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Early culture of the American Atlantic sturgeon *Acipenser oxyrinchus oxyrinchus* Mitchill, 1815 and preliminary stocking trials

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ABSTRACT

We performed rearing studies with first-feeding fry and fingerling American Atlantic sturgeons *Acipenser oxyrinchus oxyrinchus* Mitchill, 1815 of Hudson River parentage. Sturgeons were reared at initial densities of 3.7-22.2 fish/l and offered live *Artemia* sp., frozen *Artemia* sp., or a formulated diet (Biokyowa). After 26 days, mean specific growth rate was inversely proportional to fish density and ranged from 4.9-11.1 % per day. Fish fed frozen artemia were smaller but had the same survival rate as those fed live artemia. Sturgeons converted to a formulated diet with < 25 % mortality at mean length and weight (sd) of 34.5 mm (3.0) and 182 mg (50). Treatments of fingerlings established at initial densities of 0.37-2.22 g/l and fed a formulated diet (Zeigler) for 28 days exhibited mean percent survival (sd) of 87.0 (0.0) to 93.3 (2.3) and had feed conversion factors of 0.50 or less. Our study showed that first-feeding American Atlantic sturgeons require low initial rearing densities (7.4 fish/l or less) and 20-26 days of continuous live artemia to facilitate conversion to formulated feed. Fish reared similarly were released into the Hudson River in 1994 and into the Nanticoke River (a Chesapeake Bay tributary) in 1996 to evaluate survival and estimate wild recruitment. Sampling in the Hudson River from 1995 through 1997 showed that hatchery fish comprised 35-53 % of the total juvenile catch. Evaluation of fish released in the Nanticoke River from 1996 through 1998 showed that hatchery fish spread throughout Chesapeake Bay, made up 62 % of the total American Atlantic sturgeon catch, and had similar length-weight relationships as wild fish.

Key words: Density, specific growth rate, diet conversion, stocking evaluation.

RESUMEN

Primeras fases del cultivo de esturión atlántico americano* Acipenser oxyrinchus oxyrinchus *Mitchill, 1815 e intentos preliminares de repoblación

Hemos realizado estudios de cultivo con juveniles en estadios iniciales y más avanzados de esturión atlántico americano Acipenser oxyrinchus oxyrinchus *Mitchill, 1815 de linaje procedente del río Hudson. Los esturiones fueron cultivados a densidades iniciales de 3,7-22,2 peces por litro y alimentados con* Artemia *sp. viva,* Artemia *sp. congelada, o con una dieta formulada (Biokyowa). Después de 26 días, la tasa específica de crecimiento media fue inversamente proporcional a la densidad de peces y varió entre 4,9-11,1 % por día. Los peces alimentados con artemia congelada fueron más pequeños, pero tuvieron la misma tasa de supervivencia que los alimentados con artemia viva. Los esturiones transformaron una dieta formulada con menos de 25 % de mortalidad a una longitud y peso medios de 34,5 mm (desviación típica = 3,0) y 182 mg (50). Los tratamientos de estadios más avanzados, establecidos a densidades iniciales de 0,37-2,22 g/litro y alimentados con dieta formulada (Zeigler) durante 28 días, exhibieron un porcentaje de supervivencia medio entre 87,0 (d.t. = 0,0) y 93,3 (2,3) y fueron alimentados con factores de conversión de 0,50 o menores.*

Nuestro estudio mostró que los juveniles en estadios iniciales de esturión atlántico americano requieren densidades de cultivo iniciales bajas (7,4 peces/litro o menores) y 20-26 días seguidos de artemia viva para facilitar la conversión a dieta formulada. Peces cultivados de este modo fueron soltados en el río Hudson en 1994 y en el río Nanticoke (un afluente de la bahía Chesapeake) en 1996 para evaluar su supervivencia y estimar el reclutamiento silvestre. El muestreo en el río Hudson desde 1995 a 1997 mostró que los peces cultivados supusieron el 35-53 % de las capturas totales de juveniles. La evaluación de los peces soltados en el río Nanticoke desde 1996 a 1998 mostró que los peces cultivados se distribuyeron hacia la bahía Chesapeake, suponiendo el 62 % de las capturas totales de esturión atlántico americano, y tuvieron similares relaciones longitud-peso que los peces silvestres.

Palabras clave: *Densidad, tasa específica de crecimiento, conversión de dieta, evaluación de la repoblación.*

INTRODUCTION

The North American Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus* Mitchill, 1815 is considered the closest relative of the European Atlantic sturgeon *Acipenser sturio* L., 1758 through genetic analysis (Birstein and DeSalle, 1998) as well as morphological comparison (Artyukhin, 1995). Both species were distinguished by Magnin (1962) and both suffered severe declines over their respective ranges as a result of over-fishing and dam construction in the late 19th and early 20th centuries. In light of the highly endangered status of *A. sturio* (Williot *et al.*, 1997), experience gained in culture and experimental release of hatchery-reared *A. oxyrinchus* in the United States may serve as a valuable model for *A. sturio* when considering these activities as management tools for restoration. The Fishery Management Plan for Atlantic sturgeon (November, 1990) was adopted in the United States by the Atlantic States Marine Fisheries Commission to provide a framework for restoration of the species over its historical range. In anticipation of possible population management through use of hatchery-reared fish and potential interest in commercial aquaculture, the US Fish and Wildlife Service's Northeast Fishery Center - Lamar, Pennsylvania (NEFC) began developing culture techniques for the species in 1991. As a result of broodstock capture, transport, egg incubation, and rearing experiments at NEFC (McPeck, 1995; Mohler, Fynn-Aikins and Barrows, 1996; Mohler and Fletcher, 1999; Mohler, King and Farrel, 2000), five year-classes of hatchery-produced F1 generation Hudson River stock are maintained along with a number of captive wild fish.

As with many fish species, the success of a programme for restoration stocking or aquaculture depends largely on the development of reliable culture techniques for early life stages. However, development of culture techniques alone is no guarantee that hatchery-reared fish released into the wild will survive and eventually contribute towards rebuilding depleted populations. Many species are rare because of habitat loss and some may be readily propagated in the hatchery, but without suitable sites for their re-introduction into the wild, the role of the hatchery is reduced to that of providing refugia (Rinne *et al.*, 1986). Therefore, our studies were performed to: (1) refine culture parameters for first-feeding fry and fingerlings to optimise survival and growth in the hatchery; and (2) demonstrate the ability of hatchery-reared fish to survive and grow when released into two different drainages within the historical range of the species. Artificially-propagated progeny of wild American Atlantic sturgeons gill-netted from the Hudson River, New York were used in the studies.

REARING EXPERIMENTS

First-feeding fry

Six-day post-hatch sturgeons were reared at initial densities of 3.7-22.2 fish/l and offered: (1) live newly-hatched *Artemia* sp. delivered automatically via timer-controlled bellows pumps at a rate of 3 min feed delivery at 30-min intervals, 24 h/day; (2) newly-hatched frozen *Artemia* sp. hand-fed 3 times/daily (mean daily offering was 4.98×10^5 nauplii); or (3) a commercially-formulated diet offered at 10 % body weight per day (Biokyowa B-250, Biokyowa, Inc., Chesterfield, Missouri) via continuous-operation electronic feeders (model A-100, Double A Brand Co., Dallas, Texas). Feeding was observed at 10 days post-hatch and verified by the presence of artemia nauplii in the digestive tract. Random sampling showed that the number of artemia nauplii offered ranged from 3.82-5.72 × 10^5 per tank daily. Each treatment consisted of three 54-l circular, plastic tanks with a centre standpipe-drain assembly. Available grazing area on the bottom of each tank was approximately 1 631 cm^2. Water depth in each tank averaged 26.6 cm. Flows were set at 3 l/min, water temperature was 17 ± 1 °C, and dissolved oxygen ranged from 8.1-8.9 mg/l. Specific growth rate (SGR) expressed as percent gain per day was calculated using the following equation (Brown, 1957):

$$SGR = [\,ln\ (\text{final weight}) - ln\ (\text{beginning weight})\,] / \text{days} \times 100$$

After 26 days of feeding, mean SGR in live artemia treatments was inversely proportional to fish density and ranged from 4.9-11.1 % per day (figure 1). Fish fed frozen artemia were smaller but showed mean survival similar to those fed live artemia (> 93 %). Mean survival (sd) was lowest in tanks offered Biokyowa at 13.1 % (2.0) (table I). Since our supply of artemia cysts was depleted on day 26, sturgeons were offered only Biokyowa formulated diet (1:1 mix of size B-400 and C-700, Biokyowa, Inc., Chesterfield, Missouri, USA) for a subsequent 11-day period at 3 % body weight per day. During this 11-day period, fish in the two lowest density treatments were most successful at diet conversion, showing mortality estimated at < 25 %. Random sampling of 30 fish per tank showed minimum mean length and weight (sd) for the two lowest densities at the time of diet change was 34.5 mm (3.0) and 182 mg (50). This size was achieved in 20-26 days when fry were reared at initial densities of 7.4 fish/l or less (figure 2). All higher density treatments exhibited high mortality during this 11-day period of diet conversion as fish became emaciated and had difficulty maintaining normal swimming posture. Subsequent analysis of a number of these moribund fish showed starvation as the probable cause of mortality (J. Coll, pers. comm.)

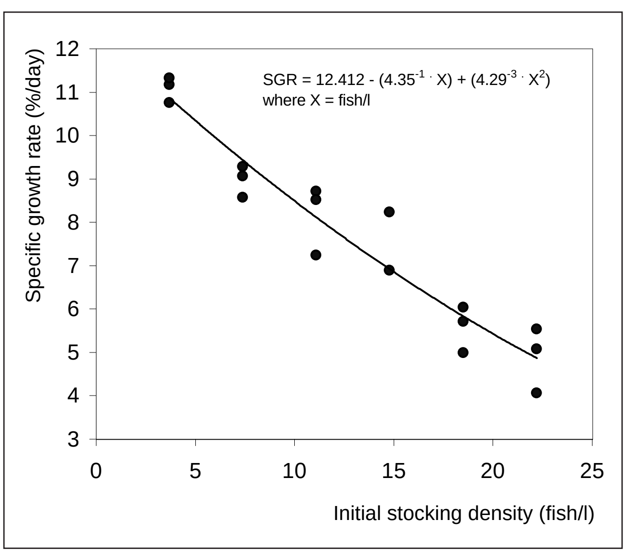

Figure 1. Specific growth rates (SGR as % per day) of first-feeding American Atlantic sturgeons reared at stocking densities ranging from 3.7-22.2 fish/l and offered equivalent amounts of live artemia nauplii for 26 days. The line of best fit is described by a second-order polynomial regression (SGR = 12.412 - (4.35^{-1} X) + (4.29^{-3} X^2) where X = density in fish/l. Dotted lines represent 95 % confidence limits for SGR. Only two replicates established for 14.8 fish/l treatment

Table I. Rearing densities, initial and final weights, feed type, and mortality in first-feeding American Atlantic sturgeon rearing study. Data with different letters are significantly different ($p < 0.05$)

Fry treatments				
Density (fish/l)	Mean weight (mg)		Feed type	% mean survival (sd)
	Initial	Final (sd)		
3.7	17.6	315 (55.7) a	Live artemia	93.8 (1.6) a
7.4	”	182 (49.6) b	Live artemia	96.3 (1.9) a
7.4	”	50 (20.6) e	Frozen artemia	94.7 (2.8) a
7.4	”	90 (25.3) e	BioKyowa B-250	13.1 (2.0) b
11.1	”	149 (45.3) c	Live artemia	96.6 (1.7) a
14.8	”	129 (43.5) d	Live artemia	96.2 (1.4) a
18.5	”	76 (27.5) e	Live artemia	97.7 (0.8) a
22.2	”	64 (22.2) e	Live artemia	96.9 (1.2) a

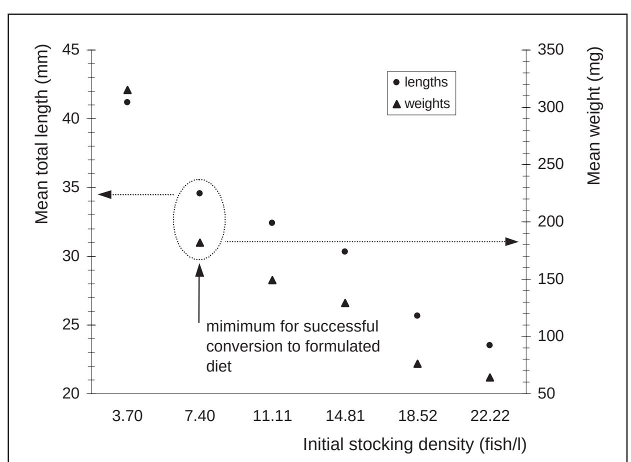

Figure 2. Mean total length (mm) and weight (mg) of first-feeding American Atlantic sturgeons offered live artemia nauplii for 26 days and observed minimum size for successful conversion to formulated diet

Fingerlings

Survivors of the fry study converted to formulated feed were pooled and redistributed at densities of 0.37-2.22 g/l using the same tanks and water quality parameters as above. Sturgeons were fed Zeigler sturgeon diet (Zeigler Brothers, Inc., Gardners, Pennsylvania) at 3 % of body weight/day via continuous-operation feeders. Afer 28 days, survival was 87 % or greater and not significantly different ($p > 0.05$) between density treatments. Feed conversion factor (FC), calculated as weight of feed offered/weight gain of fish, showed that fish reared at the low density were slightly more efficient at converting feed to flesh than those reared at the high density (FC = 0.44 vs. 0.50, respectively) (table II). Random sampling of 22-30 fish per tank showed mean weights (sd) ranged from 3.04 g (2.01) to 3.35 g (1.58) and were not significantly different between treatments ($p > 0.05$) (table II).

Table II. Rearing densities, initial and final weights, mortality, and feed conversion factors in fingerling American Atlantic sturgeon rearing study. Data with different letters are significantly different ($p < 0.05$)

Fingerling treatments				
Density (g/l)	Mean weight (g)		% survival	Feed conversion factor
	Initial	Final (sd)	Mean (sd)	Mean (sd)
0.37	0.48	3.22 (1.49) a	93.3 (2.3) a	0.44 (0.02) a
0.63	”	3.23 (1.69) a	91.3 (4.1) a	0.45 (0.02) ab
1.43	”	3.35 (1.63) a	90.0 (1.0) a	0.49 (0.03) ab
1.72	”	3.04 (2.01) a	87.0 (0.0) a	0.49 (0.03) ab
2.22	”	3.35 (1.58) a	89.3 (1.5) a	0.50 (0.03) b

EXPERIMENTAL STOCKING

Hudson River

In October 1994, 4 927 fish reared on live artemia followed by conversion to formulated feed as described above were marked with a pelvic fin amputation and a coded-wire tag under the first dorsal scute. Fish were then released into the Hudson River by the New York Department of Environmental Conservation to evaluate survival, growth, and estimate wild recruitment (mean length at release was 10.3 cm and mean weight was 4.1 g). Fish were released approximately 40 km downstream of the spawning area from which parental broodstock were captured. Gill-net sampling using stratified random sampling on the Hudson River in 1995 resulted in capture of 15 hatchery-reared fish and 14 wild fish, which were estimated to be the same age as hatchery-reared fish (Petersen, Bain and Haley, 2000). Age estimates of wild fish were based on length and pectoral spine analysis by Dovel and Berggren (1983) as cited in Petersen, Bain and Haley (2000). Assumed age-1 wild fish had greater total length than hatchery-reared fish (mean: 51.3 vs. 38.9 cm). Both marks (pelvic fin amputation + coded wire tags) were found on all hatchery fish, suggesting minimal tag loss. Petersen (1998) also reported results of targeted gill-net capture for juveniles in 1996 and 1997, where nearly 50 % of all juveniles captured were of hatchery origin (12 of 25) and (83 of 182), respectively. Hatchery-reared fish (age-3) captured in 1997 had mean fork length = 60.3 cm compared to assumed age-3 wild fish at 68.5 cm. Likewise, mean weight of captured hatchery-reared fish, at 1 554.7 g, was lower than that of assumed age-3 wild fish, at 2 403.5 g. Out-migration of hatchery-reared fish was documented since three marked fish (pelvic fin amputation + coded wire tag) were captured in the Delaware River estuary in 1997 and re-tagged with visible floy tags. One month later, one of these re-tagged indivuduals was recaptured in the Chesapeake Bay estuary (Bain, 1998). Hatchery-reared fish captured in the Delaware River three years after release clearly showed complete pelvic fin amputations (C. Shirey, pers. comm.)

Nanticoke River

In July 1996, a second experimental stocking was performed with 3 275 age-1 hatchery-reared fish. Fish were reared on live artemia followed by conversion to formulated feed in a manner similar to that described above. In October 1995, about one-half of the fish were transferred to the Maryland Department of Natural Resources, where they were held over the winter, and in June 1996 the remainder were transferred. Due to a heater malfunction, some sturgeons were kept in cold water over the winter of 1995 and ranged from 6-15 cm total length at the time of release. Others held in warm water (in Maryland) during the same time period ranged from 22-36 cm total length at release

(Welch, Skjeveland and Mangold, 1999). Weights of stocked fish were not obtained prior to release. All were marked with either a coded-wire tag or a floy T-bar tag and were stocked at two sites on the Nanticoke River, a tributary of Chesapeake Bay. Evaluation of hatchery-reared sturgeon was achieved via a monetary reward programme administered by the US Fish and Wildlife Service - Maryland Fisheries Resources Office from 1996 through 1998. Commercial fishermen were compensated for holding any live sturgeon obtained as by-catch until verified by programme administrators as either wild or of hatchery origin. Welch, Skjeveland and Mangold (1999) reported that hatchery-reared fish comprised 62 % of the total sturgeon catch (447 of 788). In addition, length-weight relationships for sturgeon ranging from 44.5 and 99.5 cm were similar between wild and hatchery-reared fish, but all sturgeon longer than 100 cm were wild fish. Age verification of wild sturgeon has not been completed to date. Even though stocked at only two sites on the Nanticoke River, hatchery fish showed wide dispersal, being captured throughout Chesapeake Bay (Welch, Skjeveland and Mangold, 1999).

DISCUSSION AND CONCLUSIONS

Rearing experiments

We found the mean minimum size (sd) for successful conversion to formulated feeds in *A. o. oxyrinchus* to be 34.5 mm (3.0) and 182 mg (50). This minimum size can be achieved in 20-26 days using initial rearing densities of 7.4 fish/l or less and a nearly continuous supply of live food (artemia nauplii). Since first-feeding fry were offered equivalent amounts of artemia nauplii regardless of density, the inverse relationship between SGR and stocking density (figure 1) suggests food was a limiting factor as density increased. However, Mohler, King and Farrel (2000) reported that after 26 days, first-feeding fry reared at 18.5 fish/l and offered supplemental artemia nauplii were similar in size to those reared at the same density which received a normal ration. This suggests that another factor limited growth regardless of ration. Observations of American Atlantic sturgeon fry from 1993 to 1998 at NEFC showed that first-feeding fry are substrate feeders, consistent with observations of Bardi, Chapman and Barrows (1998) with fry of the sub-species *A. oxyrinchus desotoi* Vladykov, 1955. There is some evidence that increasing substrate area of rearing tanks may affect sturgeon growth as reported by Sbikin and Budayev (1991) where young *Acipenser gueldenstaedtii* Brandt, 1833 reared in tanks with horizontal shelving had higher growth than those reared in a similar-sized normal tank. An attempt was made to demonstrate a density/grazing area relationship with first-feeding *A. oxyrinchus*, but excessive parasite-induced mortality precluded definitive results (Mohler, King and Farrel, 2000).

In the fingerling rearing experiment, mortality and growth after 28 days was similar in all density treatments (table II) implying that the threshold density which limits growth or mortality was not attained. Therefore, once switched to formulated feed, fingerling sturgeon can be reared at initial densities of at least 2.22 g/l and achieve feed conversion factors of 0.50 or less over a 28-day period. Hatchery-produced *A. o. oxyrinchus* fingerlings reared on live artemia as first-feeding fry then switched over to formulated food with no weaning period demonstrated adaptability in feeding behavior by subsequent exploitation of natural food items during their first three years of liberation, exhibiting growth, survival, and out-migration.

Experimental stocking

In the Hudson River stocking evaluation, hatchery-reared fish were reported as being smaller than their wild counterparts. However, ages of wild fish were not verified, but based on data obtained between 1975-1978 by Dovel and Berggren (1983). In evaluation of the Nanticoke River stocking, weight/length relationships were reported as similar between wild and hatchery-reared fish, but ages of wild fish have not been verified. Regardless of precision concerning size/age comparisons between hatchery-reared and wild fish, both experimental stockings demonstrated that American Atlantic sturgeons reared initially on live artemia with subsequent conversion to formulated diets can survive in the wild for at least 2-3 years and increase in size. Additionally, some individuals stocked into the Hudson River began out-migration at about age 3, as demonstrated by their capture in the Delaware River and Chesapeake Bay.

Long-term evaluation is needed to determine whether stocked fish have imprinted to the watershed of release and will eventually help to rebuild depleted populations through successful reproduction.

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