Sturgeon of the Hudson River

Final Report on 1993-1996 Research

001/93A
Final Report

Prepared by

Mark Bain

with

Kristin Arend, Nancy Haley, Shawn Hayes, Jeremy Knight,
Steve Nack, Douglas Peterson, and Maureen Walsh

Department of Natural Resources
Fernow Hall - Cornell University
Ithaca, New York 14853-3001

MBB1@Cornell.edu
Phone: 607-255-2840
FAX: 607-255-1895

For

The Hudson River Foundation
9th Floor - 40 West 20th Street
New York, New York 10011

May 1998

Contents

Summary 3
Life history review for Hudson River sturgeon 5
Shortnose sturgeon and zebra mussels 28
Changing abundance of Hudson River sturgeon 28
1970's tagged sturgeon recovered 30
Atlantic sturgeon feeding on spawning run 30
Changes on the species composition of Hudson River sturgeon 31
Size of the shortnose sturgeon population 33
Size conversions for Atlantic sturgeon 40
Hudson River Atlantic sturgeon caught along the Atlantic coast 41
Remote monitoring of sturgeon movements 42
Juvenile sturgeon habitat use 43
Atlantic sturgeon telemetry 47
Senescence in shortnose sturgeon 52
Trends in the abundance of Hudson River sturgeon 54
The Atlantic sturgeon spawning fish from 1992-1997 55
Marine concentrations of Atlantic sturgeon 55
Evidence for the decline in Atlantic Sturgeon 56
Morphological variation in shortnose sturgeon populations 68

SUMMARY

The primary purpose of our Foundation sponsored study of Atlantic sturgeon was to use telemetry of adults to identify spawning areas for use as sites for mark and recapture population estimation. In late spring/early summer of 1994 and 1995, adult Atlantic sturgeon were collected in the Hudson River by gill nets and tagged with ultrasonic transmitters. In each year, 15 males and 5 females were tagged. Male sturgeon ranged in size from 1.46 m to 2.2 m in total length. Female sturgeon ranged from 2.1 m to 2.4 m, and the sex of male fish was determined by the presence of milt expressed by pushing on the fishes lower abdomen. Females were sexed by presence of eggs (released from fish) or by a large extended abdomen. Fish whose sex could not be determined were not used.

Sonic tagged sturgeon were monitored by boat tracking and with three continuously operating monitoring stations. Boat tracking was conducted on a bi-weekly basis. It consisted of traveling the center of the river and stopping approximately every half mile to scan for fish (tagged fish were detectable up to two miles). Continuous monitoring stations were used because we feared that once fish were released, relocating them may be difficult. We readily concluded that boat tracking was highly effective (all tagged fish could be found over large areas) and the need for the remote stations was reduced.

In 1994, 18 of 20 sonic tagged fish were captured near the known spawning area at Hyde Park (R km 129-135 [R mi 80-84]). Two fish were tagged near Con Hook (R km 77 [R mi 48]) downstream of West Point. The trend for most fish tagged near Hyde Park was to remain stationary for one to two days following tagging. All fish then moved down river over a period of four to six weeks. Some fish moved downriver quickly covering up to 64 km in just a few days, while others seemed to move much more gradually, taking three to four weeks to cover the same distance. By early July, when river temperatures reached about 25 C, several of the sonic tagged fish had congregated in deep water at the Con Hook site. Salinity in this area ranged from 1 to 3 ppt and depths were up to 37 m. Several other large sturgeon could be seen surfacing in the immediate vicinity of the sonic tagged fish, and a gill-net survey captured several large sturgeon and two additional prespawn female sturgeon which were sonic tagged. One female moved up river over a period of 1-2 weeks and then became stationary at R km 112 (R mi 69.5; Clinton Point). Gill nets set in the vicinity recorded several other adult Atlantic sturgeon indicating a previously unknown spawning area (see notes on Study Area Map).

From mid-summer through fall, most (18 of 20) sonic tagged fish remained at or near the Con Hook site with a few fish moving about within the deeper portions of the river between Stony Point and Cornwall. Gill-net surveys at the Con Hook site in August revealed large numbers (up to 30 in one net set) of sturgeon ranging in size from 1 to 2.5 m in length. These sturgeon were a combination of spawning adults and marine-migrant juveniles. Emigration of the sonic tagged sturgeon from the river in 1994 was gradual: 75% present on August 1, 55% present in mid-August, 20% in mid-September, 2 tagged fish on October 2, and none by October 12. Not all females left the river soon after spawning as was previously thought, but rather remained with other sturgeon and gradually left the river during late summer through early fall. Two of these fish

were captured in October by commercial fisherman off the coast of New Jersey.

In 1995 we caught and sonic tagged adult sturgeon earlier and at additional sites. After 10 sturgeon were sonic tagged near the Hyde Park spawning area, these fish lead us to other productive capture areas. Fish were caught in various sites between river km's 113 and 135 (R miles 70 and 84). In nearly every instance when gill nets were set near sonic tagged fish, other adult Atlantic sturgeon were readily captured. Occasionally, the sonic tagged fish was also caught. Most fish tagged in 1995 gradually moved downriver as in 1994, however at least 5 of the 15 males turned around and made apparent "runs" back up the river. One large female, (approximately 115 kg) that was caught near Hyde Park on 28 May appeared ready to spawn due to easily released eggs. The following day, the same fish was captured at the original capture location in a clear post-spawning condition. Afterward, this female quickly moved 48 km downriver and then apparently left the river.

By the 2nd week in July 1995, the sonic tagged sturgeon congregated at the same site (Con Hook) occupied in 1994 (see Study Area Map). Water temperatures and salinity were higher than in 1994: 25 C and 2-4 ppt. By mid to late July, nearly all (11 of 12) of the sonic tagged fish detected in the river were at this location. Throughout the summer, the sonic tagged fish remained at the Con Hook site and moved little. Gill-net surveys during the summer and early fall documented the presence of numerous adult and subadult sturgeon (1-2.5 m) and jumping sturgeon were easily seen. Emigration of the sonic tagged sturgeon from the river was gradual as in 1994: 1 fish was gone on 5 September, 4 left by 20 September, and all tagged fish were gone by the end of September. A subsequent thorough search of the river located one fish near Bear Mountain bridge just downstream of the Con Hook site.

The sonic telemetry study of 1994 and 1995 revealed new concentration areas and behavior patterns. Atlantic sturgeon did not congregate in a few spawning areas but instead spawned over a long period of time at several sites (at least R km 113-184 [R mi 70-114]). The existence of a late summer concentration area used by post-pawning adults and marine-migrant juveniles has not been previously documented in the Hudson River or elsewhere. Our results indicate it will not be possible to estimate the abundance of adult Atlantic sturgeon at concentration sites: spawning is protracted and dispersed, and the late summer site included many non-spawning but large fish.

Our initial sturgeon studies on the Hudson River have grown over three years into a major research program that includes both exploited (Atlantic sturgeon) and endangered species (shortnose sturgeon), a consortium of universities and sponsors, and extensive attention by management agencies and the public. Several activities have been conducted to understand the life history, habitats, behavior, and population dynamics of the sturgeon species. Key findings to date include: Atlantic sturgeon have declined sharply in abundance, Atlantic sturgeon recruitment failure is underway, the endangered shortnose sturgeon have substantially increased in abundance to the point of possibly being fully recovered, Atlantic sturgeon display very different migratory behaviors than previously documented, shortnose sturgeon exhibit senescence, and others. This report covers this range of topics. Finally, the Cornell study team coordinated the design, construction, and operation of a state-of-the-art research vessel, an international newsletter on sturgeon, and a wide range of studies support services.

Review of the life Histories of Atlantic and Shortnose Sturgeon of the Hudson River

INTRODUCTION

The Hudson River supports substantial populations of Atlantic sturgeon (*Acipenser oxyrinchus*) and shortnose sturgeon (*Acipenser brevirostrum*). The Atlantic sturgeon is one of North America's largest fishes, and an important commercial species in the Hudson River and Atlantic coast waters (species reviewed in Smith & Clugston 1996, this volume). In contrast, the shortnose sturgeon is the smallest sturgeon species in North America, and a charter member (included in the original US Endangered Species Act, 1973) of the U. S. endangered species list (species reviewed in Kynard 1996).

Observations of sturgeon in the Hudson River date back to the earliest historical accounts of human settlement in the region. Both species were very abundant, often captured for food, and easily observed by people during some part of the year. The first scientific accounts of the Hudson River sturgeons emerged from the New York State Biological Survey conducted in the mid-1930s (Curran & Ries 1937, Greeley 1937, Townes 1937). These studies documented some basic life history attributes such as distribution in the river, sizes and ages of mature fish, and diet. Almost no additional information was collected on the Hudson River sturgeons for 40 years, but then in the 1970s major concerns emerged about the effect of electric generating stations on fish resources of the Hudson River (Barnthouse et al. 1984). William Dovel led extensive studies (Dovel & Berggren 1983, Dovel et al. 1992) which provide most of our current knowledge on the Hudson River sturgeons. Electric utilities that operate power plants along the Hudson River initiated comprehensive environmental monitoring programs that continue today. Some biologists (Carlson & Simpson 1987, Geoghegan et al. 1992, Hoff et al. 1988, Young et al. 1988) working with monitoring program samples and data provided relatively recent reports of sturgeon distributions

and life history attributes.

Understanding the complex life cycles of the sturgeons has challenged biologists for more than 50 years. Until recently, the shortnose sturgeon was believed to be an anadromous fish, and therefore the responsibility for recovering this endangered species was assigned to the National Marine Fisheries Service. Dadswell (1979) provided the first thorough study of the life history of shortnose sturgeon, and a comparably detailed analysis of the biology of any Atlantic sturgeon population has not been reported. Despite numerous and varied reports on the biology of both Hudson River sturgeons, life history reviews within the last 10 years have concluded that important life cycle attributes remain poorly known or unknown (Gilbert 1989, T. I. J. Smith 1985). In only one case (Saint John River and estuary, New Brunswick, Canada) has abundant populations of both species been studied (Dadswell 1979), and they were found to segregate on the basis of habitat, presumably to minimize competition.

Here I review the knowledge of Atlantic and shortnose sturgeon in the Hudson River Estuary by summarizing information from biologists going back to 1937. This summary is organized around distinct life stages of each sturgeon in an effort to present a complete picture for both species. Finally, the potential interactions between the two species will be considered because the Hudson River has sizable populations of both species, and some evidence (Dadswell 1979, Dadswell et al. 1984, Dovel et al. 1992) suggests that competition between them may influence habitat use.

Sturgeon are limited to the lower 246 km of the Hudson River (Fig. 1) where habitats range from a typical freshwater river channel to a brackish water fjord (for physicochemical and morphological reviews see Coch & Bokuniewicz 1986 and others in the same volume, Limburg et al. 1989, Smith 1992). This estuary system is nearly straight and oriented in a north-south direction from the New York City harbor (southern tip of Manhattan Island; km 0 [km for river location in kilometers above mouth]) to the Troy Dam (Federal Green Island Dam; km 246) near Albany, New York. The normal tidal amplitude ranges from 0.82 to 1.43 m causing a tidal

volume (mean 5 670 - 8 500 m^3/s depending on location) from 10 to 100 times river discharge (mean 623 m^3/s; Limburg et al. 1989). The Hudson River channel is large (mean width 1 280 m) and generally deep (mean depth 10 m), but lacking any significant gradient. However, channel morphology varies with sections averaging as much as 5.5-km wide and 34-m deep (maximum depth = 53 m). Much of the river channel is shaped by rock with fine grain (e.g., sand and clay) sediments composing the substrate. The lower 100 km of the Hudson River Estuary is saline (>0.1 ppt salt) during seasons of low freshwater discharge with salinity generally below 10 ppt.

SHORTNOSE STURGEON

Shortnose sturgeon is best described as an amphidromous (defined in McDowall 1987, Bemis & Birstein 1996) species since use of marine waters is limited to the estuaries of their natal rivers (Kynard 1996). On one occasion, shortnose sturgeon were reported in waters of coastal New Jersey adjacent to the mouth of the Hudson River (Dovel et al. 1992). Within the Hudson River Estuary, shortnose sturgeon display complex migratory behavior that has been inconsistently described in past investigations. The life history for Hudson River shortnose sturgeon will be reviewed in four stages that vary in characteristics (Fig. 1).

Non-spawning adult stage

In many or all populations of shortnose sturgeon, adult fish do not spawn every year. Dadswell (1979) reported that females spawn every third to fifth year, and males every second year in the Saint John River, New Brunswick. This pattern may differ in the Hudson River because Dovel et al. (1992) reported the occurrence of tagged shortnose sturgeon at the spawning grounds in successive years. Non-spawning adults appear to use different habitats and display different migratory behavior than adults within a year of spawning.

The maximum sizes reported (Dadswell et al. 1984) for Hudson River shortnose sturgeon

were a female weighing 7.2 kg (94.5 cm fork length [FL], 105 cm total length [TL]) and a male weighing 5.3 kg (89 cm FL, 99 cm TL). However, Dovel et al. (1992) documented an even larger but unsexed shortnose sturgeon from the Hudson River: 107 cm TL and 10.7 kg. The age record for shortnose sturgeon is 67 years with the oldest Hudson River specimen aged at 37 years (Dadswell et al. 1984). Most shortnose sturgeon captured in the Hudson River Estuary in research and monitoring programs (1983-1988) were adults ranging in size from about 45 to 80 cm TL (Geoghegan et al. 1992) or about 8 to 20 years of age (Fig. 2). Pooled across the sexes, maturity criteria that can be used for the Hudson population of shortnose sturgeon would be 50 cm FL (Table 1) and about 6 years of age (sexes pooled, Fig. 2). The 50 cm FL criteria (55 cm TL) is useful for field handled fish because sex cannot be determined except at the time of spawning by observation of sperm or eggs.

From late spring through early fall, adult shortnose sturgeon are distributed in deep, channel habitats of the freshwater and brackish reaches of the Hudson River Estuary. River monitoring (1969-1980) of fish distributions by the Hudson River electric utilities (Hoff et al. 1988) recorded adult shortnose sturgeon from a large portion of the estuary (Fig. 1): most captures occurred between km 38 through 122, and no captures upstream of km 166. Later river monitoring (Geoghegan et al. 1992) showed a similar pattern. During this apparent growth and feeding period, the diet of shortnose sturgeon in the Hudson River likely includes insects and crustaceans with molluscs being a major component (25 to 50% of the diet; Curran & Ries 1937, Townes 1937).

As water temperature declines in the late fall, adult shortnose sturgeon typically concentrate in a few overwintering areas. Dovel et al. (1992) concluded that most or all adults form an overwinter concentration near Kingston (approximately km 140). However, river monitoring in late fall indicates another concentration near Haverstraw (km 54-61). Life history studies for some shortnose sturgeon populations (Dadswell et al. 1984) and observations in the Hudson River (Geoghegan et al. 1992) indicate that non-spawning adults behave differently from adults entering

reproductive condition. Adults that will not be in reproductive condition the following spring concentrate in brackish waters. In the Hudson, this overwintering area appears to be located between km 54 and 61 (Fig. 1). In the spring, these fish migrate upstream and disperse through the tidal portion of the river.

Spawning adult stage

Shortnose sturgeon spawn once in spring, usually at a single location as far upriver as the population ranges. Pre-spawning adults overwinter in one large concentration widely separated from those adults that will not spawn the following spring. Females and males have the same migratory and habitat use behavior so I treat them as one life history stage (Fig. 1).

Growth rates for shortnose sturgeon vary by region and sex but all fish mature at approximately the same size throughout their range: 45-55 cm FL (50-60 cm TL) for males and females (Dadswell et al.5). For the Hudson River population, Greeley2 reported that males first spawn at 3 to 4 years of age (average 44.5 cm FL), and females first spawn at 6 to 8 years of age (average 51.5 cm FL, Table 1). However, Dadswell (1979) concluded from fin ray interannular increments that first spawning may follow maturation by 1 to 2 years in males and as much as 5 years in females. Therefore, Greeley (1937) may have overestimated the age at maturity.

From late spring through early fall, all adult shortnose sturgeon have a dispersed distribution as described above for non-spawning adults. Adult shortnose sturgeon that will spawn the following spring congregate in an overwintering site near the spawning grounds. In the Hudson, a single large overwintering concentration of pre-spawning adults is well documented to form annually in deep, channel habitats a few kilometers downstream of Sturgeon Point (km 139). Many fish were readily captured at this site by Dovel et al. (1992), and it was known as a productive fishing area prior to protection of the species. From information on other populations (Dadswell 1979), females at the overwintering site may not feed prior to spawning, but males do feed during this period. Food items are probably similar to those reported above for non-spawning

adults. In mid-April, adult fish move upstream to the spawning grounds extending from below the Federal Dam at Troy to about Coxsackie (km 239-190; Dovel et al. 1992, Hoff et al. 1988). Spawning occurs from late-April to early May. Afterward, the adults disperse downriver into the summer range.

Egg and larval stage

Eggs of shortnose sturgeon adhere to solid objects on the river bottom, and newly hatched larvae remain on the bottom (Buckley & Kynard 1981, Taubert 1980). Hatching size ranges from 7 to 11 mm TL (Buckley & Kynard 1981, Taubert 1980), with Hudson River larvae ranging in size from 15 to 18 mm TL at 10 to 15 days of age (Pekovitch 1979). After hatching, larvae gradually disperse downstream over much of the Hudson River Estuary (Hoff et al. 1988). Larval shortnose sturgeon captured in the Hudson River were associated with deep waters and strong currents (Hoff et al. 1988, Pekovitch 1979). At 20 mm TL, shortnose sturgeon in the Hudson River had fully developed external characteristics indicating a transition to the juvenile stage (Pekovitch6; Table 1). No further information is available on this stage of the shortnose sturgeon life cycle.

Juvenile stage

Juvenile shortnose sturgeon (20 mm TL - 550 mm TL; Table 1), use a large portion of the tidal reach of the Hudson River. Dovel et al. (1992) indicated that yearling juvenile sturgeon grow rapidly (to 30 cm TL in first year, Fig. 2) and disperse downriver to about km 55 by fall. Juveniles have been captured in the same deep channel habitats used by adults. During mid-summer, the juvenile distribution centers on the mid-river region (Geoghegan et al. 1992). By late fall and early winter, most juveniles occupy the broad region of the Hudson River near Haverstraw (km 55-63; Dovel et al. 1992, Geoghegan et al. 1992). However, there is no evidence that juveniles move out of the lower river into coastal marine waters.

Juvenile shortnose sturgeon feed on smaller and somewhat different organisms than adults (Carlson & Simpson 1987). Common prey items are aquatic insects (chironomids), isopods, and amphipods. Unlike adults, molluscs do not appear to be an important part of their diet (Dadswell 1979).

ATLANTIC STURGEON

Atlantic sturgeon are anadromous. Spawning occurs in freshwater, but male and female fish reside for many years in marine waters, and Atlantic sturgeon undertake long-distance migrations along the Atlantic coast. Atlantic sturgeon marked in the Hudson River by Dovel and Berggren (1983) were recaptured in marine waters and river mouths from just south of Cape Hatteras, North Carolina to just north of Cape Cod, Massachusetts. In addition to these marine movements, Atlantic sturgeon display complex migratory behavior within the Hudson River. Here, I review the life cycle for Atlantic sturgeon in the Hudson River in six stages that vary by habitat, migratory behavior, and size (Fig. 3). Also see Smith & Clugston (1996) for a general review of Atlantic sturgeon life history and fishery.

Non-spawning adult stage

The inter-spawning period for Atlantic sturgeon is thought to range from 3 to 5 years depending on sex (discussed below). During non-spawning years, adults use marine waters either all year or seasonally. Little is known about their behavior in marine waters except that adult-size fish (≥ 150 cm TL, Table 1) marked in the Hudson River have been recaptured in coastal waters and river mouths from North Carolina to Massachusetts. The largest commercial harvest of adult Atlantic sturgeon from the Hudson River population occurs in marine waters throughout the New York Bight (Waldman et al. 1996). Female Atlantic sturgeon apparently grow in marine waters, whereas males appear to grow little after maturity (Fig. 4). In marine habitats, Atlantic sturgeon

eat amphipods, isopods, shrimps, molluscs, and fish (Scott & Crossman 1973).

The maximum age for the species is 30 years (Scott & Crossman 1973) with a similar estimate for the Hudson River (T. I. J. Smith 1985). The largest known Atlantic sturgeon was a female 427 cm TL, and 368 kg (Saint John River , New Brunswick; Van Den Avyle 1984). Large Atlantic sturgeon are likely to be females because of marked sexual dimorphism (Fig. 4).

Female spawning stage

Adult female Atlantic sturgeon differ sharply from adult males in size, growth, migratory behavior, and age structure (Fig. 3). Spawning female sturgeon are age 15 or older, weigh more than 34 kg, and are greater than 200 cm TL (Van Eenennaam et al. 1996, Table 1). Dovel and Berggren (1983) reported a slightly older age at first spawning (18 years) but the same minimum size. Age and growth data (Van Eenennaam et al. 1996) clearly indicate steady growth in females (Fig. 4), and data from Dovel & Berggren (1983) are consistent with this pattern.

Adult females enter the Hudson River Estuary for spawning beginning in mid-May. They migrate directly to the spawning grounds which are deep, channel or off-channel habitats (Dovel & Berggren 1983). The female sturgeon return to marine waters quickly after spawning (C. L. Smith 1985). The spawning period ranges from May through July or possibly August in the Hudson River Estuary (Dovel & Berggren 1983, Van Eenennaam et al. 1996). Female sturgeon do not appear to feed on the spawning run in freshwater (T. I. J. Smith 1985).

Dovel and Berggren (1983) report that spawning occurs near the salt wedge (km 55) early in the season (late May), moving upstream to km 136 during June and early July. However, Van Eenennaam et al. (1996) collected spawning Atlantic sturgeon only at two historically important fishing sites known to be spawning areas (Fig. 3): near Hyde Park (km 130) and Catskill (km 182). Van Eenennaam et al. (1996) argue that spawning is unlikely to occur near brackish water because sturgeon eggs and larvae are intolerant of saline conditions, and some significant length of river habitat is needed downstream of a spawning site to accommodate dispersal of larvae.

Male spawning stage

Mature, male Atlantic sturgeon enter the Hudson River starting in April and at least some remain in the Hudson River as late as November (Dovel & Berggren 1983). Spawning males are 12 or more years old and from 150 to 210 cm TL (Van Eenennaam et al. 1996, Table 1). Van Den Avyle (1984) reported that the maximum size for males is 213 cm TL which is similar to the sizes recorded in the Hudson River spawning population (Fig. 4). No spawning males over 20 years old have been recorded in the Hudson River. Male Atlantic sturgeon may not spawn annually, and the period between spawnings has been estimated to range from 1 to 5 years (T. I. J. Smith 1985).

From limited sturgeon telemetry by Dovel & Berggren (1983), males appear to move upstream on incoming tides and then remain stationary for several hours. During their upstream migration, male sturgeon meander back and forth across the channel, but stay in water greater than 7.6 m deep. Van Eenennaam et al. (1996) observed that adult male sturgeon appear at spawning sites in association with females, indicating that they search for females while moving about in the river.

Egg and larval stage

Eggs of Atlantic sturgeon are adhesive and the larvae remain on the bottom in deep channel habitats. Atlantic sturgeon larvae have been recorded in the Hudson River from km 60 through 148 (Dovel and Berggren 1983); a range including some brackish waters. Larval sturgeon have limited salt tolerance, so larval habitat must be well upstream of the salt front (Van Eenennaam et al. 1996; as illustrated in Fig. 3). No further information is available on this stage of the Atlantic sturgeon life cycle.

Atlantic sturgeon larvae are about 7 mm TL at hatching, and in hatcheries, they reached 19.9 mm TL in 20 days (Smith et al. 1980). The transition from the larval stage to juveniles appears to occur at about 30 mm TL (Table 1) based on Hudson River specimens (Bath et al. 1981).

Juvenile riverine stage

The juvenile period of the Atlantic sturgeon life cycle is marked by major ecological changes, and it can be divided into two life history stages: early and late juvenile stages (Fig. 3). The precise division between these stages is unclear because changes are gradual, although growth is very rapid (Fig. 4). Consequently, I added a third intermediate period for age and growth statistics shown in Table 1. The first juvenile stage is limited to riverine habitats. Relatively good information is available for this stage due to research in the Hudson River Estuary.

Juvenile Atlantic sturgeon are well distributed over much of the Hudson River from July through September, and they use deep channel habitats as in other life stages (Fig. 3). The largest numbers of juveniles appear to be located from km 63 to 140 (Dovel & Berggren 1983). As water temperature drops below 20°C in the fall, juveniles form an overwintering distribution in brackish water between km 19 to 74 (Dovel & Berggren 1983). From October through June, this region of the Hudson River contains many juveniles and they appear to move little during the period. Upstream dispersion of juveniles begins in late spring. Some juvenile Atlantic sturgeon have been recorded in the overwintering area used by pre-spawning, adult shortnose sturgeon (Esopus Meadows, km 134) as early as mid-April which indicates some variation in the general migration pattern.

Juvenile Atlantic sturgeon grow quickly in the first three years of life (70 cm TL at age 3, Fig. 3) but growth slows considerably if they remain in the Hudson River Estuary (Dovel & Berggren 1983). Riverine juveniles feed on aquatic insects, amphipods, isopods, and small molluscs (Scott & Crossman 1973).

Juvenile marine stage

After 2 to 6 years of residence in the Hudson River, juvenile Atlantic sturgeon migrate to marine waters. Dovel & Berggren (1983) reported that some males leave the river in year 2, while

females may stay in the river until year 5 or 6. This migration to marine waters marks a major change in ecology, behavior, and growth for Atlantic sturgeon. Table 1 shows approximate ages and sizes for early (riverine) juveniles, late (sea migrant) juveniles, and intermediate juveniles because the later includes the group that gradually emigrates from the river during a period of rapid growth. After about 10 years at sea, juvenile sturgeon reach adult size (about 150 cm TL, Table 1 for sexes pooled).

Little is known about Atlantic sturgeon in marine waters except that large juveniles are often captured in Long Island Sound and off the Long Island and New Jersey coasts in commercial fishing gear. Reviews of Atlantic sturgeon life history (e.g., Van Den Avyle 1984) and information specific to the Hudson River Estuary (Dovel and Berggren 1983; C. L. Smith 1985) describe post-emmigration juveniles as inhabitants of marine waters. However, large juveniles (50 - 150 cm TL) may reside in riverine habitats along the Atlantic coast during warm months. Atlantic sturgeon sampling in the Hudson River has documented the occurrence of large juveniles (sometimes called pre-adults; Dovel & Berggren 1983, Van Eenennaam et al. 1996). Data of Dovel & Berggren (1983) on tag recaptures show that most fish were reported from river mouths and the lower sections of coastal rivers from Cape Cod to Chesapeake Bay. Murawski & Pacheco (1977) described a similar pattern for tagging and recaptures in the St. Lawrence River, Quebec. Late juvenile Atlantic sturgeon often enter and reside in rivers that lack active spawning sites (e.g. Merrimack River, Massachusetts; Kieffer & Kynard 1993). Most Atlantic sturgeon in rivers of the central US Atlantic coast are probably from the Hudson River population (Waldman et al. 1996). Consequently, late juvenile Atlantic sturgeon from the Hudson River may annually use other riverine habitats during warm months before returning to the Hudson for spawning.

DISCUSSION

Sturgeon (family Acipenseridae) are the modern descendents of the original ray-finned fish

that achieved greatest abundance and diversity 280 to 345 million years ago. Atlantic, shortnose, and all other sturgeon retain many ancestral body characteristics and ways of living that distinguish them as relict fishes (see Bemis et al. 1996). Among North American fishes, sturgeons exhibit a unique combination of life history attributes: advanced age and large size at maturity, eggs

that are numerous and small in relation to body size, and spawning that is episodic and seasonal (Winemiller & Rose 1992). Beyond being unique, these characteristics make sturgeon especially vulnerable to population collapse due to overfishing (Boreman 1996). Life history information on the Hudson River sturgeons fits these generalizations and it substantiates the need to carefully conserve these species. In addition, life history details such as seasonal areas of concentration, migrations times and routes, and specific spawning locations highlight the vulnerability of both shortnose and Atlantic sturgeon to easy exploitation and habitat disruption. Fortunately, in the case of the Hudson River estuary, key habitats for spawning, rearing, and overwintering are intact and suitable for the species. Also, both species of sturgeon are managed through either endangered species protection (shortnose sturgeon; US Endangered Species Act) or fishery restrictions (Smith & Clugston 1996), even though the latter may not be adequate to sustained the current population (Boreman 1996, Young et al. 1988).

The two sturgeons in the Hudson River share many common life history attributes. Both are long-lived and mature at advanced age compared to almost all other fishes in the Hudson River. Both species have rapid and similar growth rates during the first few years of life. In general, sturgeon are characterized as indiscriminant bottom-feeding carnivores, and specific information on diet indicates they feed on generally the same food items in the Hudson River. Both sturgeon have complex migratory patterns in the Hudson River with distinct, seasonal, and predictable concentration areas. Finally, both sturgeons primarily use deep channel habitats for all life stages.

Despite many similarities in life history, Atlantic and shortnose sturgeons differ in some obvious ways. Adult sizes are greatly different, and the sizes and ages at maturity diverge. The timing and location of spawning is so different that it appears impossible that the two species

behaviorally interact during this key life stage. Use of marine habitats and long-distance coastal migrations are restricted to Atlantic sturgeon. With respect to management, one species is heavily exploited while the other is fully protected under the US Endangered Species Act.

Widespread occurrence of Atlantic and shortnose sturgeons in many Atlantic Coast rivers of North America raises questions as to how two species can co-exist with so many shared life history attributes. The prevailing view (e.g., Dadswell et al. 1984, Dovel et al. 1992, Kieffer & Kynard 1993) has been that the two species are spatially segregated in rivers in association with salinity; with shortnose sturgeon oriented to freshwater, and Atlantic sturgeon concentrated in brackish water except at spawning and very early life. However, a review of the movements and habitat use of both species in the Hudson River Estuary conflicts with these interpretations.

Juvenile shortnose sturgeon and early juvenile Atlantic sturgeon have virtually identical distributions in the Hudson River Estuary during all seasons. During this period of co-occurrence, both species are very similar in size, grow at about the same rate, feed on similar foods, and share deep channel habitats. Furthermore, the distribution of adult shortnose sturgeon overlaps with that of juvenile Atlantic sturgeon. Interestingly, the period of river emigration of juvenile Atlantic sturgeon closely corresponds with the age (intermediate juveniles in Table 1) when they reach a size (ca. 55 cm TL) equal to the minimum adult size of shortnose sturgeon. The protracted period of Atlantic sturgeon emigration (4 years) indicates that the two species overlap considerably in space, food, and habitat. Also, the pattern of emigration in conjunction with comparability in size and habits between the species suggests that co-exploitation of space and food resources may be important in the migratory behavior of juvenile Atlantic sturgeon.

The apparently extensive co-occurrence of the two sturgeons in the Hudson River Estuary has not been clearly identified in previous investigations on the Hudson River. Although sturgeon biologists working on the Hudson River undoubtedly captured both species simultaneously in their work, analyses and reports have always been oriented to a single-species. This review is the first to simultaneously report details of the life history of both sturgeons in the Hudson River. The

conclusion that the two species are not spatially segregated for large parts of their life histories indicates that the Hudson River Estuary may be unique within the joint ranges of the two species.

REFERENCES CITED

Barnthouse, L. W., J. Boreman, S. W. Christensen, C. P. Goodyear, W. Van Winkle, and D. S. Vaughan. 1984. Population biology in the courtroom: the Hudson River controversy. BioScience 34:14-19.

Bath, D. W., J. M. O'Connor, J. B. Alber, & L. G. Arvidson. 1981. Development and identification of larval Atlantic sturgeon (*Acipenser oxyrhynchus*) and shortnose sturgeon (*A. brevirostrum*) from the Hudson River Estuary. Copeia 1981:711-717.

Bemis, W. E., and V. J. Birstein. 1996. Sturgeon rivers: an introduction to acipenseriform biogeography and life history. Env. Biol. Fish. 48.

Bemis, W. E., E. K. Findeis, and L. Grande. 1996. An overview of Acipenseriformes. Env. Biol. Fish. 48.

Boreman, J. 1996. Sensitivity of North American sturgeon and paddlefish populations to fishing mortality. Env. Biol. Fish. 48.

Buckley, J. & B. Kynard. 1981. Spawning and rearing of shortnose sturgeon from the Connecticut River. Prog. Fish-Cult. 43:74-76.

Carlson, D. M., & K. W. Simpson. 1987. Gut contents of juvenile shortnose sturgeon in the upper Hudson estuary. Copeia 1987:796-802.

Coch, N. K., and H. J. Bokuniewicz. 1986. Oceanographic and geologic framework of the Hudson system. Northeastern Geol. 8:96-108.

Curran, H. W., & D. T. Ries. 1937. Fisheries investigations in the lower Hudson River. pp. 124-145. In: A biological survey of the lower Hudson watershed. Supplement to the 26th

Annual Report of the New York State Conservation Department, Albany, New York.

Dadswell, M. J. 1979. Biology and population characteristics of the shortnose sturgeon, Acipenser brevirostrum LeSueur, 1818 (Osteichthyes: Acipenseridae), in the Saint John River estuary, New Brunswick, Canada. Can. J. Zool. 57:2186-2210.

Dadswell, M. J., B. D. Taubert, T. S. Squires, D. Marchette, & J. Buckley. 1984. Synopsis of biological data on the shortnose sturgeon, Acipenser brevirostrum LeSueur, 1818. NOAA Technical Report NMFS 14, National Marine Fisheries Service, Washington, DC.

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

Dovel, W. L., A. W. Pekovitch, & T. J. Berggren. 1992. Biology of the shortnose sturgeon (*Acipenser brevirostrum* Leseur, 1818) in the Hudson River estuary, New York. pp. 187-216. In: C. L. Smith (ed.). Estuarine research in the 1980s. State Univ. New York Press, Albany, New York.

Geoghegan, P., M. T. Mattson, & R. G. Keppel. 1992. Distribution of the shortnose sturgeon in the Hudson River estuary, 1984-1988. pp. 217-277. In: C. L. Smith (ed.). Estuarine research in the 1980s. State Univ. New York Press, Albany, New York.

Greeley, J. R. 1937. Fishes of the area with annotated list. pp. 45-103. In: A biological survey of the lower Hudson watershed. Supplement to the 24th Annual Report of the New York State Conservation Department, Albany, New York.

Hoff, T. B., R. J. Klauda, & J. R. Young. 1988. Contribution to the biology of shortnose sturgeon in the Hudson River estuary. pp. 171-189. In: C. L. Smith (ed.). Fisheries research in the Hudson River. State Univ. New York Press, Albany, New York.

Kieffer, M. C., & B. Kynard. 1993. Annual movements of shortnose and Atlantic sturgeons in the Merrimack River, Massachusetts. Trans. Amer. Fish. Soc. 122:1088-1103.

Kynard, B. 1996. Life history, latitudinal patterns, and status of shortnose sturgeon *Acipenser brevirostrum*. Env. Biol. Fish. 48.

Limburg, K. E., S. A. Levin, and R. E. Brandt. 1989. Perspectives on management of the Hudson River ecosystem. pp. 265-291. In: D. P. Dodge (ed.). Proceedings of the International Large River Symposium. Can. Spec. Publ. Fish. Aquat. Sci. 106.

McDowall, R. M. 1987. The occurrence and distribution of diadromy among fishes. Amer. Fish. Soc. Symp. 1:1-13.

Murawski, S. A., & A. L. Pacheco. 1977. Biological and fisheries data on Atlantic sturgeon, Acipenser oxyrhynchus (Mitchell). National Marine Fisheries Service Technical Series 10, Highlands, New Jersey. 69 pp.

Pekovitch, A. W. 1979. Distribution and some life history aspects of the shortnose sturgeon (*Acipenser brevirostrum*). Hazleton Environmental Sciences Corp. Northbrook, Illinois. 23pp.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. 184. 966 pp.

Smith, C. L. 1985. The inland fishes of New York State. The New York State Department of Environmental Conservation, Albany, New York.

Smith, C. L. 1992. Estuarine research in the 1980s. State Univ. New York Press, Albany, New York.

Smith, T. I. J. 1985. The fishery, biology, and management of Atlantic sturgeon, Acipenser oxyrhynchus, in North America. Env. Biol. Fish. 14:61-72.

Smith, T. I. J., & J. P. Clugston. 1996. Status and management of Atlantic sturgeon, *Acipenser oxyrinchus*, in North America. Env. Biol. Fish. 48.

Smith, T. I. J., E. K. Dingley, & D. E. Marchette. 1980. Induced spawning and culture of the Atlantic sturgeon, *Acipenser oxyrhynchus* (Mitchell). Prog. Fish-Cult. 42:147-151.

Taubert, B., 1980. Reproduction of shortnose sturgeon (*Acipenser brevirostrum*) in Holyoke Pool, Connecticut River, Massachusetts. Copeia 1980:114-117

Townes, H. K., Jr. 1937. pp. 217-230. In: A biological survey of the lower Hudson watershed.

Supplement to the 26th Annual Report of the New York State Conservation Department, Albany, New York.

U. S. Federal Register Vol. 39, No. 230, Pages 41367-41377; 27 November 1974.

Van Den Avyle, M. J. 1984. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic) - - Atlantic sturgeon. U. S. Fish and Wildlife Service FWS/OBS-82/11.25, Washington, DC. 17 pp.

Van Eenennaam, J. P., S. I. Doroshov, G. P. Moberg, J. G. Watson, D. S. Moore, & J. Linares. 1996 . Reproductive conditions of the Atlantic sturgeon (*Acipenser oxyrhynchus*) in the Hudson River. Estuaries, in press.

Waldman, J. R., J. Hart, & I. Wirgin. 1996. Stock composition of the New York Bight Atlantic Sturgeon fishery, based on analysis of mitochondrial DNA. Trans. Amer. Fish. Soc. In press.

Winemiller, K. O, & K. A. Rose. 1992. Patterns of life-history diversification in North American fishes: implications for population regulation. Can. J. Fish. Aquat. Sci. 49:2196-2218.

Young, J. R., T. B. Hoff, W. P. Dey, & J.G. Hoff. 1988. Management recommendations for a Hudson River Atlantic sturgeon fishery based on an age-structured population model. pp. 353-365. In: C. L. Smith (ed.). Fisheries research in the Hudson River. State Univ. New York Press, Albany, New York.

Table 1. Ages and sizes of the life stages of shortnose and Atlantic sturgeons in the Hudson River. Data reported are generalized because of minor variations in specific values reported in other studies (see text for discussion of specific data).

Life stage	Age range (yr)	Fork length[1] (cm)	Total length[1] (cm)
Shortnose sturgeon			
Larval	< 0.08		≤2
Males juveniles	0.08 - ≥3	~2 - 50	2 - 55
Females juveniles	0.08 - ≥6	~2 - 50	2 - 55
Males adults	≥3	≥50	≥55
Females adults	≥6	≥50	≥55
Atlantic sturgeon			
Larval	< 0.08		≤3
Early juveniles	0.08 - 2	~3 - 44	~3 -49
Intermediate juveniles	3 - 6	45 - 63	50 - 70
Late juveniles	6 - 11	>63 - 134	>70 - 149
Non-spawning adults	≥12	≥135	≥150
Female spawners	≥15	≥180	≥200
Male spawners	12-20	≥135 - 190	≥150 - 210

1. Fork length and total length sizes were made to fit the conversion formulae reported by Dadswell et al. (1984) for shortnose sturgeon: FL=0.9 x TL; TL=1.1 x FL.

Figure legends

Figure 1. Life stages and seasonal distribution of shortnose sturgeon in the Hudson River Estuary relative to river features, river distances upstream of upper New York City Bay, and salinity. Fall and sometimes spring distributions are not shown because these seasons are transitional periods. Width of the distribution lines and symbols indicates relative density of individuals.

Figure 2. Shortnose sturgeon sizes and ages reported for the Hudson River from Dadswell et al. (1984) using their compilation of unpublished data in modified form, and the total length of shortnose sturgeon aged by Dovel et al. (1992; open circles). The dashed line separates juvenile and adult life stages at 55 cm total length or about 50 cm fork length.

Figure 3. Life stages and seasonal distribution of Atlantic sturgeon in the Hudson River Estuary relative to river features, river distances upstream of upper New York City Bay, and salinity. Fall distributions are not shown because this season is transitional. Width of the distribution lines and symbols indicates relative density of individuals. Sea distributions includes long-distance migrations to waters outside the Hudson River Estuary.

Figure 4. Individual Atlantic sturgeon sizes and ages reported for the Hudson River by Dovel and Berggren (1983; solid dots) and Van Eenennaam et al. (1996; open dots for females, + symbols for males). The circled points indicate individuals determined to be in spawning condition by Van Eenennaam et al. (1996). The arrow for late juveniles indicates a gap in the age and size series corresponding with an absence of fish from the Hudson River.

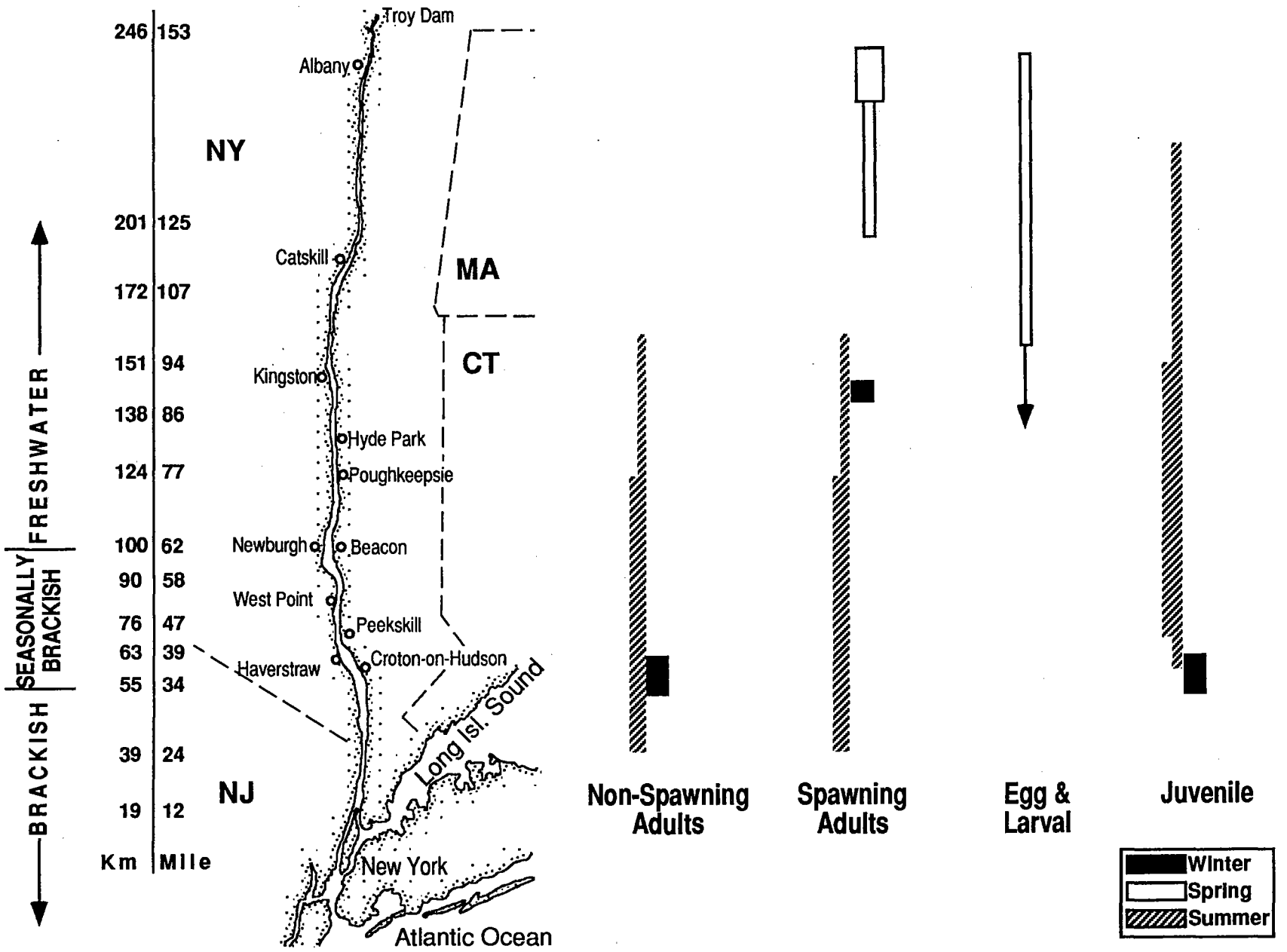

Km
Mile
246
153
201
125
172
107
151
94
138
86
124
77
100
62
90
58
76
47
63
39
55
34
39
24
19
12
BRACKISH
SEASONALLY BRACKISH
FRESHWATER
NY
NJ
MA
CT
Troy Dam
Albany
Catskill
Kingston
Hyde Park
Poughkeepsie
Newburgh
Beacon
West Point
Peekskill
Haverstraw
Croton-on-Hudson
Long Isl. Sound
New York
Atlantic Ocean
Non-Spawning Adults
Spawning Adults
Egg & Larval
Juvenile
Winter
Spring
Summer

Figure 1.

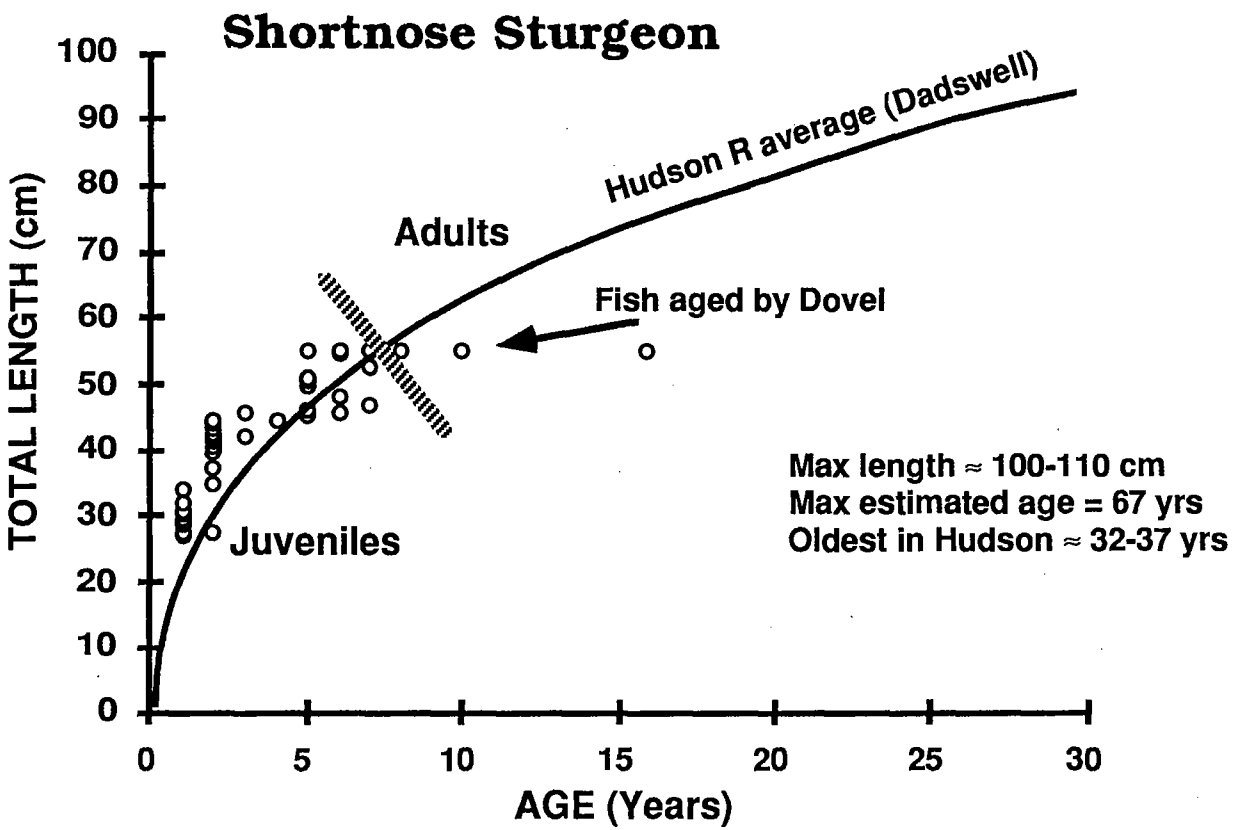

Shortnose Sturgeon
TOTAL LENGTH (cm)
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
AGE (Years)
Hudson R average (Dadswell)
Adults
Fish aged by Dovel
Juveniles
Max length ≈ 100-110 cm
Max estimated age = 67 yrs
Oldest in Hudson ≈ 32-37 yrs

Figure 2.

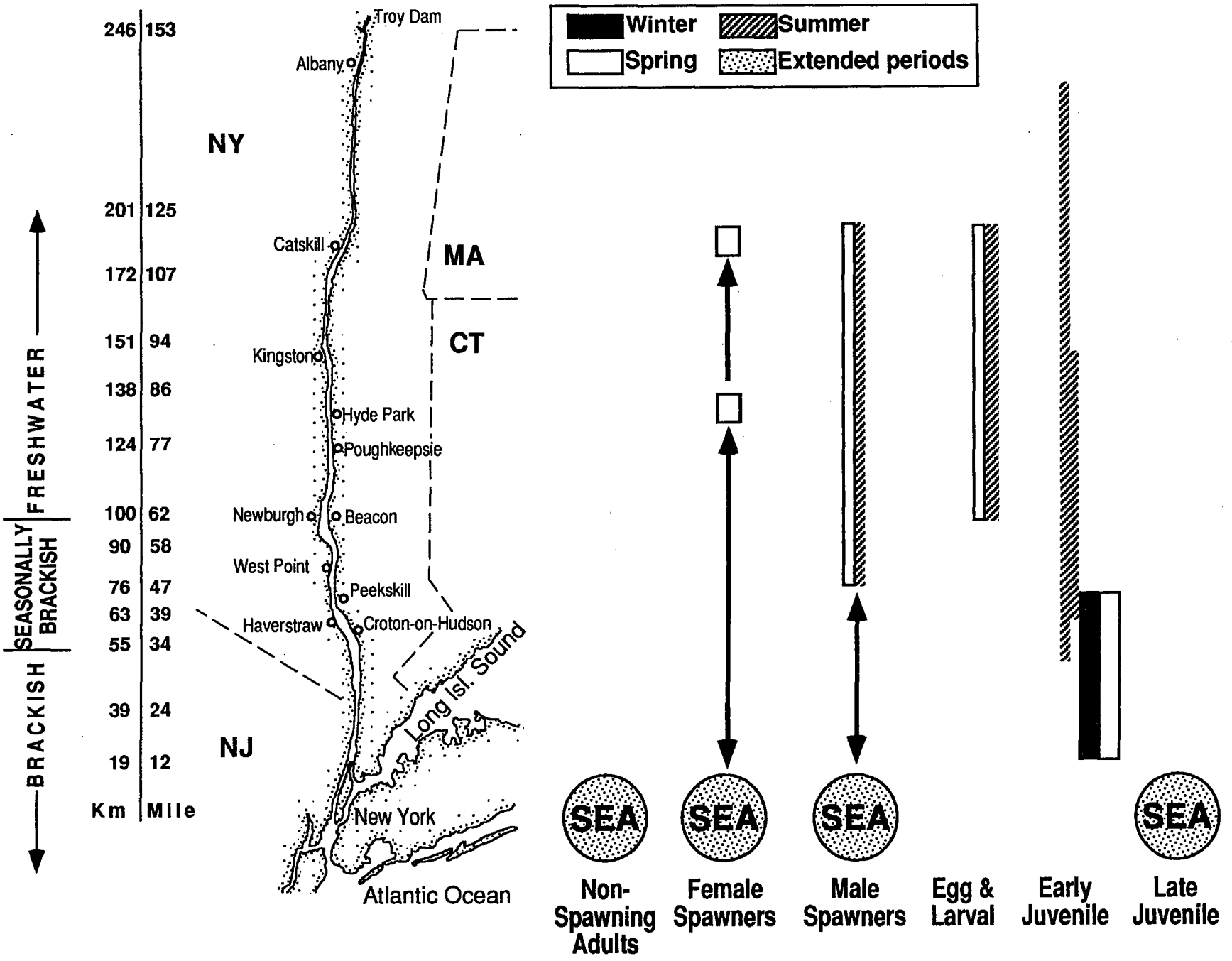

Winter
Summer
Spring
Extended periods
Troy Dam
Albany
NY
Catskill
MA
CT
Kingston
Hyde Park
Poughkeepsie
Newburgh
Beacon
West Point
Peekskill
Haverstraw
Croton-on-Hudson
Long Isl. Sound
NJ
New York
Atlantic Ocean
FRESHWATER
SEASONALLY BRACKISH
BRACKISH
246 153
201 125
172 107
151 94
138 86
124 77
100 62
90 58
76 47
63 39
55 34
39 24
19 12
Km Mile
SEA
Non-Spawning Adults
Female Spawners
Male Spawners
Egg & Larval
Early Juvenile
Late Juvenile

Figure 3.

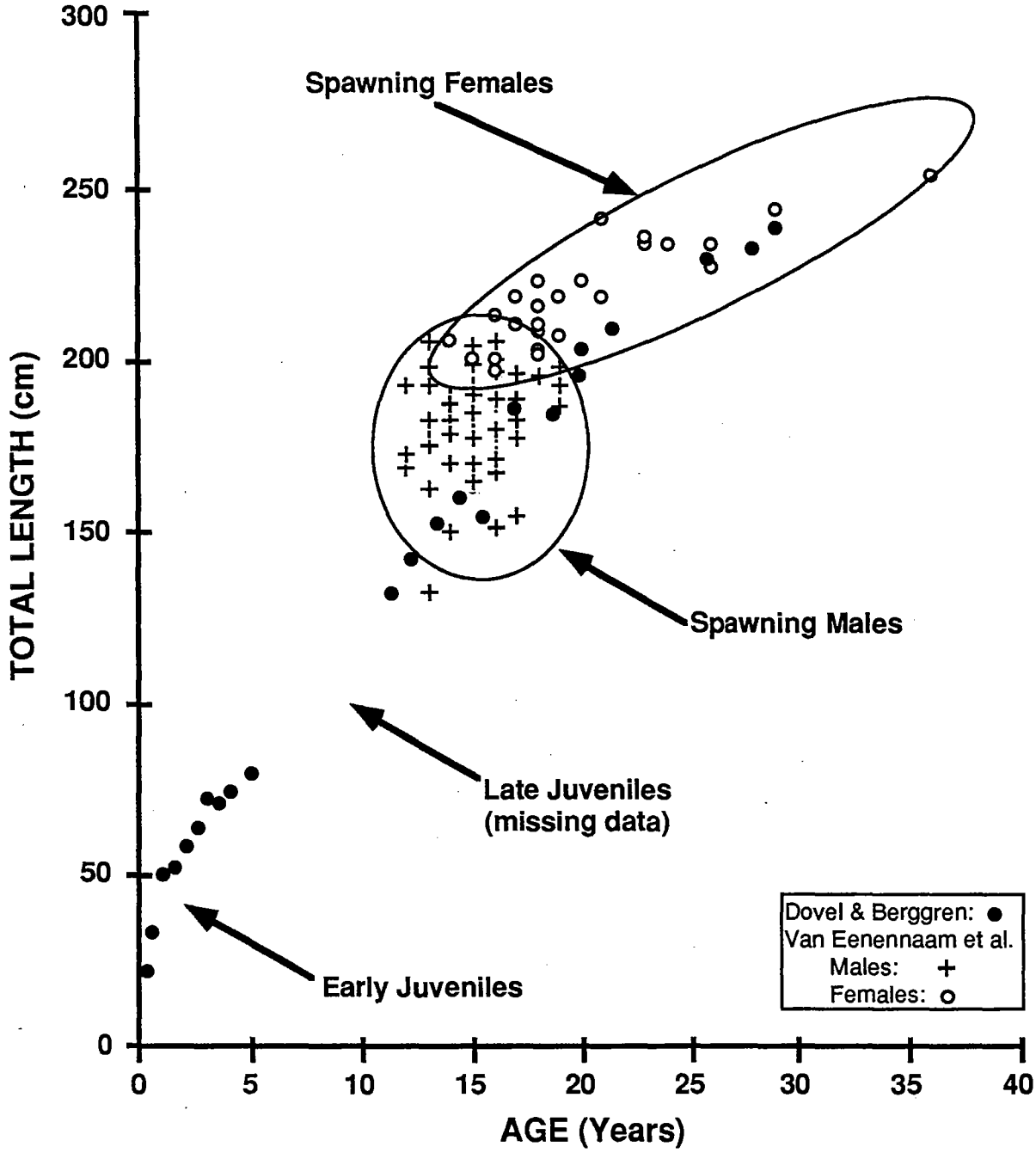

Spawning Females
Spawning Males
Late Juveniles
(missing data)
Early Juveniles
Dovel & Berggren: ●
Van Eenennaam et al.
Males: +
Females: o
TOTAL LENGTH (cm)
AGE (Years)
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40

Figure 4.

Shortnose Sturgeon Eat Zebra Mussels

On 16 July 1993, Cornell researchers captured three shortnose sturgeon in the Hudson River just south of Poughkeepsie. Fecal material was expelled from the fish while they were being untangling from the gill net. Steve Nack noticed pieces of zebra mussel (Dreissena spp.) shell during a quick look at the material on his hands. Steve kept a sample of the sturgeon feces in a jar of alcohol, and later laboratory examination confirmed the presence of many shell fragment from zebra mussels. Zebra mussels were discovered in the Hudson River near Catskill by commercial fisherman in May 1991, and they are now very abundant throughout the freshwater portion of the estuary. Sturgeon sampling after July 16th was primarily devoted to the brackish, lower Hudson River where zebra mussels are less abundant.

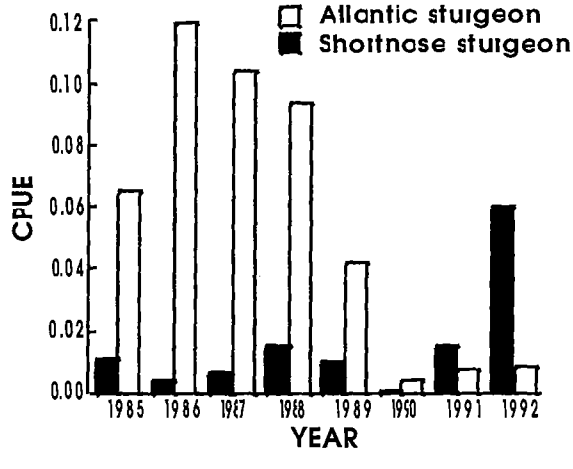
CHANGING ABUNDANCES OF HUDSON RIVER STURGEON

The Consolidated Edison Company conducts aquatic resource monitoring in the Hudson River from Albany to New York City. Part of this extensive sampling program is a trawl survey completed every year from early July and mid-October. The trawl survey is rigorously standardized, includes about 210 samples a week using a 3.0-m beam trawl towed on the bottom for approximately 5 minutes against the prevailing current. All captured sturgeon are counted and released, with lengths and weights taken from most fish. The Consolidated Edison Company provided the data from the annual trawl survey to Cornell researchers for the purpose of assessing sturgeon abundance and distribution trends during the period of record (1985 through 1992).

A initial analysis of the mean catch per effort (number of sturgeon/number of trawls) pooled by year indicates that there has been a large change in sturgeon populations during the last 8 years

(Figure below). The endangered shortnose sturgeon appears to have increased greatly in abundance, while the Atlantic sturgeon appears to have declined sharply in abundance since the late 1980's. Although the sturgeon catch rate was summarized by year, the trends should be valid because the trawl survey is a standardized sampling program. The figure shown below is based on a total catch of 167 shortnose and 625 Atlantic sturgeon. Mean total lengths and weights (+ 1 standard deviation, N) of the catch were 673.9 mm (+81.5, 112) and 1888.0 g (+923.5, 111) for the shortnose sturgeon, and 545.5 mm (+162.2, 80) and 1185.9 g (+593.9, 70) for the Atlantic sturgeon.

Additional evidence for a large change in relative abundances comes from a comparison of the ratio of shortnose sturgeon to Atlantic sturgeon in the Cornell Study and Hudson River sturgeon research by Bill Dovel in the 1970's. During the 1970's, Atlantic sturgeon were more frequently (as much as 10 times) caught than shortnose sturgeon. This year, shortnose sturgeon far outnumber Atlantic sturgeon in the study catch (see Table on page 3). Overall, these data suggest that the endangered shortnose sturgeon has increased in abundance, and the Atlantic sturgeon has declined from past levels of abundance.



Sturgeon Tagged in the 70's Recaptured

Five shortnose sturgeon tagged in the Spring of 1979 as part of research by Bill Dovel were recaptured this Summer by the Cornell Study Team. Two of these fish had readable tag numbers, and 3 had only the remains of the wire tag attachment. So far, it has not been possible to locate the body size data for the two numbered fish. It is unlikely that the tagged fish have grown much in the last 14 years because the recaptured sturgeon were caught in gill nets with a mesh size similar to that used by Bill Dovel. The recapture of sturgeon after so many years serves to remind biologists that tagging programs should be planned with a long time frame in mind.

Atlantic Sturgeon Will Feed During Spawning Migrations

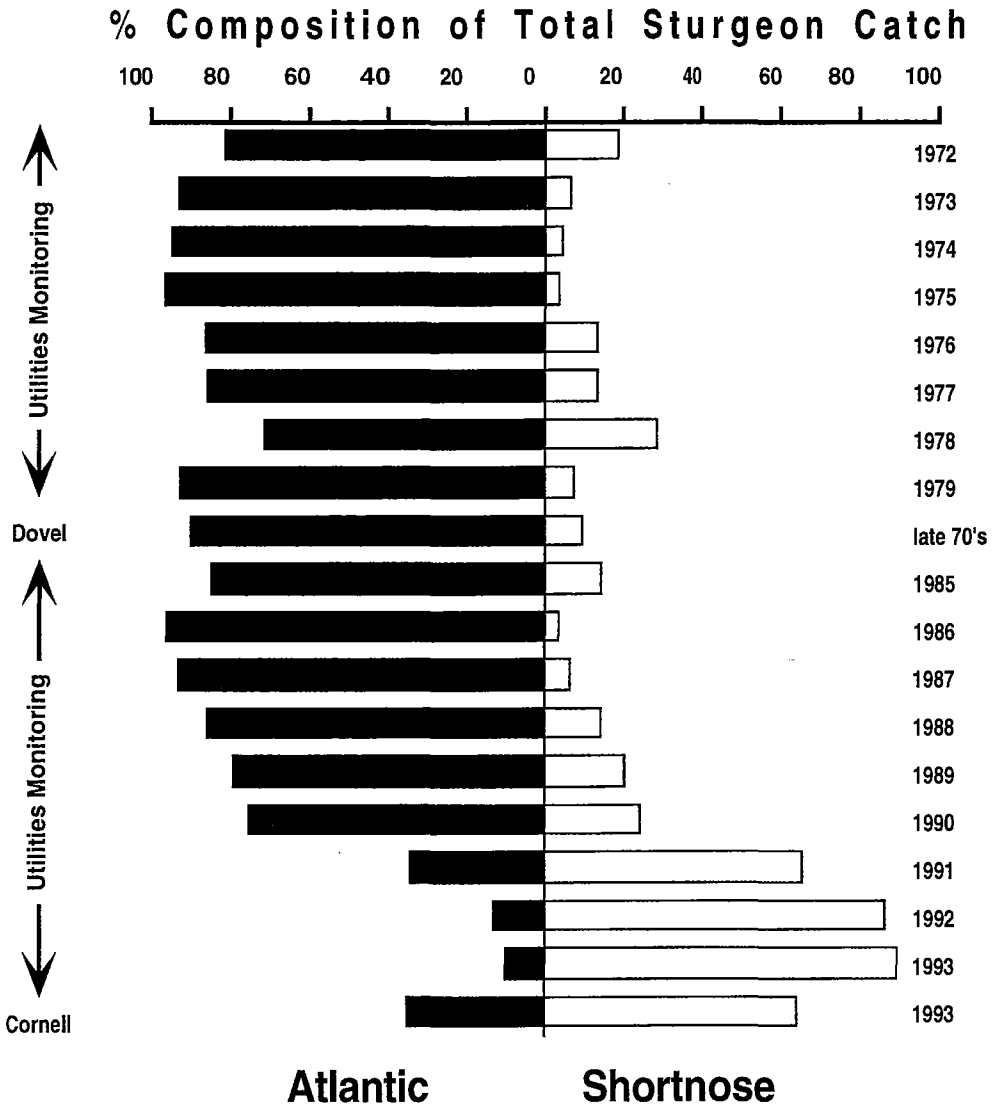
Many biologists believe adult sturgeon do not feed in freshwater while on their spawning migration. Also, Steve Nack of the Cornell Study has inspected the stomach contents of hundreds of adult sturgeon caught by fishermen and has not found food items. On June 27th, a 50-Kg male sturgeon was caught in the freshwater portion of the Hudson River near a known spawning area (Hyde Park, NY). The fish was held for two days in a large tank for the Aquarium for Wildlife Conservation in New York City. When the tank was drained to remove the sturgeon, we found a 10-cm section of an American Eel. The piece of eel appeared to be cleanly cut and did not show evidence of much digestion. We believe the sturgeon ate the eel shortly before capture, and regurgitated the piece while being held in the tank.

Sturgeon Tagged in the 70's Recaptured

Twelve shortnose sturgeon tagged in the Spring of 1979 as part of research conducted by Bill Dovel were recaptured by the Cornell Study Team. So far, we have not been able to locate the body size data for most of the numbered fish. The recaptured shortnose sturgeon ranged in fork length from 595 cm to 880 cm. Using available information on age-length relations, these recaptured sturgeon would be an estimated 13 to 30 years old. It is likely that most or all the fish were at least 20 years old and have grown little since they were originally captured 15 years ago.

Changes in the Composition of Hudson River Sturgeon

A comparison of the composition of sturgeon catches was reported from studies by Bill Dovel in the in the 1970's and the 1993 sampling by the Cornell Study Team. A more thorough review of catch composition data has been assembled using catch data from the monitoring program of the electric utilities. The chart below shows the composition of sturgeon in Hudson River studies over a 21 year period. These data show a clear change in juvenile sturgeon catches. Prior to 1990, Atlantic sturgeon heavily dominated the catch of research programs. Afterward, the shortnose sturgeon have become the dominant species of juvenile sturgeon in the Hudson River.


% Composition of Total Sturgeon Catch
100
80
60
40
20
0
20
40
60
80
100
Utilities Monitoring
Dovel
Utilities Monitoring
Cornell
1972
1973
1974
1975
1976
1977
1978
1979
late 70's
1985
1986
1987
1988
1989
1990
1991
1992
1993
1993
Atlantic
Shortnose

Sampling Success and Feasibility of Estimating the Population Size of Hudson River Shortnose Sturgeon

In 1995, both targeted and widespread sampling efforts were conducted for shortnose sturgeon in the Hudson River. The aims of this study phase were:

1. Determine the feasibility of conducting a mark and recapture population estimate, and
2. Capture, tag, and deploy marked fish in the population.

The record of sampling success under this study phase is intended to determine the feasibility of developing a firm population estimate and continuing the project. In addition, we report data on capture and marking of shortnose sturgeon prior to this study, and we include an initial estimate of adult shortnose sturgeon abundance.

Sampling

We conducted sampling from March 1995 to the present using gill nets in areas with high concentrations of adult shortnose sturgeon and over large regions of the Hudson River. Dense concentrations of adult shortnose sturgeon were found near Kingston in the early spring (March) and later on their spawning grounds downstream of the Troy Dam near Albany (mid April through May). After the spawning period, shortnose sturgeon were widely distributed in the tidal portion of the Hudson River, but primarily downstream of Kingston.

Gill nets ranging from 2 to 6 inch stretch mesh were set in channel habitats during slack tide so the set duration did not exceed 1 hour. There were no sturgeon mortalities from the gill net sampling, processing, or any other research activity. Fish were measured (total and fork length), weighed, marked, and released at the point of capture. Passive integrated transponder (PIT) tags were inserted 1 cm beneath a dorsal scute using a syringe equipped a 12 gage needle. Not all fish were fully processed (measured and marked) to minimize handling time if large numbers of

sturgeon were captured.

In March, we ceased using external Floy tags on shortnose sturgeon because of concerns received in the most recent review of our Federal Endangered Species Permit. These tags were being applied as part of the U. S. Fish and Wildlife Service coastwide sturgeon tagging program. Termination of this task will have no effect on the progress of this study.

Gill netting (single, 100 ft. x 30 ft. x 6" mesh net) for sturgeon began in March on the known overwintering concentration (Esopus Meadows reach near Kingston) area for shortnose sturgeon. Catch rates were very high (1038 fish, Table 1) and 1,008 fish were tagged by early April. At that time, the adult sturgeon moved to the spawning area near Albany where gill netting (single, 100 ft. x 30 ft. x 6" mesh net) was conducted until spawning was over in May. Again, catch rates were very high (Table 1). After spawning was complete, shortnose sturgeon disperse over a large portion of the tidal Hudson River. From June through the present, we have been conducting gill netting (3 nets per set; 100 ft. x 30 ft. x 2, 4 and 6" mesh net sizes) over much of the river at randomly located sites. During this sampling, catch rates were low and almost no marked sturgeon were recaptured (Table 1).

Table 1. Summary of shortnose sturgeon catch and tagging on the Hudson River in 1995.

Sampling period	Gill net sets	Sturgeon captured	Sturgeon marked	Sturgeon recaptured
Overwintering concentration	12	1,038	1,018	34
Spawning concentration	12	1,008	751	39
Summer and Fall	165	155	140	1

We originally expected that about 1,500 shortnose sturgeon should be captured and marked annually to obtain a reasonably accurate population estimate. This estimate was based on the number (2,750 in 2 years) of marked sturgeon used to develop a population estimate by Bill Dovel (referenced in study proposal) in the late 1970s. At this point, we are above our planned capture and marking target for 1995 (Table 1). Also, we have have exceeded the number of fish handled in Bill Dovel's study when 1995 fish are combined with past sampling (Table 2).

Table 2. Summary of shortnose sturgeon catch and tagging on the Hudson River since 1993.

Study year	Gill net sets	Sturgeon captured	Sturgeon marked	Sturgeon recaptured
1993	255	400	83	-
1994	73	1,604	925	8
1995	199	2,201	1,769	74

Initial Population Estimate

Using the data collected in 1995, we were able to conducted a preliminary capture-recapture population estimate for two purposes. First, an initial estimate demonstrates our ability to succeed in attaining the goal of the project. Second, the 1995 data allows us to replicate the estimate made by Bill Dovel in the 1970s.

Our initial capture-recapture population estimate began on 14 March and was completed 11 May. The relative short duration of this experiment allowed for intensive sampling of a highly concentrated school of adult shortnose sturgeon in an overwintering area (pre-spawning staging area) and a later concentration of fish on the spawning grounds. The short duration of the experiment and the concentration of fish in localized regions of the river allowed us to meet a primary assumption of capture-recapture models for estimating closed populations; the sampled

population is both geographically and demographically closed.

Two other assumptions of all capture-recapture studies must be satisfied: (1) animals do not lose their marks during the experiment and (2) all marks are noted and recorded correctly on each sampling occasion. PIT tags are considered the most reliable, long-term mark currently available for sturgeon, and available data indicate very high PIT tag retention. In addition, our PIT tag readers are effective for detecting the marks.

Implicit in the assumption of a closed population is that no births or deaths occur, nor immigration or emigration into or out of the area being sampled. Because we sampled the population over a short time, prior to and during its migratory spawning run, demographic changes were negligible; however, changes due to emigration and migration were a potential problem. Thus, in designing the experiment we made an additional assumption specific to this population. We assumed that fish migration is primarily cued by water temperature such that fish movement occurs over a short period when water temperature has risen above the threshold. We designed the experiment in such a way as to avoid serious violation of this assumption. Fish captures were made on the staging grounds just prior to migration and then again on the spawning ground after upstream migration was complete. Three capture periods, each representing a pooled series of samples, were designated for incorporation into the capture-recapture model. Periods one and two were taken at the Esopus Meadows overwintering area. The first period included six sample days during one week. The second period included six samples taken over 12 days. The third period included nine samples taken over 25 days and these were on the spawning grounds in the Albany area.

Data were structured into a capture history matrix for analysis using the program CAPTURE. The program version 6/30/92 incorporates recent advances in estimation theory including several procedures which allow relaxation of the equal catchability assumption of the original (null) model. Specifically, it incorporates three models which address problems of variation in capture probabilities:

1. Model M(t) assumes capture probabilities vary by time or the capture period.

2. Model M(b) assumes that capture probabilities vary by behavioral response to capture.

3. Model M(h) assumes that capture probabilities vary by individual animal (h=heterogenity among animals).

Combinations of the above models are also available in program CAPTURE when there is no single source of bias in the data.

The program also includes a model selection procedure for testing the data matrix against the null model using chi-square goodness fit tests and suggests an appropriate model. Once an appropriate model is selected the program will compute a bias-corrected population estimate (N) and standard error.

A total of 2,046 shortnose sturgeon were captured including 74 recaptures. Some recaptures were from fish marked prior to this experiment and, hence, were omitted from the analysis. That left 44 recaptured fish marked during the experiment. Of these, 15 occurred within a period and were omitted as usable recaptures. This left only 29 usable recaptures; 11 during period 2, and 18 during period 3. Water temperatures ranged from 4 to 8 C during sampling periods 1 and 2, but began rising to 14 C at the start of period 3 (spawning). The sharp rise in water temperature early in period 3 coincided with a abrupt reduction in catch rate at the overwintering area.

We computed population estimates using the bias-corrected models M(h) and M(th) in CAPTURE and the null model (M (o)) for comparison. Models M(h) and M(th) allow variation in capture probabilities across individuals (M(h) = heterogeneity) and over individuals and time (M(th) = time and heterogeneity) respectively. Heterogeneity in capture probabilities is more realistic than the equal capture probability assumption of the null model. Time effects are factors external to the animal, such as weather or unequal effort (i.e., different soak times in net sets), and can cause upward or downward shifts in all individual capture probabilities within a period. We

did not consider behavior (i.e., trapping response) a likely influence in our sampling given that the species is bottom oriented, with poor vision and monofilament netting is translucent in water.

The results of the all population estimates are given in Table 3. The M(h) estimate was the greatest: 55,265 with a standard error of 10,436. The M(th) model estimated a population size of 38,024 with a standard error of 7,199. Both estimates were greater than the null model (i.e., constant probability of capture) which was 25,255 with a standard error of 3,783. We consider the M(th) estimate to be the most appropriate considering there were changes in capture success over time.

Table 3. Population estimates (N) for their associated standard errors (SE) and 95% Confidence intervals for the three models used in the study.

Model	N	SE	Lower CI	Upper CI
M (h)	55,265	10,436	38,397	79,901
M (th)	38,024	7,199	26,427	55,072
M (o)	25,255	3,783	18,931	33,906

Our initial attempt at estimating the population of adult shortnose sturgeon demonstrates the feasibility of this study. While the initial estimates are speculative due to the low number of recaptures, they suggest that the abundance of shortnose sturgeon has increased since Dovel's estimate of 13,000 fish in the 1970s. Dovel's estimate was based on data collected in the same way as this study so his values and ours are directly comparable. However, the near lack of recaptures of marked sturgeon in our summer sampling strongly indicates that the study design used here and by Dovel substantially underestimates the number of shortnose sturgeon in the Hudson River. Apparently, the adult sturgeon that overwinter near Esopus Meadows and later spawn near Albany are not the majority of adult sturgeon in the river. This is consistent with life history data from other rivers indicating that shortnose sturgeon spawn once every three years. Nonspawning adults appear to inhabit areas other than the Esopus Meadows overwintering area,

and they do not migrate to the Albany area in the Spring. Based on life cycle information from other rivers, we believe most of the shortnose sturgeon population overwinters in a large area of the lower river and later disperse further in the growing season.

Conclusions

Even though this project has been underway for less than one year, some preliminary conclusions can be made:

1. Sampling results indicate a confident population estimate is feasible so the study should be continued.

2. There is currently not enough marked fish in the river to obtain a sound, whole population estimate.

3. The near absence of recaptures during the summer and fall of 1995 indicates the sampled overwintering and spawning concentrations include just a subset of the adult population.

4. Our initial population estimates are directly comparable to the Dovel estimate in the 1970s, and the results indicate a 2 to 4 fold increase in abundance.

5. It is highly likely that our initial population estimate and Dovel's greatly underestimates the number of adult shortnose sturgeon in the Hudson River.

6. All possible effort should be devoted to increasing the number of marked fish in the river in an effort to get usable numbers of recaptures in the summer and fall.

Size Conversions for Atlantic Sturgeon

Prediction of total length and fork length from dressed (butchered) lengths and weights is important in estimating and managing sturgeon harvests. Comparison of lengths and weights before and after sturgeon were dressed showed that dressed weight was a much better predictor of total length, fork length, and total weight than dressed length. The reason for this may be that sturgeon are somewhat anguilliform (eel or snake-like) in their body shape. Thus variation in where the tail is cut will affect length more than weight. Heads are probably consistently cut off at the same place (just behind the pectoral fins). A table of morphometric conversions is provided below for the common measurement units of pounds and inches. No significant difference in allometric relations occurred between males and females. David H. Secor, Chesapeake Biological Laboratory.

$$\text{True weight in pounds} = 0.0079 \times (\text{dressed length in inches})^{2.47}$$
$$[n=26,\ r^2=0.82]$$

$$\text{True weight in pounds} = (1.73 \times \text{dressed weight in pounds}) - 14.61$$
$$[n=27,\ r^2=0.99]$$

$$\text{Total length in inches} = 22.63 + (1.15 \times \text{dressed length in inches})$$
$$[n=27,\ r^2=0.79]$$

$$\text{Total length in inches} = -19.88 \times (\text{dressed weight in pounds})^{0.32}$$
$$[n=28,\ r^2=0.96]$$

$$\text{Fork length in inches} = 20.40 + (1.04 \times \text{dressed length in inches})$$
$$[n=27,\ r^2=0.81]$$

$$\text{Fork length in inches} = -17.36 \times (\text{dressed weight in pounds})^{0.33}$$
$$[n=28,\ r^2=0.98]$$

For example, if the dressed length of an Atlantic sturgeon is 32 inches, then the predicted dimensions of the whole fish would be: true weight 41 pounds, total length 59 inches, fork length 54 inches. If the dressed weight of an Atlantic sturgeon is 32 pounds, then the predicted dimensions of the whole fish would be: true weight 41 pounds, total length 60 inches, fork length

54 inches. Incidentally, the matching 32 inch and 32 pound values for a minimum legal-size Atlantic sturgeon is correct for this set of equations rounded to whole numbers.

Additional Conversions

Total length can be approximated from fork length using the following formula (from Dadswell 1979) for any units of measure:

$$\text{Total length}=1.11(\text{fork length})$$

The inverse formula approximates fork length from total length in any units:

$$\text{Fork length}=0.90(\text{Total length})$$

Hudson River Atlantic Sturgeon Recaptured Off the Atlantic Coast

During the fall of 1994, three Atlantic sturgeon tagged by Cornell researchers in the Hudson River were recaptured along the US East Coast by commercial fishers. One sturgeon was a 68-Kg gravid female sonic tagged in the Hudson River near Hyde Park on 30 June 1994 and regularly located in the river through the end of August 1994. On 27 October 1994, this female sturgeon was captured by a commercial fisherman off the New Jersey coast near Barnegat Light. Examination of the fish revealed it had small, white, partially developed eggs. Another adult, sonic-tagged (19 July at Hyde Park) male sturgeon was captured off the New Jersey coast near Barnegat Light on 19 October 1994. Finally, a juvenile (884 mm fork length) Atlantic sturgeon tagged in the Hudson River on 17 August 1993 was captured on 14 March 1994 in Delaware Bay (reported total length of 1,007 mm [3.5 feet]).

Remote Monitoring of Sturgeon Movements

Movements and concentration areas of adult Atlantic sturgeon are being monitored in the Hudson River as part of the Cornell Sturgeon Studies using ultrasonic telemetry. In addition to traditional manual tracking of sonic tagged sturgeon, three bankside remote receivers equipped with hydrophones were tested in 1994. The equipment is on loan from the U. S. Army Corps of Engineers and was used in a Delaware River shad tracking study. To our knowledge this technology has not been applied to sonic tagged sturgeon in a large river. The use of remote receivers can augment manual tracking data by indicating the time and date of passage of tagged fish in an area. If properly maintained, these systems can monitor movement and activity through key areas of the river, indicate the extent of upriver migration, and detect the duration of residence in known or suspected spawning areas.

The remote systems were equipped to run off of deep cycle marine batteries hooked to laptop computers, and they were placed at three key locations on the bank of the Hudson River. The remote systems worked at times, however, they had major limitations which will need to be overcome for long-term use over wide river reaches. In particular, the computers drained batteries much too quickly for continuous remote operation. It was our hope that the systems would run continuously on a fully charged battery for one week, but this was not the case. Therefore, the lower and upper river units were abandoned soon after we started using them. We were able to continue using one remote system in the middle section of the Hudson River for most of the 1994 spawning season (less a one week gap) because of the availability of AC power. This station was within the reported spawning zone of Atlantic sturgeon based on capture of gravid females, and it is from here that we could monitor tagged fish effectively.

Twenty fish were tagged just upstream of the middle river remote system and all of the tagged sturgeon were monitored passing the station at least once except four fish which were tagged during the week the system was not operating. These fish apparently went downriver without returning . Four of the tagged fish were females and unfortunately these were tagged late

in the season so we obtained little data. Two of three fish left this section without returning (one detection each) while one was detected twice. In general, fish tagged between 3 June and 30 June (11 of 13) were remotely detected for the longest periods. Most of the remotely tagged fish were repeatedly detected over a 10 to 17-day interval. Detection times indicated the period of greatest activity was during early morning hours between 22:00 and 7:00, and the few fish detected during afternoon hours occurred late in the season (mid-June or later). The afternoon activity was often associated with high flood tide ebbs between 12:00 and 6:00 hours (23-29 June) and was most common from 25 June through 2 July. The mean length of detection was 2.9 hours (std. dev. 3.3) with two fish continuously detected for 13.5 and 17.5 hours on 29 through 30 June. Omitting these two fish, the mean length of detection was 2.3 hours (std. dev. 1.6). We estimate the range of detection cone to be about 2 km. The remote systems do not indicate direction of movement; however, a general direction could often be determined from fish located manually on days before or after being remotely detected.

Continued use of remote receiving stations will require a bankside AC power supply in desired locations. Aside from the initial set up and weekly data retrieval, the systems are totally self-sufficient and easily maintained. Together with manually obtained tracking data, remote monitoring systems can provide unique behavioral data on sturgeon in large rivers like the Hudson River.

Juvenile Sturgeon Habitat Use In The Hudson River

The Hudson River supports sympatric populations of Atlantic and shortnose sturgeon. Although these ecologically similar species exhibit varying life history strategies, they appear to overlap within the Hudson River estuary during their extended juvenile period. Thus, a unique opportunity exists to study distribution and habitat association patterns of resident juvenile Atlantic and shortnose sturgeon with the goal of gaining a better understanding of how Atlantic and

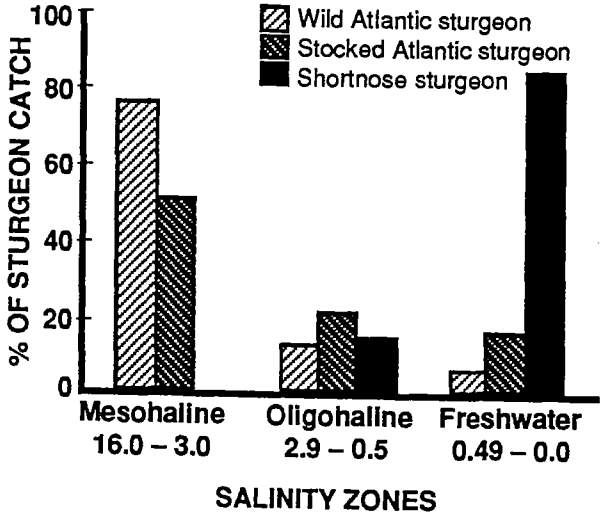
shortnose sturgeon coexist in the Hudson River. The objectives were to: assess the feasibility of using a widely dispersed sampling program to collect juvenile sturgeon in the Hudson River; identify environmental attributes associated with sturgeon summer foraging habitat; and examine species-specific patterns of habitat association.

Between June and mid-September, 1995, we sampled for juvenile sturgeon (defined as 0–1200 mm fork length [FL] for Atlantic sturgeon and 0–510 mm FL for shortnose sturgeon) within a 96-kilometer reach of the middle and lower Hudson River estuary. Four sampling strata (narrow river to narrow estuary; see map on the following page) were defined within this reach of the river and a stratified random sampling design was used to allocate effort proportionate with the size of each stratum. Small mesh gill nets were set on the bottom at each randomly selected sampling station for an average of 40 minutes. Data collected on each captured fish included measurements of total (TL) and fork (FL) lengths and weight (g). Sturgeon longer than 300 mm were tagged internally with passive integrated transponder (PIT) tags. Temperature (C), depth (m), salinity (ppt), conductivity (μmhos), and substrate data were gathered at each sampling station.

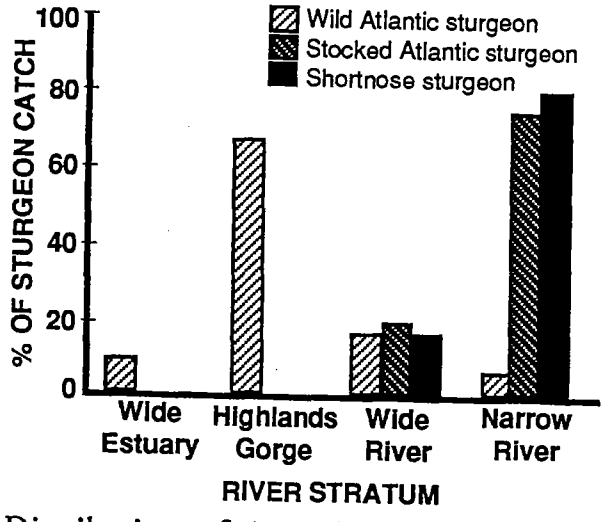
In October 1994, 4,929 hatchery-reared Atlantic sturgeon from the U. S. Fish and Wildlife Service's Lamar Fish Hatchery (Lamar, Pennsylvania) were stocked in the Hudson River just downstream of Storm King Mountain (Km 89-90). At release, these stocked fish ranged in total length from 78 to 137 mm with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

Forty-eight wild juvenile sturgeon were collected; 36 Atlantic (272–1245 mm TL, mean = 809) and 12 shortnose sturgeon (404–584 mm TL, mean = 539). An additional nine hatchery-reared Atlantic sturgeon (306–659 mm TL, mean = 426) were also captured. Juvenile sturgeon were distributed differently with respect to river stratum and salinity zones (see figure on the right). Depths used by the sturgeon also varied. No differences in their distribution with respect to substrate type and bottom water temperature were detected. Wild Atlantic sturgeon captures

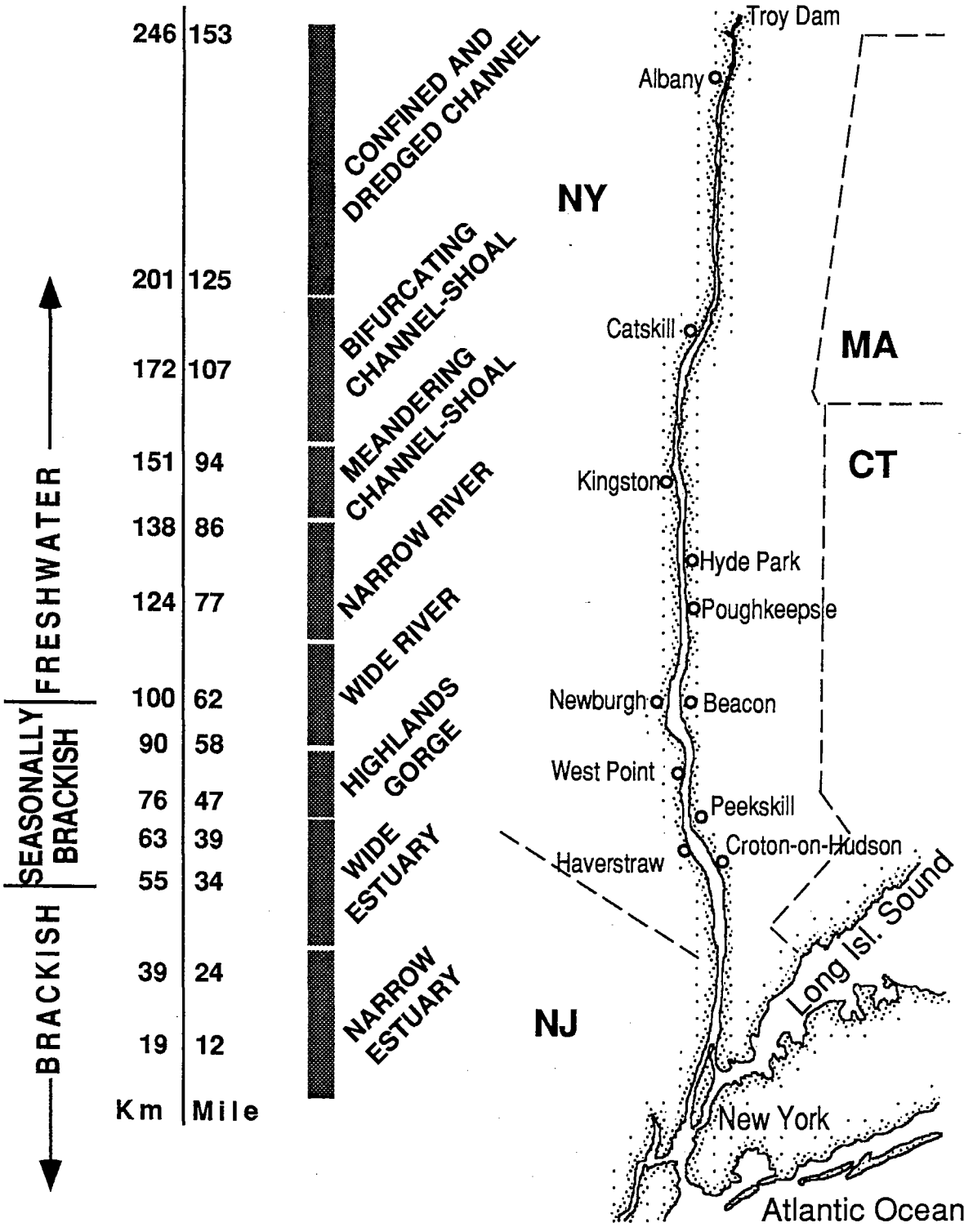
occurred most often within a relatively deep, mesohaline stratum (Highlands Gorge). Juvenile shortnose sturgeon and stocked Atlantic sturgeon were found within the two uppermost strata (wide river and narrow river). The oligohaline region of the river, which contains the biologically productive freshwater/saltwater interface, was a zone of overlap for 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 juveniles. Continued sampling and monitoring of the distribution of juvenile Atlantic and stocked sturgeon will be needed to determine if stocked fish eventually distribute themselves like their wild counterparts. Future study efforts on juvenile sturgeon in the Hudson River estuary will add to the growing database on sturgeon ecology in this system and improve the understanding of interspecific interactions and habitat use patterns. (Work of Nancy Haley supported by project)



Distribution of juvenile sturgeon by salinity zone in the lower Hudson River.



Distribution of juvenile sturgeon by river stratum in the lower Hudson River.

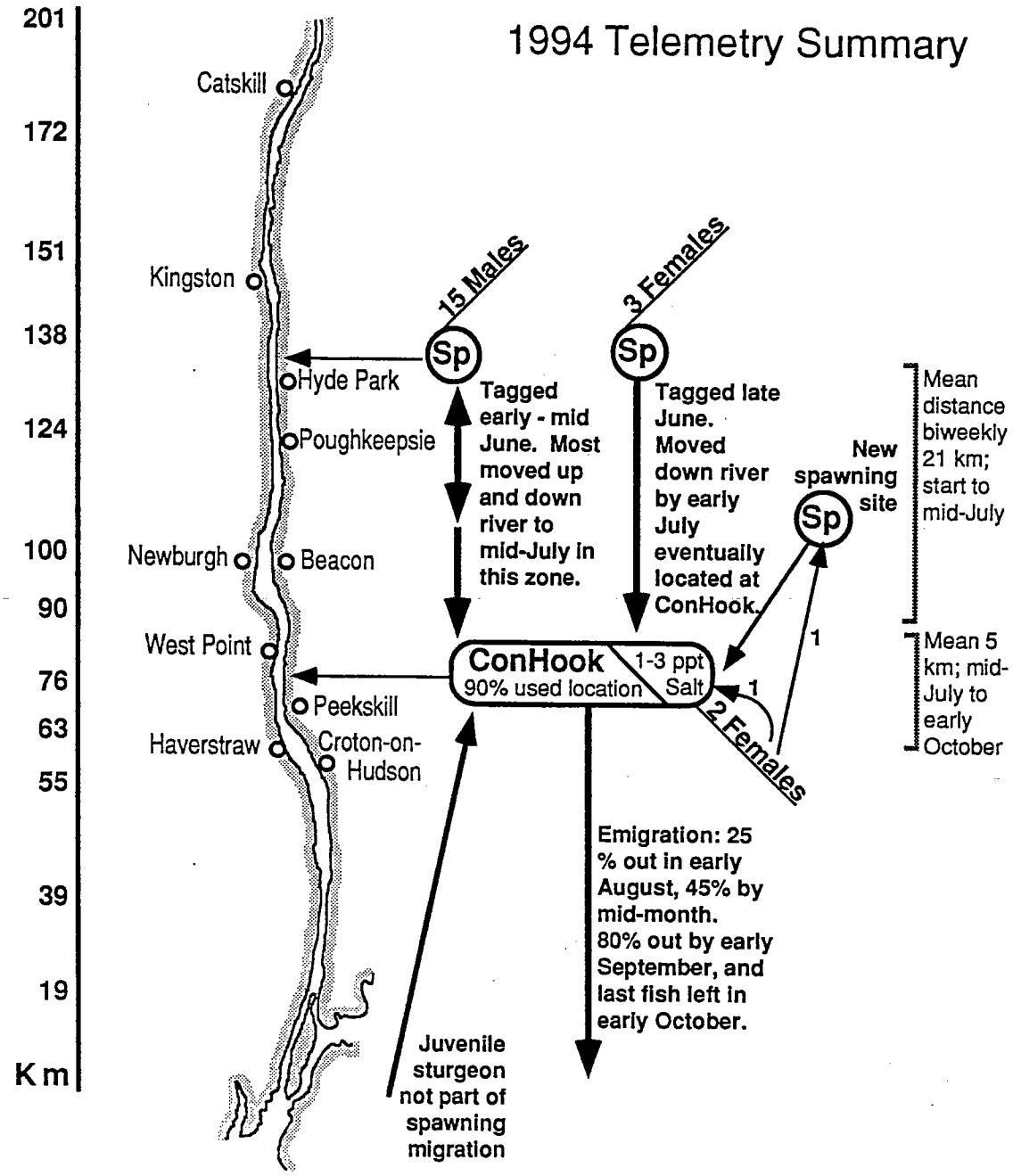

246 153
201 125
172 107
151 94
138 86
124 77
100 62
90 58
76 47
63 39
55 34
39 24
19 12
Km Mile
FRESHWATER
SEASONALLY BRACKISH
BRACKISH
CONFINED AND DREDGED CHANNEL
BIFURCATING CHANNEL-SHOAL
MEANDERING CHANNEL-SHOAL
NARROW RIVER
WIDE RIVER
HIGHLANDS GORGE
WIDE ESTUARY
NARROW ESTUARY
NY
NJ
MA
CT
Troy Dam
Albany
Catskill
Kingston
Hyde Park
Poughkeepsie
Newburgh
Beacon
West Point
Peekskill
Haverstraw
Croton-on-Hudson
Long Isl. Sound
New York
Atlantic Ocean

Atlantic sturgeon telemetry results

The primary purpose of this Foundation sponsored study of Atlantic sturgeon was to use telemetry of adults to identify spawning areas to use as sites for mark and recapture population estimation. In late spring/early summer of 1994 and 1995, adult Atlantic sturgeon were collected in the Hudson River by gill nets and tagged with ultrasonic transmitters. In each year, 15 males and 5 females were tagged. Male sturgeon ranged in size (total length; TL) from 1.46 m to 2.2 m. Female sturgeon ranged from 2.1 m to 2.4 m, and the sex of male fish was determined by the presence of milt expressed by pushing on the fishes lower abdomen. Females were sexed by presence of eggs (released from fish) or by a large extended abdomen. Fish whose sex could not be determined were not used.

Sonic tagged sturgeon were monitored by boat tracking and with three continuously operating monitoring stations. Boat tracking was conducted on a bi-weekly basis. It consisted of traveling the center of the river and stopping approximately every half mile to scan for fish (tagged fish were detectable up to two miles). Continuous monitoring stations were used because we feared that once fish were released, relocating them may be difficult. We readily concluded that boat tracking was highly effective (all tagged fish could be found over large areas) and the need for the remote stations was reduced.

In 1994, 18 of 20 sonic tagged fish were captured near the known spawning area at Hyde Park (Km 129-135; see figure next page). Two fish were tagged near Con Hook (Km 77) downstream of West Point. The trend for most fish tagged near Hyde Park was to remain stationary for one to two days following tagging. All fish then moved down river over a period of four to six weeks. Some fish moved downriver quickly covering up to 64 km in just a few days, while others seemed to move much more gradually, taking three to four weeks to cover the same distance. By early July, when river temperatures reached about 25 C, several of the sonic tagged fish had congregated in deep water at the Con Hook site. Salinity in this area ranged from 1 to 3

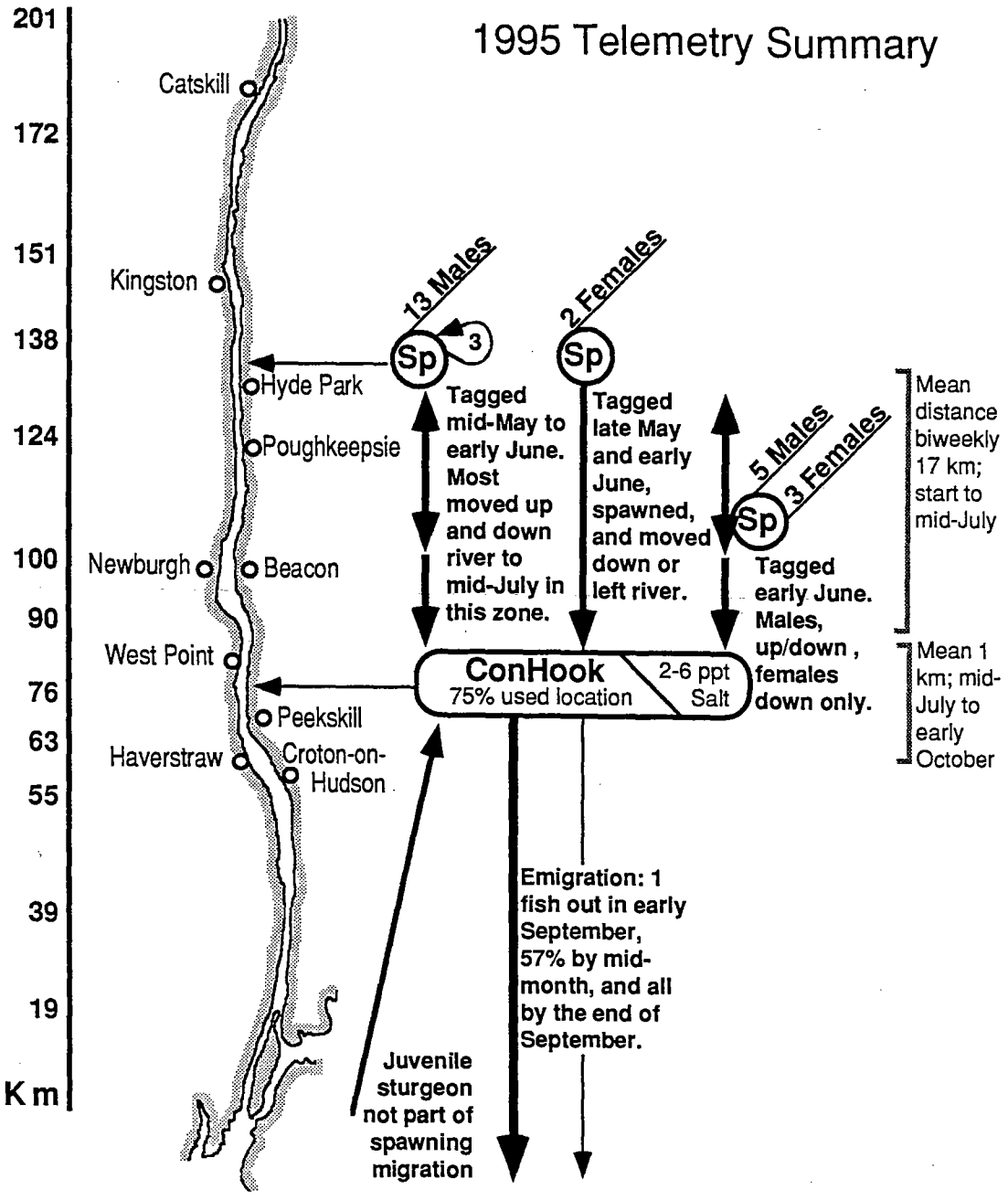


1994 movements and locations of spawning and concentration areas for Atlantic sturgeon in the Hudson River.

ppt and depths were up to 37 m. Several other large sturgeon could be seen surfacing in the immediate vicinity of the sonic tagged fish, and a gill-net survey captured several large sturgeon and two additional prespawn female sturgeon which were sonic tagged. One female moved up river over a period of 1-2 weeks and then became stationary at Km 112 (Clinton Point). Gill nets set in the vicinity recorded several other adult Atlantic sturgeon indicating a previously unknown spawning area.

From mid-summer through fall, most (18 of 20) sonic tagged fish remained at or near the Con Hook site with a few fish moving about within the deeper portions of the river between Stony Point and Cornwall. Gill-net surveys at the Con Hook site in August revealed large numbers (up to 30 in one net set) of sturgeon ranging in size from 1 to 2.5 m in total length. These sturgeon were a combination of spawning adults and marine-migrant juveniles. Emigration of the sonic tagged sturgeon from the river in 1994 was gradual: 75% present on August 1, 55% present in mid-August, 20% in mid-September, 2 tagged fish on October 2, and none by October 12. Not all females left the river soon after spawning as was previously thought, but rather remained with other sturgeon and gradually left the river during late summer thru early fall. Two of these fish were captured in October by commercial fisherman off the coast of New Jersey.

In 1995 we caught and sonic tagged adult sturgeon earlier and at additional sites (see figure next page). After 10 sturgeon were sonic tagged near the Hyde Park spawning area, these fish lead us to other productive capture areas. Fish were caught in various sites between river km's 113 and 135. In nearly every instance when gill nets were set near sonic tagged fish, other adult Atlantic sturgeon were readily captured. Occasionally, the sonic tagged fish was also caught. Most fish tagged in 1995 gradually moved downriver as in 1994, however at least 5 of the 15 males turned around and made apparent "runs" back up the river. One large female, (approximately 115 kg) that was caught near Hyde Park on 28 May appeared ready to spawn due to easily released eggs. The following day, the same fish was captured at the original capture



1995 movements and locations of spawning and concentration areas for Atlantic sturgeon in the Hudson River.

location in a clear post-spawning condition. Afterward, this female quickly moved 48 km downriver and then apparently left the river.

By the second week in July 1995, the sonic tagged sturgeon congregated at the same site (Con Hook) occupied in 1994. Water temperatures and salinity were higher than in 1994: 25 C and 2-6 ppt. By mid to late July, most of the sonic tagged fish detected in the river were at this location. Throughout the summer, the sonic tagged fish remained at the Con Hook site and moved little. Gill-net surveys during the summer and early fall documented the presence of numerous adult and subadult sturgeon (1-2.5 m TL) and jumping sturgeon were easily seen. Emigration of the sonic tagged sturgeon from the river was gradual as in 1994: 1 fish was gone on 5 September, 4 left by 20 September, and all tagged fish were gone by the end of September. A subsequent thorough search of the river located one fish near Bear Mountain bridge just downstream of the Con Hook site.

The sonic telemetry study of 1994 and 1995 revealed new concentration areas and behavior patterns. Atlantic sturgeon did not congregate in a few spawning areas but instead spawned over a long period of time at several sites (at least kms 113-184). The existence of a late summer concentration area used by post-pawning adults and marine-migrant juveniles has not been previously documented in the Hudson River or elsewhere. Our results indicate it will not be possible to estimate the abundance of adult Atlantic sturgeon at concentration sites: spawning is protracted and dispersed, and the late summer site included many non-spawning but large fish.

Senescence in Shortnose Sturgeon

From mid-1993 through the end of 1995, Cornell researchers handled 4,707 shortnose sturgeon. Of these, 44 were recaptures of shortnose sturgeon tagged between 1979 and 1980 by Bill Dovel and others [described in: Dovel, W. L., A. W. Pekovitch, and T. J. Berggren. 1992. Biology of the shortnose sturgeon (Acipense brevirostrum Leseur, 1818) in the Hudson River estuary, New York. Pages 187-216 in C. L. Smith (editor). Estuarine research in the 1980s. State University of New York Press, Albany, NY.]. Nineteen of the 44 recaptured sturgeon had external numbered tags that could be read. Bill Dovel supplied the data taken at the time of tagging. The other 25 recaptured sturgeon had wire remnants of the Carline-Ritchie external tags but they no longer had the plastic numbered disk. Data collected at the time of tagging and when recaptured is presented in the table below.

The time between tagging and recapture ranged from 14 to almost 17 years. Surprisingly, 17 of the 19 shortnose sturgeon were adults (≥550 total length [TL in table]) when tagged. On average, the recaptured shortnose sturgeon grew little (mean, 86 mm) since 1979-1980. However, growth was highly variable among individuals. The smallest sturgeon at tagging (320 mm TL) grew the most (500 mm), but other fish showing above average growth were adults of all sizes at the time of tagging. Four sturgeon were shorter at the time of recapture than when tagged. Most of this length loss is probably measurement error. Change in weight (mean, 62 g increase; WT in table) since tagging was more variable than change in length. Some of the variation in weight was probably due to change in egg biomass before and after spawning. Most of the recaptured sturgeon weighed less than in 1979-1980, but some showed substantial increase in weight during the period. The small juvenile (140 g) grew the most, but the second longest fish at tagging (830 mm TL) increased greatly in weight (1190 g, the heaviest fish on recapture).

Most of the recaptured shortnose sturgeon are of typical adult size for the Hudson River population. In Cornell samples, the mean and modal total length for Hudson River shortnose

sturgeon was about 650 mm TL with large fish being slightly over 800 mm TL. The 17 adult sturgeon listed in the table below cover this common size range indicating that many adult shortnose sturgeon in the river could be of comparable or older age as this sample of fish. However, the two longest shortnose sturgeon at tagging were among the largest fish handled by Cornell researchers between 1993 and 1995. (Mark Bain, Steve Nack, Bill Dovel)

Tagging and recapture data for 19 Hudson River shortnose sturgeon handled by Bill Dovel in 1979-1980 and 14 to 17 years later by Cornell researchers.

Tag #	Tag date	TL (mm)	WT (g)	Recap-ture	TL (mm)	WT (g)	Growth (mm)	Growth (g)
E923	04/79	320	140	04/95	820	3440	500	3300
S886	03/79	520	570	04/95	665	1150	145	580
G607	05/80	555	1640	03/95	885	2560	330	920
E117	05/79	565	960	04/95	645	1180	80	220
F069	05/79	650	1780	03/95	695	1840	45	60
F726	04/79	675	2030	12/95	758	1800	83	-230
E653	03/80	686	2150	03/95	725	1860	39	-290
F211	05/79	690	2150	04/94	737	2700	47	550
F738	10/79	690	2150	04/94	799	–	109	–
F851	03/79	711	2380	04/95	715	1720	4	-660
E366	03/79	726	2490	04/94	693	1800	-33	-690
G927	05/80	740	3540	03/95	825	2540	85	-1000
S471	03/79	760	3170	07/93	788	–	28	–
E798	03/80	762	3280	12/95	865	2820	103	-460
E405	04/79	764	2720	03/95	755	1900	-9	-820
S871	03/79	770	2265	03/95	745	1620	-25	-645
G214	04/80	820	3420	04/94	810	2700	-10	-720
S984	03/79	830	2830	03/95	925	4020	95	1190
G905	05/80	850	3050	07/95	860	2800	10	-250

Trends in Abundance Of Hudson River Sturgeons

A consortium of electric utility companies conducts aquatic resource monitoring in the Hudson River from Albany to New York City. Part of this extensive sampling program is a trawl survey completed every year from early July and mid-October. The trawl survey is rigorously standardized and includes about 1240 samples a year using a 3.0-m beam trawl towed on the bottom for approximately 5 minutes against the prevailing current. All captured sturgeon are counted and released, with lengths and weights taken from most fish. The Consolidated Edison Company provided the data from the annual trawl survey to Cornell researchers for the purpose of assessing sturgeon abundance and distribution. The figure below includes the most recent data for 1996. The catch of Atlantic sturgeon is entirely composed of juveniles and most of them are small (mean about 550 mm TL), river resident fish. The catch of shortnose sturgeon is primarily adults (mean about 670 mm TL).

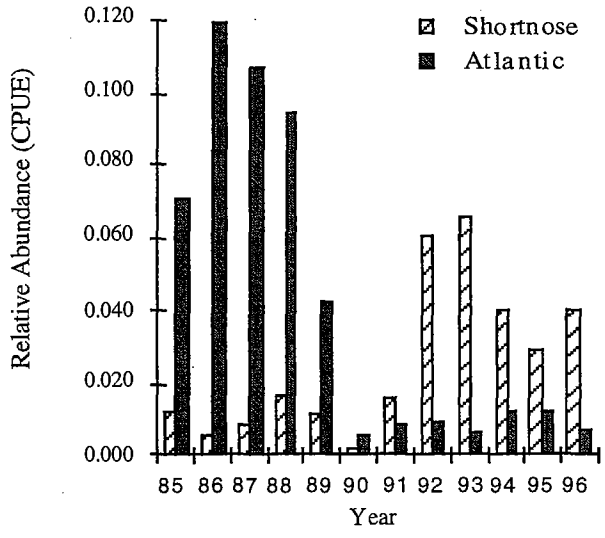


Figure. Twelve years of catch per unit effort (per trawl) data for sturgeon in the Hudson River.

Sex Composition and Male Size Observations for the Hudson River Atlantic Sturgeon Spawning Population From 1992-1997

Sex composition and male sizes (FL (mm)) were determined using data from studies and sampling conducted on the Hudson River spawning population between 1992 and 1997 (Table 1). Data were obtained from U.C. Davis (Serge Doroshov and Joel Van Eenennaam), the USFWS Northeast Fishery Center (Jerre Mohler and John Fletcher), and Cornell University (CU research team). The data suggest a possible decrease in the female to male sex ratio of the Hudson River Atlantic sturgeon spawning population. They also suggest a possible increase in the size (FL (cm)) of spawning males.

Table 1. Sex composition and male size observations of the Hudson River Atlantic sturgeon spawning population.

Source	Year	Males	Females	Mean $FL_{(males)}$
U.C. Davis	1992	49	15	1614.7
Cornell	1994	38	7	1596.5
USFWS	1994	3	2	1775
Cornell	1995	32	5	1657.5
USFWS	1995	8	3	1616
USFWS	1996	23	5	1656
Cornell	1997	9	0	1889.4
USFWS	1997	42	0	*1809

* Lengths were not provided, but 4 of the fish caught were observed to be > 1809 mm FL.

Marine Concentrations of Atlantic Sturgeon in Long Island Sound

The purpose of this project was to document the existence of marine concentrations of Atlantic sturgeon in Long Island Sound and obtain biological data on collected fish to enhance the understanding of Atlantic sturgeon life history. Our objectives were to: 1.) conduct a multi-day trawl survey within reported concentration areas to capture Atlantic sturgeon; 2.) obtain length measurements of collected fish to determine the size structure of congregations; 3.) check for tags and age unmarked fish to assess offshore movements of Atlantic sturgeon and determine potential

river origin of tagged fish; and 4.) collaborate with sturgeon researchers and obtain biological samples for use in other investigations of Atlantic sturgeon.

We completed four, one-day trawl surveys in Long Island Sound during the summer and fall of 1996. We surveyed seven of the Connecticut Division of Marine Fisheries' trawl sites within Long Island Sound with a 3-meter beam trawl. Sixty Atlantic sturgeon were collected at two adjacent sampling sites located just south of Faulkners Island between 16-17 July 1996. The capture location is a deep region (30-40 meters) with a mud bottom. One sturgeon, captured on 16 July 1996, was a recapture of a fish originally tagged in the Hudson River on 20 November 1993. When tagged in 1993 the fish measured 614 mm FL. Upon recapture, nearly three years later, its length was 880 mm FL. All but one of the fish were measured and tagged and tissue samples were obtained from 27 sturgeon for genetic typing. (Nancy Haley and Tom Savoy)

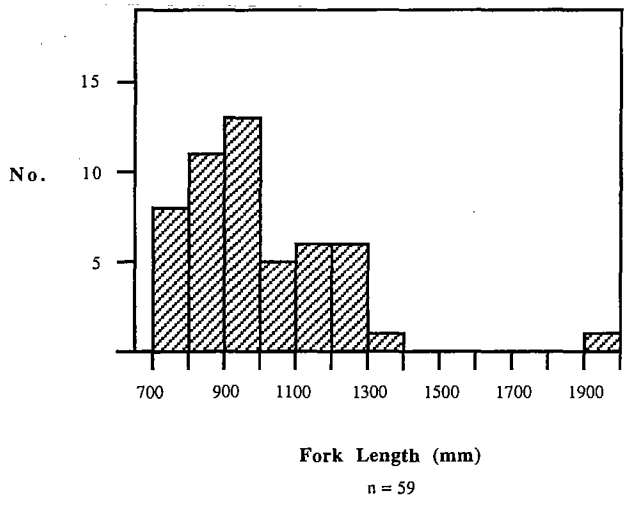


Figure 1. Length frequency of Atlantic sturgeon collected in Long Island Sound, 1996.

Evidence for Decline in the Abundance of Atlantic Sturgeon

Historically, Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) occupied most major river systems along the Atlantic coast from Labrador to the east coast of Florida. Because of its long life span, delayed maturity, and vulnerability to capture during spawning migrations, Atlantic sturgeon are particularly susceptible to overfishing (Boreman 1997). Between 1880 and 1910 unregulated harvest decimated most U.S. stocks from New York to South Carolina (Smith and Clugston 1997; Murawski and Pacheco 1977). Few fisheries have persisted at reduced levels since that time, although recent (1990-1992) U.S. landings were only 2% of the fishery at its peak. The Hudson River supports the largest remaining population of Atlantic sturgeon in U.S. waters (Bain 1997), but recent bycatch of Atlantic sturgeon in commercial shad fisheries and striped bass monitoring programs suggest that the Hudson River population has declined in recent years and may now be at record low levels (NY DEC 1995).These and other observations prompted the Atlantic States Marine Fisheries Commission's (ASMFC) Atlantic Sturgeon Management Board to request that states allowing sturgeon harvest impose an immediate two-year moratorium on those fisheries (ASMFC 1996). Within two days of the Commission action, the New York Department of Environmental Conservation (NYDEC) implemented an emergency moratorium on the New York Atlantic sturgeon fishery because of evidence for a dramatic decline in the population and concerns that additional harvest my cause irreparable harm (NYDEC 1996). This ban, however, was based primarily on circumstantial evidence as quantitative fisheries data on Hudson River Atlantic sturgeon is lacking. The primary goal of this study was to provide quantitative data on year-class abundance as a means of evaluating the need for the moratorium. Despite the moratorium, it is uncertain how much time will be needed to rebuild the population to levels adequate for a commercial fishery.

Most previous research on Atlantic sturgeon has focused on adult fish. These include studies

of habitat distribution, age and growth, and spawning behavior (Dovel and Berggren 1983; Kieffer and Kynard 1985; Young et al. 1988; Bemis and Kynard 1997; Boreman 1997). These studies have provided valuable insights into ecology and behavior of adults, information vital for assessments of adult abundance. However, population estimators such as mark-recapture are unlikely to be effective for estimating the population of spawning adults because of variable spawning periodicity (Van Eenennaam 1997), a protracted spawning season (Bain 1997; Van Eenennaam. 1997), and multiple spawning areas in large rivers (Bain 1997; Van Eenennaam. 1997). Consequently, assessment of juvenile abundance may be the only practical approach for collecting quantitative data on recruitment and relative year-class abundance. Data for assessing trends in Hudson River juvenile Atlantic sturgeon are available from trawl surveys of the Hudson River Estuary Monitoring Program (HREMP[1]), but these data have not been thoroughly analyzed to assess population trends.

Juvenile Atlantic sturgeon may reside in the Hudson River for as long as 5 years after birth, but there is some evidence of marine emigration as early as age-2 (Dovel and Berggren 1983). Therefore any assessment of juvenile abundance may need to focus on the age-1 cohort. Some means of assessing relative abundance and trends is needed to determine the effects of the recent moratorium on Atlantic sturgeon fisheries. The objectives of this study were (1) to evaluate recent trends in relative abundance of juvenile Atlantic sturgeon using data from HREMP trawl surveys, (2) to test the feasibility of conducting annual assessments of year-class abundance for juvenile Atlantic sturgeon in the Hudson River, and (3) to conduct a mark-recapture population estimate of age-1 juveniles within the Hudson River.

Methods

Trends in relative abundance of juvenile Atlantic sturgeon were determined using annual data

from the Fall Juvenile Survey of the HREMP. During this portion of the study a 3.0 m2 beam trawl was used to sample benthic juveniles of several riverine species. From 1985-1995 trawling was conducted biweekly over a 15-week period from mid summer to late fall. All samples were collected at night using a stratified random design to sample the tidal portion of the Hudson River from the George Washington Bridge (rkm 19.3) to the Troy Dam (rkm 245). The number of trawls conducted each year varied from 1,238 to 1,549 during the 10-yr period. Although age determinations were not attempted for any fish captured in trawl samples total lengths (TL) ranged from 102-1175 mm, (mean TL= 499 mm). Length frequency histograms for Hudson River Atlantic sturgeon (Dovel and Berggren 1983) indicate that only pre-emigrant juveniles were present in trawl samples. Using catch data from these surveys, we calculated an annual catch-per-unit-effort (CPUE) for juvenile Atlantic sturgeon from 1985-1995, to assess trend in juvenile abundance and recruitment.

In October 1994, 4,929 hatchery-reared Atlantic sturgeon from the U.S. Fish and Wildlife Service (USFWS) Lamar Fish Hatchery (Lamar, Pennsylvania) were stocked into the Hudson River by the New York Department of Conservation (NYDEC) just downstream of Storm King Mountain (rkm 89-90) (NYDEC 1994). The stocked fish were approximately 6-mo old with a mean total length (TL) of 103 mm (range 78-137 mm) (USFWS 1995). Left-pelvic fin clips and coded wire tags were applied to all stocked fish by personnel from the USFWS before the fish were shipped from the hatchery. The gill-net sampling program was initiated six months following the release of the hatchery fish. From May 31 to December 15, 1995, gill netting for juvenile Atlantic sturgeon was conducted at 57 randomly selected sites from the Tappan Zee Bridge (rkm 43) to Staatsburg (rkm 194), New York. This region of the river encompasses all known nursery habitat for age-1 and older Atlantic sturgeon juveniles within the Hudson River (Dovel and Berggren 1983; Haley 1996).

Collections of juvenile sturgeon were made once daily (5-7 d/week) using 5, 10, and 15-cm mesh (stretch) gill nets. The 91 X 3-m nets were set on the river bottom, perpendicular to shore

between mid-channel and the shoreline for an average of 40 min. Nets were deployed toward opposite shores on consecutive days to ensure equal effort throughout the width of the river channel. Sampling was conducted during daytime slack tides to minimize gear damage and to facilitate the capture and release of juvenile sturgeon without injury. Captured fish were immediately removed from the nets and placed into floating cages along side the research vessel. After all nets had been retrieved, each fish was weighed, measured (fork length (FL)) to the nearest mm, and inspected for fin clips and tags. All fish, including those of hatchery origin, were marked with passive integrated transponder (PIT) tags injected under the fourth dorsal scute, to identify individuals recaptured in subsequent sampling efforts. Recaptured juveniles, identified by their PIT tag, were measured, weighed and released, but were not included in subsequent estimates of the age-1 cohort. Data were recorded for each juvenile according to gill-net set and river location. All sturgeon were released within 1 hr of capture and no mortalities were observed during any aspect of capture, handling, or release.

Measures of fork length were used to construct length-frequency histograms for four consecutive intervals during the sampling period. The intervals we used, March-July, August, Sept, and October-December, were chosen to eliminate overlap of year-class modes within length-frequency histograms resulting from growth of juveniles during the sampling season. Construction of these seasonal length-frequency histograms enabled us to identify all individuals (both hatchery and wild) belonging to the age-1 cohort without collecting otoliths or spines, a practice that may increase mortality of following release. Once the length intervals for all age-1 juveniles were established, total numbers of age-1 hatchery and wild fish were determined from the gill-net catch data. Using the Peterson Mark-Recapture method with replacement (Baily 1952, Ricker 1975), the total number of juveniles comprising the age-1 cohort was estimated using captured hatchery fish as the marked portion of the population.

Results

Total annual catch from HREMP data confirmed reports of precipitous declines in the abundance of juvenile Atlantic sturgeon in the Hudson River. From 1985 to 1995 annual catch rates declined from a high of 184 fish (CPUE = 1.433 fish/hr) in 1986 to a low of 6 fish (CPUE = 0.058 fish/hr) in 1990. During this 10-yr period, the most dramatic decline occurred from 1988 to 1989 when CPUE decreased from 1.132 to 0.513 fish/hr. Since that time, catch rates of juvenile Atlantic sturgeon have remained at or near the lowest levels recorded over the 10-yr period.

During the six-month sampling period, 232 gill-net sets were made (78 sets with 5-cm mesh and 77 sets with 10-cm mesh, 77 with 15-cm mesh) yielding a total of 70 juvenile Atlantic sturgeon. Juveniles with fork lengths of 236-460 mm from March through July, 280-460 mm during the month of August, or 320-540 mm from September to mid-December were deemed to be age-1 fish (Figure 2).

Using these seasonal size criteria for age-1 fish, we determined that 29 of the captured juveniles were age-1 fish, 15 of which were of hatchery origin. Using the Peterson mark-recapture population estimator for sampling with replacement, we estimated the population size of wild age-1 Atlantic sturgeon to be 4,313 with a 95% confidence interval of 1,917-10,474. Because overwinter survival rates for stocked Atlantic sturgeon in the Hudson River are unknown, we assumed 100% post-stocking survival in order to attain the most liberal population estimate possible. The same procedure using a 90% overwinter survival rate would yield a population estimate of 3,882.

Although the mean river distribution of hatchery fish (rkm 110) was located approximately 20 km upstream from the that of wild fish (rkm 91), dates of capture and the ranges of their distributions were largely overlapping (Table 1). Mean fork length of hatchery fish (342) was slightly less than for wild fish (414), however this size difference was not significant (alpha=0.05).

Discussion

Our analysis of the HREMP data are consistent with NYDEC reports indicating recent declines in abundance of juvenile Atlantic sturgeon in the Hudson River. Although the lack of age-specific data precludes a detailed cohort analysis, the HREMP data suggest that recruitment failure since 1990 may be responsible. We estimated the population of the age-1 cohort at less than 5,000 in 1995. In, the mid 1970's Dovel and Berggren (1983) conducted similar population estimates for juvenile Atlantic sturgeon in the Hudson river. Compared with their estimate of about 25,000 juveniles in successive year classes from 1976 to 1978, our findings indicate that juvenile abundance has declined at least 80% during the last 20 years. The HREMP data and our population estimate of the 1995 age-1 cohort provide two independent lines of evidence supporting the conclusion that recruitment failure in recent years may limit recovery of Atlantic sturgeon in the Hudson River, despite the 1995 moratorium.

Several assumptions are required for use of the Peterson population estimator, however the most critical assumptions in our study were that (1) hatchery and wild fish were randomly mixed within the population (2) hatchery and wild fish were equally vulnerable to the sampling gear, and (3) age-1 fish could be distinguished from older juveniles. Atlantic sturgeon stocked in the Hudson were released 6 mo before sampling was initiated to allow ample time for random mixing with wild fish. Although hatchery fish were distributed slightly further upstream than their wild counterparts, the range of river kilometers where hatchery and wild fish were captured was similar and we found no evidence of spacial segregation between the two groups. Furthermore, sampling was conducted according to a stratified random design that ensured equal effort throughout the known range of juvenile distribution within the river. We had no way of comparing relative vulnerability of hatchery and wild fish to capture in our gill nets. Although we used 5, 10, and 15-cm mesh gill nets to minimize the potential for a size-selective gear bias, hatchery fish were, on

average, slightly smaller than wild fish. Despite this size difference, both hatchery and wild fish were captured in the same gill-net set on several occasions, suggesting that size-selective gear bias was most likely not a significant factor in this study.

Without collecting pectoral fin rays or otoliths from many of the wild fish captured, age determinations based on length-frequency histograms can not be verified. Nonetheless, the age-1 cohort appeared to comprise a distinct mode, clearly discernable from older cohorts, within the length-frequency histograms. Furthermore, the length criteria we used to identify wild age-1 juveniles were consistent with those established by Dovel and Berggren (1983), who did use pectoral fin rays to determine ages of juvenile Atlantic sturgeon, also collected from Hudson River.

Although declines in Atlantic sturgeon are widely recognized accurate assessments of sturgeon populations are not available and there are no methods to monitor population responses to fishery restrictions or moratoria. Methods that can at least assess population trends are needed to evaluate management regulations and to determine when an end to any fishery moratorium can be determined. Despite low catch rates of juveniles in the HREMP trawl surveys, we believe that annual surveys of juvenile abundance may be feasible if areas of juvenile concentration (nursery habitats) can be identified and effective sampling methods can be developed for these regions of the Hudson River. Presently, the development of this type of monitoring program is the only plausible means of acquiring the biological data that will be vital for future management decisions regarding Atlantic sturgeon fisheries of the Hudson River and other fisheries along the Atlantic coast. Further studies of juvenile Atlantic sturgeon are needed to identify cost-effective sampling methods, to locate juvenile nursery habitats, and to determine how variable environmental factors may influence early survival and recruitment

References

Atlantic States Marine Fisheries Commission. 1996. ASMFC recommends two-rear moratorium for Atlantic sturgeon. News Release March 20, 1996, Washington, DC.

Baily, N. T. J. 1952. Improvements in the interpretation of recapture data. Journal of Animal Ecology 21:120-127

Bain, M. B. 1997. Atlantic and shortnose sturgeons of the Hudson River: common and divergent life history attributes. Environmental Biology of Fishes 48:347-358.

Bemis, W. E. and B. Kynard. 1997. Sturgeon rivers: and introduction to acipenseriform biogeography and life history. Environmental Biology of Fishes 48:167-183.

Boreman, J. 1997. Sensitivity of North American sturgeons and paddlefish to fishing mortality. Environmental Biology of Fishes 48:399-405.

Dovel, W. L. 1981. The biology and management of shortnose and Atlantic sturgeon of the Hudson River. Final Report AFS9-R to the New York State Department of Environmental Conservation, Albany, NY.

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.

Haley, N., J. Boreman, and M. Bain. 1996. Juvenile sturgeon habitat use in the Hudson River. Section VIII: 39 pp, *in* J. R. Waldman and E. A. Blair, editors. Final Reports of the Tibor T. Polgar Fellowship Program, 1995. Hudson River Foundation, New York, New York.

Kieffer, M. and B. Kynard. 1993. Annual movements of shortnose and Atlantic sturgeon in the Merrimack River, Massachusetts. Transactions of the American Fisheries Society, 122:1088-1103.

Murawski, S. A., and A. L. Pacheco, 1977. Biological and fisheries data on Allantoic sturgeon, *Acipenser oxyrhynchus* (Mitchill). Technical Series Report 10, National Marine Fisheries Service.

New York Department of Environmental Conservation. 1995. Atlantic sturgeon management in New York State. NYDEC Discussion Document. Stony Brook, NY.

New York Department of Environmental Conservation. 1996. New York Department of Environmental Conservation announces emergency moratorium on Atlantic sturgeon fishing. New York State Department of Environmental Conservation, Press Release of 20 March, Albany, NY.

Ricker, W. E 1975 Computation and interpretation of biological statistics of fish populations. Bulletin 191 of the Fisheries Research Board of Canada.

Smith, T. I. J. and J. P. Clugston. 1997. Status and management of Atlantic sturgeon, *Acipenser oxyrinchus*, in North America. Environmental Biology of Fishes 48:335-346.

U.S. Fish and Wildlife Service. 1995. 1995 Biological Activities Report, Northeast Fishery Center, Lamar, Pennsylvania.

Van Eenennaam, J. P., S. I. Doroshov, G. P. Moberg, J. W. Watson, D. S. Moore, and J. Linares. 1996. Reproductive Condition of the Atlantic sturgeon (*Acipenser oxyrinchus*) in the Hudson River. Estuaries 19:769-777.

Young, J. R., T. B. Hoff, W. P. Dey, and J. G. Hoff. 1988. Management recommendations for Hudson River Atlantic sturgeon fishery based on an age-structured population model. Pages 353-365 *in* C. L. Smith, editor. Fisheries Research in the Hudson River. The Hudson River Environmental Society, Albany, New York.

Footnote

1. The Hudson River Estuary Monitoring Program was established in 1973 by a consortium of electric utilities to monitor distributions and abundances of striped bass, white perch and several other species of economic importance to Hudson River fisheries (not including sturgeon). Detailed descriptions of the objectives and methods of the program may be obtained from annual reports available from the Consolidated Edison Company of New York, Inc. (4 Irving Pl., New York, NY 10003).

Figure 1. Trends in abundance of juvenile Atlantic sturgeon within the Hudson River from 1985 to 1995. Catch per unit effort (CPUE) was determined from the Juvenile Trawl Survey of the Hudson River Estuary Monitoring Program.

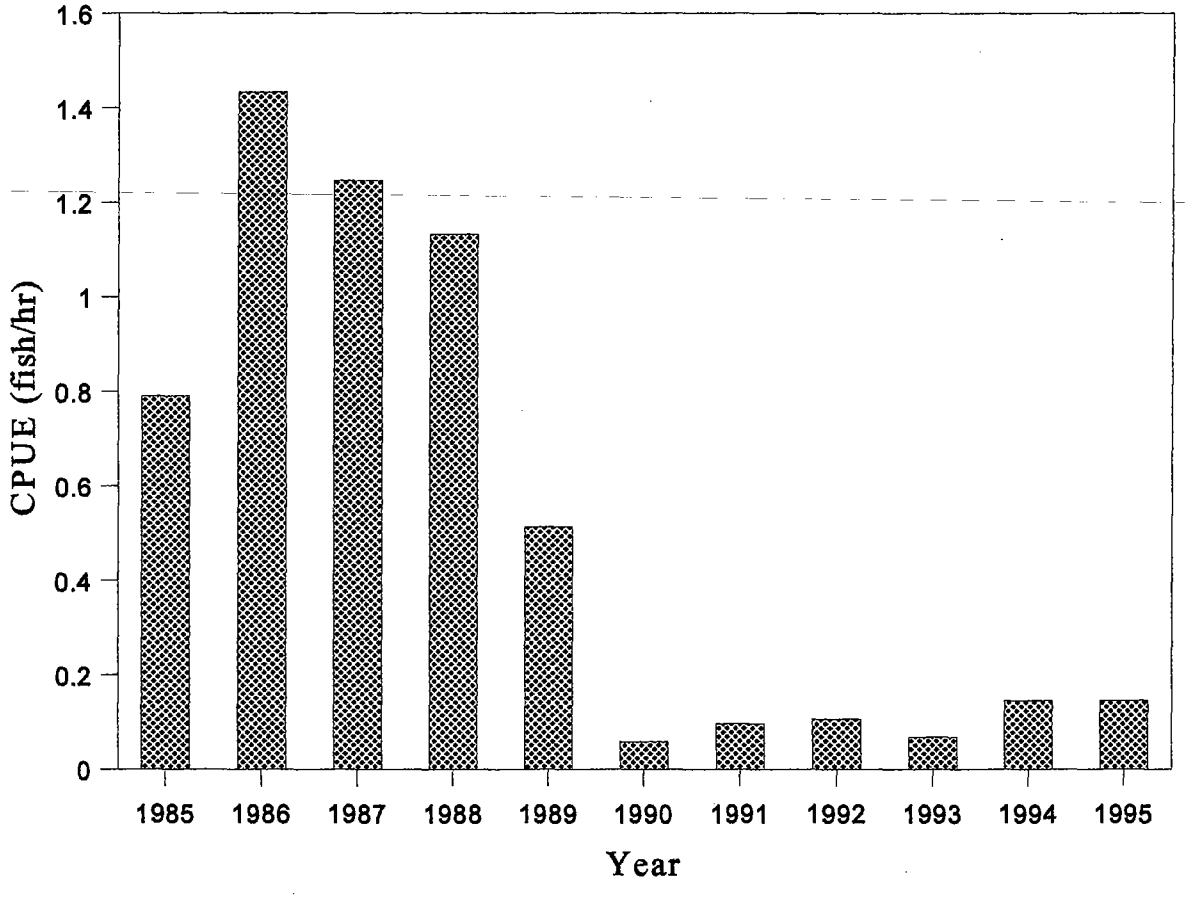
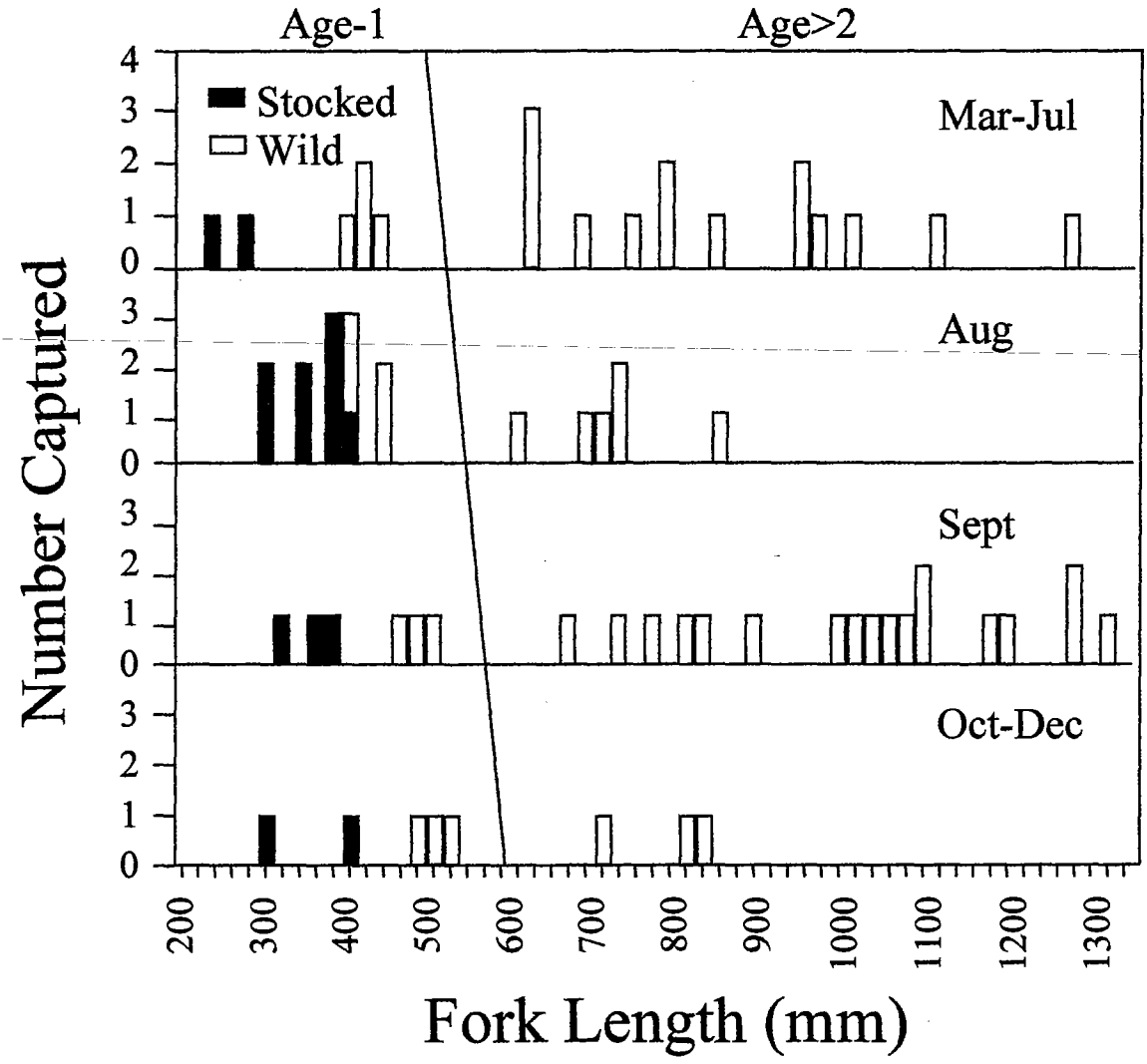


Table 1. Comparison of total catch, distribution by river-kilometer (rkm), date of captures, and fork lengths (mm) of age-1 hatchery and wild Atlantic sturgeon from the Hudson River, 1995.

	Stocked Fish	Wild Fish
Total Catch	15	14
Date of Capture	June 20 to October 26	July 18 to August 28
Distribution (rkm)		
Mean	110	91
Range	62-144	65-110
Fork Length (mm)		
Mean	342	414
Range	267-385	382-450

Figure 2. Seasonal length-frequency histograms of juvenile Atlantic sturgeon collected from the Hudson River, 1995.



Morphological Variation Among Shortnose Sturgeon From The Hudson Rivers And Rivers In Maine

The shortnose sturgeon is a small, amphidromous sturgeon (family Acipenseridae) species that occupies freshwater and estuarine portions of rivers along the east coast of North America from New Brunswick to Florida (Vladykov and Greeley 1963, Dadswell et al. 1984). The basic body form of today's sturgeon, which includes a unique blend of primitive and derived characters, was established by end of the Cretaceous (Bemis 1997). While important in an evolutionary context, the unusual appearance, economic value, and life history of sturgeon has attracted public and government agency interest in preserving these fishes for aesthetic, ecological, and pragmatic reasons.

Shortnose sturgeon were commercially fished along with Atlantic sturgeon in the late 1800's, but a combination of overfishing and habitat destruction caused populations to crash by the early 1900's (NMFS 1996, NOAA 1996). As a result, shortnose sturgeon have been federally protected since the inception of the U.S. Endangered Species Act (ESA) in 1973. Shortnose sturgeon are long-lived and do not reach sexual maturity until ages 7-10 (Dadswell et al. 1984), leaving them vulnerable overexploitation. Limited abundance and recruitment, combined with complicated migratory and spawning behavior (Bain 1997) have made the study and recovery of this species difficult.

Decreased population size has limited the range of shortnose sturgeon to isolated river and estuary systems along the east coast (Dadswell et al. 1984). The National Marine Fisheries Service (NMFS), the federal agency responsible for the protection and recovery of shortnose sturgeon, considers each of the seventeen remaining populations distinct under the definition of "species" (NMFS 1996). Two such habitats supporting shortnose sturgeon are located in the Hudson River Estuary, New York, and the Kennebec Estuarine Complex, Maine. Both areas

have been targeted for research on shortnose sturgeon due to the relatively large size of the populations; at least 38,000 adult fish were present in the Hudson River in 1995 (Bain et al. 1995), and 5,000-10,800 (95% confidence interval) were estimated to occupy the Kennebec Estuarine Complex (lower portions of the Kennebec and Androscoggin Rivers) in the early 1980's (Dadswell et al. 1984).

Measurement of morphological characters has been widely applied in the systematics and classification of fish, and research of this type has identified significant variation between and within species of Acipenseridae. Morphometric variation has been used to distinguish between similar sturgeon species and detect hybrids (Carlson et al. 1985, Keenlyne et al. 1994). Significant differences in morphology have been documented between disjunct populations of some sturgeon species (Keenlyne et al. 1994, Guenette et al. 1992), and differences have also been reported between wild and hatchery-reared sturgeon (Ruban and Sokolov 1986, Ruban 1990). However, no morphometric and meristic differentiation between populations of shortnose sturgeon inhabiting different rivers has been reported.

Dadswell et al. (1984) briefly addresses geographic separation in their extensive compilation of biological data on shortnose sturgeon. In particular, the authors note that the extent to which geographic separation may have affected populations of shortnose sturgeon had not been studied. Since then, many studies have been conducted on the abundance, distribution, and life history attributes of the shortnose sturgeon, but analyses of either morphological or genetic variation among populations of this species has not been attempted. Though the NMFS considers each population as a separate entity, they note that, "available genetic and morphometric data do not support any taxonomic splitting of the species" (NMFS 1996).

Questions regarding the differentiation among populations of shortnose sturgeon were raised in 1994 by a petition to remove the shortnose sturgeon in the Kennebec Estuarine Complex from the endangered species list (NOAA 1996). Biological and ecological characteristics of shortnose sturgeon in this area were reviewed by NMFS and it was determined that the species was still in

jeopardy (NOAA 1996). Thus the petition was denied because full protection under the ESA was determined to be required for recovery of this population. One issue that was important in the NOAA decision was the possibility that the Kennebec Estuarine Complex may support two river-specific populations (Kennebec and Androscoggin Rivers).

The purpose of this study was to compare morphological and meristic attributes between the shortnose sturgeon collected in the Kennebec, Androscoggin, and Hudson Rivers. The possibility of variation between populations has important ramifications for the ecology and management of this species. Understanding the degrees of differentiation among these populations will hopefully further our understanding of shortnose sturgeon and lead to new perspectives on the species' recovery.

Methods

Morphometric and meristic data from shortnose sturgeon captured in the Kennebec and Androscoggin rivers were collected between 1980 and 1981 by Thomas Squiers of the Maine Department of Marine Resources (MDMR). The Kennebec, Androscoggin, and Sheepscot Rivers form a complicated estuarine system on the coast of Maine. A shortnose sturgeon spawning sites is located below the Augusta Dam on the Kennebec River, and another spawning site is located below the Brunswick Dam on the Androscoggin River (NMFS 1996). These two large rivers and some smaller ones are tributaries to a series of brackish water bays and channels sometimes called the Kennebec Estuarine Complex.

Twenty-four shortnose sturgeon were captured from the Kennebec River and 267 shortnose sturgeon were captured from five sites on the Androscoggin River. Experimental gillnets with stretch mesh sizes ranging from 152 mm to 203 mm were set overnight and left in the water for approximately 20-24 hours. Six morphometric and five meristic characters were measured according to terms outlined in Vladykov and Greeley (1963): total length (TL), fork length (FL),

head length (HL; anterior tip of snout to the rearmost point of the opercle excluding the opercular membrane), snout length (SNL; anterior tip of snout to the anterior margin of the orbit with the membranous rim excluded), mouth width (MW; greatest transverse distance across the mouth slit with the lips excluded and mouth closed), interorbital width (IOW; maximum distance across top of head between the bony edges of the orbit), dorsal scute count (DSC), left lateral scute count (LLSC), right lateral scute count (RLSC), left ventral scute count (LVSC), and right ventral scute count (RVSC).

Shortnose sturgeon in the Hudson River range from the brackish waters of the lower estuary near New York City to the Troy Dam near Albany, New York (Bain 1997). For this study, sturgeon were collected at Esopus Meadows (river kilometer [RKM] 140) near Kingston, New York; a known overwintering site for most or all shortnose sturgeon in this river (Dovel et al. 1992). Monofilament gill nets (152-mm stretch) were set during slack tide for approximately 30 minutes. A total of 68 shortnose sturgeon were collected from the Hudson River in 1966, and all fish were returned to the river unharmed after the measurements were completed.

Data on the 11 morphological characters of shortnose sturgeon captured in the Androscoggin, Kennebec, and Hudson Rivers were compiled and descriptive statistics generated for each character. Pearson product-moment correlations were computed between fork length and all other morphological and meristic characters to identify those that varied by fish length. For characters related to length, multivariate analysis of covariance (MANCOVA) and analyses of covariance (ANCOVA) were used to determine significant differences among river fish groups using fork length as the covariate to adjust for size. Multivariate analysis of variance (MANOVA) and analyses of variance (ANOVA) were used to test for significant variation among the three river groups when characters were not related to fish size. For all cases where ANCOVA and ANOVA tests had a significant results (main effects, $P<0.05$), least significant difference post-hoc tests were used to identify pairwise differences among rivers.

Results

Shortnose sturgeon captured in the Kennebec River were the longest (mean total length = 910 mm; Table 1) of the three sample groups, with the Hudson River fish were the shortest (mean length = 784 mm). The differences among rivers in fish size (fork length) were significant (ANOVA, $F_{2,356}$=22.22, P≤0.0001) and each river was distinct from the others in post-hoc tests (P≤0.028 in all pairwise comparisons). All shortnose sturgeon measured in this study were larger than 616 mm total length and by established size and age criteria (reviewed in Bain 1997) all the sturgeon would easily fall into the adult life stage. Thus, the measurements were made on fish likely to range in age from about one to as many as six decades of age.

Like length differences among river groups, mean values (Table 1) for the four morphometric characters (head length, snout length, mouth width, interorbital width) were the largest for the Kennebec River population, followed by the Androscoggin River. The morphometric characters were mostly well correlated with fork length (8 of 12 correlation coefficients ≥0.80, range = 0.41 - 0.96), so further analyses of morphometric characters were adjusted by fork length. Meristic characters (4 scute counts; table 1) were similar among shortnose sturgeon from the three rivers, but these characters were not related to fish size (10 of 12 fork length correlation coefficients <0.20, range -0.18 - 0.29). Consequently, further analyses of the meristic character differences among rivers did not employ adjustments for fish size.

Overall, the morphological characters reflected significant differences in fish shape among the three rivers (MANCOVA, P≤0.0001, Table 2). Each of the four individual morphometric characters also differed among rivers (ANCOVA, P≤0.0001, Table 2). For three of the characters (head length, snout length, mouth width), the two Maine rivers did not appear different and the Hudson was distinct (Table 2). This pattern was the same as that seen in Figure 1 where head length is plotted against fork length by river group. The head length versus fork length relations (Figure 1) for the Androscoggin and Kennebec Rivers were very nearly the same in position and

slope, while the Hudson relation appears the same in slope but lower in scale (consistently smaller in dimensions at all sizes). Interorbital width differences among rivers did not maintain this pattern. The Androscoggin River was distinct from the Kennebec and Hudson Rivers (Table 2), but the plot of interorbital width and fork length suggests inconsistency in the slopes. This indicates the statistical results should be interpreted cautiously for this character.

The five scute counts (Dorsal, lateral and ventral, left and right sides of the fish) indicated significant meristic character differences among shortnose sturgeon collected in the three rivers (MANCOVA, $P \geq 0.0001$, Table 2). The two ventral scute counts did not differ among the rivers (ANOVA, $P \leq 0.8012$, Table 2) but the dorsal scute counts clearly varied among rivers ($P \leq 0.0001$, Figure 2). The Hudson River was distinct in terms of dorsal scute counts with the highest mean value (Table 2). The lateral scute counts varied among rivers ($p \leq 0.0051$) but the specific between river comparisons were mixed (indicated in Table 2). For the right lateral counts, the two Maine rivers appeared different ($P=0.0184$, Figure 2) and the Kennebec and Hudson sturgeon were similar ($P=0.5261$). In the case of left lateral scute counts, the two Maine rivers appeared marginally different ($P=0.0698$, not indicate as different with boxes in Table 2) but the Androscoggin and Hudson River groups of sturgeon were distinct ($P=0.0043$, Figure 2). A relatively high variance in lateral scute counts for the Kennebec River (Figure 2) largely explains these between river differences. In general, the scute counts distinguish shortnose sturgeon from the Hudson River from the two Maine rivers, and the lateral scute counts indicate that all three river fish groups may be distinct.

Discussion

While the Hudson River population of shortnose sturgeon differed markedly from the other two river groups for most morphological characters, significant differences were still suggested between fish from the Androscoggin and Kennebec rivers for at least one morphometric

(interorbital width) and one set of meristic characters (lateral scute counts). Our analyses provide some evidence for considering the two Maine rivers as having unique populations. However, the lack of clear and persistent character differentiation, as seen with the Hudson River fish, raises the question of what degree of morphological variation between populations justifies their treatment as separate management units.

Although shortnose sturgeon are now endangered, they were likely once abundant in all large river systems along the east coast of North America. It is possible these larger populations commingled through marine emigration because marine captures have been reported on rare occasions in many locations along the Atlantic coast (reviewed in Dadswell et al. 1984). Recently, a shortnose sturgeon tagged in the Hudson River as an adult in 1995 was recaptured in the Connecticut River in 1997 (T. Savoy, Connecticut Department of Marine Resources, personal communication). Kynard (1997) associates the presence of marine captures of shortnose sturgeon to exchange of individuals among separate river populations. He also links population size to the frequency of marine emigration, hypothesizing that emigration by shortnose sturgeon is density regulated. Therefore, as the number of shortnose sturgeon greatly decreased early in this century, this species may have become isolated into small, river-restricted populations. Today the few relatively large populations, such as in the Hudson and Kennebec Rivers, would be the most likely populations contributing individuals to populations in other rivers.

Morphological differences observed in this study do not strongly support the theory that fish from different rivers have continued gene flow due to exchanges of fish. Analyses of both morphometric and meristic data clearly indicate intraspecific morphological variation between shortnose sturgeon of the New York and Maine rivers. One explanation for differences in morphology is that it is a product of genetic divergence alone -- if populations are geographically isolated, gene flow between the two areas is prevented, so genetic divergence is inevitable (Barlow 1961). An alternative argument is that environmental influences can produce significant morphological variation in sturgeon. White and Turner (1986) documented how genetic variation

between isolated populations may be no more than the variability inherent within one population, and that the effects of locality had more influence on morphology than genetics. Induced morphological changes from experimental manipulations of the environment have also raised questions about the relative influence of genetics (Wimberger 1992; Bronmark and Miner 1992).

Lack of evidence for gene flow between populations would suggest that ecological differences between the two estuaries primarily influences morphology of its sturgeon inhabitants. Environmental conditions and growth rates during larval development have been shown to affect the relative sizes of body parts and the development of serial features (Martin 1949). Guenette et al. (1992) suggests that differences in growth rate between separated sturgeon populations of could result in differing head proportions. Likewise, meristic features have been observed to vary with developmental rate in sturgeon and other fishes (Martin 1949; Stouracova et al. 1988; Ruban 1990). When growth is retarded during larval development, such as in cases of low temperature, serial characteristics are allowed more time to form, resulting in a higher number (Martin 1949). While this trend has been primarily studied for characters such as fin rays and vertebrae, Ruban and Sokolov (1986) suggested that the same pattern is likely applicable to sturgeon scutes. Whether the variation we document is a result of genetic drift or divergence and selection due to ecological differences between the rivers cannot be resolved without additional study.

Casselman et al. (1981) argues that spatially separated populations with varying degrees of differentiation should be managed separately to preserve the integrity of each population. However, it was recommended that lake sturgeon in the St. Lawrence system be managed as one integrated unit despite significant differences (Guenette et al. 1992). Intraspecific variation, whether genetic or morphological, must be interpreted in conjunction with each specific species and management environment, and particular consideration of possible ramifications must be given in the case of an endangered species, such as the shortnose sturgeon. Quattro et al. (1996) stress the need to understand the historical and evolutionary connections between extant populations of endangered species, and also recommend the use of a variety of biological information when

making management decisions. Variation observed in this study combined with current knowledge about the life history attributes of shortnose sturgeon indicate that conservative decision making is necessary. Possibly distinct genetic lines of shortnose sturgeon should be protected to the fullest extent until further morphological and genetic studies on shortnose sturgeon populations can be completed to determine the extent and meaning of morphological differentiation among populations.

Literature Cited

Bain, M. B. 1997. Atlantic and shortnose sturgeon of the Hudson River: common and divergent life history attributes. Environmental Biology of Fishes 48:347-358.

Bain, M. B., S. Nack, and J. G. Knight. 1995. Population status of shortnose sturgeon in the hudson river; sampling success and feasibility of population estimation. Report to the U.S. Army Corps of Engineers by the New York Cooperative Fish and Wildlife Research Unit, Cornell University, Ithaca, New York.

Barlow, G. W. 1961. Causes and significance of morphological variation in fishes. Systematic Zoology 10:105-116.

Bemis, W. E., E. K. Findeis, and L. Grande. 1997. An overview of Acipenseriformes. Environmental Biology of Fishes 48:25-71.

Bronmark, C. and J. G. Miner. 1992. Predator-induced phenotypic change in body morphology in crucian carp. Science 258:1348-1350.

Carlson, D. M., W. L. Pflieger, L. Trial, and P. S. Haverland. 1985. Distribution, biology, and hybridization of Scaphirhynchus albus and S. platorhynchus in the Missouri and Mississippi Rivers. Environmental Biology of Fishes 14:51-59.

Casselman, J. M., J. J. Collins, E. J. Crossman, P.E. Ihssen, and G. R. Spangler. 1981. Lake whitefish (Coregonus clupeaformis) stocks of the Ontario waters of Lake Huron.

Canadian Journal of Fisheries and Aquatic Sciences 38:1772-1789.

Dadswell, M. J., B. D. Taubert, T. S. Squiers, D. Marquette, and J. Buckley. 1984. Synopsis of biological data on the shortnose sturgeon, Acipenser brevirostrum LeSueur 1818. NOAA Technical Report NMFS 14, National Marine Fisheries Service, Washington, D. C.

Dovel, W. L., A. W. Pekovitch, and T. J. Berggren. 1992. Biology of the shortnose sturgeon (Acipenser brevirostrum LeSeuer 1818) in the Hudson River estuary, New York. New York Fish and Game Journal 30:140-172.

Guenette, S., E. Rassart, and R. Fortin. 1992. Morphological differentiation of lake sturgeon (Acipenser fulvescens) from the St. Lawrence River and Lac des Deux Montagnes (Quebec, Canada). Canadian Journal of Fisheries and Aquatic Sciences 49:1959-1965.

Keenlyne, K. D., C. J. Henry, A. Tews, and P. Clancey. 1994. Morphometric comparisons of upper Missouri River sturgeons. Transactions of the American Fisheries Society 123:779-785.

Kynard, B. 1997. Life history, latitudinal patterns, and status of shortnose sturgeon, Acipenser brevirostrum. Environmental Biology of Fishes 48:319-334.

Martin, W. R. 1949. The mechanics of environmental control of body form in fishes. Publication of the Ontario Fisheries Research Laboratory. 76 pp.

NMFS (National Marine Fisheries Service). 1996. Status Review of Shortnose sturgeon in the Androscoggin and Kennebec Rivers. Northeast Regional Office, National Marine Fisheries Service, Gloucester, MA.

NOAA (National Oceanic and Atmospheric Administration). 1996. Listing threatened and endangered species: shortnose sturgeon in the Kennebec and Androscoggin River, ME. Federal Register 61(201):53893-53896.

Ruban, G. I. 1989. Clinal variation of morphological characters in the Siberian sturgeon, Acipenser baeri, of the Lena basin. Journal of Ichthyology 29:48-55.

Ruban, G. I. and L. I. Sokolov. 1986. Morphological variability of Siberian sturgeon (Acipenser

baeri), in the Lena River in relation with its culture in warm waters. Journal of Ichthyology 26:88-93.

Stouracova, I., M. Penaz, J. Kouril, andd J. Hamackova. 1988. Influence of water temperature on some meristic counts in carp. Folia Zoologica 37:375-382.

Quattro, J. M., P. L. Leberg, M. E. Douglas, and R. C. Vrijenhoek. Molecular evidence for a unique evolutionary lineage of endangered Sonoran Desert fish (Genus Poeciliopsis). Conservation Biology 10:128-135.

Vladykov, V. D. and J. R. Greeley. 1963. Order Acipenseroidei, p. 24-60 in Fishes of the western North Atlantic, Part III. (Yngre H. Olsen, ed). Memoir Sears Foundation for Marine Research, No. 1.

White, M. M. and B. J. Turner. 1986. Geographic isolation, gene flow and population differentiation in Goodea atripinnis (Pisces: Goodeidae). Genetica 69:157-160.

Wimberger, P. H. 1992. Plasticity of fish body shape: the effects of diet, development, family and age in two species of Geophagus (Pisces: Cichlidae). Biological Journal of the Linnean Society 45:197-218.

Table 1. Body measurements (mm) and mersitic counts for three populations of shortnose sturgeon with the mean values and the 95% confidence intervals (CI) of the means.

	Androscoggin River		Kennebec River		Hudson River	
Measurement	Range	Mean ± CI	Range	Mean ± CI	Range	Mean ± CI
Total length	616 - 1085	807 ± 10.5	673 - 1165	910 ± 49.4	634 - 962	784 ± 16.4
Fork length	525 - 962	705 ± 9.9	585 - 1030	808 ± 45.6	548 - 895	680 ± 15.8
Head length	124 - 206	157 ± 2.0	136 - 225	176 ± 8.8	119 - 176	145 ± 12.7
Snout length	47 - 82	63 ± 0.8	56 - 81	67 ± 2.4	37 - 76	58 ± 1.5
Mouth width	28 - 63	40 ± 0.7	32 - 63	48 ± 3.3	22 - 42	35 ± 0.9
Interorbital width	38 - 71	52 ± 0.8	43 - 81	61 ± 4.3	44 - 65	52 ± 1.2
Dorsal scute count	6.0 - 16.0	10.1 ± 0.8	8.0 - 11.0	9.9 ± 0.3	9.0 - 15.0	11.3 ± 1.2
Left lateral scute count	20.0 - 39.0	26.6 ± 0.3	22.0 - 31.0	27.5 ± 0.9	23.0 - 33.0	27.5 ± 0.5
Right lateral scute count	21.0 - 39.0	26.6 ± 0.3	23.0 - 33.0	27.8 ± 0.9	23.0 - 33.0	27.5 ± 0.6
Left ventral scute count	5.0 - 14.0	8.1 ± 0.1	6.0 - 10.0	8.0 ± 0.4	7.0 - 10.0	8.1 ± 0.2
Right ventral scute count	6.0 - 13.0	8.1 ± 0.1	7.0 - 10.0	8.0 ± 0.3	6.0 - 10.0	8.1 ± 0.2

Table 2. Statistical results of tests for differences in morphological and meristic characters among shortnose sturgeon collected in the three study rivers. Multivariate analyses of covariance and variance were used for tests involving groups of characters, analyses of covariance and variance were used for single characters, and the least significant difference post-hoc tests were used to identify specific differences between rivers in univariate cases.

	Degrees of Freedom				Means and adjusted means[1] by river with boxes enclosing values that were were not different in post-hoc tests		
	Main effect	Error	Test statistic[2]	Probability level	Andro-scoggin	Kennebec	Hudson
Morphological characters	8	704	0.65	≤0.0001			
Head length	2	355	26.72	≤0.0001	158	159	150
Snout length	2	355	25.53	≤0.0001	63	64	59
Mouth width	2	355	43.53	≤0.0001	41	42	37
Interorbital width	2	355	9.84	≤0.0001	52	54	54
Meristic characters	10	704	0.84	≤0.0001			
Dorsal scute count	2	356	26.99	≤0.0001	10.1	9.9	11.3
Left lateral scute count	2	356	5.17	0.0061	26.6	27.5	27.5
Right lateral scute count	2	356	5.35	0.0051	26.6	27.8	27.5
Left ventral scute count	2	356	0.22	0.8012	8.1	8.0	8.1
Right ventral scute count	2	356	0.08	0.9272	8.1	8.0	8.1

1. Adjusted means are reported for univariate morphological characters because the absolute values were related to fish lengths. The adjustment removes length differences among rivers and it was the same adjustment used in the analysis of covariance tests.
2. The test statistic for multivariate tests were the Wilks Lambda criteria, and an F-ratio is reported for univariate tests.

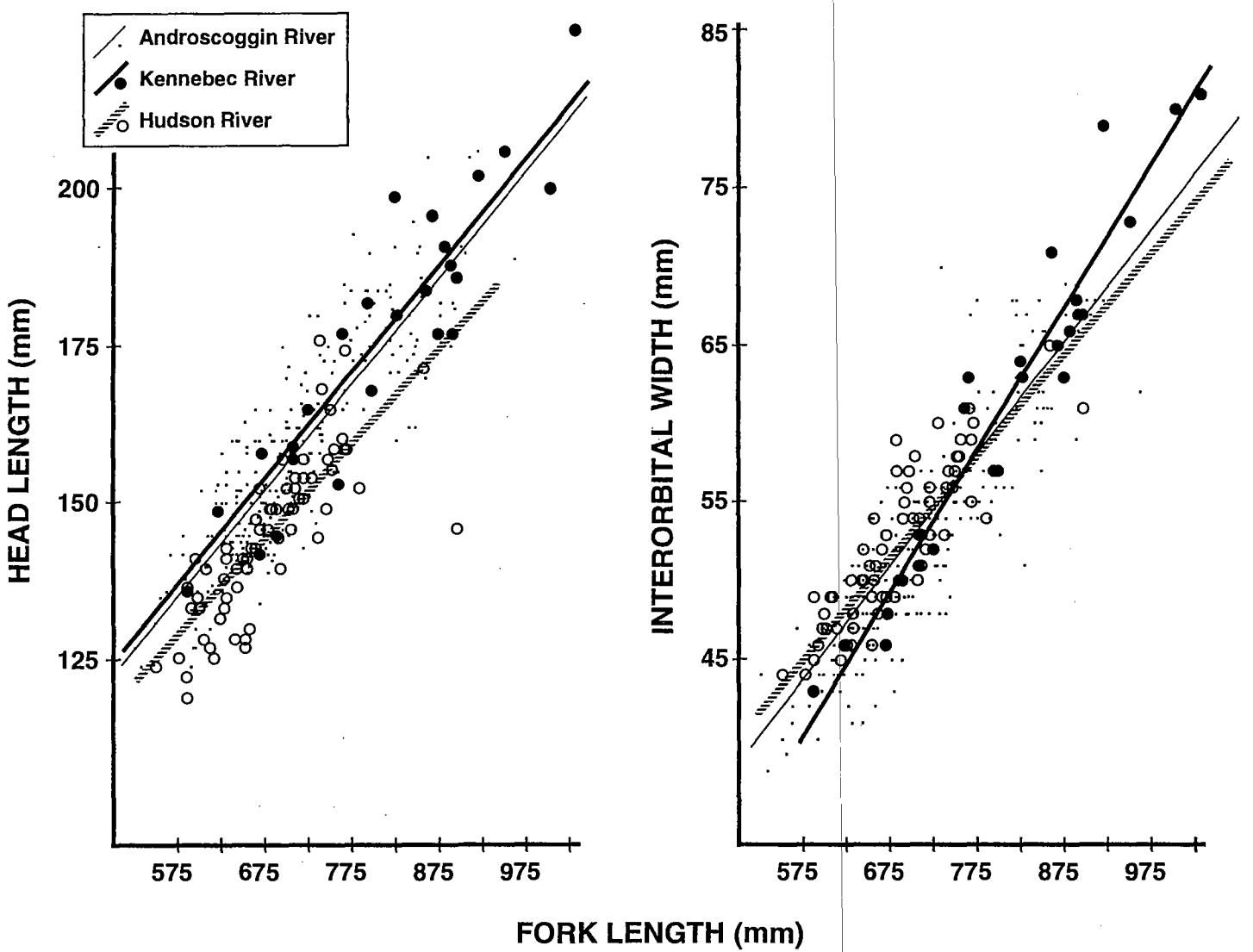


Figure 1. Head length and interorbital width versus fork length relations for shortnose sturgeon collected by study river. The pattern of measurement and size relations and among river differences shown for head length was very similar to the patterns found for snout length and mouth width. Interorbital width changes by fish size were inconsistent among rivers suggesting that ANCOVA test results should be interpreted with caution.

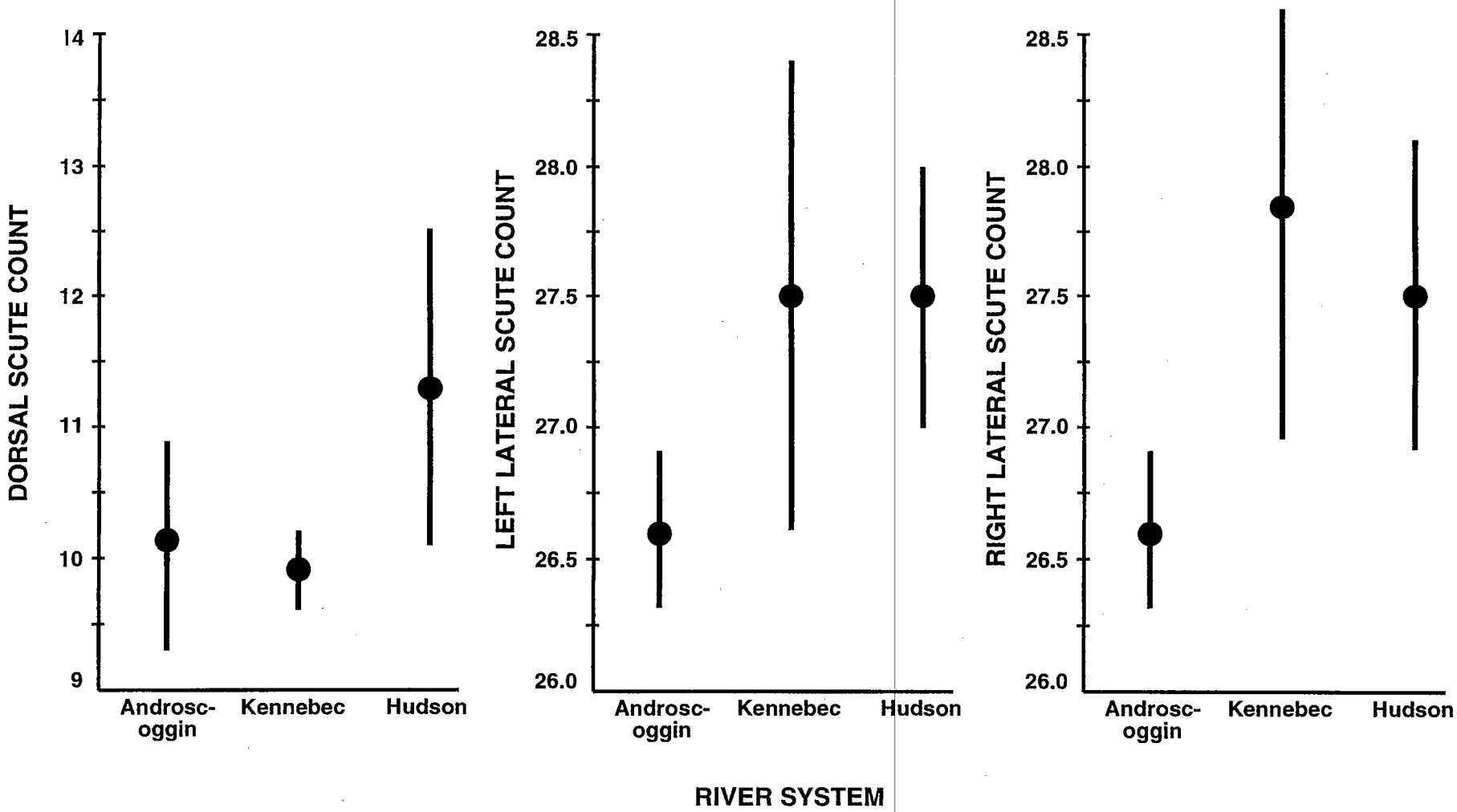


Figure 2. Select results of scute count differences among rivers. Means are plotted as filled circles with lines corresponding to the 95% confidence intervals for the means.