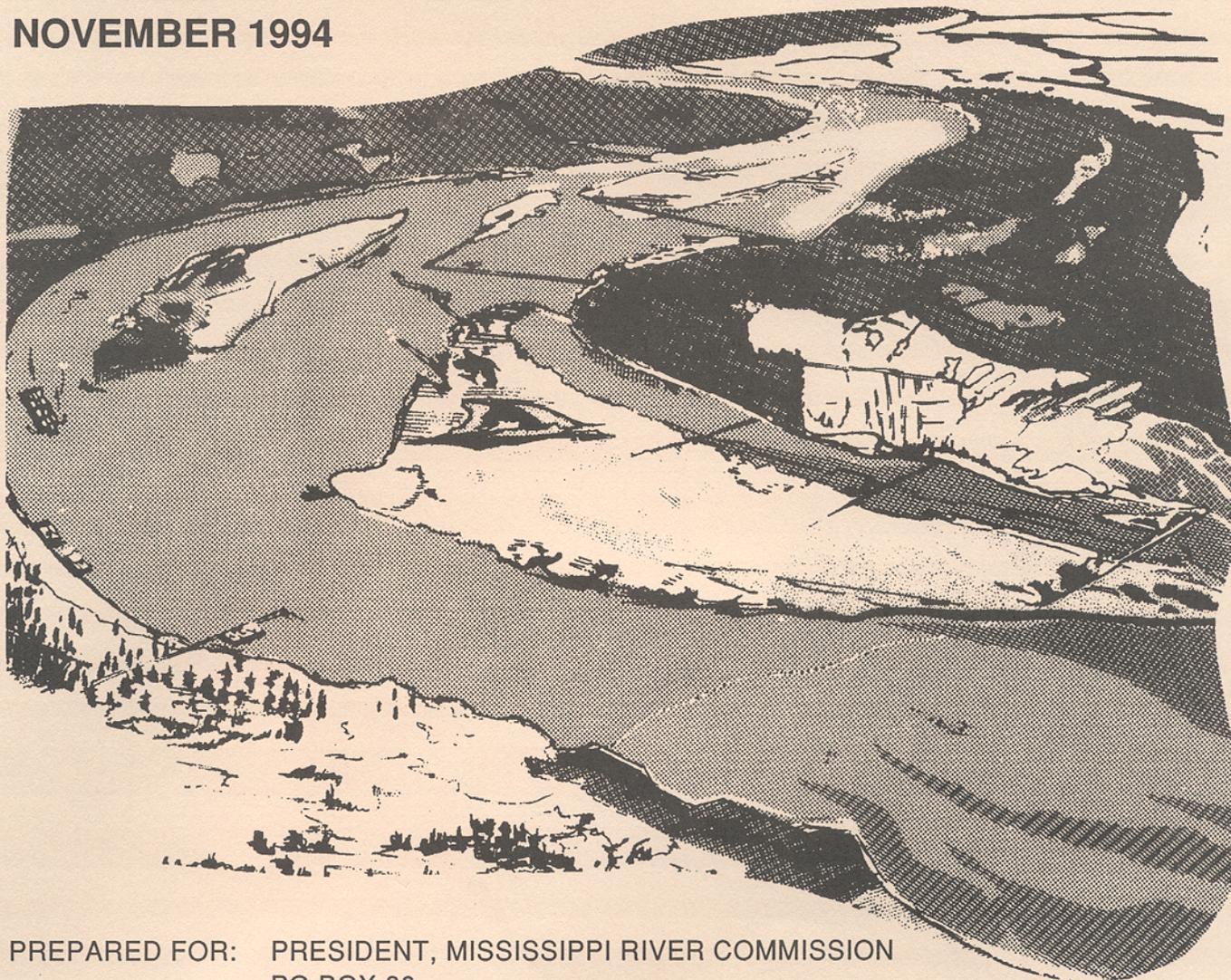




US Army Corps
of Engineers
Mississippi River
Commission

GROWTH RATES AND YEAR-CLASS STRENGTH OF SELECTED FISHES AS RELATED TO STAGE AND DISCHARGE OF THE LOWER MISSISSIPPI RIVER

LOWER MISSISSIPPI RIVER ENVIRONMENTAL PROGRAM
REPORT 20
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**Lower Mississippi River
Environmental Program**

November 1994

**Growth Rates and Year-Class Strength of Selected Fishes as Related to Stage
and Discharge of the Lower Mississippi River**

by D. A. Rutherford, W. E. Kelso, G. C. Constant

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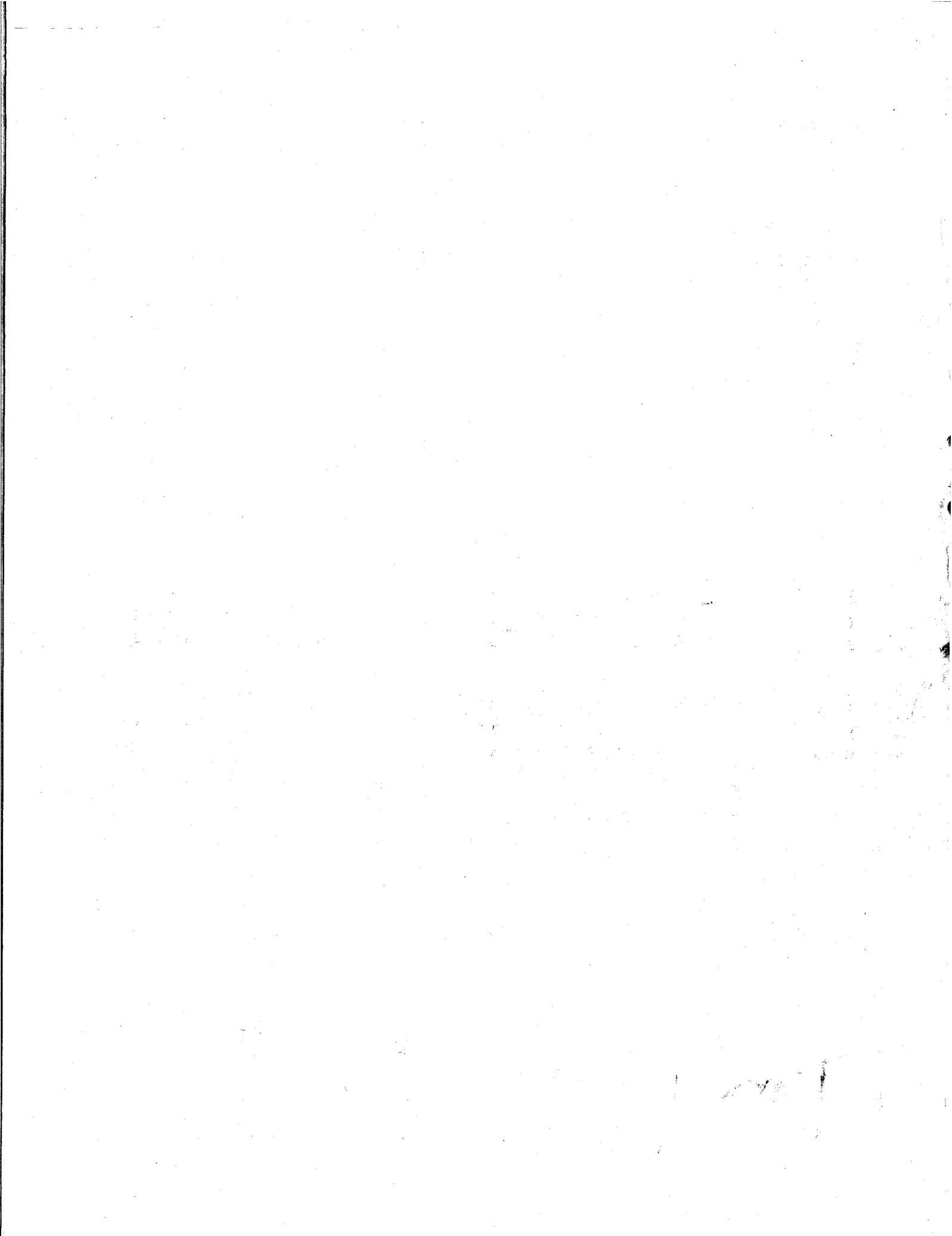
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Final report

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**Prepared for
President, Mississippi River Commission**



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Preface

The Lower Mississippi River Environmental Program (LMREP) conducted by the Mississippi River Commission of the U.S. Army Corps of Engineers is a comprehensive program of environmental studies on the lower Mississippi River system. Objectives of the LMREP are to develop an environmental resource inventory and to examine environmental design considerations for channel training and levee maintenance activities undertaken as part of the main stem Mississippi River and Tributaries Project.

One part of the LMREP is the Dike System Investigation. This report concerns a study of growth and year-class strength of four commercially important fishes (*Ictalurus furcatus*, *I. punctatus*, *Aplodinotus grunniens*, and *Dorosoma cepedianum*) collected from dike systems (river km 669.0 to 883.2; river mile 415 to 548.6) during September and October 1987-1990. Fishes were collected by personnel from the U.S. Army Corps of Engineers, Tennessee Valley Authority, and the School of Forestry, Wildlife, and Fisheries at Louisiana Agricultural Experiment Station and Louisiana State University.

This report was prepared by Drs. D. A. Rutherford, W. E. Kelso, and G. C. Constant of the Louisiana Agricultural Experiment Station, Louisiana State University, Baton Rouge, Louisiana, and Dr. C. F. Bryan, Leader, Louisiana Cooperative Fish and Wildlife Research Unit, Louisiana State University, Baton Rouge, Louisiana.

The investigation was managed by the Planning Directorate and was sponsored by the Engineering Directorate of the MRC. Mr. Stephen P. Cobb, MRC, was the program manager for the LMREP. The investigation was conducted under the direction of the President of the MRC, BG Eugene S. Witherspoon, EN.

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1 Introduction

Background

Exceeded in size only by the Amazon, Congo, and Nile Rivers, the Mississippi River drains an area of approximately 3.24 million km² (1.25 million square miles) from its source in Lake Itasca, Minnesota, to its mouth in the Gulf of Mexico below New Orleans, Louisiana. The Lower Mississippi River (LMR) is defined as that portion of the river from the confluence of the Ohio at Cairo, Illinois, to the mouth, a distance of about 1,570 river km (RK) (975 river miles (RM)) (Zimpfer et al. 1988). Although fall, winter, and spring floods are common, highest discharges in the river usually occur from March through May. Discharge at Vicksburg, Mississippi (RK 704; RM 437), averages 15,637 cubic meters per second (m³/sec) (552,000 cubic feet per second (cfs)), with maximum and minimum mean monthly discharges of 26,855 cms (948,000 cfs) in April and 7,394 cms (261,000 cfs) in September. The difference in river stage between mean maximum and minimum discharges is 8.23 m (27 ft) at Vicksburg (Zimpfer et al. 1988).

There are approximately 1.01 million ha (2.5 million acres) of leveed floodplain along the LMR, which include 192,375 ha (475,000 acres) of main channel, abandoned channel, oxbow lake, and levee borrow pit habitats. A system of dikes and revetted banks is being constructed along the LMR for navigation and flood control purposes.

Purpose and Scope

The Lower Mississippi and Atchafalaya Rivers support one of the largest riverine commercial fisheries in the United States, with annual harvests of fishes and crustaceans estimated to range from 3 to 9 million kg (6.6 to 19.8 million lb) from 1979-1985 (Fremling et al. 1989). However, little is known about the production characteristics of the commercially harvested stocks, and the lack of accurate data on harvest and effort by commercial fishermen (Fremling et al. 1989) has precluded traditional catch-per-unit-effort (CPUE) analyses of stock dynamics (Ricker 1975). Of particular interest is the relationship between fluctuations in the river environment and annual variation in year-class strength. The effects of environmental factors (e.g., temperature,

river discharge, and wind patterns, etc.) on recruitment have been reported for a number of fishes in freshwater and marine systems (Havey and Davis 1970; Turner and Chadwick 1972; Crecco, Savoy, and Whitworth 1986; Kocik and Taylor 1987; Holland-Bartels and Duval 1988), and a relationship between year-class strength of commercially important organisms and Mississippi River physicochemistry is intuitively appealing. However, attempts to discern such a relationship have failed (Risoto 1982; Risoto and Turner 1985; Fremling et al. 1989), probably because of inaccuracies in commercial landings data (Fremling et al. 1989).

As an alternative to CPUE analyses, this study was designed to assess year-class strength and growth of four commercially important fishes captured in dike system rotenone collections and to determine the relationships between the production characteristics of Mississippi River fishes and physicochemical characteristics of the river. Specifically, the objectives of the study were as follows:

- a. Describe associations between year-class strengths and physicochemical characteristics of the LMR for four commercial fish species.
- b. Examine the growth history of each species relative to recorded physicochemical characteristics of the LMR.

2 Methods

Rotenone Collections

To obtain fishes for growth and year-class strength analyses, dike system pools associated with 10 Mississippi River dikes (located from RK 668.96 to 883.25; RM 415.5 to 548.6; Table 1) were selected by the Mississippi River Commission (MRC) for fall (September to October) rotenone sampling from 1987 through 1990. Rotenone applications and fish collections were conducted according to guidelines established by Holland and Cobb (1989). Under these guidelines all fishes from each dike system pools were collected and sorted by species into 25-mm length groups. To better define age-class structure, MRC collections were subsampled to obtain a minimum of 20 individuals in successive 10-mm length classes, which were used for age determination. The volume of each dike system pool sampled during each collection was estimated from area and mean depth measurements, and density (fish/100 m³) and biomass (kilograms per cubic meter) estimates were determined for each length group.

Age and Growth Analyses

An attempt was made to determine age-class structure and growth of six Mississippi River fishes using various calcified structures in individuals from 1989 and 1990 rotenone subsamples. Pectoral spines were removed from blue catfish (*Ictalurus furcatus*) and channel catfish (*I. punctatus*), and sagittae were removed from gizzard shad (*Dorosoma cepedianum*) and freshwater drum (*Aplodinotus grunniens*). Because of the lack of recognizable otoliths in smallmouth buffalo (*Ictiobus bubalus*) and largemouth buffalo (*I. cyprinellus*), vertebrae, scales, and subopercles from these two species were examined for annular marks. However, none of the structures exhibited identifiable annular rings, so the two buffalo species were not included in further analyses.

Pectoral spines of both ictalurid species were sectioned with a low-speed sectioning saw equipped with a diamond-tipped blade. Spines were cross-sectioned according to Jearld (1983). Otoliths from freshwater drum and gizzard shad were dorso-ventrally sectioned with a hand-held grinder equipped with a carbide grinding disk. Annual growth increments on otolith sections

were measured under 400X magnification with an ocular micrometer. Spine sections were magnified 50X on a microprojector and annual growth increments measured with a transparent ruler.

Annuli from spine and otolith sections were measured in a similar manner. The first annular measurement originated at the focus and extended to the outer edge of the first annulus. Subsequent annular measurements originated at the outer edge of an annulus and extended to the outer edge of the next successive annulus. Section radius was then calculated as the sum of all growth increments plus the measurement from the outer edge of the last annulus to the edge of the section. Mean annual increments measured from otolith and spine sections were used to determine differences in growth among years for each species.

Year-Class Strength

Fishes from the 1989 and 1990 subsamples were grouped into 25-mm length groups to correspond with length groups used in the original rotenone collections. Ages of fish in the subsamples were used to determine the percentage of each age class within each 25-mm length group for each species. Relative abundance of age classes in the subsample length groups was assumed to be representative of the age class structure in the original rotenone collections. Accordingly, age-class distributions in rotenone collections were estimated for each 25-mm length group by multiplying subsample percentages by abundances of each length group in the overall rotenone collections. Density of each cohort (age-class) in each dike system pool was estimated by summing the densities of same-aged fish from successive length groups (e.g., the densities of age-2 channel catfish in all 25-mm length classes containing age-2 fish would be summed). Mean cohort densities were calculated across dike system pools within years.

Physicochemistry

Measures of the 19 physicochemical water quality variables used in this analysis were obtained from several sources. The U.S. Environmental Protection Agency STORET system for the Mississippi River monitoring station at St. Francisville, Louisiana, provided a monthly record for temperature ($^{\circ}\text{C}$), dissolved oxygen (mg/L), pH, specific conductance ($\mu\text{mhos/cm}$), total organic carbon (mg/L), total phosphorus (mg/L), total Kjeldahl nitrogen (mg/L), $\text{NO}_2 + \text{NO}_3$ nitrogen (mg/L), turbidity (NTU's), and total alkalinity (mg/L). Daily river discharge (m^3/sec) data were collected by the U.S. Army Engineer District, New Orleans, from Tarbert Landing, Mississippi. Daily river stage (m) and temperature ($^{\circ}\text{C}$) data were obtained from the U.S. Army Engineer District, Vicksburg. From these data, number of days over bank (3.66 m) and the number of days over 12, 13, 14, 15, 16, and 17 $^{\circ}\text{C}$ were determined. The values selected to determine the number of days over temperature were based

on a range of possible temperatures below which growth ceases for many warmwater fish species. Total hectares flooded were computed by the MRC from a geographic information system (GIS) for the LMR. This analysis involved the development of river stage - flooded area regression equations by overlaying elevation and aquatic habitat map layers in the GIS. Daily river stage values for the study period were used to derive estimates of flooded area from stage area regression equations.

Statistical Analyses

Analysis of variance (ANOVA) was used to detect pairwise differences in abundance for cohorts of each of the four species (i.e., pairwise difference in age-0 cohort densities of blue catfish from 1987-1990) (PROC GLM, LSMEANS, SAS Institute, Inc., 1987). Similarly, ANOVA was used to detect differences in mean annual growth increments for cohorts of each species. ANOVA was also used to examine the relationships between each of the physicochemical variables and (a) mean annual cohort densities, and (b) mean annual growth increments for cohorts. (PROC GLM, SAS Institute, Inc., 1985).

3 Results and Discussion

Abundance and Year-Class Strength

The importance of dike systems as habitat for Mississippi River commercial fishes is evidenced by the 238,075 blue catfish ($N = 8,313$), channel catfish ($N = 4,183$), freshwater drum ($N = 22,253$), and gizzard shad ($N = 223,326$) captured during 1987-1990 dike system pool rotenone collections. The abundance of these fishes varied considerably during the 4 years, ranging from 5.32 fish/100 m³ in 1989 (51.5 percent shad) to 82.10 fish/100 m³ in 1990 (88.5 percent shad). Lentic backwaters created by these dike systems serve an important role as current refugia for riverine fishes (Welcomme 1979) and greatly increase river habitat complexity, which is likely reflected in an overall increase in primary productivity and in the diversity and abundance of macroinvertebrate forage organisms in these low-flow areas (Welcomme 1979, 1985).

Although the dike systems supported a diverse and abundant fish fauna, it is apparent that the age-frequency histograms of fishes collected in the rotenone samples did not accurately reflect cohort abundance, with the possible exception of channel catfish. In the absence of information on sampling bias, spatial variability in year-class distributions (i.e., migration and recruitment), the abundance of fish in each cohort sampled in the pools should have decreased in successive years because of mortality. However, this trend of declining cohort abundance across years was only exhibited by channel catfish; exceptions included increasing abundance of the 1988 blue catfish cohort between ages 1 and 2 (Figure 1), the 1988 cohort of freshwater drum between ages 1 and 2, and the 1987 (ages 0 and 1), 1988 (ages 1 and 2), and 1989 (ages 0 and 1) cohorts of gizzard shad. In addition, examination of fish age-frequency distributions from each pool reveals substantial variability among pools within years, as well as within pools across years (Appendixes A and B). Because of the apparent variability in the spatial distribution of different-aged fishes in the river, analyses were limited to age-0 fishes. The rotenone collections probably provided an accurate index of age-0 abundance, primarily because the low-flow habitats created by these dike systems are similar to overflow areas that serve as important nursery habitats for young riverine fishes (Gallagher and Conner 1980; Schramm and Pennington 1980; Zimpfer et al. 1988; Crance 1988; Sabo and Kelso 1991; Sabo et al. 1991).

Studies of marine fishes have shown that early life history stages are strongly influenced by environmental conditions (Smith and Lasker 1978; Peterman and Bradford 1987; Horne and Campana 1989), although mathematical models developed to quantify the relationship between fish recruitment and environmental factors seem to have limited predictive ability (see review in Frank 1991). Despite the failures of marine fish recruitment models, models for fishes in temperate river systems may prove to have better predictive value. Relative to marine environments, lotic systems are extremely variable environments and are subject to substantial (but relatively predictable) annual fluctuations in water levels, floodplain inundation, temperature, turbidity, etc, which may be more consistently reflected in fish year-class abundance.

Age-0 abundances of blue catfish (Figure 1) in 1989 (0.599 fish/100 m³) and 1990 (0.578 fish/100 m³) were significantly higher than in 1987 (0.137 fish/100 m³) and 1988 (0.132 fish/100 m³) ($P < 0.02$). A significant proportion ($P < 0.05$) of the variation in age-0 blue catfish abundance across years was explained by five physicochemical variables: discharge ($t = 6.81$, $P < 0.02$, $r^2 = 0.96$), number of days over bank ($t = 5.17$, $P < 0.03$, $r^2 = 0.93$), river stage ($t = 4.77$, $P < 0.04$, $r^2 = 0.92$), dissolved oxygen concentration ($t = -8.73$, $P < 0.01$, $r^2 = 0.97$), and total Kjeldahl nitrogen concentration ($t = -4.66$, $P < 0.04$, $r^2 = 0.92$) (Figures 2-6).

Higher abundances of blue catfish in 1989 and 1990 during periods of high discharge and discharge-related variables did not appear to be related to increased survival because of superior growth (see below); although blue catfish spawning and early life history in rivers are poorly understood, it is conceivable that a relationship between higher discharge (increased flooding of suitable spawning habitat) and year-class strength could exist. A positive relationship between discharge and year-class strength has been reported for pink salmon, *Oncorhynchus gorbuscha*, in Lake Michigan tributaries, with higher water levels providing increased spawning habitat and less nest over-seeding and superimposition (Kocik and Taylor 1987). Higher summer discharge has also been reported to increase fry survival in Atlantic salmon, *Salmo salar* (Lishev 1958; Havey and Davis 1970), although higher temperatures also appeared to promote higher year-class strength. Recruitment of west coast striped bass, *Morone saxatilis*, was found to be higher in high-discharge years, although cause-and-effect relationships were unclear (Turner and Chadwick 1972).

Although no statistical indication of exceptional year-class strengths in channel catfish was found, there was a trend of reduced abundances during higher water years (1989 and 1990; Figure 1). In a study of the upper Mississippi River, Holland-Bartels and Duval (1988) reported that high discharge was negatively associated with year-class strength in channel catfish, a phenomenon also observed in American shad, *Alosa sapidissima* (Crecco and Savoy 1985; Crecco, Savoy, and Whitworth 1986), Colorado squawfish, *Ptychocheilus lucius* (Tyus and Haines 1991), the darter, *Etheostoma flabellare* (Coon 1987), and smallmouth bass, *Micropterus dolomieu* (Graham and Orth 1986). Because high water levels probably result in increased flooding of

overflow spawning areas, poor year-class success of channel catfish in high discharge years may not have been due to limited spawning habitat, but rather to increased mortality of larvae and juveniles (Holland-Bartels and Duvall 1988). Of particular interest are the apparent differences in the relationships between discharge and year-class strengths of the two catfishes (Figure 1). However, because so little is known about the early life history of these fishes in large river systems, whether these year-class phenomena are due to differences in preferred spawning habitat or survival of early life history stages is unknown.

The 1987 cohort of freshwater drum was significantly less abundant (0.238 fish/100 m³) than that of the 1988 cohort (2.30 fish/100 m³, $P < 0.024$; Figure 1), but neither year was significantly different from the intermediate year classes in 1989 (0.917 fish/100 m³) and 1990 (0.798 fish/100 m³). The number of days over 16 °C and the concentration of total organic carbon explained a significant proportion of the variation in age-0 freshwater drum abundance across years ($t = 8.27$, $P < 0.01$, $r^2 = 0.97$; $t = 8.27$, $P < 0.01$, $r^2 = 0.97$, respectively; Figures 7 and 8).

The positive relationships between temperature and total organic carbon levels and year-class strength of age-0 freshwater drum may have been related to larval production as well as larval growth and survival. Butler (1965) reported a positive relationship between May temperature and year-class strength of freshwater drum in the Upper Mississippi River from 1939-1948, and he attributed lower year-class abundance to egg and larval mortality during years with below average May temperatures. In addition, strong year classes may be related to increased survival because of faster growth (see below) in years of higher productivity and a longer growing season. Positive relationships between temperature, growth, and year-class strength (emphasizing the importance of reduced predation rather than intraspecific competition in determining early survival) have been reported for a number of fishes (Shepherd, Pope, and Cousens 1984) including Pacific halibut, *Hippoglossus stenolepis* (Hagen and Quinn 1991), and dace, *Leuciscus leuciscus* (Mills and Mann 1985). Leggett, Frank, and Carscadden (1984) reported such a relationship for beach spawning capelin, *Mallotus villosus*, with higher temperatures promoting greater food production, faster growth, increased swimming abilities, and improved predator avoidance. In riverine systems, faster growth and increased swimming abilities might additionally reduce downstream transport from eddies and other low current areas, also resulting in higher survival (Frank and Leggett's (1982) "safe site" hypothesis). As in this study, Butler (1965) found no relationship between discharge and year-class strength for freshwater drum in the Upper Mississippi River from 1939-1948. Because these fish are pelagic spawners (Daiber 1953), early survival may be less related to discharge (and its effects on the amount of flooded habitat for substrate spawners) than the other fishes.

These authors expected that age-0 gizzard shad abundance would be related to overbank flooding and the extent of inundated batture land, which provides nursery areas for larvae and juveniles (Sabo and Kelso 1991). However,

although the abundance of age-0 gizzard shad was highly variable over the 4-year period (Figure 1), significant relationships were not found with any of the measured physicochemical variables. High age-0 densities were found during both high and low water years, and densities during 1989 and 1990, both high water years, differed by a factor of 39.

Growth

Growth increments from 1,573 individual fish species were used to assess differences in growth between years for age-0 and -1 blue catfish, age-0, -1, and -2 freshwater drum, age-0 channel catfish, and age-0, -1, and -2 gizzard shad (Table 2). A few individuals above age 3 were present in the aged subsamples for all four species, but it was felt that sample sizes were inadequate for analysis of differences in growth between years.

There were no significant differences in age-0 growth increments for blue catfish in 1986 and 1988 (Table 2), but growth in these 2 years was significantly higher than in 1987 and 1989 ($P < 0.024$). Growth of age-0 fish in 1987 was particularly slow, with a mean growth increment significantly less than that exhibited in 1989 ($P < 0.013$). The growth pattern of age-1 blue catfish resembled age-0 fish, with growth in 1988 being significantly higher than age-1 growth in 1987 ($P < 0.001$) and 1989 ($P < 0.0005$). As in age-0 fish, the lowest age-1 mean growth increment was in 1987, although this was not statistically different from 1989 ($P < 0.106$). Age-0 incremental growth for channel catfish was similar to blue catfish, with significantly greater growth in 1988 relative to 1987 ($P < 0.012$). In fact, age-0 growth increments for both catfishes were significantly related to the length of the growing season (Table 2; Figures 9-11). In addition, growth of age-1 blue catfish was negatively associated with turbidity (Figure 12) and positively associated with total organic carbon levels (Figure 13).

Growth of age-0 and -1 freshwater drum was similar over the years examined with the exception of 1988 (Table 2). Growth in 1988 for both age classes was significantly higher than other years (1983-1987 and 1989; $P < 0.013$ and $P < 0.018$, respectively). However, in contrast to the catfishes, age-0 and -1 growth was not significantly associated with river temperatures, but was negatively associated with several variables that were related to the quantity of water in the river: discharge (Figure 14), days over bank (Figure 15), mean river stage (Figure 16), and (age-1 fish only) extent of overbank flooding (Figure 17; all $P < 0.05$; Table 3). Age-2 freshwater drum grew slower in 1986 than in 1988 ($P < 0.013$) and 1989 ($P < 0.05$), but growth was not significantly related to measured physicochemical variables.

Growth of gizzard shad was quite variable, and the patterns of growth across years were different for the three age classes. For age-0 shad, growth was significantly lower in 1984 than from 1985-1988 (all $P < 0.05$) and was positively associated with river temperatures over 12 °C (Table 3; Figure 18). Age-1 gizzard shad exhibited significantly lower growth in 1985 than in 1987

($P < 0.05$), and growth was positively related with the duration and a real extent of overbank flooding (Table 3; Figure 19). Growth patterns of age-2 fish resembled those of catfishes and drum, with significantly higher growth in 1988 than in 1986 ($P < 0.02$) and 1989 ($P < 0.04$). However, there were no significant associations between river physicochemistry and growth of age-2 gizzard shad.

Growth of age-0 and -1 blue catfish, age-0 channel catfish, and age-0 gizzard shad was positively associated with length of the growing season (Table 3). This is certainly not surprising, as temperature is a primary factor affecting growth in fishes (Warren and Davis 1967; Magnuson, Crowder, and Medvick 1979; Ricker 1979), and its effects are reflected both in production of food organisms (Leggett, Frank, and Carscadden 1984) and fish feeding rates (Tytler and Calow 1985). In this regard, low current areas created by Mississippi River dike systems probably provide more productive habitats for riverine phytoplankton, zooplankton, and macroinvertebrate organisms (Zimpfer et al. 1988), which may be reflected in growth rates of some fishes during warmer, low discharge years.

Relationships between age-1 blue catfish growth and turbidity (negative) and total organic carbon levels (positive) may reflect growing conditions in the river during higher and lower water years, respectively. During years with higher discharge, increased turbidity probably reduces primary and secondary production and may result in unfavorable foraging conditions, although catfish are not primarily visual predators. Conversely, primary production is favored during periods of lower discharge, which would result in increased production of dissolved and particulate organic matter (Wetzel 1983). However, the use of annual means is obviously an oversimplification of an inherently volatile river physicochemistry (Bryan, Rutherford, and Walker-Bryan 1992), and the above hypotheses are certainly tenuous given the fact that growth of age-1 fish shows no relationship to river discharge ($r^2 = 0.02$, $P > 0.05$).

The negative relationships between age-0 and -1 drum and age-1 shad growth-discharge-related variables suggest that these fishes forage most efficiently in low flow conditions. This might be particularly true for age-0 drum and age-1 shad, as zooplankton constitutes the major portion of the age-0 diet for drum (Swedberg 1968). Lower flow conditions might also promote sediment deposition and production of infaunal macroinvertebrates such as *Hexagenia*, which are important forage organisms for individuals over 60 mm in length (Swedberg 1968). Low flow conditions also promote increased primary production in the river. Gizzard shad are abundant in shallow overflow areas such as levee borrow pits (Cobb et al. 1984), and conditions in these lentic habitats support substantial densities of phytoplankton and zooplankton (Sabo 1989) that comprise the gizzard shad diet (Baker, Martin, and Schmitz 1971). During low flow periods the Mississippi River is more similar to conditions routinely found in shallow overflow areas (increased primary and secondary production) and thus may present more favorable conditions for growth.

Overall, evidence was found to address cause-and-effect questions regarding year-class strength and growth of certain commercial Mississippi River fishes and selected physicochemical characteristics of the river. However, additional years of abundance and growth data are necessary to further investigate these relationships, particularly for age-2 and older fishes, which were typically rare in rotenone collections.

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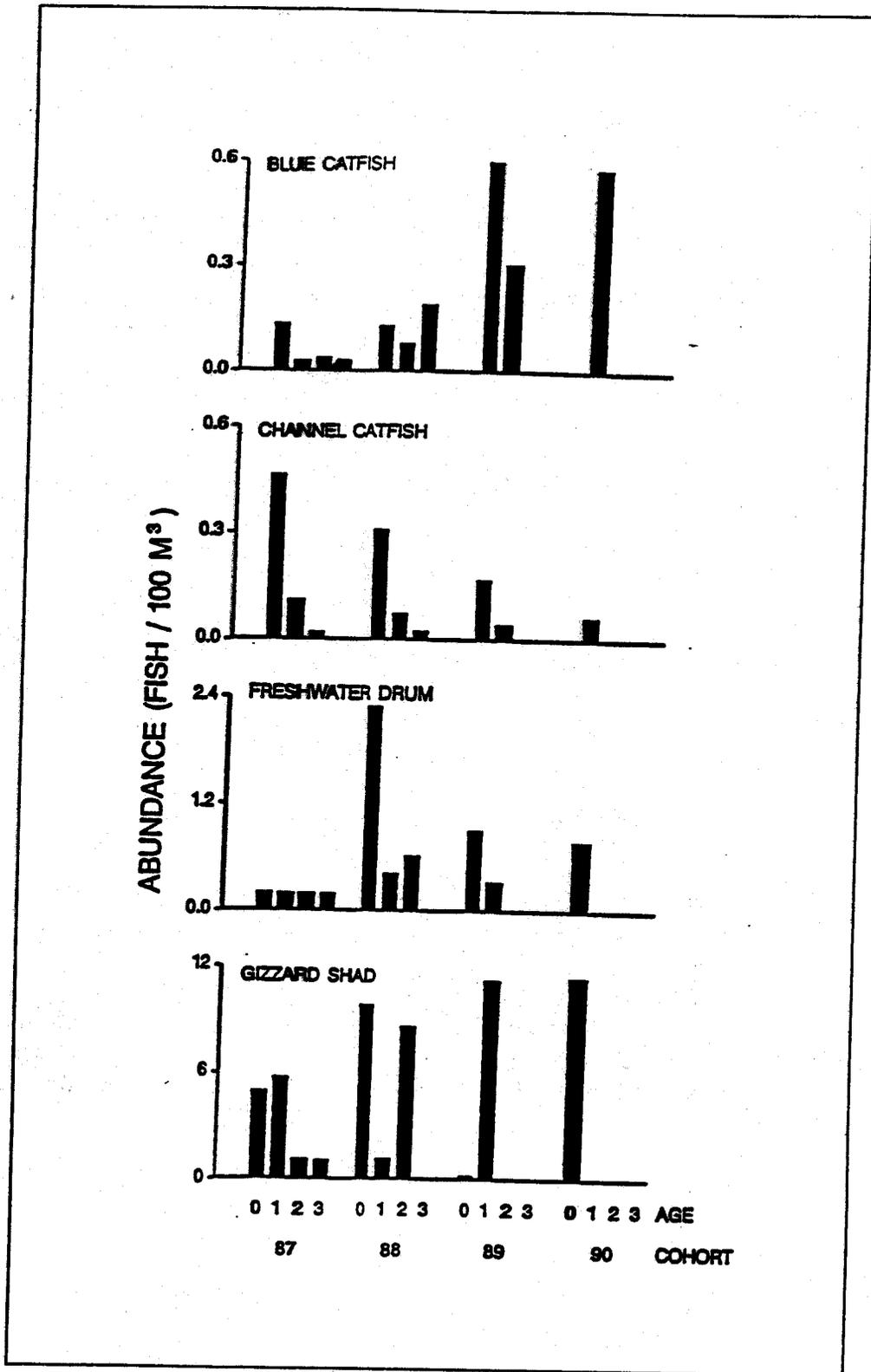


Figure 1. Cohort abundance (fish/100 m³) for blue catfish, channel catfish, freshwater drum, and gizzard shad from 1987 through 1990 dike system rotenone collections

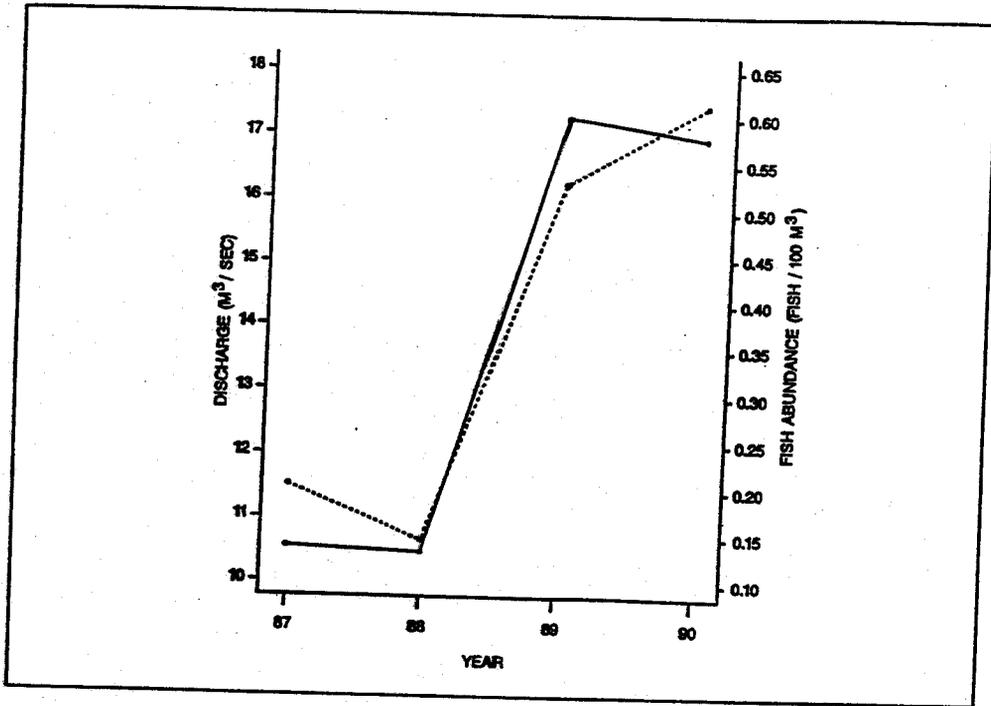


Figure 2. Relationship between age-0 blue catfish density (fish/100 m³) (—) and discharge (m³/sec) (-----)

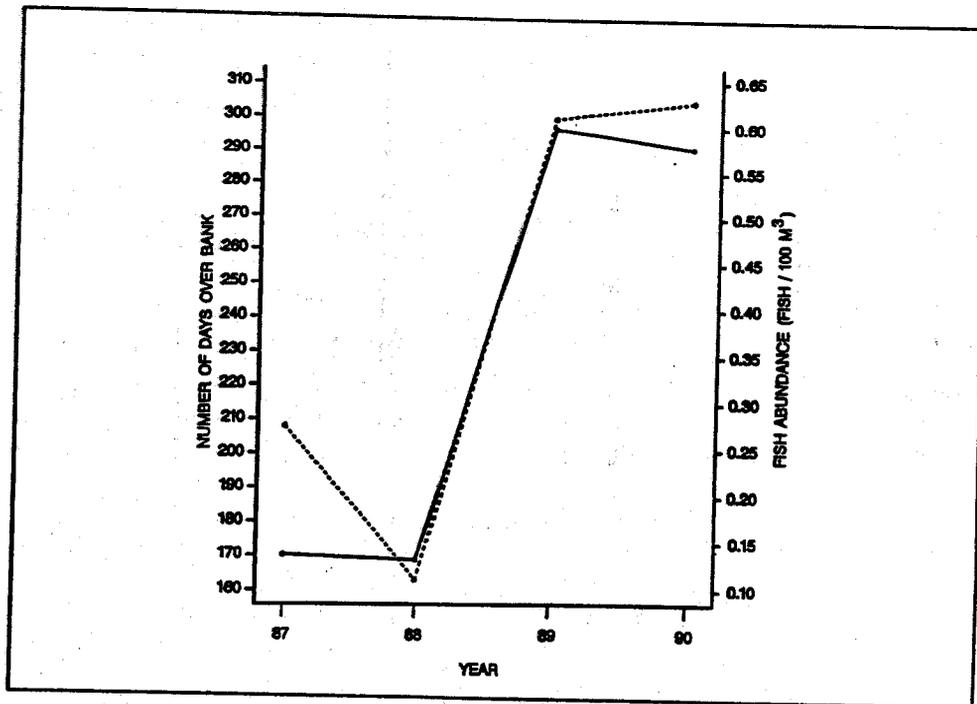


Figure 3. Relationship between age-0 blue catfish density (fish/100 m³) (—) and number of days over bank (3.66 m) (-----)

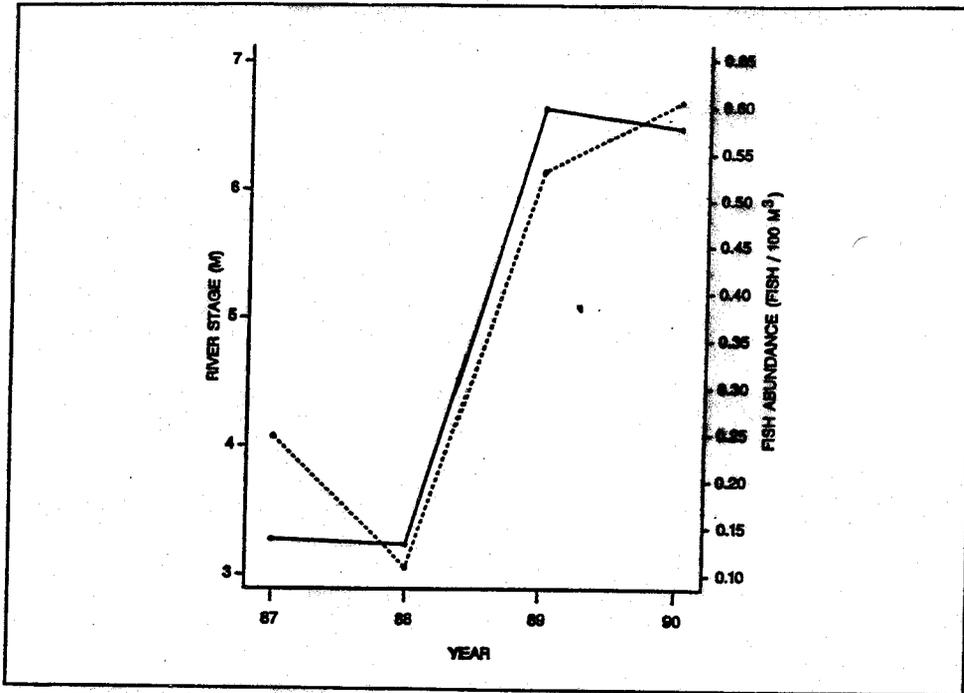


Figure 4. Relationship between age-0 blue catfish density (fish/10 m³) (—) and river stage (m) (-----)

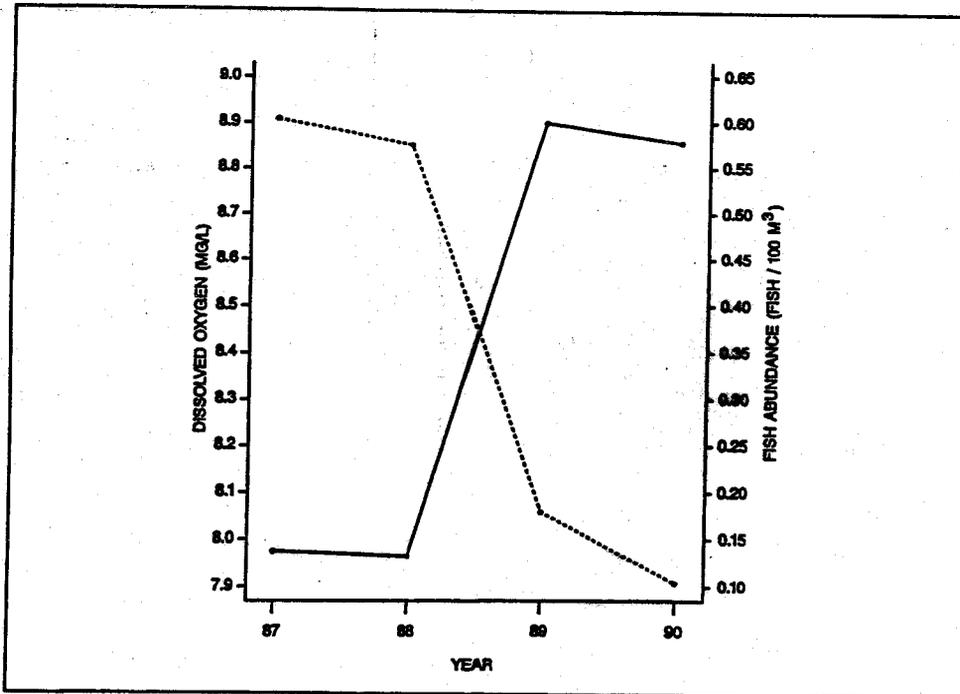


Figure 5. Relationship between age-0 blue catfish density (fish/100 m³) (—) and dissolved oxygen (mg/L) (-----)

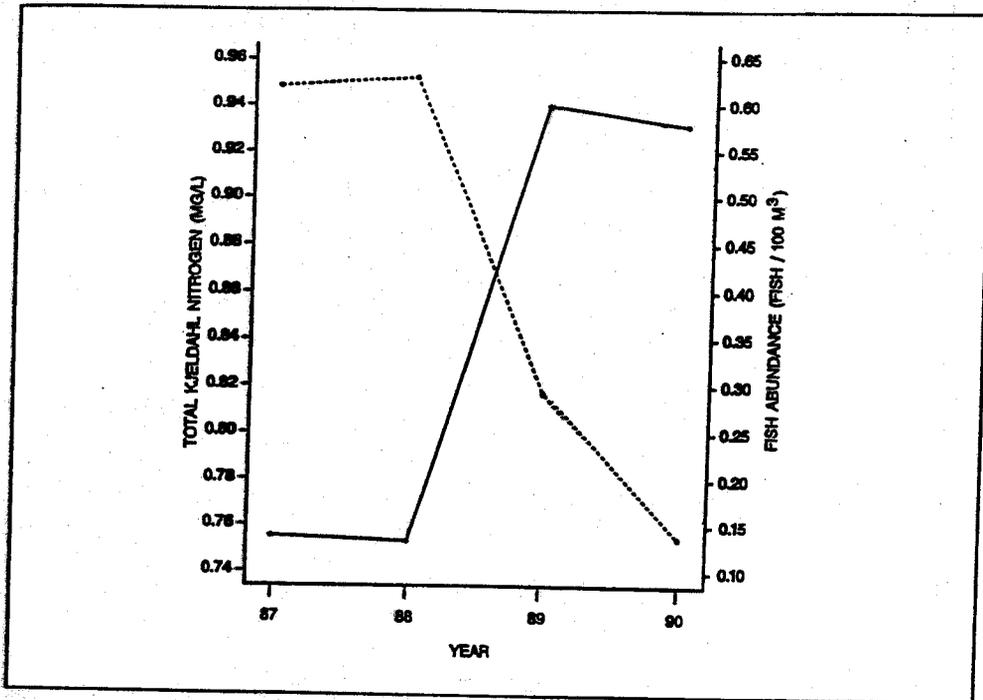


Figure 6. Relationship between age-0 blue catfish density (fish/100 m³) (—) and total Kjeldahl nitrogen (mg/L) (-----)

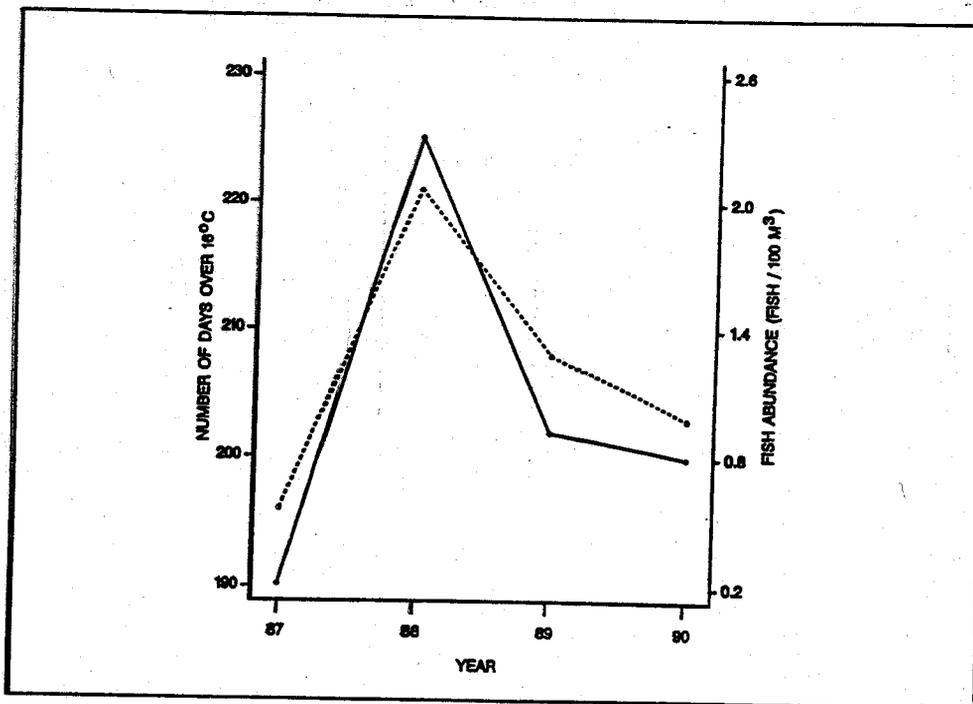


Figure 7. Relationship between age-0 freshwater drum density (fish/100 m³) (—) and number of days over 16 °C (-----)

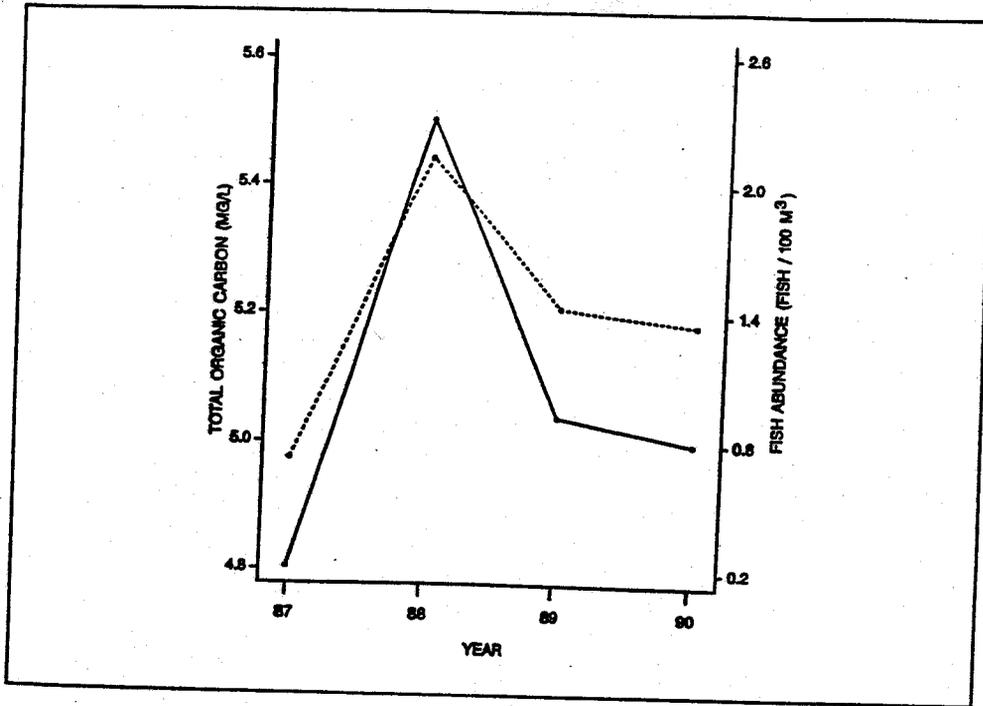


Figure 8. Relationship between age-0 freshwater drum density (fish/100 m³) (—) and total organic carbon (mg/L) (-----)

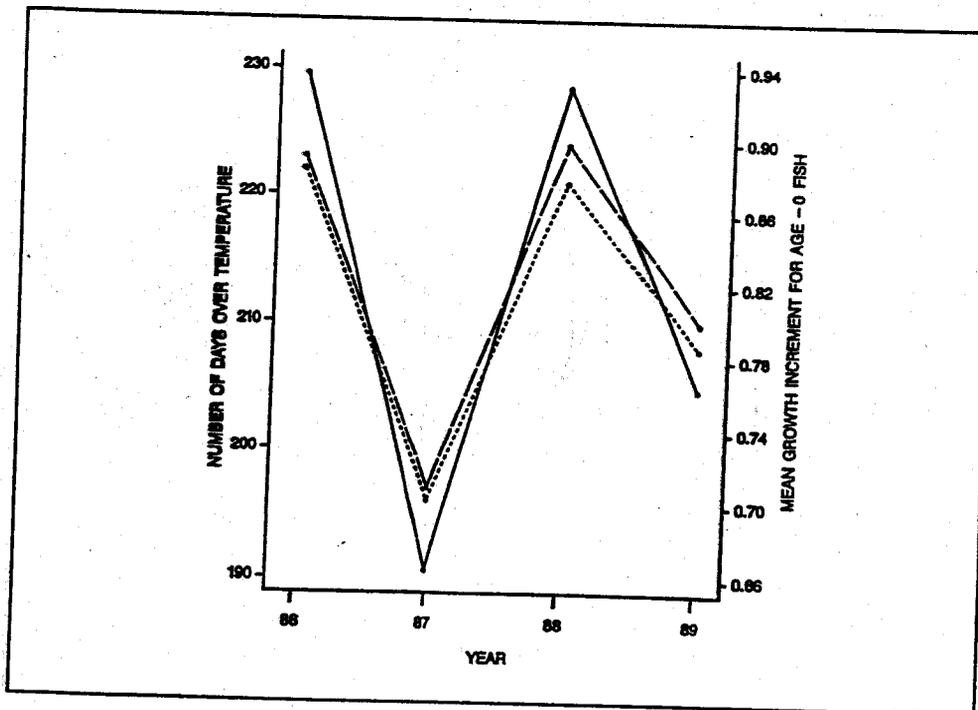


Figure 9. Relationship between mean annual growth increment for age-0 blue catfish (—) and number of days over 15 °C (---) and 16 °C (-----)

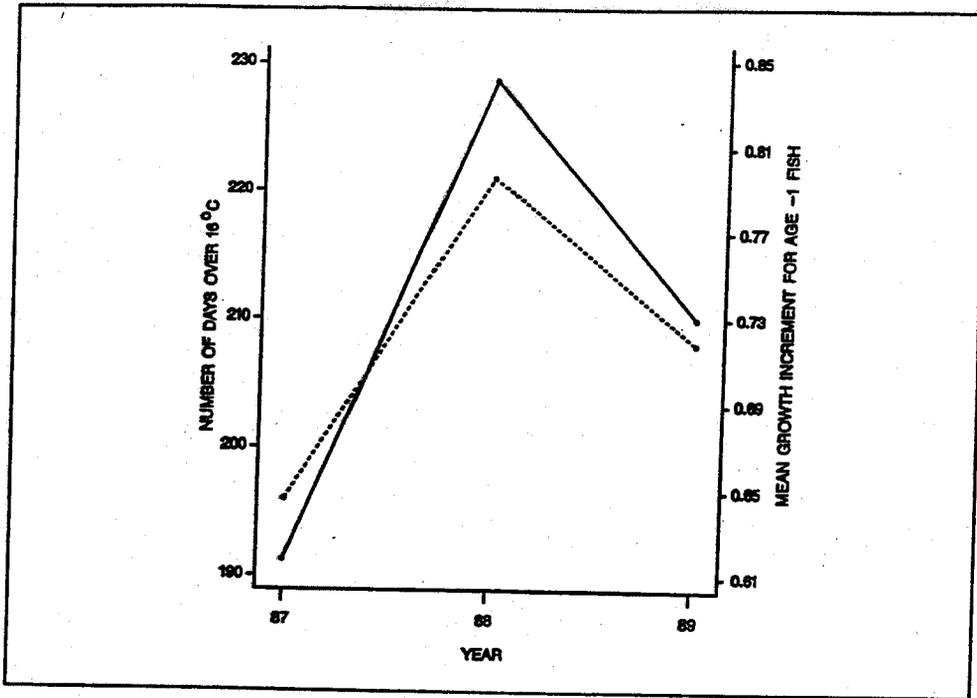


Figure 10. Relationship between mean annual growth increment for age-1 blue catfish (—) and number of days over 16 °C (-----)

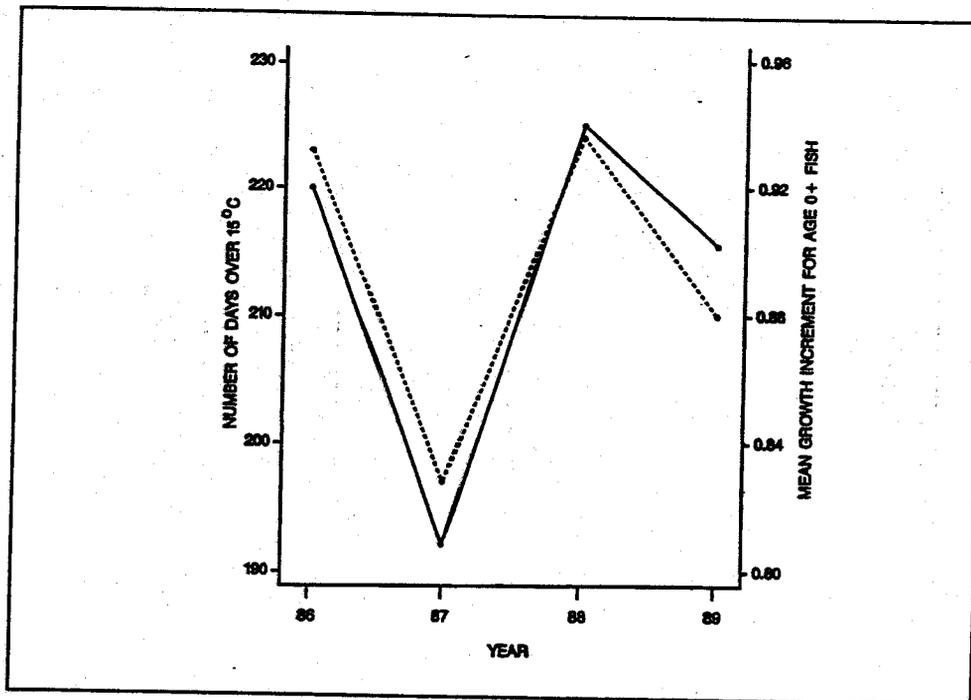


Figure 11. Relationship between mean annual growth increment for age-0 channel catfish (—) and number of days over 15 °C (-----)

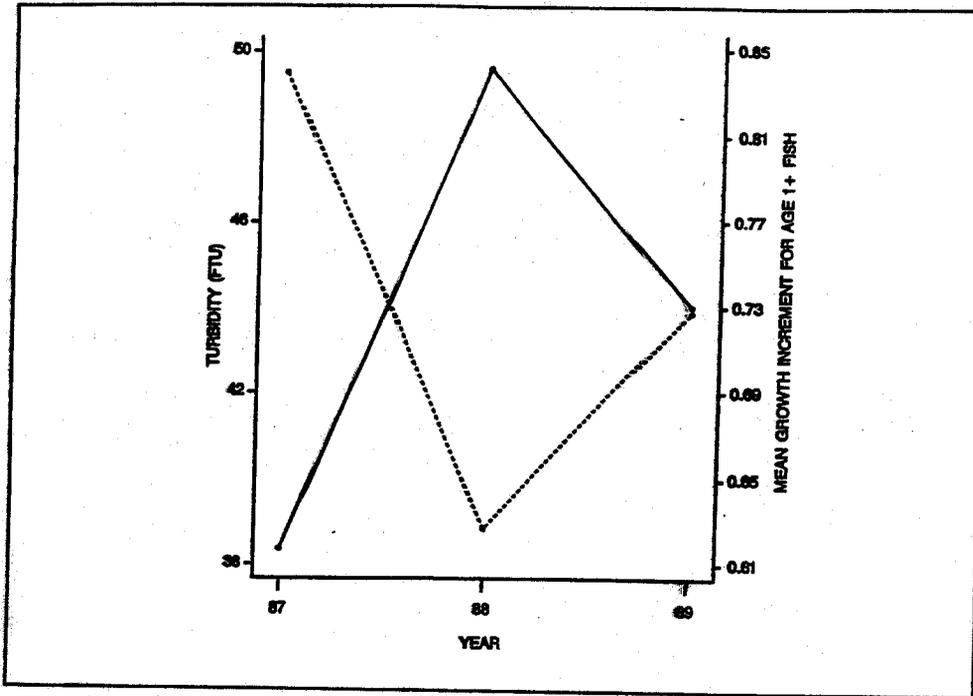


Figure 12. Relationship between mean annual growth increment for age-1 blue catfish (—) and turbidity (NTU's) (.....)

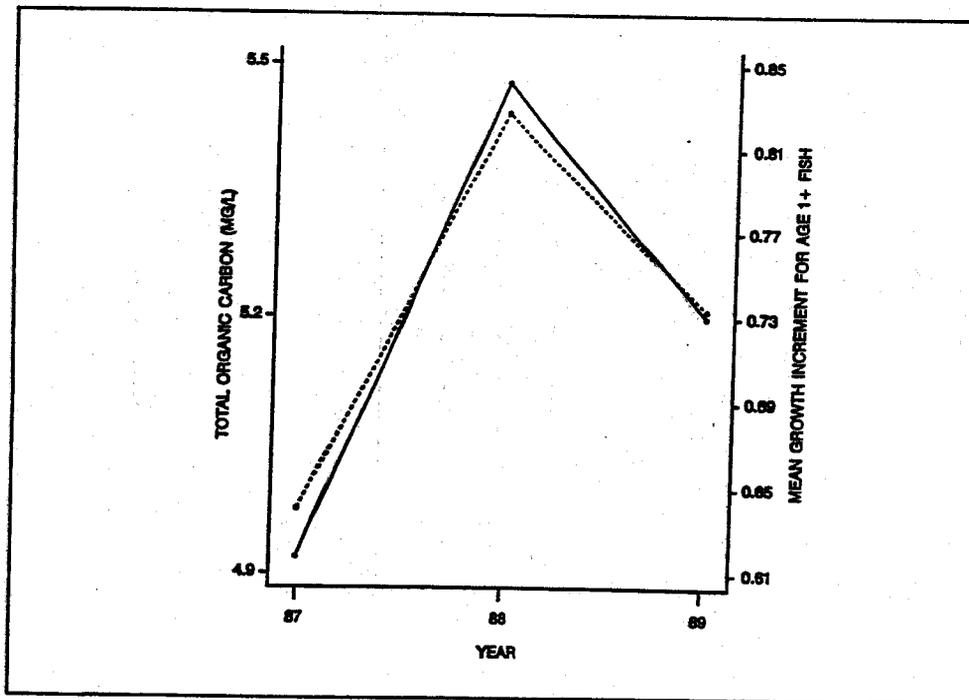


Figure 13. Relationship between mean annual growth increment for age-1 blue catfish (—) and the total organic carbon (mg/L) (.....)

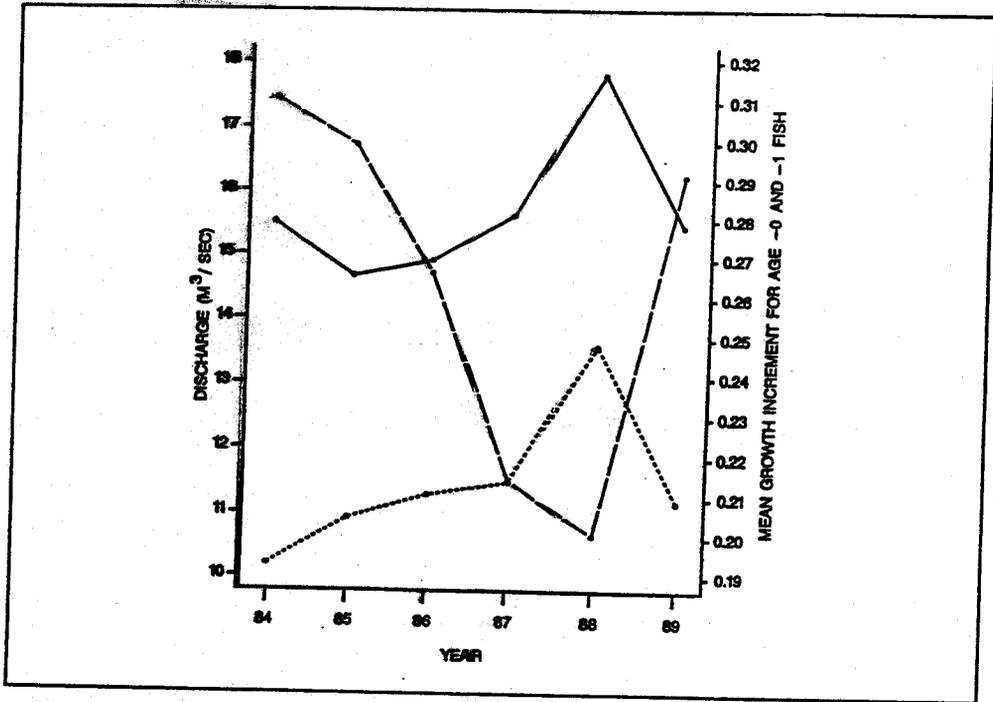


Figure 14. Relationship between mean annual growth increment for age-0 (—) and -1 (----) freshwater drum and discharge (m³/sec) (-.-)

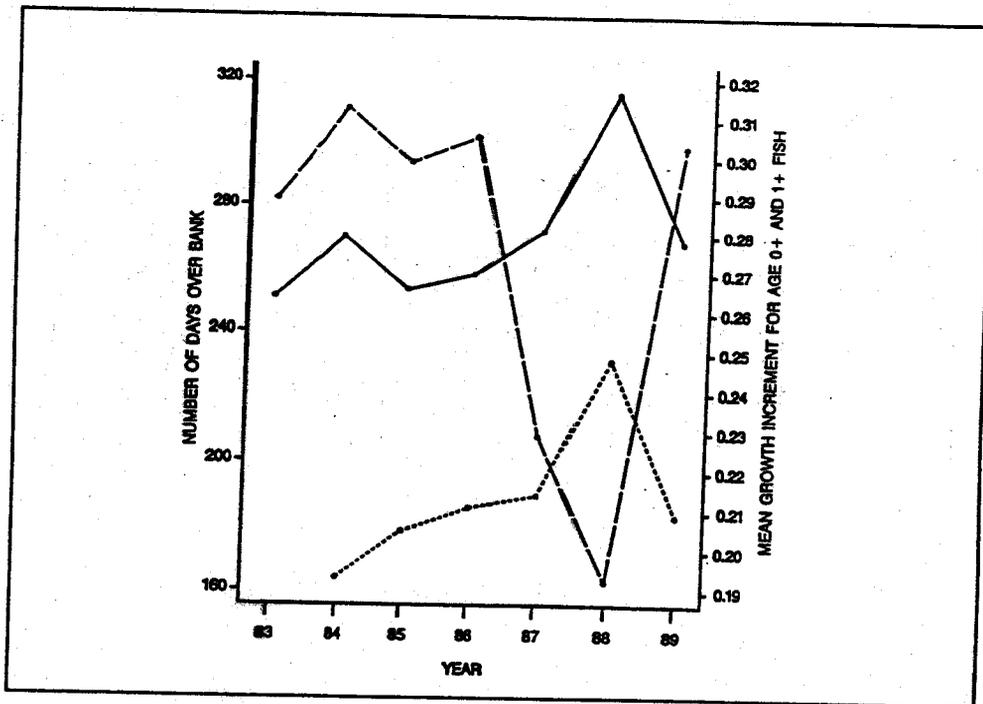


Figure 15. Relationship between mean annual growth increment for age-0 (—) and -1 (----) freshwater drum and number of days over bank (3.66 m) (-.-)

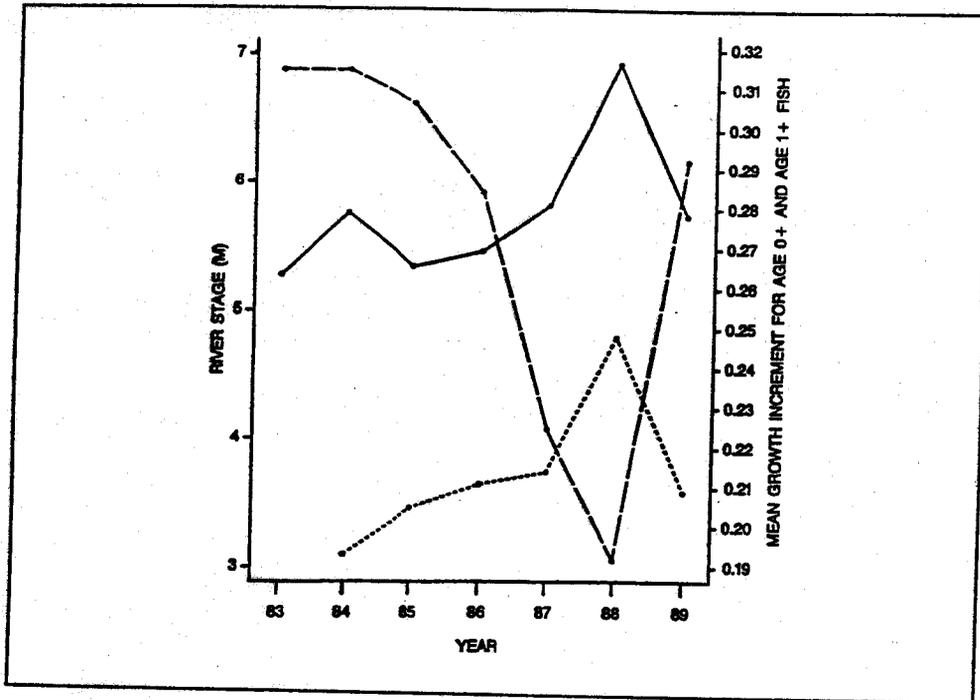


Figure 16. Relationship between mean annual growth increment for age-0 (—) and -1 (-----) freshwater drum and river stage (m) (-.-)

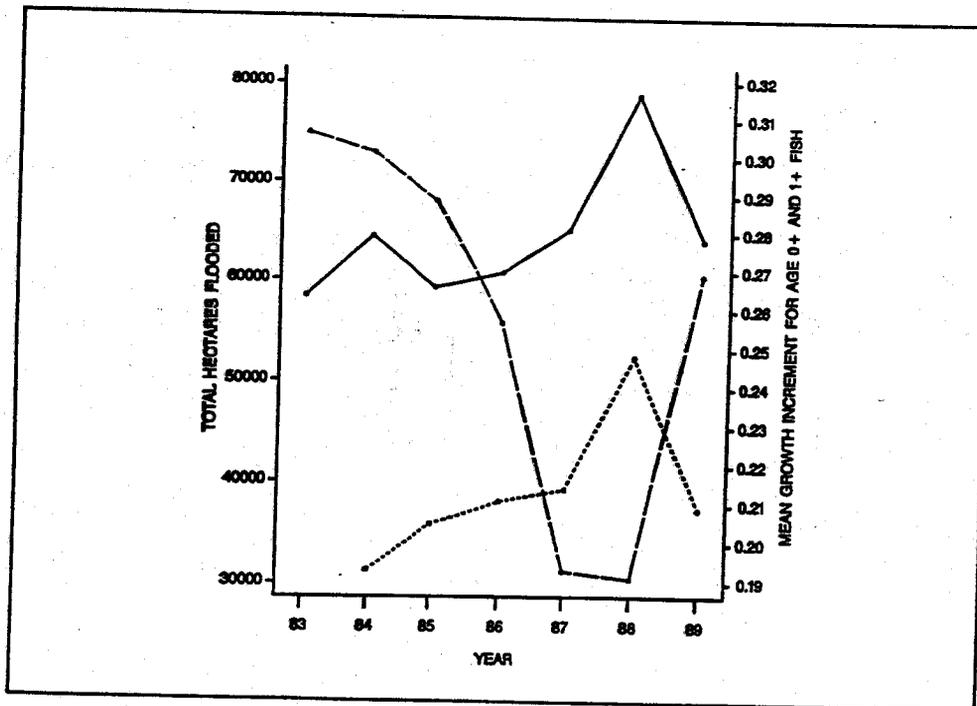


Figure 17. Relationship between mean annual growth increment for age-0 (—) and -1 (-----) freshwater drum and total hectares flooded (-.-)

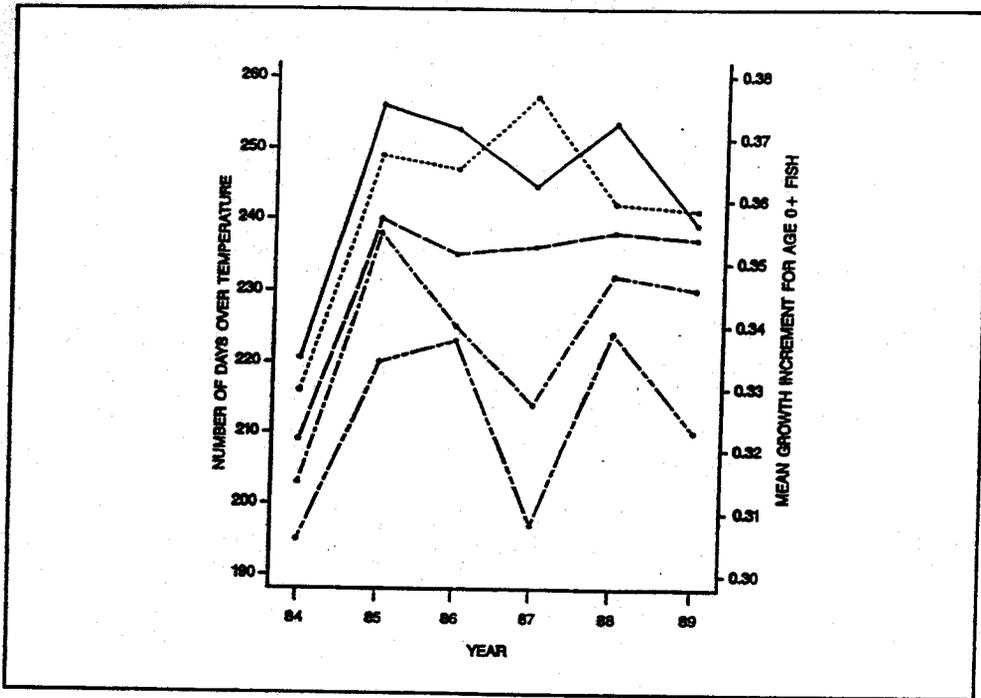


Figure 18. Relationship between mean annual growth increment for age-0 (—) gizzard shad and number of days over 12 °C (-----), 13 °C (---), 14 °C (---), and 15 °C (-----)

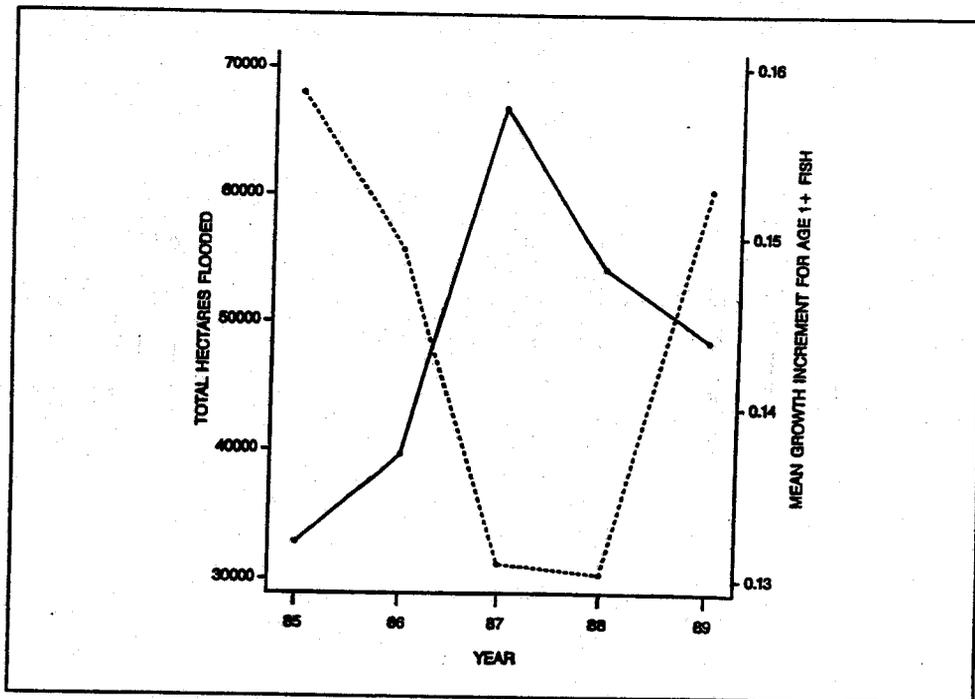


Figure 19. Relationship between mean annual growth increment for age-1 (—) gizzard shad and total hectares flooded (-----)

Table 1
Locations of Stations in the Lower Mississippi River Dike System
Where Rotenone Samples Were Collected

Year Sampled	River Kilometer (Mile)	Dike System Name
1987	819.3 (508.9)	Lower Craecraft Dike 3L
1987	817.1 (507.5)	Lower Craecraft Dike 3
1987	669.0 (415.5)	Togo Island Dike 2
1988	883.2 (548.6)	Ashbrook Cutoff Dike 3
1988	882.6 (548.2)	Ashbrook - Miller Bend Right Dike 1
1988	869.9 (540.3)	Tarpley Cutoff Dike 3
1988	669.9 (416.1)	Togo Island Dike 1
1989	869.9 (540.3)	Tarpley Cutoff Dike 3
1989	821.7 (510.4)	Lower Craecraft Dike 1
1989	782.9 (486.3)	Ben Lemond Dike 3
1990	875.7 (543.9)	Island 82 - Miller Bend Right Dike 3
1990	869.9 (540.3)	Tarpley Cutoff Dike 3
1990	819.3 (508.9)	Lower Craecraft Dike 3L
1990	669.0 (415.5)	Togo Island Dike 2

Table 2
Mean Annual Growth Increments (mm) for Mississippi River Fishes
(N = number of growth increments in an age class measured)

Species	Age Class	Year	Mean Increment	N	Standard Error
Blue catfish	0	1986	0.937	12	0.091
	0	1987	0.664	112	0.022
	0	1988	0.930	138	0.024
	0	1989	0.763	63	0.026
	1	1987	0.618	12	0.067
	1	1988	0.841	112	0.020
	1	1989	0.730	98	0.024
Freshwater drum	0	1983	0.264	16	0.013
	0	1984	0.279	18	0.011
	0	1985	0.266	12	0.022
	0	1986	0.270	33	0.009
	0	1987	0.281	81	0.007
	0	1988	0.317	212	0.004
	0	1989	0.278	66	0.007
	1	1984	0.193	16	0.009
	1	1985	0.205	18	0.014
	1	1986	0.211	12	0.012
	1	1987	0.214	33	0.009
	1	1988	0.248	81	0.006
	1	1989	0.209	132	0.004
	2	1985	0.146	16	0.008
	2	1986	0.137	18	0.014
	2	1987	0.163	12	0.015
	2	1988	0.168	33	0.006
	2	1989	0.160	65	0.005
	Channel catfish	0	1986	0.920	1
0		1987	0.808	32	0.044
0		1988	0.940	164	0.026
0		1989	0.902	12	0.100
Gizzard shad	0	1984	0.335	14	0.015
	0	1985	0.375	11	0.012
	0	1986	0.372	25	0.010
	0	1987	0.362	49	0.006
	0	1988	0.372	109	0.004
	0	1989	0.356	33	0.008
	1	1985	0.132	14	0.005
	1	1986	0.137	11	0.009
	1	1987	0.158	25	0.007
	1	1988	0.148	47	0.006
	1	1989	0.144	88	0.004
	2	1986	0.101	14	0.005
	2	1987	0.109	11	0.007
	2	1988	0.126	24	0.005
	2	1989	0.110	38	0.006

Table 3
Significant Associations Between Physicochemical Variables
and Mean Annual Growth Increments for Blue Catfish, Fresh-
water Drum, Channel Catfish, and Gizzard Shad for Each Age
Class and Year of Growth

Species	Growth Increment, mm	Physicochemical Variable	$P = t $	r^2	Years
Blue catfish	1	Days over 15 °C	0.009	0.98	1986-89
	1	Days over 16 °C	0.005	0.99	1986-89
	2	Days over 16 °C	0.017	0.99	1987-89
	2	Turbidity (NTU's)	-0.019	0.99	1987-89
	2	Total organic carbon (mg/L)	-0.002	0.99	1987-89
Freshwater drum	1	Days over bank (>3.66 m)	-0.026	0.66	1983-89
	1	Discharge (m ³ /sec)	-0.048	0.58	1983-89
	1	Mean river stage (m)	-0.018	0.70	1983-89
	2	Days over bank (>3.66 m)	-0.023	0.76	1984-89
	2	Discharge (m ³ /sec)	-0.035	0.71	1984-89
	2	Mean river stage (m)	-0.016	0.80	1984-89
	2	Total hectares flooded	-0.051	0.65	1984-89
Channel catfish	1	Days over 15 °C	0.047	0.91	1986-89
Gizzard shad	1	Days over 12 °C	0.052	0.65	1984-89
	1	Days over 13 °C	0.015	0.81	1984-89
	1	Days over 14 °C	0.042	0.68	1984-89
	1	Days over 15 °C	0.046	0.67	1984-89
	2	Hectare - days	-0.037	0.81	1985-89
	2	Total hectares flooded	-0.050	0.75	1985-89

Appendix A Fish Age-Frequency Distributions Within Dike System Pools Across Years

(Comparisons were made only for pools that were sampled more than once over the collection period (1987-1990).)

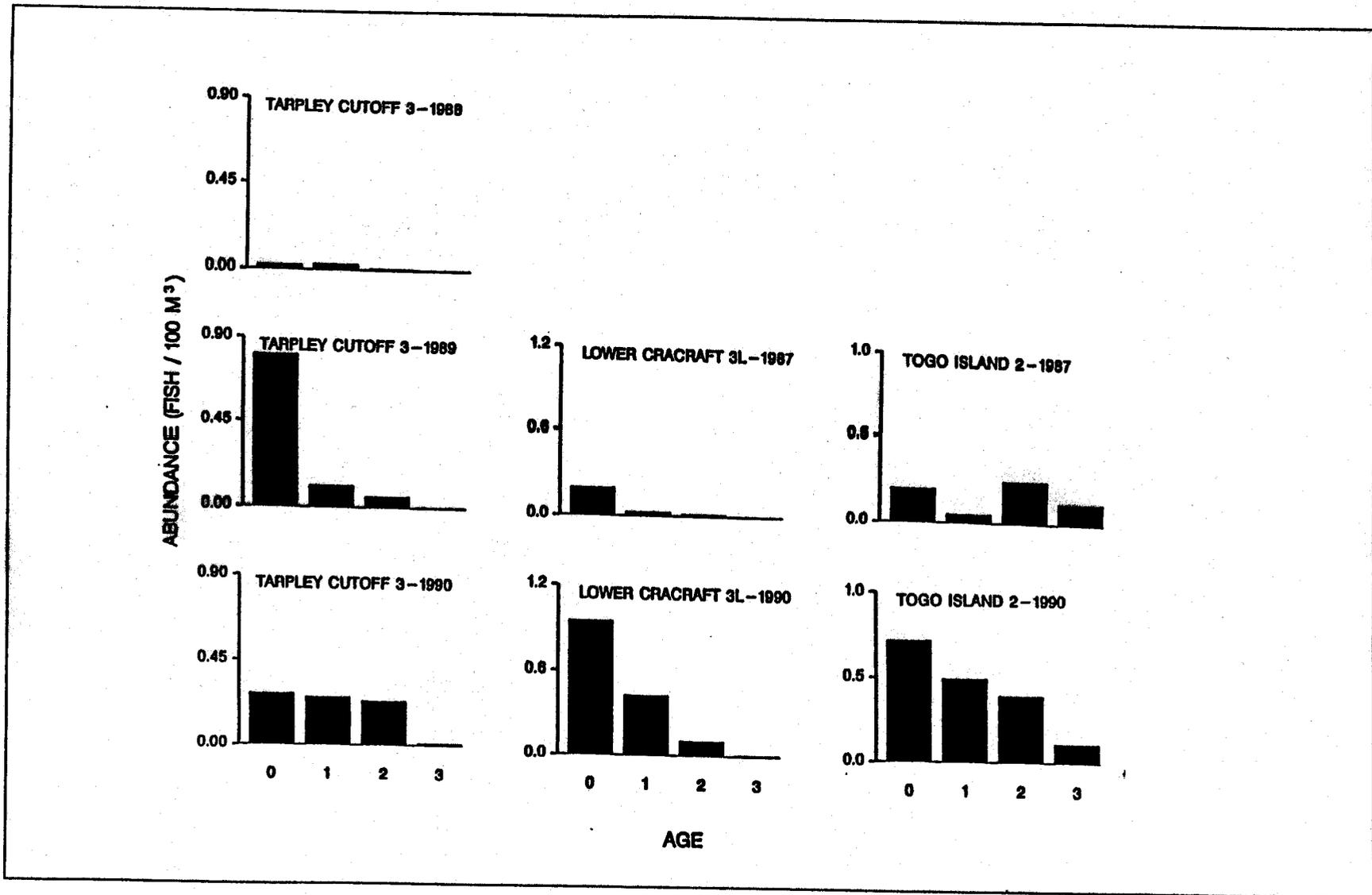


Figure A1. Comparisons of blue catfish age-frequency distributions within dike system pools across years

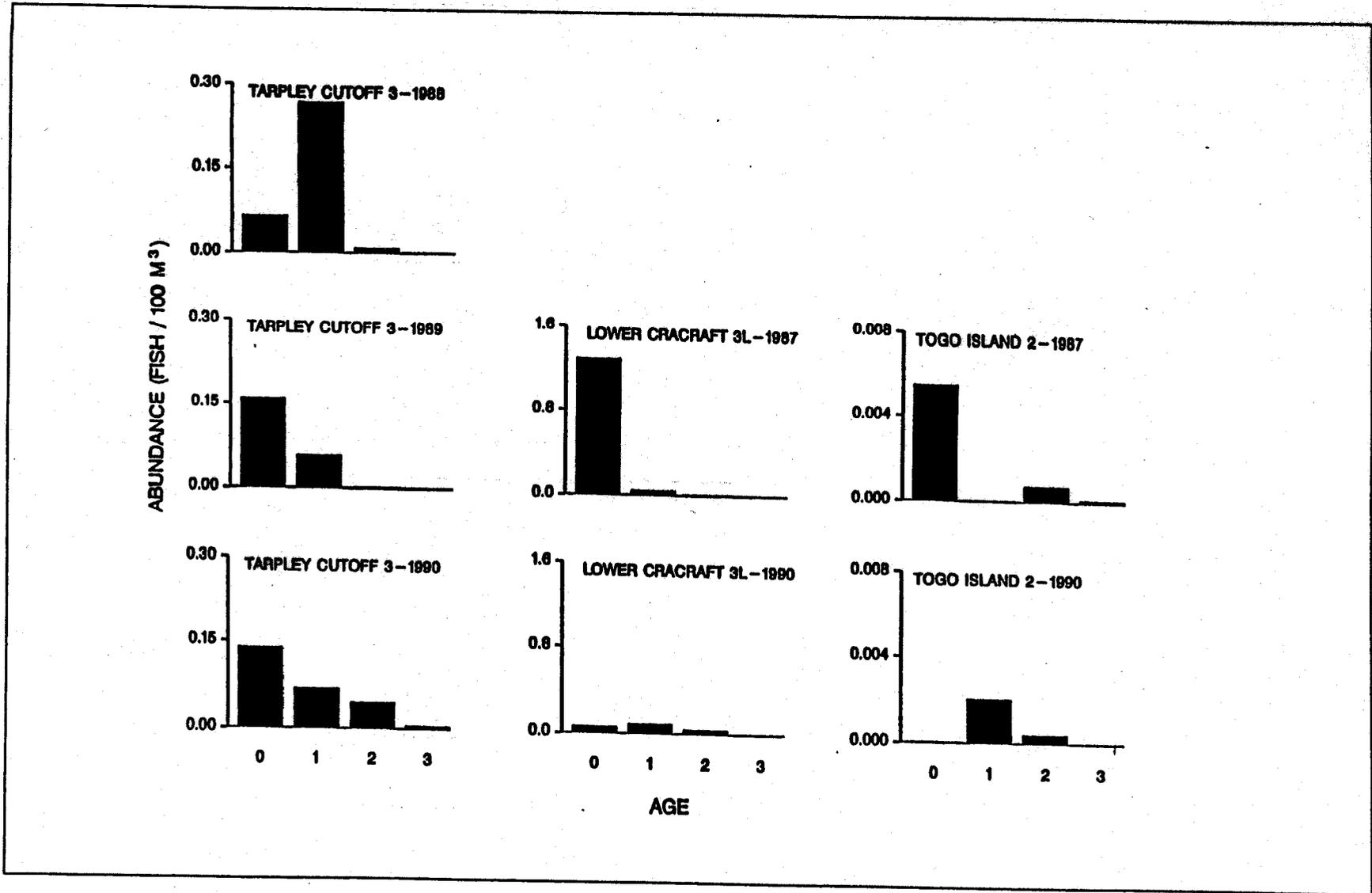


Figure A2. Comparisons of channel catfish age-frequency distributions within dike system pools across years

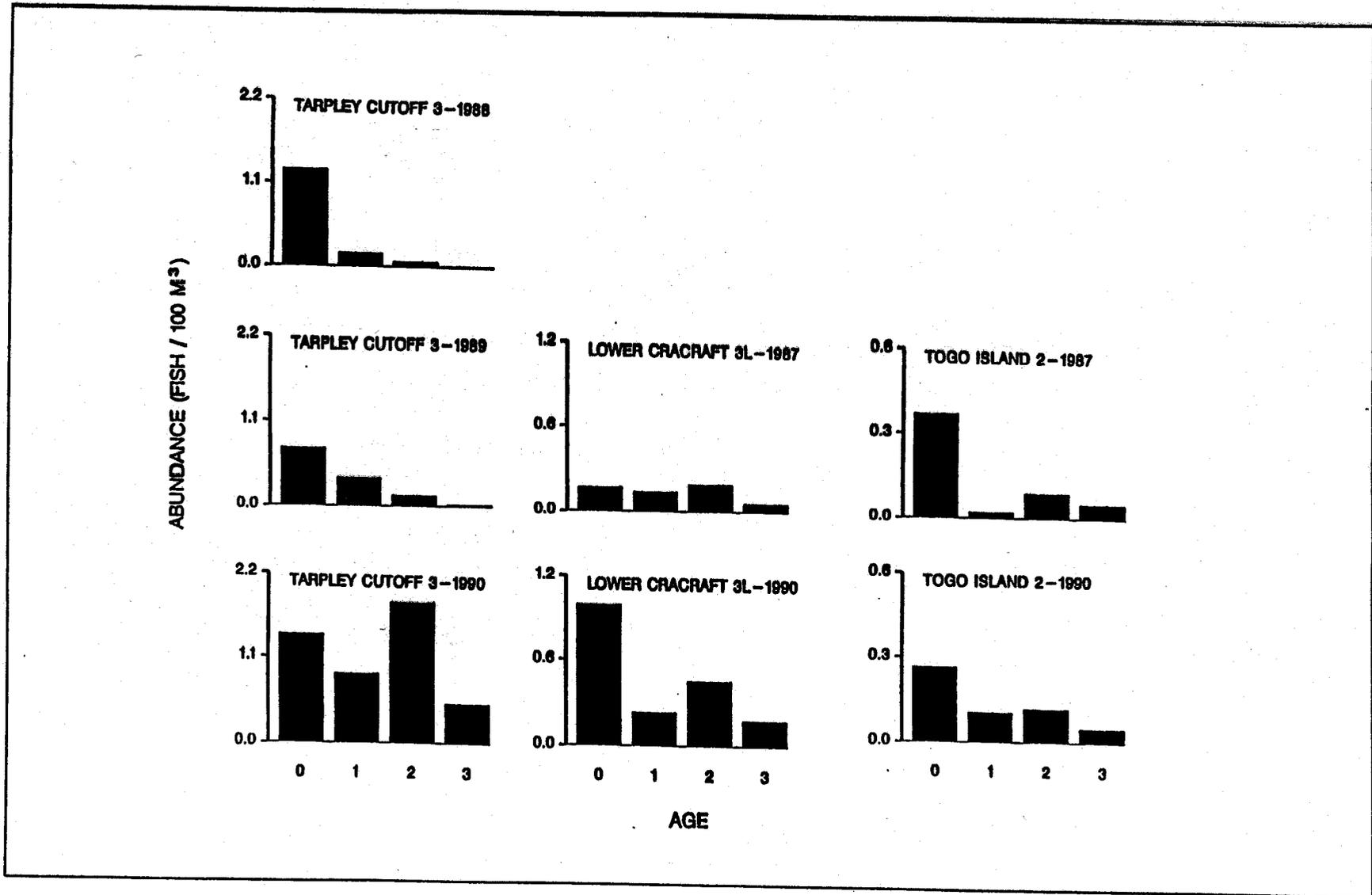


Figure A3. Comparisons of freshwater drum age-frequency distributions within dike system pools across years

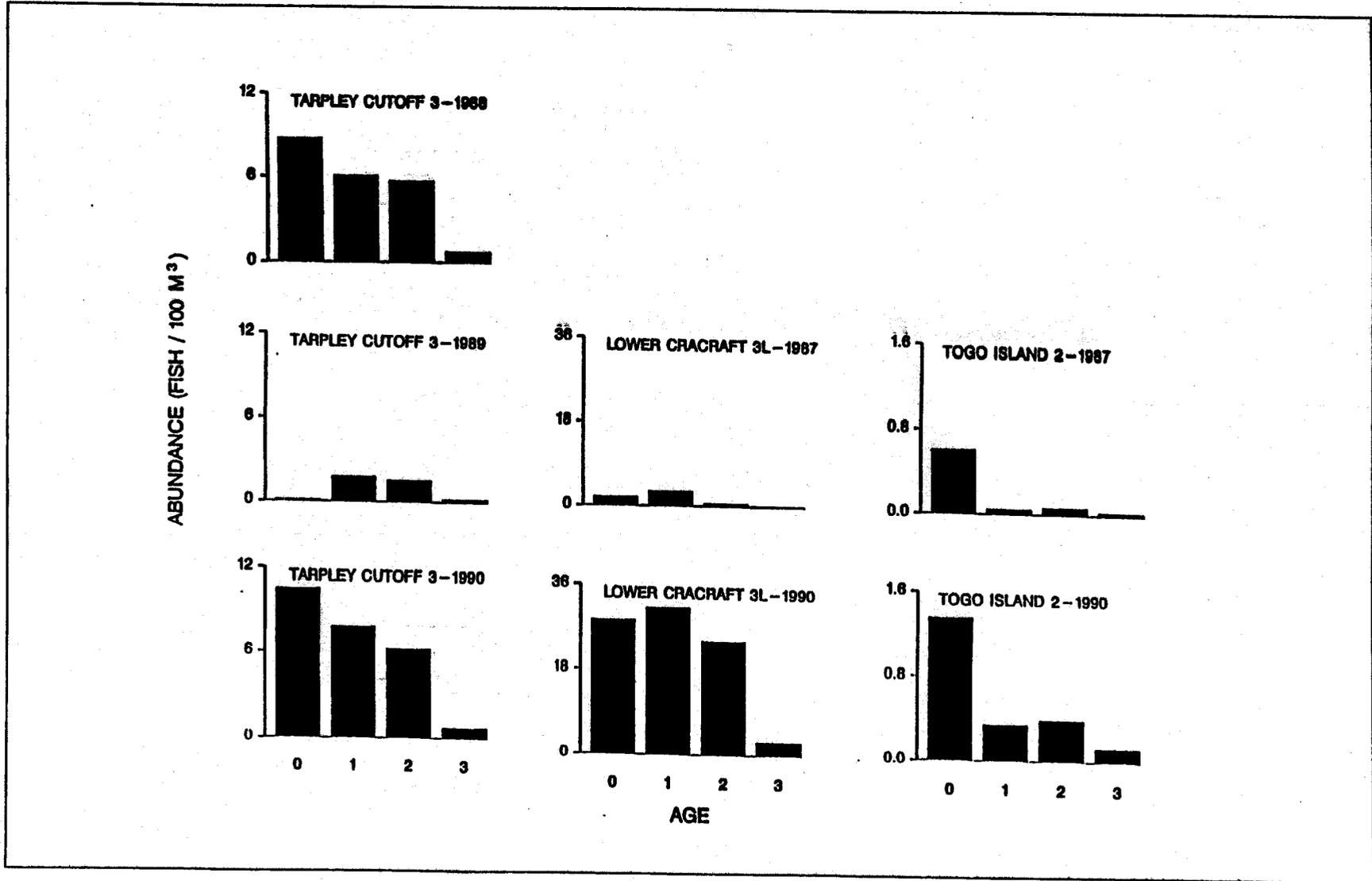


Figure A4. Comparisons of gizzard shad age-frequency distributions within dike system pools across years

Appendix B Fish Age-Frequency Distributions Among Dike System Pools Within Years

(Fishes were from dike-field rotenone collections made from 1987-1990.)

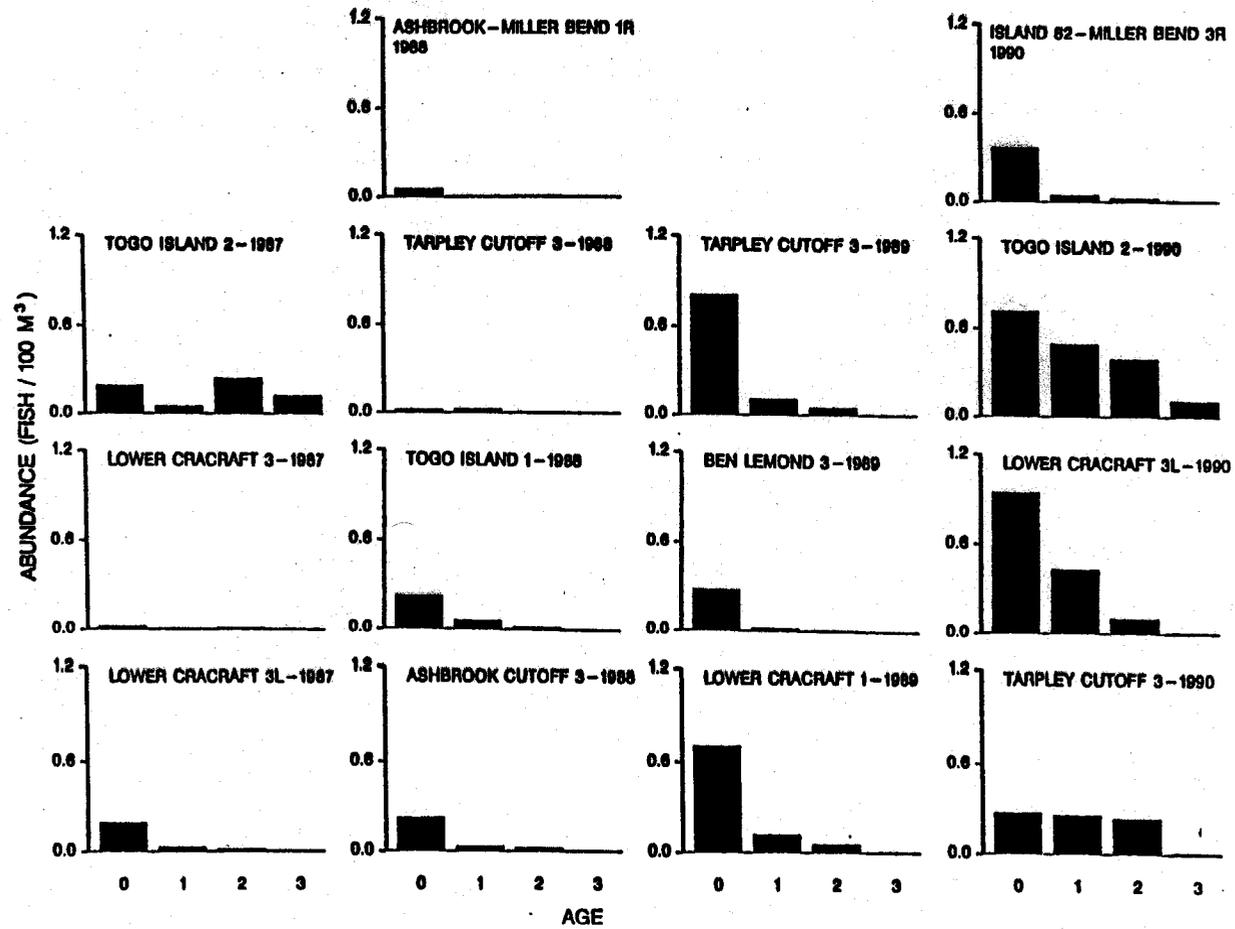


Figure B1. Comparisons of blue catfish age-frequency distributions among dike system pools within years

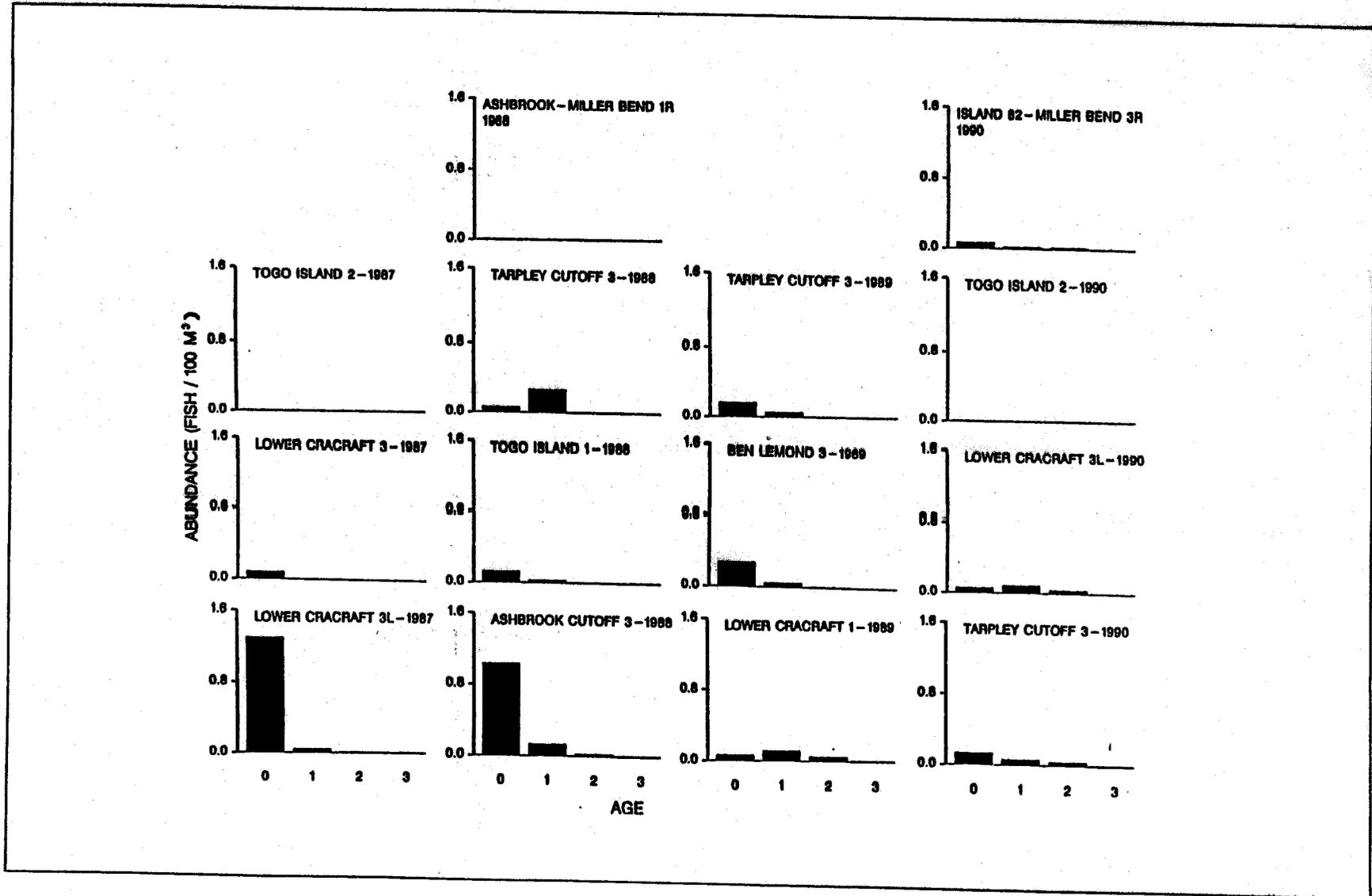


Figure B2. Comparisons of channel catfish age-frequency distributions among dike system pools within years

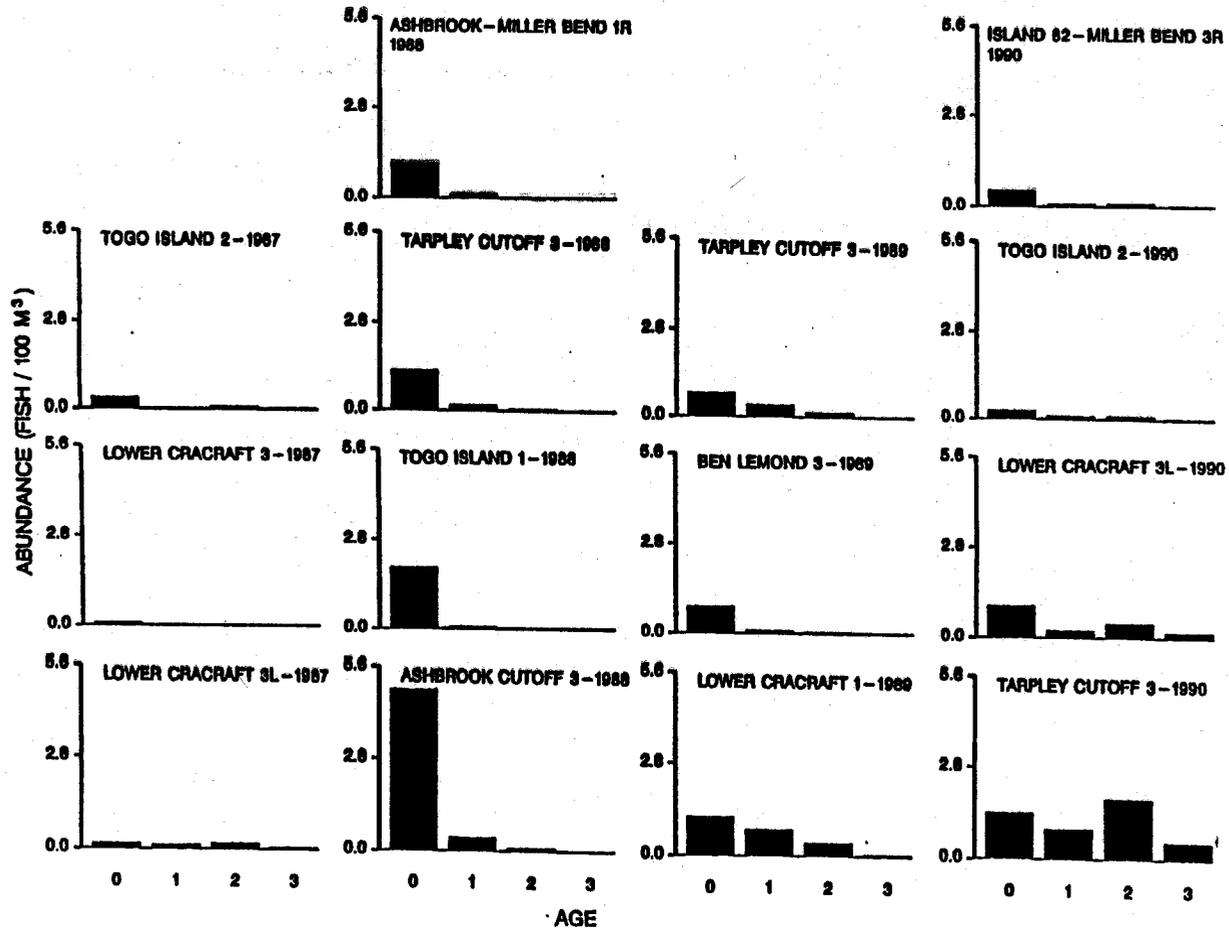


Figure B3. Comparisons of freshwater drum age-frequency distributions among dike system pools within years

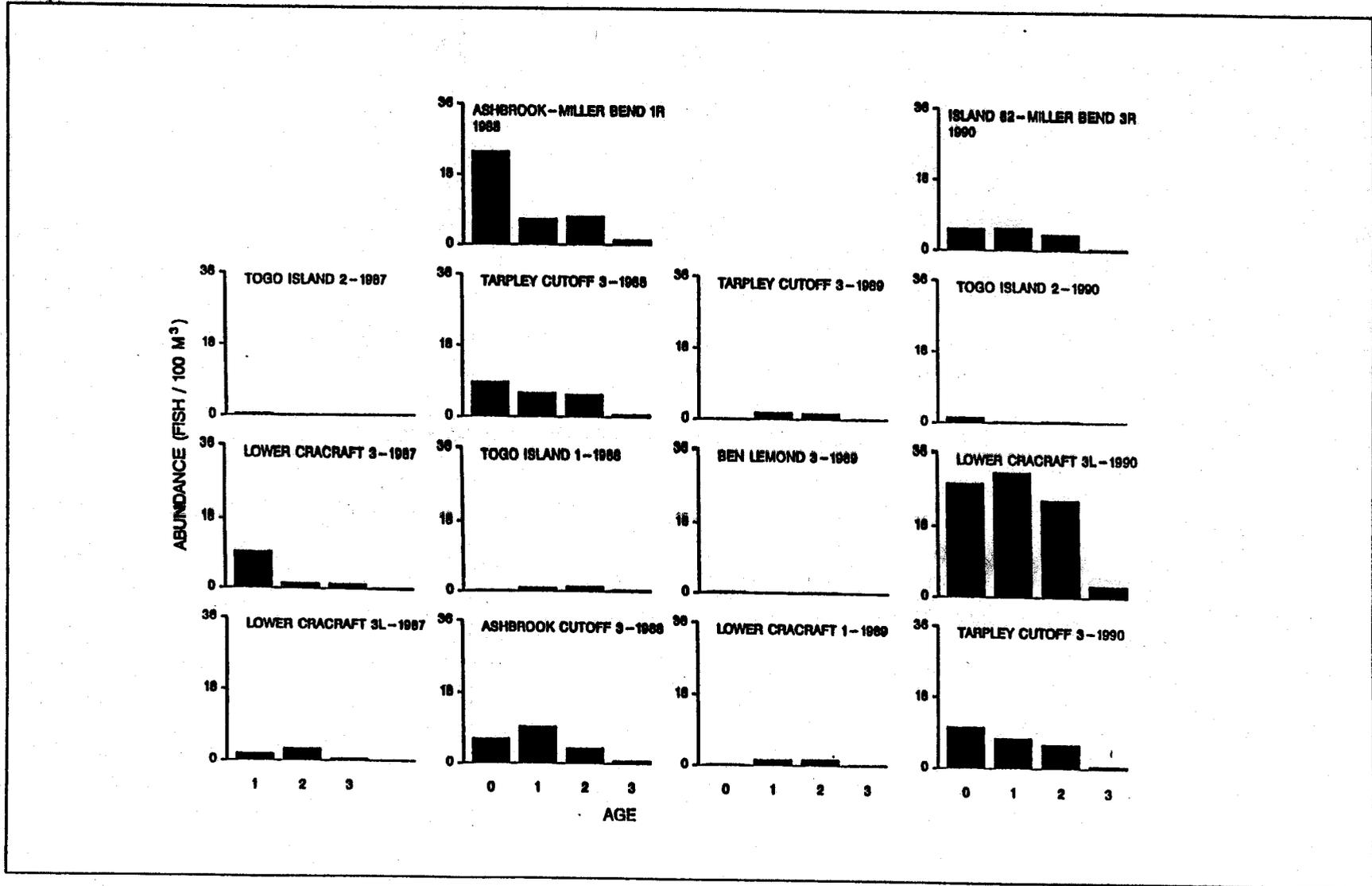


Figure B4. Comparisons of gizzard shad age-frequency distributions among dike system pools within years

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13. ABSTRACT (Maximum 200 words)

Growth and year-class strength of four commercially important fishes (*Ictalurus furcatus*, *I. punctatus*, *Aplodinotus grunniens*, and *Dorosoma cepedianum*) collected from dike system pools during September and October 1987-1990 on the Lower Mississippi River (LMR) were examined. The objectives were to examine the relationships between year-class strengths and the growth history of each species and 19 physicochemical characteristics of the LMR. The determination of age-class structure and growth was made using various calcified structures from individual fishes subsampled in 1989 and 1990. Age and length relationships were used to assign age-class membership, and from this mean cohort densities were calculated across dike system pools within years. For each cohort, analysis of variance (ANOVA) was used to detect pairwise differences in abundance and differences in mean annual growth increments. ANOVA was also used to examine the relationships between each of the 19 physicochemical variables and both mean annual cohort densities and mean annual growth increments for cohorts.

Age-0 abundances of blue catfish in 1989 and 1990 were significantly higher than in 1987 and 1988. A significant proportion of the variation in age-0 blue catfish abundance across years was explained by five physicochemical variables: discharge, number of days over bank, river stage, dissolved oxygen concentration, and total Kjeldahl nitrogen concentration. The 1987 cohort of freshwater drum was significantly less abundant than that of the

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1988 cohort, but neither year was significantly different from the intermediate year classes in 1989 and 1990. The number of days over 16 °C and the concentration of total organic carbon explained a significant proportion of the variation in age-0 freshwater drum abundance across years.

Growth increments from 1,573 individuals to assess differences in growth between years for age-0 and -1 blue catfish; age-0, -1, and -2 freshwater drum; age-0 channel catfish; and age-0, -1, and -2 gizzard shad were examined. There were no significant differences in age-0 growth increments for blue catfish in 1986 and 1988, but growth in these 2 years was significantly higher than in 1987 and 1989. The growth pattern of age-1 blue catfish resembled age-0 fish, with growth in 1988 being significantly higher than age-1 growth in 1987 and 1989. Age-0 incremental growth for channel catfish was similar to blue catfish, with significantly greater growth in 1988 relative to 1987, and growth increments for both catfishes were significantly related to the length of the growing season. In addition, growth of age-1 blue catfish was negatively associated with turbidity and positively associated with total organic carbon levels.

Growth of age-0 and -1 freshwater drum was similar over the years examined with the exception of 1988. Growth in 1988 for both age classes was significantly higher than other years. Age-0 and -1 growth was negatively associated with several variables related to the quantity of water in the river: discharge, days over bank, mean river stage, and (age-1 fish only) extent of overbank flooding. Age-2 freshwater drum grew slower in 1986 than in 1988 and 1989, but growth was not significantly related to measured physicochemical variables.

Growth of gizzard shad was variable, and the patterns of growth across years were different for the three age classes. For age-0 shad, growth was significantly lower in 1984 than from 1985-1988 and was positively associated with river temperatures over 12 °C. Age-1 gizzard shad exhibited significantly lower growth in 1985 than in 1987, and growth was negatively related to the duration and areal extent of overbank flooding. Growth patterns of age-2 fish resembled those of catfishes and drum, with significantly higher growth in 1988 than in 1986 and 1989. However, there were no significant associations between river physicochemistry and growth of age-2 gizzard shad.

Growth of age-0 and -1 blue catfish, age-0 channel catfish, and age-0 gizzard shad was positively associated with length of the growing season. Relationships between age-1 blue catfish growth and turbidity (negative) and total organic carbon levels (positive) may reflect growing conditions in the river during higher and lower water years, respectively. The negative relationships between age-0 and -1 drum and age-1 shad growth and river discharge-associated variables suggest that these fishes forage most efficiently in low flow conditions. Overall, there appear to be two general responses to growth, one related to length of the growing season and one related to discharge.