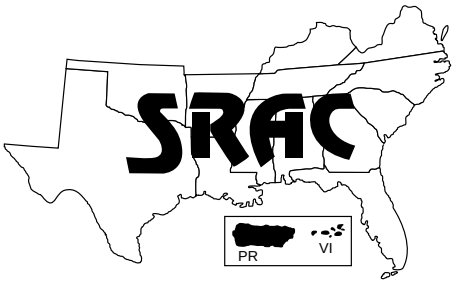
SRAC Publication No. 437

Southern
Regional
Aquaculture
Center



November 1999

Production of Paddlefish

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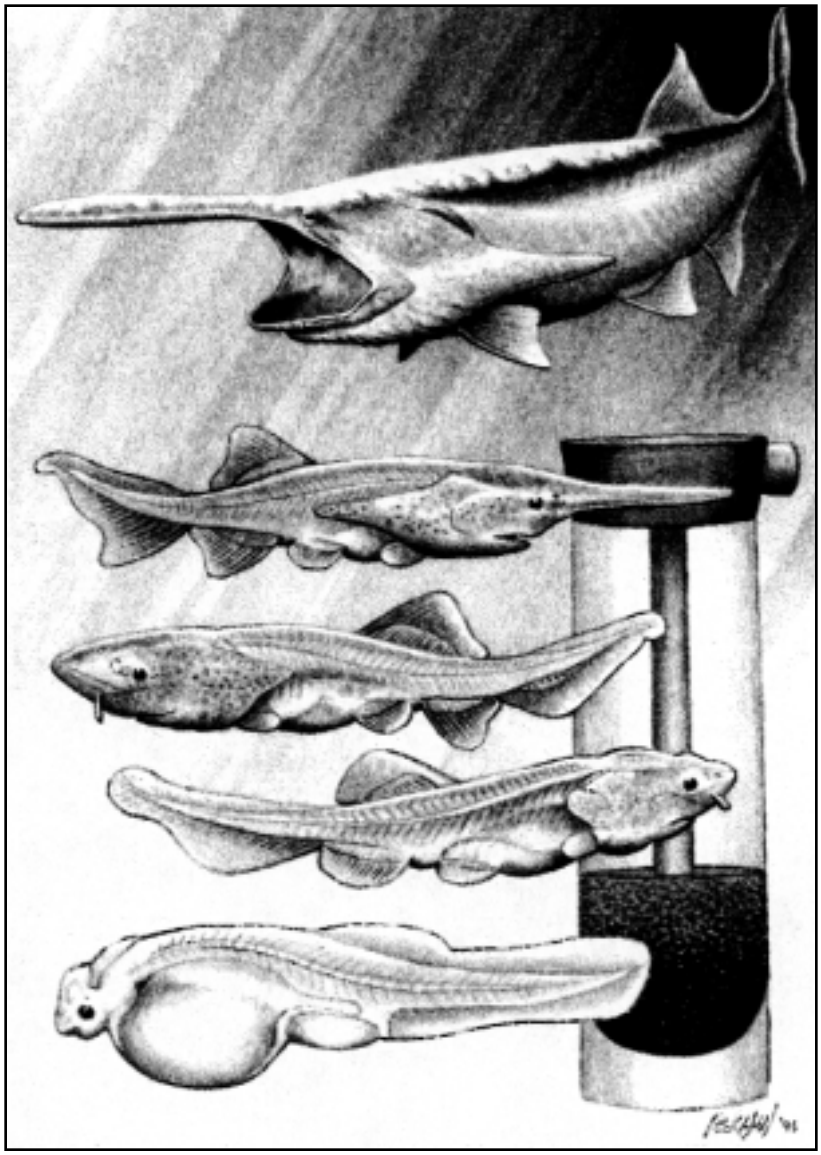
Paddlefish, spoonfish, spoonbill cat and *Polyodon spathula* are among several names given to this unique prehistoric fish. The paddlefish is one of the largest freshwater fish in the United States. It grows to 6 feet (1.8 m) and more than 200 pounds (90kg). It is found in 22 states that have large streams, rivers and impoundments within the Mississippi River basin and adjacent Gulf Coast drainage. Paddlefish are closely related to sturgeons, a group of fish having a cartilaginous skeleton. Unlike most fishes the paddlefish is a filter feeder most of its life; it removes zooplankton (minute free-floating animals) from the water as its main food source.



Paddlefish, like sturgeon, are highly valued for their greyish-black roe (eggs), which is processed into caviar, and for their boneless, firm, white meat. Most paddlefish products are obtained from wild populations. However, overexploitation and contamination by organochlorine pollutants such as polychlorinated biphenyls (PCBs) and chlordane have made it necessary for many

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state agencies to close down this valuable fishery. In 1992, because of concern about illegal poaching for the international caviar trade, paddlefish were added to the Appendix II list of the United Nations' Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES). This CITES listing prevents the import or export of paddlefish and their products into or out of the United States unless a CITES permit is obtained through the U.S. Fish and Wildlife Service. Therefore, the growing demand for caviar and other paddlefish products will have to be met through commercial paddlefish production.

Paddlefish products

Caviar

At one time caviar was defined as salted sturgeon roe from fish caught in the Caspian Sea. However, caviar can be obtained from two families of fish—the sturgeons (Acipenseridae, 26 species) and the paddlefish (Polyodontidae, two species). The fish must be sacrificed to obtain high quality caviar.

In recent years, there has been a major decline in sturgeon stock from the Caspian Sea, which is increasing the demand for alternative sources of caviar. Paddlefish caviar, which is often compared to sevruga (*Acipenser stellatus*), the most popular Caspian Sea caviar, is an alternative product. Paddlefish and sevruga have similar egg size (known as small grains) and a greyish color with a mild, less salty taste.

A 40-pound (20-kg) female paddlefish can yield 4 to 6 pounds (about 2 to 3 kg) of roe. Current wholesale prices range from $30 to 65 per pound ($65 to 143 per kg), with retail prices of more than $150 per pound ($330 per kg). Caviar is marketed through buyers who sell to exclusive restaurants, gourmet shops and mail-order retail outlets.

Caviar from paddlefish raised in ponds and reservoirs could alleviate pressure on wild fish stocks. The contaminants sometimes found in caviar from wild fish have not been found in cultured paddlefish caviar. Further, caviar from cultured paddlefish has been described as having a more buttery taste (more fat in egg) than caviar from wild paddlefish. In a blind taste test comparing cultured paddlefish caviar with the top three types of Caspian Sea sturgeon caviar (beluga, osetra and sevruga), the paddlefish caviar tied for second with osetra (*A. gueldenstaedti*) and was second only to beluga (*Huso huso*).

Meat

Paddlefish meat is firm, white, boneless, and very similar to sturgeon in taste and texture. Paddlefish meat has been well accepted by consumers. Even those who do not eat fish regularly liked paddlefish meat products in taste tests. Several smoked paddlefish meat products have been developed and are well received in exclusive restaurants and gourmet shops. Smoked paddlefish wholesales for $9 to 11 per pound ($20 to 24 per kg) and retails for more than $18 per pound ($40 per kg). Paddle-fish meat also has been tested for surimi (imitation crab meat) production with promising results.

Pros and cons of paddlefish production

Paddlefish require only zooplankton as a food source for most of their life, and grow rapidly (up to 10 pounds or 4.5 kg per year). They can be harvested easily with gill nets or seines. Paddlefish can be propagated artificially and fingerlings raised intensively up to 12 inches or 30 cm (total length) in ponds, then grown for meat and/or roe extensively in reservoirs or intensively in ponds with catfish. Mature female paddlefish can produce about 15 percent of their body weight in roe (3 to 10 pounds or 1.5 to 4.5 kg per fish).

There are also some disadvantages to paddlefish production. They have poor tolerance for low dissolved oxygen (< 2 mg/L), and show handling stress when water temperatures are higher than 70° F (21° C). Artificial propagation and fingerling production is complex, and fingerlings are vulnerable to bird predation. Also, there is a waiting period of at least 7 years before females produce eggs, and fish must be sacrificed to harvest caviar.

Although the paddlefish is still considered an experimental food fish, ongoing research and demonstrations have shown commercial potential. This publication provides the basic, current information about propagation, production and marketing of paddlefish. More detailed information can be found in the references listed.

Propagation

Collection and transport of broodstock

Broodstock are generally obtained from wild sources because of their long maturation period (7 to 9 years in the southern U.S.). Broodstock are captured in 6-inch (15-cm) or larger bar-mesh gill nets that are set in rivers and lakes in the winter or early spring when water temperature is less than 60° F (16° C). Males usually weigh about one-half to two-thirds as much as females, and have minute tubercles on their heads and opercular flaps. Mature females have few, if any, tubercles, and swollen abdomens. The gonopore areas may be distended and reddish in color during the prespawning period.

Broodstock can be transported to the hatchery in conventional hauling tanks holding 200 to 300 gallons (750 to 1100 L) of water supplied with agitation and oxygen and mixed with 0.25 to 0.50 percent sodium chloride salt. Approximately 2 pounds of broodstock per gallon of water (0.25 kg/L) is a safe quantity for transport. Broodstock can be held in ponds until water temperatures are suitable for propagation.

Hormone injections

Paddlefish can be propagated when water temperature is 55 to 65° F (13 to 18° C). Broodstock

must be held in circular tanks (diameter ≥8 feet or 2.4 m) in the hatchery so the fish can swim continuously and aerate their gills (known as ram ventilation). Water temperatures of 62 to 65º F (16 to 18º C), flow rate exchange of 25 percent of the total tank volume per hour, and water saturated with oxygen (100 percent; about 10 mg/L at 62º F) are optimal conditions for broodstock in the hatchery tanks.

Broodstock should be injected intraperitoneally with LHRH analogue of des-Gly10(D-Ala6) LHRH ethylamide (currently not approved by FDA; Investigational New Animal Drug permit is required). Females should receive a total dosage of 100 µg/kg body weight (BW) administered in a priming injection (10 µg/kg BW) and a resolving injection (90 µg/kg BW) 12 hours apart. At 63º F (17º C), females can be expected to ovulate within 12 to 24 hours after the resolving dose. Males should receive a single dose of 50 µg per kg BW when the females are given the priming injection; they will spermiate within 24 hours and continue for 3 to 4 days.

Milt and egg collection

For milt (sperm) collection, the fish is blotted dry around the gonopore area. Tygon tubing (diameter of $^{3}/_{16}$ inch or 0.5 cm; length 2 inches or 5 cm) attached to a 10-cc plastic syringe is inserted into the urogenital pore. With gentle suction, milt is collected from the fish. A large volume (five to ten syringes) of milt can be obtained each time from one male for 3 to 4 days. However, milt from two to three males should be used to fertilize the eggs in order to increase genetic diversity. Milt is checked microscopically and 75 to 100 percent of the sperm should be motile. If sperm motility is less than 75 percent, the milt should be discarded and milt from other males should be considered. Milt can be collected several hours before needed and stored without aeration in sealed containers placed in a refrigerator (39º F or 4º C) or on wet ice (ice sprinkled with water).

Hand-stripping was the traditional method of collecting eggs when culturists believed that paddlefish could not ovulate all their eggs at one time. The method was labor intensive and often required three or more individuals to collect and fertilize a small portion of the eggs (4 to 5 ounces or 120 to 150 ml) every 30 to 60 minutes over a 12-hour period before the majority of eggs were removed. We now know that all eggs do ovulate within 1 hour; however, because of a unique oviductal system not all the eggs can flow freely out of the fish. Therefore, two other methods have been developed to expedite egg collection—Caesarean section and the Minimally Invasive Surgical Technique (MIST). Caesarean section is a relatively quick surgical method (30 minutes) that removes eggs through a 4-inch (10-cm) external abdominal incision; however, suturing is time consuming and muscular stress on the incision usually results in poor suture retention and low survival of broodstock. The MIST makes removal of ovulated eggs even faster (about 10 minutes) and requires much less handling than the other methods and no suturing. With the MIST method a small internal incision (0.5 inches or 1.3 cm) is made in the posterior-dorsal area of the oviduct. This permits direct stripping of eggs from the body cavity through the gonopore, but bypasses the oviductal funnels. Regardless of the method used, eggs must be collected free of water. A female paddlefish weighing 20 to 80 pounds (9 to 36 kg) can release 70,000 to 300,000 eggs.

Fertilization and hatching

The eggs should be fertilized using the "wet method." Milt is added to water at a 1:100-200 ratio (milt to water) and then immediately poured onto the eggs (0.5 ounces of undiluted milt per quart of eggs or 13 ml/L). There are approximately 50,000 eggs per quart. The fertilized eggs are stirred for 1 minute and then coated with a Fuller's earth suspension (2/3 cup of Fuller's earth per gallon of water or 40 ml/L) for 20 minutes. The eggs are then rinsed free of Fuller's earth, volumetrically measured, and loaded into McDonald incubation jars at about 75,000 eggs per 2.5-gallon (10-L) jar. Fungus can be controlled by frequently siphoning dead eggs that float on the top layer and maintaining water temperature near 64º F (18º C). Incubating eggs at this temperature will allow fry to hatch in approximately 6 days. Fry require another 5 to 6 days before they will consume external (exogenous) food. During this interim, the mouth and fore-gut develop and the residual yolk is absorbed. Dark pigmented material that can be seen in the spiral valve of the hindgut will be excreted at about the time exogenous feeding begins. Cannibalism is not uncommon during this period, especially if fry are different sizes.

Nursery phase

Pond culture

Pond preparation should begin about 2 weeks before propagation. Ponds should be drained completely and dried if possible. After fish have been propagated, the pond should be flooded with well water or with water from a reservoir that is filtered through a saran sock. Rice bran (11.4 percent crude protein) has been recommended as the best organic fertilizer for paddlefish nursery ponds in Kentucky. The quantities and application schedules of rice bran and liquid inorganic fertilizer (10-34-0) are indicated in Table 1. Other organic fertilizers such as cottonseed, soybean and alfalfa meals can be used, but quantities should be adjusted for a total nitrogen amount of 40 pounds per acre or 45 kg/ha. During the initial fertilization period (week 0), large zooplankton such as *Daphnia* spp. should be inoculated into the pond at eight *Daphnia* per gallon (2/L). Other zooplankton such as copepods, rotifers and ostracods will not substitute for daphnia because they are fast swimming and/or too small for fry to capture. Fry can be stocked at a rate of 25,000 fish per acre (62,000 fish per ha) in fertilized earthen ponds

Table 1. Quantities and application schedules of rice bran and inorganic fertilizer in paddlefish nursery ponds.

Week	Rice bran[1]		Inorganic fertilizer[2]	
	lbs./ac	kg/ha	gals./ac	l/ha
0[3]	1260	1410	10.0	37
1	275	310	0.5	4.6
2	143	160	1.0	9.3
3	143	160	1.0	9.3
4[4]	143	160	1.0	9.3

[1]Other organic fertilizers can be used based on a total application of 40 pounds per acre (45 kg per ha) of nitrogen.

[2]Inorganic fertilizer 10-34-0.

[3]Fertilizers were applied to filled ponds three times per week during a 2-week period before stocking.

[4]Fish should be offered extruded diet (1/16-inch or 1.5-mm) during week 4.

when water temperature is higher than 65º F (18º C). Fish can grow up to 1/3 pound (150 g) and 14 inches (35 cm) in total length in about 6 months. During this time, survival rate can range from 30 to 80 percent. Bird predation can be controlled by covering ponds with netting.

Raceway culture

Raceways or flow-through systems have been successful for producing fingerlings (less than 10 inches or 25 cm). Ground water or surface water can be used. Ground water should be aerated and heated to more than 72º F (22º C). Surface water should be filtered and, if possible, aerated and heated. Regardless of the source, incoming water should be tested for contaminants and other poor water quality parameters. However, with proper flow-through of about 50 percent of the tank volume per hour, water quality doesn't need to be monitored regularly except for temperature and oxygen (see water quality section). Outdoor raceways should be covered with 95 percent shade cloth to minimize sunlight and ultraviolet light exposure, which can cause sunburn and even mortality. Shade cloth also may provide some protection against predation by birds.

Fry are initially stocked at eight fish per gallon (two fish per L). After 14 days, fry should reach about 2 inches (5 cm) in length. To prevent crowding, fish should be reduced to 2.5 fish per gallon (0.7 fish per L). After another 14 days, the fish should reach about 4 inches (10 cm) and the density should be further reduced to three-fourths fish per gallon (two-tenths fish per L). Culturists should watch for fish swimming at the surface with their paddles above the water—a behavior known as "billing." Billing indicates stress caused by high density; reducing fish density will usually stop this behavior. Because of the large space requirements, fish in raceways are usually harvested when less than 10 inches (25 cm) long rather than 12 inches (30 cm) as in pond culture. In raceways, survival rates can range from about 50 to 80 percent.

Feeding

In pond culture, fry initially feed on relatively large, slow-swimming zooplankton such as *Daphnia* spp. (water fleas) and insect larvae. These food items are preferred during the first 3 to 4 weeks. Fry cannot effectively filter-feed until their gill rakers are developed, at about 5 inches (12 cm) long or 5 to 6 weeks old. During this initial feeding period, some culturists supplement the fish diet with trout/salmon crumbles (#00-03; 50 percent protein) at a rate of 15 pounds per acre (17 kg/ha). Once the fish are about 3 inches (7.5 cm) long they can be trained to accept extruded pellets (1/16-inch or 1.5-mm; 45 percent protein). If fish are trained on a prepared diet, larger extruded pellets will be accepted by larger fish. Feed conversion ranges from 1.5 to 2 pounds of feed per pound of fish.

In raceway culture, fry can be trained on a sinking diet of trout/salmon #00-03 crumbles (more than 50 percent protein). Some culturists use a 1/16-inch (1.5-mm) extruded pellet once the fish reach about 3 inches (7.5 cm) in 3 to 4 weeks. Fry (3/4 to 1.5 inch or 2 to 4 cm) are fed by automatic feeders every 15 to 20 minutes for the first 7 to 10 days. Thereafter, a combination of automatic feeders and hand feeding is used to feed the fish about every 2 hours until they are stocked into ponds or reservoirs. At this time, feed conversion ranges from 2 to 4 pounds of feed per pound of fish.

Water quality

Dissolved oxygen is particularly important; a daily oxygen monitoring program is necessary to achieve maximum yields. Because paddlefish have a rostrum (paddle), they are unable to obtain oxygen from the surface film of water as catfish do when dissolved oxygen is low (less than 2 ppm or mg/L). It is recommended that the dissolved oxygen be kept above 30 percent of saturation at any given water temperature to prevent stress or loss of paddlefish. (For example, 100 percent of DO saturation at a water temperature of 85º F would be about 7.6 mg/L, so at 30 percent of saturation the DO would be about 2.3 mg/L). Paddlefish can survive a wide range of water temperatures from just above 32º F (0º C) to about 100º F. Water temperatures for best fish growth are 70 to 80º F (18 to 27º C). However, paddlefish handle best at stocking and harvesting when water temperature is less than 70º F (less than 21º C). Other water quality parameters are similar to those required by catfish: pH 6-9; un-ionized ammonia less than 0.2 ppm as N; and nitrite level dependent upon chloride level.

Diseases

Diseases have not appeared to be a problem in production of paddlefish in ponds or reservoirs, probably because of low stocking densities. However, a few diseases have been reported and studied for intensively cultured paddlefish in raceways. Rostrum (paddle) degenerative disease causes deformity of the rostrum, including a narrowing and/or downward curvature. Both *Aeromonas* bacteria and columnaris disease bacteria have been isolated from the rostrum and are believed to cause this disease. Chloramine-T at a rate of 20 mg per L for 1 hour has experimentally stopped the progress of this disease in raceways. Paddlefish have also been known to have "Ich" infections (*Ichthyophthirius multifilis*). Both treating with salt at 3 ppt and raising water temperature to 86º C for several days have been successful in eliminating this parasite in raceways.

Production strategies

Reservoir ranching and pond culture with catfish are two practical systems of raising paddlefish for caviar and/or meat. Both systems rely on the presence of natural zooplankton so that paddlefish grow-out requires little cost and management. Diet-trained paddlefish stocked into these systems (at low stocking rates) will switch to filter feeding and will not compete with the other fish for prepared diets.

Reservoir ranching is an extensive aquacultural production system in which young fish (more than 12 inches or 30 cm) are stocked into a reservoir, permitted to forage on the natural food supply, and harvested after 2 or more years. This system is a very economical one for paddlefish caviar production. It uses existing reservoirs that were primarily developed for the storage of water, flood control and hydroelectric purposes. It has been demonstrated that paddlefish stocked at low densities of four to eight fish per acre (ten to twenty fish per ha) can reach 10 pounds (4.5 kg) in about 18 months (Alabama and Kentucky). They then can be sold for their meat or permitted to grow until mature, and then harvested for their roe. Fish are harvested with gill nets with nearly 90 percent efficiency. It is estimated that 50 to 150 pounds per acre (55 to 170 kg/ha) could be harvested yearly depending on the fertility, food supply and temperature of the water. There is ongoing research on reservoir ranching.

Pond culture of paddlefish with catfish is a more intensive system than reservoir ranching. Paddlefish stocked at 30 per acre (75/ha), with catfish at 5,000 per acre (12,500/ha) have been reported to reach up to 7 pounds (3.2 kg) in about 12 months (Kentucky). Producing paddlefish with catfish depends on the pond system's production of zooplankton and the water quality. If catfish feeding rates are increased, more zooplankton could be produced and higher yields of paddlefish could be expected. However, higher feeding rates for catfish will cause greater oxygen demand and possibly lower water quality. Fish can be harvested by seining with nearly 100 percent efficiency. Paddlefish are easily sorted by hand from the catfish and can be held in holding nets (at a water temperature less than 60º F) until loaded for transport to a processing plant. Because of the typical harvest cycle for catfish (every 6 to 12 months), this system is best for paddlefish meat production, even though the fish can be returned to the pond for further grow-out to maturity. More information is needed on stocking paddlefish with catfish in commercial operations in different parts of the South.

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The work reported in this publication was supported in part by the Southern Regional Aquaculture Center through Grant No. 94-38500-0045 from the United States Department of Agriculture, Cooperative States Research, Education, and Extension Service.