The Progressive Fish-Culturist 58:173–177, 1996
American Fisheries Society 1996

COMMUNICATIONS

Feeding Trials with Juvenile Atlantic Sturgeons Propagated from Wild Broodstock

JERRE W. MOHLER

U.S. Fish and Wildlife Service, Northeast Fishery Center
Post Office Box 75, Lamar, Pennsylvania 16848, USA

KOFI FYNN-AIKINS[1]

National Biological Service, Tunison Laboratory
3075 Gracie Road, Cortland, New York 13045, USA

RICK BARROWS

U.S. Fish and Wildlife Service, Fish Technology Center
4050 Bridger Canyon Road, Bozeman, Montana 59715, USA

Abstract.—Juvenile Atlantic sturgeons *Acipenser oxyrinchus* produced by hormone-induced spawning of wild broodstock from the Hudson River, New York, were used in a diet study. Fish fed live *Artemia* sp. as first-feeding fry for 35 d were observed to convert readily to formulated diets. At 79 d posthatch, four formulated feeds were offered: sturgeon starter 9304, Biokyowa, Zeigler esocid diet, and Tunison sturgeon starter. At the end of 60 d, fish fed Biokyowa had the greatest growth and best feed conversion ($P \leq 0.05$). Feed conversions were significantly different between all treatments, indicating wide variability in growth response to the diets tested. Proximate analyses of diets showed Biokyowa highest in protein (59.43%) and dry matter (97.28%).

Declining numbers of Atlantic sturgeons *Acipenser oxyrinchus* have sparked an increased interest in the biology of this species. Overexploitation has generally been considered the cause of the decline, but other factors have interfered with recovery of the stock from low levels (Dovel and Berggren 1983). A management plan has been formulated by the Atlantic States Marine Fisheries Commission (ASMFC), Washington, D.C., which seeks to restore Atlantic sturgeon commercial fishery landings to 10% of the 3.2 million kg recorded in 1890. Management objectives of the ASMFC include aquaculture research to evaluate the potential for stock restoration or enhancement through the release of cultured fish. Therefore, knowledge of culture techniques, including the identification of effective diets for rearing juvenile Atlantic sturgeon, is important to restoration efforts.

Some success was reported by Smith et al. (1980) in Atlantic sturgeon culture with wild broodstock from South Carolina. Hatchery-produced fry were offered various combinations of beef liver, salmon mash, and live *Artemia* sp., but all fish died after 131 d. A second study by Smith et al. (1981) showed that fry actively fed and grew on a similar feed mixture. However, unexplained high mortality resulted in 95% fish loss after 30 d posthatch. Successful spawning and incubation of Gulf sturgeon *A. oxyrinchus desotoi*, a subspecies of the Atlantic sturgeon, was reported by Parauka et al. (1991), but all fry died within 21 d of hatch. Mason et al. (1992) reported survival and growth of two Gulf sturgeon reared from fry to 17 months of age on live and homogenized invertebrates, but use of formulated feeds was not reported. Development of culture techniques for Atlantic sturgeon has been hindered by a lack of broodstock and the loss of eggs from fungal infestation (Smith et al. 1984). However, reliable spawning and culture techniques have been developed for white sturgeon *A. transmontanus*; first-feeding fry have been successfully reared on formulated diets (Conte et al. 1988). In California, hatchery-produced white sturgeon are fed different types of salmonid diets in domestic broodstock production efforts (Moberg and Doroshov 1992). Though similarities may exist in applicable culture methods between sturgeon species, there is a paucity of information specific to Atlantic sturgeon culture, including feeding techniques and diets. This study evaluated the performance of fingerling Atlantic sturgeons fed four different formulated diets.

---

[1] Present address: U.S. Fish and Wildlife Service, South Florida Ecosystems Office, Post Office Box 2676, Vero Beach, Florida 32961-2676, USA.

Methods

Spawning and incubation.—A ripe female Atlantic sturgeon (total length, 216 cm; weight, 60.8 kg) was captured from the Hudson River (water temperature, 24.5°C) near Norrie Point State Park, Staatsburg, New York on 29 June 1993. The fish was transported for 6.5 h by tank truck in 19°C freshwater to the Northeast Fishery Center (NEFC) at Lamar, Pennsylvania. Techniques for spawning, fertilization, and egg de-adhesion were employed as suggested by Conte et al. (1988) for white sturgeon, resulting in the production of approximately 13,000 fry. At the onset of exogenous feeding, fry were fed combinations of live *Artemia* sp. or formulated diets, or both, at NEFC and the National Biological Service Laboratory, Wellsboro, Pennsylvania, for 35 d. Subsequently, interim feeding of all fish commenced with sturgeon starter 9304 (U.S. Fish and Wildlife Service, Bozeman, Montana) at a rate of 6% of body weight daily.

Diet trial.—Fish that survived to 79 d posthatch were pooled and placed randomly into 12 cylindrical tanks (60 L; water flow rate, 3 L/min; water temperature, 17 ± 1°C). Each tank contained from 45 to 55 fish at a biomass of 134 ± 1 g (1.74 kg/m^3). The four diets used in the feeding trial were (1) sturgeon starter 9304 (2) Zeigler esocid diet[2] (Zeigler Brothers, Inc., Gardners, Pennsylvania), (3) Tunison sturgeon starter (U.S. Fish and Wildlife Service, Cortland, New York), and (4) Biokyowa (Biokyowa, Inc., Chesterfield, Missouri). Feed was offered at 3% body weight/d in automatic feeders (model A-100; Double A Brand Co., Dallas, Texas) that were modified to dispense feeds continuously over 24 h. Diet treatments were assigned randomly to triplicate groups of tanks. Feed amounts were adjusted biweekly, and tanks were cleaned every other day to remove waste. Overhead fluorescent lighting was maintained from 0730 to 1600 hours each day. At the end of the 60-d study, percent daily body weight increase (BWI) was determined by use of average initial body weight (W_i) and final body weight (W_f) in the following formula:

$$BWI = 100\,[(W_f - W_i)/W_i]/60.$$

In addition, weight of feed offered (FW) was used to calculate feed conversion (FC) by the following formula:

$$FC = FW/(W_f - W_i).$$

Proximate analyses were performed on a wet weight basis for diets and on a dry weight basis for fish. Protein was measured with a nitrogen determinator (model FP-228, Leco Corp., St. Joseph, Michigan). Moisture and lipid were determined according to the methods of Jones (1984).

Statistical analyses.—Data were analyzed with a microcomputer software program (SAS, version 6.04, SAS Institute, Cary, North Carolina) by analysis of variance and the general linear model procedures described by Littell et al. (1991). Differences between means were compared with Tukey's honestly significant difference test. The significance level chosen was 5% for all comparisons. Data collected as percentages were arcsine-transformed prior to statistical analyses.

Results

Weight gain of fingerling Atlantic sturgeons was affected by diet during the 60-d period. Fish fed Biokyowa had the highest mean weights (30.59 g), followed in decreasing order by those fed sturgeon starter 9304 (24.02 g), Tunison sturgeon starter (17.05 g), and Zeigler esocid diet (15.30 g) (Table 1). Growth differences among treatment groups became apparent after 28 d of study (Figure 1). Fish fed Biokyowa had the highest BWI (18.70); those fed Zeigler esocid diet had the lowest (7.83). Mean BWI of fish fed sturgeon starter 9304 and Tunison sturgeon starter were intermediate at 13.47 and 9.39, respectively. Mortality ranged between 6.74% (Zeigler esocid diet) and 1.88% (Biokyowa), with a significant difference ($P \leq 0.05$) between those two treatment groups (Table 1). Feed conversions were significantly different among all treatments, with fish being most efficient on Biokyowa (0.54) and least efficient (0.93) on Zeigler esocid diet ($P \leq 0.05$) (Figure 2).

Analyses of diets showed Biokyowa to be highest in protein (59.43%) and dry matter (97.28%) but low in fat (Table 2). Analyses of sacrificed fingerling Atlantic sturgeon (Table 2) showed that fish fed sturgeon starter 9304 had a significantly ($P \leq 0.05$) lower protein content (58.73%) than fish from other treatments. Fish fed Zeigler esocid diet had a significantly ($P \leq 0.05$) lower fat content (11.29%).

Discussion

In the 60-d diet trial with juvenile Atlantic sturgeon, significant differences were found between diet treatments in feed conversion, daily percent

---

[2] Reference to trade name or commercial products does not imply U.S. government endorsement of the product.

TABLE 1.—Initial weight (W_i) final weight (W_f), body weight increase (BWI), feed conversion (FC), and mortality of juvenile Atlantic sturgeons fed one of four diets over 60 d. Sample statistics are means of three replicates with ± SDs in parentheses. Within a column, values without a letter in common are significantly different ($P \leq 0.05$).

Diets	W_i (g)	W_f (g)	BWI (%/d)	FC	Mortality (%)
Biokyowa[a]	2.50 (±0.12) z	30.59 (±1.67) z	18.70 (±0.13) z	0.54 (±0.01) z	1.88 (±0.07) z
SS9304[b]	2.65 (±0.20) z	24.02 (±1.75) y	13.47 (±0.69) y	0.63 (±0.03) y	3.31 (±1.20) zy
Tunison SS[c]	2.57 (±0.11) z	17.05 (±0.57) x	9.39 (±0.17) x	0.81 (±0.02) x	5.73 (±1.84) zy
Zeigler esocid[a]	2.69 (±0.25) z	15.30 (±1.17) x	7.83 (±0.63) w	0.93 (±0.03) w	6.74 (±3.23) y

[a] The commercial feeds are closed-formula diets.

[b] Sturgeon Starter diet, SS9304, contained (as percent of diet, unless noted otherwise) krill, 23; egg solid, 22.4; ultra meal, 12; plankton meal, 11; squid meal, 6; squid liver oil, 5; clam powder, 2; lecithin, 2; liver extract, 2; yeast extract, 2; betaine, 2; ascorbic acid, 2; inositol, 0.1; TIC 515 (TIC Gums, Inc.), 3; AP 820 plasma (American Protein Corp.), 2; vitamin premix 30 (Hoffman-LaRoche), 3 (containing per kilogram of diet: Vitamin A 50,000 IU; Vitamin D_3 3,600 IU, Vitamin E, 2,650 IU; Vitamin B_{12} 150 μg, calcium pantothenate 900 mg, riboflavin 400 mg, thiamin mononitrate 250 mg, pyroxidine hydrochloride 225 mg, folacin 65 mg, menadione sodium bisulfate 125 mg, biotin 5 mg, niacin 1,650 mg); mineral premix, 0.5 (Silver Cup Feeds, Inc.).

[c] Tunison SS (Sturgeon Starter) diet contained (as percent of diet, unless noted otherwise) low temperature fish meal, 67; dried whey, 6; shrimp meal, 6; vitamin mix, 1.5 (containing per kilogram of diet: vitamin A palmitate, 10,000 IU; vitamin D_3, 4,000 IU; menadione $NaHSO_3$, 10 mg, DL-alpha-tocopherol, 780 IU; thiamine HCl, 40 mg; riboflavin, 30 mg; D-Ca-pantothenate, 150 mg; niacinamide, 150 mg; pyridoxine HCl, 20 mg; D-biotin, 3 mg; folacin, 15 mg; vitamin B_{12}, 0.2 mg; ethoxyquin, 150 mg; inositol, 1,000 mg); mineral mix, 0.5 (Bernhart-Tomarelli, U.S. Biochemical Co.); L-ascorbic acid, 0.1; nutristim, 1.4; herring oil, 15; pellet binder (Ameribond), 2.

body weight increase, and final mean weights. Differences in growth due to diet quality have also been observed in other sturgeon species (Buddington and Doroshov 1984; Ceskleba et al. 1985; Dabrowski et al. 1985). Fish fed Biokyowa had the greatest growth in this study, and proximate analyses showed that this diet contained the greatest proportion of dry matter and crude protein among the four diets. Biokyowa and Zeigler esocid diet are closed-formula feeds. It is possible that the amino acid composition of the feeds may have contributed to the observed differences in growth among the treatment groups. Fauconneau et al. (1986) found differences in amino acid metabolism when the Siberian sturgeon *A. baeri* was fed different diets, which resulted in disparities in protein synthesis and growth among fish. Furthermore, some amino acids (L-serine, L-analine, and L-leucine) have been shown to elicit feeding response in white sturgeon (Lindberg 1988). Lindberg (1988) speculated that the incorporation of chemicals from tubificid worms, which contain

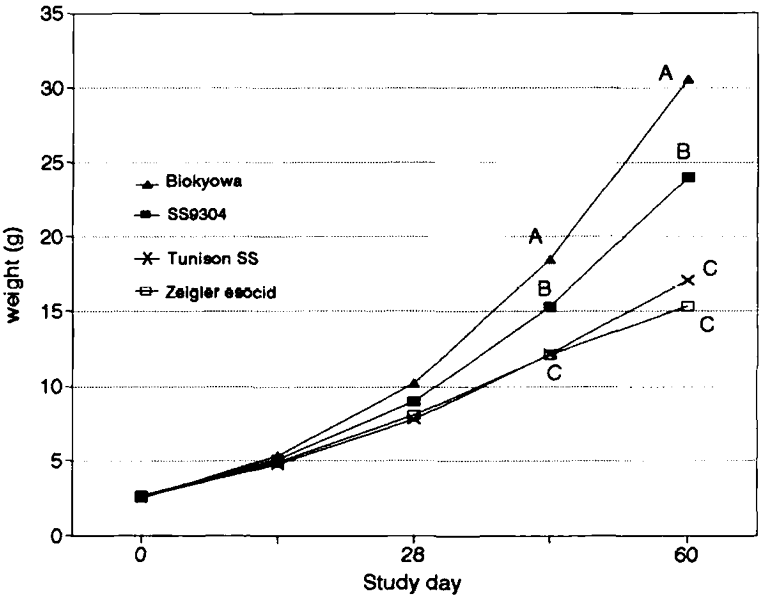

FIGURE 1.—Mean weights of juvenile Atlantic sturgeons fed one of four diets over 60 d; SS = sturgeon starter. Within a study day data points without a letter in common are significantly different ($P \leq 0.05$).

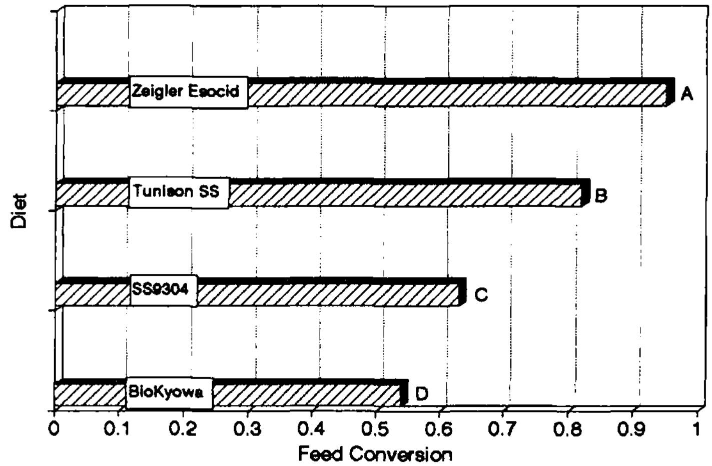

FIGURE 2.—Mean feed conversion (weight of feed offered/increase in fish wet weight) of Atlantic sturgeons fed one of four diets over 60 d; SS = sturgeon starter. Graph data with different letters are significantly different ($P \leq 0.05$).

these amino acids, into larval feeds could improve feed acceptance and growth in sturgeon. Although it was not a primary objective of the study, it is of interest that Atlantic sturgeon fry raised on live *Artemia* sp. or *Artemia*-supplemented diets for 35 d were observed to rapidly convert to a variety of formulated diets without a weaning period. Dry feed offered to 70-d-old lake sturgeon *A. fulvescens* was poorly accepted (Ceskleba et al. 1985). In addition, Monaco et al. (1981) reported between 70 and 80% mortality in attempting to convert fingerling white sturgeon from live *Tubifex* sp. to formulated feed pellets. Lindberg and Doroshov (1986) suggested that sturgeons are more prepared physiologically and anatomically to accept and assimilate a natural diet than a prepared diet during early life stages. However, first-feeding white sturgeon fry have been successfully cultured on formulated diet (Conte et al. 1988). Additional study is needed to define the dietary requirements and other environmental conditions necessary for acceptable growth of cultured Atlantic sturgeons.

References

Buddington, R. K., and S. I. Doroshov. 1984. Feeding trials with hatchery produced white sturgeon juveniles (*Acipenser transmontanus*). Aquaculture 36: 237–243.

Conte, F. S., 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. University of California, Division of Agriculture and Natural Resources, Cooperative Extension, Publication 3322, Oakland.

Ceskleba, D. G., S. AveLallemant, and T. F. Thuemler. 1985. Artificial spawning and rearing of lake stur-

TABLE 2.—Results of proximate analyses of four experimental diets (wet weight basis) and fingerling Atlantic sturgeons (dry weight basis) fed one of four diets over 60 d. Data for fish are means of three replicates; parenthetical values are SDs. Within a column, means without a letter in common are significantly different ($P \leq 0.05$).

Diet	Dry matter (%)	Protein (%)	Fat (%)	Ash (%)
		Diets analysis		
Biokyowa	97.28	59.43	15.99	12.43
SS9304	88.47	53.77	21.29	7.62
Tunison SS	91.76	52.72	22.46	12.96
Zeigler esocid	89.11	54.07	13.07	8.22
		Fish analysis		
Biokyowa	19.46 (±2.01) zy	63.58 (±2.58) y	18.81 (±4.42) y	10.84 (±1.21) yx
SS9304	20.79 (±0.74) z	58.73 (±0.76) x	26.00 (±0.74) z	10.42 (±0.16) x
Tunison SS	19.40 (±0.37) zy	65.22 (±0.73) zy	18.09 (±1.34) y	13.11 (±0.95) z
Zeigler esocid	17.45 (±0.25) y	68.90 (±1.59) z	11.29 (±1.11) x	12.93 (±0.58) zy

geon, *Acipenser fulvescens*, in Wild Rose State Fish Hatchery, Wisconsin, 1982–1983. Environmental Biology of Fishes 14:79–85.

Dabrowski, K., S. J. Kaushik, and B. Fauconneau. 1985. Rearing of sturgeon (*Acipenser baeri* Brandt) larvae. 1. Feeding trial. Aquaculture 47:185–192.

Dovel, W. L., and T. J. Berggren. 1983. Atlantic sturgeon of the Hudson Estuary, New York. New York Fish and Game Journal 30:140–172.

Fauconneau, B., P. Aguirre, K. Dabrowski, and S. J. Kaushik. 1986. Rearing of sturgeon (*Acipenser baeri* Brandt) larvae. 2. Protein metabolism: influence of fasting and diet quality. Aquaculture 51: 117–131.

Jones, C. E. 1984. Animal feed. Pages 152–169 *in* S. Williams, editor. Official methods of analysis, 14th edition. Association of Official Analytical Chemists, Arlington, Virginia.

Lindberg, J. C. 1988. Feeding preferences and behavior of larval and juvenile white sturgeon (*Acipenser transmontanus*). Doctoral dissertation. University of California, Davis.

Lindberg, J. C., and S. I. Doroshov. 1986. Effect of diet switch between natural and prepared foods in growth and survival of white sturgeon juveniles. Transactions of the American Fisheries Society 115: 166–171.

Littell, R. C., R. J. Freund, and P. C. Spector. 1991. SAS system for linear models, 3rd edition. SAS Institute, Cary, North Carolina.

Monaco, G., R. K. Buddington, and S. I. Doroshov. 1981. Growth of white sturgeon (*Acipenser transmontanus*) under hatchery conditions. Journal of the World Mariculture Society 12(1):113–121.

Mason, W. T., J. P. Clugston, and A. M. Foster. 1992. Growth of laboratory-held Gulf of Mexico sturgeon *Acipenser oxyrhynchus desotoi*. Progressive Fish-Culturist 54:59–61.

Moberg, G. P., and S. I. Doroshov. 1992. Reproduction in cultured white sturgeon, *Acipenser transmontanus*. NOAA Technical Report NMFS 106:99–104.

Parauka, F. M., W. J. Troxel, F. A. Chapman, and L. G. McBay. 1991. Hormone-induced ovulation and artificial spawning of Gulf of Mexico sturgeon *Acipenser oxyrhynchus desotoi*. Progressive Fish-Culturist 53:113–117.

Smith, T. I. J., E. K. Dingley, and D. E. Marchette. 1980. Induced spawning and culture of Atlantic sturgeon. Progressive Fish-Culturist 42:147–151.

Smith, T. I. J., E. K. Dingley, and D. E. Marchette. 1981. Culture trials with Atlantic sturgeon, *Acipenser oxyrhynchus*, in the USA. Journal of the World Mariculture Society 12(2):78–87.

Smith, T. I. J., D. E. Marchette, and G. F. Ulrich. 1984. The Atlantic sturgeon fishery in South Carolina. North American Journal of Fisheries Management 4:164–176.