BIOLOGY OF PADDLEFISH IN A MISSISSIPPI DELTA RIVER

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INTRODUCTION

Paddlefish, *Polyodon spathula* (Walbaum), occur throughout the Mississippi valley and Gulf slope drainages but are declining in abundance (Burr 1978). Declines are attributed to overfishing for their highly prized flesh and caviar and from habitat alteration of large rivers (Eddy et al. 1928; Rosen et al. 1982; Ruelle and Hudson 1977). They are considered extirpated from several states (Gengerke 1986), and many states list the species as endangered, threatened, or of special concern. Complicating efforts at conservation, however, are deficiencies in data for local populations. In Mississippi, paddlefish are known from a wide variety of habitats (Baker et al. 1991) and are considered "secure within the state" (Mississippi Natural Heritage Program 1993), although the number of recent substantiated records (Ross and Brenneman 1991) is disparate from reported abundance prior to 1960 (Cook 1959).

There are numerous (> 555) scientific studies and popular accounts published of paddlefish biology (Graham 1986). Few, however, have been conducted in the lower Mississippi Basin, despite the species conspicuous position in local ichthyofaunas (Baker et al. 1991; Reed et al. 1992). Published studies exist primarily for populations in large rivers and reservoirs of the central northern states (e.g., Purkett 1963; Rosen and Hales 1981; Rosen et al. 1982; Ruelle and Hudson 1977; Pasch et al. 1980)

During recent fish surveys of the Big Sunflower River (Hoover and Killgore 1994), we (SGG, JJH, KJK) observed paddlefish at several locations, capturing only a few specimens. A fisherman (WEL) reported paddlefish in moderate numbers as by-catch from commercial fishing for buffalo suckers (*Ictiobus spp.*); these specimens were frequently dead or moribund, depending on time of year and length of time in net. Collaboration allowed us to conduct life history study with no extraneous pressures on the fish population (i.e., by retaining and processing non-viable fish), resulting in the first known field study of paddlefish in the Yazoo River Basin of the Mississippi delta. This paper presents work-in progress and describes: 1) relative abundance in three reaches of the Big Sunflower river; 2) associations between river stage and catch; 3) length-weight relationships; 4) food habits; 5) demography; 6) cranial morphology.

METHODS

Study Area. The Big Sunflower River is a 330 km, channelized tributary of the Yazoo River. The watershed is 7100 km^2 and dominated by cultivated agricultural land, bottomland hardwoods, scatters, brakes, and fallow land. Agriculture is intensive. Hypoxia (dissolved oxygen $\leq$ 3 ppm) and high turbidity (250-600 NTUs) are common (Hoover and Killgore 1994). Substrates are soft, unconsolidated mud. Alluvial deposits, ranging from sandy loam to clay, extend more than 45 m in depth (USACE 1955). Permanent tributaries of substantial flow are limited to a few streams. Gradients are low and erosion not a problem, historically (USACE 1955). Gravel and sandbars are rare, occurring in isolated patches.

Our study area consists of approximately 60 km of the Big Sunflower River, upstream from abandoned Lock-and-Dam #1: from Round Lake, north of Indianola in Sunflower County (Sec. 16, T19N, R4W), downstream to Osceola, east of Hollandale, Mississippi, in Washington County (Sec. 17, T16N, R5W). In summer 1993, we recorded channel widths of 33-99 m, maximum depths of 3-8 m, maximum velocities of 0-49 cm/s. "Design flow" for this reach is 410-580 m^3/s (USACE 1955). Tributaries are small, intermittently flowing bayous. Two permanent streams discharge near the upper and lower limits of our study area. Dawson Bayou, 27 km long, discharges in the upper reach near Kinlock; "design flow" is 69 m^3/s (USACE 1962). Bogue Phalia, is 130 km long, with permanent flow and frequent high discharge; "design flow" for the Bogue Phalia is 102 m^3/s (USACE 1955).

Field Collections. Dead and moribund paddlefish were obtained as commercial bycatch 1 Mar 94 - 28 Feb 95. Fish were collected with hoop nets when river was flowing, gill nets when river was static. Hoop nets were 5.0 m long, and mesh 7.62 cm; diameter of upstream hoop was

1.5 m. Gill nets were 2.4 m high, 91.4 m long, with a 10.2 cm mesh. Thirty nets (primarily hoop nets) were fished daily; number of sets exceeded 6,000. Number of net sets cannot be stated precisely since nets were sometimes sampled more than once a day and since some nets could not be fished during certain river stages. When a paddlefish was collected, location and date were recorded. If paddlefish appeared healthy, it was counted and released immediately; other specimens were retained and frozen. Data were obtained for 340 paddlefish, 206 of which were dead or moribund.

Laboratory Protocol. All paddlefish retained were sexed, weighed, and measured for total length (TL), and eye-to-fork length (EFL). Sex was determined by examination of gonads and sexually mature females (i.e., those with developing ova) were noted. Total length, the greatest dimension from most anterior point on the rostrum to the farthest tip of caudal fin, taken in a straight line, was measured to the nearest millimeter (Hubbs and Lagler 1949). Because of the extreme length of the rostrum and of the upper caudal lobe and because of the possibility of injury or wear to either biasing estimates of size, eye-to-fork length was also measured. EFL is the distance from the middle of the eye to the closest point in the concavity of the caudal fin (Ruelle and Hudson 1977). Fish were weighed to the nearest gram. Fish were examined for injuries, deformities, and anomalies which were described qualitatively and recorded.

Ninety-six stomach and the lower esophagus were removed, labeled, and preserved in 10% formalin. Stomach contents were processed by removing large organisms (aquatic insects) prior to subsampling smaller prey (zooplankton). Smaller prey were diluted to a known volume (e.g., 250-2000 ml), stirred automatically in a beaker with a magnetic stirrer, and 1-ml aliquots removed with a calibrated pipette. Subsamples were examined under 16 and 40 X magnification and all organisms identified and enumerated. A minimum of 3 subsamples was used to characterize gut contents of an individual fish. Variability among subsamples was minimized by thorough automatic stirring of sample and figure-8 manual stirring prior to withdrawing aliquot. When variation in subsamples was notable, additional subsamples were examined. Organisms were identified to the lowest practical taxon (typically order or family).

To evaluate intraspecific variation in morphology, cranial measurements were made on twenty-one specimens (411-705 mm EFL). Measurements included: interorbital distance (head width from eye to eye), distance from eye to spiracle, and rostrum length (middle of eye to anterior tip of rostrum). Rostrum width was measured at 10 equidistant points along the length. Measurements were made with dial calipers and were recorded to the nearest millimeter.

The left dentary bone from 30 fish was removed for aging, following methods of Adams (1942) and Reed et al. (1992). Specimens were preserved in 10% formalin and later transferred to 50% isopropanol for storage. Voucher specimens were deposited at: 1) Museum of Zoology, Northeast Louisiana University; 2) Department of Biological Sciences, University of Southern Mississippi; 3) Environmental Laboratory, Waterways Experiment Station. Tissue samples were sent to Upper Mississippi Science Center, National Biological Service. Additional information on availability and deposition of specimens is available from the senior author.

Analytical Techniques. Daily river stage was obtained at Little Callao gage (Sec.2, T15N, R5W) Lock and Dam #1 from the US Army Corps of Engineers, Vicksburg District. These were plotted as a hydrograph and catches of paddlefish projected onto corresponding days.

Total length (TL), eye-fork length (EFL), and weight were $\log_{10}$ transformed. Relationships between size and weight were described using linear regression; length as independent variable, weight as dependent variable. Robustness of individuals was expressed using a ponderal index or "condition" factor (Carlander 1969). Condition is calculated as:

$$K = \frac{W(10^5)}{L^3}$$

in which W = weight in grams,
L = length in mm, and
10^5 is used as a multiplier resulting in K values that approximate unity.

Condition may be calculated for any measurement of length. K_{TL} and K_{EFL} are condition factors based on total length and eye-fork length respectively.

Diet is described as a species-abundance list. Because of disparities among taxa in numbers of prey eaten (5 orders of magnitude), date were log-transformed (Steele and Torrie 1960) and very rare taxa (log abundance < 0.02 individuals/fish) deleted. Intraspecific variation in diet was evaluated using principal components analysis or PCA (SAS 1985). This technique provides data reduction by plotting points (96 paddlefish stomachs), originally plotted in a high-dimension space (18 prey taxa), into space of lower dimensions (two components) while preserving as much of the original configuration as possible. It allows visual representation of dietary differences among fish (based on spread of points) and identification of important prey (those responsible for greatest data set variance). We present an ordination based on the first two principal components (PCI, PCII), each with eigenvalues > 2.00, collectively accounting for 44% of data set variance. Variables identified with principal components exhibited loadings (eigenvectors) > [0.30] and were linearly correlated with each other ($r = 0.31 - 0.87$, $p < 0.01$). Guidelines for application and interpretation of PCA typically emphasize requirements of linear relationships among variables and potential for describing pattern among large numbers of observations and variables (Gaugh 1982; Ludwig and Reynolds 1988).

We evaluated intraspecific differences in diet using four variables: sex and size of fish, seasons, and place of collection. Gender was conclusively established for all fish, and individuals were classified as small (< 600 mm EFL), medium (601 - 700 mm EFL), or large (> 701 mm EFL). The study area was divided into an upstream reach (above Kinlock, MS), middle reach (Kinlock to Bogue Phalia) and lower reach (below Bogue Phalia). Food habits were evaluated for calendar spring-summer and autumn-winter. For each variable, we sorted data by class, calculated mean values, and standard errors (SE), for PCI and PCII coordinates, and constructed ellipses from axes of mean coordinates $\pm$ 2 SE. Each ellipse includes majority of observations (fish) for that class in multivariate (diet) space.

Intraspecific variation in cranial morphology was expressed using coefficients of variation, i.e., ratio of standard deviation to the mean (Steel and Torrie 1960), for 5 morphometric characters. Facial characters, exclusive of the rostrum, were presumed conservative and used as points of reference. These were interocular distance and distance from eye to spiracle, both standardized as ratios to EFL. Rostrum characters were presumed plastic. These were length and maximum width perpendicular to long axis of rostrum, both standardized as ratios to EFL. A third index of rostral morphology, the ratio of maximum rostral width to minimal rostral width near its base at the head, was used to describe degree of anterior expansion (i.e., spatulate morphometry of the "spoon" bill). Relationships among morphological variables were identified using Pearson product moment correlations (SAS 1985).

RESULTS

Distribution and Abundance. A total of 340 paddlefish were collected as bycatch on 56 occasions throughout the entire study area. Distribution was non-uniform; 23% were collected in a 2 km reach at Kinlock, MS, 51% from a 4 km reach downstream of Bogue Phalia, near the Osceola gravel pit. These two locations have deep pools and permanently flowing tributaries. Assuming 9,000 net sets (approximately 25 sets/day during 365 day period), paddlefish were caught in approximately 1-4% of all net sets (based on frequency of occurrence and total numbers caught respectively).

Scarring and morphological anomalies of the head were not uncommon. Twenty-seven fish (13%) exhibited scarring: 3 with severed rostra, 20 with damaged or irregular rostra, 7 with body gashes (includes 6 confirmed motor boat fatalities). Two fish exhibited apparent developmental anomalies: one a missing eye, another a missing dentary bone.

Paddlefish Catch and River Stage. Paddlefish were collected throughout the year and catches were comparable during high and low river elevations, but seasonal trends associated with hydrograph were apparent (Figure 1). Few fish were collected in July and August, during high water fluctuations; few fish were also collected in December and January, coinciding with low water temperatures and (presumably) reduced fish movement. Catches were strongly associated with falling and stabilized water levels while fewer fish were collected during periods of rising and cresting water:

River Stage	Number of fish
static	110
rising	8
cresting	18
falling	106
nadir	98

Length-Weight Relationships. Specimens ranged from 685-1505 mm TL, 397-975 mm EFL. Positive correlations between length and weight were highly significant ($p < 0.01$). Relationships were slightly more variable between TL and weight (R^2=0.87) than for EFL and weight (R^2=0.93) due to higher variability in rostral and caudal lengths compared with corporal length. Relationships between length and weight were:

$$\log_{10} WT = 3.64 \log_{10}(TL) - 7.35$$

$$\log_{10} WT = 3.35 \log_{10}(EFL) - 5.75$$

Mean condition factor was $K_{TL} = 0.39$ ($K_{EFL} = 1.7$). There was substantial variation, but gender-based differences in condition factors were not appreciable (Figure 2). Both males and females showed a weak, but significant increase in condition with total length size ($R^2 \leq 0.20$). Condition factors were also weakly correlated with eye-fork length in both genders; correlation was weaker in males ($R^2 = 0.10$) than in females ($R^2 = 0.14$.

Food Habits. Diets of paddlefish were dominated by zooplankton, with minor indication of intraspecific differences in food habits. Stomachs typically contained over a quarter of a million arthropods: 53% Copepoda, 45% Cladocera, 1% Ostracoda, 1% Insecta and Hydracarina (Table 1). Numerically dominant taxa included pelagic, fast-swimming Calanoida, and taxa that occasionally occupy substrates, such as Cyclopoida, Bosminidae, and some Daphnidae. Littoral Chydoridae, large benthic insects, and emergent/terrestrial insects were rare. Importance of Diptera may be underrepresented by numerical percentage. Chaoboridae and Chironomidae were consumed by the hundreds and are substantially larger than most zooplanktors.

Most variation in food habits was in consumption of Copepoda and non-littoral Cladocera (Table 2). The first two principal components account for 44% of data set variance, but points (stomach samples) were almost linearly arranged along PCI with only minor spread along the vertical component, PCII, which was identified with several insect taxa. Medium and larger individuals and females were more likely to feed on insects. Numbers of zooplankton consumed were lower in the upper reach and during autumn-winter (Figure 2).

Demography. Males outnumbered females 1.4 : 1.0. Annuli were observed on dentary bones of individuals representing a wide range of sizes of both sexes. Sections of dentary bones from larger females (849-975 mm EFL) had up to seven annuli indicating individuals in their eighth year of life. Smaller fishes of both sexes (397-469 mm EFL) typically showed 1-2 annuli, indicating fish in their second and third years. Three males (659 - 671 mm EFL), exhibited 12-13 annuli. These could indicate greater ages and lower growth rates, but were more likely lulls in summer feeding or false growth rings, ("halos") attributed by other researchers (Rosen et al. 1982; Reed et al. 1992).

Four mature specimens suggest that reproduction occurs Dec-Apr, possibly later. Two females containing eggs were collected in the Big Sunflower River on 12 Apr 94 and 14 Feb 95. The April specimen was the largest collected during the study: 1505 mm TL, 975 mm EFL, 15.4 kg. The February specimen was also very large: 1355 mm TL, 862 mm EFL, 11.9 kg. Eight annuli were counted on cross sections of the dentary bones of each of these fish. Two paddlefish collected from the Yazoo River 12 Dec 94 also contained eggs. Both fish were large: 1344 mm TL, 862 mm EFL, 11.5 kg; 1146 mm TL, 894 mm EFL; 11.4 kg. Ovaries of the second specimen weighed 2.3 kg. Eggs of all four specimens, however, appeared immature (i.e., they lacked a vitelline membrane).

Cranial Morphology. Variability in cranial morphometrics was low, but indices describing rostrum width were twice as variable as those describing facial characteristics and rostrum length:

Character	Coefficient of variation
Interocular distance	5.8 %
Eye to spiracle distance	6.5 %
Rostrum length	6.7 %
Maximum width of rostrum	10.7 %
Maximum/minimum width of rostrum	11.4 %

Significant negative correlations ($r < -0.44$, $p \leq 0.05$) existed between eye-fork length of paddlefish and the following indices: rostrum length, maximum width of rostrum, and maximum/minimum width of rostrum. This suggests that as paddlefish grow, their bills become shorter, narrower, and straighter.

DISCUSSION

Size, depth, and water quality of the Big Sunflower River are lower than many other systems in which paddlefish have been studied. Biological characteristics of this population, however, are consistent with those other studies. In the upper Mississippi River and lower Missouri Rivers, paddlefish congregated in deep holes, below tailwaters and behind structures (Moen et. al. 1992; Rosen et al. 1982); in the Big Sunflower River they were concentrated near mouths of a tributary and a gravel pit. Diets dominated by Copepoda and the assumption of open-water, surface feeding, were reported previously, but some studies document sand and benthos in stomachs suggesting that paddlefish may feed near the bottom (Stockard 1907; Eddy and Simer 1928; Rosen and Hales 1981). Age and length-weight relationships in the Big Sunflower were similar to those for Lake Pontchartrain, LA (Reed et al. 1992). Condition factors for Missouri River fish (K_{EFL} = 1.5) and for populations elsewhere were nearly identical to those of the Big Sunflower (Rosen et al. 1982; Carlander 1969). Changes in rostral length relative to body length were observed in oxbow populations in oxbow lakes of the Mississippi (Stockard 1907).

Some differences between Big Sunflower River paddlefish and other populations were observed, but none suggest a population in jeopardy. Ontogenetic changes in condition were not consistently observed in earlier studies, but this could be due to substantial point scatter in length-condition plots (Figure 2), geographic variation in morphology (Carlander 1969), or to local hydraulic conditions; riverine paddlefishes are more streamlined than those from oxbow lakes (Stockard 1907). Injury rates in the Missouri River (36%) and incidence of severed rostra (10%) were substantially higher than those in the Big Sunflower (13% and 1.5% respectively) (Rosen and Hales 1980). Male : female ratios in the Missouri River (0.9 : 1.0) were lower than those in the Big Sunflower, ratios on the Yellowstone River (2:1) higher (Rehwinkle 1978).

Because historical data are limited, assessment of long-term population trends is impossible. In the early 1900s, declines in paddlefish populations were observed in some oxbow lakes of the lower Mississippi Basin, but the species was still abundant and attained sizes up to 64 kg (Stockard 1907). Even by the early 1950s, numbers were still high and individuals 16-45 kg were not uncommon in areas where commercial fishing had been suspended (Cook 1959). Low densities in the Yazoo watershed were observed after 1952, but numbers are apparently increasing, and the status of the fish is considered "stable-increasing" (Gingerke 1986), although very large, presumably very old specimens were not observed. This concurs with personal observations of a professional fisherman (WEL) in the Big Sunflower River: comparable effort annually produced no paddlefish during 1969-1979 and increasing numbers of paddlefish from 1980-present.

ACKNOWLEDGMENTS

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Table 1. Composition of diets of 96 paddlefish from the Big Sunflower River, MS. Organisms < 0.1% indicated with a T.

	Mean Number/Fish	Percentage
Macrophytes[1]	0.9	T
Hydracarina	19.0	T
Crustacea		
Copepoda		
Small Male Cyclopoida	78,811.9	29.2
Other Cyclopoida	46,037.4	17.1
Calanoida	18,574.1	6.9
Total Copepoda	**143,423.4**	**53.2**
Cladocera		
Bosminidae	110,000.0	40.8
Daphnidae	12,862.6	4.8
Chydoridae	50.3	T
Total Cladocera	**122,912.9**	**45.6**
Ostracoda	2,339.5	0.9
Diptera		
Chironomidae (larvae)[2]	82.4	T
Chaoboridae (larvae)	671.6	0.2
Ceratopogonidae (larvae)	7.1	T
Chironomidae (pupae)	0.5	T
Chaoboridae (pupae)	22.7	T
Total Diptera	**784.3**	**0.2**
Other Insecta		
Ephemeroptera: Caenidae	0.2	T
Ephemeroptera: Ephemeridae	0.2	T
Odonata: Coenagrionidae	0.1	T
Hemiptera: Corixidae	0.1	T
Hemiptera: Notonectidae	0.1	T
Trichoptera: Hydropychidae	0.3	T
Coleoptera: Elmidae	0.2	T
Coeloptera: Staphyllinidae	T	T
Coleoptera: Other	T	T
Hymenoptera: Formicidae	0.1	T
Terrestrial insects	T	T
Total Miscellaneous Insecta	**1.4**	**T**
Total Prey	269,481.4	100.0

[1] Includes small leaves, duckweed (Lemna), and twigs.
[2] Includes Chironomini and Tanypodinae.

Table 2. Principal component analysis of diets of 96 paddlefish from the Big Sunflower River, MS: eigenvectors (loadings) of prey taxa were for the first two principal components. Asterisks (*) indicate prey identified with individual components.

	PCI	PCII
Eigenvalue	5.82	2.07
Percent variance	32.35	11.50
Macrophytes	0.15	- 0.29
Hydracarina	0.13	0.27
Small Male Cyclopoida	0.37 *	- 0.09
Other Cyclopoida	0.37 *	- 0.13
Calanoida	0.37 *	- 0.03
Bosminidae	0.32 *	- 0.03
Daphnidae	0.33 *	- 0.16
Chydoridae	0.07	- 0.21
Ostracoda	0.29	- 0.02
Chironomidae (larvae)	0.22	0.33 *
Chaoboridae (larvae)	0.25	- 0.07
Ceratopogonidae (larvae)	0.14	0.48 *
Chironomidae (pupae)	0.13	- 0.08
Chaoboridae (pupae)	0.16	0.13
Ephemeroptera: Caenidae	0.16	0.46 *
Trichoptera: Hydropychidae	0.13	0.32
Coleoptera: Elmidae	0.16	- 0.14
Coleoptera: Other	0.05	- 0.20

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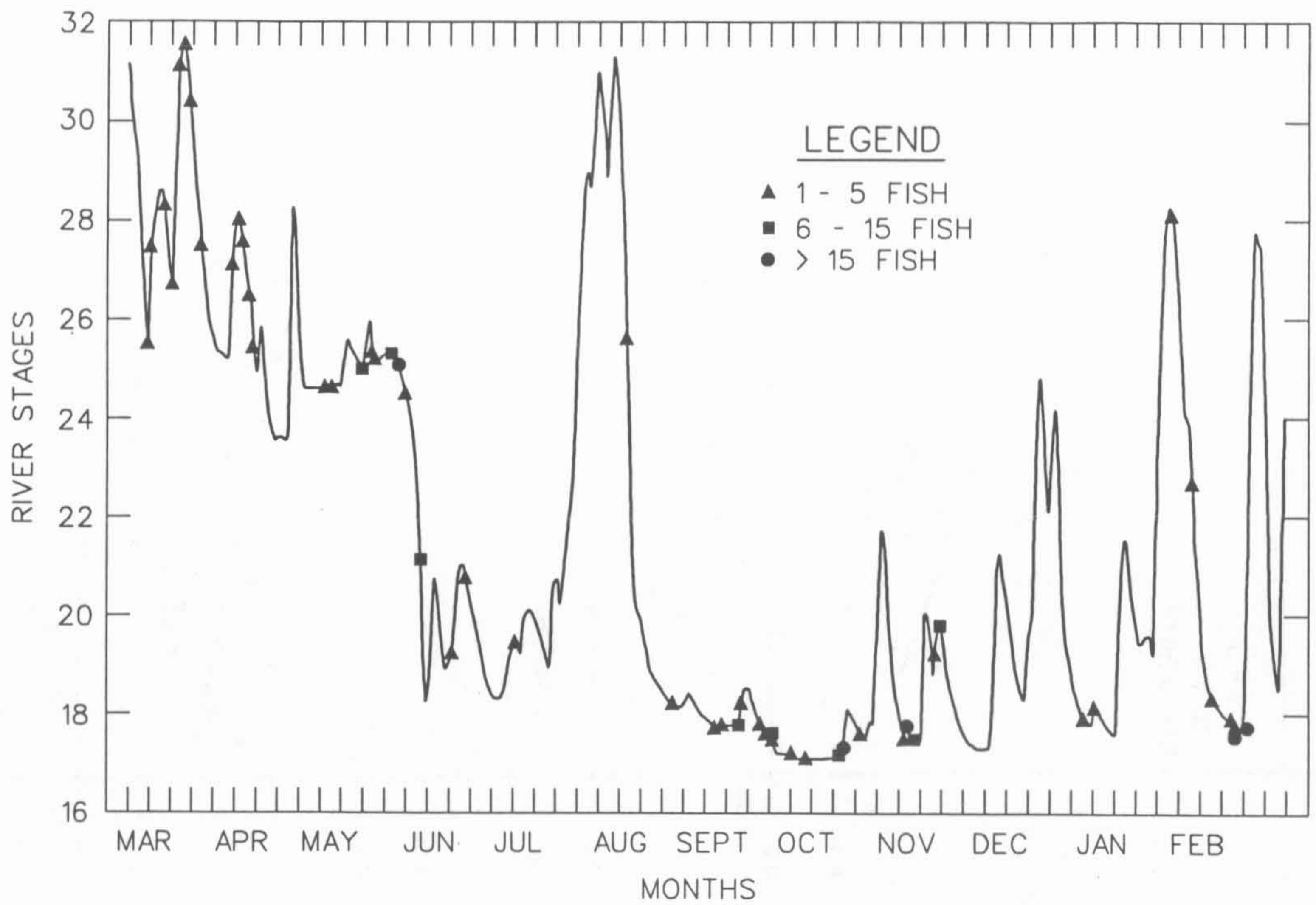
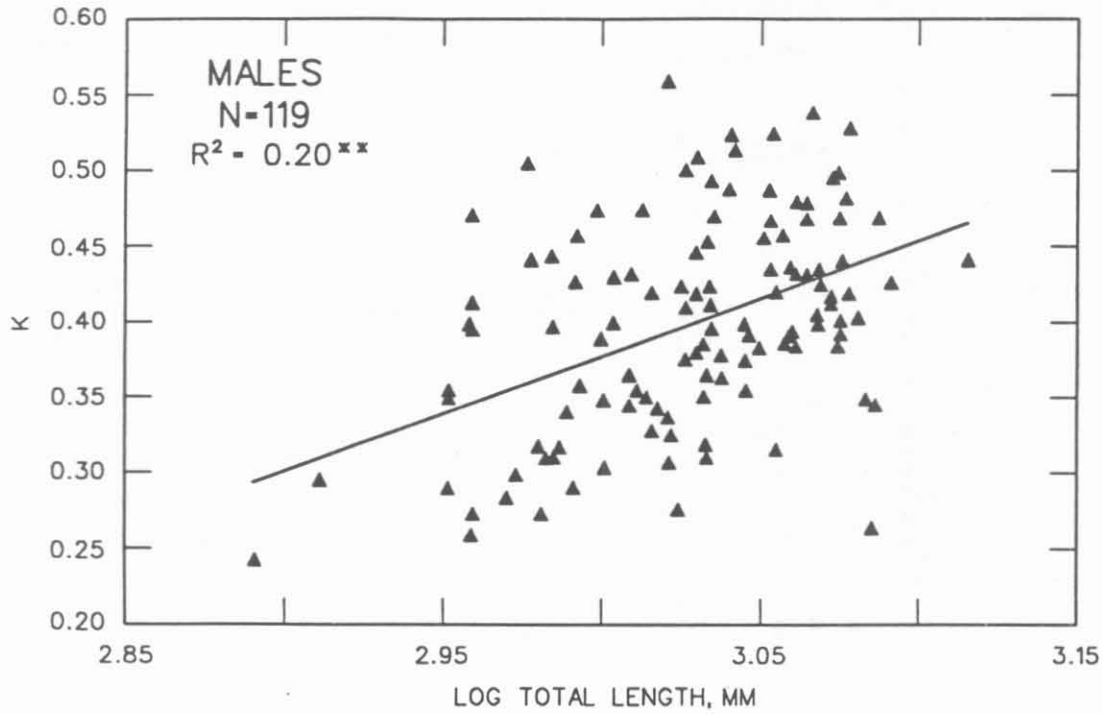


Figure 1. Hydrograph 1 Mar. 94 - 28 Feb.95 and daily paddlefish catch.


MALES
N=119
R^2 = 0.20**
K
0.60
0.55
0.50
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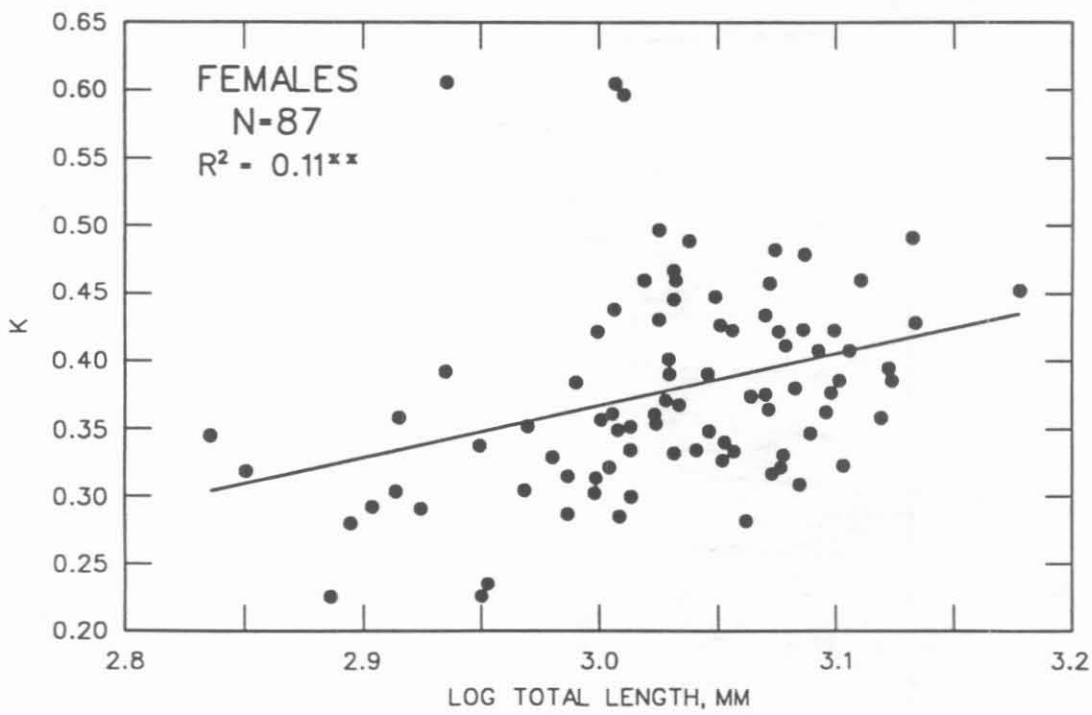
LOG TOTAL LENGTH, MM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N=87
R^2 = 0.11**
K
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0.60
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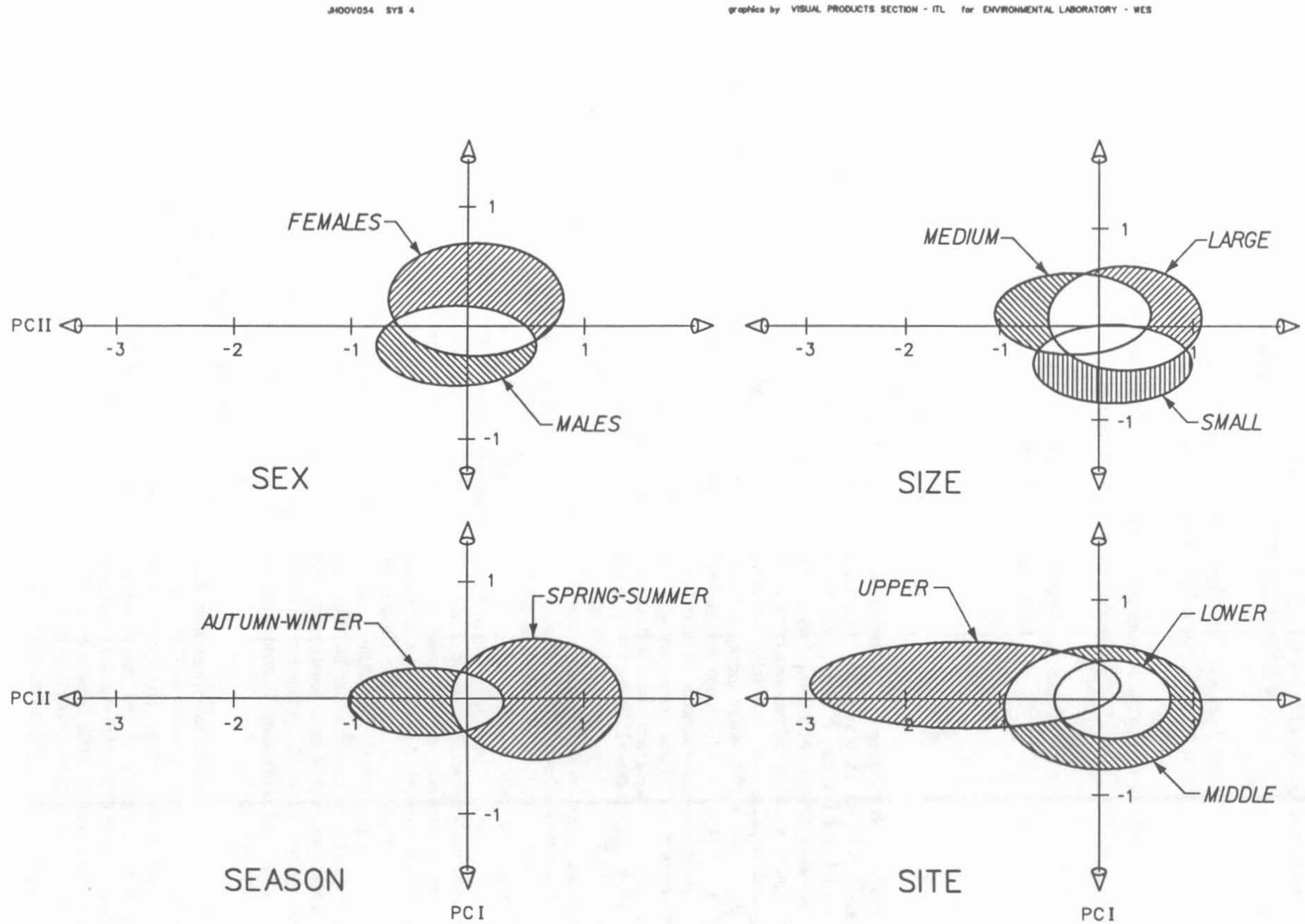
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PCI
-3
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