

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

STEVEN D. MIMS¹ AND RICHARD S. KNAUB²

Aquaculture Research Center, Kentucky State University, Frankfort, Kentucky 40601 USA

Paddlefish, *Polyodon spathula*, is valued as a commercial fish for its roe as well as a sport fish (Carlson and Bonislowsky 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 propagat-

ed 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) \pm standard deviation (SD) of 16.8 ± 0.4 mm and mean weight \pm 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 \pm SD of 125 ± 15 mm and mean weight \pm 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

¹ Corresponding author.

² Current address: Biological Sciences, Clemson University, Clemson, South Carolina, USA.

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

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

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	8.899×10^{-6} a
2	108	25-52	7.777×10^{-6} b
3	108	46-90	5.107×10^{-6} c
4	108	75-123	3.703×10^{-6} d
5	108	68-153	3.441×10^{-6} e
6-7	239	85-160	3.039×10^{-6} e
11-56	164	318-890	2.420×10^{-6} f

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 spatulated 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 (Michaletz 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 (Michaletz 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.

Acknowledgments

The authors express their appreciation to Julia Clark for assistance in weighing and measuring the fish. This research was supported by a USDA/CSRS grant to Kentucky State University under agreement KYX-80-85-01A.

Literature Cited

- Anderson, R. O. and S. J. Gutreuter. 1983. Length, weight, and associated structural indices. Pages 283–300 in L. A. Nielsen and D. L. Johnson, editors. Fisheries techniques. Southern Printing Company, Inc., Blacksburg, Virginia, USA.
- Carlson, D. M. and P. S. Bonislawsky. 1981. The paddlefish (*Polyodon spathula*) fisheries of the Midwestern United States. Fisheries 6:17–27.
- Chatteriji, A. 1980. The relative condition factor and length–weight relationship of a freshwater carp *Labes gonius* (Ham.) Cyprinidae, Teleostei. Journal of Bombay Natural History Society 77:435–443.
- Conte, F. B., S. I. Doroshov, P. B. Lutes and E. M. Strange. 1988. Hatchery manual for the white sturgeon (*Acipenser transmontanus* Richardson) with application to other North American Acipenseridae. Cooperative Extension University of California Publication 3322.
- Gengerke, T. W. 1978. Paddlefish investigations. Iowa Conservation Commission. United States National Marine Fisheries Service Project 2-225-R. Segment 1-3. Final Report.
- Graham, L. K., E. J. Hamilton, T. R. Russell and C. E. Hicks. 1986. The culture of paddlefish in a review of methods. Pages 78–94 in J. G. Dillard, L. K. Graham and T. R. Russell, editors. The paddlefish: status, management, and propagation. Modern Litho-Print Co., Jefferson City, Missouri, USA.
- Michaeletz, D. H., C. F. Rabeni, W. W. Taylor and T. R. Russell. 1982. Feeding ecology and growth of young-of-the-year paddlefish in hatchery ponds. Transactions of the American Fisheries Society 111:700–709.
- Mims, S. D. 1984. Evaluation of *Daphnia* as a food for paddlefish, *Polyodon spathula* (Walbaum), fry under intensive culture conditions. Master's thesis. Auburn University, Auburn, Alabama, USA.
- Piper, R. G., I. B. McElwain, L. E. Orme, J. D. McCraren, L. G. Fowler and J. R. Leonard. 1982. Fish hatchery management. United States Fish and Wildlife Service, Washington, D.C., USA.
- Royce, W. F. 1972. Introduction to the fishery sciences. Academic Press, New York, New York, USA.
- Ruelle, R. and P. L. Hudson. 1977. Paddlefish (*Polyodon spathula*): growth and food of young of the year and suggested techniques for measuring length. Transactions of the American Fisheries Society 106:609–613.
- Russell, T. R. 1986. Biology and life history of the paddlefish: a review. Pages 2–20 in J. G. Dillard, L. K. Graham and T. R. Russell, editors. The paddlefish: status, management and propagation. Modern Litho-Print Co., Jefferson City, Missouri, USA.
- SAS Institute, Inc. 1988. SAS/STAT user's guide. release 6.03 edition. Cary, North Carolina, USA.
- Semmens, K. J. and W. L. Shelton. 1986. Opportunities in paddlefish aquaculture. Pages 106–113 in J. G. Dillard, L. K. Graham and T. R. Russell, editors. The paddlefish: status, management and propagation. Modern Litho-Print Co., Jefferson City, Missouri, USA.
- Steele, R. G. D. and J. H. Torrie. 1980. Principles and procedures of statistics. McGraw-Hall, Inc., New York, New York, USA.
- Swingle, W. E. 1965. Length–weight relationships of

Alabama fishes. Agricultural Experiment Station, Auburn University Fisheries No. 3.

Yeager, B. and R. Wallus. 1982. Development of larval *Polyodon spathula* (Walbaum) from the Cumberland River in Tennessee. Pages 73-77 in

C. F. Bryan, J. V. Connors, and F. M. Truedale, editors. The proceedings of the fifth annual larval fish conference. Louisiana Cooperative Fishery Research Unit, Louisiana State University, Baton Rouge, Louisiana, USA.

•
•
•

•
•
•