 1990. Long term trends in abundance indices for 19 species of Chesapeake Bay fishes: reflections of trends in the Bay ecosystem. in New Perspectives in the Chesapeake System: A Research and Management Partnership. Proceedings of a Conference. Chesapeake Research Consortium Publication No. 137. Baltimore, MD.

Van Veld, P. 1980. Uptake, Distribution, Metabolism and Clearance of Kepone by Channel Catfish, *Ictalurus punctatus*. Thesis presented to the School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Pt., VA.

VCU (Virginia Commonwealth University). Unpublished data. Richmond, VA.

VDGIF (Virginia Department of Game and Inland Fisheries). Unpublished data. Williamsburg, VA.

VIMS (Virginia Institute of Marine Science). 1983 to 1993. Unpublished data. Gloucester Pt., VA.

VMRC (Virginia Marine Resources Commission). 1992 to 1997. Unpublished data. Newport News, VA.

Walburg, C.H. 1971. Loss of young fish in reservoir discharge and year-class survival, Lewis and Clark Lake, Missouri River. Pages 441-448 in G.E. Hall, editor. Reservoir Fisheries Limnology, Special Publication 8, American Fisheries Society, Washington, D.C.

Weinrich, D.R., M.E. Dore and W.R. Carter. 1981. Investigation of American Shad in the Upper Chesapeake Bay, 1980. Maryland Department of Natural Resources, Tidewater Administration. Annapolis, MD.

Weinrich, D.R., M.E. Dore and W.R. Carter. 1982. Investigation of American Shad in the Upper Chesapeake Bay, 1981. Maryland Department of Natural Resources, Tidewater Administration. Annapolis, MD.

Weiser, C. 1969. Predation on Juvenile River Herring and Shad by Catfish and Other Fishes. VIMS Nat. Sci. Foun. Rep. Virginia Institute of Marine Science, Gloucester Pt., VA.

Welcomme, R.L. 1988. International transfers of inland fish species, p. 22-40. in W.R. Courtenay, Jr. and J.R. Stauffer, Jr., editors. Distribution, biology, and managment of exotic fishes. Johns Hopkins University Press, Baltimore, MD.

APPENDIX A. LAWS AND REGULATIONS

Maryland

Regulatory Agency:

- Maryland Department of Natural Resources
  Fisheries Service
  580 Taylor Ave., Tawes State Office Bldg.
  Annapolis, MD 21401
  (410) 260-8280
  www.dnr.state.md.us

Size Limit

- 10" size limit for commercial and recreational harvest of white and channel catfish.

Prohibited Harvest Methods

- Harvest by snagging and with cross bows is prohibited.
- Prohibited: gig, gig iron, purse net, beam trawl, otter trawl, trammel net, troll net, or drag net.
- Limit of two hooks or two sets of hooks per rod or line.
- Threshing streams is prohibited (exception: Kent and Queen Anne's Counties)
- Dynamiting streams is prohibited
- June 15 through September 15, a person may not fish from the Conowingo Dam catwalk using artificial lures or bait other than worms, except bloodworms; dough; scent baits; or chicken livers.

License Requirements

- Commercial harvesters must purchase a Tidal Fish License; commercial harvest is permitted in tidal waters only.
- Recreational anglers must purchase a freshwater fishing license for catfish in nontidal waters and a Chesapeake Bay Sportfishing License for catfish in tidal waters.

Commercial Nets

- Minimum mesh size limit: hedging or lead attached to a fish trap, fyke net, or pound net, twine size #12 or larger
- Minimum mesh size limits: pound net, fyke or hoop net, and haul seine, 1.5"; gill net, 2.5".
- Maximum mesh size limit: gill net, 6.0"
- Monofilament gill nets prohibited.
- The setting of anchored gill nets, pound nets, and fyke or hoop nets or any line of these nets more than one third the distance across a water body is prohibited except in Baltimore and Hartford Counties for carp and catfish only.
- A minimum unobstructed interval of 200 feet between successive pound or stake nets
- For maximum lengths of single line of net stakes, see Annotated Code of Maryland, 4-711.
- Hauling any seine or net more than one third of the distance across a water body is prohibited except in Baltimore and Harford County to catch catfish and carp.

- A person may not drag or haul any seine with two or more vessels propelled by power.
- Haul seines may not exceed 1,800 feet in length.
- A power winch may be used to haul a seine only if it is anchored in a vessel not propelled by power and the vessel is anchored in 4 feet of water or less.
- A person may not empty a seine on shore or in water less than 12 inches deep and small fish must be returned to the water.
- Minimum of 200' between successive pound or stake nets.
- Pound nets may not exceed 1000' to 1650' in length, depending on the area the net is set.
- Haul seines are limited to a depth or width of 15' graduating to a width of 22' at the back. A haul seine may not have a length at its back greater than 100'.
- Haul seining is prohibited from Friday midnight until sunrise on Monday in tidal waters.
- Pound nets restricted to permitted areas only (see Annotated Code of Maryland, 4-714 through 4-728.

Area Restrictions

- Areas may be closed to all fishing seasonally, closed to all fishing except rod, hook and line, closed to certain types of commercial gear, or otherwise restricted:
  For area closures and restrictions in Chesapeake Bay; See Annotated Code of Maryland, 4-728; in Choptank River, 4-729; in Patuxent River, 4-730; in Susquehanna River, Department of Natural Resources, title 08 subtitle 02, chapter 05.
  For area closures and restrictions by county; See Annotated Code of Maryland, 4-714 through 4-727.

Aquaculture (Department of Natural Resources, title 08 subtitle 02, chapter 14)

- Permit required for all aquaculture activities, including culture of native and naturalized species, the capture of broodstock, and demonstration or experimental culture.
- Permits may be issued for catfish, family Ictaluridae.
- Aquaculture activities for non-native fish may only be permitted in approved nontidal ponds, lakes, and impoundments which are constructed to assure that the cultured species are precluded from entering tidal waters of the State.
- Aquaculture activities are prohibited if they will adversely affect wild stocks of fish, result in the release of non-native species into un-confined waters, or result in the contamination of native or naturalized species.
- A facility may not discharge its effluent into Maryland waters without approved treatment.
- Brood stock or the progeny of native or naturalized species may be obtained from an out-of-state supplier, registered to do business in Maryland, and must be certified to be free of known disease.
- Imported hybrid or non-native fish shall be certified free of know diseases.
- There are no size requirements for any species of finfish propagated from aquaculture in nontidal ponds, lakes, and impoundments.

Virginia

Regulatory Agencies:

- Virginia Department of Game and Inland Fisheries
  4010 W. Broad St.
  Richmond, VA 23230
  (804) 367-1000
  www.state.va.us/~dgif/index.htm
- Virginia Marine Resources Commission
  PO Box 756
  2600 Washington Ave.
  Newport News, VA 23607-0756
  (757) 247-2200
  www.state.va.us/mrc/homepage.htm

License Requirements

- Recreational anglers must purchase a freshwater fishing license for catfish in nontidal waters and a saltwater license for catfish in estuarine waters. Either license may be accepted in transitional areas of tidal fresh and estuarine.
- Maryland saltwater fishing license is reciprocal in Chesapeake Bay and saltwater reaches of tidal tributaries.
- Commercial license and registration required for commercial harvest.

Size and Harvest Restrictions

- No size limit.
- No creel limit below the fall line
- Creel limit above the fall line, 20 of each species per person per day. Bullhead species may be taken in unlimited numbers.
- Commercial fishing activities prohibited on Sundays

Harvest Methods

- Use of lime, firearms, dynamite, or other substances to destroy fish are prohibited.
- Above the fall line, catfish and bullhead species may be taken by hand, hook and line, seine (maximum size 4' deep x 10' long), umbrella type net (maximum size 5' x 5' square), cast net (maximum radius 6'), and hand held bow net (maximum radius 20", maximum handle length 8').
- Below the fall line, catfish and bullhead species may be taken by rod and reel, hook and line, gig, spear, cast net or dipnet.
- Trotlines, juglines or set poles may be used for catfish and bullhead harvest. Gear must be clearly marked and checked daily.
- Live bait may be used on trotlines in some counties.
- Within designated stocked trout waters, hook and line only is permitted.

Health Advisories

- Consumption advisory in James River near Richmond

Stocking

- Unlawful to stock any species in inland waters, with the exception of private ponds, without written approval from the Dept. of Game and Inland Fisheries.

Potomac River

Regulatory Agency

- Potomac River Fisheries Commission
  PO Box 9
  Colonial Beach, VA 22443
  (804) 224-7148 or (800) 266-3904

- Potomac River fishing license or license from Virginia or Maryland is required.
- Size limits for commercial and recreational:
  - Channel catfish - 8";
  - White catfish - 10";
  - Bullheads (brown and yellow) - 6"

Washington, D.C.

Regulatory Agency:

- Government of the District of Columbia
  Environmental Regulation Administration
  DC Fisheries Management Program
  2100 MLK Jr. Ave. S.E.
  Suite 203
  Washington, DC 20020
  (202) 645-6616

License Requirement

- Recreational fishing license required between the ages of 16 and 64.
- Commercial harvest is prohibited.

Size and Harvest Restrictions

- Minimum size for channel catfish, 12".
- Creel limit for channel catfish, 3/person/day.

Harvest Methods

- Harvest permitted only by rod, hook and line, not to exceed 3 lines per person and no more than 2 hooks per line.
- Artificial lures or plugs with multiple gang hooks are considered one unit.

- Harvest by dipnet prohibited except to land a fish caught by hook and line.
- Catfish and bullhead harvest with seine prohibited.
- Use of explosives, chemicals, firearms, or electricity for catfish or bullhead harvest is prohibited.

Health Advisories

- Consumption advisory for channel catfish from Potomac and Anocostia Rivers within District boundaries. Recommend no more than one meal per week of channel catfish with skin and fat removed.

Stocking

- Introduction of nonindigenous species is prohibited in District waters.

Pennsylvania

Sport harvest of panfish, which includes catfish species in Pennsylvania, is restricted to a combined daily angler possession limit of no more than 50 panfish. Size restrictions and seasonal harvest restrictions do not apply. Commercial harvest is not permitted in Pennsylvania's portion of the Susquehanna River system.

APPENDIX B. CATFISH WORKGROUP

The following were consulted by the FMP Workgroup during the development of this document:

Edward R. Dent	Virginia catfish harvester
Jessie E. Dent	Virginia catfish harvester
Carlton G. Edwards	Maryland catfish harvester
Robert Evans	Maryland catfish harvester and dealer
Marvin L. Harley	Virginia catfish harvester
Joseph B. Hicks, III	Virginia catfish harvester
Jim Jacquette	Maryland catfish harvester
Stanley E. Oliff, Jr.	Virginia catfish harvester
Suzie Robertson	Maryland catfish dealer
Artis Schoen	Virginia catfish harvester
Peggy L. States	Maryland catfish harvester
Albert Strong	Maryland catfish harvester
John P. Travis	Maryland catfish harvester

APPENDIX C. GLOSSARY OF TERMS

Atlantic slope: Area of land and waterways that drain into the Atlantic ocean.

CBPO: Chesapeake Bay Program Office

DC: District of Columbia

Gulf slope: Area of land and waterways that drain into the Gulf of Mexico.

LC_{50} (median lethal concentration): The concentration of a substance at which 50% of test organisms die.

Length at age: Average length of fish from a particular age group (year 1, year 2, and so on) sampled from a population.

MDNR: Maryland Department of Natural Resources

MRFSS: Marine Recreational Fishery Statistic Survey.

PFBC: Pennsylvania Fish and Boat Commission

ppt: Parts per thousand. Unit of measure for elements or compounds in solution.

VCU: Virginia Commonwealth University

VDGIF: Virginia Department of Game and Inland Fisheries

VIMS: Virginia Institute of Marine Science

U.S. Environmental Protection Agency
Chesapeake Bay Program Office
410 Severn Avenue
Annapolis, MD 21403
1-800-YOUR BAY
www.chesapeakebay.net/bayprogram