The Biology of the Paddlefish in Lake Cumberland, Kentucky[1]

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Abstract: The biology of the paddlefish (*Polyodon spathula*) in Lake Cumberland, Kentucky, was studied extensively from September 1982 to July 1984. Females were larger and lived longer than males. Males grew faster than females during the first 6 years of life and females more in later years. Twelve age groups were identified. Age groups V and VI represented 33% of the population. Males were more numerous than females in the winter and spring. Annual gonad development began in October and spawning occurred in late April and early May. Males matured at age V and females at age VIII. Prominent fat body development was related to gonad development. Cyclopoid copepods and cladocerans were the dominant food items. Tag returns were high indicating a high fishing mortality. Adult paddlefish congregated in large groups and moved extensively. Harvest data suggest the need for regulations governing commercial utilization of the species in Lake Cumberland.

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The family Polyodontidae consists of 2 extant species, *Psephurus gladius* (Martens) in the Yangtze River system in China and the paddlefish in the Mississippi River drainage system in North America. Paddlefish are widely distributed and are reported to extend into 22 states (Carlson and Bonislawsky 1981). Much work has been done on the biology of the paddlefish and Carlson and Bonislawsky (1981) provided an excellent literature review on the species.

An increased demand for paddlefish by both commercial and sport anglers and

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a concern for possible disruption of its breeding habitat by dam construction, has stimulated renewed interest in the life history of the species. The success of artificial propagation experiments by Meyer and Stevenson (1962), Purkett (1963*a*), Ballard and Needham (1964), Needham (1965), Friberg (1972), Russell (1973), and Kallemeyn (1974) have helped make the species a potentially manageable resource. Consequently, many states having exploitable populations of paddlefish have made a directed effort to identify and describe the resource.

Lake Cumberland, Kentucky, provided a unique setting for the study of the biology of the paddlefish. The paddlefish population in that water body represents a closed gene pool being separated from the Cumberland River paddlefish downstream by the Wolf Creek Dam and being free from any genetic input from upstream populations due to the headwater nature of the impoundment. Objectives of this study were to determine the dynamics of the paddlefish population in Lake Cumberland using mark and recapture techniques and to describe the biology of the species there.

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Methods

Lake Cumberland has a surface area of 20,336 ha at summer pool and is approximately 161 km long with a shoreline in excess of 1,700 km. The 2 major tributaries to the lake are the Cumberland River and the Big South Fork of the Cumberland River.

Paddlefish were collected from Lake Cumberland and its major tributaries from October 1982 through May 1984. Collecting trips were made from 1 to 3 times monthly, generally once monthly in the summer and fall and 2 to 3 times monthly in the winter and spring. No collections were made in July, August, and November 1983. From October through February 1982–1983 and 1983–1984, most collecting trips were made on the main body of the lake, while from March through June, most collections were made alternately on the 2 major tributaries. Fish were sampled with gill nets 91 m long 5 m deep tied (hobbled) to 4 m, of 10, 12.7, and 15.2 cm bar measure mesh. A net-day was 1 net fished for 24 hours. Nets were set across, or as close as possible to, the original river channel on the main lake. In the tributaries, nets were stretched from bank to bank across the channel. Effort on each collecting trip included 48 hours sampling time.

Paddlefish captured alive were weighed to the nearest 0.1 kg, measured to the nearest cm from the tip of the tail to the tip of the rostrum (TL), and tagged with a number 16 bird band around the dentary bone just lateral the symphysis. Live fish were revived alongside the boat before being released. Dead paddlefish were weighed, measured, the lower jaw removed, and the entire body cavity contents removed, placed in plastic bags, and fixed in 10% formalin. Tag number, date,

location, capture mesh size, weight and length of recaptured tagged paddlefish were recorded. The paddlefish were then released. Population estimates were provided by Dr. Kenneth Pollock, Department of Statistics, North Carolina State University, using the Jolly-Seber model (Seber 1973:196).

Data including complete body cavity contents, total body length (TL), eye fork length (EFL), body weight, and location of capture were obtained monthly from a local commercial fishing outlet near Lake Cumberland during the second year of the study (September 1983–July 1984). The body cavity contents, including data cards, were placed in large plastic bags and frozen in monthly lots.

Viscera were thawed and processed in the laboratory. Gonads were separated from the viscera, identified, and tagged as right and left side. Gonads were then separated from adjacent fat bodies, the sex recorded, and the weights taken for fat bodies and gonads. The hindgut was removed from the digestive tract and the weight of the combined foregut, midgut, and cecum recorded. The digestive tract, minus the hindgut, was opened, a food sample taken, and the weight of the tract recorded before and after the removal of the stomach contents. The region of the foregut from the papillae to the onset of stomach rugae was removed and weighed to determine the weight of the fat bodies. The liver was removed, cleaned, and weighed. The hindgut from every fifth fish was opened. Contents were removed, filtered, and all parasites counted and identified. The number of parasite cysts on the outer surface of the cecum and midgut and on the inner and outer surface of the hindgut were counted.

Fecundity was determined by subsampling using gravimetric methods. Approximately 10% of a gravid ovary was selected, weighed, the remaining fat body and membranes removed and weighed, and the eggs counted. This subsample count and fat body weight were then used to proportionally determine total fecundity and fat body content. Ova diameters were measured with a standard millimeter rule calibrated to 0.25 mm increments.

Age was determined by sectioning the dentary bone with cutting discs in a Dremel Moto-tool mounted in a fish-spine sectioning base. Four sections were taken from each jaw just laterad the symphysis, soaked approximately 10 minutes in a solution of 10 ml concentrated nitric acid and 90 ml 70% ethanol, washed in 95% ethanol, placed on glass slides in a thin layer of Perm-mount, and covered with a cover slip. Sections were read with a Bausch and Lomb TriSimplex microprojector at 12X magnification. Growth rings were counted following the method of Adams (1942). Distances between rings were measured from the center of the dentary along the mediary arm.

Results

A total of 28 collecting trips were made during the study, 16 during the first year from October 1982 through June 1983, and 12 during the second year from September 1983 through June 1984. Of 612 paddlefish captured during the study

(369 during the first year and 243 during the second year), 527 were tagged and released (317 in the first year and 210 in the second). An additional 469 paddlefish were purchased from commercial fishermen for biological measurements.

The average total length of paddlefish captured with gill nets during both study years was 129.6 cm (range 65 – 167). Most fish (63.5%) ranged from 121 – 140 cm TL. Mean total length was slightly longer in 1984 than 1983, 132.4 and 127.7 cm, respectively. Females had greater average total lengths than males, 144.8 cm vs. 134.2 cm, respectively, during both years of the study. Eye fork lengths of specimens collected during the second year exhibited the same trend. Eye fork lengths represented 66% of total length.

The average weight of paddlefish captured with gill nets during both years of the study was 9.7 kg (range 1.6 to 24.3 kg). Weights of fish taken with gill nets averaged 9.3 kg in 1983 and 10.4 kg in 1984. Eighty-two percent of all fish weighed between 5 and 13.6 kg with more fish occurring in that weight range in 1984 (89%) than in 1983 (78%). Paddlefish captured with snag line tackle averaged more in weight and length than net caught specimens, 12.5 kg vs 9.7 kg, and 138.4 cm TL vs 129.6 cm TL. Female weights averaged more each year than males, 10.5 kg vs 9.0 kg and 15.3 kg vs. 10.7 kg, for 1983 and 1984, respectively.

Eye fork lengths calculated at the time of annulus formation indicated that males grew faster and more in length than females up to the sixth year but grew increasingly less than females after the sixth year (Fig. 1). Annual weight increments for age groups II through IX ranged from 1.5 kg to 3.9 kg. No consistent trend of weight gain was observed throughout all age groups; the least weight gained, 1.5 kg, was between the fifth and sixth year. Males showed an initial faster weight gain than females averaging more each year through the fifth year. Females averaged more than males from the sixth year on.

Length-weight relationships were determined for male and female, and all paddlefish taken in 1984 using TL and EFL (Fig. 2). Length-weight formulae and $\log_{10}$ expressions are as follows:

TL Males $N = 307$	$\text{Log}_{10}W_{kg} = -2.49 + 2.08\ \text{Log}_{10}TL_{cm}$.
TL Females $N = 195$	$\text{Log}_{10}W_{kg} = -7.63 + 3.73\ \text{Log}_{10}TL_{cm}$.
TL Total $N = 502$	$\text{Log}_{10}W_{kg} = -5.73 + 3.12\ \text{Log}_{10}TL_{cm}$.
EFL Males $N = 283$	$\text{Log}_{10}W_{kg} = -3.79 + 2.65\ \text{Log}_{10}\ EFL_{cm}$.
EFL Females $N = 186$	$\text{Log}_{10}W_{kg} = -5.09 + 3.09\ \text{Log}_{10}EFL_{cm}$.
EFL Total $N = 469$	$\text{Log}_{10}W_{kg} = -4.85 + 3.01\ \text{Log}_{10}EFL_{cm}$.

Coefficients of condition (K) determined from eye fork lengths were greater than total length values (1.55 vs 0.45), but showed the same trends for all comparisons. Paddlefish taken in gill nets had slightly lower values than those taken with snag lines (0.44 vs 0.45). K values increased with age and were slightly greater in females than males (1.59 vs 1.53 for EFL and 0.48 vs 0.46 for TL). Seasonally, K values fluctuated in both sexes with peaks occurring in November, April, and July.

A total of 469 paddlefish were aged in the study. Twelve age groups were identified, II through XIV, with no age XII specimens being present. Ages V and

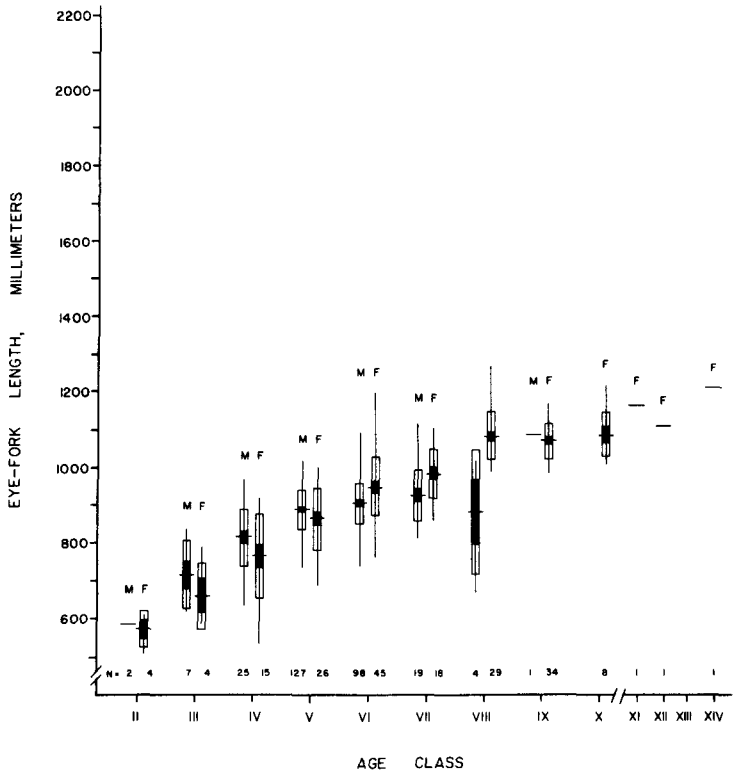

Figure 1. Average eye-fork length measurements in millimeters of male and female paddlefish by age groups collected from Lake Cumberland, Kentucky, September 1983–July 1984. Horizontal line represents the mean; the vertical line, the range; the open box, 1 standard deviation; and the black box, 1 standard error of the mean.

VI represented the dominant groups making up 33% and 30% of the total, respectively. Males and females had different age group compositions with age groups V and VI dominating in males with 45% and 34% of the individuals, respectively. Females had 5 age groups, V through IX, that represented from 10% to 24% of the total.

The rate of growth of the body and the rostrum was compared to determine any differential growth rates. A close relationship was observed between the 2 growth features among harvestable adults as indicated by the regression formula, $Y = 17.16 + 3.67\,X$, with an r value of 0.68 ($N = 469$). The growth of the rostrum was determined to begin at a total length of 17 mm and represented an average of 27% TL for harvestable adults.

Of 503 individuals sexed in the study, 307 males and 196 females were observed, a significant difference ($P \leq 0.05$). Sex ratios varied seasonally. There were

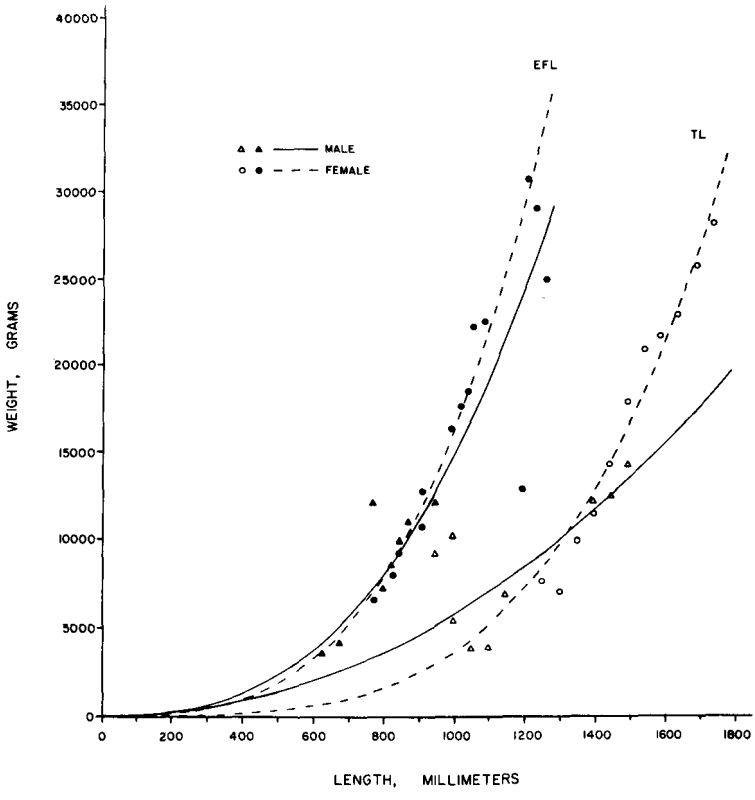

Figure 2. Length-weight relationship curves for eye-fork and total lengths of male and female paddlefish collected from Lake Cumberland, Kentucky, September 1983–July 1984.

significantly more males than females in the winter (118 vs 35) and spring (92 vs 61) and statistically similar numbers in the fall (81 and 72) and summer (16 and 28). Females appeared with greater frequency than males only in the summer.

Gonad weights, total and separate, were determined for 290 males and 140 females during the second year of the study. In both sexes, the weight of the left gonad averaged slightly more than the right (31.5 g vs 26.9 g in males and 194 g vs 186 g in females). Male gonads showed a high degree of development from November through April with peak weights occurring in November and December and minimum weights in June and July. Females exhibited a different pattern of gonad development. Prominent peaks of ovarian development occurred in November-December, February, and April, and low values in May, June, and July.

Gonosomatic ratios showed similar patterns to that of gonad weights for both sexes. Maximum values for males of 0.9% and 0.8% were observed in November and December, respectively, and decreased to 0.1% in July (Fig. 3). Females exhibited maximum values in February, April, November, and December, with 6.6, 7.8,

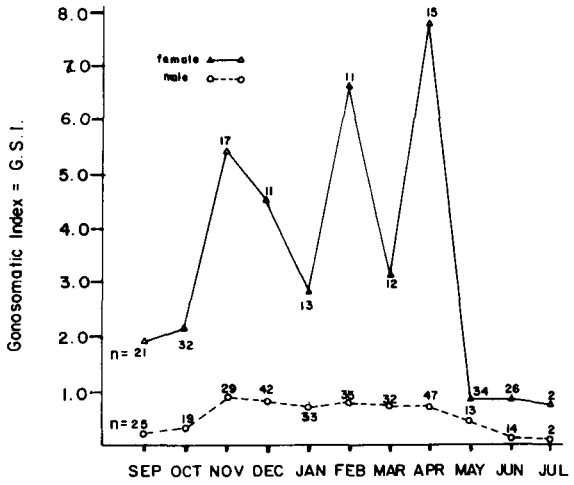

Figure 3. Gonosomatic indices of male and female paddlefish collected from Lake Cumberland, Kentucky, September 1983–July 1984.

5.4, and 4.5%, respectively. Sexual maturity as determined by gonosomatic ratios occurred at age V (0.7%) in males and at age VIII (3.0%) in females. Sexually mature males (age V≥) were observed throughout the lake during the second year of the study, whereas mature, gravid females were concentrated in the upper tributaries of the lake and mature, non-gravid females were found in the main lake.

Gravid females were collected in October, November, December, February, March, and April. Estimates of the number of mature ova from five specimens taken during these months ranged from 186,266 to 311,450, with an average of 226,787. No correlation was observed between ova number and fish size. However, ova diameters ranged from a mean of 2.0 mm in October to 3.0 mm in April.

Throat fat, liver weight, and gonad fat body weights expressed as a percent of total body weight were inversely related to gonosomatic indices in females. In males, liver and throat fat indices were inversely related to those of the gonads. Also, gonad fat bodies in males were small in comparison to those in females and were directly related to gonad development.

Cyclopoid copepods and cladocerans (*Bosmina*) were the dominant food items of paddlefish during most of the study. Other common food items were midges in September, October, May, and June and prominent green masses of algal and/or plant cells during October. Stomach contents were less in February than any other month.

During the study, 527 paddlefish were tagged and released and 88 were recaptured for a total return of 17%. Returns were similar for each of the 2 years, 11.7% (37 of 317) in 1982–1983, and 12.4% (26 of 210) in 1983–1984. Twenty-five fish captured during the first year were caught a second time during the second year of the study, which, when coupled with the first and second year recaptures, produced the higher total recapture rate. The estimate of the number of harvestable sized

paddlefish in Lake Cumberland was limited to data taken during the first year of the study. An estimate of 13,000 was determined using commercial fishing data for the months of March and April 1983.

A total of 586 net days, 335 the first year and 251 the second, were fished during the study. More paddlefish were caught per net day during 1982–1983 than 1983–1984, 1.1 vs. 1.0, respectively. However, greater weights per unit effort were taken during 1983–1984 than 1982–1983, 10.9 vs. 10.2 kg, respectively.

Of 88 paddlefish recaptured in the study that had been at large at least 2 weeks, 74 indicated some movement. As a general rule, fish in the lake proper tended to move into the uplake tributaries twice during the year, September-October and April-May. This movement into the tributaries did not proceed as far upstream in the fall as in the spring. Of all recaptured specimens, 34% had moved upstream at the time of recapture. In the winter and spring, many recaptured fish were observed to move well upstream in the Cumberland River only to reverse their direction, move back down to the main lake body, and up the South Fork, a distance of up to 110 km in as little as 2 weeks. Thirty-three percent of all recaptured paddlefish exhibited this behavior. A reverse pattern from the South Fork to the Cumberland River was observed in only 5 cases, 4 of these occurred in May and June, after spawning was completed.

Tagging and movement patterns indicated the paddlefish moved in large groups. Of 21 fish released on the Cumberland River on 5 March 1983, 15 were recaptured an average of 5 weeks later an average distance of 78 km away in the Big South Fork.

A total of 27 commercial fishermen purchased licenses to fish Lake Cumberland during the 1983–1984 fishing year. Of these, 10 responded to a questionnaire regarding their fishing activity during the previous fishing year. A total of 75,528.7 kg of paddlefish was captured by these 10 fishermen over the 2 years of the study for an average harvest of 1.86 kg/ha/year. More fish were caught during the second year of the study, 3,843 vs 3,289, with a greater harvest ratio, 2.18 kg/ha vs 1.5 kg/ha, than the first year, respectively. Whereas fishing effort was distributed throughout the lake, most fish were caught in the Big South Fork during September-November and May-June.

Parasites and outer gut wall encystments were counted from the foregut and hindguts of 87 paddlefish, 39 females, and 48 males. Two kinds of parasites were observed, the cestode *Marsipometra* and the nematode *Comallanus*. Tapeworms outnumbered nematodes by approximately an 8:1 ratio. Gut wall encystments were more numerous in the hindgut wall than in the foregut and were most abundant throughout the gut from February through June. Cestode incidence was greater in the hindgut than in the foregut for all months except February. Cestode densities were considerably greater in May and June than during the remaining months.

Discussion

Much variability exists in the growth of paddlefish, especially early growth, as reported by Houser (1965), Purkett (1963*b*), Pasch et al. (1980), and Hoyt (1984). Length, weight, and age information gathered on the paddlefish population in Lake Cumberland indicated that the species grows faster, reaches sexual maturity sooner, and has a faster recruitment potential than similar populations in most large rivers. Whereas a maximum age of 14 was observed in Lake Cumberland, Gengerke (1978) reported Mississippi River paddlefish to represent 18 age groups; Rosen et al. (1982) observed 26 age groups in Missouri River fish; Purkett (1963*b*), 30 age groups in Osage River, Missouri, fish; Robinson (1966), 25 year classes in Montana's Missouri River and Yellowstone River fish; and Elser (1973), 25 years in Garrison Reservoir on the Missouri River in North Dakota. Other studies reporting paddlefish age group compositions similar to that observed in Lake Cumberland, Kentucky, include Adams (1942) who observed 14 age groups in the Mississippi River in Illinois, lakes Tippecanoe and Manitou in Indiana, and Lake Okobogi in Iowa; Boehmer (1973) observed 16 age groups in Gavins Point Dam tailwaters on the Missouri River in South Dakota and Nebraska; and Combs (1981), 13 years in the Neosho River, Oklahoma. Several biological explanations are possible to explain differences in age group compositions; the likelihood of sampling bias, the time of year most sampling was conducted, the influence of varying environmental conditions among water bodies, and the type of sampling gear used. Also, interpretations of dentary growth annuli versus disturbance annuli in determining age counts might be responsible for much of the age group variation present in the paddlefish literature today. In this study, only prominent annuli bodies were recorded, halo bands being excluded from the age counts.

Lake Cumberland paddlefish represent a fast growing, medium lived population. Alexander and Peterson (1982) suggested a mean annual growth of 25 to 30 mm for Norris Lake, Tennessee, paddlefish. Annual increments averaged 86 mm over the first 10 years of growth in the Lake Cumberland population. Likewise, average EFL coefficients of condition for Lake Cumberland paddlefish (1.55) were slightly greater than those reported in the Missouri river below Gavins Point Dam (1.50) by Rosen et al. (1982).

Sexual dimorphism as reported by Alexander and Peterson (1982), Rosen et al. (1982), and others was not conspicuous in this study. Females were heavier bodied than males but not to the extent reported by Alexander and Peterson (1982) and Friberg (1972). Breeding tubercles were common among sexually mature females and males.

Reproductive behavior and development in Lake Cumberland paddlefish was similar to that reported in the literature. Sex ratios of males to females ranged from 1.5 to 3 during the winter and spring months prior to spawning and approximately 1:1 in the summer and fall following spawning. Alexander and Peterson (1982) and Rosen et al. (1982) among others reported similar ratios. Robinson's 1966 report

of a 36:1 ratio was well out of line with the observations in the present study for any season.

The presence of favorable environmental conditions of high, fast flowing water, and water temperatures of 10° to 15° C (Purkett 1963*a*, *b*; Pasch et al. 1980; Hoyt 1984) were necessary in Lake Cumberland to bring about the final concentration and movement of paddlefish into the 2 headwater tributaries for spawning. Spawning occurred during the last 2 weeks of April and the first 2 weeks of May in Lake Cumberland.

The onset of sexual maturity, as determined by gonosomatic ratios, at Age V for males and Age VIII for females in Lake Cumberland was earlier than that reported in the literature. Whereas several studies indicate sexual maturity occurs earlier in males than females (Friberg 1972, Elser 1973, Russell et al. 1980, Carlson and Bonislawsky 1981), only Russell et al. (1980) and Carlson and Bonislawsky (1981) suggested sexual maturity occurring as early as proposed herein for Lake Cumberland paddlefish. Sexually mature, non-gravid females occurring in the lake portion of Lake Cumberland while only mature, gravid females concentrated in the upper tributaries of the lake during the spawning season lent credence to the theory proposed by Houser and Bross (1959), Meyer (1960), and Carlson and Bonislawsky (1981) that mature female paddlefish do not spawn every year, but do so on an alternate year basis.

Fecundities of Lake Cumberland paddlefish were similar to those reported by Robinson (1966). Likewise, no correlation was observed between fish size and egg size in either this study or that of Robinson's (1966). Mean ova diameters at the time of spawning were slightly larger in Lake Cumberland than reported by Stockard (1907), Larimore (1950), or Robinson (1966).

The development of the gonads and concomittant decrease in prominent fat storage bodies in paddlefish as observed in this study have not been reported in the literature. Paddlefish have distinct fat storage bodies in the roof of the foregut and alongside the gonads, coupled with fat storage in the liver. These bodies were observed to serve as important energy sources in the development of the gonads in Lake Cumberland paddlefish; their sizes were inversely related to gonosomatic indices.

The foods of Lake Cumberland paddlefish, mainly copepods, cladocerans, and midge larvae, were similar to other reports for the species (Carlson and Bonislawsky 1981, Rosen and Hales 1981).

Return of tags in the present study was similar to other tagging studies on the species, ranging from 7 to 17 percent (Friberg 1971). This rate of return implies a high fishing mortality, an important consideration in management planning. The population estimate determined for the Lake Cumberland paddlefish population was considered an underestimate with a large standard error, but it was consistent for all 3 sets of data tested. The estimated harvestable population of 0.6 fish per surface hectare of lake water was similar to that determined by Alexander and Peterson (1982) for Norris Reservoir, Tennessee.

Paddlefish have been documented to move great distances and exhibit complex movement patterns. Most movements described in the literature are related to prespawning behavior. In Lake Cumberland, paddlefish moved into upstream tributaries in the early fall and spring. These movements were complex, moving well up into 1 tributary and then reversing the direction and moving up into the other tributary. These movements were correlated with the onset of gonad development as early in the fall as October and were probably stimulated by changing day length and water temperature. Alexander and Peterson (1982) also observed similar intralake movements in Norris Lake, Tennessee.

The commercial harvest of paddlefish from Lake Cumberland averaged approximately 3,500 individuals weighing 43,750 kg per year during the 2 years of the study. Based upon an estimated 13,000 harvestable individuals in the lake, the age structure of the population, the fishing mortality of the species, and the 15–18% harvest rate suggested by Gengerke (1978) and Alexander and Peterson (1982), the rate of removal is too high and suggests that the harvest of paddlefish should be regulated.

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