Growth, Condition, and Color of Juvenile Bowfin in Medium-Sized Aquaria

Jan Jeffrey Hoover and Tyler Strange

(JJH) U.S. Army Engineer Research and Development Center, Waterways Experiment Station, 3909 Halls Ferry Rd., Vicksburg, MS 39180-6199, hooverj@wes.army.mil; (TS) 1205 Cook Rd., Oak Grove, LA 71263

"The Gar-Pikes and Bow-Fins, which are principally North American fishes, are voracious species that are of no value as food, and without any special points of interest."
— Ernest Protheroe, 1937

John A. Grindle and John Q. Public

The preceding statement by Ernest Protheroe appears in his 1937 book *New Illustrated Natural History of the World*, and is the only mention he makes of gars and bowfin. Mr. Protheroe was apparently unfamiliar with those species. Gars (*Lepisosteus* spp.) and bowfin (*Amia calva*) are both quite edible and both have numerous special points of interest, such as their ability to breathe air, their status as "living fossils," and distinctive canine dentition (Robison and Buchanan, 1988). Bowfin, in particular, have other intriguing attributes, such as an external (gular) plate across their throat, extreme paternal care of their young, and a unique method of swimming performed by undulating their dorsal fin. These features are probably responsible for the diversity of names that have been applied to this fish: mudfish, dogfish, lawyer, and John A. Grindle, usually shortened to grindle or grinnel (Buffler and Dickson, 1990). The failure of certain natural history writers, like Mr. Protheroe, to appreciate and promote these unusual traits certainly influenced public opinion regarding the bowfin.

Historically, the bowfin was deemed unattractive, detrimental to fishing, inedible, and useless to anglers (Miles, 1912). A writer for the American Museum of Natural History once described it as "evil-tempered" and "ugly," with a "sloping forehead" and "small, wicked eyes" (East, 1959). It was widely believed to be a ravenous predator on sport fishes and was the victim of misguided "control" programs intended to enhance populations of other exploitable fish species (Scarnecchia, 1992). Anglers still resent this fish for its allegedly unpalatable flesh and its reputation as a "tackle-buster" (Hester, 1995). This unfortunate history of bad press for bowfin, coupled with a more recent enlightened appreciation for its ecological and potential economic values, make it an excellent subject for educational outreach.

We recently took the opportunity to create a bowfin display at the Clinton Community Nature Center, in Clinton, Mississippi. The center hosts summer day camps, seminars, weekend workshops, and other nature-related activities at its newly constructed visitor's center, Price Hall. We found a suitable location near the entrance and in early June 2001, set up a 116-liter (29-gallon) aquarium with an undergravel filter, rocks, and dense artificial plants. We stocked it with four juvenile fish. Next to the aquarium, we placed a dried head of an adult bowfin in a wide-mouth jar so that interested people could examine the details of the skull, scales, and teeth. Behind the aquarium we posted some color fliers with photographs of freshly-caught bowfin and text describing the natural history.

Two Long-Unanswered Questions

Our bowfin exhibit was a success with visitors but we began to wonder: How long could juvenile bowfin be kept in a medium-sized aquarium like this before they outgrew it? Could their "voracious" appetites and uncertain nutritional requirements be satisfied sufficiently so that they would not lose weight? Despite more than a century of observational studies in the field and in aquaria (Wilder, 1875; Breder and Rosen, 1966; Carlander, 1969; Wolff, 1996; Katula, 1998),

Fig. 1. Juvenile bowfin from Bayou Meto, Arkansas. Photograph by Jan Jeffrey Hoover.

growth rates and robustness of juvenile bowfin have not been measured precisely.

Size and weight data, although easy to obtain, are extremely important to professional and amateur ichthyologists. Aquaculturists try to grow bowfin in large numbers. Their principal interest in the fish is as a source of caviar (Huner, 1994), but biologists are also interested in bowfin for predator restocking programs (e.g., Scarnecchia, 1992; Mundahl et al., 1998) and as zoological study material (e.g., undergraduate comparative anatomy courses). Native fish aquarists usually keep bowfin in small numbers or as individual specimens. They need to know how quickly bowfin will outgrow home aquaria. This determines how many specimens they can responsibly collect in the field and reasonably support in their tanks and ponds.

The bowfin at the Nature Center were appreciably growing so we decided to measure growth rates of 25 of their kin residing at the Waterways Experiment Station (WES) in a Ferguson flume (a rectangular tank with internally rounded corners and a central partition that allows elliptical flow). These fish (Fig. 1) could be fed more intensively, monitored more closely, and removed more frequently for measurements of size and weight.

Fish Care and Data Analyses

Fish were collected 3 May 2001 from Bayou Meto, Arkansas. Because they were intended for swimming experiments, handling was minimized and bowfin were not measured immediately after capture. Here we represented initial size of fish by using data from a preserved sample collected concurrently with the live bowfin on the same date.

Bowfin were maintained in a 347-liter Ferguson flume. An external foam filter circulated water at 1-8 cm/s. Water depth was 50 cm. Tank bottom was bare. Small pieces of PVC pipe and a large floating artificial plant provided bottom and overhead cover. Partial (10-20%) water changes were made at least weekly, and complete water changes made monthly. Photoperiod and water temperature were not controlled. Overhead lights were on from approximately 8 a.m. to 5 p.m., but low levels of indirect lighting came in from a nearby window, so "daylength" approximated natural conditions. Water temperature ranged from 17 to 23°C. Temperatures >21°C occurred early May and in August; temperatures <19°C in late May and in October. Conductivity ranged from 188 μS/cm to 297 μS/cm. Dissolved oxygen was >7.50 mg/l. Water was typically circumneutral (pH=6.9-7.5), but acidic conditions (pH <6.5) were observed on two occasions. The study concluded on 23 November 2001.

In nature, juvenile bowfin feed on fish and a wide range of insects and crustaceans (Schneberger, 1937; Frazer et al., 1989); in captivity bowfin will eat beef liver, beef heart, crayfish, shrimp, and pieces of fish (Huner, 1994; Wolff, 1996). Because certain "non-aquatic" foods (i.e., beef liver) have been associated with high juvenile mortality, we initially tried to approximate a natural diet. Fish were fed frozen bloodworms (Chironomidae) and shrimp chunks twice daily at a ration of approximately 15-30 bloodworms/bowfin and 2-4 5-mm shrimp chunks/bowfin during each feeding. Once or twice a week, live minnows (25-35 mm TL rosey reds or common goldfish) were fed at a ration of 1-2 minnows/ bowfin. During the latter months, commercially prepared dry pelleted foods (Silver Cup Salmon Crumbles or Wardley Shrimp-el-ettes) were substituted occasionally for one of the twice-daily feedings.

Bowfin were measured and weighed once during each calendar month, June through November. They were removed from the flume, placed in 12-liter buckets (5-7 fish/bucket) for 1-2 hours. Buckets were blue to encourage fish to darken. Fish were then individually placed in a plastic sandwich bag to facilitate handling and restrict their movement. They were allowed to relax along a metric straightedge and total length was measured to the nearest mm. They were then weighed on an Ohaus top-loading balance (model E400) to the nearest 0.01 g. Notes were recorded for each individual on coloration: marbling, fin colors, intensity of the caudal spot. After that, each fish was released from its bag and returned to the tank. It was not practical to identify individual fish and track them over time, so growth and condition were analyzed for the group using average values for each date (arithmetic means) and ranges (minimum and maximum values).

Growth was described by relating fish size (total length) to time (days in captivity). Time was the independent or "predictor" variable (x) and size was the dependent or "response" variable (y). A bivariate (x-y) plot graphically showed the increase in mean size and the change in size range (minimum, maximum) over time. The mathematical relationship between time and size was calculated using linear regression analysis which fits a line to the points (or fish) as they were plotted in two-dimensional space. The general form for this kind of relationship is:

$$y = mx + b$$

in which x is a value for the predictor variable, m is the slope of the line that best fits the points, b is the point where that best-fit line crosses the y-axis, and y is the estimated value for the response. For our study, x is the length of time a juvenile bowfin spent in captivity, b is the predicted starting size of the fish, m is the rate of growth, and y is the estimated size of the fish for that time in captivity. The predictive capability of a regression model is given by the value r^2 which can range from 0.00 (no predictive ability) to 1.00 (perfect predictive ability). An explanation of the theory and mathematics for linear regressions can be found in any beginning statistics book, but the shortest, simplest, best-illustrated, and most entertaining explanation is found in *The Cartoon Guide to Statistics* by Larry Gonick and Woollcott Smith (1993).

Condition, or robustness of each fish was measured using the condition factor (or "ponderal index"), K (Carlander, 1969). For each observation of each fish,

$$K = \frac{\text{Weight } \times 10^5}{\text{Total length}^3}$$

in which weight is in grams and total length is in mm. Values for K approximate 1.00, with higher values indicating plumper, more robust fish, and lower values slender, less robust fish.

How Big? How Fat? How Fast?

Bowfin ranged in size from 75 to 190 mm TL and in weight from 4.8 to 54.1 g during the six-month study period. This is the size range of bowfin most commonly encountered when seining, and most likely to be kept by aquarists. It was sufficient to show that for six months, bowfin grew steadily but became slimmer.

The average size of a bowfin at the beginning of the study was 83.7 mm TL; at the end of the study, 204 days later, average size was 157.0 mm TL (Fig. 2). Days in captivity was a very good predictor of size ($r^2 = 0.87$). Relationship between the two variables was:

$$\text{Total Length, mm} = 0.4(\text{Days in captivity}) + 83.7$$

Estimated size of a fish at the start of the study was identical to the observed mean size (83.7 mm TL). Overall growth rate was 0.4 mm TL/day. Variation in growth rate over time was almost imperceptible. During the first month, when fish were being fasted and tested for swimming performance, growth rate was slightly lower, 0.3 mm/day, indicated by mean size of fish for that date occurring slightly below the line. During the second and third months in captivity, when experimentation had ceased, growth rates were slightly faster: 0.5 mm/day,

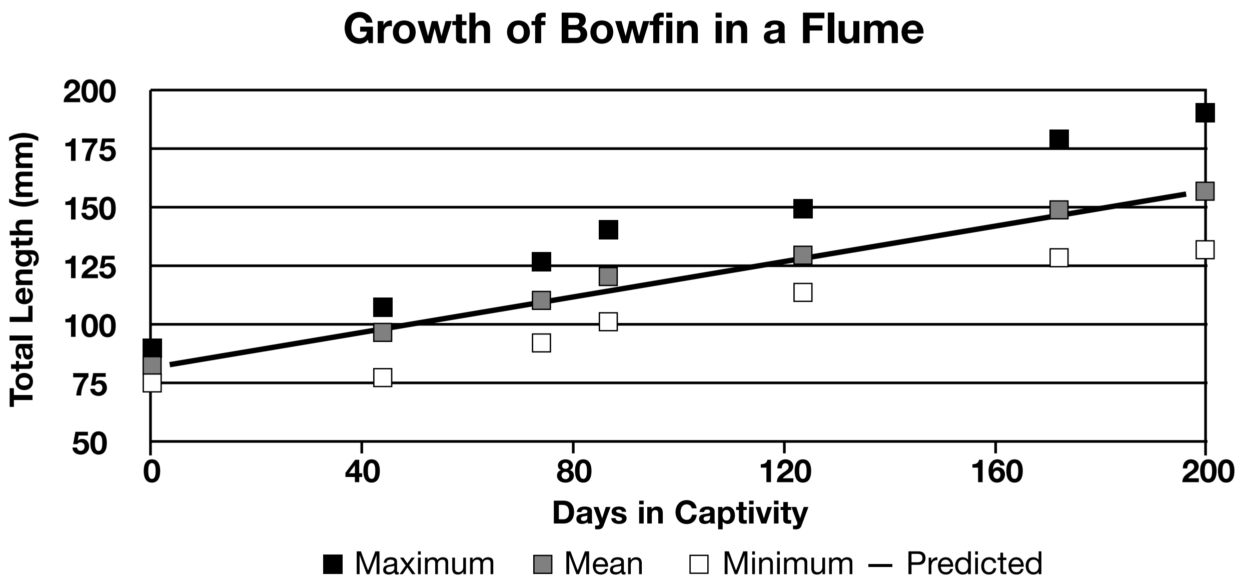


Fig. 2. Relationship between time in captivity and size of Bayou Meto bowfin, May-November 2001.

indicated by mean sizes for those dates occurring on and slightly above the line, respectively. Range of sizes increased with prolonged time in captivity.

Growth observations were comparable to those made by NANFA member Ray Wolff a few years ago (Wolff, 1996). He raised baby bowfin in standard 77 x 32 x 32 cm, 76-liter (20-gallon long) tanks. They attained sizes of 102-152 mm in six months, which is comparable to the 129-190 mm we observed at the end of this study. His report—that fish transferred to 123 x 34 x 41 cm, 151-liter (40-gallon), and 123 x 34 x 54 cm, 208-liter (55-gallon) tanks reached sizes of 305-406 mm in 12 months—suggested that growth was slow but uniform. Wolff's bowfin were fed chopped earthworms and shrimp, dried tubifex and dry pelleted foods, and ground beef products.

Jay Huner, in contrast, reported more rapid and variable growth of juvenile bowfin in a shallow, flat, flow-through aquarium (Huner, 1994). Huner's culture container was 91 cm x 213 cm, and 8 cm (later 15 cm) deep, holding 155 liters (later 310 liters). His bowfin, approximately 50 mm when stocked, were 100-125 mm after approximately one month, and 254-355 mm after eight months. More than 90% of these fish however were beaten to death or cannibalized by their siblings, a level of aggression we did not observe at any time. The Huner bowfin were fed cut fish, crayfish, and a wet pellet. Intraspecific aggression, territoriality, and cannibalism among captive bowfin has been reported by others (Quinn, 1990; Schleser, 1998), including an instance in which one specimen carried another in its mouth for 24 hours before swallowing it (Eddy and Underhill, 1974). Since tank depth (>25 cm) and diet (dry foods, shrimp) of the WES bowfin more closely approximated conditions provided by Ray Wolff than by Jay Huner, it is possible that those factors contributed to slower, steadier growth, and reduced intraspecific mortality.

WES bowfin may have been small for their age. Juveniles reportedly stunt easily in home aquaria (Schleser, 1998; Katula, 1998). In an Alabama pond, 50 mm bowfin grew to 406 mm and 680 g during a four month period that included a 21-day interval when the pond was drained (Green, 1966).

Condition factor for individual bowfin ranged widely from K = 0.79 to K = 1.41. Differences in average values indicated some long-term reduction in bowfin robustness. Average condition was highest for field-collected fish in May (K = 1.26), intermediate during the period June through September (K = 0.90 to 1.02), lower in October (K = 0.88) and lowest in November (K = 0.85). These numbers suggest that our bowfin were becoming skinnier the longer they remained in captivity. One captive bowfin deprived of food was described as "gaunt," but that fish had not eaten for a year (Eddy and Underhill, 1974). Condition, however, is not a simple measure of nutritional state, but varies with size for many species of fish that change shape as they grow (Carlander, 1969). Bowfin become more elongate as they grow and might be expected to have lower condition factors at greater sizes. This seems to be the case with our fish which appear every bit as robust, if not more so, than other aquarium-residing juveniles (e.g., Pycraft, undated; Frey, 1961; Frank, 1973). It is not possible for us to rigorously compare the condition of our bowfin to those in other studies. Weights and condition factors for young-of-year bowfin are poorly documented (Carlander, 1969). For our larger specimens (>130 mm TL), average condition factors (K = 0.86) and range of condition factors (K=0.76 to 0.94) were comparable to average condition factor (K = 0.82) and range of condition factors (K =0.70 to 0.95) for a series of larger (400-480 mm TL) wild-caught bowfin from Oklahoma (Horn and Riggs, 1973).

What's Green and Orange and Gray All Over?

Bowfin of all sizes had base colors of olive to slate gray. Caudal fin was orange, especially bright in the ventral half. All fish had visible caudal spots throughout the study, but one specimen's spot began to fade conspicuously when it was 109 mm TL. Several specimens exhibited vermiculations when their size exceeded 95 mm TL, but bold marbled markings were not seen until fish were >130 mm TL. Green fins were not seen until October in fish >140 mm TL. Pectoral fins colored first, and color brightened with size of the fish, from a faint lime green in smaller individuals to an emerald green in fish >165 mm TL. In November, however, a few of the larger fish (143-190 mm TL) showed no green coloration in the fins, while fish of comparable size or smaller were brightly colored.

In nature and in aquaria, bowfin range in color from a dull gray with faint markings to a dry ash color with bold, black reticulations (e.g., see photographs in Frank, 1973; Robison and Buchanan, 1988; Hester, 1995; Katula, 1998; Schleser, 1998). The intensity of color in the fins is influenced by growth, by seasonal phenomena, and by environmental conditions. The colors we observed were probably muted due to the starkness and the brightness of the tank. Reid (1949) collected much smaller (<70 mm TL) young that were still "guarded by a somewhat vicious adult" and commented on how "brightly colored" they were. Although the water in the flume was comparatively cool, we doubt that colors were subdued because of temperature. Frey (1961) reported that captive bowfin become attractive at 14.5°C and do best at 18-20°C, which was the prevailing temperature range during our study.

An *Amia*ble Reintroduction

The four bowfin at the Clinton Community Nature Center entertained and educated visitors for six months. The aquarium was intended as a rotating exhibit of native aquatic species, however, so on 22 November 2001 (Thanksgiving Day) the bowfin were respectfully retired from public life and replaced with darters. The bowfin were taken back to the Waterways Experiment Station in Vicksburg to rejoin their brothers and sisters occupying the flume.

Before reintroducing them to the flume and their kin, the fish were measured and weighed. They ranged in size from 135 to 152 mm TL and in weight from 19.3 to 27.9 g. They were not as long or as heavy as the average bowfin maintained in the flume (157 mm TL, 33.6 g), but they were within the range of sizes (132-190 mm) and weights (20.9-54.1 g). The bowfin at the Nature Center inhabited a tank approximately one-fourth the size of the bowfin flume at Waterways Experiment Station, and were fed half as often, but their growth was only slightly below average, a difference so slight that it is statistically nonsignificant. This may be attributable to container-specific differences in bowfin behavior. The Nature Center bowfin were more sedentary than the bowfin at Waterways Experiment Station so their energy requirements were lower.

We will continue monitoring the growth, condition, and color changes of the bowfin from Bayou Meto, but our first six months of observations have given us some preliminary answers to our original questions. Slow but continuous growth of fish to sizes of nearly 200 mm TL (for the larger specimens) indicate that bowfin could outgrow smaller aquaria in a matter of months. Stunting, if it occurs, must take place when fish are older and larger. Fish became slimmer over time but this loss of condition seems to be a natural process associated with growth. Our specimens are as robust in appearance as other specimens kept in aquaria and their condition is comparable to some fish in nature.

The ability of our two groups of bowfin to comparably thrive under very different aquarium conditions (i.e., in the Ferguson flume at WES and in the aquarium at the Nature Center) underscores the remarkable capabilities of a species that has persevered over millions of years while other species have failed.

And that, Mr. Protheroe, certainly qualifies as a "special point of interest."

Acknowledgments

Steven George, Bradley Lewis, and Neil Douglas helped collect bowfin. Neil measured and weighed specimens of bowfin preserved in the field. Jim Dolan and Kathleen Wilson obtained reference materials. Chris Scharpf provided us with several articles on bowfin of which we were unaware. Jack Killgore and Dena Dickerson reviewed an earlier version of this manuscript. Field and laboratory research were funded by the Ecosystem Management and Restoration Research Program. Permission to publish was granted by the Chief of Engineers. Our thanks to all of the above.

Literature Cited

Breder, C. M., Jr. and D. E. Rosen. 1966. *Modes of reproduction in fishes*. Garden City, N.Y.: American Museum of Natural History.

Buffler, R. and T. Dickson. 1990. *Fishing for buffalo*: *a guide to the pursuit, lore & cuisine of buffalo, carp, mooneye, gar and other "rough" fish.* Minneapolis: Culpepper Press.

Carlander, K. D. 1969. *Handbook of freshwater fishery biology. Volume one*. Ames, Ia.: Iowa State University Press.

East, B. 1959. The bowfin is a hang-over. Pp. 474-475 in *The Natural Sciences Illustrated.* N.Y.: J.J. Little and Ives Co..

Eddy, S. and J. A. Underhill. 1974. *Northern fishes*. 3rd ed. Minneapolis: University of Minnesota Press.

Frank, S. 1973. *The pictorial encyclopedia of fishes*. London: Hamlyn.

Frazer, K. S., H. T. Boschung, and R. L. Mayden. 1989. Diet of juvenile bowfin, *Amia calva* Linnaeus, in the Sipsey River, Alabama. *Proceedings of the Southeastern Fishes Council* 20: 13-15.

Frey, H. 1961. *Illustrated dictionary of tropical fishes*. Jersey City, N.J.: TFH Publications. [Originally titled *Das aquarium von A bis Z*, published in East Germany in 1958 and 1959].

Gonick, L., and W. Smith. 1993. *The cartoon guide to statistics*. N.Y.: Harper Perennial.

Green, O. L. 1966. Observations on the culture of the bowfin. *Progressive Fish-Culturist* 28 (3): 179.

Hester, F. E. 1995. Big, bad bowfin. *Wildlife in North Carolina* 59 (7): 14-17.

Horn, M. H. and C. D. Riggs. 1973. Effects of temperature and light on the rate of air-breathing of the bowfin, *Amia calva*. Copeia 1973 (4): 653-657.

Huner, J. V. 1994. Bowfin culture at the University of Southwestern Louisiana. *Aquaculture Magazine* 20 (5) [Sept.-Oct.]: 28-37.

Katula, R. 1998. The amazing Amiidae—bowfins of North America. *Tropical Fish Hobbyist* 48 (1) [Sept.]: 58-64.

Miles, G. W. 1912. A defense of the humble dogfish. *Transactions of the American Fisheries Society* 42: 51-59.

Mundahl, N. D., C. Melnytschuk, D. K. Spielman, J. P. Harkins, K. Funk, and A. M. Bilicki. 1998. Effectiveness of bowfin as a predator on bluegill in a vegetated lake. *North American Journal of Fisheries Management* 18: 286-294.

Protheroe, E. 1937. *New illustrated natural history of the world*. Garden City, N.Y.: Garden City Publishing Co. [Note: Book is not dated, so date of publication was determined from antiquarian book lists. Protheroe was requested to write this book as a modernization of Rev. J. G. Woods' *Popular Natural History*, first published by George Routledge and Sons of London in 1920.]

Pycraft, W. P. Undated. Travelling without legs or wings. Pp. 603-616 in *Wonders of Animal Life*, J. A. Hammwerton (Ed.). London: Waverley Book Company, Ltd.

Quinn, J. R. 1990. *Our native fishes: the aquarium hobbyists's guide to observing, collecting, and keeping them.* Woodstock, Vt.: Countryman Press.

Reid, G. K., Jr. 1949. The fishes of Orange Lake, Florida. *Journal of the Florida Academy of Sciences* 12: 173-183.

Robison, H. W., and T. M. Buchanan. 1988. *Fishes of Arkansas*. Fayetteville, Ar.: University of Arkansas Press.

Scarnecchia, D. L. 1992. A reappraisal of gars and bowfins in fishery management. *Fisheries* 17 (5): 6-12.

Schleser, D. M. 1998. *North American native fishes for the home aquarium*. Hauppage, N.Y.: Barron's.

Schneberger, E. 1937. The food of small dogfish, *Amia calva*. *Copeia* 1937 (1): 61.

Wilder, B. G. 1875. Notes on the American ganoids. I. On the respiratory actions of *Amia* and *Lepidosteus*. II. On the transformations of the tail of *Lepidosteus*. III. On the transformation of the pectoral fins of *Lepidosteus*. IV. On the brains of *Amia*, *Lepidosteus*, *Acipenser*, and *Polyodon*. *Proceedings of the American Association for the Advancement of Science* 24: 151-193.

Wolff, R.W. 1996. Bowfin basics. *American Currents* Fall 1996: 10-11.

How to join NANFA's e-mail lists.

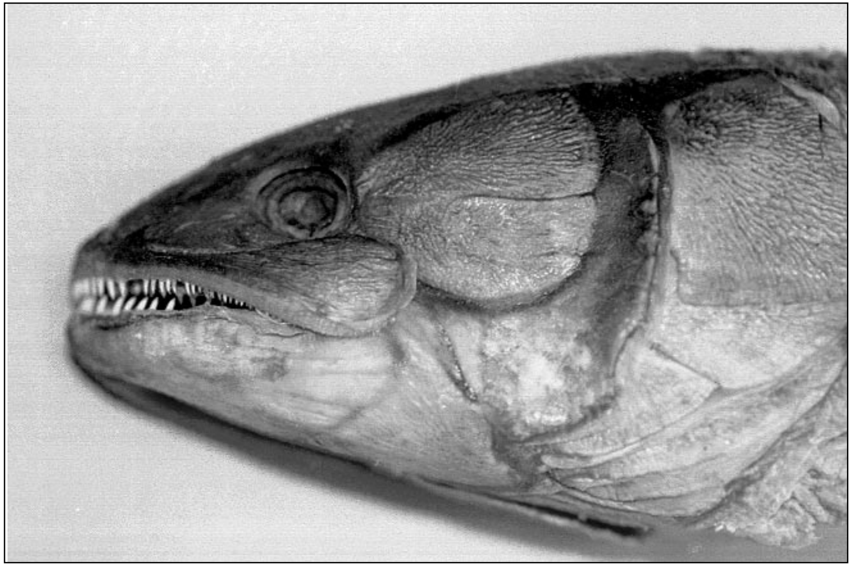
Feel free to join NANFA's e-mail lists: one for the discussion of native fish keeping and appreciation, and a Board of Directors (BOD) list for the discussion of NANFA management. To join the general NANFA list, send the word "subscribe" in the body (not subject) of an e-mail to:

`nanfa-request@aquaria.net`

To join the BOD list, send the word "subscribe" to:

`nanfa-bod-request@aquaria.net`

Further instructions will be issued when you subscribe.



Top: lateral view of a bowfin skull. The dried head of this fish retains its original skin, scales, and distinctive bullet-shape, but nearly all of the 70 bones are clearly visible. Bottom: frontal view of a bowfin skull. The wide gape of the mouth and the numerous canine teeth may be responsible for two other common names for this species: grinner and dogfish. Teeth, some of which are 4 mm long, occur in multiple rows.

Bowfin skulls are popular specimens for study in zoology lab courses. They serve as modern anatomical models for the crossopterygian fishes (which include coelacanths and a group intermediate between fishes and amphibians). Readily available from biological supply companies, professionally prepared specimens are handsomely symmetrical and beautifully bleached, with jaws agape. Do-it-yourself naturalists, however, can prepare their own specimens by fixing the head of a bowfin in 10 percent formalin, rinsing it thoroughly with tap water, and then air-drying it. The dried skin will stick tightly to the skull preserving much of the original appearance of the fish while allowing most of the numerous bones to be easily distinguished and identified. This 105 mm skull of an adult bowfin was on display for several months at the Clinton Community Nature Center, in Clinton, Mississippi. Visitors there were able to examine for themselves the complex construction of the skull and the multiple rows of sharp, white teeth, and then watch four younger versions of this “living fossil” as they swam in an aquarium.

Photos and skull mount by Steven George. Text by Jan Jeffrey Hoover

“He is the Dogfish, Bowfin, or Grindle, depending upon where you cross purposes with him . . .”
— Byron W. Dalrymple