JUVENILE STURGEON HABITAT USE

IN THE HUDSON RIVER

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Haley, N., J. Boreman, and M. Bain. 1996. Juvenile Sturgeon Habitat Use in the Hudson River. Section VIII: 36 pp. *In*: J.R. Waldman, W.C. Nieder, and E.A. Blair (eds.), Final Reports of the Tibor T. Polgar Fellowship Program, 1995. Hudson River Foundation, NY.

Abstract

The Hudson River supports sympatric populations of Atlantic (*Acipenser oxyrinchus*) and shortnose sturgeon (*Acipenser brevirostrum*). These ecologically similar fish exhibit varying life history strategies yet, during their extended juvenile period, they appear to overlap within the Hudson River estuary. Thus, an opportunity exists to study distribution and habitat association patterns of resident juvenile Atlantic and shortnose sturgeon. My objectives were to: (1.) assess the feasibility of using a widely dispersed sampling program to collect juvenile sturgeon in the Hudson River; (2.) identify environmental attributes associated with sturgeon summer foraging habitat; and (3.) examine species-specific patterns of habitat association. Between early June and mid-September, 1995, I deployed small-mesh gill nets to capture juvenile Atlantic and shortnose sturgeon and collected physicochemical data at randomly selected sampling stations within a 96-kilometer reach of the Hudson River estuary. Forty-eight wild juvenile sturgeon were collected: 36 Atlantic and 12 shortnose sturgeon. An additional nine hatchery-reared Atlantic sturgeon, products of a recent U.S. Fish and Wildlife Service breeding and stocking effort, were also captured. Juvenile sturgeon were distributed differently with respect to river stratum, salinity zone, and depth. No differences in their distribution with respect to substrate type and bottom water temperature were detected. Wild Atlantic sturgeon occurred most often within a relatively deep, mesohaline stratum within the study area. Juvenile shortnose sturgeon and stocked Atlantic sturgeon were restricted to the two uppermost strata within the study area. The oligohaline region of the river, which contains the biologically productive freshwater/saltwater interface, was a zone of overlap for wild Atlantic, shortnose, and stocked Atlantic sturgeon. Stocked Atlantic sturgeon exhibited a seasonal distribution pattern more similar to juvenile shortnose sturgeon than similar-sized Atlantic sturgeon. Future studies should investigate behavioral, ecological, and physiological factors influencing seasonal distributions of juvenile sturgeon in the Hudson River.

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Introduction

Sturgeon are large, long-lived benthic fish that inhabit the channel regions of large coastal rivers and estuaries and the coastal marine environment (Vladykov and Greeley 1963). Atlantic (*Acipenser oxyrinchus*) and shortnose sturgeon (*Acipenser brevirostrum*) have overlapping ranges along the east coast of North America. Historically, both species were harvested for meat and caviar, though overfishing and deteriorating water quality during the early part of this century severely impacted stocks of both species. Shortnose sturgeon were listed as endangered throughout their range in 1967. Thus, the species is protected from commercial harvest. A reduced fishery for Atlantic sturgeon still exists, though concern for declining stock sizes necessitates vigilant regulation of the fishery (Taub 1990). The commercial importance of these species combined with their vulnerability to overfishing, extensive evolutionary history (circa 150 million years), and unusual morphology, render them premier subjects of estuarine and freshwater research.

To date, most efforts to study Atlantic or shortnose sturgeon have centered on estimating adult population sizes and identifying adult distributions to gain insights about population dynamics and general movement patterns (Buckley and Kynard 1985; Dovel et al. 1992; O'Herron et al. 1992). Consequently, much of the basic biology and ecology, particularly for juveniles of both species, remains unstudied. Dadswell (1979) attributed a lack of a general understanding about the distribution of all life stages of sturgeon in many rivers to the fish's occurrence in large rivers and preference for "interface" habitats: estuarine areas in which tidal currents, varied basin morphometry, and scattered debris inhibit effective sampling. Identification of basic distributional patterns and areas of high use (i.e., potential nursery areas) are important areas of study and essential precursors to more detailed ecological research on sturgeon. Locating sites where juvenile sturgeon concentrate seasonally or annually would provide for more efficient sampling of younger age groups in addition to helping fishery managers protect sensitive younger life-stages.

The Hudson River supports sympatric populations of Atlantic and shortnose sturgeon. Atlantic sturgeon are anadromous species and thus only use the Hudson River as spawning and nursery habitat, while the shortnose sturgeon spends its entire life in the estuary. Both species are benthic predators and appear to consume a diverse array of macroinvertebrates (Dadswell 1979; Carlson and Simpson 1987). Food habits data on sturgeon are surprisingly limited, though the shortnose sturgeon's protected status and the minimal focus on juvenile Atlantic sturgeon (the life-stage most likely to feed in the Hudson River) best explains this oversight. Feeding is considered to occur primarily during the summer months (Dadswell 1979), coinciding with peaks in invertebrate prey abundance (Gladden et al. 1988).

William Dovel conducted much of the initial ecological research on Atlantic and shortnose sturgeon within the Hudson River estuary and reported basic life history patterns and movements of both species, with emphasis on adults, in Dovel and Berggren (1983) (Atlantic sturgeon) and Dovel et al. (1992) (shortnose sturgeon). Dovel (1981) considered "the whereabouts of most juvenile sturgeon in the estuary, especially two-year-old fish" a significant gap in our knowledge of Hudson River sturgeon.

Preliminary information about the distribution of juvenile sturgeon in the Hudson River is available from Dovel and Berggren (1983), Dovel et al. (1992), and incidental captures of both species in annual surveys conducted by Hudson River utility companies (Hoff et al. 1988; Geoghegan et al. 1992). Dovel et al. (1992) broadly defined a nursery area for juvenile shortnose sturgeon as the "freshwater" portion of the Hudson River from Haverstraw Bay to the Troy Dam. Dovel and Berggren (1983) believed that young-of-the-year and older juvenile Atlantic sturgeon concentrated in brackish waters of the Hudson estuary. Hoff et al. (1988) and Geoghegan et al. (1992) later reported collections of juvenile Atlantic and shortnose as bycatch in trawl surveys conducted by Hudson River utility companies (April through December) between the Tappan Zee Bridge and Coxsackie.

Based on the data derived from previous surveys, juvenile sturgeon could be dispersed throughout the 160-kilometer area of the river between Yonkers and Coeymans, New York. Possibly, juvenile Atlantic and shortnose sturgeon may overlap in some specific habitats. Dovel and Berggren (1983) and Dovel et al. (1992) suggested that the freshwater/saltwater boundary region might constitute nursery grounds for shortnose and Atlantic sturgeon and that the two species may segregate across this boundary with shortnose more abundant in freshwater. Previous studies on Atlantic and shortnose sturgeon in other systems have also pinpointed the freshwater/saltwater interface to be a region of potential interspecific overlap or segregation between juveniles (Dadswell 1979; Flournoy et al. 1992; Hall et al. 1991).

The extent to which juvenile Atlantic and shortnose sturgeon actually overlap (i.e., spatially and temporally), and possibly compete for space or food, is critical to understanding the ecological interactions between these two related species.
Recent interest in stocking Atlantic sturgeon in the Hudson River (St. Pierre 1995) for research or supplementation purposes further underscores this need. My objectives in undertaking this study were to: (1.) assess the feasibility of collecting juvenile sturgeon with a dispersed gill-net sampling program during the summer foraging season; (2.) identify environmental attributes associated with sturgeon summer foraging habitat; and (3.) examine species-specific patterns of habitat association within the middle and lower Hudson River.

Methods

Study Area

Between May 31 and September 13, 1995, I sampled within the region of the Hudson River extending from the Tappan Zee Bridge (river kilometer (rkm) 43) to Staatsburg, New York (rkm 138). Based on geologic and geomorphic characteristics of the Hudson system, Coch and Bokuniewicz (1986) divided the middle and lower Hudson River into six strata. Four of the strata fell within the study area; Wide Estuary (WE), Highlands Gorge (HG), Wide River (WR), and Narrow River (NR) (Figure 1). A stratified random sampling program was used to sample evenly within the 96-kilometer study area. Using a random numbers table, I selected individual sampling stations and expended effort within the four strata proportional to the relative size of each stratum (Table 1, Figure 2).

Sturgeon Collections

I deployed three small-mesh gill nets at each station, using mesh sizes determined to be suitable for capturing a full range of juvenile-sized sturgeon (5-, 10- and 15-centimeter stretch mesh). From parameters described in Dovel and Berggren (1983) and Dadswell et al. (1984), I defined size ranges of juvenile sturgeon. Atlantic sturgeon with a fork length of 1200 mm or smaller were considered to be juveniles. Juvenile shortnose sturgeon consisted of fish with fork lengths less than 510 mm. Gill nets were 91 meters long and stood 3 meters off the bottom. Nets were anchored on the bottom and set perpendicular to shore for an average of 40 minutes. All nets were set in daylight and during slack tide for optimal fishing and to minimize gear damage. Nets were set between mid-channel and the shoreline, extending from shoal to channel bottom. I alternated shores to ensure equal effort on both sides of the river's main channel. On one occasion, a three-meter beam trawl was used to collect fish. The sampling team held captured fish in a live car alongside the research vessel and processed the fish individually. Data collected on each fish included measurements of total (TL in mm) and fork (FL in mm) lengths and weight (g). Sturgeon longer than 300 mm were tagged internally with passive integrated transponder (PIT) tags. Tags were placed intramuscularly, immediately posterior to the fourth dorsal scute on the left side of the fish. The sampling team did not observe any mortalities during any aspect of data collection or fish release.

In addition to our sampling efforts, data were also collected by a Cornell University study team using similar methodology. A total of 57 stations were sampled over the course of the study (16 by Cornell University researchers and 41 by me).

Physicochemical Attributes

Temperature (°C), depth (m), salinity (ppt), conductivity (μohms), and substrate data were collected by the sampling team at each station. A YSI Model 5500 S-C-T meter was used to obtain bottom and surface (i.e., one meter below the surface) measurements of salinity, conductivity, and temperature. A depth sounder was used to estimate depth. I classified substrate types according to substrate maps and categories described in Coch (1986).

Table 1. Physical characteristics of the sampling strata.

Stratum	Location (rkm)	Attributes
Wide Estuary (WE)	43-67	Widest section of the estuary. Channel of uniform depth. Channel margin contains wide subtidal flats encompasing two-thirds of the river width in some spots.
Highlands Gorge (HG)	68-90	Narrowest and deepest section of the estuary. Channel meanders and consists of very high relief and deep holes. Channel margin is very restricted; channel extends to shoreline in many places.
Wide River (WR)	91-107	Widest, freshwater portion of the estuary. Unform channel depths with extensive subtidal bank development on the east shore.
Narrow River (NR)	108-138	Region consists of a straight, featureless channel. Channel and river width are nearly equal with very narrow subtidal banks along the shoreline.

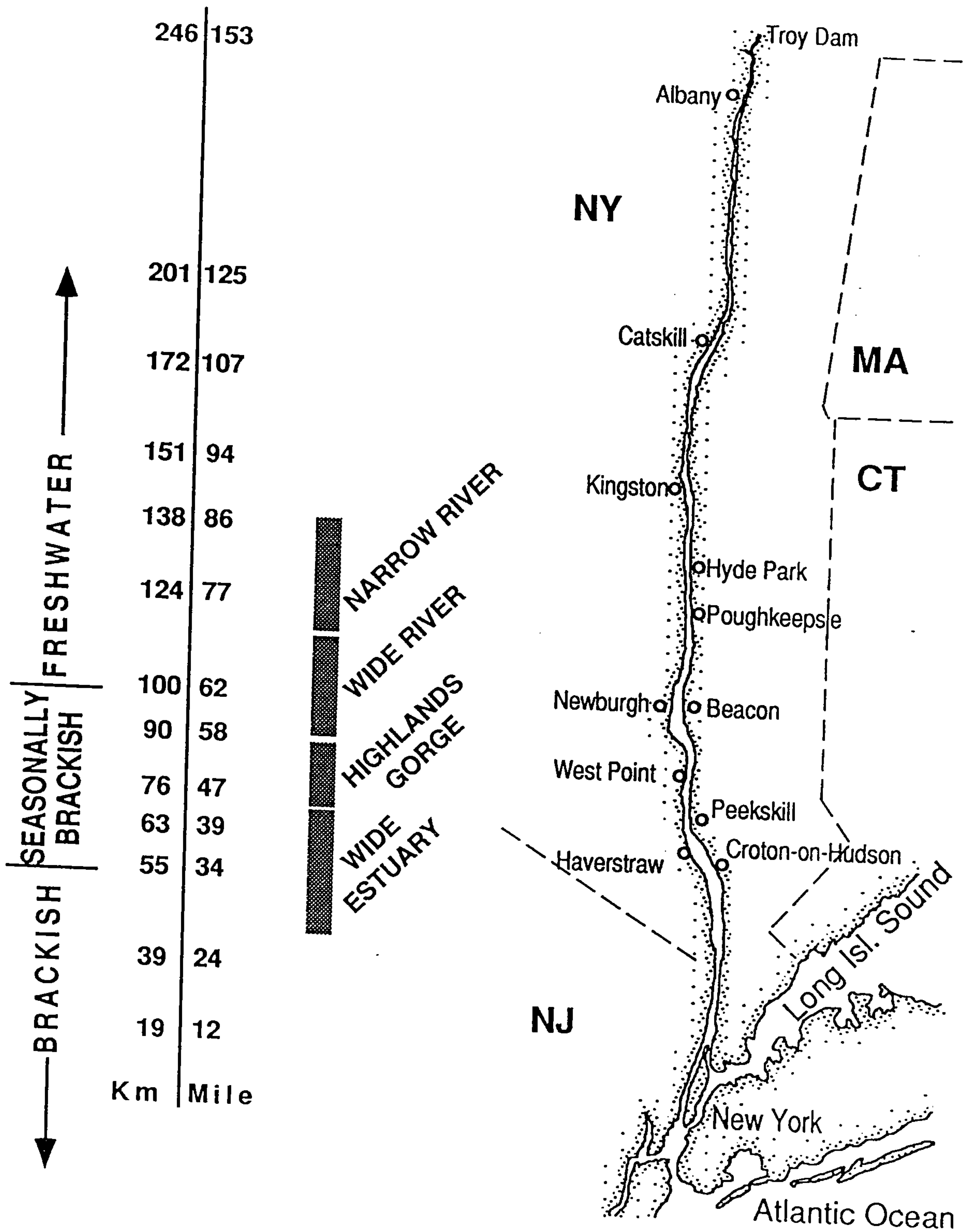


Figure 1. Map of the study area showing the locations of the sampling strata.

Experimental stocking

In October, 1994, 4,929 hatchery-reared Atlantic sturgeon from the U.S. Fish and Wildlife Service's Lamar Fish Hatchery (Lamar, Pennsylvania) were stocked in the Hudson River just below Storm King Mountain (rkm 89-90) (U.S. Fish and Wildlife Service 1995). At release, these stocked fish ranged in total length from 78 to 137 mm with a mean total length of 103 mm. Periodic collections of stocked fish, identifiable due to clipped left pelvic fins, enabled me to include them as study subjects.

Statistical Analyses

I tested relationships between independent variables (temperature, river stratum, salinity, depth, and substrate) and sturgeon occurrence. Sturgeon data were tested for goodness-of-fit (GOF) to the null hypothesis of uniform distribution among selected categories of discrete variables (i.e., river strata, salinity zone, and substrate type). Secondly, for the same environmental variables, I tested whether shortnose, wild Atlantic, and stocked Atlantic sturgeon were distributed similarly by using a chi-square test of homogeneity under the null hypothesis of identical distribution for all three "groups" of sturgeon.

Within the study area I encountered seven different substrate types, as defined by Coch (1986). Silt, sand, and gravel were the predominant base substrate categories though occasionally I sampled over mixed but distinct categories such as "clayey-sandy-silt" or "clayey-silty-sand." For my analyses of sturgeon occurrence by substrate type, I grouped substrates according to the base type (i.e., silt, sand, or gravel) because of low effort in many of the "mixed categories" which yielded extremely small expected values.

I grouped salinity values into three zones, as defined in Gosner (1971): freshwater (< 0.5‰); oligohaline (0.5 - 3.0‰); and mesohaline (3.0 - 16.0‰). Chi-square GOF and homogeneity tests were computed by comparing occurrence of sturgeon in each salinity zone to expected values. Expected values, or the expected number of sturgeon per substrate type, salinity zone, and river stratum, were derived by multiplying the total number of fish per sample (e.g., shortnose sturgeon) by the percentage of effort expended within each variable category. Thus, expected values varied for each group of sturgeon.

An analysis of variance (ANOVA) was used to test for differences between mean bottom water temperatures and depths associated with collections of juvenile Atlantic, shortnose, and stocked sturgeon. Since water temperatures fluctuated during the summer, separate ANOVAs were computed to test for differences in sturgeon occurrence by temperature in July and August. June was excluded because only one Atlantic sturgeon and one stocked Atlantic sturgeon were captured during this month. Sample sizes varied for each species so I was unable to use a multiple ANOVA which would have compared mean temperatures by month and sturgeon, and would have eliminated the need to use two separate tests.

Results

Fifty-seven juvenile sturgeon were collected during my study. The majority of the fish collected were wild Atlantic sturgeon (n = 36), followed by juvenile shortnose (n = 12) and stocked Atlantic sturgeon (n = 9). PIT tags were not detected on any of the captured sturgeon. The stocked fish were the smallest fish collected both in terms of mean length and weight (Table 2), whereas the wild Atlantic sturgeon were the largest sturgeon caught.

Table 2. Means (± s.d.) and ranges of fork lengths, total lengths, and weights recorded from juvenile sturgeon collected in the Hudson River, June 1 - September 13, 1995.

	N	Fork Length (mm)		Total Length (mm)		Weight (g)	
		Mean	Range	Mean	Range	Mean	Range
Shortnose	12	470.2 (± 49.9)	349-509	539.3 64)	404-584 (±	877.5 (±290)	300-1200
Atlantic	36	700.9 (± 234.5)	236-1092	808.7 (± 272.9)	272-1245	2780.9 (±1641)	80-4940
Stocked	9	368 (± 93.2)	267-591	426 (± 101.3)	306-659	510 (±677.3)	120-2030

Physicochemical Variables

I tested for correlations among independent variables (river stratum, salinity, conductivity, depth, and temperature) using Spearman's Rank Correlation test (n = 5). Bottom salinity and conductivity were highly correlated (r_s = 0.94, p-value < 0.01), which was expected since the YSI 5500, the instrument used to measure salinity and conductivity, calculates salinity from a measure of conductivity. River strata were also correlated to salinity and conductivity (n= 2, (r_s (river strata and salinity) = -0.82, p-value < 0.05, r_s (river strata and conductivity) = -0.90, p-value < 0.01). Therefore, my analyses of associations between sturgeon occurrence and river stratum and sturgeon occurrence and salinity may also reflect correlations between sturgeon occurrence and conductivity.

River Strata

Juvenile sturgeon were collected in all four sampling strata (Figure 3). Wild Atlantic sturgeon were distributed nonuniformly with respect to the four river strata sampled (X^2 = 32.67, p-value (3 d.f.) < 0.001), occurring more often than expected in the Highlands Gorge stratum and less than expected in the Narrow River stratum (Figure 4). Juvenile shortnose sturgeon also did not follow a uniform distribution (X^2 = 15.80, p-value (3 d.f.) < 0.01); they were not collected below rkm 100 or downriver

Table 3. Mean values (± s.d.) of physicochemical variables measured in the sampling strata during the summer of 1995.

Strata	N	Bottom Salinity (ppt)	Bottom Conductivity (microhmos)	Bottom Water Temp. (°C)	Depth (m)
Wide Estuary	13	7.5 ± 2.7	11533 ± 4367.8	25.8 ± 2.2	9.4 ± 7.2
Highlands Gorge	15	4.3 ± 2.3	6770.3 ± 3440.4	24.4 ± 3.9	21.1 ± 7.7
Wide River	11	1.36 ± 2.0	1672 ± 1498	25.5 ± 2.2	12.1 ± 4.4
Narrow River	18	0.61 ± 1.3	506.9 ± 391.7	25.7 ± 1.8	16.8 ± 5.2

Figure 2. Percent of juvenile sturgeon collected as compared to percent of effort expended within the sampling strata. Percent of kilometers is the percentage of kilometers of study area contained within the strata.

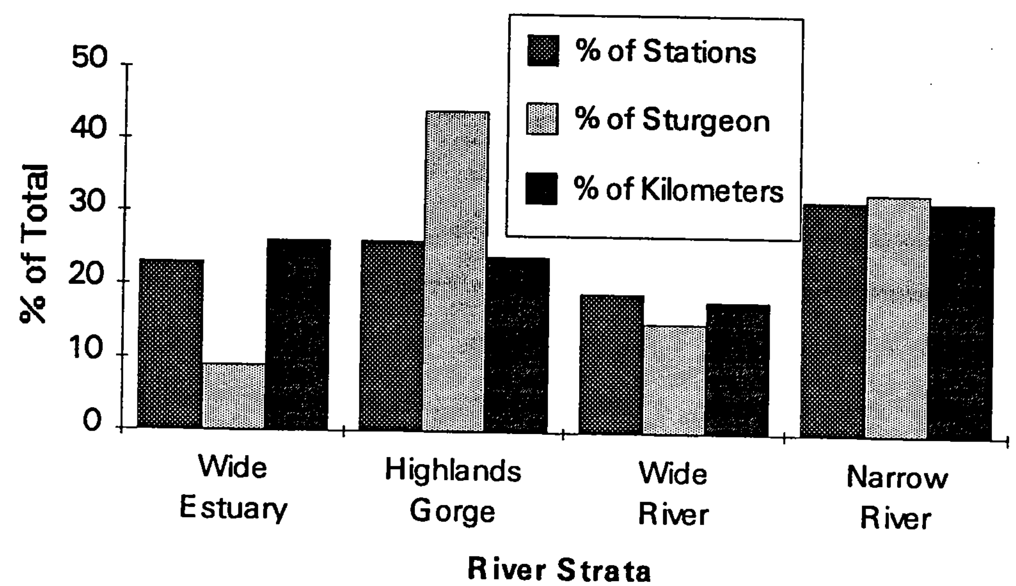
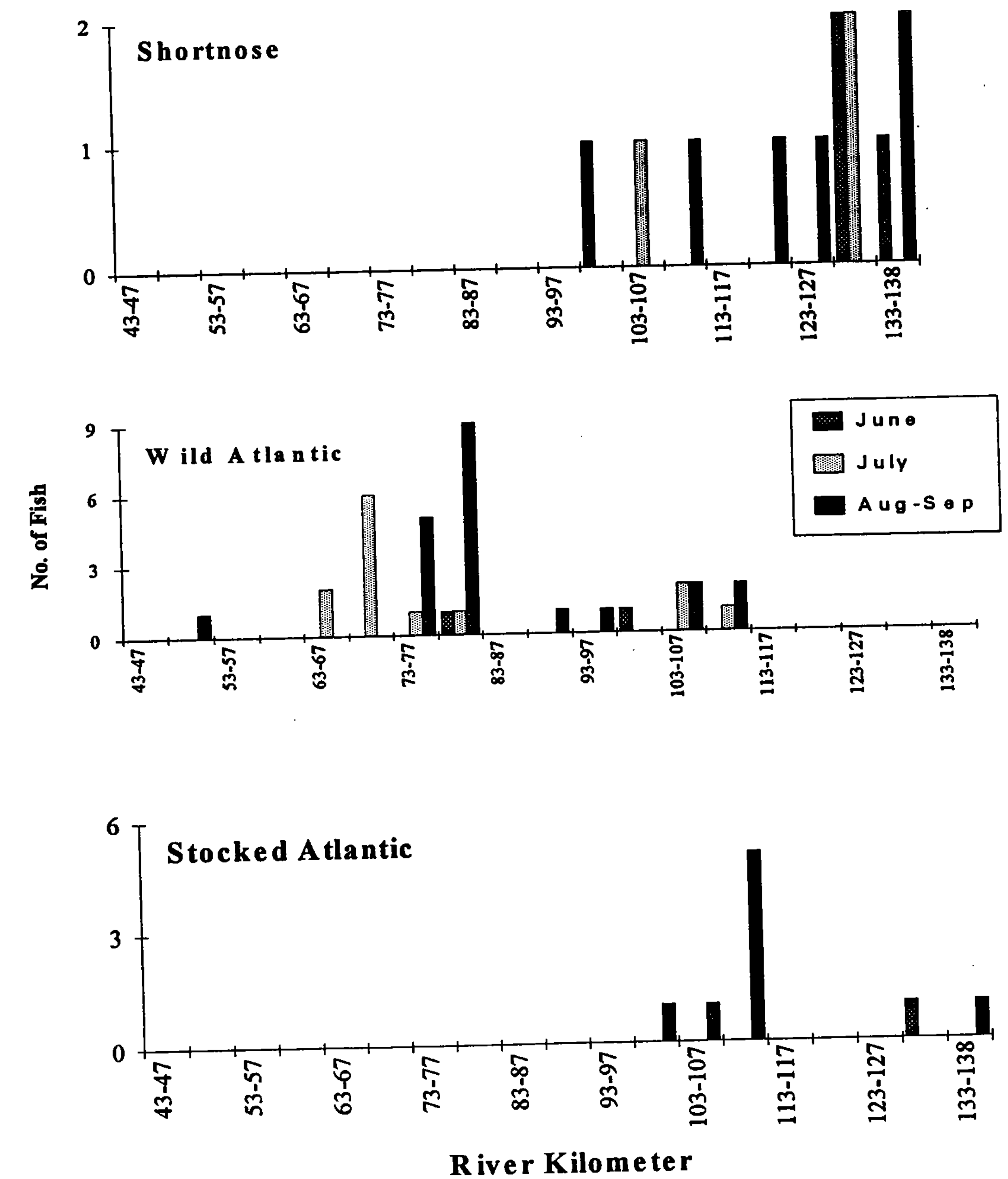


Figure 3. Numbers of juvenile sturgeon collected during June, July and August-mid-September, 1995, over all river kilometers sampled.



from the freshwater/saltwater interface (defined as the region with a salinity of 0.1 ppt). Shortnose sturgeon were found only in the upriver strata and were captured more than expected in the Narrow River stratum (Figure 4). Stocked Atlantic sturgeon were distributed similarly to the juvenile shortnose sturgeon; they were found only in the Wide River and Narrow River strata. Stocked fish were collected in the Wide River stratum more often than juvenile shortnose sturgeon and with about equal frequency to wild Atlantic sturgeon. Thus, stocked fish also exhibited a nonuniform distribution with respect to the four river strata ($X^2 = 10.35$, p-value (3 d.f.) < 0.05). Similar to shortnose sturgeon, stocked Atlantic sturgeon were collected more than expected in the Narrow River stratum. Wild Atlantic sturgeon were distributed differently from juvenile shortnose and stocked sturgeon ($X^2 = 35.86$, p-value (6 d.f.) < 0.001).

Since the disparity between the distribution of wild Atlantic and stocked Atlantic sturgeon juveniles might be due the differences in the sizes of the two groups, I compared the distribution of stocked Atlantic and shortnose sturgeon juveniles with wild Atlantic sturgeon juveniles less than 600 mm FL (n = 11, mean = 413 mm) (the size range of the stocked and shortnose sturgeon; Figure 6). Fifty percent of the wild Atlantic sturgeon less than 600 mm FL were collected in the Wide River and Narrow River strata. However, only 10% of the small wild Atlantic sturgeon occurred in the Narrow River stratum as compared to 78% of the stocked Atlantic sturgeon and 80% of the juvenile shortnose sturgeon. Juvenile shortnose sturgeon were captured further uptsream in the freshwater zone of the Narrow River stratum in contrast to the stocked sturgeon, which were found in higher numbers in the lower, more saline portion of the stratum.

Salinity

Salinity was also a good predictor of sturgeon occurrence. Wild Atlantic sturgeon were found predominantly in mesohaline zones (3.0 - 16.0 parts per thousand (ppt)). A chi-square GOF test for equal occurrence in each of the three salinity zones revealed that Atlantic sturgeon were distributed unequally though they were captured in salinities

ranging from 0 - 14.0 ppt ($X^2 = 9.19$, p-value (2 d.f.) < 0.05). Shortnose sturgeon juveniles were found mostly in freshwater, but a small percentage were captured in the oligohaline zone (Figure 6) ($X^2 = 14.22$, p-value (2 d.f.) < 0.01). Juvenile shortnose sturgeon were not collected in salinities above 1.5 ppt. Stocked Atlantic sturgeon were collected in freshwater, oligohaline, and mesohaline zones ($X^2 = 0.19$, p-value (2 d.f.) $>$ 0.05), but were not captured in salinities greater than 5.0 ppt. I tested for differences in occurrence by salinity zone for the three "groups" of sturgeon using a chi-square test of homogeneity. Although I obtained a highly significant result indicating that wild Atlantic, shortnose, and stocked Atlantic sturgeon exhibited varying distributions with respect to salinity zone, further analysis of standardized residuals showed that rejection of the null hypothesis was attributable to the distribution of shortnose sturgeon. Shortnose sturgeon were found more than expected in the freshwater zone and less than expected in the mesohaline zone.

Substrate

Three base substrates were encountered during sampling: silt, sand, and gravel. Silty areas constituted 80% of the stations sampled, while sand and gravel accounted for 17.4% and 2.3% of my samples, respectively. I examined whether collected sturgeon were distributed equally or not with respect to substrate type. Again, I used a chi-square GOF to test expected versus observed values for occurrence in each substrate type. I failed to detect an unequal distribution among the three groups of sturgeon with respect to the three substrate types (Table 3). Chi-square GOF tests of shortnose, wild Atlantic, and stocked Atlantic sturgeon versus substrate type were not significant. A chi-square test of homogeneity failed to detect any differences in the distributions of each group of sturgeon with respect to substrate type ($X^2 = 0.73$, p-value (2 d.f.) $= 0.69$).

Figure 4. Percentage of juvenile sturgeon captured in the sampling strata.

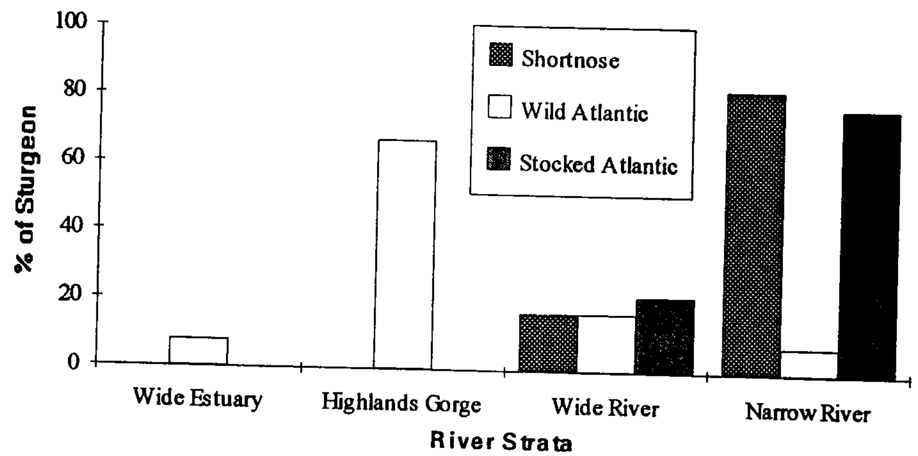


Figure 5. Percentage of juvenile sturgeon, less than 600 mm FL, captured in the sampling strata.

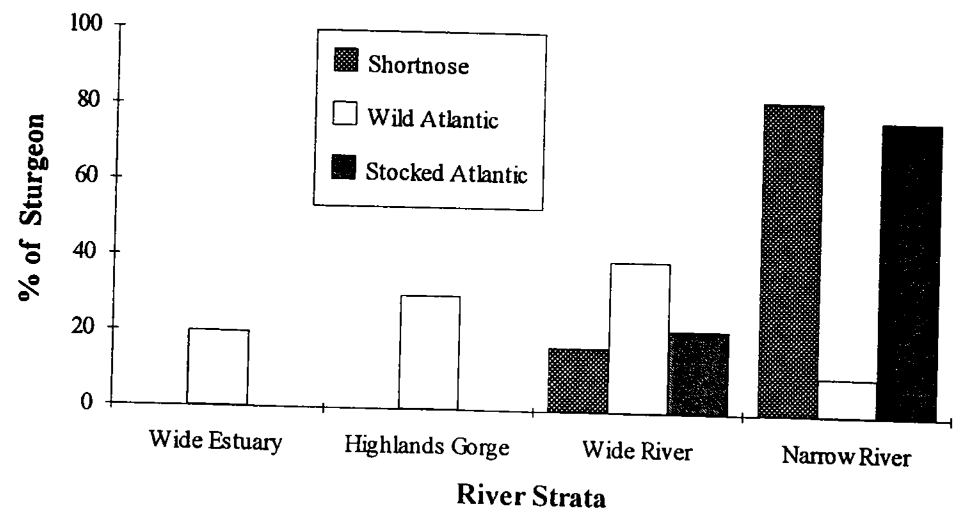


Figure 6. Percentage of juvenile sturgeon captured in sampled salinity zones.

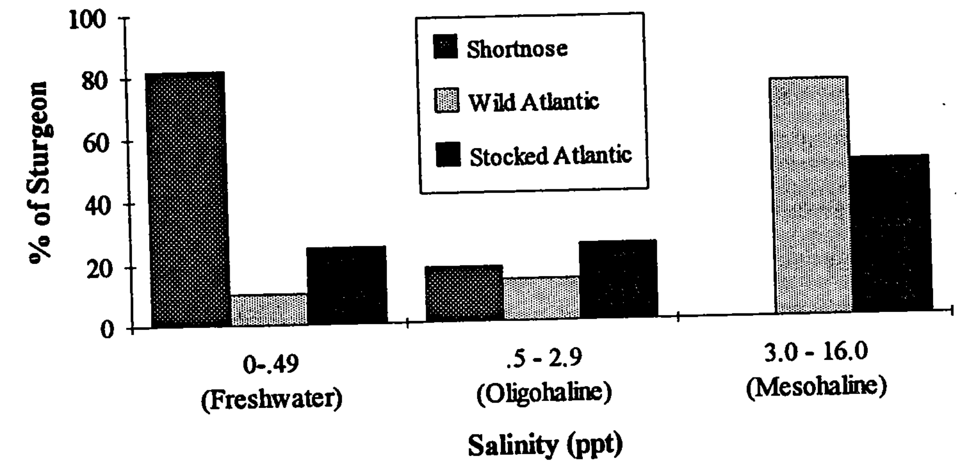


Table 4. Percentage of effort and numbers of juvenile sturgeon collected over substrate types sampled. Chi-square (X^2) values were not signficant at the $\alpha = 0.05$ level (df = 2).

Substrate	% of Effort	Shortnose	Atlantic	Stocked
Silt	80.4	11	34	9
Sand	17.4	1	2	0
Gravel	2.3	0	0	0.00
	X^2	**1.03**	**4.61**	**2.20**

Depth and Temperature

Significant differences were detected for mean depths among sites occupied by shortnose and stocked Atlantic sturgeon as compared with wild Atlantic sturgeon (Table 4). Means for each group of sturgeon were compared using Scheffe's test for pairwise comparisons (Table 5). Wild Atlantic sturgeon were captured at a mean depth (22.7 meters) significantly greater than either juvenile shortnose (17.2 meters) or stocked Atlantic sturgeon (16.5 meters). There was no significant difference between the depths at which shortnose versus stocked Atlantic sturgeon were captured. Relative to the frequency of depths sampled, juvenile sturgeon were found in depths between 10.6 and 21.5 meters (Figure 7).

In July, juvenile wild Atlantic sturgeon appeared to occupy sites with temperatures higher than sites occupied by juvenile shortnose sturgeon (Table 4). In August, all groups of sturgeon were found at sites with similar average temperatures. Compared to June and August, the average July temperature for the Highlands Gorge stratum was higher than the other strata (Figure 8), which may explain, at least in part, the higher mean temperature at which wild Atlantic sturgeon were collected during this month since they were captured more frequently in that stratum. The July result is probably spurious and due to greater sampling during the slack before flood period (63% as compared to 36% for slack before ebbing tide) when incoming, warmer salt water may have influenced temperature readings.

Table 5. F statistics and p-values from an ANOVA of temperatures and depths recorded at sturgeon capture locations.

Variable	F	df	p-value
Temperature (July)	10.57	9	0.01
Temperature (August)	2.05	31	0.15
Depth	5.81	54	0.005

Table 6. Scheffe's test pairwise comparisons of mean depths and temperatures (July and August) at sites occupied by captured sturgeon. Asteriks indicate homogeneous means. No stocked Atlantic sturgeon were captured in July.

	Mean Depth (meters)	Mean Temperature (July) (°C)	Mean Temperature (August) (°C)
Shortnose	17.3*	24.2	27.5*
Atlantic	22.8	27	26.6*
Stocked	16.6*		26.9*

Figure 7. Frequency of occurrence by depth of juvenile sturgeon compared to frequency of depths sampled.

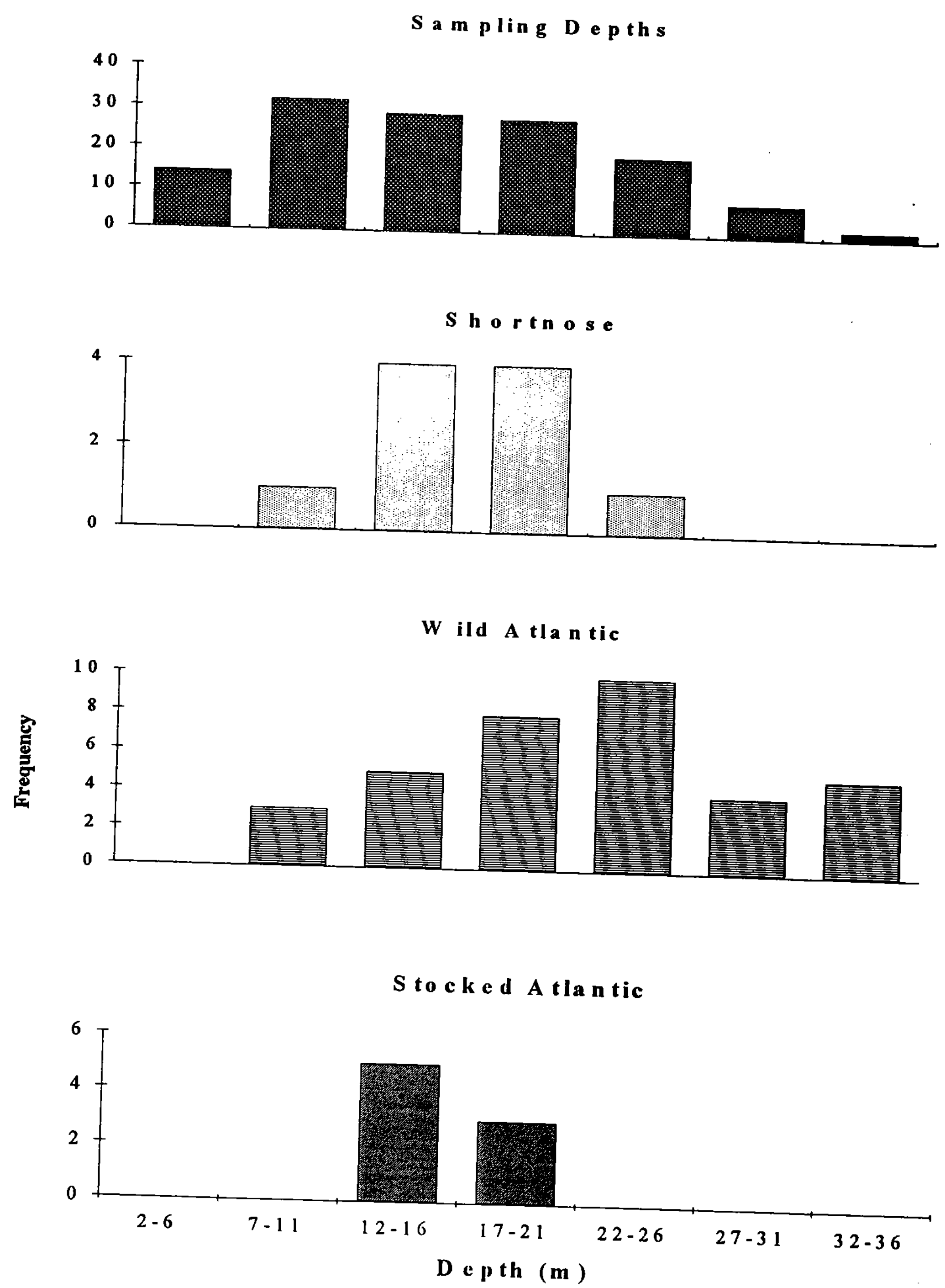
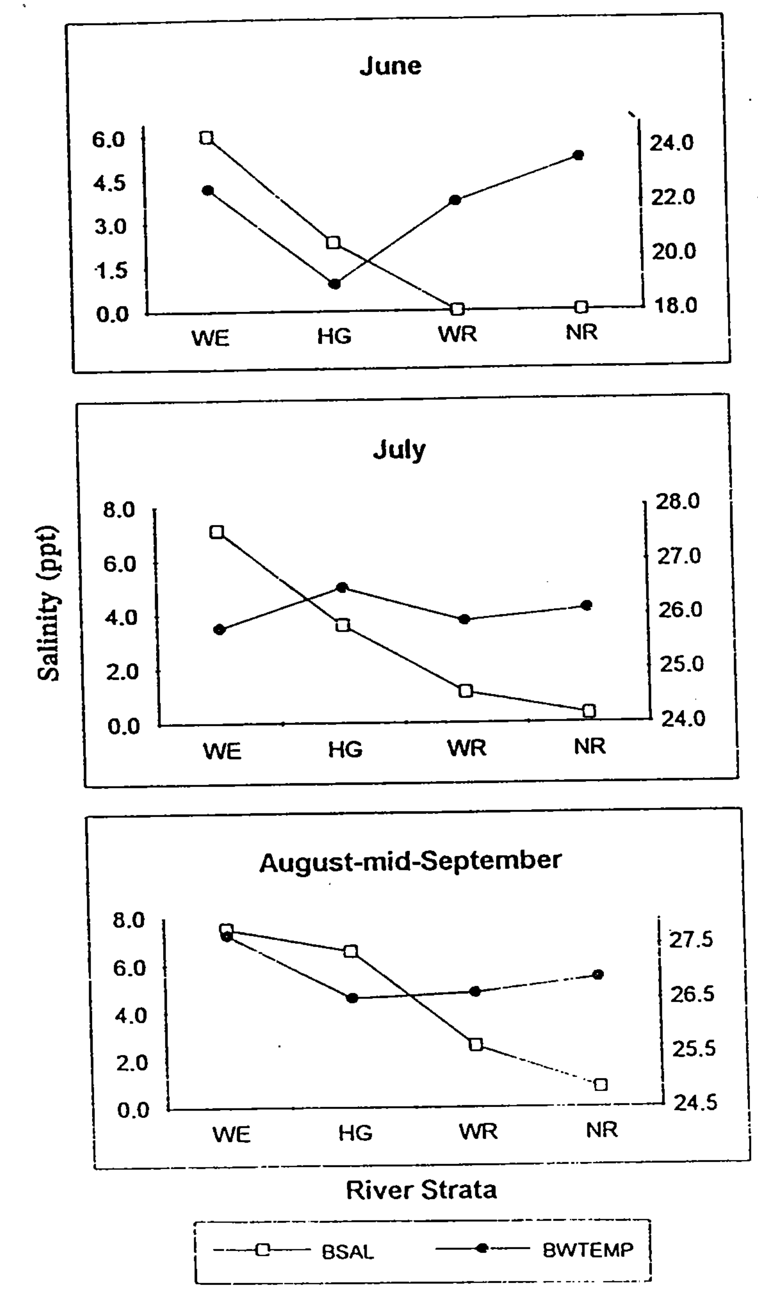


Figure 8. Average bottom salinity and bottom water temperatures recorded within the sampling strata in June, July, and Aug-mid-September, 1995.



Discussion

Juvenile shortnose, wild Atlantic, and stocked Atlantic sturgeon captured in the middle and lower Hudson River during the summer of 1995 were found to be distributed differently among the strata sampled. Accordingly, the habitats used by the juvenile sturgeon studied varied by species and between wild and stocked sturgeon. Wild Atlantic sturgeon were collected most often in the Highlands Gorge stratum (rkm 68-90), while shortnose sturgeon and stocked Atlantic sturgeon were found most often in the Narrow River stratum (rkm 108-138). The Highlands Gorge stratum is a deep, mesohaline habitat dominated by silty substrates (Table 3) – all characteristics associated with juvenile wild Atlantic sturgeon captured in the study. The upper Narrow River stratum is a freshwater zone; most of the juvenile shortnose sturgeon sampled were found in this stratum. The lack of salt intrusion to this stratum supports the shortnose sturgeon's apparent preference for freshwater habitats. Stocked Atlantic sturgeon were found most often in the lower Narrow River stratum and were associated with salinities intermediate between those where most wild Atlantic and shortnose sturgeon were captured.

Salinity and depth appear to be signficant factors influencing the distribution of juvenile sturgeon in the Hudson River. Juvenile Atlantic sturgeon were captured predominantly in deeper, mesohaline regions of the river. I collected juvenile shortnose sturgeon most often in the relatively shallower, freshwater zones of the river. Stocked Atlantic sturgeon, which were smaller on average than the wild Atlantic sturgeon juveniles captured in the study, were found primarily in oligohaline and freshwater zones of the river at depths similar to those occupied by juvenile shortnose sturgeon.

Juvenile sturgeon captured in the study distributed similarly with respect to substrate and occupied habitats with similar temperature ranges. In large part, the null hypothesis of equal occurrence over each substrate type was not rejected because the study area was dominated by silty substrates (Coch and Bokuniewicz 1986) and, therefore, most of my

river regions containing different substrates to determine if the observed patterns of substrate use represent substrate preference.

I captured the majority of juvenile Atlantic sturgeon (67%) in the Highlands Gorge stratum. In particular, one section of the river (between rkm 69 and rkm 78) is known for dense concentrations of adult Atlantic sturgeon (M. Bain, Cornell University, personal communication). This site also contained high numbers of juvenile Atlantic sturgeon (n = 24), thus indicating that this region may represent an important concentration area for the Hudson River population. On average, the deepest depths and lowest water temperatures occurred in this stratum. Mean salinities (4.3 ppt ± 2.3 s.d.) measured in this stratum were intermediate between oligohaline and mesohaline. Which of these environmental factors, if any, best explains the Atlantic sturgeon's apparent preference for this river region is a key question. Additional data on juvenile Atlantic sturgeon habitat use and the application of multiple regression techniques may help elucidate factors influencing their seasonal distributions.

Although mean salinities and bottom water temperatures varied within the Highlands Gorge stratum over the course of the summer (Figure 8), wild Atlantic sturgeon remained prevalent in this stratum suggesting that such seasonally-variable characteristics may not be strong predictors of wild Atlantic sturgeon occurrence in this stratum. Other biological, chemical, and physical factors, including prey availibility and dissolved oxygen, should be examined as possible explanations for the apparent preference of wild Atlantic sturgeon for the Highlands Gorge stratum.

During the summer of 1995, the salt wedge straddled the Wide River and Narrow River strata and was a region of overlap for all three groups of sturgeon. The actual location of the salt wedge fluctuated during the season and would be hard to pinpoint precisely without more accurate monitoring. However, based on my measurements, I bracket the river region between rkm 101 and rkm 112 as the approximate extent of salt front intrusion during the summer of 1995. Juvenile shortnose, wild Atlantic, and stocked Atlantic sturgeon were found with about equal frequency in this region during June, July, and August-mid-September, 1995 (Figure 3).

The finding that juvenile Atlantic and shortnose sturgeon overlap in the freshwater/salterwater interface is consistent with the results of previous attempts to characterize juvenile sturgeon habitat in other rivers. Hall et al. (1991) and Smith et al. (1993) reported evidence that juvenile shortnose and Atlantic sturgeon occupied the freshwater/saltwater boundary region in the Savannah River. They concluded that this region serves as an important nursery and feeding area for both species. Dadswell (1979) conducted extensive studies of shortnose and Atlantic sturgeon in the Saint John estuary and found that the freshwater/saltwater interface was a point of segregation for juveniles of the two species. Dadswell found that, within higher salinity regions (> 3 ‰), Atlantic sturgeon juveniles outnumber shortnose sturgeon juveniles by an approximate ratio of 10:1. Conversely, in freshwater reaches of the estuary, the relative abundance of each species was reversed, indicating that the freshwater/saltwater boundary may serve as an ecological barrier between Atlantic and shortnose sturgeon juveniles. The freshwater/saltwater interface contains an abundance of invertebrate fauna (Cooper et al. 1988), and, therefore, sturgeon may congregate in this region for foraging purposes. Atlantic and shortnose sturgeon may compete for food within this overlap region if they consume similar prey items that are in short supply.

Scant information exists regarding sturgeon food habits in the Hudson River. Carlson and Simpson's (1987) analysis of juvenile sturgeon gut contents removed from fish impinged on power plant intake screens provides only preliminary information about the types of prey consumed in the Hudson River. Prey preferences of juvenile Atlantic sturgeon in the Hudson River are not known. Pottle and Dadswell (1982) examined gut contents of juvenile Atlantic and shortnose sturgeon collected in the Saint John River and reported differences in food types consumed between the two species. Juvenile shortnose sturgeon ate mostly cladocerans, amphipods, and molluscs in addition to insect larvae. Juvenile

Atlantic sturgeon consumed diptera and trichoptera and some amphipods. Pottle and Dadswell (1982) did not find any evidence for mollusc consumption by juvenile Atlantic sturgeon. Predation on molluscan prey may allow shortnose sturgeon to gain a competitive refuge from sympatric Atlantic sturgeon.

Stocked Atlantic sturgeon, like juvenile shortnose sturgeon, were found only in upriver strata (Wide River and Narrow River). Although the sample size is quite small (n = 9) and thus may not be truly representative of the population at large, the distribution of this group of sturgeon, as compared with similar-sized wild Atlantic sturgeon, is intriguing (Figure 5). Stocked Atlantic sturgeon sampled in the study were not captured in the Wide Estuary or Highlands Gorge strata while 50% of the similar-sized wild Atlantic sturgeon were collected in the Wide Estuary and Highlands Gorge strata. Stocked Atlantic sturgeon exhibited a distribution pattern more similar to juvenile shortnose sturgeon than similar-sized wild Atlantic sturgeon. The mean size of the smaller wild Atlantic sturgeon (413 mm ± 93.2) was still greater than the mean size of stocked Atlantic sturgeon (368 mm ± 81.6). This size difference may explain the disparity between the observed distributional patterns in that, for example, an increased tolerance for higher salinities is achieved at sizes greater than 450 mm. Continued sampling and monitoring of the distribution of wild Atlantic and stocked Atlantic sturgeon will be needed to determine if stocked fish eventually distribute themselves like their wild counterparts.

Dovel et al. (1992) suggested that the benthic habitat of the middle and lower Hudson River estuary might be a limiting factor for sympatric sturgeon populations. Determining precisely what factors influence the distribution of juvenile sturgeon in the Hudson River is the important next step in the study of juvenile sturgeon ecology. During summer, when feeding is believed mainly to occur, the distribution and abundance of preferred prey items may dictate observed patterns of distribution and affect interactions between Atlantic and shortnose sturgeon. Future studies should emphasize behavioral, ecological, and physiological factors influencing seasonal distributions of juvenile sturgeon in the Hudson River. Critical ecological information on sympatric Atlantic and shortnose sturgeon, including food habits and microhabitat use, is lacking and limits a meaningful understanding of species-specific resource use patterns including the mechanisms underlying specific patterns.

As an important step towards improving the knowledge of juvenile sturgeon ecology, my research demonstrated the success of using a dispersed sampling program to capture juvenile sturgeon in a wide range of the Hudson River. Continued efforts, employing similar methodology, will add to a growing database on juvenile sturgeon ecology in the Hudson River. Several modifications can and should be made to the sampling protocol to ensure broader coverage of the Hudson River estuary and maximize gear efficiency. More effort should be expended in upstream reaches (above rkm 96) to assess the range of the feeding season distribution of juvenile sturgeon. Additional effort in upstream reaches may also increase sample sizes of sturgeon and reveal species-specific habitat patterns more accurately.

Further refinement of fish capture methodology should also be explored, particularly in terms of expanding the range of mesh sizes deployed for capturing juvenile fish. The mesh sizes I chose for this study were targeted towards a fairly wide range of juvenile-sized sturgeon (200-1200 mm). The 10- and 15-centimeter mesh sizes were suitable for capturing fish greater than 500 mm and thus my sampling favored larger-sized juvenile Atlantic sturgeon. Increasing the deployment of smaller mesh sizes ($\leq$ 5 cm) may help to increase sample sizes of juvenile Atlantic and shortnose sturgeon smaller than 500 mm.

Acknowledgments

I am grateful to Carol Adams and Tom Hughes for their assistance in the field. Steve Nack provided data for the foregoing analyses and advice about sampling in the Hudson River. Mark Bain, with support from the Hudson River Foundation, provided equipment and a vessel from which to conduct this research. I appreciate the guidance and support of John Boreman and Mark Bain who supervised this research and thank the Tibor T. Fellowship Program for enabling me to conduct this work.

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