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# Condition Factors and Length-Weight Relationships of Pond-Cultured Paddlefish *Polyodon spathula* with Reference to Other Morphogenetic Relationships

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Paddlefish, *Polyodon spathula,* is valued as a commercial fish for its roe as well as a sport fish (Carlson and Bonislawsky 1981). Interest in paddlefish as an intensively cultured species has increased in recent years (Graham et al. 1986; Semmens and Shelton 1986). Many state and federal hatcheries are rearing paddlefish for repopulation programs.

Length–weight tables and condition factors are basic tools in fish culture management (Piper et al. 1982). Length–weight relationships allow for interchangeable calculations during hatchery and production operations. Condition factors are calculated as the ratio of weight to length cubed. These ratios are a measure of fish fitness and are sometimes used to indicate ability of fish to spawn (Anderson and Gutreuter 1983).

Current length–weight information of paddlefish is limited to small sample sizes of larval and juvenile fish caught from rivers and reservoirs (Swingle 1965). Such data used for cultured fish probably do not give a reliable indication of growth, conditioning, or age because of the lack of controlled environmental conditions (Piper et al. 1982). If paddlefish research and production are to advance further, basic information on these conditions from paddlefish reared in controlled systems should be made available.

## Materials and Methods

Paddlefish broodstock from Cumberland Lake, Kentucky, were artificially propagated as described by Graham et al. (1986) during the springs of 1988 and 1989 at Kentucky State University Aquaculture Research Center in Frankfort. Larvae were stocked at 8 d from hatch, when they had actively begun to search for food. Larvae with a mean total length (TL) ± standard deviation (SD) of 16.8 ± 0.4 mm and mean weight ± SD of 19.8 ± 0.3 mg were stocked at 61,775 fish/ha in nine 0.02 ha fertilized ponds 1.2 m deep for a 40 d grow-out period. Ten fish from each pond were sampled weekly. Surviving paddlefish with a mean TL ± SD of 125 ± 15 mm and mean weight ± SD of 6.8 ± 2.5 g were restocked at 1,235, 2,471, 4,242, and 9,884 fish per ha in each of three 0.04 ha ponds and 247 fish per ha in one 0.6 ha pond for further grow-out. Ten fish were sampled every 4 to 8 weeks. A total of 973 live fish measuring 17–890 mm TL, 13–510 mm in eye-fork length (EF), and 0.02–1,870.00 g in weight were included in the study.

Paddlefish were sacrificed for gonadal observation, because there are no reliable external characteristics for determination of sex (Graham et al. 1986). Tissue from all age classes was removed from the area where gonads would develop and viewed under a dissecting scope. No histology was completed on the excised tissues.

Total length, weight, and age were recorded in spreadsheet format before being converted and transferred to PC-SAS files. Within each age class, data were normally distributed. However because of increasing variance between weekly samples, data analyzed by week were log transformed prior to statistical analysis to reduce heteroscedasticity (Steel and Torrie 1980), pooled data

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TABLE 1. *Percent eye-fork length (body length) of total length (TL) of pond-cultured paddlefish. Means with the same letter in each column are not significantly different at* P > *0.01.*

| Age (wk) | Number of fish | TL Range (mm) | % Body length |
|---|---|---|---|
| 1 | 48 | 17–26 | 76% a |
| 2 | 18 | 25–52 | 71% b |
| 3 | 18 | 46–90 | 66% c |
| 4 | 18 | 75–123 | 60% d |
| 5–56 | 211 | 68–890 | 57% d |

TABLE 2. *Condition factor by age classes of pond-cultured paddlefish. Means with the same letter in each column are not significantly different at* P > *0.01.*

| Age (wk) | Number of fish | TL Range (mm) | Condition factor |
|---|---|---|---|
| 1 | 138 | 17–26 | $8.899 \times 10^{-6}$ a |
| 2 | 108 | 25–52 | $7.777 \times 10^{-6}$ b |
| 3 | 108 | 46–90 | $5.107 \times 10^{-6}$ c |
| 4 | 108 | 75–123 | $3.703 \times 10^{-6}$ d |
| 5 | 108 | 68–153 | $3.441 \times 10^{-6}$ e |
| 6–7 | 239 | 85–160 | $3.039 \times 10^{-6}$ e |
| 11–56 | 164 | 318–890 | $2.420 \times 10^{-6}$ f |

were not transformed. Transformation allowed the assumption of equal variances to be met for parametric analysis. Regression analysis of transformed length–weight data and analysis of condition factors were conducted using the general linear model procedure (SAS Institute 1988). Duncan's multiple range test was used to compare individual means. Level of significance was $P \leq 0.01$.

## Results

Adult and juvenile paddlefish are fusiform with a large rostrum and heterocercal caudal fin; these morphological features develop during larval transformation. Because morphological developments occur during the early weeks of life, a pooled analysis of total body length (TL) compared to eye to fork (EF) length was performed prior to calculation of condition factor. The TL to EF length ratio varied significantly ($r = 0.968$) as the conical snout developed into the characteristic "paddle" with age (Table 1). Condition factors were calculated using both TL and EF on an abbreviated pooled data set. Comparisons of TL ($r = 0.975$) indicated a more significant relationship than EF ($r = 0.860$). Based on this finding, all further analyses were conducted on TL.

Condition factors calculated on the total data set decreased significantly by week during the larval production period through week 4 (Table 2). Average condition factor of week 5 fish was not significantly different from those of week 6 and 7 fish. Condition factors of fish from weeks 11 to 56 were not significantly different. Means separation tests indicated that average condition factors by week fell into six statistically significant categories ($r = 0.943$).

Linear regression analysis on the data indicated slope values ranging from 4.012 on week 1 to 2.125 on weeks 3 to 5 (Table 3). Total length as a predictor of weight had high coefficient of determination values among age classes.

Gonads were not isolated from any fish under 565 mm TL, but were observed in fish ≥ 710 mm TL. A total of 104 fish from the same age class (11–56 wk) stocked in different production systems could not be differentiated as male or female. However, sex of fish was easily determined in the 60 sampled fish ≥ 710 mm TL.

## Discussion

Two contrasting opinions are offered as to the correct measurement of paddlefish length: 1) the rostrum is considered an addition to the body and 2) the rostrum is part of the total length. Traditionally, TL was used as the standard measure. Ruelle and Hudson (1977) proposed that EF be the standard measure, based on inconsistency in TL measurements because of physical damage or deformities of the rostrum or caudal fin. Russell (1986) suggested that continued use of TL would permit comparisons to data prior to changes proposed by Ruelle and Hudson (1977). He also pointed out all lengths of small (82–291 mm TL) paddlefish have been reported in TL.

TABLE 3. *Regression equation of weight (W) on total length (L) of pond-cultured paddlefish.*

| Age (wk) | TL Range (mm) | Regression equations | $r^2$ |
|---|---|---|---|
| 1 | 17–26 | Log W = −6.391 + 4.012 (Log L) | 0.903 |
| 2 | 25–52 | Log W = −4.760 + 2.782 (Log L) | 0.969 |
| 3–5 | 46–153 | Log W = −3.680 + 2.125 (Log L) | 0.972 |
| 6–52 | 85–890 | Log W = −5.931 + 3.113 (Log L) | 0.991 |

Yeager and Wallus (1982) indicated that rostrum development begins at 17 mm TL and continues to the adult spathulated form at ≥ 89 mm TL. This period of rostrum development, when a large part of the present data was collected, raises questions on the correct length measurement to use. Comparisons of coefficient values for condition factors based on EF and TL indicated that TL ($r$ = 0.975) correlated better than EF ($r$ = 0.860). This result supports Russell (1986) who reported that TL is probably the more appropriate length measurement for calculating condition factors of small paddlefish (≤ 890 mm).

Condition factors have been found to decrease as size increases in numerous fish species (Chatteriji 1980). Paddlefish demonstrated a significant decline in condition factor from week 1 to week 5. This was probably because of the rapid growth of the rostrum during the first five weeks. Between week 5 and 7, at lengths of 100–153 mm TL, paddlefish begin to develop gill rakers, which indicates a switch from particulate to filter feeding (Michaeletz et al. 1982). Filter-feeding efficiency could improve as fish size and gill raker development increase with a corresponding improvement in condition factor. Thereafter, condition factors could stabilize for pond-cultured fish.

Because of missing data between 161–317 mm TL, it was not possible to analyze a condition factor in this size class. However, it was noted that condition factors of paddlefish between 318–890 mm TL were not significantly different when analyzed by ages which ranged from 11–56 wk. This study supports the conclusions of Graham et al. (1986) that paddlefish of similar age and weight between 2–17 yr and 1–32 kg, respectively, gained weight proportionally to each unit increase in length.

The length–weight relationships among fish should follow the 'cube law' with a slope value of 3; however, values from 2 to 3.5 are commonly found (Royce 1972). The length–weight relationship for paddlefish for this study closely followed the 'cube law' except for weeks 1 and 3 to 5. Fish one week old had a high slope value (4.012) which indicated the weight of the fish increased more than the cube of the length. Mims (1984) found relative consumption, as defined as total wet weight of ingested *Daphnia* relative to wet body weight of paddlefish larvae, increased with larvae age up to 8 d after initiation of exogenous feeding. Thereafter, relative consumption decreased with increasing age up to 18 d. This could explain the rapid increase in weight with respect to length during week 1 and rapid decrease during weeks 3 through 5. Increased length of the rostrum between week 2 and 5 could also play a part in the lower slope values. Between week 6 through 52, the slope value was near 3, which indicated the fish were growing without change in shape or specific gravity (Royce 1972). This corresponds to completed rostrum development and improved filter-feeding efficiency (Michaeletz et al. 1982).

Paddlefish are long-lived and do not reach sexual maturity at a young age. Gengerke (1978) found in the Mississippi River that males sexually mature between 4–9 yr of age and females between 10–12 yr of age.

In this study it is interesting to note that the larger (≥ 710 mm TL) and younger (21 wk) fish had differentiated gonads while smaller (< 565 mm TL) but older (48–52 wk) fish did not appear to have gonadal differentiation. This suggests that age may be less of a factor in maturation than size of fish. Similar observations have been recorded for white sturgeon *Acipenser transmontanus* (Conte et al. 1988).

This factor of size would suggest broodstock management for mature fish may require less time than previously believed. Young fish, intensively cultured, may be ready to spawn sooner than wild fish allowing for a more rapid domestication. Selection programs for body characteristics, fecundity, behavior, and other desirable traits could be better achieved with shorter generation times.

With a growing number of states interested in paddlefish culture, the need for these basic tools has increased dramatically. Previous length–weight data of larval and some juvenile paddlefish have been based on wild-caught fish of unknown ages. This study serves as a benchmark to allow length–weight relationships and condition factors of known age fish to serve as bases for work leading to broodstock selection, improved rearing methods, and guidelines for categorizing young wild-caught paddlefish into age groups.

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