1999

Distribution of the Sucker Family (Pisces: Catostomidae) in the Ohio River

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Thesis submitted to
The Graduate School of
Marshall University

In partial fulfillment of the
Requirements for the Degree of
Master of Science
Biological Sciences

by

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Huntington, West Virginia

September 22, 1999

This thesis was accepted on September 22, 1999
Month Day Year

as meeting the research requirements for the master's degree.

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Leonard J. Deutsch 12/14/99
Dean of the Graduate College

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ACKNOWLEDGEMENTS

I extend my thanks not only to, but also for, all of the people who helped with this thesis in any way. Dr. Tarter, your patience and understanding are immeasurable. Thank you for giving me the guidance and also the independence needed to make this a truly incredible learning experience. Erich Emery, Bob Ovies, and ORSANCO, you provided an opportunity for research that would have never otherwise been available to me and answered many questions along the way. Dr. Stewart Thomas, you were invaluable in your help with the statistics. Your interest, time, and thoughtfulness are deeply appreciated. Thank you Drs. Tom Pauley and Mike Little for serving on my committee and providing constructive criticism and encouragement. Drs. Jim Brumfield and Ralph Oberly, you have given me an introduction to a field I knew almost nothing about that has served me well in the past few months. Many thanks for all of your help with the substrate characterization studies. Special thanks are also in order for Ian Farrar. Ian, if it weren't for you and your laptop, I'd still be digitizing my little heart out right this very minute. I owe you one!

Jenn Aderman, Rusty Shrader, Eric Wilhelm, Alyce Bradbury, Wes Gladwell, Terri Holt, Robin Dolin, Ann Schoolcraft, Jeff Ginger, Jason Morgan, Matt Wooten, Jim Hawkes, Ben Lowman, Terry Tomasek, Kirk Barnett, Stephen Greene, Steve Foster, Jennifer Wykle, Mindy Hamilton, John Campbell, Brian Lindley, Sandy Raimondo, Mark Barker, Alan Thompson, Gail Perrine, and Pam Bailey…what can I say? You guys made my time at Marshall what it was. Many thanks to you all.

Dr. and Mrs. Karl Fezer, thank you for taking such a heartfelt interest in my career. It was in your classes at Concord, Dr. Fezer, where I first began to see the kind of scientist and teacher I wanted to be. Thank you Brett Marshall (the "rock scrubbin', water wadin', boot wearin', butt slidin', scrubbie scuffin', etc. guru of aquatic entomology), Ken Stevens, Dr. Roger Sheppard, and Dr. Felecia Briscoe for allowing me to "get my feet wet" in aquatic ecology. Dr. Bird, Dr. Towers, Jeff Lashbrook, Dr. Howe, Dr. Manzo and Dr. Bayless, you guys are wonderful! Dr. Wayne Elmore, I couldn't have asked for an employer that would be more understanding, especially when it came to "looking over my shoulder."

To my family and parents especially, where do I even begin? I would be lost without you. Thank you for the support, encouragement, and love you've shown me in the last two years and always.

Special thanks to the U.S. Army Corps of Engineers for providing the sonar data used in this study. To the 1998 ORSANCO field crew, thanks for allowing me to crash your party and for collecting my wonderful gut samples throughout the river. I am also grateful for the additional funding for this research provided by the Smith-Goodno Fellowship and the Marshall University Graduate School.

With an attitude of gratitude—thank you.

ABSTRACT

The family Catostomidae represents a major component of the fish fauna in the Ohio River. Because of their abundance, large biomass, and susceptibility to environmentally-induced anomalies, suckers are expected to significantly influence the Ohio River Fish Index (ORFIn), a biological index being developed by the Ohio River Valley Water Sanitation Commission (ORSANCO) for large river systems. To correctly interpret information obtained from ORFIn, the impact of suckers upon the index must be thoroughly understood, including relative importance and uneven spatial distribution of Ohio River suckers. In this study, suckers represented 7.1 percent of the total fish captured and 36.6 percent of the biomass taken during boat electrofishing collections between 1991 and 1998. Round-bodied and deep-bodied suckers were approximately equal in abundance; however, deep-bodied suckers contributed a greater proportion of the total biomass than did round-bodied suckers. All species of sucker studied showed longitudinal spatial distribution significantly different from expected riverwide distribution. All round-bodied suckers and three deep-bodied suckers were found in greatest numbers in the upper Ohio River, while the three remaining deep-bodied species were more abundant in the lower river. Longitudinal changes in spawning stream availability, food habits, and substrate composition were primary influences on the distribution of Ohio River suckers. The extreme lower river was relatively lacking in available spawning streams. Deep-bodied suckers showed increasingly generalist food habits in the lower river, resulting in an extended range over the round-bodied suckers of the upper river. Coarse substrates and higher gradients in the upper river represented optimal sucker habitat. Round-bodied suckers showed a slightly greater abundance in the upper sections of navigational pools than in the lower sections, most likely the result of changes in substrate and gradient. Suckers have increased significantly in abundance during the last 40 years, particularly in the last 20 years. This increase appears to have resulted from improved water quality brought about by clean water legislation in the early 1970s. Although suckers increased in number throughout the entire river, the increase was greatest in the upper one-third of the river, where water quality was exceptionally poor at the beginning of the study period.

CHAPTER I

INTRODUCTION

The sucker family (Pisces: Catostomidae) is a major component of the fish community in the main channel of the Ohio River. Fishes of the Ohio River have been studied extensively since the days of Rafinesque's *Ichthyologia Ohiensis* (1820), in which three species of Ohio River suckers were first described. Suckers comprise a substantial proportion of the numbers and biomass of fish captured from the river. Recent preliminary studies completed by the Ohio River Valley Water Sanitation Commission (ORSANCO) indicated that suckers can represent up to 90 percent of the total fish biomass collected during electrofishing collections in the mainstem of the Ohio River (Emery, unpublished).

As a family, catostomids are also somewhat pollution intolerant and vulnerable to environmentally-induced anomalies, making them potentially useful to determine water quality (Karr, 1981). Exceptions are the white sucker (*Catostomus commersoni*) (Karr, 1981), carpsuckers (*Carpiodes*), and buffalofishes (*Ictiobus*) (Simon and Emery, 1995).

Because of their abundance, large biomass, and susceptibility to pollution, catostomids are expected to have a profound influence upon the Ohio River Fish Index (ORFIn). ORFIn is an Index of Biological Integrity (IBI) developed by ORSANCO as part of their large river biocriteria program (Simon and Emery, 1995). IBI's provide information on the fish community and water quality in a stream or river and are currently used by many state and federal agencies that monitor aquatic ecosystems. The goal of ORFIn is to adapt the original fish community IBI, proposed by Karr in 1981 for smaller streams, to the Ohio River.

Suckers are expected to influence ORFIn both directly and indirectly. The most obvious direct influences result from metrics that record the percentages of round- and deep-bodied suckers (Simon and Emery, 1995). Round-bodied suckers (genera *Catostomus*, *Cycleptus*, *Hypentelium*, and *Moxostoma* in the Ohio River) are somewhat intolerant of pollution and are therefore considered indicators of good water quality. Conversely, deep-bodied suckers (genera *Carpiodes* and *Ictiobus* in the Ohio River) are fairly pollution-tolerant fishes and can therefore indicate degraded conditions. In addition, the blue sucker (*Cycleptus elongatus*), once considered a common Ohio River fish, is presently rare in the Ohio River. Presence of this species directly contributes to the measurement of the number of sensitive species found in the river.

Most species of sucker are susceptible to environmentally-induced abnormalities and play a substantial role in determining the percentage of fish that diplay DELT anomalies (Deformities, Eroded fins, Lesions, and Tumors) (Simon and Emery, 1995). These anomalies most likely result from decreased water quality and pollution. A higher percentage of fish with DELT anomalies can indicate low water quality in a stream or river.

The large abundance and biomass of Ohio River suckers indirectly affect several ORFIn metrics (Simon and Emery, 1995). These metrics include total number of species captured, percentage large river faunal group, percentage omnivores, percentage insectivores, and percentage simple lithophils. Greater biodiversity, as represented by a relatively high number of species captured, indicates habitat and water conditions capable of supporting a diverse fish fauna. Fishes identified by Pflieger (1971) as large river inhabitants are specialists. Their numbers decline in response to decreased water quality. Similarly, a high percentage of omnivores reveals a strong presence of habitat generalists and also suggests impaired water quality. Greater percentages of insectivores indicate greater biological integrity, as do higher percentages of simple lithophils (fishes who require clean, rocky substrate for spawning).

Understanding the influence of the sucker family on ORFIn metrics is essential to the correct interpretation of the water quality information provided by the index. Factors such as uneven spatial distribution of suckers in the river will obviously influence ORFIn results. Previous studies show that suckers are found in greatest numbers in the upper two-thirds of the Ohio River (Emery, unpublished; Preston and White, 1978). Despite the ecological importance of suckers, the distribution of Ohio River suckers and factors thought to explain this distribution have not yet been thoroughly investigated.

The purpose of this study was to more clearly define the spatial and temporal distribution patterns observed in Ohio River suckers. Specific objectives included: 1) determine of the relative importance of Ohio River suckers in terms of biomass and abundance; 2) pinpoint recent longitudinal spatial distributions of suckers in the Ohio River; 3) describe temporal trends in Ohio River sucker abundance; and 4) investigate three factors believed to influence sucker distribution (food availability and consumption, changes in substrate composition, and the availability of suitable spawning habitat).

CHAPTER II

LITERATURE REVIEW

Distribution of Ohio River Suckers

Many abiotic and biotic factors are known to influence the distribution of fish species in large rivers. In a review of changes in the fish fauna of the upper Ohio River basin, Lachner (1959) identified those factors that have affected the distribution of fishes in the Ohio River in relatively recent times. Natural influences discussed by Lachner included conjoined headwater streams during periods of heavy rainfall, topography, hydrography, physical barriers such as waterfalls, and biological barriers related to the interaction of fish species with one another. Lachner also discussed several anthropogenic factors that influence Ohio River fish distribution, such as impoundment, pollution, siltation, rises in water temperature due to deforestation and industrial cooling processes, and consumption of water by both industrial and domestic sectors.

Topography and hydrography determine stream gradient and often decide the size and species of fish that occupy a stream or river (Lachner, 1956). Many fishes are found only in the headwaters of Ohio River tributaries, where cool, clear water flows over rock and gravel substrates. Other fishes may be classified as large river species. These fishes inhabit the slower, warmer and relatively sluggish Ohio River and its larger tributaries. Examples of large river species include many suckers, such as smallmouth buffalo and blue sucker, as well as species in other families (e.g. the paddlefish (*Polyodon spathula*) and the blue catfish (*Ictalurus furcatus*). Topography and hydrography also affect the placement of riffles and pools in a river and therefore indirectly affect the distribution of fish species that occur in these habitats.

Although fishes of the Ohio River have been studied extensively over the years, little work has been completed with specific regard to distribution of suckers. Several studies have, however, concluded that there is variation in species composition between the upper, middle, and lower sections of the river. Forty-six Ohio River fish species were found to inhabit either the upper, middle, or lower sections of the Ohio River (Van Hassel et al., 1988). Larimore and Smith (1963) related species composition to stream size. Many Ohio River suckers fall into the large river category (*Carpiodes* and *Ictiobus* spp.) (Simon and Emery, 1995), and studies show that these species are indeed found in greatest numbers in the wide, sluggish waters of the lower Ohio River (Krumholz, 1962, 1981; Van Hassel, 1988). Reash and Van Hassel (1988) correlated Ohio River species distribution with tributary abundance, habitat preference, pollution tolerance, range proximity, and temperature.

Van Hassel et al. (1988) identified the white sucker (*Catostomus commersoni*), northern hog sucker (*Hypentelium nigricans*), and black redhorse (*Moxostoma duquesnei*) as species of the upper Ohio River. They also found the river carpsucker (*Carpiodes carpio*), quillback carpsucker (*C. cyprinus*), highfin carpsucker (*Carpiodes velifer*) and smallmouth buffalo (*Ictiobus bubalus*) to be lower river species.

Several studies reported that the Ohio River fish community has increased in diversity and range since the enactment of clean water legislation in 1972

(Preston and White, 1978; Krumholz, 1981; Pearson and Krumholz, 1984; Van Hassel et al., 1988; Pearson and Pearson, 1989; Cavanaugh and Mitsch, 1989; Yougher and Mitsch, 1989). Fish community response to improved water quality was illustrated by the recovery of environmental conditions and fauna to the month-long steel industry shutdown in 1959 (Krumholz and Minckley, 1964). Preston and White (1978) characterized the upper Ohio River fauna as "indicative of improving water quality" and the lower Ohio River fauna as "reflecting stable water conditions." Van Hassel et al. (1988) concluded that the "overall water quality of the Ohio River improved from 1973 to 1985." More recent studies, although not compared directly with older studies such as ORSANCO (1962) and Lachner (1956), show a greater abundance of suckers in the Ohio River than do their earlier counterparts, presumably as a result of pollution abatement (Krumholz, 1981).

Food Habits

As their name implies, suckers are benthic feeders that use thick, fleshy lips to remove aquatic invertebrates from the bottoms of streams and rivers. Some suckers also ingest vegetation and detritus. Until recently, catostomids were considered "random bottom-feeders", or generalists that show little selectivity in their feeding habits (White and Haag, 1977). It is now widely accepted that most suckers are quite selective in their diets, and catostomids even have the ability to "sort" their foods by ejecting unwanted food items out through the mouth and gill slits (Jenkins and Burkhead, 1994). Some species, such as the river carpsucker, are highly selective for benthic macroinvertebrates. A few species are more general in their food habits (e.g. bigmouth buffalo) and have long coiled intestines and no well-defined stomach. Most suckers seasonally become more generalized in their food habitats as their predominant invertebrate foods become scarce. An example is the white sucker, which has been shown to increase ingestion of detritus as populations of benthic organisms decrease seasonally (Ahlgren, 1996). Detritus has also been shown to be too low in nutritional value to support growth in white suckers and concluded to be consumed only for the maintenance of necessary physiological functions during seasonal unavailability of food items (Ahlgren, 1990a, 1990b).

Suckers generally feed at dusk or at night (Jenkins and Burkhead, 1994). Most suckers feed with their heads tilted downward and their caudal regions pointing slightly upward. Using their thick subterminal lips, they dislodge rocks and debris from the substrate and engulf the benthic aquatic organisms displaced by their actions. An exception to this feeding behavior occurs in the bigmouth buffalo, which displays a nearly terminal mouth and only a near-bottom feeding behavior with both limnetic zooplankton and semi-benthic organisms being consumed. Most larval suckers also have terminal mouths and feed in the water column. Suckers generally develop subterminal mouths and bottom feeding habits as adults. Food habits of the 15 suckers included in the this study are listed in Tables 1 and 2.

Habitat Associations

Suckers are found in a variety of habitats, including the headwaters of streams, larger rivers, lakes, and reservoirs. Some larger species prefer lacustrine habitats and calm backwaters, while other smaller species are found most frequently in swift rapids. It is generally accepted that deep-bodied fish inhabit sluggish, slow-moving pools with silty substrates, while round-bodied fishes are morphologically adapted to swiftly-flowing, riffle-run areas of streams and rivers. Jenkins and Burkhead (1994) confirmed that the deep-bodied carpsuckers and buffalofishes are found in large, low-gradient rivers, such as those in the Mississippi Valley lowlands. They also reported that the round-bodied redhorses of the genus *Moxostoma* are found mostly in medium-sized rivers with a modest gradient and are found in the greatest abundance in the upper Mississppi Valley. Smaller round-bodied species, such as hogsuckers (*Hypentelium*) and the spotted sucker (*Minytrema melanops*) show the streamlined body, reduced swim bladder, and roughened areas on the pectoral and pelvic fins characteristic of fish that inhabit swifter water and headwater streams. Habitat associations for the 15 Ohio River sucker species included in this study are found Tables 3 and 4.

Spawning

Suckers are rarely caught by angling; however, they can be captured quite easily by snagging or gigging during spawning runs (Pflieger, 1975). Each spring and early summer, larger suckers migrate upstream into small tributaries of lakes and rivers to spawn over coarse, rocky substrates in areas of high current or rapids. Environmental cues that signal sucker spawning runs include temperature and flooding (Page and Johnston, 1990). Spawning generally occurs when the temperature remains above 10° C for several days and often corresponds with higher flow rates during spring floods. Segregation of spawning by time, habitat, and stream size helps to minimize competition among species.

Sexual dimorphism is present in most species (Page and Johnston, 1990). Males are generally smaller than females and are present in greater numbers on spawning riffles. They have longer fins than do females of the same species and develop breeding tubercles and brighter colors during the spawning season. Male suckers ripen earlier in the spawning season than do females and also enter spawning areas first.

Spawning behavior is quite similar among sucker species, especially when compared with the differences in spawning behavior between other large families of fishes (Page and Johnston, 1990). Generally two males will spawn with a single female, with the female positioned in between the two males. The three fishes vibrate rapidly with their heads pointing toward the surface of the water and use their caudal and anal fins dislodge particles of the substrate. Eggs are scattered randomly over the substrate and buried while they are being fertilized. No parental care is provided to the eggs after spawning. Exceptions to this generalized model of sucker spawning behavior include the river redhorse (*Moxostoma carinatum*), in which the male prepares the spawning habitat by removing silt and debris, leaving a gravelly pit, and the bigmouth buffalo (*Ictiobus cyprinellus*), which forms the spawning trio near the surface of the water. Other spawning behaviors consist of territoriality in some species, presence of additional males in some spawning aggregations (e.g. the northern hog sucker), periodic spawning in some species (Behmer, 1965; Quinn and Ross, 1985), homing tendencies in white suckers, and various degrees of selectivity for substrate types.

Balon (1975) placed suckers into several non-guarding, open substrate reproductive guilds. Spawning habitat associations for each species are found in Tables 5 and 6.

CHAPTER III

TAXONOMY AND DISTRIBUTION

Taxonomy

The family Catostomidae (*catostom-* "under mouth") belongs to the Class Osteichthyes (bony fishes), the subclass Actinopterygii (ray-finned fishes), and the superorder Teleostei (modern bony fishes) (Lagler, 1977). The common name "sucker" comes from the strongly subterminal mouth and thick, fleshy lips used to by these fishes to remove aquatic macroinvertebrates, detritus, and plant material from the bottoms of streams and rivers. The lips may be either papillose, composed of numerous small, fleshy bumps, or plicate, consisting of fleshy, parallel striations. The acutely sensitive plicate and papillose types of lips found among suckers are shown in Fig. 1.

More reliable taxonomic characters used to identify suckers include absence of spiny rays, presence of more than 10 dorsal rays (in most cases), cycloid scales, a scaleless head, and no greater than 10 rays in the anal fin (Pflieger, 1975). Suckers also possess a single, continuous dorsal fin that originates well before the pelvic fins (Jenkins and Burkhead, 1994). Pectoral fins are placed low on the body, and pelvic fins are abdominal in position. Suckers do not possess barbels or an adipose fin; however, they do have Weberian ossicles comprised of fused vertebrae and ribs and connected to the swim bladder. Weberian ossicles, also found in the family Cyprinidae (minnows), function in the detection and amplification of sounds. Suckers range from shimmering silver, brass, or copper to grayish-olive or golden in color. Brighter breeding colors and tubercles appear during spawning in some genera (e.g. *Catostomus*).

Suckers, along with minnows (family Cyprinidae), are members of the order Cypriniformes (Ostariophysi). Because of their similar evolutionary history and close taxonomic relationship, suckers are frequently confused with minnows. The two families can be distinguished by the presence of a single row of numerous pharyngeal teeth in suckers (minnows have two rows of only a few pharyngeal teeth) and by more posterior placement of the anal fin in suckers (Pflieger, 1975). In general, the distance between the origin of the anal fin and the beginning of the caudal fin is contained more than two and one-half times in the distance from the snout to the anal fin in suckers and less than two and one-half times in minnows. Suckers also lack the stout spine present in front of the dorsal and anal fins of two common cyprinid species, the common carp (*Cyprinus carpio*) and the goldfish (*Carassius auratus*). Despite the similar physical appearance of suckers and minnows, the closest relatives to the suckers are probably the loaches (family Cobitidae) (Jenkins and Burkhead, 1994).

In North America three subfamilies of suckers contain 73 species (Jenkins and Burkhead, 1994). This includes up to nine undescribed species. The subfamily Ictiobinae, with its numberous dorsal fin rays (23 - 35) is represented in the main channel of the Ohio River by two genera, the carpsuckers (*Carpiodes*) and the buffalofishes (*Ictiobus*). The subfamily Cycleptinae contains only two monotypic genera, one of which (*Cycleptus*) is found in the Ohio River. The most evolutionarily recent of the subfamilies, the Catostominae, has fewer dorsal rays (9 – 17) than the Ictiobinae and Cycleptinae and is divided into three tribes (Stauffer et al., 1995). The tribe Catostomini contains one Ohio River species in the genus *Catostomus*, and the tribe Erimyzontini is represented by three Ohio River species in the genera *Minytrema* (one species) and *Erimyzon* (two species). Because of their relatively small size and biomass, the two *Erimyzon* species have been excluded from this study. The third Catostominae tribe, Moxostomatini, includes five species in the Ohio River in the genus *Moxostoma* (redhorses) and one species in the genus *Hypentelium*.

Suckers can be divided into two general categories based upon their morphology. The round-bodied suckers have a cylindrical, torpedo-shaped body and include nine Ohio River species in the genera *Catostomus*, *Cycleptus*, *Hypentelium*, *Minytrema*, and *Moxostoma*. Conversely, deep-bodied suckers are taller from belly to dorsal surface than round-bodied suckers and are represented in the Ohio River by six species in the genera *Carpiodes* and *Ictiobus*. The 15 Ohio River sucker species included in this study, along with their etymologies, morphological categories, and characteristics that can be used in the field identification of each species, are found in Tables 7 and 8.

Distribution

Suckers are primary division fishes, which means that they are found only in freshwater. A few exceptional species will enter estuaries with low salinities (Jenkins and Burkhead, 1994). Catostomids are holartic in distribution and originiated from a pro-catostomid stock of fishes found in Eurasia during the

Cretaceous Period (120 million years ago). The first suckers evolved between the Cretaceous Period and the Eocene Epoch and came to dominate Laurasia approximately 50 million years ago. Around this time the Cyprinidae appeared, and by the Oligocene Epoch (35 million years ago) cyprinids dominated Eurasia while suckers declined in this region. By the Miocene Epoch (20 million years ago) only a relict population of suckers existed in Europe; however, catostomids remained dominant in North America. Suckers are currently subdominant to minnows in North America. The only two species found outside of North America today are the relict Chinese sucker (*Myxocyprinus asiaticus*), found in the Yangtze River in China, and the longnose sucker (*Catostomus catostomus*) which crossed over the Bering Strait into Siberia during the Wisconsin glaciation of the Pleistocene Epoch (Darlington, 1963). The present-day worldwide distribution of suckers is shown in Fig. 2. Excellent range descriptions for the 15 Ohio River suckers included in this study can be found in Kay et al., 1994.

CHAPTER IV

DESCRIPTION OF STUDY AREA

Ohio River Main Channel

The Ohio River begins with the confluence of the Allegheny and Monongahela Rivers in Pittsburgh, Pennsylvania, and flows 1,578 km (981 mi) southwest to Cairo, Illinois, where it empties into the Mississippi River (Preston and White, 1978). In the United States, only ten other rivers are of greater length. The Ohio River also has the highest discharge of all of the Mississippi River tributaries.

The Ohio River crosses four ecoregions: the Western Allegheny Plateau, the Interior Plateau, the Interior River Lowland, and the Mississippi Alluvial Plain (Simon and Emery, 1995). Most of the river is contained in a slender valley with steep banks and few riparian wetlands (Preston and White, 1978). Underlying sedimentary rocks range from fine-grained siltstone and shale to coarse sandstone and limestone.

There are 20 high-lift dams on the river which maintain a minimum nine foot depth for transportation purposes (Frost and Mitsch, 1989). The water level is as much as 45 feet, however, behind the dams (Preston and White, 1978). In 1993, average depth of the river was 23.9 ft, average width was 1,948 ft, and average stream flow was 14.4 cfs (ORSANCO, 1994). The surface area of the river is approximately 40,000 hectares (100,000 acres) (Preston and White, 1978).

Ohio River Drainage Basin

The Ohio River drainage basin, contained within 14 states, is shown in Fig. 3. The Ohio River drains an area of approximately 528,000 km^2 (204,000 mi^2), or seven percent of the United States (Frost and Mitsch, 1989). Coal mining, power plants, and chemical plants are the major industries in the Ohio River basin (Kay et al., 1994). The most abundant resources in the drainage area are coal, timber, iron ore, salt, clay, and oil (Frost and Mitsch, 1989). Several large metropolitan areas are found in the Ohio River basin, including Pittsburgh, Cincinnati, Louisville, Lexington, Knoxville, Chattanooga, and Nashville (Kay et al., 1994).

Hannibal Pool

Hannibal pool begins at river mile 84.2 and continues through river mile 126.4 (42.2 mi (67.9 km) in length). It is the sixth pool from the beginning of the Ohio River in Pittsburgh, Pennsylvania and is located in the Western Allegheny Plateau ecoregion. Average depth is 21 ft (6.4m), average width is 1133ft (345.3 m), and mean flow ranges from 20.4 kcfs to 70.5 kcfs (ORSANCO, personal communication). Normal pool elevation is 12 ft. One major city (Wheeling, West Virginia) lies in the vicinity of Hannibal Pool.

CHAPTER V

MATERIALS AND METHODS

Electrofishing Collections

Fishes from the Ohio River were collected by boat electrofishing. Electrofishing has been used extensively in fish surveys and is considered more economical and efficient than mark-recapture studies (Coble, 1992). Factors that affect electrofishing catch per effort include temperature, season, size of fish, size of area, turbidity, conductivity, vegetation present, time of day, and fish population density (Edwards et al., 1997).

Electrofishing collections began in 1991 and continued through 1998. Samples were collected between the months of July and October of each year. Four hundred ninety-one zones, each 500 m in length, were fished with a 5000-watt generator and a Smith-Root Type VI-A electrofishing unit (pulsed DC current). The electrofishing unit was mounted on an 18 ft aluminum john boat manned by a two- to four-person crew. Each zone extended a maximum of 75 ft from shore and was fished in a zigzag pattern for 2000 – 3000 seconds, depending on habitat structure. To avoid glare and take advantage of increased foraging activity near the shorline at night (Dumont and Dennis, 1997; Sanders, 1992), electrofishing began no sooner than 30 min after sunset. Stunned fish were netted, placed into an aerated live-well, measured to the nearest 0.1 cm, weighed to the nearest 1 g, and returned safely to the water unless retained for further studies. Effective depth of the sampling gear was 10 –15 feet.

Relative Importance

Population data from the electrofishing collections were used to determine the relative importance of the family Catostomidae to the Ohio River fish community. Percent abundance and percent biomass of suckers taken during the eight years of electrofishing were calculated. Relative importance of each species of sucker was determined by calculating percent abundance and percent biomass contributed by that species to the total sucker catch. Percents for round- and deep-bodied sucker abundance and biomass were also determined.

Spatial Distribution

Recent riverwide spatial distribution of suckers in the Ohio River was determined by dividing the river into longitudinal tenths, each tenth 98.1 mi long. Cumulative percents of electrofishing events were compared with cumulative percents of capture at each tenth using the Kolmogorov-Smirnov goodness of fit test for cumulative frequencies. This test is similar to the chi square goodness of fit test; however, the Kolmogorov-Smirnov test compares cumulative frequencies rather than discrete frequencies.

Spatial distribution within navigational pools was also investigated. Eight pools representative of the entire length of the Ohio River were divided into longitudinal quarters. The chi-square goodness of fit test was used to determine if significant differences were present in the number of suckers captured in the quarters of the each pool. Deep- and round-bodied sucker distributions were also analyzed by this method. Differences in the number of electrofishing events per quarter were taken into account by weighting expected values by the percent of the total number of events in that pool that took place in each quarter and comparing observed values to expected values. If a significant difference was present between numbers of suckers in the quarters of the pool, cell chi square values were used to determine which quarters contributed to the difference.

Lock Chamber Surveys

Lock chamber surveys conducted between 1957 and 1996 were used to determine the temporal distribution of suckers in the Ohio River. Sampling with rotenone, an icthyocide most often made into an emulsifiable form from powdered derris root (Krumholz, 1950), is considered one of the most efficient methods available to estimate the population density of fishes in a given area (Krumholz, 1981). Its efficiency, however, is dependent upon factors that affect fish mortality (e.g. size and species) and retrieval (e.g. number of available personnel, skill of personnel, level of glare present) (Bayley and Austin, 1990). Some species are more resistant to rotenone than others, and there is a noted tendency for workers to overlook smaller individuals for the larger ones when netting (Krumholz, 1981). Death from rotenone poisoning is the result of respiratory failure (Krumholz, 1948). Physiological effects of rotenone on fishes include paralysis of the respiratory function control center of the brain, breakdown of the gill epithelium, and vasoconstriction.

Three hundred thirty-two lock chambers were surveyed during the 40-year study period. Lock chambers were closed and rotenone applied at a concentration of at least 0.5 ppm (Krumholz, 1948). Fish were netted after rising to the surface. Captured fish were returned to the shoreline, separated according to species and size, weighed to the nearest g, and measured to the nearest 0.1 cm.

Temporal Distribution

Population data from the lock chamber surveys were used to determine the temporal distribution of suckers in the Ohio River. The 40-year study period (1957 – 1996) was divided into 10 year intervals, and changes in the abundance of total, round- and deep-bodied suckers, as well as each of the 14 species of sucker captured during the lock chamber surveys, were analyzed with a chi square goodness of fit test. Because the number of surveys differed each 10-year period, the expected values were weighted by the percent of total surveys completed during each 10-year period. Observed values were compared to expected values. In cases where more than 20 percent of the expected values were less than five, the chi-square test was considered invalid and only the observed results were reported. Temporal changes in spatial distribution were investigated by dividing the river into equal longitudinal thirds, each 327 mi in length, and comparing the abundance of suckers in each third of the river with the same chi-square goodness of fit test as for changes in sucker abundance.

Stomach Content Analysis

Stomach contents of suckers throughout the length of the river were analyzed to investigate changes in food habits that may influence sucker distribution. The entire alimentary canal of suckers captured during the 1998 electrofishing surveys was removed and preserved in ten percent formalin. Since the original goal of 15 fish per species per third of river was not met in all cases, only the categories of deep- and round-bodied suckers were investigated.

An ANOVA was performed on the electrofishing population data collected for deep- and round-bodied suckers between 1991 and 1997, followed by Duncan's multiple range test. This divided the river into five and four sections for deep- and round-bodied suckers, respectively. The contents of up to 15 guts from each river section were examined in the laboratory.

Most suckers do not have well-defined stomachs; therefore, the contents of the anterior portion of the alimentary canal, extending to the first caudal loop of the intestine, is generally considered the "stomach" in suckers. In this study, each gut was divided into anterior and posterior sections with a single cut at the first caudal loop of the intestine.

Contents of each gut section were washed into collection jar and preserved in 70 percent ethanol. Anterior and posterior gut contents were observed separately using a 45X dissecting microscope, and the relative abundance of each organism in the sample was recorded. No attempt was made to obtain actual counts, volumes, or weights of organisms or other stomach contents.

Stomach contents were reported as food categories, including plant material, detritus, sand, benthic organisms, and zooplankton. Relative abundance for each category was qualitatively compared between the river sections for both deep-bodied and round-bodied suckers.

Substrate Composition Analysis

Substrate composition for Hannibal Pool was qualitatively investigated using sonar data collected by the United States Army Corps of Engineers Pittsburgh District. A high-resolution side scan sonar survey of the pool was conducted between August and September of 1997 and followed by a ground-truthing assessment with Ponar grab samples and video drop methods. Both point coverages and Geographic Information Systems (GIS) polygons were generated and georeferenced with Arcview GIS software.

The resulting Hannibal theme was converted into a shape file and two sections, each approximately 16,000 ft in length, were cut from the file. One section was cut from the upper part of the pool just below the dam, and the other section was taken from the lower part of the pool in order to compare qualitative differences in the substrate composition in the upper and lower portions of the pool. Both sections were classified by four substrate classes (silt, sand/gravel, gravel/cobble, and cobble/boulder) with ten equal intervals. Resulting graphics for each substrate type were visually analyzed for qualitative differences in substrate composition between the lower pool and the upper pool.

Relationships between substrate composition and actual distribution of suckers were analyzed from information collected during electrofishing surveys. Habitat data were collected from 391 electrofishing zones (500 m each) at 100 m intervals along the shoreline. Data collection extended up to 100 ft from the shoreline, and substrate type (fines, sand, gravel, cobble, and boulder) was identified at intervals of 10 ft. From the point data collected, percent coverage for each substrate type was estimated. Correlation analysis was first performed between river mile and each substrate type, as well as between each sucker category (total, deep, and round) and substrate type. Since these correlations could be biased by the influence of river mile (i.e. significant correlations between a species of sucker and a particular substrate type may be the result of a correlation between that species and river miles represented by that substrate type), a second correlation analysis was performed that excluded river mile. The second correlation analyses therefore reflect only true correlations between a species and a particular type of substrate.

Spawning Area Analysis

Influence of available spawning streams on the distribution of Ohio River suckers was investigated with United States Army Corps of Engineers Ohio River navigation charts. An ANOVA, followed by Duncan's multiple range test, was performed on the electrofishing population data collected between 1991 and 1998. This identified five distinct river sections based on sucker abundance. Numbers of streams expected to provide suitable habitat for sucker spawning were counted from the navigation charts for each of the five sections. Numbers of streams per mile for each section were then calculated to determine if number and quality of available spawning streams in each section influenced the distribution of suckers established by the electrofishing surveys.

CHAPTER VI

RESULTS AND DISCUSSION

Relative Importance

Electrofishing collections yielded 93,609 fish in 16 families (113 species). Because the blue sucker (*Cycleptus elongatus*) was not captured during these collections, only 14 species of sucker were included in calculation of percent abundance and percent biomass. Fig. 4 shows the percent abundance of suckers in this collection. Suckers represented 7.1 percent of total fish collected. Round-bodied suckers represented 3.5 percent (3,297) of the total fish abundance and were approximately equal in abundance to deep-bodied suckers (3,414, or 3.6 percent of the total fish abundance). Thus, in terms of abundance, suckers are fairly important to the Ohio River fish community, with 14 out of 113 species captured during the electrofishing surveys representing 7.1 percent of the total fish caught during the study. Smallmouth buffalo were the most abundant of the suckers (30.8 percent of total suckers), followed by golden redhorse (27.2 %), river carpsucker (13.5 %), shorthead redhorse (11.9 %) and silver redhorse (5.2 %) (Fig. 5).

Relative biomass of suckers in the Ohio River was high in comparison to sucker abundance. Of the 12,176 kg of fish collected, 4,454 kg (36.6 percent) were attributed to suckers (Fig. 6). Although deep-bodied suckers are represented by fewer species in the river, they were much greater than round-bodied suckers in biomass. Deep-bodied suckers (six species) contributed 24.4 percent (2974 kg) of the total fish biomass collected, while round-bodied suckers (nine species) made up only 12.2 percent (1481 kg) of the total biomass collected. These results are as expected since deep-bodied suckers are generally larger in size than most round-bodied suckers and the two groups were approximately equal in abundance. The five suckers found in greatest number in the Ohio River also represented the largest sucker catches by biomass. Smallmouth buffalo made up 46.0 percent of the total biomass, followed by golden redhorse (19.7 %), river carpsucker (14.5 %), shorthead redhorse (4.9 %), and silver redhorse (5.4 %) (Fig. 7). Although the golden redhorse is generally smaller in size and weight than the river carpsucker, higher numbers of golden redhorses captured resulted in a larger biomass of that species than river carpsucker.

Spatial Distribution

A significant difference ($p < 0.05$) was found between the observed distribution and an expected even distribution (null hypothesis) in all 14 suckers analyzed with the Kolmogorov-Smirnov goodness of fit test. Figure 8 shows the expected and observed distribution of suckers. If suckers were distributed evenly, then cumulative percent capture at each tenth would equal cumulative percent of electrofishing events in that tenth. This data shows that suckers are more abundant in the upper Ohio River. This is most clear in the first tenth (98.1 miles) of the river, where over 30 percent of the total catch was made within only 14 percent of electrofishing events. Distribution of suckers appears to approach an even distribution around Ohio River Mile (ORM) 590.

When suckers are divided into round- and deep-bodied categories (Fig. 8), both groups significantly more abundant in the upper river ($p < 0.05$). Round-bodied species were found in greatest numbers in the extreme upper river, with 40 percent of the total catch reached within the first 98.1 miles and 14 percent of electrofishing events. This trend continued until 97 percent of the total round-bodied catch was completed around ORM 590, or within only six-tenths of the total length of the river. Deep-bodied suckers were more abundant in the upper river than the lower river; however, they were found to be less extreme upper river species than round-bodied suckers. Deep-bodied suckers approached an even distribution at around ORM 490.

Observed and expected distributions of deep-bodied suckers are shown in Figs. 9 and 10. The quillback carpsucker, highfin carpsucker, and smallmouth buffalo all showed a slightly but significantly greater capture in the upper river. Bigmouth buffalo, black buffalo, and river carpsucker, were found predominantly in the lower river. Both bigmouth buffalo and black buffalo may be considered extreme lower river species. The bigmouth buffalo was not captured until the last eight-tenths of the river. The black buffalo does not appear in the first three tenths of the river and nearly 80 percent of the electrofishing events yielded only 40 percent of total black buffalo capture. Deep-bodied suckers were expected to inhabit the lower river since they are more suited to lake-like habitats with sluggish water than are round-bodied suckers (Simon and Emery, 1995).

All species of round-bodied sucker were most abundant in the upper Ohio River (Figs 11, 12, and 13). The white sucker was captured only in a narrow range of the extreme upper river (ORM 295 and ORM 392). The northern hog sucker, silver redhorse, and black redhorse were also found to be extreme upper river species. The spotted sucker was not captured in the first tenth of the river was still found in high numbers only in the upper river.

All eight navigational pools show mixed but statistically significant results regarding the distribution of suckers (Figs. 14 and 15). Montgomery, Markland, and McAlpine pools show a slight preference for both the first and fourth quarters of the pool. Preference for the upper half of the pool is shown in Hannibal Pool, while Greenup Pool indicates a preference for only the second quarter of the pool. Total sucker species in Newburgh Pool are found in greater abundance in the fourth quarter and near their expected abundance in the first half of the pool. Smithland Pool displays a noted lack of suckers in the first quarter of the pool, and Pool 53 shows a preference for the second and third quarters of the pool. It is possible that these mixed results actually do show uneven distributions that vary from pool to pool; however, when it is considered how randomly the individual pool preferences appear, it is more likely that total suckers actually show no general preference for specific areas of the pools. Deep-bodied suckers also random in their navigational pool distributions (Figs. 16 and 17).

Round-bodied sucker species (Figs. 18 and 19) may, however, show a slight tendency toward greater abundance in the upper portions of navigational pools. Three out of the five pools where the chi square test was valid indicate a preference for at least the first quarter of each pool. Only data from the first pool in the lower half of the river, (McAlpine Pool) was considered valid for the chi square test, attesting to the lack of round-bodied suckers in the lower portion of the river. The apparent slight preference for the upper portion of individual pools in round-bodied suckers is probably due to the presence of faster currents and clean-swept substrates in the tailwaters of the dam preceding the pool. Deep-bodied suckers appear to be generalists with regard to substrate, which helps to explain their more or less random distribution within navigational pools.

Temporal Distribution

Riverwide temporal distribution of suckers during the 40-year lock chamber survey period is shown in Fig. 20. Suckers increased significantly ($X^2(3) = 7.81$, $p < 0.005$) in abundance during this period, especially between the last two decades of the study. This data appears to support the findings of the previously mentioned studies that attribute increased fish diversity and abundance in the Ohio River to improved water quality brought about by the Clean Water Act of 1972. .

When the temporal distribution of round-bodied and deep-bodied suckers is examined independently (Fig. 20), it is concluded that both categories significantly increased during the study ($X^2(3) = 7.81$, $p < 0.05$). Increase in deep-bodied suckers begins between the first and second decades of the study. Round-bodied suckers, however, do not begin to increase until the third decade of the study. Since round-bodied suckers are considered much more pollution intolerant than deep-bodied suckers (Simon and Emery, 1995), this data provides more evidence that better water quality may be the reason for increased sucker abundance in the Ohio River. Both deep- and round-bodied sucker species increased dramatically between the last two decades of the study (Fig. 20).

Three deep-bodied suckers significantly increased over the study period: the river carpsucker, quillback carpsucker, and smallmouth buffalo (Figs. 21 and 22) The highfin carpsucker increased in overall numbers during the study period, but it declined between the second and third decades (Fig. 21). The bigmouth buffalo showed only a slight increase between the second and third decades (Fig. 22), and black buffalo increased after the first decade of the study but then decreased to below expected numbers throughout the remainder of the study period (Fig. 22).

Only white suckers, the most pollution tolerant of the 15 species, declined in overall abundance during the survey (Fig. 23). The remaining round-bodied species (Figs. 24 and 25) either slowly increased in abundance (spotted sucker, black redhorse, and golden redhorse) or a dramatically increased between the last two decades of the study (shorthead redhorse). The chi square test was not valid for the silver redhorse, river redhorse, or blue sucker, attesting to the rarity of these species during the study period. Of these, only the blue sucker may have declined. Increased numbers in silver redhorse and river redhorse were not able to provide a large enough sample size to insure a valid statistical test.

All results in the longitudinal temporal distribution of suckers were significant where the chi square test was valid. Longitudinal temporal distribution of suckers (Fig.26) showed increased sucker abundance in all three sections of the river between the last two decades. Fewer suckers than expected were found in the last two-thirds of the river during the first decade; however, the first third of the river revealed observed numbers only slightly below expected values during this time. Deep-bodied suckers (Fig. 27) show similar longitudinal temporal patterns to the total suckers.

Round-bodied suckers (Fig. 28) increased in abundance in the upper and lower thirds of the river and decreased slightly in the middle third of the river. Between the first two decades of the study, round-bodied suckers decreased in abundance in the upper two-thirds of the river and increased in the lower third of the river. Round-bodied suckers then increased steadily in the upper third throughout the study and decreased in the middle third. In the lower third of the river, round-bodied suckers remained near expected abundance until they increased drastically between the last two decades. Increases in the upper and lower thirds of the river were most likely the result of improvements in water quality. Before the enactment of the Clean Water Act in 1972, the upper portion of the Ohio River was the most heavily polluted segment (Lowe, 1956). Because the upper portion of the river was heavily polluted and the lower portion did not provide suitable habitat, fish were found in greatest numbers in the middle of the river during this time. As conditions of the upper portion of the river improved, fish migrated back up into this section of the river (Krumholz, 1981). The temporary decrease seen in the middle third of the river may have resulted from migration of suckers into upper third of the river as conditions improved.

Stomach Content Analysis

Stomach content analysis for deep-bodied suckers showed an abundance of detritus for all four river sections in which deep-bodied suckers were caught. The first section of the river did reveal greater diversity and more abundant zooplankton (primarily cladocerans), protozoans, and benthic organisms (Chironomid midges). An increase in the relative amount of detritus was noted in progressive river sections, as well as an increase in filter-feeding benthic organisms (primarily Hydropsychid caddisflies), filamentous algae, and vegetation. Higher numbers of filter-feeding aquatic insects in the guts of suckers captured from the lower river is not surprising since the succession of benthic communities throughout the continuum of a river results in more collector-filterer species in the lower reaches of a river (Vannote et al., 1980). Large amounts of detritus and plant material present in the stomachs of the deep-bodied suckers also reflect the more general food habits of the deep-bodied suckers as found in the literature (Tables 1 and 2). Thus, it appears that Ohio River deep-bodied suckers exhibit a change from a relatively diverse diet in the upper reaches of the river to a more generalist diet in the lower sections of the river where a variety of benthic organisms are not always present in great numbers.

Round-bodied suckers showed a much more diverse diet in all sections of the river than did deep-bodied suckers. The first section of the river again showed the most diversity and a greater abundance of benthic organisms (primarily Chironomidae, Ephemeridae, Mollusca, cladocerans, and ostracods). The shorthead redhorse diet in the upper reaches of the river consisted almost entirely of zebra mussels. Only two round-bodied suckers were caught in the fourth and last section of the river, and both of these suckers had more detritus and plant material in their guts than their counterparts from the upper section of the river. Relatively few shell fragments and chironomid larvae were found in these two guts when compared with upper river suckers. It appears possible that unavailability of preferred food items of round-bodied suckers in the lower portion of the river is a limiting factor in the distribution of round-bodied suckers. These results may be somewhat skewed, however, since only two fish were examined from the lower river and that seasonal changes in diet were not considered in this study.

Substrate Composition Analysis

Results of the silt, sand/gravel, gravel/cobble, and cobble/substrate type analyses of the two river sections from Hannibal Pool are shown in Figs. 29, 30, 31 and 32, respectively. As, expected, all four analyses showed strong qualitative differences in substrate composition. The upper pool showed only small patches of silt substrate, while silt made up the majority of the substrate in the lower pool. Sand/gravel substrate was found in greater abundance in the upper pool section than in the lower, as was gravel/cobble substrate. Cobble/boulder substrates showed the least qualitative difference between upper and lower pool sections, but there was still a marked absence of significant cobble/boulder substrate in the lower pool section. Mean size of substrate particles also appears to be larger in the upper pool than in the lower pool (Fig. 33).

This data suggests that substrate composition of at least one Ohio River navigational pool does appear change from the tailwaters of the dam at the beginning of the pool to the more sluggish water behind the dam at the end of the pool. The upper substrate appears to be swept free of silt by the rapid water flow of the tailwaters, leaving mostly sand/gravel, gravel/cobble, and some cobble/boulder substrates. Slower moving, deeper waters behind the dam at the end of the pool allow the silt carried by the water to settle down in the lower sections of the pool. This longitudinal change in substrate composition is expected to be found in other Ohio River navigational pools as well. Since suckers utilize clean-swept gravel and cobble substrates rather than silt-laden bottoms, the primarily silty substrate of the lower pools helps to explain the lower numbers of suckers captured in the lower sections of the pools.

Correlation analysis between substrate type and sucker abundance (inclusive of river mile) revealed six significant positive correlation and eight negative correlations. River mile was positively correlated with sand substrate ($p = 0.0010$) and negatively correlated with boulder ($p = 0.0001$), cobble ($p = 0.0001$), and gravel ($p = 0.0031$), substrates. This suggests that sand substrate increases in abundance toward the lower portion of the river and that the clean-swept boulder, cobble, and gravel substrates are found predominantly in the upper river. Prevalence of preferred habitat along with increased abundance of sucker species in the upper portions of the river suggest that substrate composition plays an important role in Ohio River sucker distribution.

With the influence of river mile present, suckers were positively correlated with gravel (p = 0.0115) and cobble (p = 0.0012) substrates and negatively correlated with sand substrate (p = 0.0001) and river mile (p = 0.0001). Deep-bodied suckers were negatively correlated with both river mile (p = 0.0230) and sand substrate (p = 0.03). Round-bodied suckers, however, were positively correlated with boulder (p = 0.0011), cobble (p = 0.0001), and gravel (p = 0.0019) substrates and negatively correlated with river mile (p = 0.0001). These correlations may be biased by the influence of river mile, however, and a significant correlation does not necessarily suggest a correlation between a species and a certain substrate type.

When river mile is not factored into the correlation, only one positive correlation and two negative correlations were found. Round-bodied suckers were positively correlated with cobble substrate (p = 0.0081) and negatively correlated (p = 0.0095) with sand substrate. Total suckers were negatively correlated with sand substrate (p = 0.0020). Since river miles do not influence this correlation analysis, it can be concluded that Ohio River round-bodied suckers appear to inhabit cobble substrates while avoiding sandy substrates. Use of clean-swept substrates in round-bodied sucker species is well-supported in the literature (Jenkins and Burkhead, 1994) and also helps to explain the abundance of round-bodied suckers in the upper portions of the river. Conversely, the absence of any correlation between deep-bodied suckers and substrate type helps to explain the extended longitudinal distribution of deep-bodied suckers over round-bodied suckers in the Ohio River. The negative correlation between total sucker species and sand substrate appears to reflect mostly the influence of the round-bodied sucker species. Since deep-bodied and round-bodied sucker species were found in almost equal abundance during the electrofishing studies, it is possible that deep-bodied suckers are captured in fewer numbers over fine substrates. Low numbers of deep-bodied sucker species captured in the extreme lower river also suggests a slight avoidance of fine substrate by deep-bodied suckers.

Spawning Area Analysis

The greatest availability of spawning streams was seen in the second river section, extending from ORM 98 to ORM 195 (1.7 streams/mi), followed by the third section (ORM 196 – ORM 391) with 1.5 streams/mi and the fourth section (ORM 392 – 784) with 1.4 streams/mi. The first and last sections (ORM 1 – ORM 97 and ORM 785 – ORM 981, respectively) showed the fewest available spawning streams. Only 1.2 streams/mi were available for spawning in the first section of the river and 1.1 spawning streams/mi were found in the last section. The abundance of spawning streams in the middle sections of the river (including ORM 98 – 784) most likely plays a significant role in the abundance of suckers in that area of the river. Likewise, fewer available spawning streams in the extreme lower river is probably a factor in the rarity of sucker species in that portion of the river. The first 98 miles of the river, however, have both an abundance of suckers and a lower number of available spawning streams. It may be that the sucker species captured in the upper 98 miles of the Ohio River make extensive use of the Monongahela and Allegheny River basins for spawning. Topography and hydrography probably also play a significant role in the availability of actual spawning sites. Tributary streams in the upper portions of the Ohio River tend to be shorter in length and flow in a straight direction due to greater distances in elevation from source to mouth. Stream gradient is therefore much greater in these tributaries than in the long, slow, meandering tributaries of the lower river and provides more of the faster flow rates and clean-swept rocky substrate necessary for sucker spawning. Thus, a combination of the number of available spawning streams and the topography and hydrography of these streams play a significant role in the distribution of Ohio River sucker species.

SUMMARY

1. The family Catostomidae is important to the Ohio River fish community in terms of biomass and abundance.

2. Suckers represented 7.1 percent of total fishes taken during an eight year electrofishing survey. Round- and deep-bodied suckers were approximately equal in abundance.

3. Suckers represented 36.6 percent of the biomass taken during electrofishing studies. Deep-bodied suckers contributed more biomass to the total than did round-bodied suckers.

4. Suckers are found in greatest number in the upper reaches of the Ohio River.

5. Round-bodied suckers are significantly greater in abundance in the upper Ohio River. Deep-bodied suckers are also significantly greater in number in the upper river but show a longer longitudinal distribution than do round-bodied suckers.

6. Round-bodied suckers are slightly but significantly greater in number in the upper reaches of navigational pools than in the lower portions of pools.

7. Suckers increased significantly in abundance between 1957 and 1996. Most of this increase occurred after the enactment of the Clean Water Act in 1972.

8. Deep-bodied suckers began to increase in overall abundance before round-bodied suckers did. Round-bodied suckers did not begin to increase until after the enactment of the Clean Water Act in 1972.

9. Round-bodied suckers increased more drastically in numbers over the 40-year study period than did deep-bodied suckers.

10. Sucker increased significantly in all sections of the Ohio River; however, the most drastic increase was seen in the upper one-third of the river where environmental conditions were extremely poor.

11. Deep-bodied suckers ingested considerably more detritus and plant material than did round-bodied suckers. Round-bodied suckers consumed primarily benthic macroinvertebrates. Deep-bodied suckers increased in generalist food habits in the lower sections of the river, extending their range into portions of the lower river not abundant in round-bodied suckers.

12. Substrate composition in Hannibal Pool changes from primarily clean-swept

sand/gravel and gravel/cobble substrate in its upper reaches to almost exclusively silt substrate in its lower reaches. Changes in substrate within navigational pools helps to explain the significantly greater abundance of round-bodied suckers in the upper portions of pools.

13. In the Ohio River, suckers were positively correlated with gravel and cobble substrates and negatively correlated with sand substrate. Deep-bodied suckers were negatively correlated with sand substrate and round-bodied suckers were positively correlated with boulder, cobble, and gravel substrates. All three sucker categories were negatively correlated with river mile.

14. Round-bodied suckers were positively correlated with cobble substrate and negatively correlated with sand substrate in the absence of Ohio River river miles. Total suckers were negatively correlated with sand substrate.

15. Spawning habitat was greatest between ORM 196 and ORM 391. Lack of suitable spawning streams in the extreme lower Ohio River is likely a significant factor in the lack of suckers in that region of the river.

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APPENDIX

Table 1. Food habits and feeding classifications for adult deep-bodied Ohio River suckers.

SPECIES	MAIN FOOD HABITS	FIRST LEVEL TROPHIC CLASSIFICATION[1]	SECOND LEVEL TROPHIC CLASSIFICATION[1]	TROPHIC MODE[1]
River Carpsucker[1,2,3] *Carpiodes carpio*	zooplankton and phytoplankton; some vegetation	Planktivore/ Detritivore	Filter Feeder	Suction Feeder
Quillback Carpsucker[1,2,3] *Carpiodes cyprinus*	aquatic invertebrates; organic material	Invertivore/ Detritivore	Benthic/ Filter Feeder	Grazer/ Suction Feeder
Highfin Carpsucker[1,2,3] *Carpiodes velifer*	detritus; algae; few benthic invertebrates	Detritivore	Filter Feeder	Suction Feeder
Smallmouth buffalo[4,5] *Ictiobus bubalus*	zooplankton (cladocerans and copepods) algae; Mollusca; Entomostraca; insect larvae	Invertivore/ Herbivore		
Bigmouth Buffalo[4,5,6,7] *Ictiobus cyprinellus*	zooplankton (cladocerans and copepods) algae; diatoms; detritus	Invertivore		
Black Buffalo[1,2,3] *Ictiobus niger*	zooplankton; aquatic insects			

[1]Goldstein and Simon, 1999 [2]Etnier and Starnes, 1993 [3]Kay et al., 1994 [4]McComish, 1967 [5]Minckley et al., 1970
[6]Johnson, 1963

Table 2. Food habits and feeding classifications for adult round-bodied Ohio River suckers.

SPECIES	MAIN FOOD HABITS	FIRST LEVEL TROPHIC CLASSIFICATION[1]	SECOND LEVEL TROPHIC CLASSIFICATION[1]	TROPHIC MODE[1]
White Sucker[2,3,4,5,6,7] *Catostomus commersoni*	chironomid larvae ephemeropteran larvae water mites, copepods ostracods (seasonally)	Invertivore/ Detritivore	Benthic/ Filter Feeder	Grazer/ Suction Feeder
Blue Sucker[8,9] *Cycleptus elongatus*	aquatic insects; crustaceans; algae and plant material	Invertivore/ Herbivore		
Northern Hog Sucker[10,11] *Hypentelium nigricans*	aquatic insects; diatoms	Invertivore/ Herbivore		
Spotted Sucker[11,12] *Minytrema melanops*	detritus; zooplankton (cladocerans and copepods); occasional benthics	Invertivore		

[1]Goldstein and Simon, 1999 [2]Ahlgren, 1990a [3]Ahlgren, 1990b [4]Ahlgren, 1996 [5]Barton, 1980
[6]Geen et al., 1966 [7]Trippel and Harvey, 1987 [8]Moss et al., 1983 [9]Rupprecht and Jahn, 1980
[10]Raney and Lachner, 1946 [11]Etnier and Starnes, 1993 [12]White and Haag, 1977

Table 2 (continued). Food habits and feeding classifications for adult round-bodied Ohio River suckers.

SPECIES	MAIN FOOD HABITS	FIRST LEVEL TROPHIC CLASSIFICATION[1]	SECOND LEVEL TROPHIC CLASSIFICATION[1]	TROPHIC MODE[1]
Silver Redhorse[2,3] *Moxostoma anisurum*	chironomid larvae; other aquatic insects; plant material	Invertivore		
River Redhorse[3,4,5] *Moxostoma carinatum*	aquatic invertebrates; molluscs	Invertivore	Benthic	Crusher
Black Redhorse[3,6] *Moxostoma duquesnei*	aquatic insects; zooplankton; amphipods	Invertivore		
Golden Redhorse[2,3] *Moxostoma erythrurum*	aquatic insects; worms; molluscs	Invertivore		
Shorthead Redhorse[2,3] *Moxostoma macrolepidotum*	aquatic insects; molluscs; oligochaetes; crustaceans; diatoms	Invertivore		

[1]Goldstein and Simon, 1999 [2]Meyer, 1962 [3]Etnier and Starnes, 1993 [4]Parker, 1988 [5]Yoder and Beaumier, 1986 [6]Bowman, 1970

Table 3. Habitat associations for adult deep-bodied Ohio River suckers.

SPECIES	SUBSTRATE	PHYSICAL CHARACTERISTICS
River Carpsucker[1,2] *Carpiodes carpio*	silt to mix of sand, gravel, and mud	sluggish backwater and deep pools tolerant of silt and turbity
Quillback Carpsucker[2,3] *Carpiodes cyprinus*	sand, silt, and mud with no vegetation	low gradient main channels pools and backwater
Highfin Carpsucker[2,3] *Carpiodes velifer*	sand or gravel with no vegetation	pools and backwater reservoirs
Smallmouth Buffalo[4,5,6] *Ictiobus bubalus*	fine	clear, swift water in larger rivers
Bigmouth Buffalo[4,5,6,7,8,9] *Ictiobus cyprinellus*	fine with vegetation	deeper pools and backwater tolerant of turbidity
Black Buffalo[2] *Ictiobus niger*	mud	med. to large rivers in strong current also swamp-like areas

[1]Behmer, 1965 [2]Kay et al., 1994 [3]Beecher, 1980 [4]McComish, 1967 [5]Minckley et al., 1970 [6]Osburn and Self, 1965 [7]Johnson, 1963 [8]Starostka, 1970 [9]Burr and Heidinger, 1983

Table 4. Habitat associations for adult round-bodied Ohio River suckers.

SPECIES	SUBSTRATE	PHYSICAL CHARACTERISTICS
White Sucker[1,2,3,4] *Catostomus commersoni*	gravel or sand	smaller streams with clear water/ tolerant of a variety of conditions
Blue Sucker[5,6] *Cycleptus elongatus*	sand, gravel, rock, and exposed limestone	deep, swift riffles
Northern Hog Sucker[7,8] *Hypentelium nigricans*	gravel and rock	riffles and runs in smaller swift streams cool, clear water
Spotted Sucker[9,10] *Minytrema melanops*	sand, gravel, or firm clay	low gradient streams lakes, reservoirs, sluggish waters

[1]Barton, 1980 [2]Geen et al., 1966 [3]Raney and Webster, 1942 [4]Trippel and Harvey, 1987 [5]Moss et al., 1983 [6]Yeager and Semmens, 1987 [7]Matheney and Rabeni, 1995 [8]Raney and Lachner, 1946 [9]White,1974 [10]Kay et al., 1994

Table 4 (continued). Habitat associations for adult round-bodied Ohio River suckers.

SPECIES	SUBSTRATE	PHYSICAL CHARACTERISTICS
Silver Redhorse[1,5] *Moxostoma anisurum*	soft or rocky gravel	varies most often in pools of larger rivers
River Redhorse[2,3] *Moxostoma carinatum*	rock, boulder, rubble, and gravel	med. to large rivers swift water or pools
Black Redhorse[4] *Moxostoma duquesnei*	gravel, rock, sand	swifter pools of larger rivers
Golden Redhorse[1,5] *Moxostoma erythrurum*	sand, gravel, boulder, bedrock	med. to large rivers with moderate flow also reservoirs
Shorthead Redhorse[1,5] *Moxostoma macrolepidotum*	sand, rock, gravel, or rubble	larger streams with moderate flow

[1]Geen et al., 1966 [2]Parker, 1988 [3]Yoder and Beaumier, 1986 [4]Bowman, 1970 [5]Kay et al., 1994)

Table 5. Spawning habitat characteristics for deep-bodied Ohio River suckers.

SPECIES	SUBSTRATE	PHYSICAL CHARACTERISTICS	DEPTH (m)	VELOCITY (m/s)	SEASON
River Carpsucker1 *Carpiodes carpio*	firm or silty sand	shallow water in reservoirs/streams intolerant of turbidity	0.3 - 1.0		mid-May through late June
Quillback Carpsucker[2] *Carpiodes cyprinus*	sand or mud gravel or organic matter	small streams <10 m wide/low flow in deep riffles	0.3 - 2.0		April through late May
Highfin Carpsucker[3] *Carpiodes velifer*	gravel	shallows or deep riffles			mid-March through May
Smallmouth buffalo[4,5] *Ictiobus bubalus*	all types	near submerged vegetation at tributary mouths	1.0 - 6.0 1.2 - 3.3		late April through late May
Bigmouth Buffalo[5,6,7] *Ictiobus cyprinellus*	packed red clay with some gravel	small streams/shallow water with debris and vegetation	0.5 - 0.75		late May
Black Buffalo[3,8] *Ictiobus niger*	probably most types	small tribs/swamp margins with veg. brackish water	2.1		late April through early June

[1]Behmer, 1965 [2]Gale and Mohr, 1976 [3]Etnier and Starnes, 1993 [4]Heard, 1958 [5]Osburn and Self, 1965 [6]Burr and Heidinger, 1983 [7]Johnson, 1963 [8]Yeager, 1936

Table 6. Spawning habitat characteristics for round-bodied Ohio River suckers.

SPECIES	SUBSTRATE	PHYSICAL CHARACTERISTICS	DEPTH (m)	VELOCITY (m/s)	SEASON
White Sucker[1,2,3,4,5,6,7] *Catostomus commersoni*	mix of sand, med. gravel, and large rocks	riffles to riffle-pools in headwaters	0.2 - 0.25 <1.0	0.5 -0.59	late March through April
Blue Sucker[8,9,10,11] *Cycleptus elongatus*	cobble and limestone bedrock	deep riffles with low flow	1.43 1.0 - 1.7 1.0 - 2.0	1.8 0.6 - 2.1	April through June
Northern Hog Sucker[12,13] *Hypentelium nigricans*	gravel	riffles in smaller tributaries	0.4 0.3 - 0.6 0.08 - 0.46 0.35 - 0.45	0.4 - 0.9 0.40 - 0.56	late March through early May
Spotted Sucker[13,14] *Minytrema melanops*	coarse rubble	riffle areas above large pools	0.3 - 0.5	0.24	late April through May

[1]Barton, 1980 [2]Corbett and Powles, 1983 [3]Dion and Whoriskey, 1993 [4]Dion et al., 1994 [5]Geen et al., 1996 [6]Raney and Webster, 1942 [7]Reighard, 1920 [8]Moss et al., 1983 [9]Rupprecht and Jahn, 1980 [10]Semmens, 1985 [11]Yeager and Semmens, 1987 [12]Raney and Lachner, 1946 [13]Etnier and Starnes, 1993, [14]White, 1974

Table 6 (continued). Spawning habitat characteristics for round-bodied Ohio River suckers.

SPECIES	SUBSTRATE	PHYSICAL CHARACTERISTICS	DEPTH (m)	VELOCITY (m/s)	SEASON
Silver Redhorse[1,2] *Moxostoma anisurum*	gravel or rubble shoals/rocky gravel	upper reaches of riffles or shoals in smaller streams	>1.0 0.3 - 0.9 0.9 - 1.5	0.45 - 1.00	late March through April
River Redhorse[2] *Moxostoma carinatum*	gravel or med. to coarse rubble	riffles	0.15 - 1.07		mid-April through May
Black Redhorse[2,3] *Moxostoma duquesnei*	mix of rubble, sand, and gravel	swift riffles and shoals short distances up tributaries	0.1 - 0.6 0.15 - 0.60 0.1 - 0.6		late April through early May
Golden Redhorse[1,2] *Moxostoma erythrurum*	coarse to medium gravel or rubble	riffles in small streams short distances up tributaries	0.3 - 0.6	0.4 - 0.9 0.9 - 1.2	late April through mid-May
Shorthead Redhorse[1,2] *Moxostoma macrolepidotum*	gravel or med. to coarse rubble	riffles or near edge of sandbars short distances up tributaries	0.15 - 0.21 0.3 - 0.6	0.4 - 0.9 0.6 - 0.9	mid-May

[1]Meyer, 1962 [2]Etnier and Starnes, 1993 [3]Bowman, 1970

Table 7. Characteristics of deep-bodied Ohio River suckers (Etnier and Starnes, 1993).

GENUS	LATERAL LINE	DORSAL FIN RAYS	ANAL FIN RAYS	GENERAL DESCRIPTION	OTHER IDENTIFYING CHARACTERISTICS
CARPIODES "carp-like"					triangular subopercle
River carpsucker *C. carpio*	33 - 37	23 - 30	7 - 8	silvery-golden sides brownish gray dorsally	depressed first dorsal ray does not reach past middle fin base
Quillback carpsucker *C. cyprinus*	35 - 41	25 - 33	7 - 8	silvery-golden sides brownish gray dorsally	lacks nipple like projection on lower jaw
Highfin carpsucker *C. velifer*	33 - 37	21 - 27	7 - 8	silvery-golden sides brownish gray dorsally lateral body scales with dark pigment	depressed anterior rays of dorsal fin reach as long or longer than fin base
ICTIOBUS "bull fish"					semi-circular subopercle
Smallmouth buffalo *I. bubalus*	32 - 41	23 - 32	7 - 11	olive dorsally	deeper body and larger eye than *I. niger*
Bigmouth buffalo *I. Cyprinellus*	32 - 41	23 - 32	7 - 11	olive dorsally	terminal mouth
Black buffalo *I. Niger*	32 - 41	23 - 32	7 - 11	dark olive dorsally	body more slim and eye smaller than *I. bubalus*

Table 8. Characteristics of Ohio River round-bodied suckers (Etnier and Starnes, 1993).

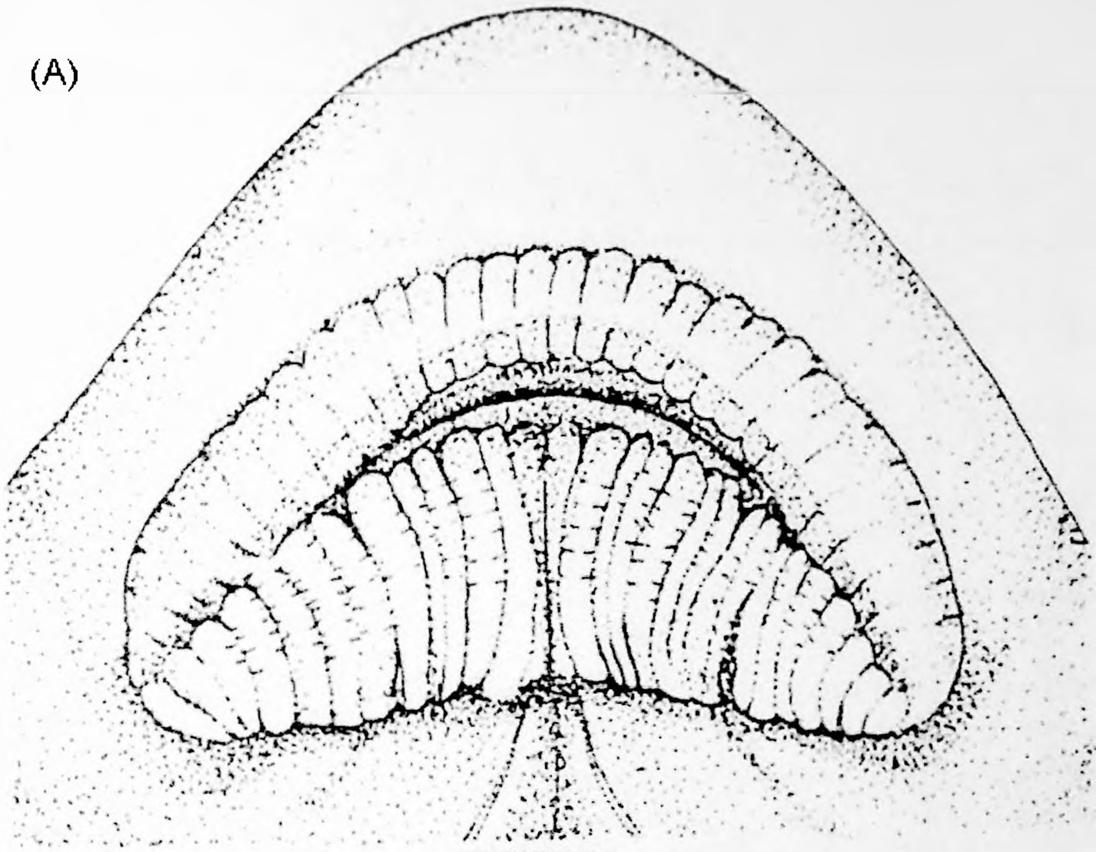
GENUS	LATERAL LINE	DORSAL FIN RAYS	ANAL FIN RAYS	GENERAL DESCRIPTION	OTHER IDENTIFYING CHARACTERISTICS
CATOSTOMUS "inferior mouth"					
White sucker *C. commersoni*	53 - 85	10 - 13	7	mottled olive or gray dorsally lower sides and belly white	scales crowded and small anteriorly
CYCLEPTUS					
Blue sucker *C. elongatus*	53 - 60	28 - 37	7 - 8	dark blue gray dorsally lower caudal fin especially dark	papillose lips
HYPENTELIUM "lower lip five-lobed"					
Northern hog sucker *H. nigricans*	42 - 55	10 - 12	7	slender cylindrical body four dark saddles	head concave between eyes fleshy papillose lips
MINYTREMA "reduced lateral line"					
Spotted sucker *M. melanops*	42 - 47	10 - 13	7	olive dorsally pale ventrally	lateral line incomplete "spot" on every scale

Table 8 (continued). Characteristics of Ohio River round-bodied suckers (Etnier and Starnes, 1993).

GENUS	LATERAL LINE	DORSAL FIN RAYS	ANAL FIN RAYS	GENERAL DESCRIPTION	OTHER IDENTIFYING CHARACTERISTICS
MOXOSTOMA "to suck" "mouth"					
Silver redhorse *M. anisurum*	38 - 48	13 - 17		silvery lower fins often orange	large head long dorsal fin
River redhorse *M. carinatum*	41 - 47	12 - 15		silvery fins red to orange	molariform pharyngeal teeth dorsal lobe of caudal fin triangular
Black redhorse *M. duquesnei*	43 - 51	11 - 15		silvery slightly orange lower fins	use lateral line scales dorsal fin deeply concave
Golden redhorse *M. erythrurum*	37 - 45	12 - 14		silvery lower fins yellow to orange	use lateral line scales to compare with *M. duquesnei*
Shorthead redhorse *M. macrolepidotum*	40 - 46	11 - 14		silvery caudal fin bright red	lower lips form straight line dorsal fin concave

Fig. 1. Papillose (A) and plicate (B) lips of suckers.

(A)



(B)

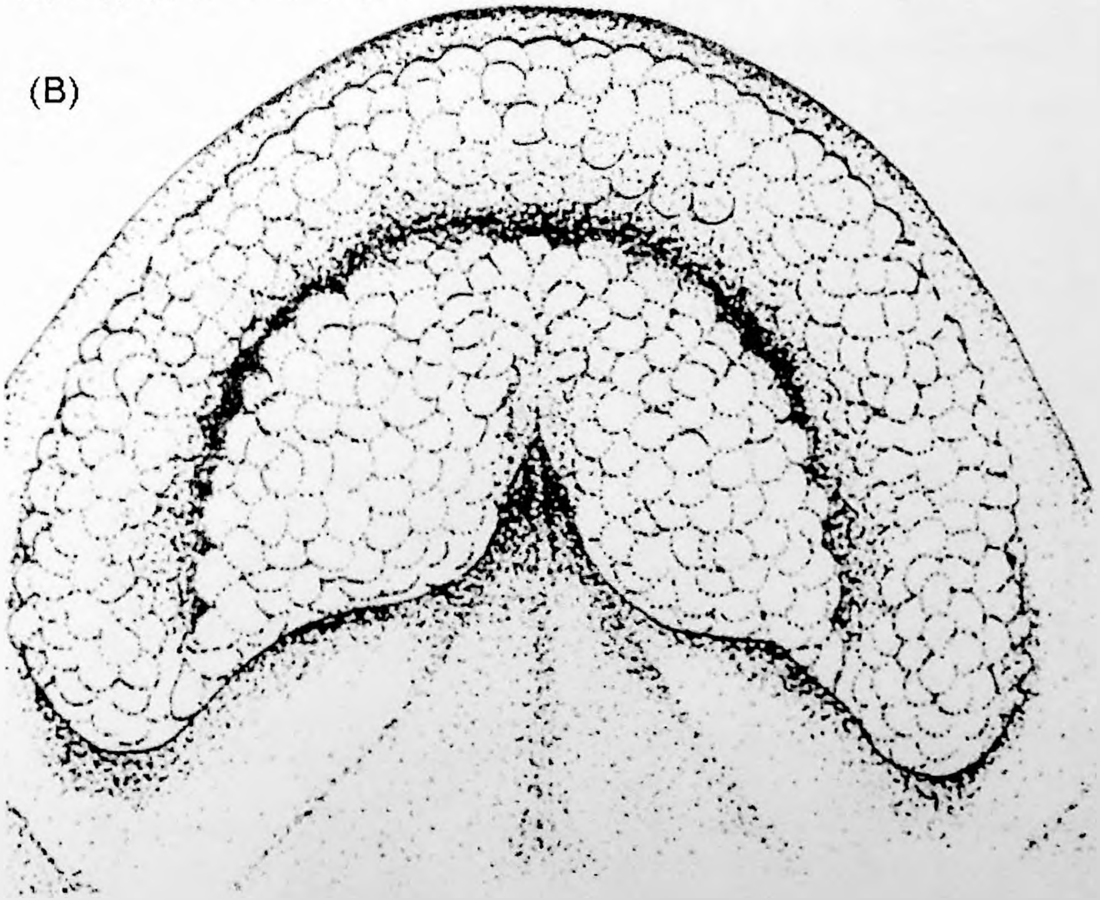
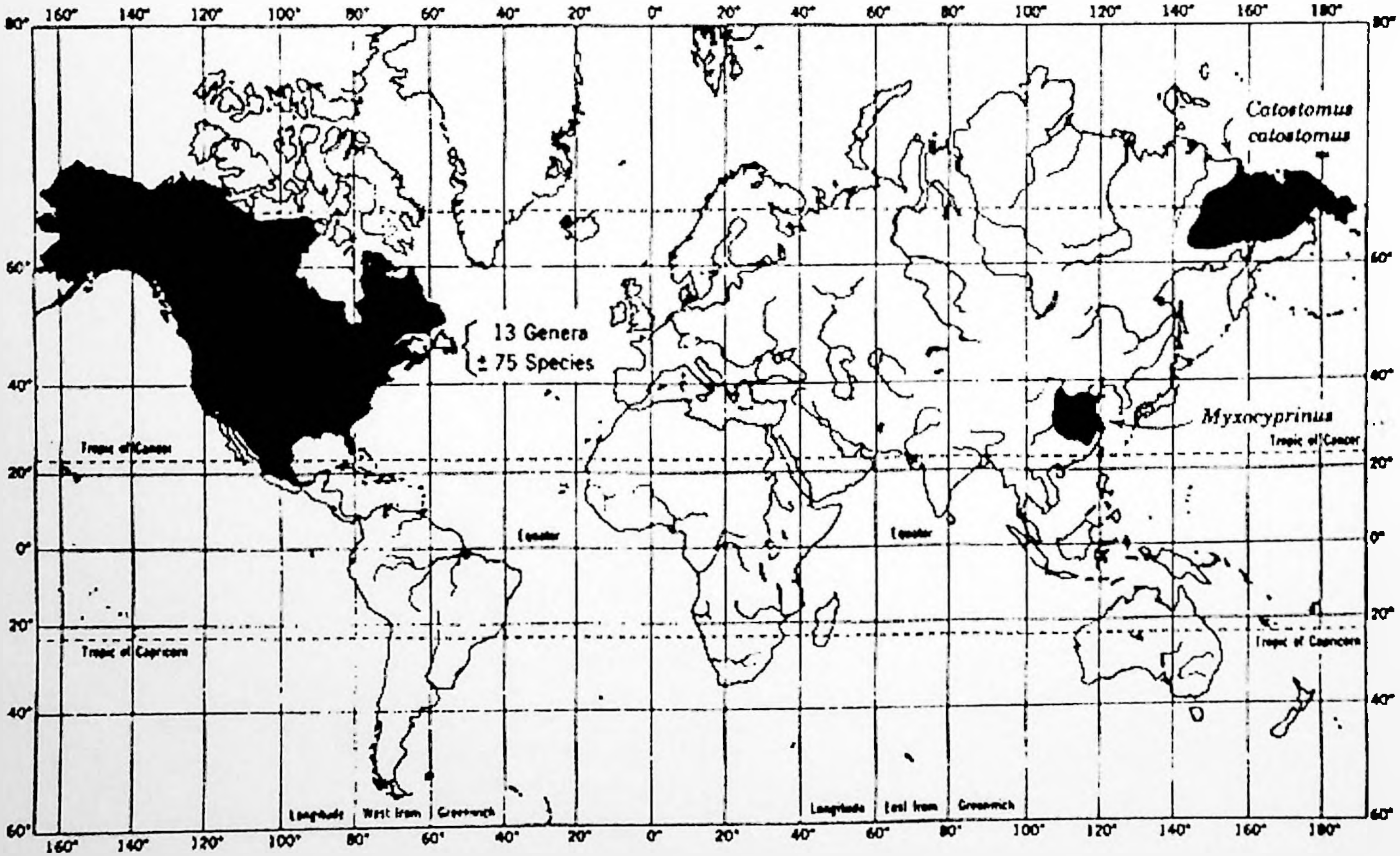


Fig. 2. Worldwide distribution of suckers (Family Catostomidae) (*from* Lagler et al., 1977).



13 Genera
± 75 Species
Catostomus catostomus
Myxocyprinus
Tropic of Cancer
Equator
Tropic of Capricorn
Longitude West from Greenwich
Longitude East from Greenwich

Fig. 3. The Ohio River drainage basin.

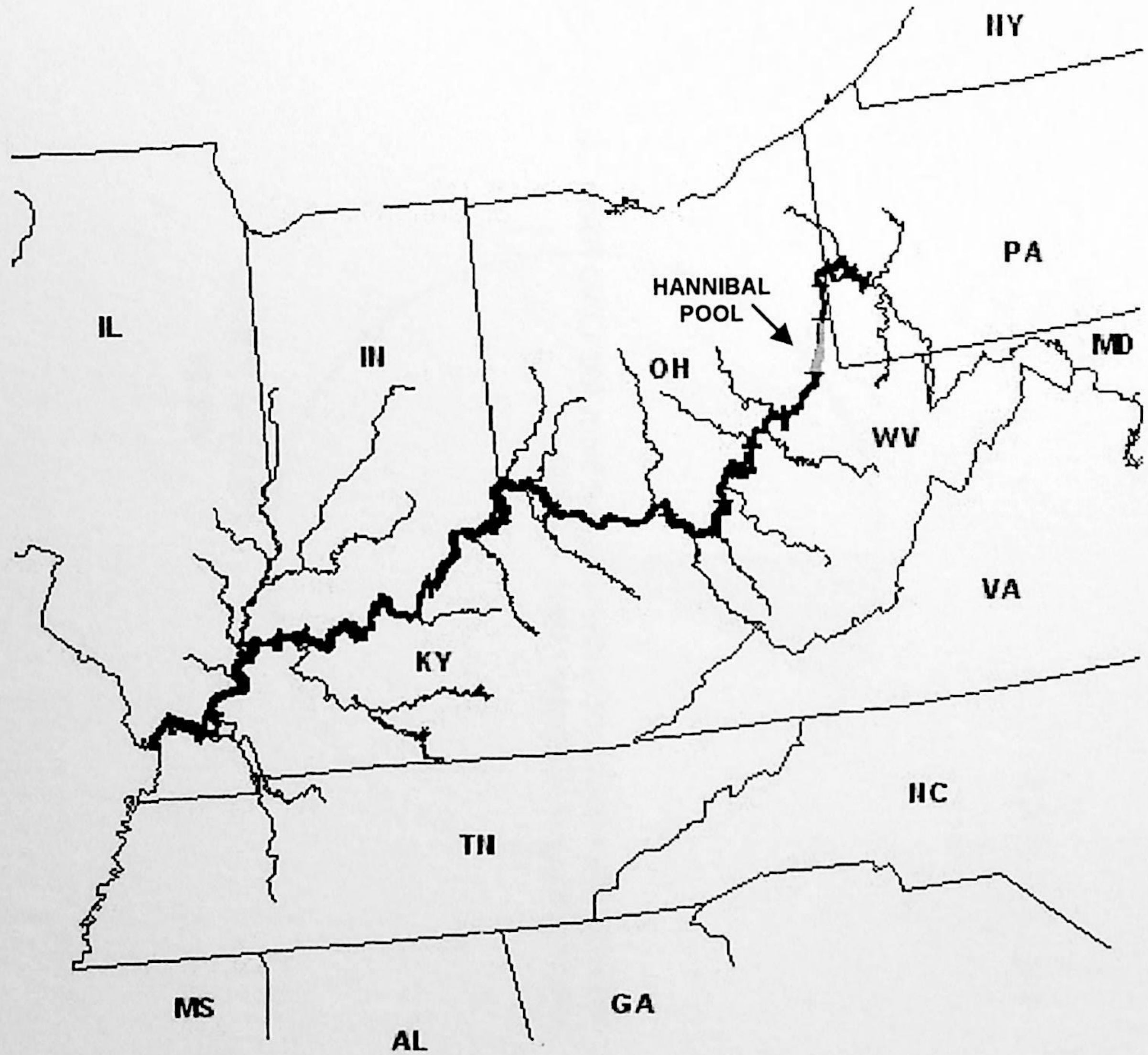

NY
PA
MD
HANNIBAL
POOL
IL
IN
OH
WV
VA
KY
NC
TN
MS
AL
GA

Fig. 4. Relative abundance of suckers taken from the Ohio River during boat electrofishing collections (1991 – 1998).

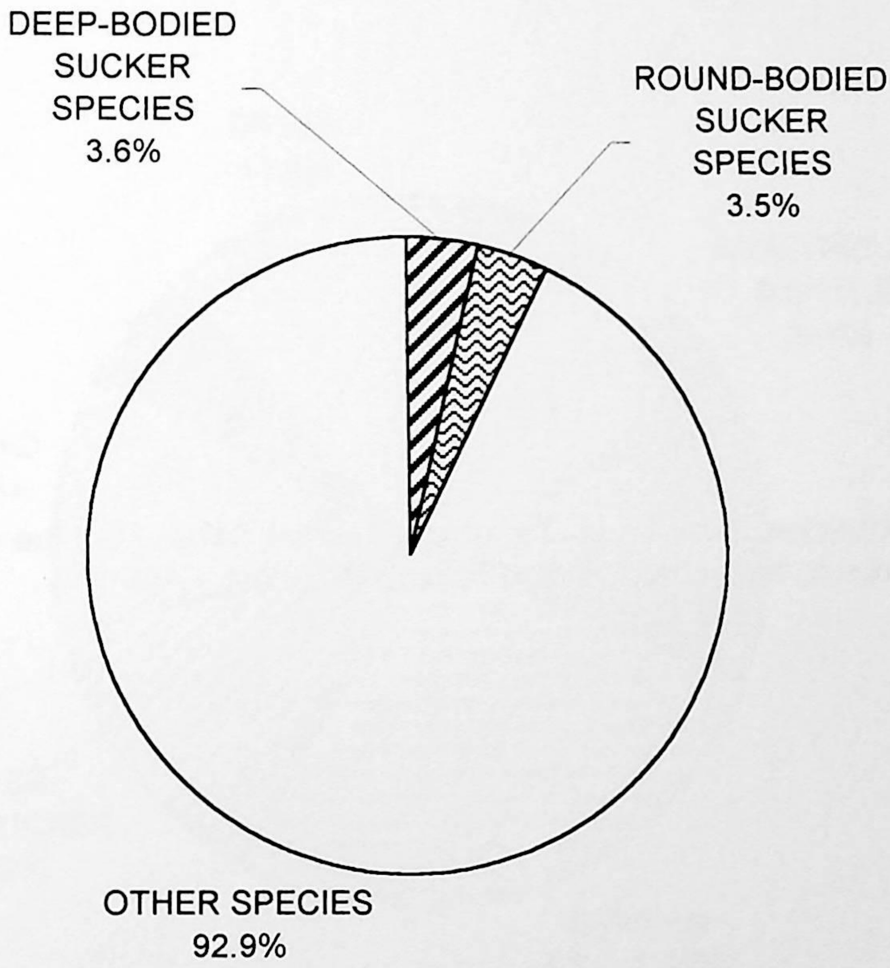

DEEP-BODIED SUCKER SPECIES 3.6%
ROUND-BODIED SUCKER SPECIES 3.5%
OTHER SPECIES 92.9%

Fig. 5. Relative abundance of species of sucker taken from the Ohio River during boat electrofishing collections (1991 – 1998).

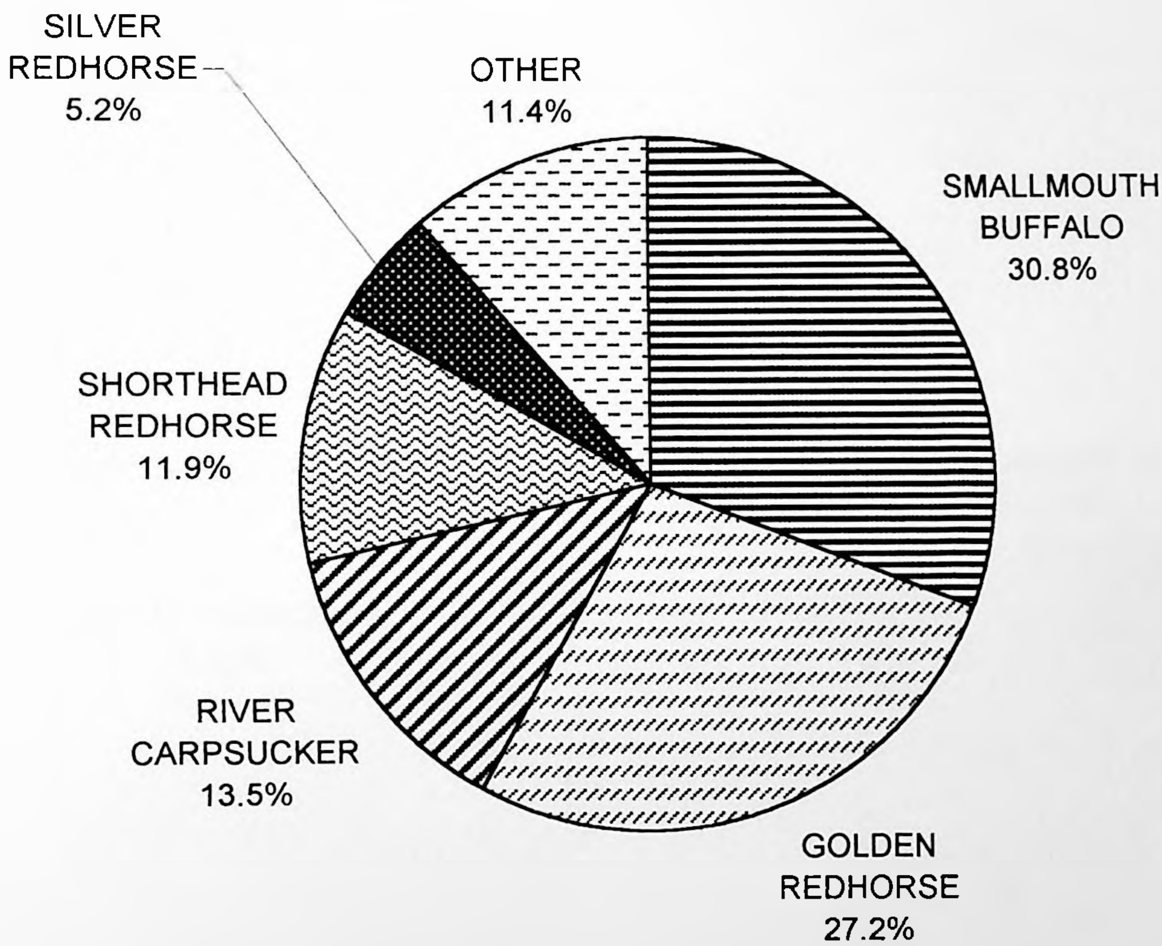

SILVER
REDHORSE
5.2%
OTHER
11.4%
SMALLMOUTH
BUFFALO
30.8%
SHORTHEAD
REDHORSE
11.9%
RIVER
CARPSUCKER
13.5%
GOLDEN
REDHORSE
27.2%

Fig. 6. Relative biomass of suckers taken from the Ohio River during boat electrofishing collections (1991 – 1998).

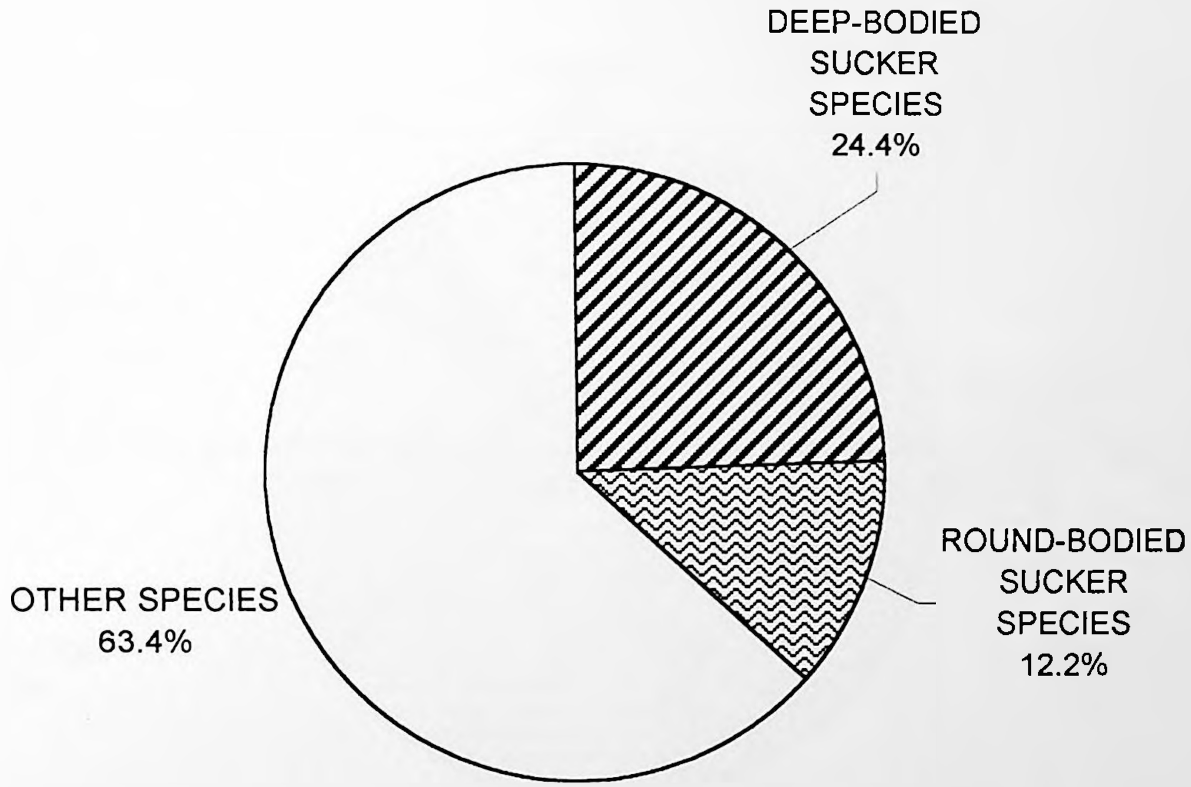

DEEP-BODIED
SUCKER
SPECIES
24.4%
ROUND-BODIED
SUCKER
SPECIES
12.2%
OTHER SPECIES
63.4%

Fig. 7. Relative abundance of species of sucker taken from the Ohio River during boat electrofishing collections (1991 – 1998).

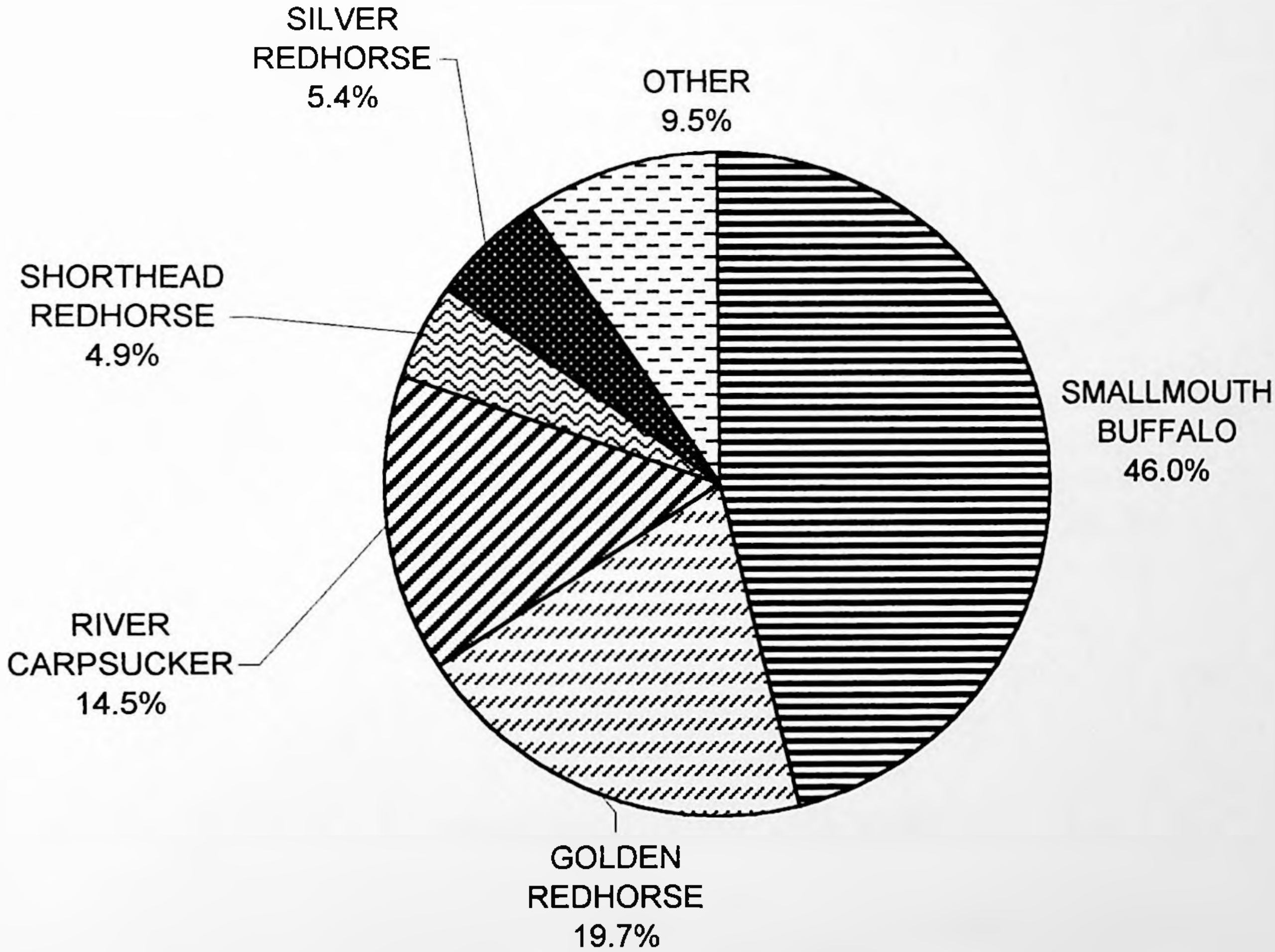
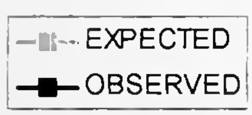

SILVER REDHORSE 5.4%
OTHER 9.5%
SHORTHEAD REDHORSE 4.9%
SMALLMOUTH BUFFALO 46.0%
RIVER CARPSUCKER 14.5%
GOLDEN REDHORSE 19.7%

Fig. 8. Kolmogorov-Smirnov goodness of fit analysis of Ohio River sucker population data from electrofishing collections (1991 – 1998). (A) Total suckers ($p < 0.05$) (B) Deep-bodied suckers ($p < 0.05$) (C) Round-bodied suckers ($p < 0.05$)



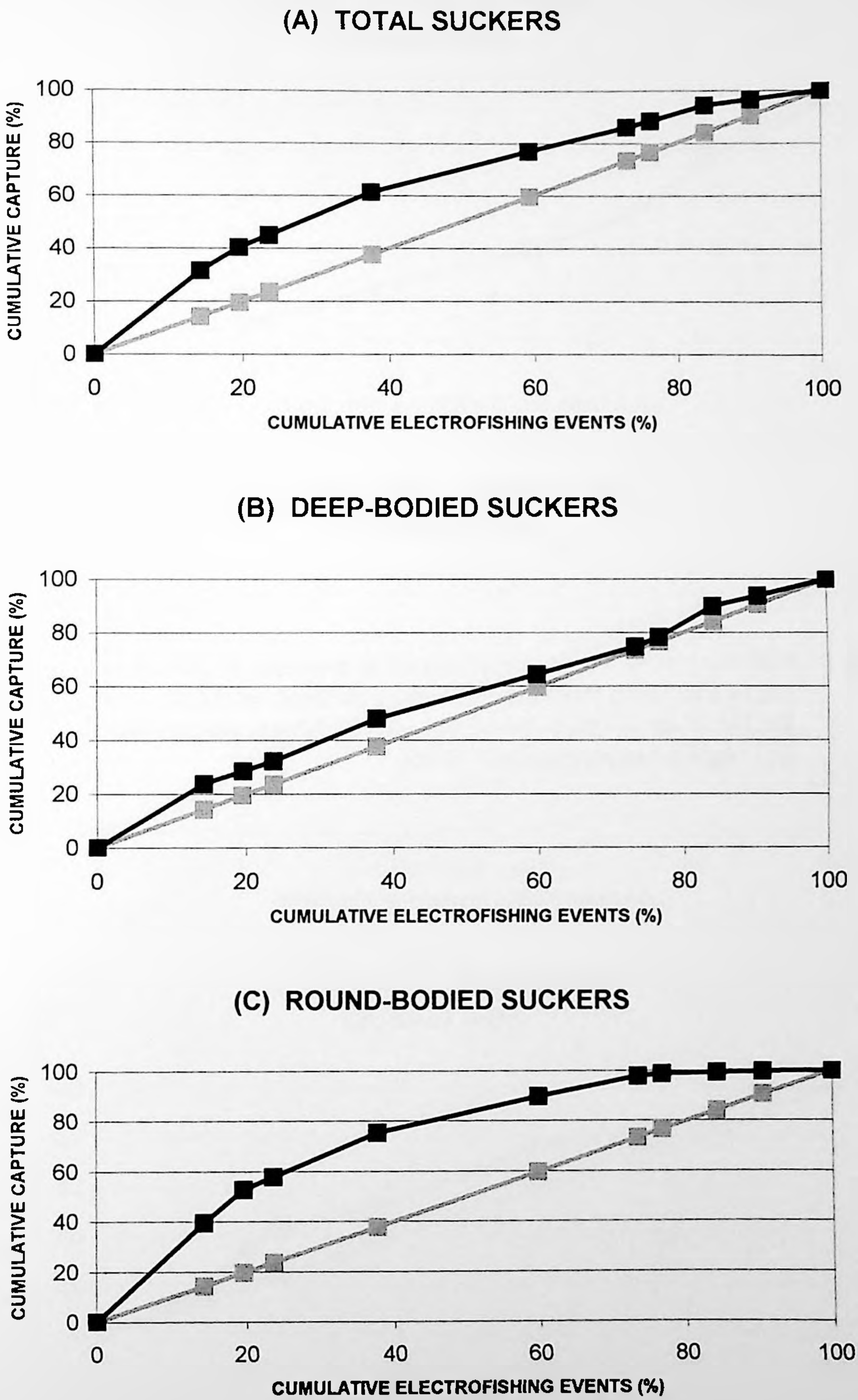
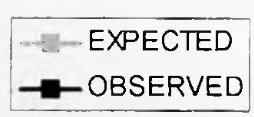
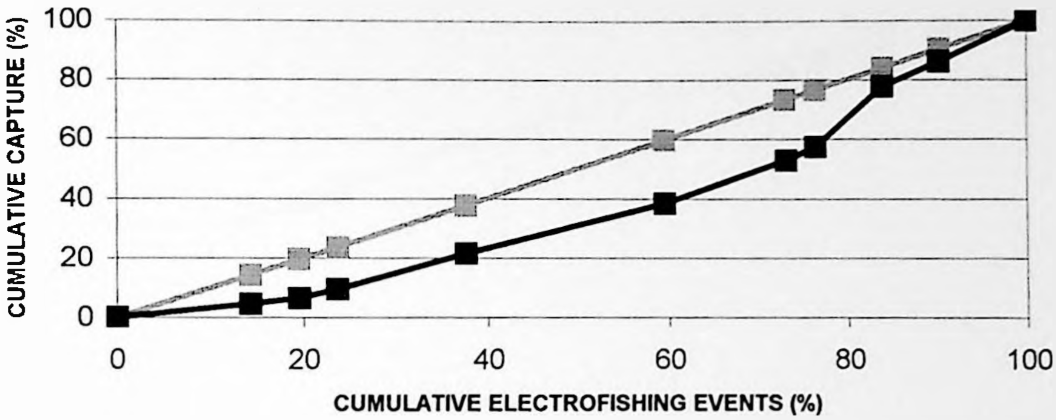

(A) TOTAL SUCKERS
CUMULATIVE CAPTURE (%)
0
20
40
60
80
100
CUMULATIVE ELECTROFISHING EVENTS (%)
(B) DEEP-BODIED SUCKERS
CUMULATIVE CAPTURE (%)
0
20
40
60
80
100
CUMULATIVE ELECTROFISHING EVENTS (%)
(C) ROUND-BODIED SUCKERS
CUMULATIVE CAPTURE (%)
0
20
40
60
80
100
CUMULATIVE ELECTROFISHING EVENTS (%)

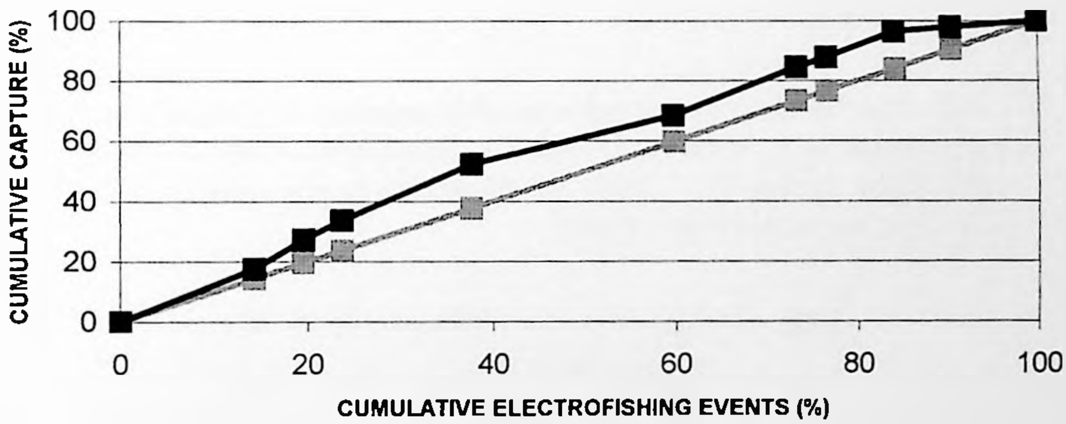
Fig. 9. Kolmogorov-Smirnov goodness of fit analysis of Ohio River sucker population data from electrofishing collections (1991 – 1998). (A) River carpsucker ($p < 0.05$) (B) Quillback carpsucker ($p < 0.05$) (C) Highfin carpsucker ($p < 0.05$)



(A) RIVER CARPSUCKER
Carpiodes carpio



(B) QUILLBACK CARPSUCKER
Carpiodes cyprinus



(C) HIGHFIN CARPSUCKER
Carpiodes velifer

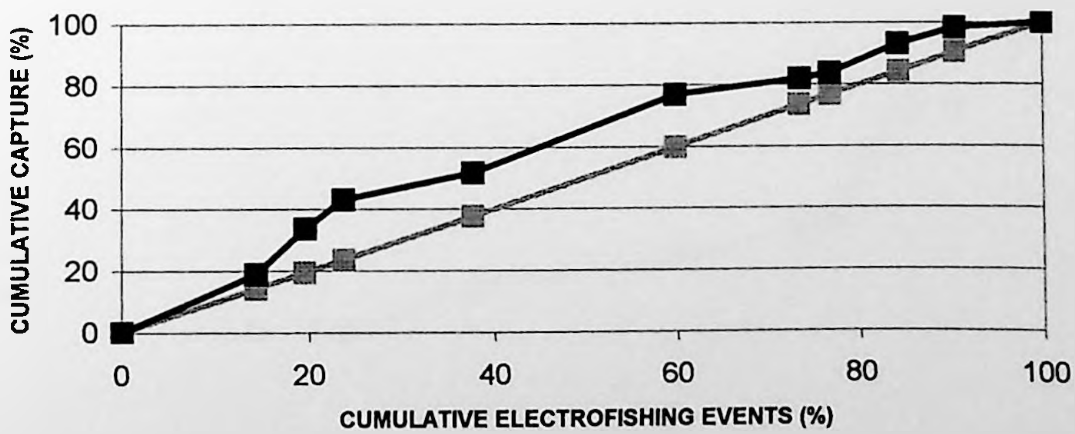
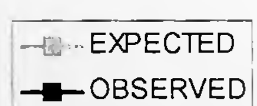
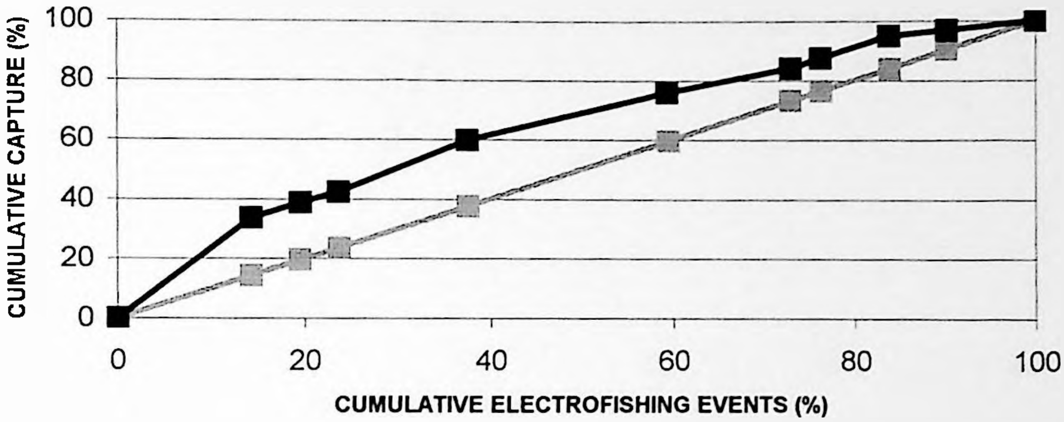


Fig. 10. Kolmogorov-Smirnov goodness of fit analysis of Ohio River sucker population data from electrofishing collections (1991 – 1998). (A) White sucker ($p < 0.05$) (B) Northern hog sucker ($p < 0.05$) (C) Spotted sucker ($p < 0.05$)



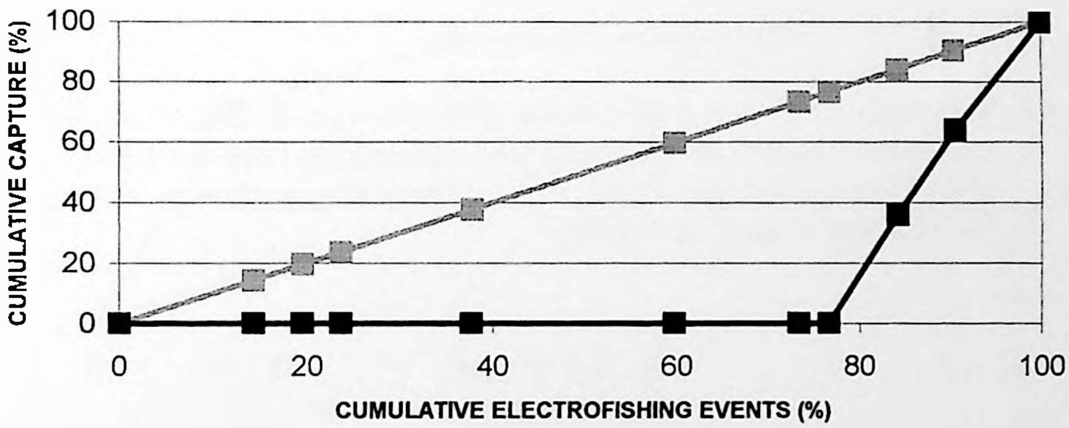
(A) SMALLMOUTH BUFFALO

Ictiobus bubalus



(B) BIGMOUTH BUFFALO

Ictiobus cyprinellus



(C) BLACK BUFFALO

Ictiobus niger

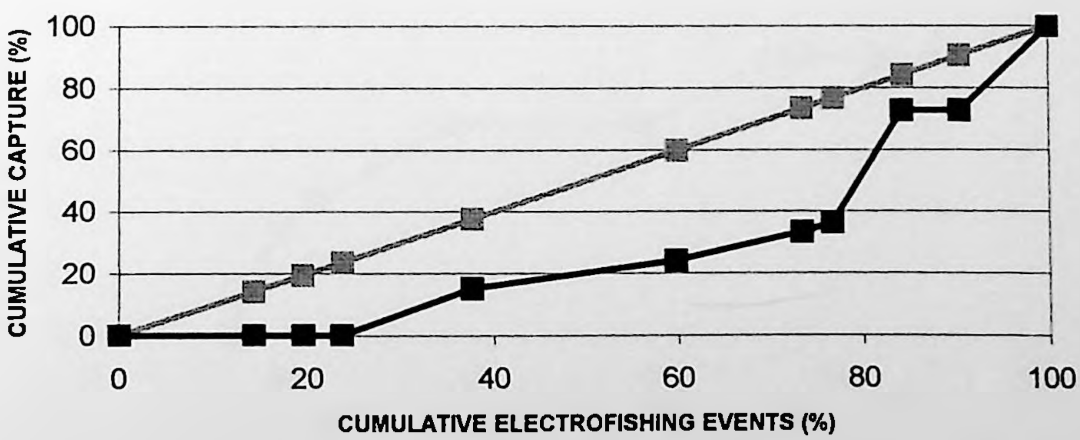
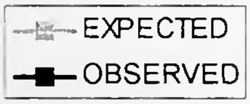
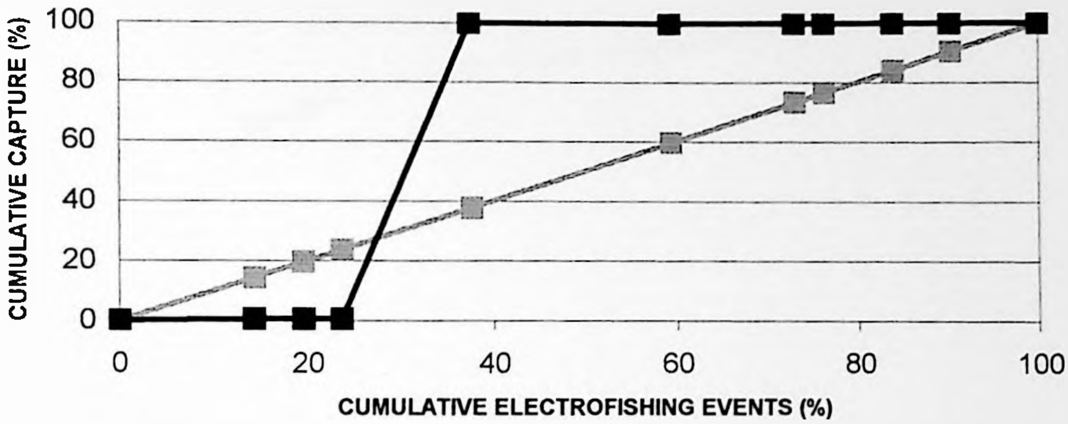


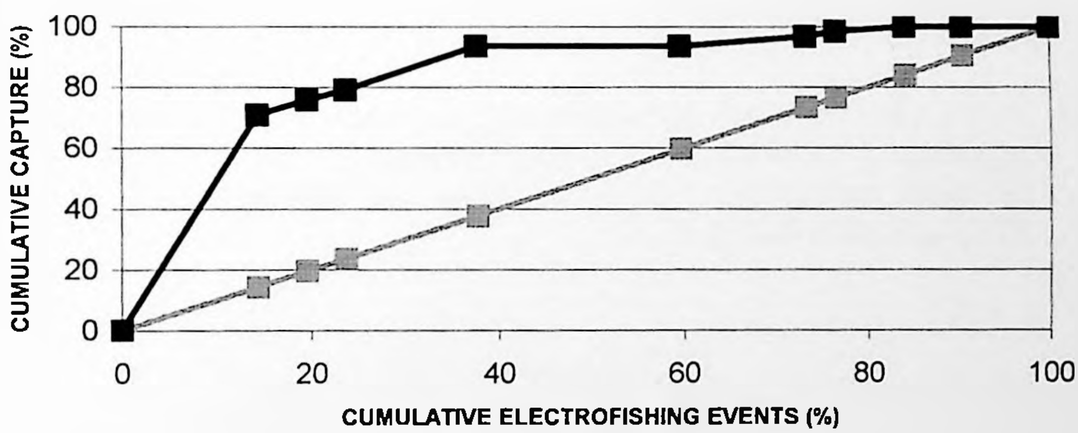
Fig. 11. Kolmogorov-Smirnov goodness of fit analysis of Ohio River sucker population data from electrofishing collections (1991 – 1998). (A) White sucker ($p < 0.05$) (B) Northern hog sucker ($p < 0.05$) (C) Spotted sucker ($p < 0.05$)



(A) WHITE SUCKER
Catostomus commersoni



(B) NORTHERN HOG SUCKER
Hypentelium nigricans



(C) SPOTTED SUCKER
Minytrema melanops

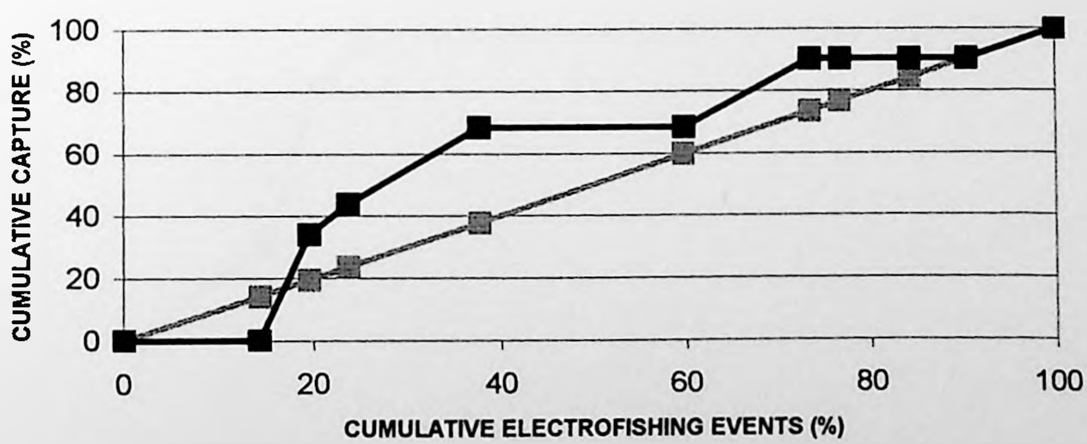
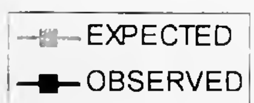
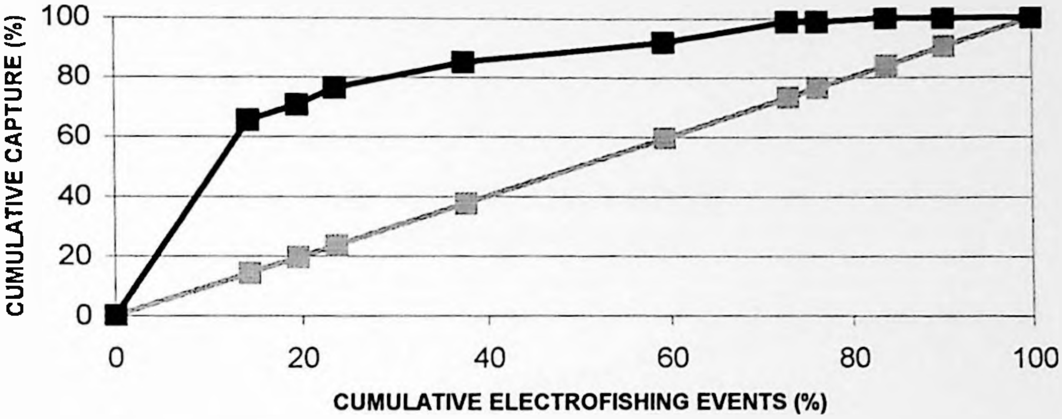


Fig. 12. Kolmogorov-Smirnov goodness of fit analysis of Ohio River sucker population data from electrofishing collections (1991 – 1998). (A) Silver redhorse ($p < 0.05$) (B) River redhorse ($p < 0.05$) (C) Black redhorse ($p < 0.05$)



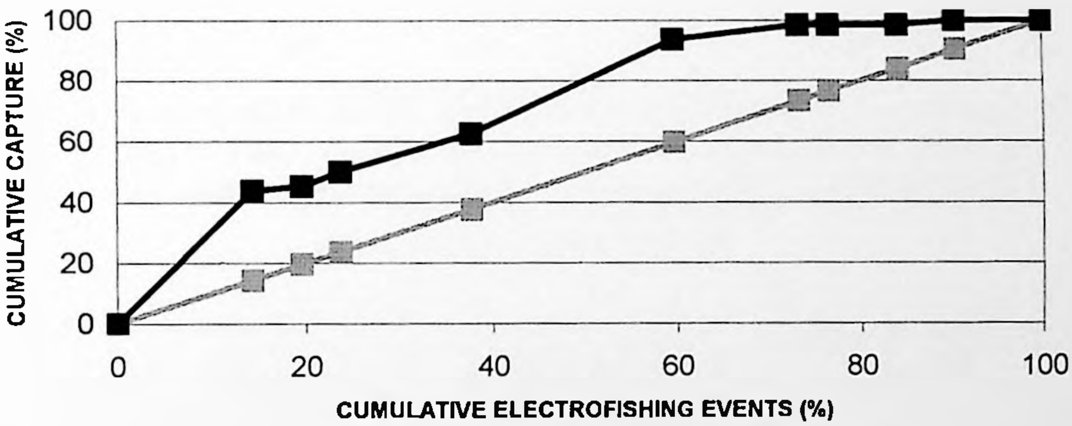
(A) SILVER REDHORSE

Moxostoma anisurum



(B) RIVER REDHORSE

Moxostoma carinatum



(C) BLACK REDHORSE

Moxostoma duquesnei

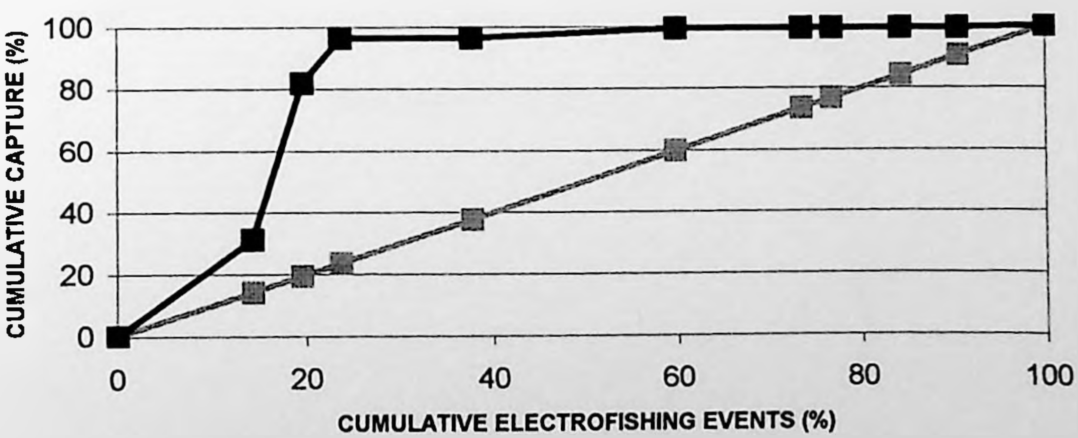
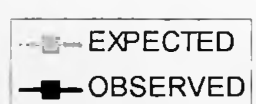
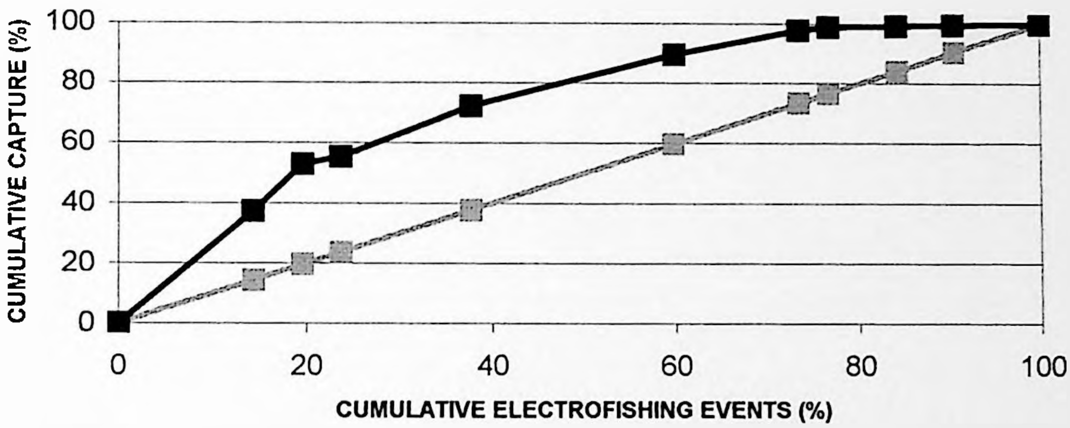


Fig. 13. Kolmogorov-Smirnov goodness of fit analysis of Ohio River sucker population data from electrofishing collections (1991 – 1998). (A) Golden redhorse ($p < 0.05$) (B) Shorthead redhorse ($p < 0.05$)



(A) GOLDEN REDHORSE
Moxostoma erythrurum



(B) SHORTHEAD REDHORSE
Moxostoma macrolepidotum

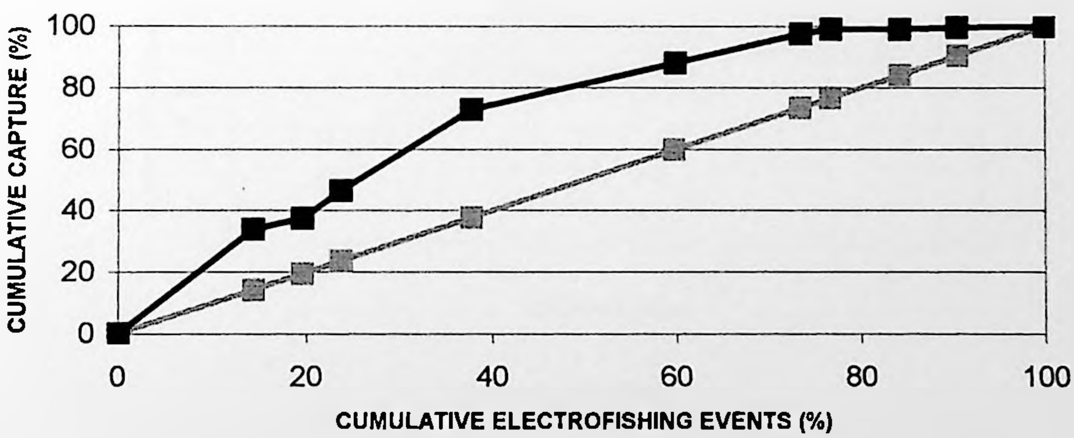
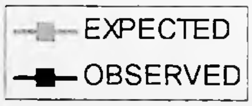
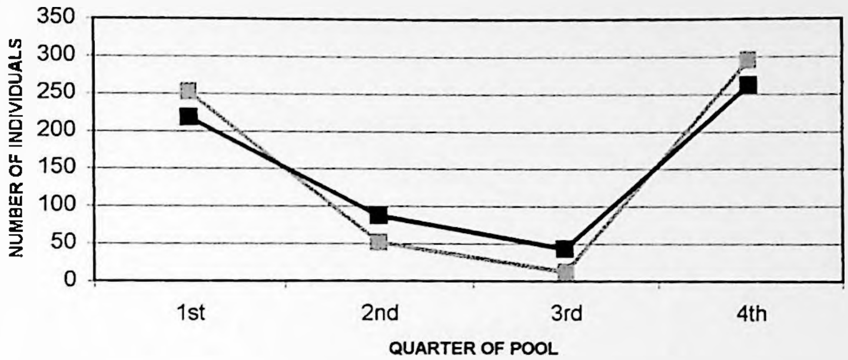


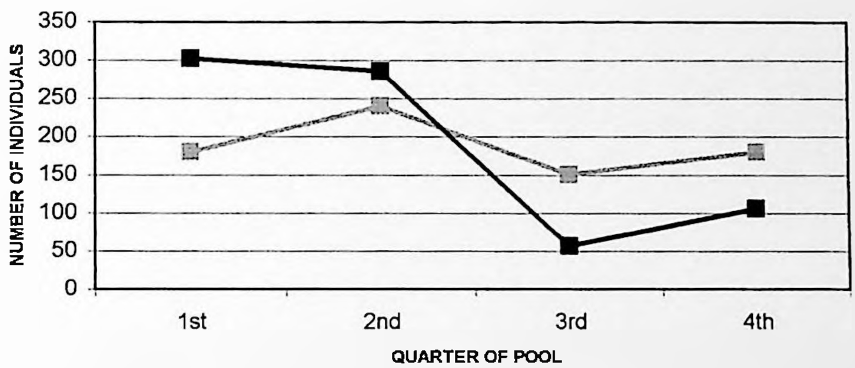
Fig. 14. Distribution of suckers in four upper Ohio river navigational pools. $X^2(3) = 7.81$, $p < 0.05$.



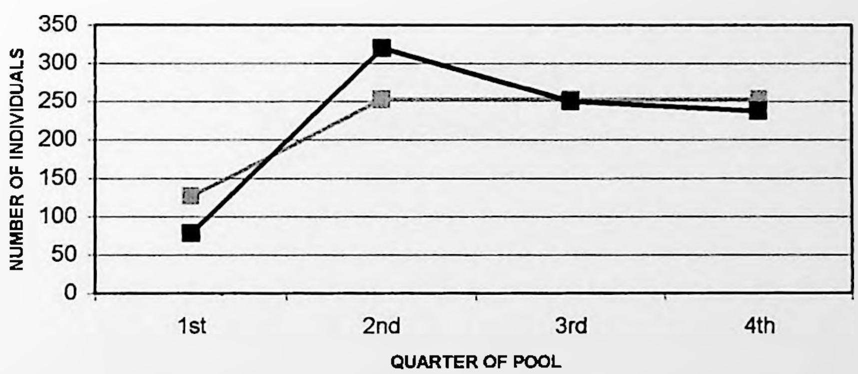
MONTGOMERY POOL



HANNIBAL POOL



GREENUP POOL



MARKLAND POOL

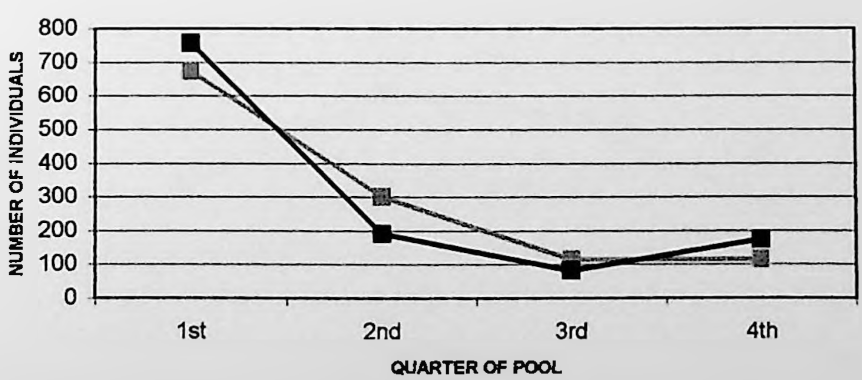
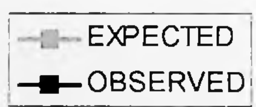
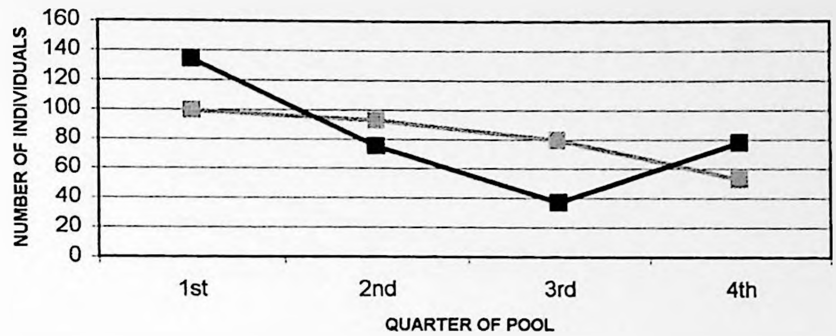


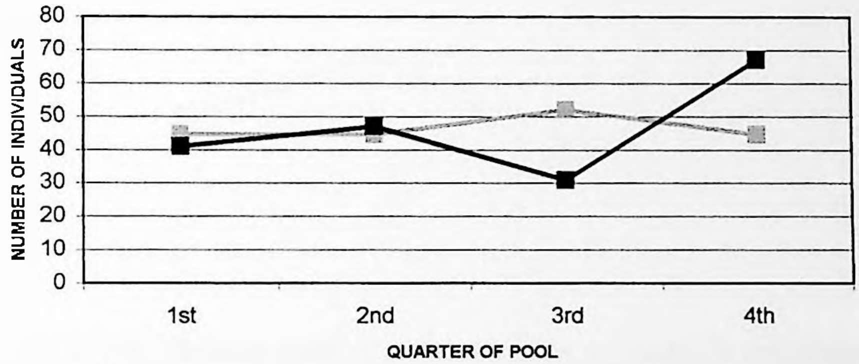
Fig. 15. Distribution of suckers in four lower Ohio river navigational pools. $X2(3) = 7.81$, $p < 0.005$.



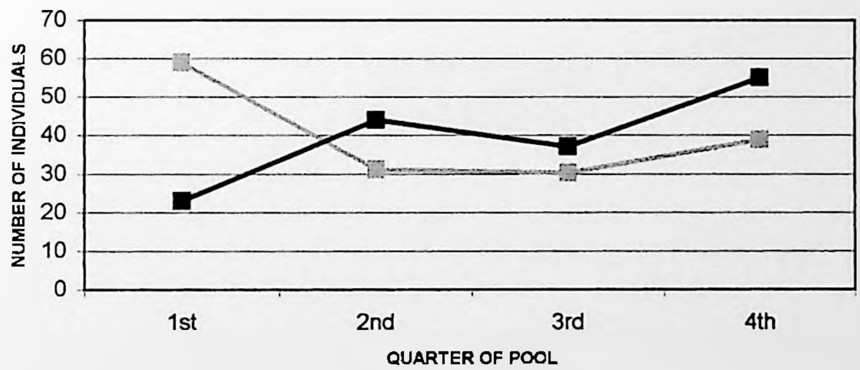
MCALPINE POOL



NEWBURGH POOL



SMITHLAND POOL



POOL 53

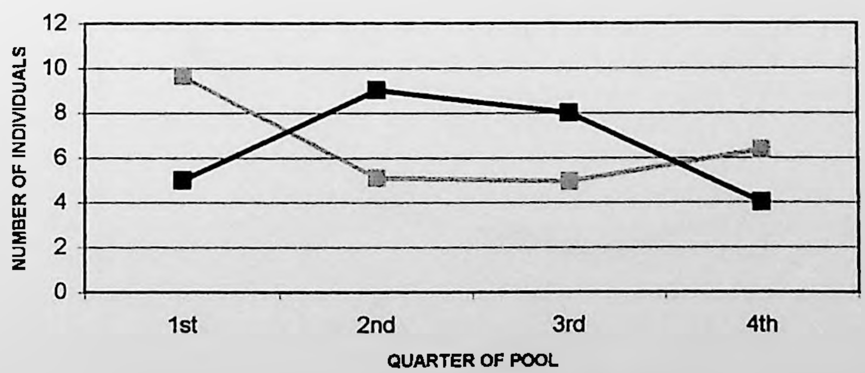
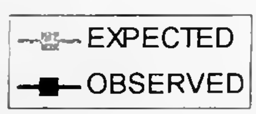
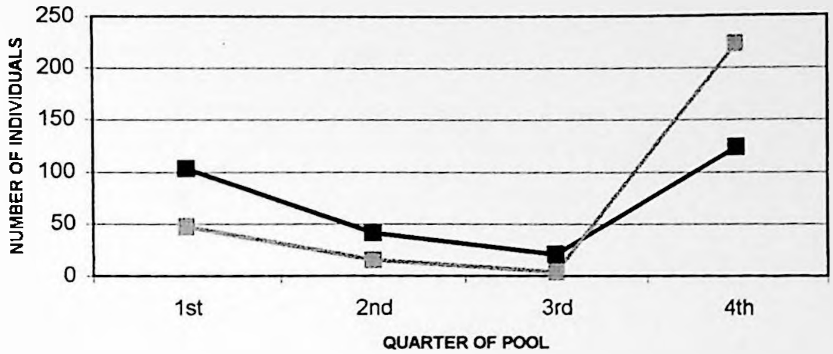


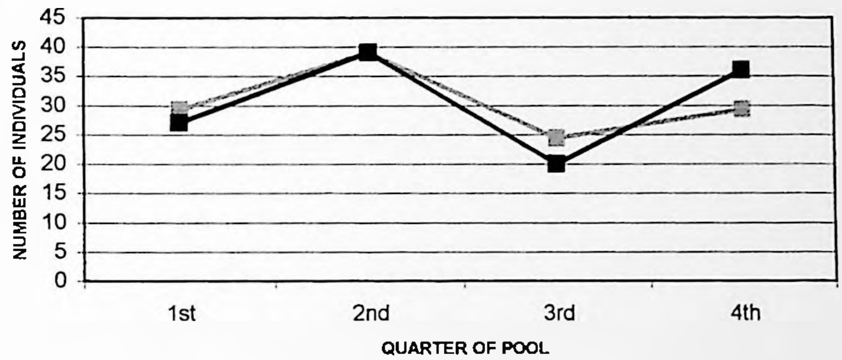
Fig. 16. Distribution of deep-bodied suckers in four upper Ohio River navigational pools. $X^2(3) = 7.81$, $p < 0.05$.



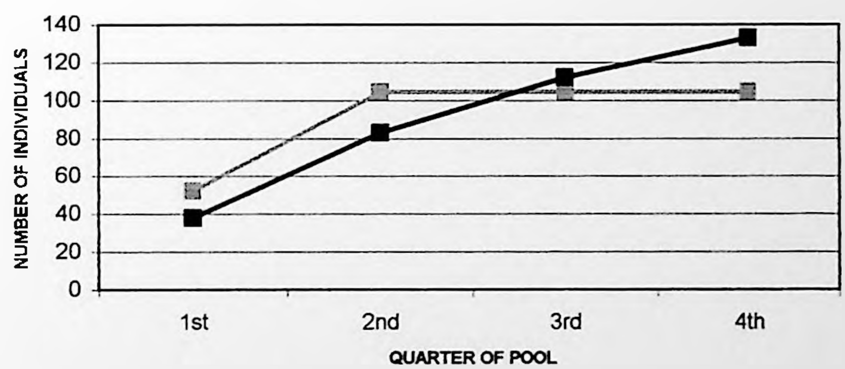
MONTGOMERY POOL



HANNIBAL POOL



GREENUP POOL



MARKLAND POOL

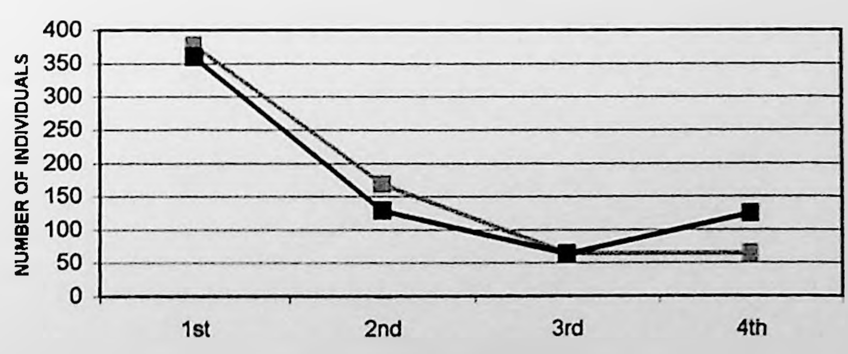
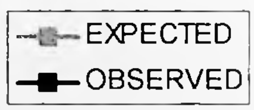
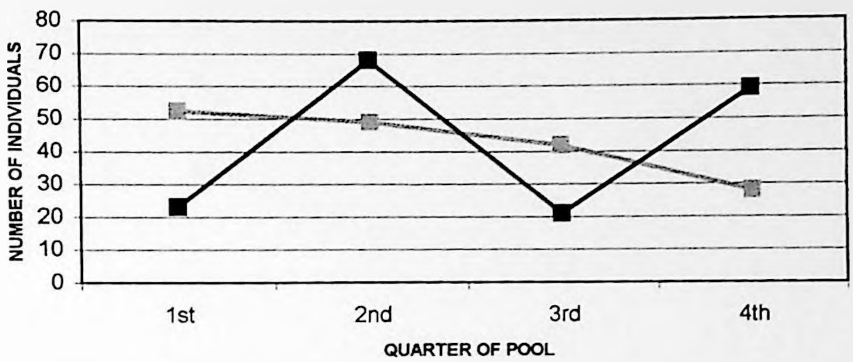


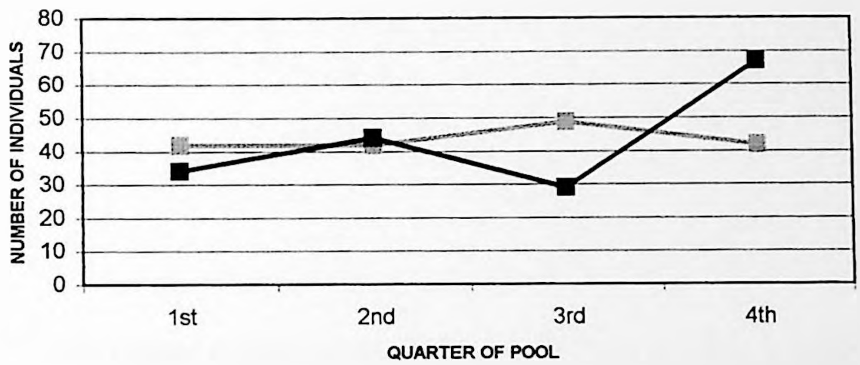
Fig. 17. Distribution of deep-bodied suckers in four lower Ohio River navigational pools. $X^2(3) = 7.81$, $p < 0.05$.



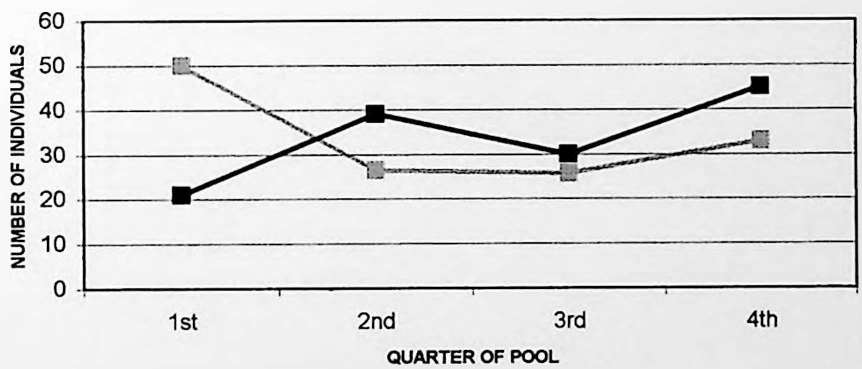
MCALPINE POOL



NEWBURGH POOL



SMITHLAND POOL



POOL 53

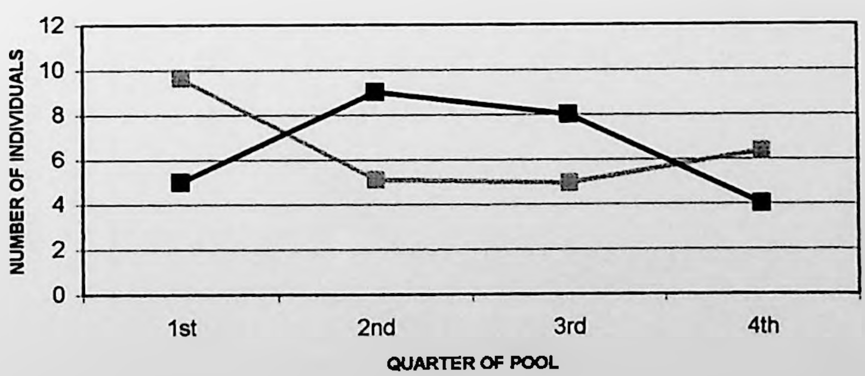
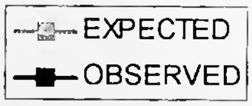
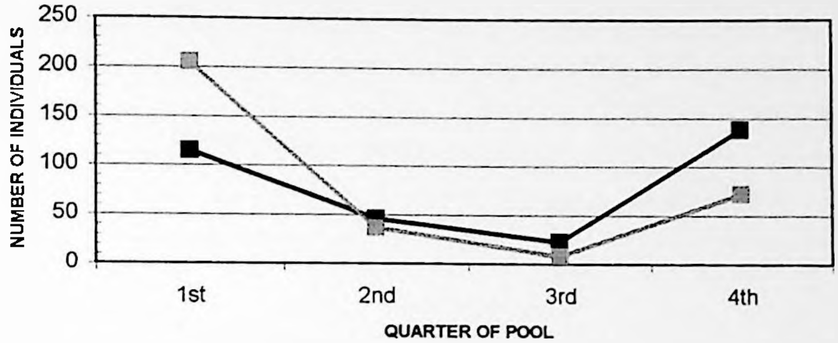


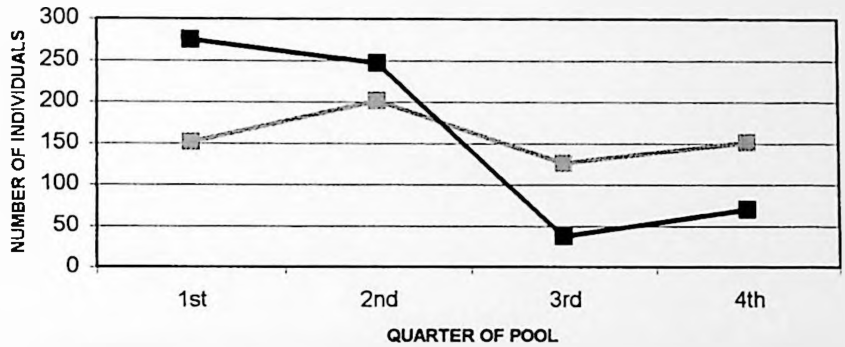
Fig. 18. Distribution of round-bodied suckers in four upper Ohio River navigational pools. $X^2(3) = 7.81$, $p < 0.05$.



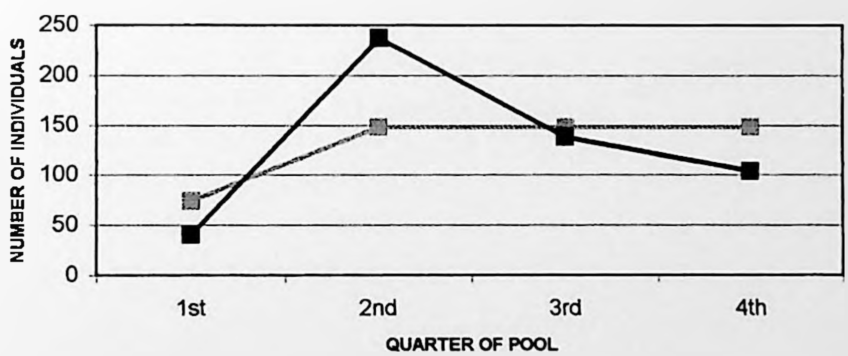
MONTGOMERY POOL



HANNIBAL POOL



GREENUP POOL



MARKLAND POOL

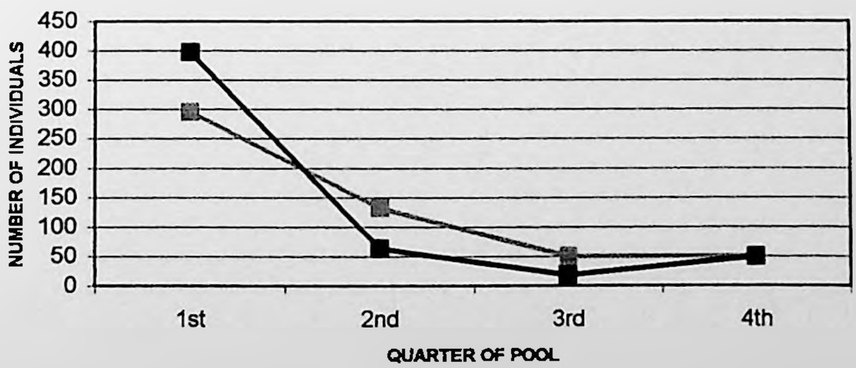
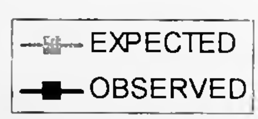
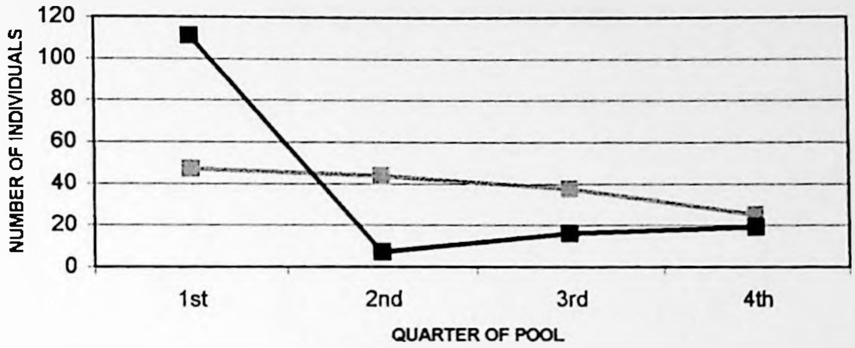


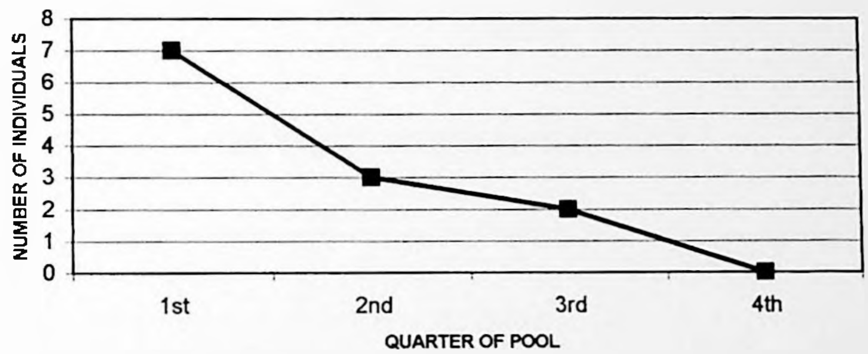
Fig. 19. Distribution of round-bodied suckers in four lower Ohio River navigational pools. $X^2(3) = 7.81$, $p < 0.05$.



MCALPINE POOL



NEWBURGH POOL



SMITHLAND POOL

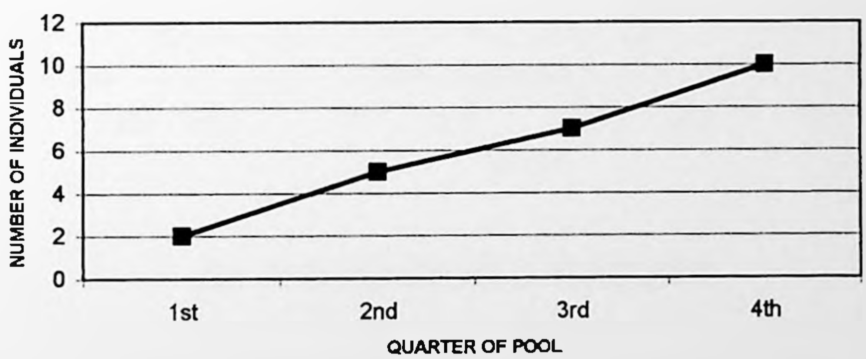
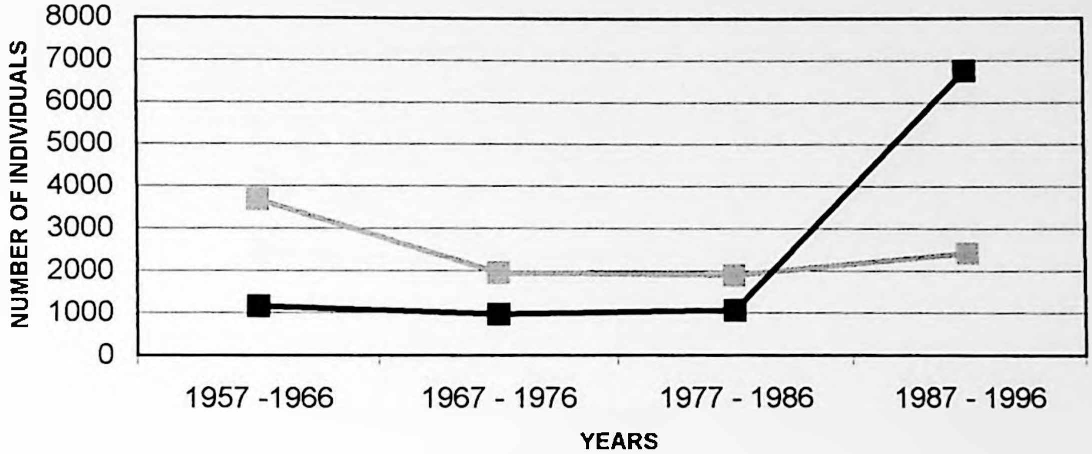
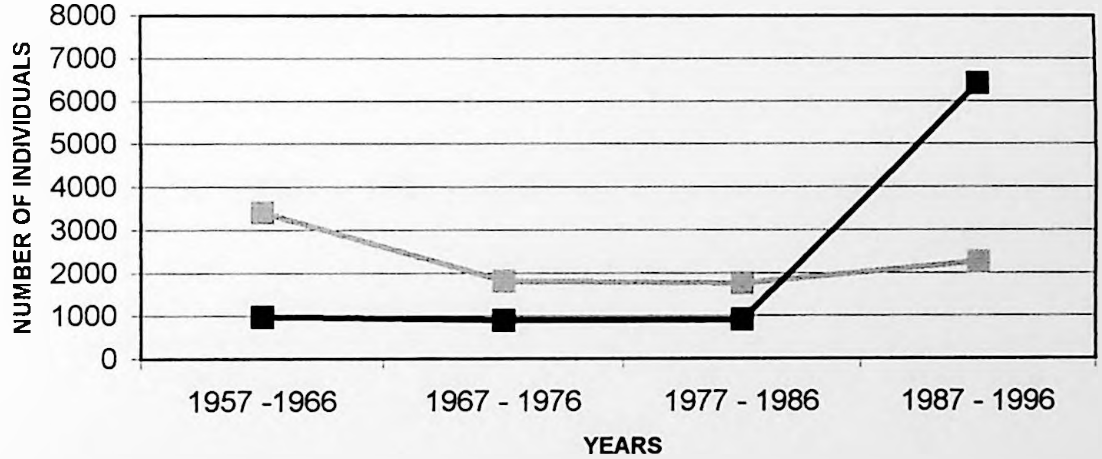


Fig. 20. Riverwide abundance of Ohio River suckers over a 40-year lock chamber study (1957 – 1996). $X^2(3) = 7.81$, $p < 0.05$

(A) TOTAL SUCKERS



(B) DEEP-BODIED SUCKERS



(C) ROUND-BODIED SUCKERS

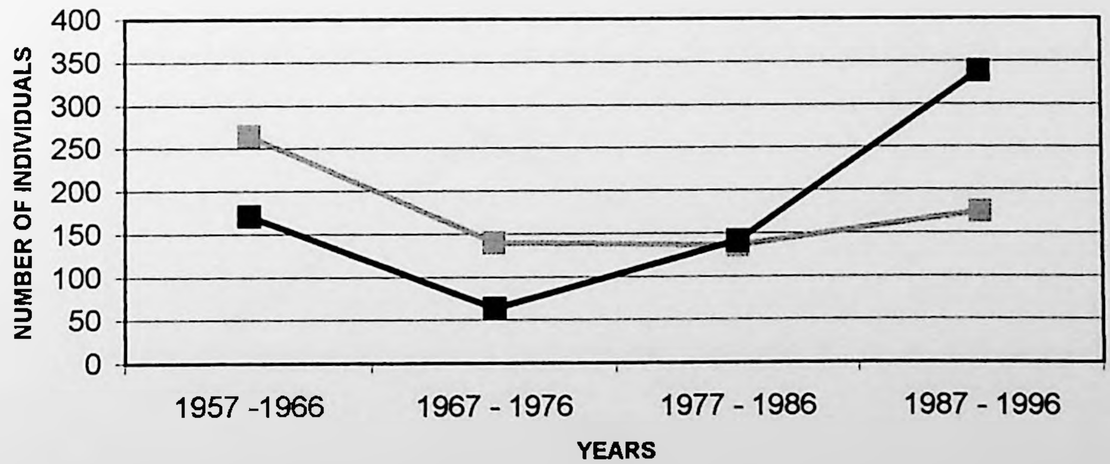
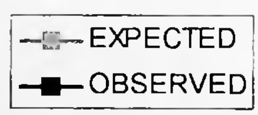
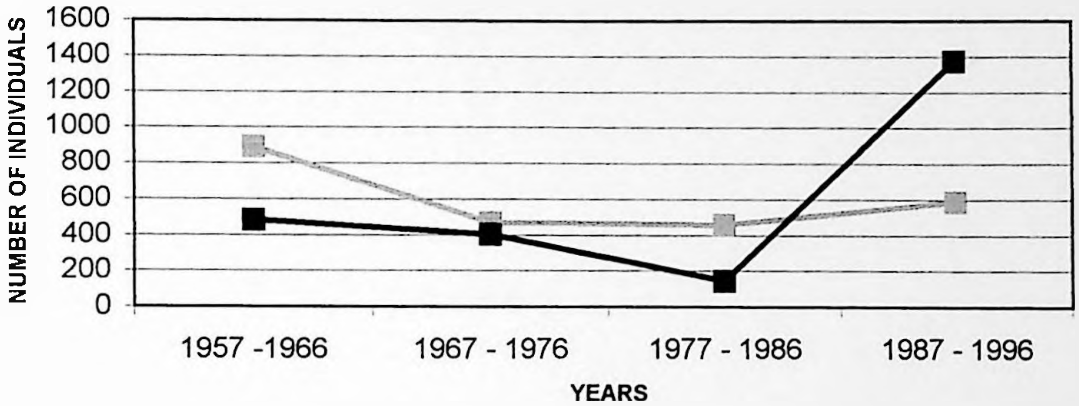


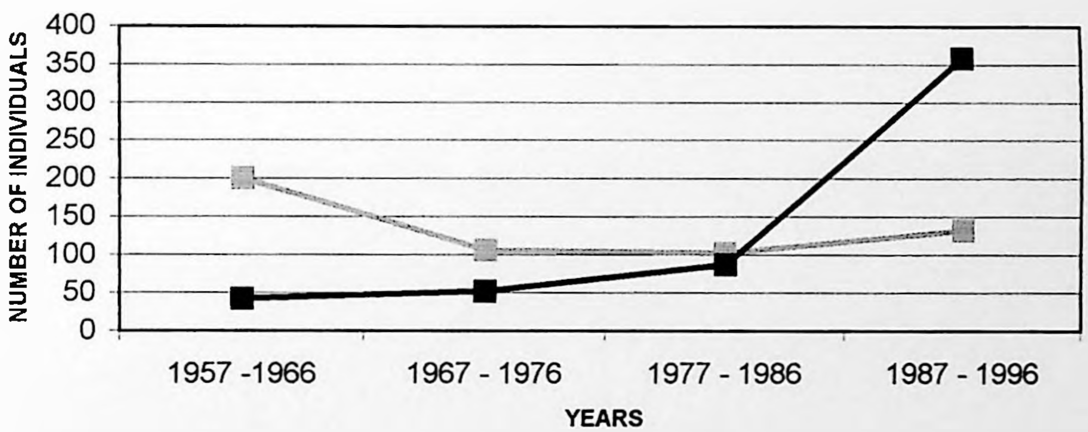
Fig. 21. Riverwide abundance of *Carpiodes* (1957 – 1996). $X^2(3) = 7.81$, $p < 0.05$



(A) RIVER CARPSUCKER
Carpiodes carpio



(B) QUILLBACK CARPSUCKER
Carpiodes cyprinus



(C) HIGHFIN CARPSUCKER
Carpiodes velifer

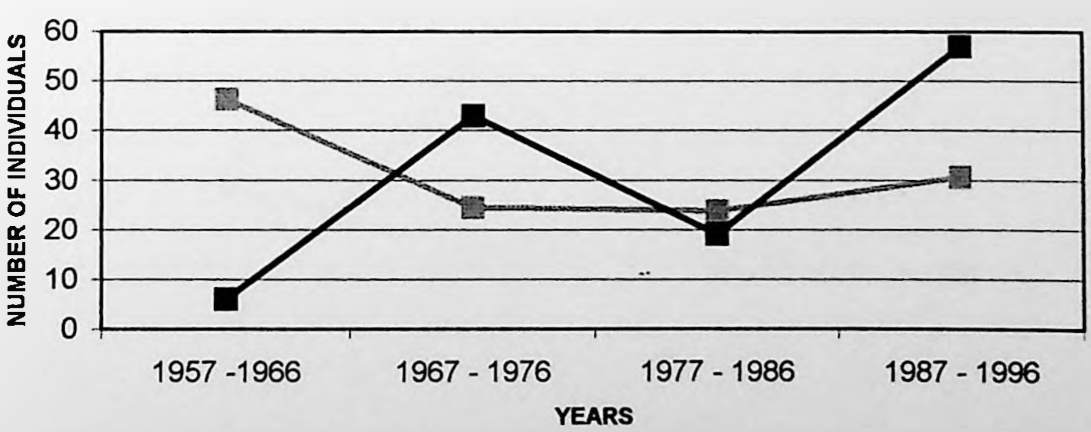
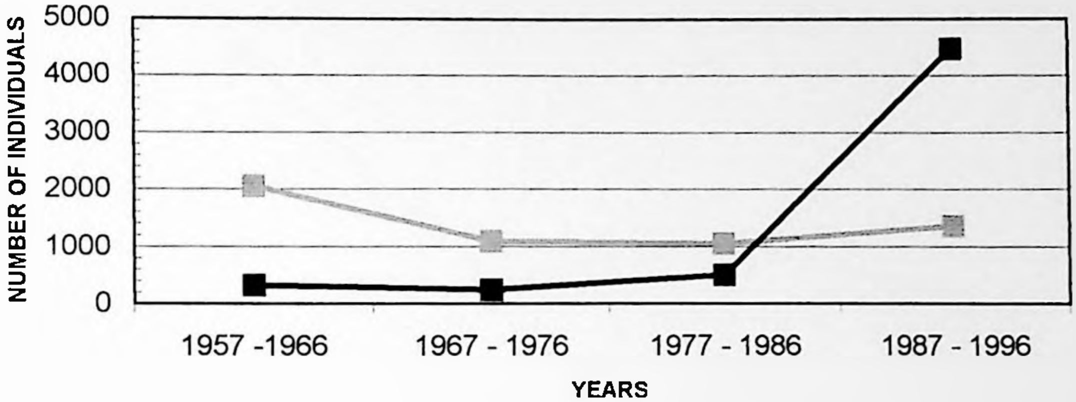


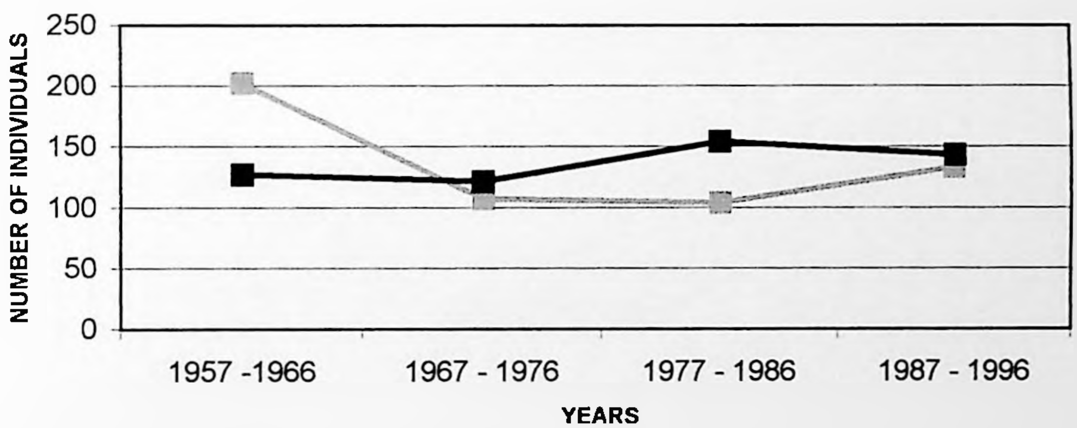
Fig. 22. Riverwide abundance of *Ictiobus* (1957 – 1996). $X^2(3) = 7.81, p < 0.05$

EXPECTED
OBSERVED

(A) SMALLMOUTH BUFFALO
Ictiobus bubalus



(B) BIGMOUTH BUFFALO
Ictiobus cyprinellus



(C) BLACK BUFFALO
Ictiobus niger

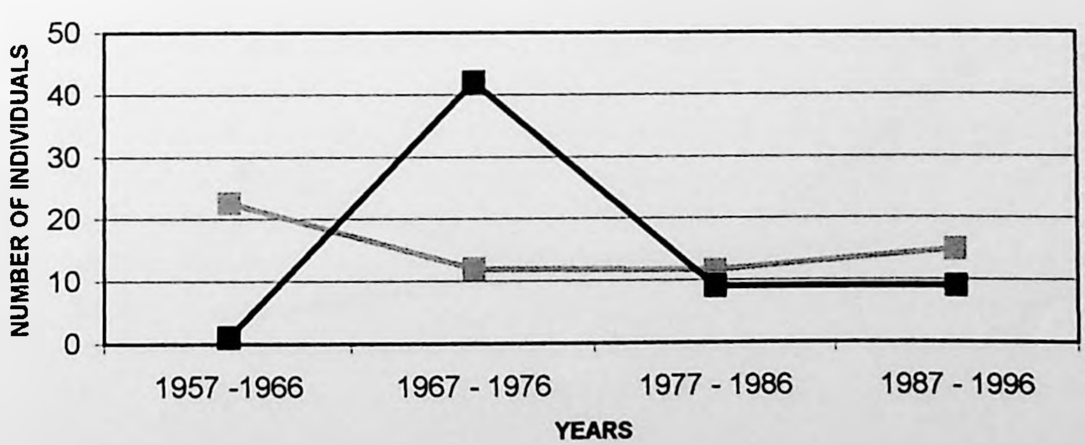
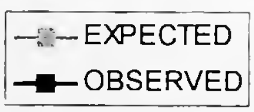
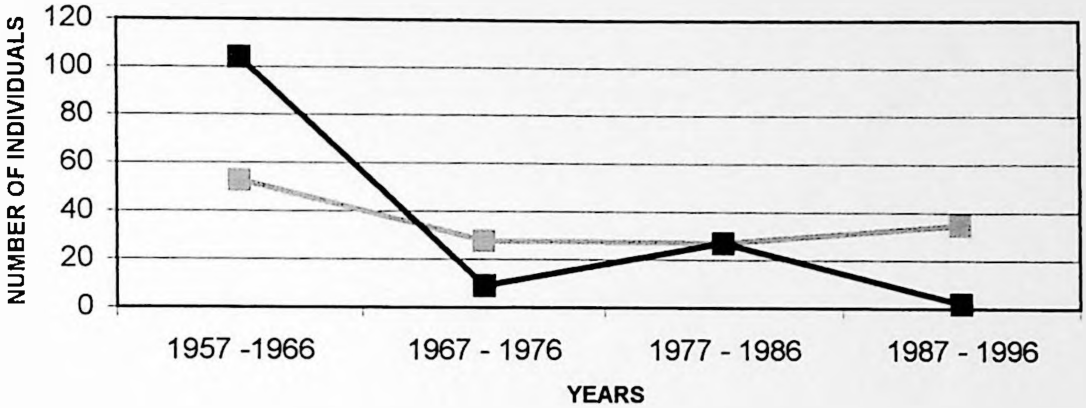


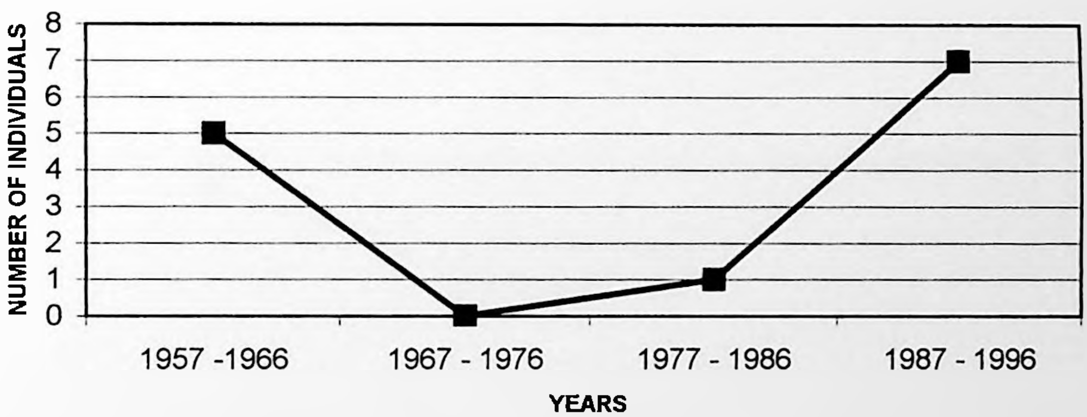
Fig. 23. Riverwide abundance of several suckers (1957 – 1996). $X^2(3) = 7.81$, $p < 0.05$



(A) WHITE SUCKER
Catostomus commersoni



(B) BLUE SUCKER
Cycleptus elongatus



(C) SPOTTED SUCKER
Minytrema melanops

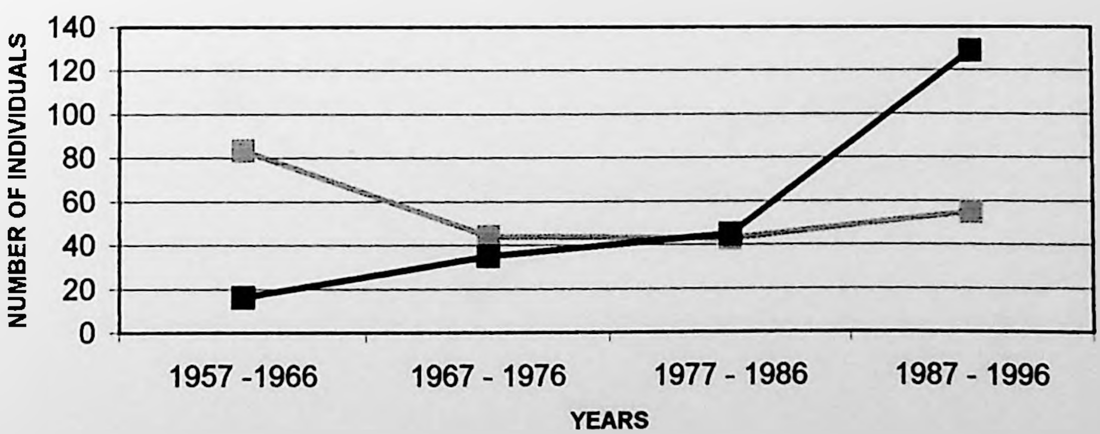
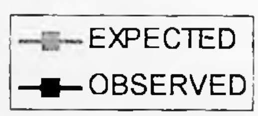


Fig. 24. Riverwide abundance of three redhorses (1957 – 1996). $X^2(3) = 7.81$, $p < 0.05$



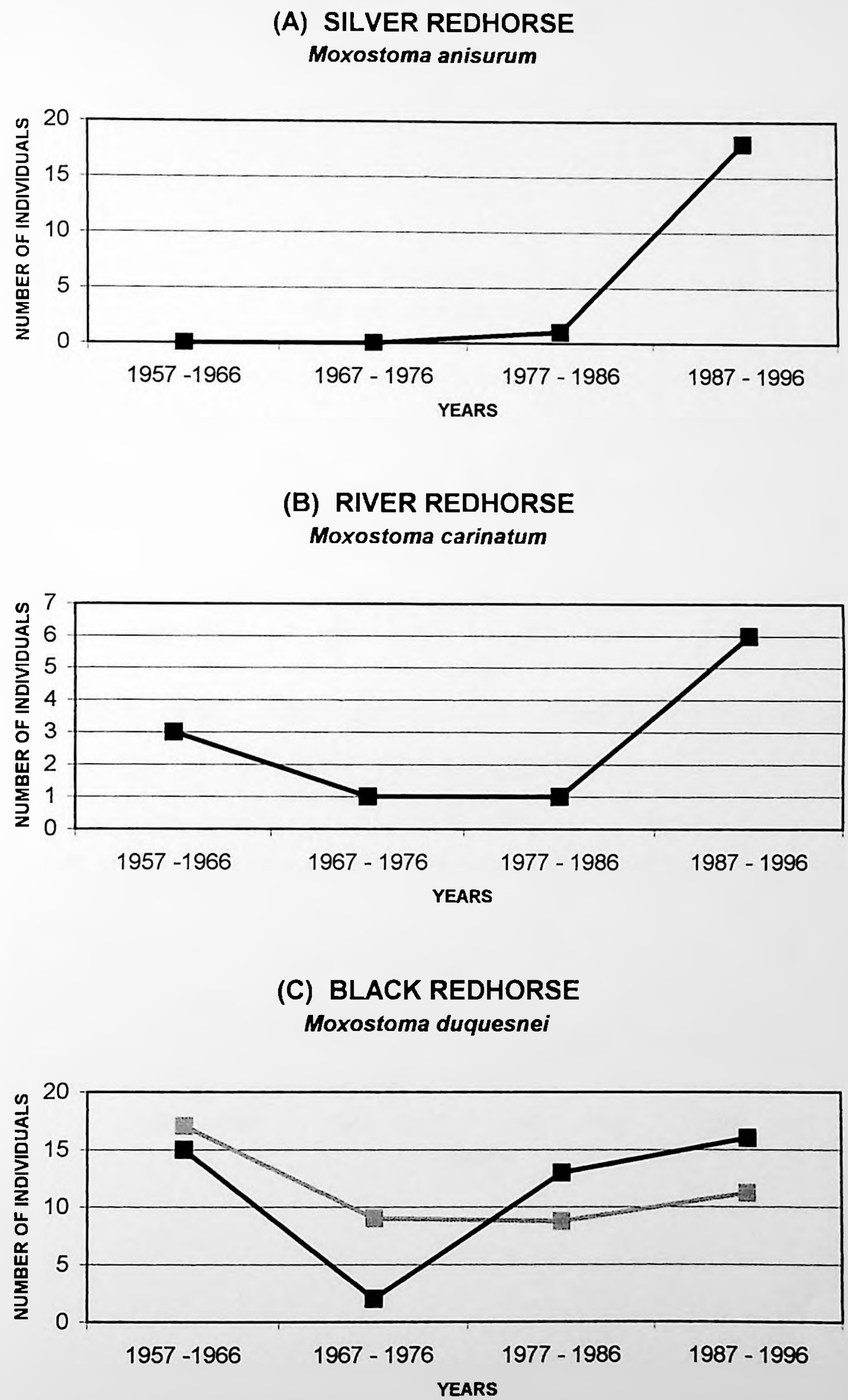
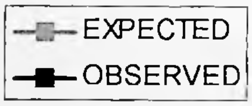
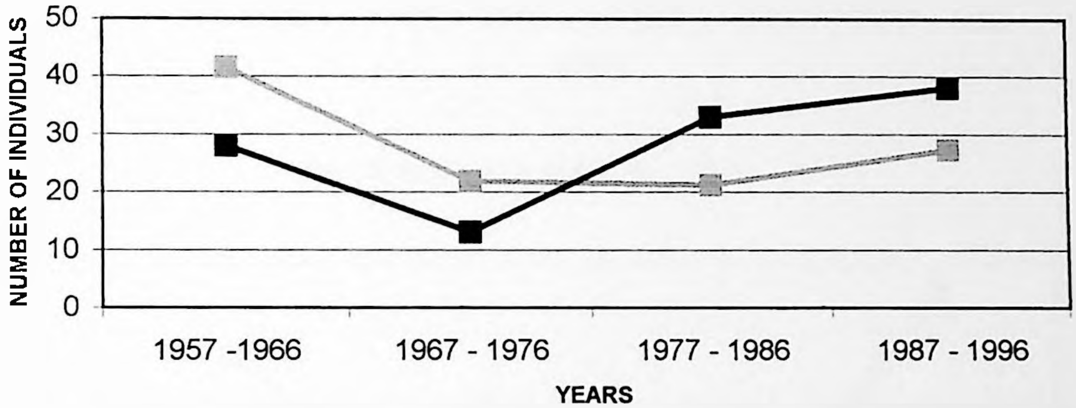

(A) SILVER REDHORSE
Moxostoma anisurum
NUMBER OF INDIVIDUALS
20
15
10
5
0
1957 -1966
1967 - 1976
1977 - 1986
1987 - 1996
YEARS
(B) RIVER REDHORSE
Moxostoma carinatum
NUMBER OF INDIVIDUALS
7
6
5
4
3
2
1
0
1957 -1966
1967 - 1976
1977 - 1986
1987 - 1996
YEARS
(C) BLACK REDHORSE
Moxostoma duquesnei
NUMBER OF INDIVIDUALS
20
15
10
5
0
1957 -1966
1967 - 1976
1977 - 1986
1987 - 1996
YEARS

Fig. 25. Riverwide abundance of two redhorses (1957 – 1996). $X^2(3) = 7.81$, $p < 0.05$



(A) GOLDEN REDHORSE
Moxostoma erythrurum



(B) SHORTHEAD REDHORSE
Moxostoma macrolepidotum

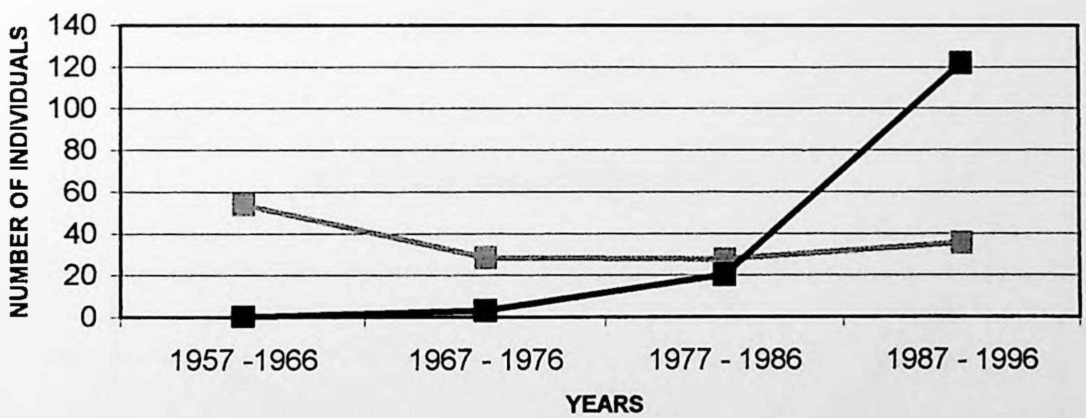
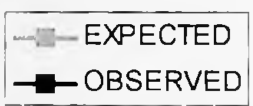
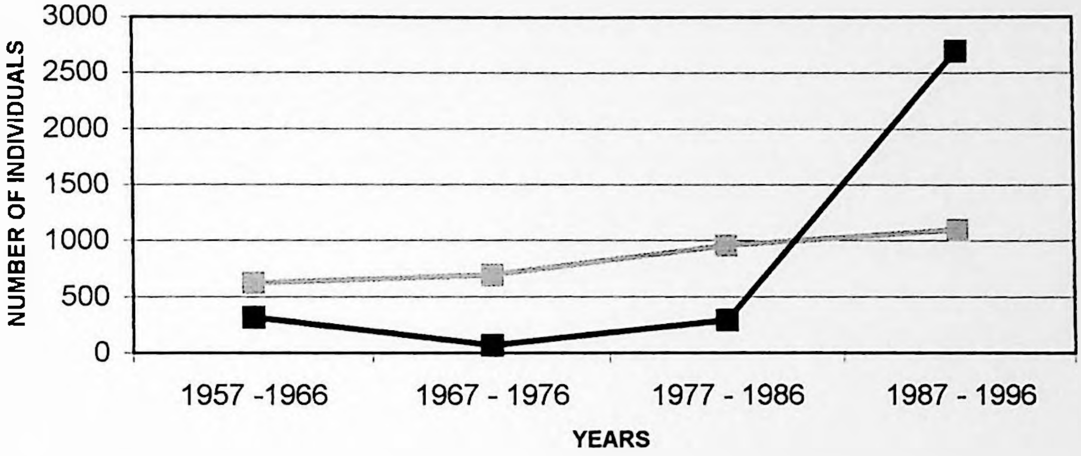


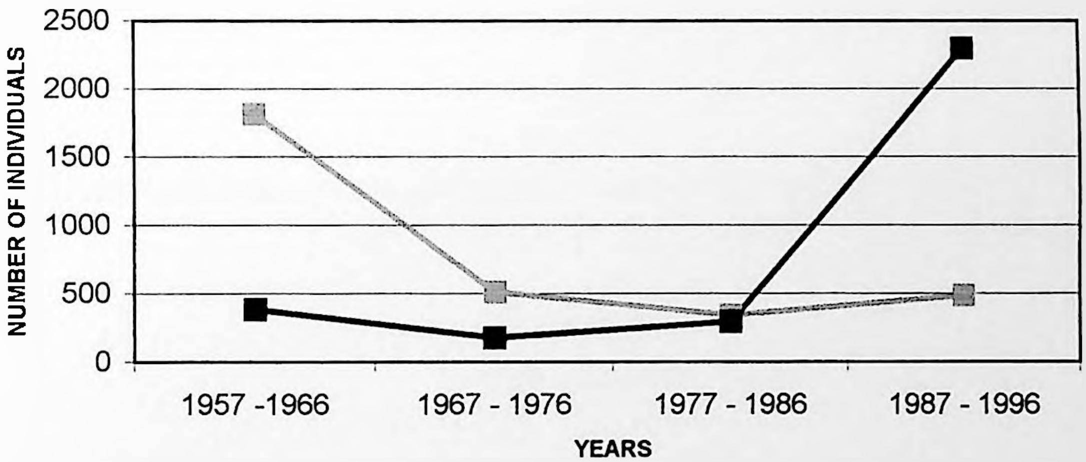
Fig. 26. Longitudinal temporal trends for suckers over a 40-year lock chamber study (1957 – 1996) ($X^2(3) = 7.81$, $p < 0.05$)



(A) RIVER MILES 0 - 327



(B) RIVER MILES 327 - 654



(C) RIVER MILES 654 - 981

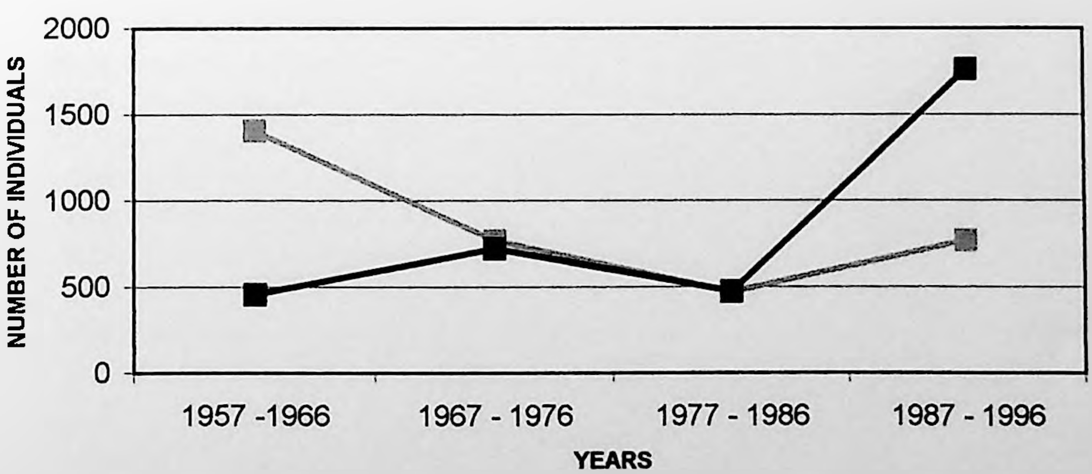
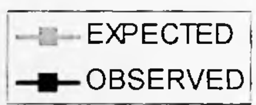
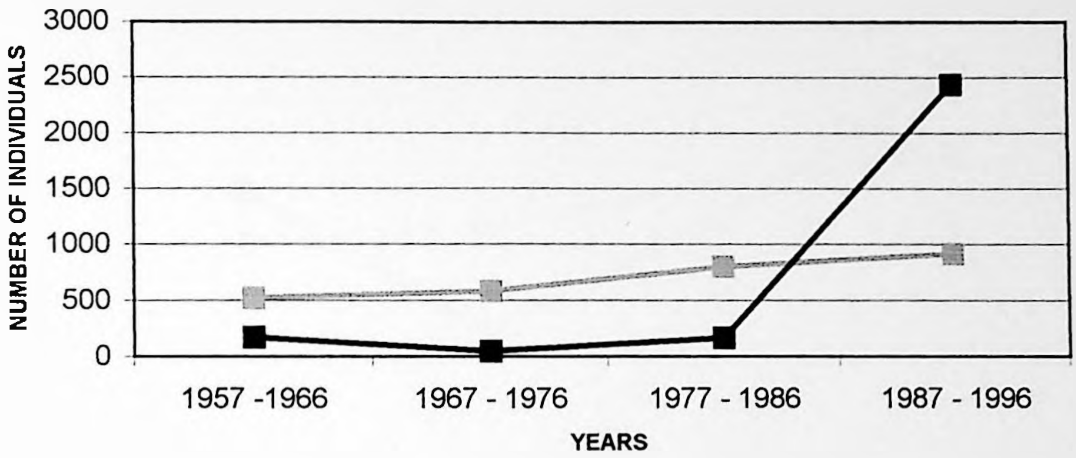


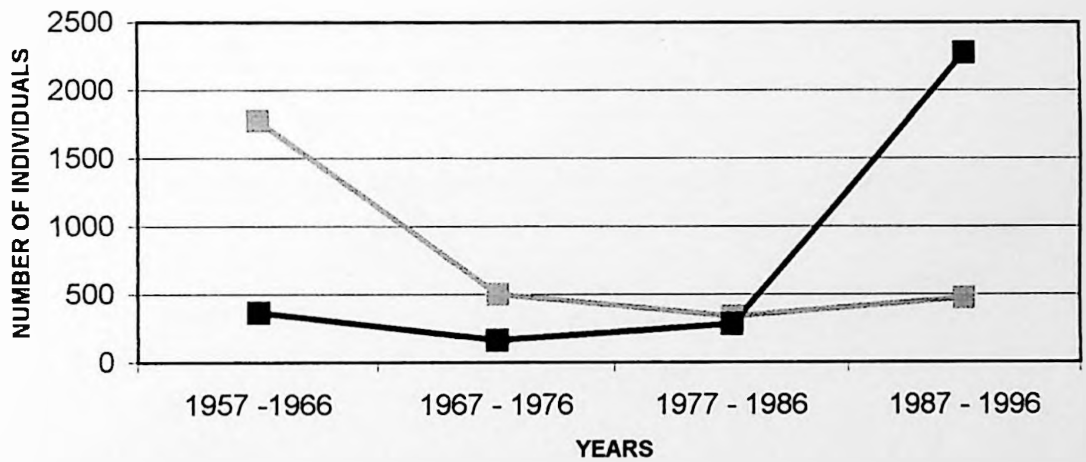
Fig. 27. Longitudinal temporal trends for deep-bodied suckers (lock chamber study: 1957 – 1996). $X^2(3) = 7.81$, $p < 0.05$



(A) RIVER MILES 0 - 327



(B) RIVER MILES 327 - 654



(C) RIVER MILES 654 - 981

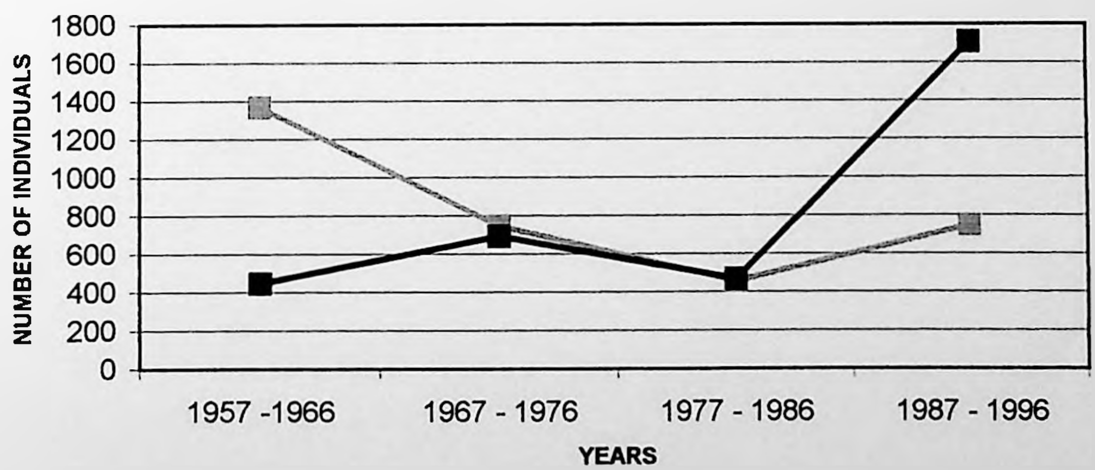
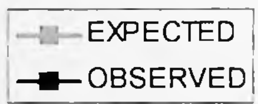
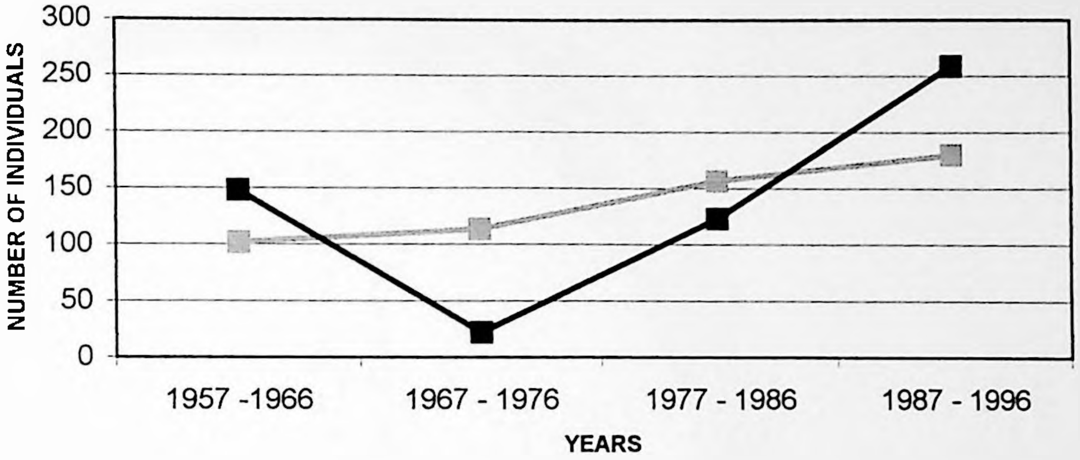


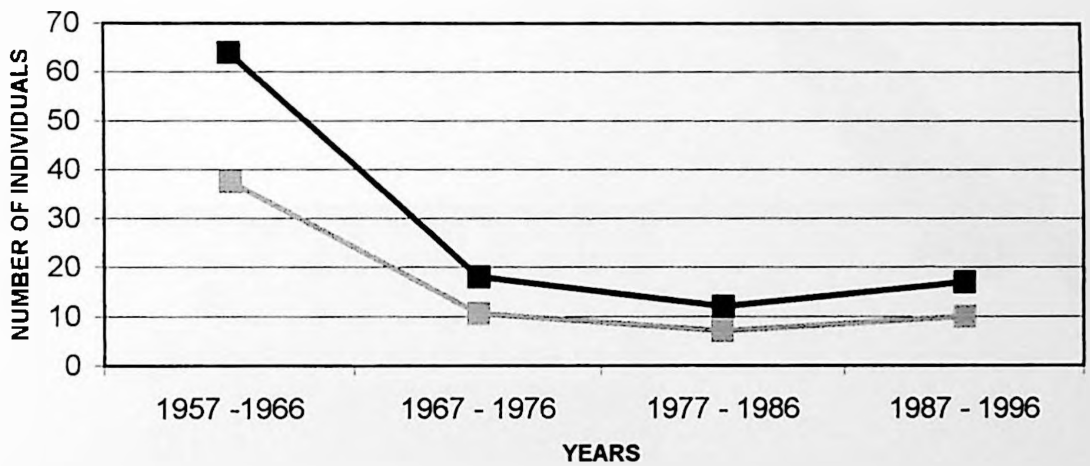
Fig. 28. Longitudinal temporal trends for round-bodied suckers (lock chamber study: 1957 – 1996). $X^2(3) = 7.81$, $p < 0.05$



(A) RIVER MILES 0 - 327



(B) RIVER MILES 327 - 654



(C) RIVER MILES 654 - 981

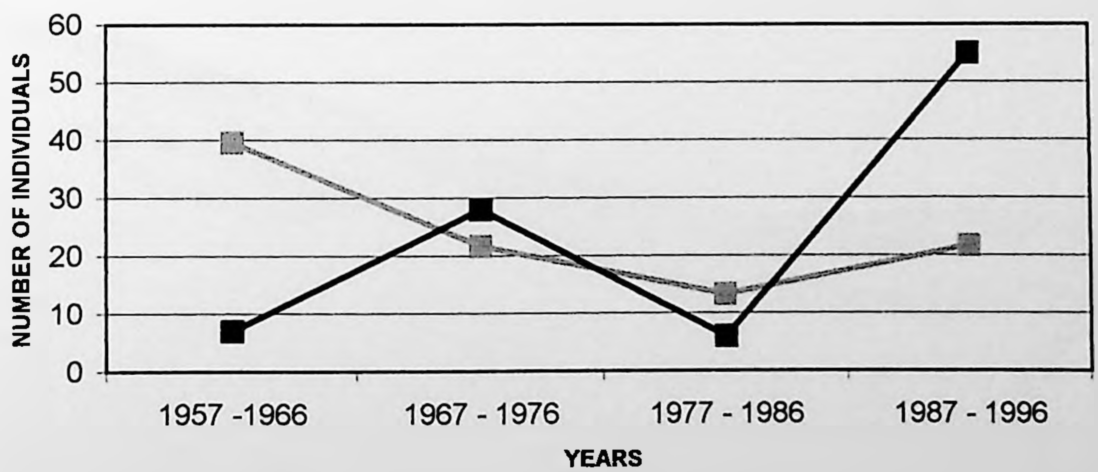


Fig. 29. Silt substrate characterization of two sections from Hannibal Pool in the Ohio River.

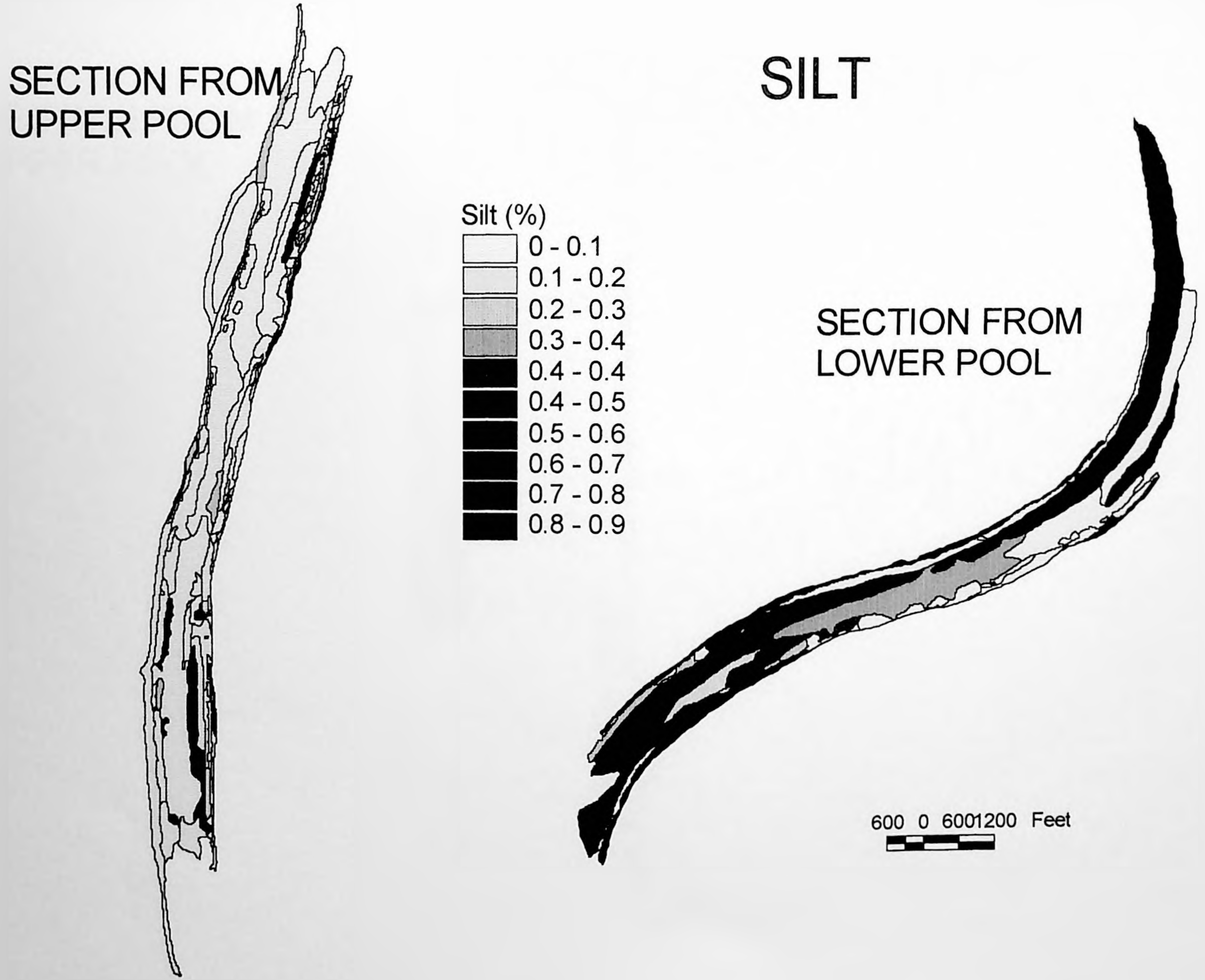

SILT
SECTION FROM UPPER POOL
Silt (%)
0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
SECTION FROM LOWER POOL
600 0 6001200 Feet

Fig. 30. Sand/gravel substrate characterization of two sections from Hannibal Pool in the Ohio River.

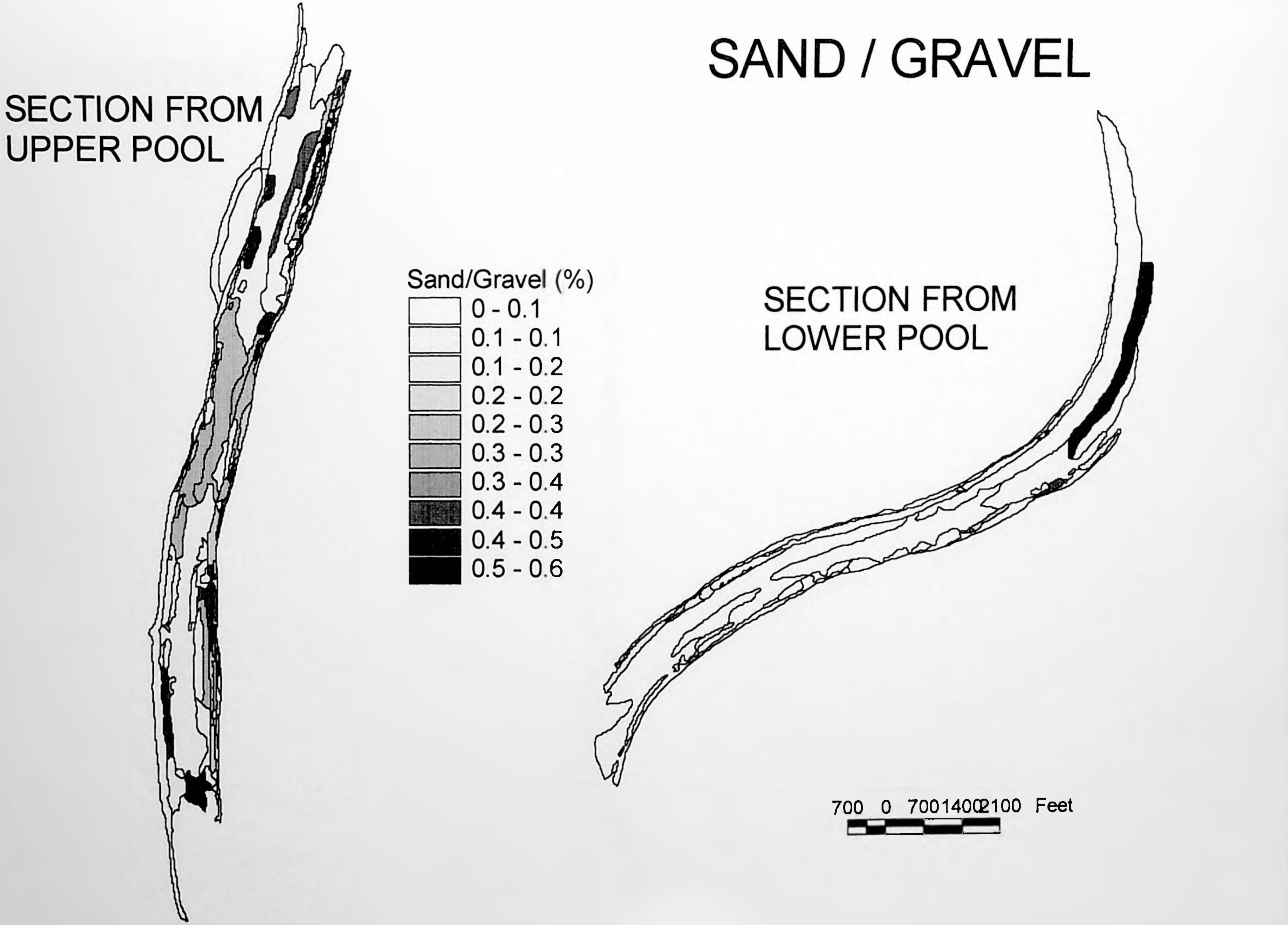

SAND / GRAVEL
SECTION FROM
UPPER POOL
SECTION FROM
LOWER POOL
Sand/Gravel (%)
0 - 0.1
0.1 - 0.1
0.1 - 0.2
0.2 - 0.2
0.2 - 0.3
0.3 - 0.3
0.3 - 0.4
0.4 - 0.4
0.4 - 0.5
0.5 - 0.6
700 0 700 1400 2100 Feet

Fig. 31. Gravel/cobble substrate characterization of two sections from Hannibal Pool in the Ohio River.

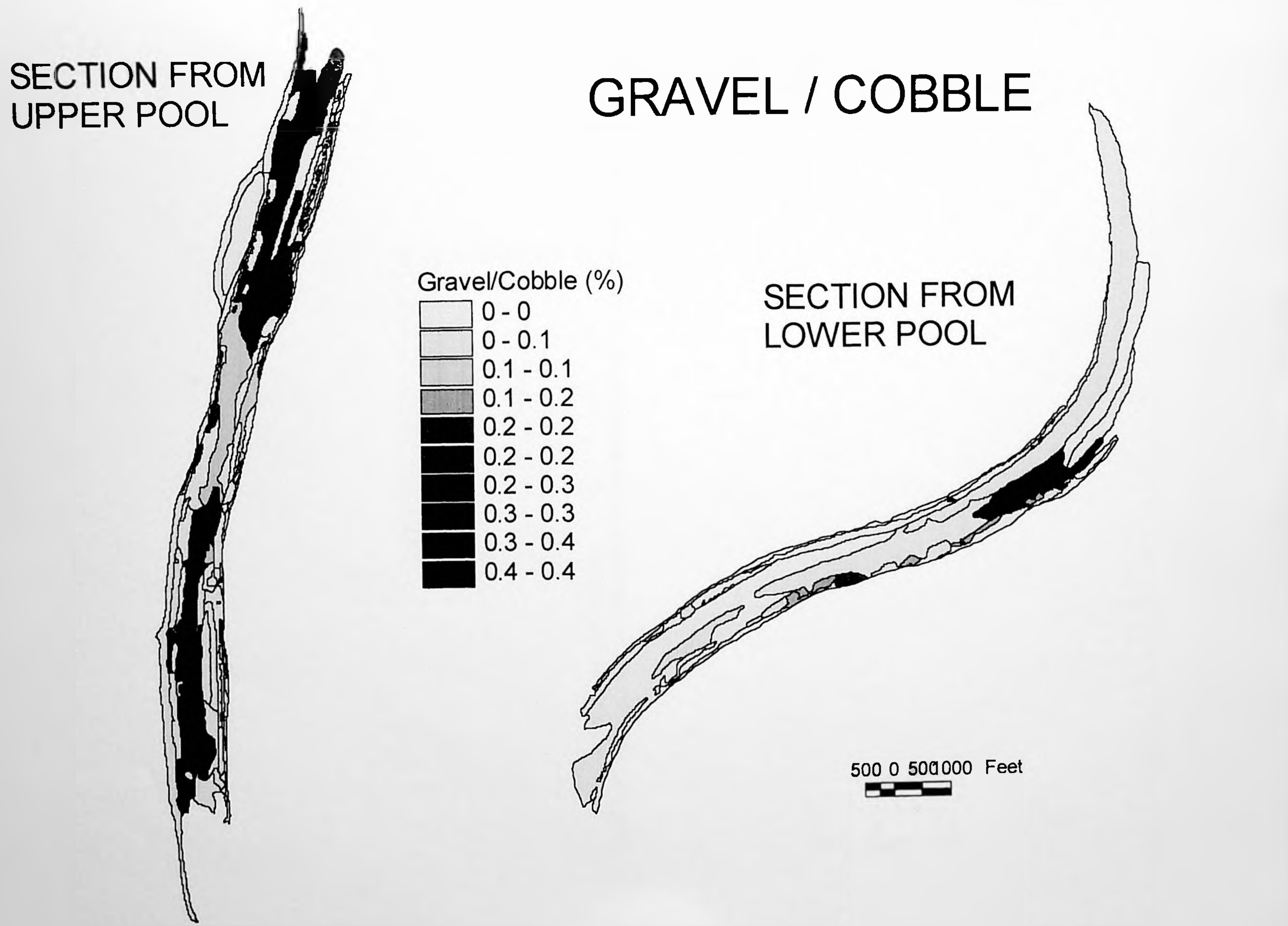

GRAVEL / COBBLE
SECTION FROM UPPER POOL
SECTION FROM LOWER POOL
Gravel/Cobble (%)
0 - 0
0 - 0.1
0.1 - 0.1
0.1 - 0.2
0.2 - 0.2
0.2 - 0.2
0.2 - 0.3
0.3 - 0.3
0.3 - 0.4
0.4 - 0.4
500 0 5001000 Feet

Fig. 32. Cobble/boulder substrate characterization of two sections from Hannibal Pool in the Ohio River.

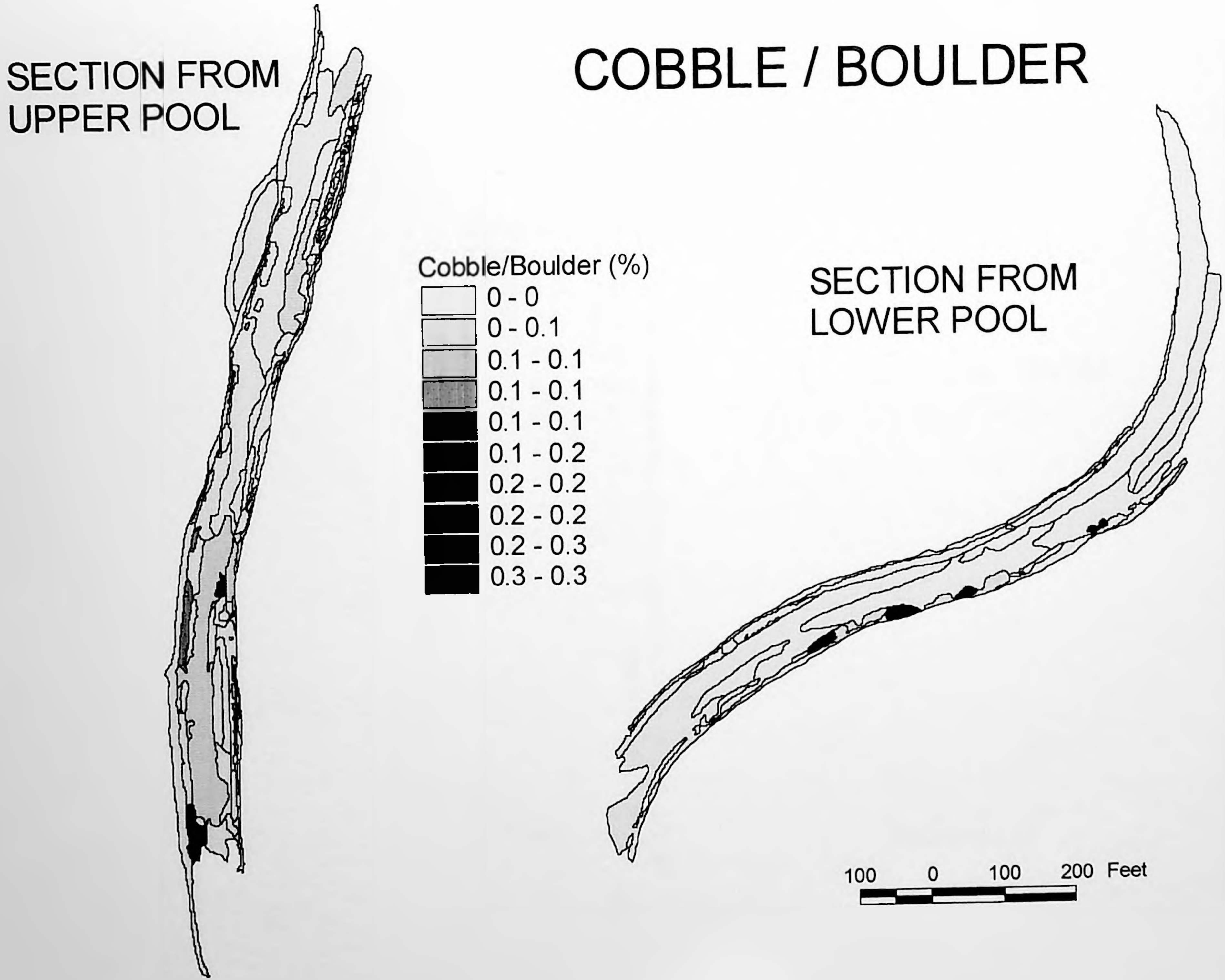
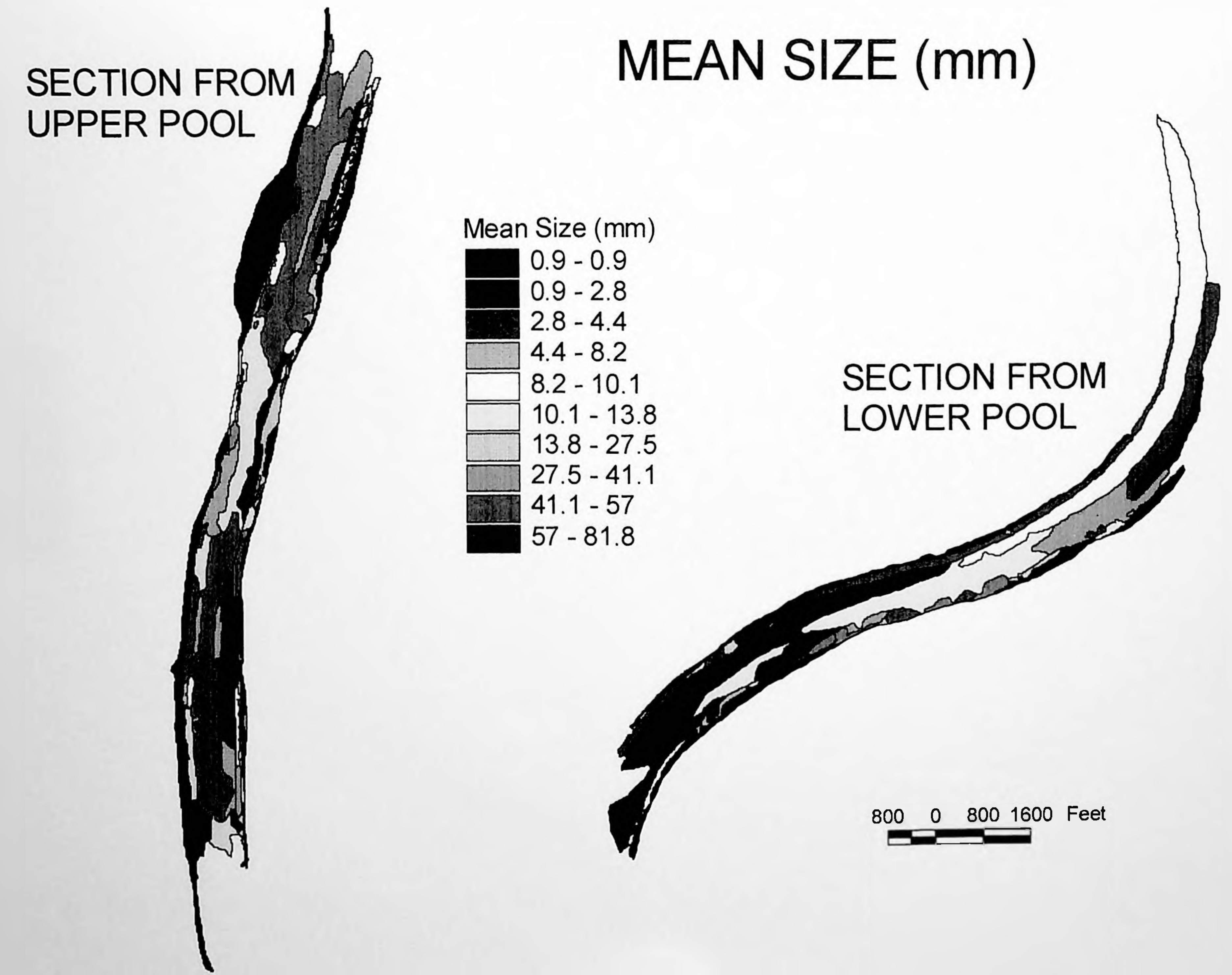

COBBLE / BOULDER
SECTION FROM UPPER POOL
SECTION FROM LOWER POOL
Cobble/Boulder (%)
0 - 0
0 - 0.1
0.1 - 0.1
0.1 - 0.1
0.1 - 0.1
0.1 - 0.2
0.2 - 0.2
0.2 - 0.2
0.2 - 0.3
0.3 - 0.3
100 0 100 200 Feet

Fig. 33. Mean size of substrate particles of two sections from Hannibal Pool in the Ohio River.


MEAN SIZE (mm)
SECTION FROM
UPPER POOL
Mean Size (mm)
0.9 - 0.9
0.9 - 2.8
2.8 - 4.4
4.4 - 8.2
8.2 - 10.1
10.1 - 13.8
13.8 - 27.5
27.5 - 41.1
41.1 - 57
57 - 81.8
SECTION FROM
LOWER POOL
800 0 800 1600 Feet