Dispersal and growth of yearling Atlantic sturgeon, *Acipenser oxyrinchus*, released into Chesapeake Bay*

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Abstract—Significant fisheries for Chesapeake Bay Atlantic sturgeon, *Acipenser oxyrinchus,* have been absent for nearly a century, and there has been no evidence of recovery in the intervening years. Endangerment of Atlantic sturgeon in the Chesapeake Bay has stimulated interest in aquaculture-based restoration programs. A critical and unknown issue is whether hatchery released fish would encounter habitats that support growth and survival. In July 1996, approximately three thousand Atlantic sturgeon yearlings were released into Nanticoke River (Maryland) and subsequently tracked to evaluate their growth and dispersal. Biotelemetry of 32 individuals showed down-estuary emigration into the Chesapeake mainstem habitat during summer and fall at average ground speeds below 0.5 km/d. During the first year after release, 262 yearlings were captured by commercial fishermen. All yearlings and two-year-old fish were determined to be of hatchery origin (8% capture rate). Yearlings were captured throughout the Chesapeake Bay mainstem and tributaries. Two released sturgeon were captured in the Albemarle Sound System (Chowan River, NC). Juveniles captured during summer and fall experienced ca. 1.5% daily specific growth rate. Diets comprised annelid worms, isopods, amphipods, and mysids. Wide dispersal, high incidence of feeding, and positive growth rates suggested that hatchery-produced juveniles dispersed to areas that supported consumption, growth, and survival. Because the Chesapeake Bay continues to support juvenile habitats, we propose that curtailed or absent spawning stock or spawning habitat, or both, are principal factors that have contributed to lack of Atlantic sturgeon recovery during the twentieth century.

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In Chesapeake Bay, Atlantic sturgeon, *Acipenser oxyrinchus,* may be functionally extirpated (Secor[1]; Speir and O'Connell[2]). Although sporadic observations of yearlings and adults have been reported over the last two decades (Colligan et al., 1998), the probability of population extirpation based upon the infrequency of these observations, is high (Grogan and Boreman, 1998). Depletion of Atlantic sturgeon in the Chesapeake Bay followed a period of high exploitation in the late 19th century (Fig. 1), during which overfishing occurred for most Atlantic sturgeon populations (Murawski and Pacheco, 1977; Secor and Waldman, 1999). Also, sedimentation and eutrophication have dramatically affected the Chesapeake Bay's environment during the past century (Officer et al., 1984; Cooper and Brush, 1991), resulting in loss and degradation of spawning and nursery habitats that may have contributed to loss in viability of sturgeon populations.

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[1] Secor. D. H. 1995. Chesapeake Bay Atlantic sturgeon: current status and future recovery. Unpubl. manuscript. Chesapeake Biological Laboratory, P.O. Box 38, Solomons, MD 20688-0038, 10 p.

[2] Speir, H., and T. O'Connell. 1996. Status of Atlantic sturgeon in Maryland's Chesapeake Bay. Unpubl. Manuscript. MD Dep. Natural Rrsources, Tawes State Office Building, 580 Taylor Avenue, Annapolis, MD 21401, 7 p.

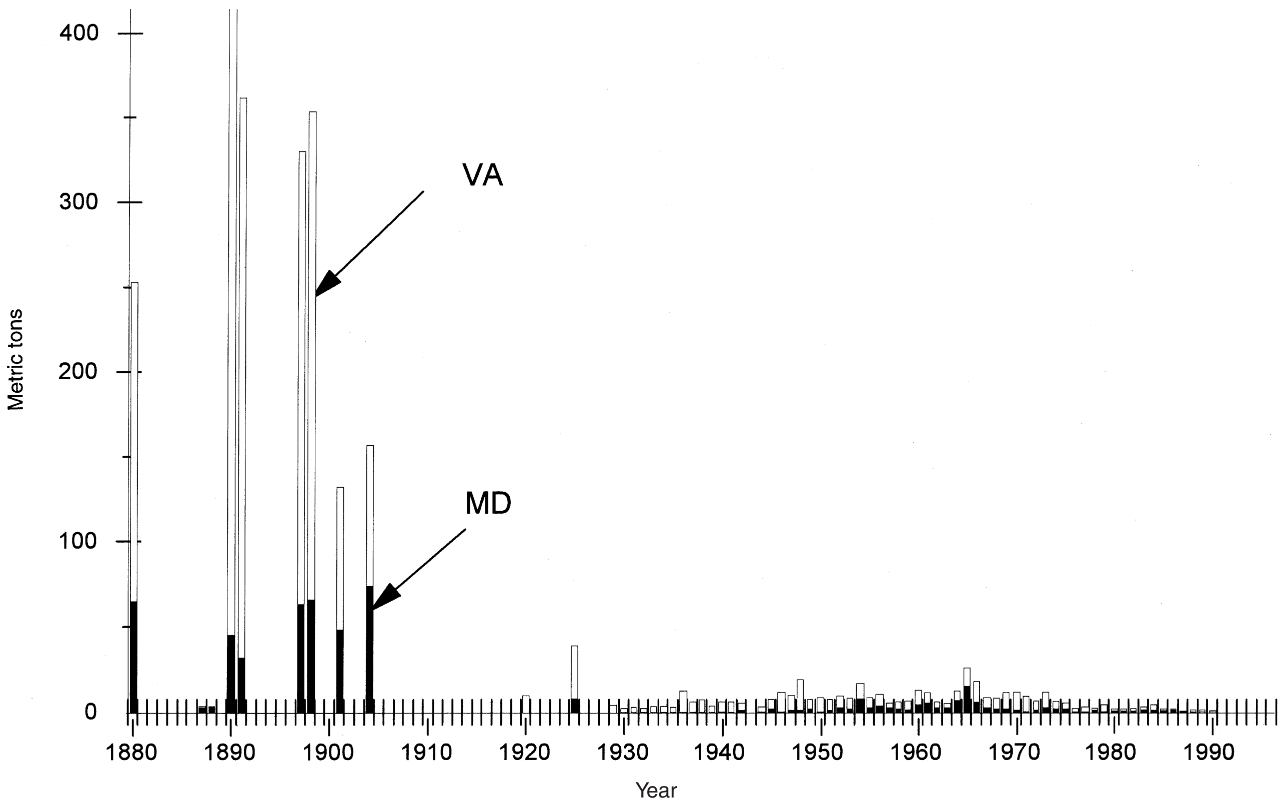

Figure 1

Atlantic sturgeon landings in Chesapeake Bay. Data from Murawski and Pacheco (1977) and Colligan et al. (1998). VA = Virginia; MD = Maryland.

During their first year of life, Atlantic sturgeon remain close to their natal habitats within estuaries (Dovel and Berggren, 1983; Bain, 1997). Following spawning migrations by adults, benthic eggs are deposited on hard, structured surfaces (e.g. cobble) in regions between the salt front and fall-line of large rivers. Historically, Chesapeake Bay Atlantic sturgeon spawned during April–June (Hildebrand and Schroeder, 1927). Young hatch at ca. 4–6 days after spawning, and following a 7–10 d period swimming upriver, adopt a benthic lifestyle (Smith et al., 1980). Young-of-the-year juveniles initiate seasonal migrations within estuaries (Dovel and Berggren, 1983). Emigration from natal estuaries to primarily marine habitats occurs at ages 1 to 5 years, after which subadults wander among coastal and estuarine habitats until maturation, undergoing rapid growth rates (Dovel and Berggren, 1983; Stevenson and Secor, 2000).

Lack of strong evidence of natural recovery has lead state, federal, academic, and nonprofit organizations to consider an aquaculture-based restoration program for Atlantic sturgeon in the Chesapeake Bay. To examine the feasibility of such a program, 3275 hatchery-produced yearlings (Hudson River progeny produced from a single female and four males) were released into the Nanticoke River (Chesapeake Bay) and their subsequent dispersal and growth was monitored over a one-year period. Specifically, we 1) characterized the dispersive behavior of non-native (hatchery-produced) Atlantic sturgeon yearlings through biotelemetry and the capture of sturgeons by fishermen, 2) explored potential relationships between the observed distribution and abiotic environmental factors, and 3) compared growth rate and diet of released juveniles observed in our study to those reported in the literature for naturally produced sturgeon.

Methods

Juvenile Atlantic sturgeon were obtained from the U.S. Fish and Wildlife Service (USFWS), Northeast Fishery Center, Lamar, Pennsylvania. During June 1995, Center personnel collected a large female (2.4 m total length) and three male Atlantic sturgeons from the Hudson River near Hyde Park (river km [rkm] 135). Fish were transported to the Center for artificial spawning and larval rearing. Larvae and early juveniles were reared in fresh water at 17°C and fed *Artemia* nauplii until 30 days after hatching. Juveniles (0.7–2.0 mm diameter) were then fed Biokyowa© fry feed *ad libitum* during their first year of life. A failure of the water heating system at the Center resulted in loss of temperature control, and juveniles >45 days after hatching, were subjected

Table 1

Capture data of coded wire tagged (CWT) and Floy-tagged Atlantic sturgeon, Chesapeake Bay 1996. 95% confidence intervals, based upon a binomial distribution, are given for the proportions of experimental groups in the capture sample. Note that because most fish were captured without T-tags and relatively few fish were sacrificed for CWT information, most of the 262 captures were not identified for release site or size class. Size at stocking could not be evaluated for differences in recapture rate due to small sample size.

Release site or size at stocking	Number released	% total released	Number identified from 262 captures	% group membership in capture sample (±95% CI)
Vienna (rkm 36)	1657	51	61	51 ±9
Sharptown (rkm 50)	1618	49	57	49 ±9
Total	3275		118	
Size class I (6–15 cm TL)	2306	70		
Size class II (22–36 cm TL)	969	30		
Total	3275			

to water temperatures of 10°C. At 6 months of age, ca. 1000 juveniles were transferred to Maryland and reared at 17°C at Maryland Department of Natural Resources (Maryland-DNR) and Potomac Electric Power Company hatchery facilities (Charles County, MD). Owing to differences in rearing temperature between juveniles held in Pennsylvania and Maryland hatcheries, two size classes resulted. At time of stocking, size class I ranged between 6 and 15 cm TL. Size class II ranged between 22 and 36 cm TL.

All stocked sturgeon were injected with an internal coded wire tag (CWT) to identify size class and stocking site. In tank-rearing studies conducted at the MD-DNR hatchery, CWT retention was >95%. Size class II juveniles were also tagged with external Floy T-tags inserted through their dorsal musculature below the fourth dorsal scute. Totals of 2306 and 969 juveniles from size classes I and II, respectively, were released into the Nanticoke River (MD) at river kilometers 36 and 50 on 7 July 1996 (Table 1, Fig. 2). River conditions at stocking sites were 0 and 3.0 ppt salinity, 26° and 27°C, and 4.2 and 7.7 mg/L dissolved oxygen (D.O.) at rkm 36 and 50, respectively. Site conditions varied less than anticipated in the study design, which stipulated release into divergent salinity levels because of high freshwater discharge rates to the Nanticoke River during spring and summer 1996.

Telemetry

To investigate short-term dispersal in the Nanticoke River, 32 juveniles were released at 5 sites over 7 occasions (Table 2) and tracked with Sonotronics© ultrasonic transmitters. Two size transmitters were used: 28 mm long by 8 mm diameter (2.5 g) and 64 mm long by 16 mm diameter (8 g) for Atlantic sturgeon <45 cm TL (released 7 July–12 August) and >45 cm TL (released 21 October), respectively. Both transmitters had a detection radius of 1 km; life spans were 60 days and 14 months for the small and large transmitters, respectively. Transmitters were attached by using a leather punch to drive 4.5-kg test monofilament through the third and fifth dorsal scutes. Line was affixed to the transistor by using a cyanocrylate glue, looped through the scutes and glued to the other end of the transmitter. A 50-day laboratory experiment on 10 dummy-tagged sturgeon showed 100% retention of transmitters with this method.

Table 2

Date and site of release of Atlantic sturgeon with ultrasonic transmitters, Nanticoke River, 1996.

Date	Release site	Number released	Number relocated	Mean length (cm) at release
8 Jul 96	rkm 36	3	2	39.2
	rkm 50	4	2	37.7
22 Jul 96	rkm 13	4	4	41.4
	rkm 36	4	4	40.9
12 Aug 96	rkm 24	3	2	39.2
	rkm 38	6	4	37.8
21 Oct 96	rkm 24	8	8	52.9
Sum		32	26	

Thirteen biotelemetry surveys were conducted throughout the Nanticoke River from July 1997 to February 1998. Tagged fish were located by using a hydrophone and identified by their coded signals. Position, temperature, salinity, and dissolved oxygen were recorded at each location site. On seven surveys, an otter trawl or 5-cm square gill net, or both, were deployed to capture juveniles that might be in the vicinity of the individual located through telemetry.

Relocation data were used to characterize overall displacement and to evaluate potential correlations with salinity, temperature, and dissolved oxygen conditions. Fish released at river kilometers 36 and 38 were com-

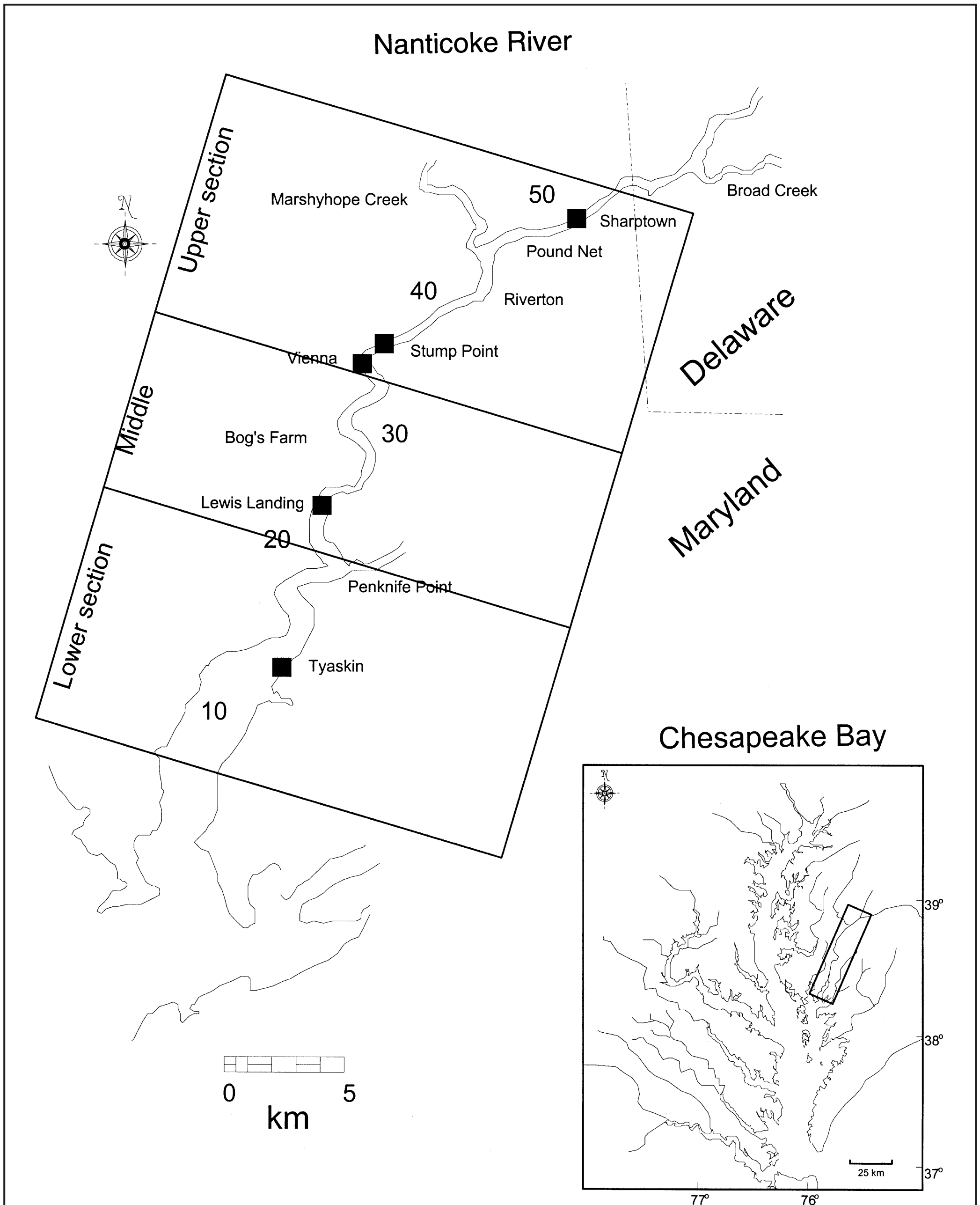

Figure 2

Map of Nanticoke River showing survey region, sites of release of yearling Atlantic sturgeon, and river sections utilized for statistical analysis. On 7 July 1996, >3000 yearlings were released at rkm 36 and 50. Later in summer and fall smaller releases of yearlings fitted with ultrasonic devices (Table 2) were made at rkm 13, 24, 36, and 50.

bined into a single group for statistical analysis. Consistency of mean trajectories and parallelism within and among released fish groups was tested by using multiple regression analysis, after modeling within-individual correlations (repeated measures) through a spatial power covariance model (Littel et al., 1996). Degrees of freedom were adjusted using Satterthwaite's approximation.

On the basis of upon multivariate analysis of available water quality data, the Nanticoke River was divided into three relatively homogeneous sections (Fig. 2): lower river: rkm 8 to 19.9, middle river: rkm 20 to 33.9, and upper river: rkm >34 (Table 3). Discriminate analysis indicated that this classification resulted in consistent differences in temperature, dissolved oxygen, and salinity records across

Table 3

Mean and standard deviations of measured environmental factors in Nanticoke River 8 July 1996–23 October 1996, by river section (see Fig. 2).

	River section			
Factor	Lower	Middle	Upper	Overall
River kilometers	8–19.9	20–33.9	34–59	8–59
Temperature (°C)	25.0 ±3.6	24.2 ±4.5	26.1 ±1.6	25.4 ±3.1
Dissolved oxygen (% saturation)	82.9 ±7.5	79.4 ±11.2	81.2 ±11.3	81.2 ±10.4
Salinity (ppt)	5.0 ±1.7	2.3 ±1.1	0.7 ±0.7	2.2 ±2.1
Depth (m)	2.9 ±1.1	5.8 ±2.1	5.8 ±2.5	5.1 ±2.4
Number of observations	32	35	60	125

summer and fall months (Wilk's approximated F, $P<0.001$). The upper river exhibited the highest mean temperature and salinities usually below 1 ppt. The middle section showed intermediate salinity (1–3 ppt), and highly variable temperature and dissolved oxygen conditions. The lower section corresponded to a shallow area with the highest salinity and dissolved oxygen means (Table 3, Fig. 3). Logistic regression analysis was used to explore potential relationships between probability of fish relocation within a river-section and corresponding water quality conditions.

Reward program

Maryland-DNR, in cooperation with USFWS and the Chesapeake Bay Foundation, offered a $25 reward to Chesapeake Bay fishermen for the capture and holding of live juvenile Atlantic sturgeon. The program was initiated in Maryland in July 1996 and extended to Virginia waters after February 1997. Capture data were documented by USFWS agents and measurements and tag information were recorded. In some instances, juveniles were sacrificed for CWT identification (n=22). Twelve of these fish, captured between 24 October 1996 and 8 January 1997, were made available to us for examination of diet (mean TL=56.1 cm ±7.40 SE; mean weight=823 g ±301.6 SE). Prey were classified at the lowest possible taxonomic level and evaluated according to numerical and volumetric contribution to diet.

Captured fish were measured for total length in mm (TL), fork length in mm (FL), and weight in g (W). Because all three measures were not consistently taken, we developed the following regressions to interconvert size measurements:

$$FL = 0.860 - 2.01\ TL \quad (r^2=0.96, n=214) \quad (1)$$

$$\log_e W = -9.25 + 2.52 \log_e TL \quad (r^2=0.64, n=211) \quad (2)$$

Growth was estimated by comparison of size at release (W_0) and size at capture (W_C) according to the formula

$$G_1 = (\ln W_c - \ln W_0)/t, \quad (3)$$

where t = days after release.

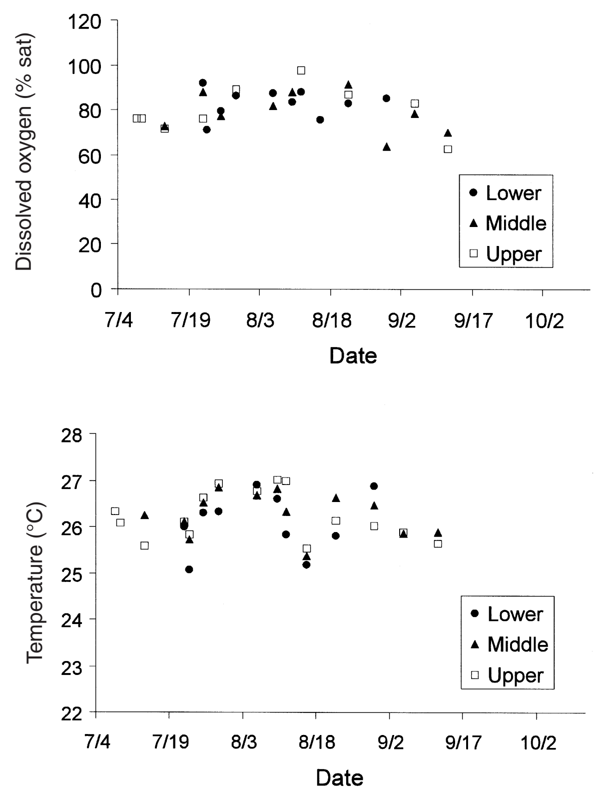

Figure 3

Mean records of (**A**) dissolved oxygen and (**B**) temperature by river section during summer 1996.

Results

Twenty-six fish were relocated during telemetric surveys at least once after release. The mean duration over which fish were tracked (35 days ±37 SD) and the number of relocations (4 relocations ±3.8 SD) were limited, perhaps owing to egress to the lower river and the Chesapeake mainstem (see "Discussion" section). Fish released at the three most upstream sites (rkm 50, 36, and 24) showed a significant pattern of downriver displacement (P<0.01) at average ground speeds of 0.4 ±0.08 SE, 0.11 ±0.04 SE, and 0.08 ±0.02 SE km/day, respectively (Fig. 4). Fish released at rkm 13 did not show a consistent up or downriver movement (P>0.9). There were also significant differences in dispersal patterns between fish released at different dates within the same section. For instance, fish released 22 July at rkm 36, and 12 August at rkm 24 did not show a consistent downriver dispersal pattern.

The average probability of relocation tended to be higher in the middle section of the river (0.46 ±0.071 SE) than in the lower and upper sections, where average probabilities of relocation were 0.30 ±0.065 SE and 0.28 ±0.064 SE, respectively. However, such probabilities were not significantly different from each other, as indicated by logistic regression analysis (P=0.13). No significant correlations were found between dissolved oxygen, water temperature or salinity, and proportion of total relocations occurring within a given section (P>0.11). Although no significant correlation occurred between salinity and distribution of fish relocations, most fish had left freshwater areas (0 to 1 ppt) within one week of being released. More than 90% of later relocations occurred in the range 1 to 7 ppt. All attempts to capture sturgeon where position of fish was triangulated through biotelemetry were unsuccessful. In 25 bottom trawls and five gillnet deployments, only two cultured juveniles were physically captured, one in a gill net on 26 July (24 cm TL) and the other in an otter trawl on 24 October (43 cm TL).

During fall and winter (earliest capture 1 November 1996), fishermen captured juveniles as an incidental catch in the mainstem of the Chesapeake Bay. Location of captures varied seasonally (Fig. 5). During fall and winter months (November–March) most captures occurred in the vicinity of the mouth of the Nanticoke River and north of the Nanticoke River in the mainstem of Chesapeake Bay. As winter progressed, sturgeon captures were concentrated at upper Bay mainstem sites. The distribution of captures tended to spread toward the lower Chesapeake Bay and into tributaries during late winter (March) and spring months, where several sturgeon were captured high up in major tributaries (Patuxent, Potomac, Rappahannock, and James rivers). Much of the shift in captures during spring and summer may have been an artifact of delayed implementation of a reward program in Virginia (initiated February 1997) and seasonal changes in fishing effort (see "Discussion" section). In March 1997, two individuals were captured outside of Chesapeake Bay in the Chowan River (Albemarle-Roanoke estuary, North Carolina).

The majority of juvenile sturgeon (60%) captured by commercial fishermen were ensnared in drift or anchored gill nets set for striped bass, white perch (*Morone americana*), and catfish (*Ictalurus punctatus, Ameiurus catus*); 40% of the captures were from pound nets principally set for menhaden (*Brevoortia tyrannus*). Gillnet captures occurred most often between January and early March, with a mean capture length (TL) of 61 cm ±5.6 SE. Poundnet captures were concentrated between April and late June. Mean length for poundnet captures was 66 cm TL

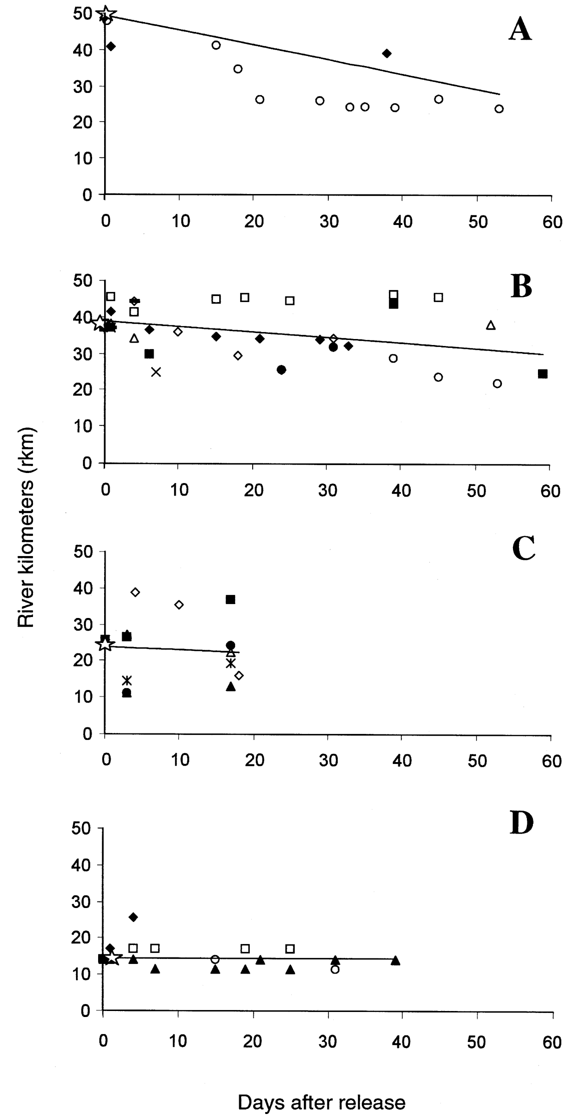

Figure 4

Relocation site (river kilometer) and mean trajectories for fish fitted with ultrasonic devices and released at different locations in the Nanticoke River. (**A**) release site 1 (rkm 50), (**B**) release site 2 (rkm 36–38), (**C**) release site 3 (rkm 24), and (**D**) release site 4 (rkm 13). Star icons indicate release site. Other icons within a graph indicate individual fish. Note that mean trajectories have been corrected for autocorrelation within individuals.

±5.7 SE. Captured yearlings were kept for up to 2 days by fishermen, prior to inspection by USFWS agents, by holding sturgeon in pens and tanks, or by tying them (by the mouth or tail) to fixed structures in the water. Juveniles inspected by agents were all judged to be in good condition and released without apparent harm to the fish.

Overall, 8% of stocked juveniles were taken incidentally. Sixteen Floy-tagged juveniles (size class II) were multiple

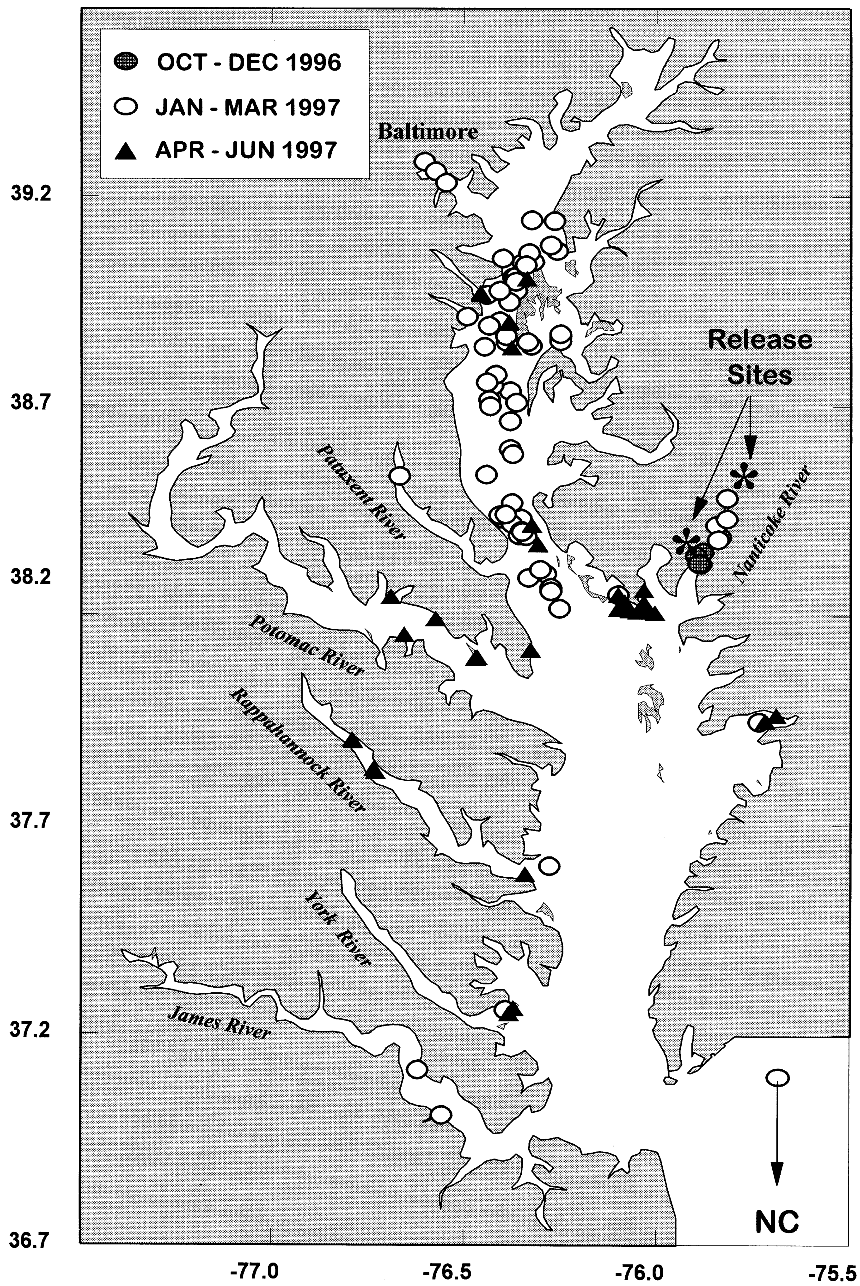

Figure 5

Spatial and temporal distribution of juvenile Atlantic sturgeon captures made by commercial fishermen in Chesapeake Bay.

recaptures but no fish were recaptured more than once. Capture rates of juveniles released at either up- or down-river sites were similar and indicated no differential survival between these groups (Table 1). All yearling sturgeon captured by fishermen contained a tag, or evidence of a lost tag. For those that had apparently lost a tag, a subsample of yearlings was determined to be of hatchery origin through analysis of microsatellite nuclear DNA.[3]

Released fish reached an average size of 67.2 cm TL ±3.8 (SE) and an average weight of 1536 g ±69 (SE), after 12 months in the wild (Table 4). Average growth rates, estimated from release to capture sizes, ranged between 0.64 and 1.83%/d. Estimated growth rates from monthly mean lengths and weights showed strong seasonality, with nil or negative growth rates between January and March (Fig. 6). One-third of the juveniles sacrificed for diet information had empty guts. Sand, silt, and detritus accounted for 34% of the combined gut contents. Of the remaining identified diet items, annelid worms were most important by volume

[3] King, T. 1997. Personal commun. Dep. of Interior, Leetown Science Center, 1700 Leetown Road, Kearneysville, WV 25430.

Table 4

Mean lengths and weights at ages 1 and 2 for juvenile Atlantic sturgeon observed in current study and reported in the literature.

Age 1 yr		Age 2 yr			
Fork length (cm)	Weight (g)	Fork length (cm)	Weight (g)	Geographical area	Source
20.0		25.0		St. Lawrence River	From Murawski and Pacheco (1977)
36.0		47.0		St. John River	From Murawski and Pacheco (1977)
40.8	500.0	47.7	770.0	Hudson River	Dovel and Berggren (1983)
28.4		43.9		Delaware River	Lazzari et al. (1986)
26.2	103.5	55.5	1535.8	Chesapeake Bay	Our study
57.8		74.4		Winyah Bay	Collins et al. (1996)
35.0		51.0		Suwannee River	From Murawski and Pacheco (1977)

(61%), followed by isopods (*Cyathura polita* and *Cyathura* sp., 23%), amphipods (*Leptocheirus plumulosus* and *Gammarus* sp., 10%), chironomid larvae (1.6%), and mysids (*Neomysis americana*, 1.5%). Occurrence data among yearlings indicated about 50% probability of finding all major food categories—worms, amphipods, and isopods—in feeding fish.

Discussion

Failure to capture a single wild yearling (<70 cm TL; see Peterson et al., 2000, for size criterion) during the course of our study is a strong indication of the Atlantic sturgeon's endangered status in Chesapeake Bay. In the fall of 1997, the floating carcass of a 2.6-m-TL female Atlantic sturgeon was observed in the James River.[4] Also, wild yearlings (<50 cm TL) were observed during 1998 in Virginia tributaries (Musick[5]) suggesting that some reproduction was still occurring in lower Chesapeake Bay. On the other hand, absence of yearling Atlantic sturgeon during Virginia Institute of Marine Science trawl monitoring over the past 15 years led Grogan and Boreman (1998) to predict >95% probability of extirpation in Virginia. Although this prediction has proven false, it still provides strong evidence of extremely depressed reproduction rates.

Results from our study indicated that the Chesapeake Bay can support nursery functions for juvenile Atlantic sturgeon. High capture rates by fishermen suggest high survival of released fish and high vulnerability to the gear types deployed. Wide dispersal and positive growth rates indicate that juveniles dispersed to areas that supported consumption and metabolic needs. Indeed, mean weight increased nearly 20-fold over the first year after release. Sizes at the end of the second year of life (summer 1997) were intermediate between size estimates for 2-year-old juvenile sturgeons from the Hudson River (Dovel and Berggren, 1983) and those from southern populations (Table 4). Thus, hatchery-produced fish had grown at levels that might be expected for juveniles naturally occurring in the Chesapeake Bay.

Although limited by a small sample size, our diet analysis seems consistent with the few published reports on food habits of juvenile Atlantic sturgeon. Aquatic insects, amphipods, isopods, and both polychaete and oligochaete worms are the most common items previously reported for juveniles residing in fresh and brackish waters (Vladykov and Greeley, 1963; Smith, 1985; Moser and Ross, 1995; Haley, 1998). Contrary to Vladykov and Greeley (1963) and Moser and Ross (1995), we found no evidence of juvenile sturgeon predation upon mollusks, which represent the highest biomass of benthic invertebrates in the Chesapeake Bay.

We failed to detect any significant selection among tracked individuals for certain water temperatures or dissolved oxygen conditions. Overall, tracked fish did not encounter severe hypoxia or extremely high temperatures (Table 3, Fig. 4). However, on at least one occasion, other than the day of release, yearlings encountered dissolved oxygen saturations close to 50% (4.3 mg/L, 25.9°C)—a level that might reduce growth and survival rates for this species (Secor and Gunderson, 1998). Preferential use of cooler areas or deep thermal refuges, or both, has been observed in field studies on juvenile Atlantic (Moser and Ross, 1995) and Gulf (Clugston et al., 1995) *A. oxyrinchus desotoi* sturgeons. Such refuges are unavailable in the Nanticoke River, a shallow system (Table 3) with little thermal stratification.

Low rates of use of habitats of salinity below 1 ppt agree with past observations that yearling Atlantic sturgeon principally use brackish water habitats (Dadswell, 1979; Brundage and Meadows, 1982; Smith, 1985; Moser and Ross, 1995; Haley et al., 1996). Observed down-estuary movement is consistent with seasonal movements reported for juvenile Atlantic sturgeon responding to summer peak temperatures in the Hudson River (Dovel and Berggren, 1983). Use of areas below rkm 10 was probably underestimated because river width substantially exceeded the detection range of ultrasonic transmitters and shallow reefs or sills probably obstructed detection.

[4] Spells, A. 1997. Personal commun. USFWS, 11110 Kimages Road, Charles City, VA, 23030.

[5] Musick, J. 1999. Personal commun. Virginia Institute of Marine Science, Gloucester, VA.

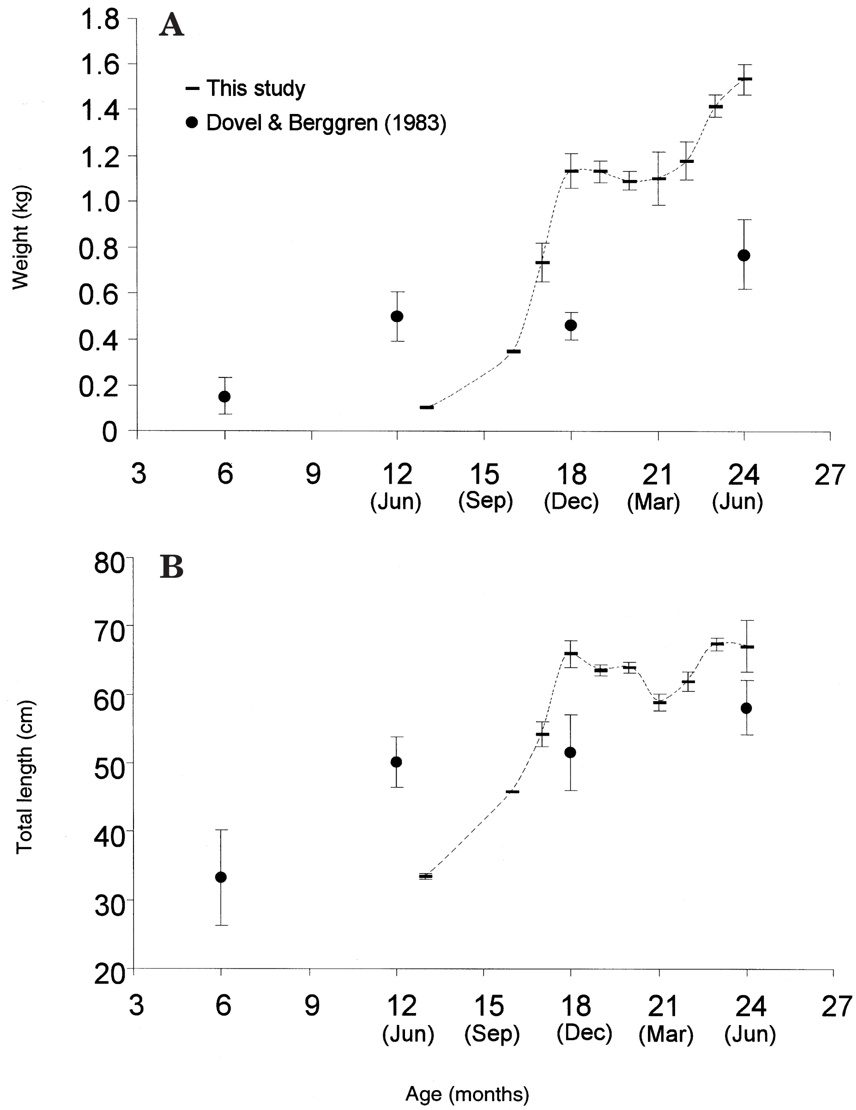

Figure 6

Growth curves as observed from released and captured juvenile Atlantic sturgeon in Chesapeake Bay. (**A**) Mean weight at age (month) ±SE. (**B**) Mean length at age (month) ±SE. Values reported by Dovel and Berggren (1983) are included for comparison. Note that Dovel and Berggren's data are averaged for all fish falling within a six-month age interval. Monthly values were fitted with a spline function (dashed line).

Tagging and telemetry studies on North American sturgeons (mostly on subadult and adult fish) tend to show seasonal or reproductive migrations but reduced displacements during intermigratory periods. Estimated home ranges for nonmigrating sturgeon were 0.8 km for landlocked white sturgeon (Haynes et al., 1978), 4 km for Gulf sturgeon (Clugston et al., 1995), and 2–3 km for shortnose sturgeon (Buckley and Kynard, 1985). Nonetheless, extensive wandering behavior was observed in adult shortnose sturgeon by McCleave et al. (1977), i.e. home ranges up to 30 km at average ground speeds around 0.21 body lengths (BL)/s. Moser and Ross (1995) observed gross movements ranging from 0.7 to 1.3 km/d in nonmigratory juvenile Atlantic sturgeon (68–122 cm TL) in Cape Fear River, NC. During seasonal or reproductive migrations, gross movement may increase to 0.8–7 km/d in juvenile (38–79 cm FL) Atlantic sturgeon (Gilbert, 1989), 0.6–6 km/d in Gulf sturgeon (Clugston et al., 1995), and 6.4–36 km/d in shortnose sturgeon (Buckley and Kynard, 1985; Kieffer and Kynard, 1993). We interpret our telemetry observations on initial yearling dispersal as a roving behavior, where fish are oriented toward searching for productive benthic forage conditions. This is supported by the relatively low rates of dispersal (0–0.4 km/d; 0.1 BL/s), low horizontal gradient observed in abiotic parameters, and a lack of correlation between relocation probability and water quality data. More intensive sampling and benthic resource mapping in Chesapeake Bay could confirm this speculation.

A moderate reward system was highly effective in helping to evaluate the release of hatchery sturgeon. Although we expect more juveniles may have actually been captured than reported, fishermen were keenly interested in the program and very cooperative with USFWS agents in their collection of biological measures. High capture rates of yearling Atlantic sturgeon by fishermen showed that small sturgeons were highly vulnerable to gill and pound nets, as found by Collins et al. (1996). Due consideration needs to be given to incidental catches of juvenile-stage sturgeon in recovery programs.

Seasonal and spatial patterns of captures by fishermen were the result of both seasonal dispersal and distribution of fishing effort in Chesapeake Bay. In winter and early spring months, drift and anchor gill nets were set for striped bass, white perch, and catfish in the upper bay and in tributaries. Later in the spring and summer, pound nets were set for menhaden, croaker (*Micropogonias undulatus*), and spot (*Leiostomus xanthurus*), which tend to occur down-estuary. Therefore, the apparent displacement of captures from the upper to lower Chesapeake Bay may be related to seasonal changes in fishing effort. In addition, Virginia began a reward program in February 1997; therefore captures were less likely to occur prior to that date.

The dispersal of released fish into Chesapeake Bay mainstem by fall 1996 and reported captures in North Carolina by the end of the winter also are consistent with seasonal movement patterns described for Atlantic sturgeon in other systems. Seasonal migration in juvenile Atlantic sturgeon seems primarily regulated by changes in temperature gradients between fresh and brackish waters (Van Den Avyle, 1984). Juveniles tend to use brackish waters close to estuary mouths during the colder months as reported in Hudson River (Dovel and Berggren, 1983; Gilbert, 1989), Delaware River (Brundage and Meadows, 1982; Lazzari et al., 1986), and the Winyah Bay system (Smith et al., 1982). In the Hudson River, juveniles begin moving to saltier waters by July (Dovel and Berggren, 1983), whereas in the Delaware River many fish remain in tidal water until January (Lazzari et al., 1986). A different pattern was observed by Moser and Ross (1995), who noted that juvenile Atlantic sturgeon in the Cape Fear River kept the same center of distribution all year round.

High dispersal rates of released yearlings and absence of schooling behavior were somewhat unexpected. Hatchery-produced striped bass and Pacific salmon (*Oncorhynchus* spp.) juveniles are known to school and remain in restricted regions for weeks and months following release (Nickelson et al., 1986; Hume and Parkinson, 1987; Dorazio et al., 1991; Nagata et al., 1994; Andreasen, 1995). Recent genetic studies indicate strong population structuring within the geographic range of the Atlantic sturgeon (Waldman and Wirgin, 1998), which suggests high fidelity to natal estuaries. Gene flow studies also support consistent homing behavior by the Gulf subspecies (Wirgin et al., 1997). However, the rapid dispersal we observed might suggest that yearlings had insufficient opportunity to imprint to the Nanticoke River and thus might be unlikely to home to it in future spawning migrations. Apart from work on salmonids, little is known on homing behavior in anadromous fishes. In Pacific salmon, the window of imprinting occurs during the premigratory smolt stage (Hasler and Scholz, 1983). Stocking young-of-the-year Atlantic sturgeon in any future hatchery-based restoration program would be prudent because it might increase the duration of exposure to imprinting stimuli.

This study demonstrates that the Nanticoke River and Chesapeake Bay can continue to support nursery roles for Atlantic sturgeon yearlings. Still, several questions remain before we embark on a program of restoration through hatchery-based reintroduction. What are the main factors defining suitable habitat for Atlantic sturgeon juveniles? Would available habitat support historical abundances? Can we obtain sufficient numbers of brood stock from the Hudson River or elsewhere to ward against inbreeding depression? A critical question is whether released juveniles will return and find spawning habitat. Spawning habitats are probably quite degraded from siltation and sedimentation over the past two centuries. Unfortunately, evaluating whether such habitats remain or can be restored will be nearly impossible until an adult biomass can be restored.

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