Final Report

Status of Shortnose Sturgeon in the Potomac River

PART I – FIELD STUDIES

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Gravid shortnose sturgeon female captured at river kilometer 63 on the Potomac River. Project leader, Matthew Breece (USGS), is shown with the fish on March 23, 2006.

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Summary

Field studies during more than 3 years (March 2004–July 2007) collected data on life history of Potomac River shortnose sturgeon *Acipenser brevirostrum* to understand their biological status in the river. We sampled intensively for adults using gill nets, but captured only one adult in 2005. Another adult was captured in 2006 by a commercial fisher. Both fish were females with excellent body and fin condition, both had mature eggs, and both were telemetry-tagged to track their movements. The lack of capturing adults, even when intensive netting was guided by movements of tracked fish, indicated abundance of the species was less than in any river known with a sustaining population of the species. Telemetry tracking of the two females (one during September 2005–July 2007, one during March 2006–February 2007) found they remained in the river for all the year, not for just a few months like sturgeons on a coastal migration. Further, one fish used the same freshwater reach during three summers. The two sturgeons used different reaches during some seasons, with one fish using saline water more than the other. The adults homed to small reaches in the same month each year, like shortnose sturgeon in their natal river. The total reach used by tracked sturgeons was 124 km (rkm 63–187), of which the lowermost 78 km, which was used for summering and wintering, contained the freshwater: saltwater interface. The most upstream reach used (rkm 185–187) contained potential spawning habitat. This reach was visited by one female on a pre-spawning migration in April 2006, but spawning was likely unsuccessful. Water quality (dissolved oxygen and temperature) in the summering–wintering reach was adequate all the year, although during the summer it was minimally acceptable. We periodically recaptured the same tagged female and found she healed well after tagging, appeared healthy in body and fins, grew well, and rapidly matured a new clutch of eggs. All surveys indicated adults had sufficient habitat and water quality needed to complete their life history. While we studied only two adults, all data strongly suggests shortnose sturgeons are a permanent resident of the Potomac River diadromous fish community. Life-history movements of the Potomac River adults were similar to adults in north-central rivers, like the Delaware River, not to adults in southern rivers. We did not identify a unique life history behavior that separated Potomac River adults from other populations. Life history data indicates Potomac River shortnose sturgeons are most likely remnants of the natal population or colonizers from a north-central river, like the Delaware River.

Background

Populations of shortnose sturgeon *Acipenser brevirostrum* likely existed in all major Atlantic coast rivers between northern Florida and Canada (Kynard 1997), but scientific evidence for a natal population in many rivers, like the Potomac River, is poor. Four documents between 1876 and 1929 state that shortnose sturgeon inhabited the Potomac River. However, the only specimen of the species from the Potomac River that remains today was collected by J. W. Milner, who collected it at Washington, D.C on 19 March 1876. The lateral scutes and some skin are archived at the Smithsonian Institute. Based on this evidence, Uhler and Lugger (1876) included shortnose sturgeon in their list of Maryland fishes and state that the species was present in the Potomac River. Smith and Bean (1898) also included shortnose sturgeon in their list of fishes that inhabited the waters of Washington, D.C. and vicinity (the upper Potomac and Patuxent Rivers). Their list of fishes was mostly based on collections of the U.S. Fish Commission (Ryder 1890) and collections at the U.S. National Museum. As far as we can determine, these collections did not contain any shortnose sturgeon. McAtee and Weed (1915) sampled the Potomac River mainstem in the area of Plummers Island (between Little Falls and Great Falls, but collected no sturgeons and stated that sturgeons did not occur in the river above Little Falls. They mentioned two types of sturgeons inhabited the Potomac River: a small species, the shortnose sturgeon, and a large species, the Atlantic sturgeon *A. oxyrinchus oxyrinchus*. Finally, shortnose sturgeon was included in the Fishes of Maryland, its locality: the Potomac River (Truitt et al. 1929).

Uhler and Lugger (1876) as well as Smith and Bean (1898) based their assessment on the sample collected by Milner in 1876. No additional shortnose sturgeons were collected in the river after 1876 by any scientist until the late-20th Century. Thus, scientists failed to collect specimens that explain the status of the species in the Potomac River. Hildebrand and Schroeder (1928) did not find shortnose sturgeon during their survey of the fishes of Chesapeake Bay, but noted the species previously occurred in the Potomac River.

The specimen collected in the Potomac River on 19 March 1876 is the only scientific evidence that supports the idea that a shortnose sturgeon population lived in the river. This is much like the situation in the Merrimack River, MA. In the Merrimack River, there was no scientific evidence for their occurrence, even from the former intense commercial sturgeon fisheries, prior to a survey in the late-1980s that found a small population of < 100 adults (Kieffer and Kynard 1993). The present sturgeon in the Merrimack River fish are likely either remnants of a natal Merrimack River population, which could have been extirpated by fishing, or colonizers from the Androscoggin River, Maine, the nearest river with a large population of the species.

Fishery data from the Potomac River also provides no clarification on the historical presence of shortnose sturgeon. There is poor documentation of the commercial sturgeon fishery that occurred in the late 19th and early 20 th Centuries, and many of the Virginia records were lost in a series of fires and during warfare. Further, shortnose sturgeons were mixed with Atlantic sturgeons and fishers did not separately identify the two species when reporting fisheries catch.

In recent years, eight adult shortnose sturgeons have been captured by commercial fishers in the Potomac River, some occurring far upstream in fresh water (Welsh et al. 2002, Mike

Mangold personal communication). This suggests one (or more) of several possibilities, i.e., 1) a few adults from a natal remnant Potomac River population remain, 2) non-natal migrant adults are colonizing the river and remaining permanently, or 3) non-natal coastal migrants are entering the river to forage, then depart, like non-natal juvenile Atlantic sturgeon *A. oxyrinchus* (Buckley and Kynard 1985, Kieffer and Kynard 1993).

The goal of the present multi-year field study conducted from March 2004 to July 2007 was to collect information on the status and life history of shortnose sturgeon in the Potomac River. We used two approaches: studying life history and studying the genetics of captured fish. Life history studies addressed critical aspects of determining the status for any population: 1) abundance of adults, 2) presence of spawning, foraging, and wintering habitats, and 2) occurrence of spawning. We also determined several aspects of river use by telemetry-tagged adults that indicated whether sturgeons were permanent residents: 1) duration of river use, 2) occurrence of homing and repeated use of the same reach, and 3) adaptation to the river as indicated by seasonal changes in home range, particularly in relation to water quality. Finally, we determined the suitability of water quality for adult shortnose sturgeon and examined their growth rate and ability to develop an egg clutch. The only water quality data we found for the reach used by tagged sturgeons was a survey done in the 1970s (Lippson 1979).

Part–II of this report (separately bound) is concerned with the genetic identification of Potomac River shortnose sturgeon captured during the present field studies and a genetic comparison of river populations throughout the range of the species.

Study Area

The study area was 104 km of the main-stem Potomac River from Little Falls Dam (LFD) at rkm 189 to rkm 85 just downstream of the mouth of the Port Tobacco River at rkm 87 (Figure 1). The reach just downstream of LFD is a high gradient, rocky raceway and rapids. We refer to it as the LFD area. The area across the width of the river at the dam contains five deep depressions that could be holding areas for pre-spawning sturgeons. In the spring, we sampled the holes for adults. Boating between LFD and Chain Bridge was too dangerous for sampling or passage.

Downstream of the LFS area, the river goes through a fast-water chute just upstream of Chain Bridge, and the rocky fast-water reach ends in a rocky low-gradient reach (Chain Bridge–Fletchers Landing; Figure 1, inset map). Downstream of Fletcher's Landing (= Fletchers), the river bottom is sandy and mud with a moderate to low gradient. Tidal influence extends upstream to the Chain Bridge area. The inset map shows the Fletchers–LFD reach where we sampled each April for pre-spawning adults and just spawned early life stages (to document successful spawning). This reach between LFD and Fletchers is the only area with a rocky bottom that is required by spawning shortnose sturgeon (Kynard 1997).

Methods

I. Summer-fall sampling for adult shortnose sturgeons

***Anchored gill-net sampling*.—**In 2004, we used the atlas of Lippson (1979) to select the reaches that should have a solid bottom (mud and silt free) and were likely to be used by foraging shortnose sturgeon. In 2005, we identified the extent of salinity penetration and surveyed the river down to Potomac Creek at low tide for suitable dissolved oxygen (DO), salinity, and temperature conditions to compare with the conditions required by shortnose sturgeon. We identified the best locations to set gill nets for shortnose sturgeon as fresh water with ≥ 5 mg/L of DO.

For setting both anchored gill nets and a drifting gill net in the main-stem downstream of Fletchers, we used a 22 ft C-Hawk boat of the FWS. We set anchored multifilament gill nets (100 m long x 1.7 m deep with 15-cm stretch mesh) parallel to river flow. Nets were set overnight when water temperature was ≤ 27°C (Moser et al. 2000) and when submerged aquatic vegetation (SAV) did not foul nets. Otherwise, we set nets for 2–3 h.

***Drift-net sampling*.—**In 2005 and 2006, we drifted a sinking multifilament gill net (150 m long x 3.1m deep with 12.5-cm stretch mesh) with the current in the channel, on the channel edge, and in shoals. After tracking sturgeons found they did not use shoals, we ceased setting nets there. A drift net set was one net drifted perpendicular to the current for 1 h. This netting method sampled more bottom area than the anchored gill nets and fouling from SAV was reduced due to the shorter drifts and movement of the net with the current.

In 2006, we tracked sturgeons several times per month and used this information to direct setting of gill nets in summer–fall. We used all data on movements of tracked fish to select netting locations.

II. Physical characteristics of potential spawning areas

***Characteristics of the LFD area*.—**During 16–17 November 2004, we characterized substrate type and bottom velocity. After surveying the area using a portable boat, we concluded sampling the entire area was not safe due to many boulders, which could damage the outboard motor and strand us. Thus, we restricted sampling to an area where boating was safe. We selected an area for intensive study that resembled the size and characteristics of other known spawning areas of shortnose sturgeon (Kieffer and Kynard 1996, Kynard 1997). The area we selected was the weakly defined channel along the southern (Virginia) shoreline (Figure 1, inset). The geomorphology of this entire area is a fast raceway.

In the study site, we established two parallel, longitudinal, transects (up- to downstream, each 100 m long) by anchoring two 100-m floating lines spaced 20 m apart. We sampled along each transect using the following procedures: we began sampling at the downstream end of a transect line; we pulled the boat upstream along the line, stopping at 10-m intervals to collect two samples; one about 2–3 m to the left of the stationary line position and one about 2–3 m to the right of the line. We swung the boat in an arc from left to right from the anchor point to get left and right samples. We collected 20 samples along each transect (total, 40 samples).

At each sample site, we collected water depth (m), water velocity (cm/s), and characterized substrate type. We determined water depth directly using a metal pole inscribed at each centimeter. We measured water velocity at 30 cm above the bottom with an electronic velocity meter attached to the metal pole. We characterized substrate type as sand (< 2 mm), gravel (2–15 mm), pebble (16–63 mm), rubble (64–256 mm), boulder (> 256 mm), and bedrock by probing the bottom with the metal pole and by direct visual observation of the bottom in the clear water. We characterized a 1-m diameter bottom area surrounding the center of each sample site for dominant substrate (estimated at ≥ 75% of the area) and sub-dominant (≤ 25%).

***Characterization of the Fletchers–Chain Bridge reach*.—** We surveyed bottom substrate on 24 January 2007. We used a rope suspended across the river at Chain Bridge to hold a tether rope that allowed us to drift downstream and establish a longitudinal channel transect.

On the survey boat, we suspended an underwater video camera above the bottom to record substrate type. We mounted the underwater video camera and light on a hydrodynamic weight and used a rope to lower the unit to about 0.5 m above the bottom (as indicated by a weight suspended from a string attached to the camera mount). We continuously recorded bottom type as we slowly eased the boat downstream on the tether rope.

To characterize the dominant substrate type on three transects, each 200 m long, we randomly selected ten video frames within each transect and determined the percent abundance of five substrate types modified from the particle size classification of Cummings (1962). We only used 10 samples to characterize each transect because there was little variation for substrate type. We used the same substrate categories stated previously, except for the boulder category, which we divided into small (256–625 mm) and large (> 625 mm) to separate small boulders that were within the video frame from large boulders that were larger than the video frame.

We characterized bottom velocity on 3 April 2007. We used a 20 kg hydrodynamic weight and a sounding reel to lower the velocity probe to 50 cm above the bottom. We attempted to sample several sites along the same transect line in the channel sampled for substrate in January.

III. Spring sampling at the two potential spawning areas

Capturing pre-spawning adults.—To capture and tag pre-spawning sturgeons in March–April 2004–2006 at the LFD area, we set five to six short (15–40 m long) multifilament gill nets in deep pools at LFD using a portable inflatable boat. We also set several long gill nets in the Fletchers–Chain Bridge reach, like those used for sampling in summer. In 2006, we also set nets near the 05 female in the Fletchers–Chain Bridge area.

Tracking movements of pre-spawning tagged adults at Fletchers–LFD.—We established two remote tracking stations each spring, 2006–2007 to monitor movements of tagged adults that migrated upstream to spawn. One was at LFD and one was at Fletchers. Fletchers was the most downstream reach with a rocky bottom (potential spawning substrate), so a station there should detect any tagged pre-spawning adult.

The Fletchers station consisted of a wireless hydrophone (Lotek Wireless, Inc., WHS-1100) that received an acoustic signal from the fish tag, converted the signal to a radio signal, and transmitted the radio signal by air to a radio receiver placed in the Concessions Building at Fletchers. This site, which we could interrogate remotely by wireless modem, notified us when a tagged sturgeon approached. No tagged fish could pass Fletchers without the acoustic signal being detected. We left a CART (combined acoustic and radio tag) tag in the river to provide a known tag signal and serve as a constant reliability test of the detection system. After a tagged fish was detected by the Fletcher's station, we manually tracked it by boat between Fletchers and Chain Bridge using manual tracking methods (portable hydrophone and receiver).

The most upstream remote station was placed on the north end of the dam at LFD (Figure 1, inset). This station relied on detecting the radio signal of a CART tag on a sturgeon. The radio signal of a CART tag could be detected from fish on the far south side of the river (within about 1.5 km of LFD). We left a tag at LFD to provide a known signal and test of the system was working. We interrogated the receiver by wireless modem.

Spring sampling for ELS.—Spawning by adult shortnose sturgeon in the rocky reach downstream from LFD (LFD area to Fletchers) would result in early life stages, i.e., ELS (eggs, free embryos, and larvae) drifting downstream for about 30 d (Kynard and Horgan 2002a). To determine if spawning by any sturgeon occurred upstream of Fletchers, we used methods of Kieffer and Kynard (1996) to set D-drift nets (2-mm clear square mesh) on the bottom to capture ELS. Each net had a mechanical velocity meter suspended in the net mouth to estimate the volume of water sampled. Each year we set D-nets in the Fletchers–Chain Bridge reach, and during some years, we also set a few nets at the LFD area.

Annual river conditions during potential sturgeon spawning period.—Based on spawning conditions for shortnose sturgeon in other rivers, temperature and flow conditions are likely acceptable during late-March–late-April (Kynard 1997). Water temperature and discharge were monitored during the likely sturgeon spawning period by the USGS gauge at LFD (gauging station number 01646500). For each year, we made a time-series plot of 1) the days we sampled for adults or ELS during March and April, and 2) the water temperature and discharge at LFD.

IV. Telemetry tagging of sturgeon

We immobilized captured sturgeon with electrical-narcosis and internally tagged fish with a CART tag transmitter (18 mm diameter x 85 mm long and 38 g weight in air; Lotek Wireless, Inc.). Tags had a 2-year transmission life and transmitted on 164.3 MHz (radio frequency) and 76.8 KHz (acoustic frequency).

We implanted tags using techniques described in the shortnose sturgeon tagging protocol (Moser et al. 2000) that have been modified by new results from tagging shortnose sturgeon in the Connecticut River. Each fish was also injected with a small PIT tag to identify it if it was recaptured. We also removed a small piece of fin tissue (1 cm^2) for genetic analysis.

V. Sturgeon movements, seasonal reach and habitat use, and home range

Tracking of tagged shortnose sturgeons.— We tracked adults from a boat (19 ft SeaArc of the FWS) using a mobile tracking system (Lotek Wireless, Inc.). During spring–fall, we located fish weekly recording latitude and longitude location. During winter, we attempted to locate fish monthly, but weather made tracking difficult. We plotted fish locations by month and calculated the monthly home range to show changes in river reaches used and home range.

Water quality and habitats used by tagged sturgeons.—At tracked fish locations, we measured water temperature, salinity and dissolved oxygen (DO) levels at about 1 m above the bottom. Salinity (ppt) was measured using an YSI 85 meter; water temperature (ºC) and DO (mg/L) were measured with an YSI 550A meter. We used the water quality data from fish locations to reveal changes in water quality used each month by tagged sturgeons. We also characterized macro-habitat at fish locations as channel, channel edge, and shoal.

VI. Available water quality, substrate, and benthic invertebrates

Monthly water quality.—In 2006, the available water quality in a 52 km long reach of the river used by tagged sturgeons was sampled monthly at 14 navigation buoys from Craney Island to Port Tobacco River (Figure 1). Near each buoy, we surveyed DO level (mg/L), water temperature (°C), and salinity (ppt) in the water column (surface –1 m deep and within 1 m of bottom and at three macro-habitat types: channel, channel edge, and shoal.

Substrate and bottom invertebrates at fish locations.—At most fish locations and several netting locations, we used a Ponar dredge to sample bottom substrate. We determined bottom type (mud, sand, gravel, or mixture) and the number and type of benthic food items captured that could be forage for sturgeons (bivalve mollusks and worms).

Results

I. Sampling for adults during summer–fall

2004

We set 47 anchored gill nets (total effort, 747 net hours). Two nets were set far downstream during 2 d in July at Aquia Creek and Craney Island (Figure 1, Table 1), but the nets were fouled with SAV. In August–October, we moved gill netting to a reach just downstream of Theodore Roosevelt Island, where SAV was less dense, but we captured no sturgeons.

Benthic fishes (channel catfish *Ictalurus punctatus*, carp *Cyprinus carpio*, and gizzard shad *Dorosoma cepedianum*) dominated the catch (Table 1). We captured no commercially important fish. Thus, the nets were set appropriately for a benthic species like shortnose sturgeon, but captured zero sturgeon.

In the freshwater Theodore Roosevelt Island reach, maximum temperature was 28.4°C and DO was ≥ 6 mg/L. These conditions are acceptable for sturgeons, but temperature was too high for much activity or foraging by shortnose sturgeon (personal observation). Thus, if present they would likely be sedentary.

2005

From 13 June to 15 November, we set 138 anchored gill nets (total effort: 1,320.1 net hours). We set nets from Potomac Creek to Fort Belvoir (43 km; Figure 2). Our preliminary surveys found the channel had slightly higher DO levels, so we set most nets in the channel.

As in 2004, the same benthic fishes as in 2004 dominated the catch. We captured only one striped bass *Morone saxatilis* (Table 2). The capture of benthic fishes show the nets were set appropriately for a benthic species like shortnose sturgeon. Nets set a few days in June at Chain Bridge after a visual sighting of a fish resembling a sturgeon captured zero sturgeon.

On 20 September, an anchored gill net set in the channel near Craney Island captured an adult shortnose sturgeon (Table 2). The physical environment at the net location follows: water depth – 21 m; DO – 5.17 mg/L; salinity – 0.1 ppt; water temperature – 26.9^{o}C. The fish was an adult female that weighed 4.3 kg (Table 3). During implantation of the CART tag, we observed the fish had late-stage eggs, i.e., 1.5–2.0 mm diameter black eggs that could be spawned the following spring (2006). The appearance of the fish's fins, body condition, and color was normal and her body condition was excellent. We designated this fish the 05 female.

From 11 August to 24 October, we fished 22 drift gill net sets (total effort, 21.1 net hours; Figure 2, Table 4). We captured no shortnose sturgeon, but the typical benthic fishes dominated the catch. Thus, nets were fishing well for shortnose sturgeon. We captured no striped bass in the drift net.

2006

From 18 May to 25 September 2006, we set 64 anchored gill nets between Nanjemoy Creek (rkm 94) and Craney Island (rkm 139; Figure 3) for a total effort of 746.5 net hours (Table 5). Sample reaches were chosen near where we located tagged sturgeons and nets were set in similar habitat types (channel and channel edges) used by tagged sturgeons. The same benthic fishes dominated the catch showing that nets were set appropriately for shortnose sturgeon. Anchored nets captured no shortnose sturgeon. We captured two adult American shad *Alosa sapidissima* and zero striped bass.

From 23 May to 1 November, we set 78 drift net sets (total effort, 75.9 net hours; Table 6), so each drift was about 1 h. Netting locations are shown in Figure 3. Benthic fishes (channel catfish and gizzard shad) dominated the catch and we captured zero striped bass or American shad. We captured no shortnose sturgeon.

During 15 August–21 September, drift nets captured three juvenile Atlantic sturgeons *A. oxyrinchus* (Table 6). The first Atlantic sturgeon (690 mm TL; 2.3 kg weight) was captured near Quantico VA (rkm 115). The other two Atlantic sturgeons (one was 810 mm TL and 3.0 kg weight, the other was 700 mm TL and 1.5 kg weight) were captured near Maryland Point (rkm

99). Characteristics of habitat and water quality where we captured Atlantic sturgeon follows: all were in channel habitat; water depth = 9–16 m; DO = 6 mg/L; water temperature = 22.8–27.5°C; and salinity = 1.1–4.0 ppt.

On 4 August, a gill net set just downriver of Craney Island recaptured the 05 female (characteristics in Table 3). Habitat and water quality at the August recapture site follows: channel habitat; water depth = 13 m; DO = 6.6 mg/L; salinity = 0.1 ppt; water temperature = 31.9°C. Body weight of the 05 female decreased 0.5 kg (17 %) between the initial capture date in September 2005 and the first recapture date in April 2006 at Fletchers. Between April (at Fletchers) and a later recapture in August, the female's body weight increased slightly (0.25 kg), an indication she did not spawn or eject eggs the previous spring at Fletchers–Chain Bridge.

On 22 March, a commercial gill net fisher captured a shortnose sturgeon at rkm 63. The fisher contacted us and held the fish in a live car. In the shoals at the capture site, salinity was 5.6 ppt, and water temperature was 9.6. The fish was a pre-spawning female. We internally tagged it with a CART tag and released it on 23 March. After release, we did not track this female (designation, 06 female) again until May because we were busy upstream at the Fletchers–LFD reach. The fish did not migrate upstream to this reach after tagging.

II. Sturgeon use of the river during foraging and wintering

River reach used and home range.—During September 2005 through June 2007, we obtained 115 locations on the two fish. All tracking locations during summering–wintering locations of both tagged females were in the 78-km reach from rkm 63 (initial capture site of the 06 female during wintering) to rkm 141, just upstream of Craney Island (Figure 4).

The 05 female used the same reach during fall–winter of 2005 and 2006 (Figure 5A). In 2005, she used a 24-km long reach from Quantico (rkm 115) to Craney Island (the capture site at rkm 139). She used only the Craney Island reach during September; then, during October–November, she moved the widely up- and downstream creating a large home range. She restricted up- and downstream movement again in December and especially in January–March. The checkered plots of winter use by the 05 female on Figure 4 show the small home range she used during wintering. After the pre-spawning run to Chain Bridge–Fletchers in April (Figure 5A), we tracked the 05 female in May and found she had moved downstream to the most saline reach she ever used. During June–September 2006, home range of the 05 female was small, and she only used the short reach from Quantico (rkm 115) to rkm 141, upstream of Craney Island. Then, like in fall 2005, in October–November 2006, the home range of the 05 female was the largest of the year. Home range decreased in December and was small again in February. Further, the 05 female used the same wintering reach as in 2005. We did not track her during March–April, but in May 2006 she was located downstream at the same reach she used in May 2005. In June 2007, she moved upstream to the same reach (Craney Island) used the previous June–September 2006.

We recaptured the 05 female for the third time near Craney Island in July 2007 (Table 3) and implanted a new CART tag. During the 12 months since her last recapture, she had increased weight by 0.5 kg and fork length by 6 cm, a good level of growth. Since April 2006, her late-stage eggs had been replaced by early-stage eggs (small and yellow-brown, not black). The rapid accumulation of a new clutch of eggs in the past 15 months creates the possibility that she could spawn in 2008 (a 2-year interval between spawning).

The seasonal pattern of home range was similar for the two fish, but the 06 female used lower river reaches with higher salinity much more than the 05 female. We captured the 06 fish at the end of the wintering period in saline water (9 ppt on the shoreline) and this river kilometer was the lowermost location of either fish during tracking. The 06 female used the same freshwater reach as the 05 female in June–July 2006, and their home range sizes were similar and moderate in size (10–20 km) during this period; Figures 5A, B). In August, home range of both females was the smallest for any month of the summering season. The largest home range of both fish was in the fall (about 20 km in October and November for the 05 female) and about 20 km in October for the 06 female (Figure 5B). In the fall (October), when water temperature was decreasing, the 06 female left fresh water and moved downstream to near Maryland Point (rkm 99) and weak salinity, a move never duplicated by the 05 female. Despite tracking during winter 2006–2007 and spring 2007 in the freshwater wintering area of the 05 female, we only located the 06 female one time in February 2007 at rkm 85 in slightly saline water (5.3 ppt). Repeated failure to locate the 06 female upstream of rkm 90 suggests she used a saline reach during the winter, spring, and early summer of 2007. Besides the February 2007 location of the 06 female, the most downstream location of either fish was near Nanjemoy Creek (rkm 94; Figure 4) in May 2006 when both fish used this reach. The 06 female was never tracked as far downstream as rkm 63, her original capture site. However, tracking did not locate her during many months in 2007 (January and March–June), so she could have moved farther downstream, possibly to rkm 63 or farther.

Habitat and water quality use.—The two tracked sturgeons mostly used channel habitat, regardless of water temperature, season, or river condition. Of 102 tracking locations of both fish during 2005–2006, 91 (89.2%) were in the channel, eight locations were on the channel edge, and zero locations were in shoals. The range of water depths used by tracked fish was 4.1–21.3 m. Fish used shallow water the most in late fall and winter when they left the channel. During the winter of 2005–2006, the 05 female used an area just downstream of Craney Island on the Virginia side that is a deposition site for dredge material.

Water quality at fish locations show a seasonal change in water quality use and a big difference between the two females for use of salinity, i.e., the 06 female used freshwater mostly in 2006 (Figure 6), but in 2007 has entirely used the saline reach. In 2006, the 05 female used fresh water every month, except for the brief downstream trip to 5 ppt salinity in May (a movement repeated in May 2007). This movement to saline water followed the pre-spawning upstream migration to Fletchers in 2006, whereas in 2007, the movement occurred after wintering. Thus, the 05 female moved briefly into saline water in May following both life history activities. The 06 female also used fresh water in 2006, but she also used salinity of 1–4 ppt several times during summering–fall, particularly during August–October. In summary during 2006, the two tagged females mostly used fresh water with 56 locations in 0.1–1.3 ppt salinity and only six locations in 1.9–4.6 ppt. Of the six locations in higher salinity, four were locations of the 06 female in September–October and the other two locations were one for each fish in May (Figure 6). The downstream movement of the 06 female into higher salinity water began in fall 2006 (Figures 5, 6), and it is likely that in November 2006, she continued to move downstream into higher salinity. We never relocated the 06 female in fresh water, and when we located her in February 2007 at rkm 85, she was in 5.3 ppt salinity. She had likely been there since November and during all the winter.

Fish used a wide range of water temperature (5.0–32.0 ºC) and DO use ranged from 4.8–14.6 mg/l (Figure 6). This water quality is acceptable for shortnose sturgeon (NMFS 1998).

In 2007, the 05 female was located 12 times, of which two times were in May, when she used 0.7 ppt salinity near Maryland point (rkm 101). At the other locations, the salinity was 0.1 ppt; thus, except for the May locations, she used fresh water. The 5.3 salinity used by the 06 female in February 2007 was much higher than any salinity used by the 05 female during wintering and illustrates a major difference between the two females for use of saline water.

III. Spawning habitat availability

LFD area.—Histograms showing the percent frequency of habitat occurrence, i.e., water depth, water velocity, and substrate type are shown in Figure 7A–C. For comparison of known spawning habitat with habitats available at LFD, we included habitat use data from spawning Connecticut River shortnose sturgeon females.

Seventy percent of the 40 stations had water depths of 1.0–1.9 m (Figure 7A). Eighty-five percent of the stations had water velocities of 20–99 cm/s (Figure 7B). The most abundant dominant substrate was boulder and gravel (Figure 7C); the most abundant subdominant substrate was sand and boulder. Comparison of available habitat (LFD area) and habitat used by Connecticut River adults show there is spawning habitat for shortnose sturgeon in the LFD area. Cobble substrate, which was used by Connecticut River females, was not abundant, but in general, rocky habitat was abundant at LFD.

Fletchers–Chain Bridge reach.— Large and small boulders dominated channel habitat in the reach, accounting for 70.0–78.0 % of the substrate type (Figure 8). Suitable spawning substrate (gravel–pebble and cobble–rubble) in the three transects was also present, at lesser percentages (15.5–24.0 %). The typical pattern of spawning substrate distribution in all transects was small pockets of gravel–rubble substrate isolated by large areas of boulders. We rarely observed a patch of gravel–pebble or sand that filled the entire video frame (an area of river bottom approximately 50.0 x 62.5 cm). We found one large patch (many square meters) of gravel–rubble in Transect 1. Our survey indicates this situation is rare, but a more detailed survey could find a few other large patches of gravel–rubble substrate.

Determination of bottom velocities on 3 April 2007 (river discharge = 419 m^3/s) was limited due to the swift current, the deep channel (about 12 m), and insufficient weight to lower the cable with the velocity probe to the channel bottom. Measurement of velocity at four locations on the channel shoulder (mean depth, 6.3 m; range, 4.6–7.6 m) was a mean of 1.05 m/s. Video images of rocks on the channel bottom were clean of sediment and debris, like rocks used for sturgeon spawning.

IV. Spring sampling for and tracking of pre-spawning adults at spawning areas and water conditions during sampling

2004

Gill nets fished well in the LFD area and were mostly free of debris after an overnight set. Total fishing effort was 141.6 net hours (6 nets set for 3 d; net locations are shown in Figure 1 (inset map). We captured one adult walleye *Stizostedian vitreum and* one adult quillback sucker *Carpiodes cyprinus*, but no shortnose sturgeon. The nets fished well with little debris.

Gill-net effort at the Fletchers–Chain Bridge reach was 50 net/h (24 h sets on 3 d in March and April; Table 1). We captured several species of benthic fishes, so the nets were fishing well for shortnose sturgeon. High river discharge prevented setting more gill nets.

River conditions during late-March to late-April, when we sampled for adults and ELS, is shown in Figure 9A. Water temperature was acceptable for spawning for about one month (late March–late April). There were two peaks in river discharge during the potential spawning period with about a week of decreasing flow between peaks, plenty of time for a female to spawn. All netting was limited, but the timing of netting was appropriate for capturing pre-spawning adults and drifting ELS.

2005

We set gill nets on 5–18 April at the LFD area and they were mostly free of debris after overnight sets. Fishing effort was 35 net sets for a total of 759.1 net hours. Net locations are shown in Figure 2 (inset map).

At the Fletchers–Chain Bridge reach during 20–28 April, we set nine sets for a total of 19.1 net hours at locations shown in Figure 2 (inset map). We captured four species of benthic fishes, so the nets were fishing well for shortnose sturgeon, but we captured none (Table 2).

River conditions during sampling are shown in Figure 9B. Water temperature suitable for spawning was present for about one month during late-March to late-April. During most of this period, river discharge was decreasing and was likely acceptable during April. Sampling for adults at LFD was done during high and low discharge and cool and warm temperatures. Sampling for ELS was over a wide range of river temperature and discharge. We captured no pre-spawning adults or drifting ELS.

2006

During 29 March–13 April, gill nets fished well overnight at the LFD area with no fouling by algae. We fished 16-gill net sets for a total of 370.4 net hours (Table 5). Netting locations are shown in Figure 3 (inset map). Nets captured two American shad and two benthic riverine species, but no shortnose sturgeon.

Nine gill net sets (213.5 net hours) were fished during 9 d (11–18 April) in the Fletchers–

Chain Bridge reach (locations in Figure 3, inset map). We captured six species of benthic fishes (Table 5). It only took 2 d of netting to recapture the 05 female at Fletchers on 12 April (characteristics in Table 3). If other sturgeons (particularly, males) were present, it seems likely we would have captured them. Visual inspection found she was in good condition, the incision site was healed, the tag's antenna was free from bio fouling, and body tissue at the antenna exit was not irritated. She was not running eggs, but had lost 0.5 kg weight in 7 months since capture and tagging in September 2005. Because spawning females lose 20–30% of their body weight (Kynard et al. In press), the 05 female had not spawned before we recaptured her. After release on 12 April, the 05 female did not leave the area and move downstream as is common for pre-spawning females intercepted far downstream from their spawning site. Instead, the female remained in the Fletchers–Chain Bridge reach until 14 April (2 d). Although the gill nets in this reach were fishing well for benthic fish, we captured no additional sturgeon.

Temperature and river flow at LFD when the pre-spawning 05 female arrived at Fletchers on 9 April was 12ºC and 174 m^3/s (Figure 10A). River flow remained low and stable (range, 157–178 m^3/s) during the entire 6 d the female was at the Fletchers–Chain Bridge reach. Water temperature gradually increased to 16°C by the time the 05 female departed on 14 April. Gill netting for adults occurred over a wide range of water temperature and early sampling for ELS occurred when flow and temperature were stable.

The 05 female was tracked at her wintering area at rkm 119 on 8 March 2006. She was first detected 65 km upstream by the Fletcher's monitoring station at 1142 h on 9 April (Figure 11). Departure date and travel time to Fletchers of the female are unknown.

The 05 female was detected daily by the Fletcher's station until 1958 h on 14 April (6 d; Figure 11). The greatest frequency of the total signal hits (3,475) was on 11–13 April. Of the total signal hits, 79.3% occurred during daylight and 20.7% occurred at night. By comparing manual tracking locations recorded during the same period (Figure 12), it appeared that at night, when the fish was absent from Fletchers, it was upstream close to Chain Bridge.

Manual tracking of the fish on 14 April at 1100 h was also logged by the Fletcher's station. This showed the Fletchers station was logging signals when the sturgeon was almost 0.5 km upstream. Assuming a similar detection range when the tag was downstream of Fletcher's station, then the total detection range was about 1 km. The high number of signal hits on 12 April was likely related to the fish's inactive recovery after recapture that morning (Table 3).

Manual tracking of the 05 female upstream of Fletchers was infrequent, but we obtained one daytime track of the 05 female at Chain Bridge on 10 April (Figure 12). Of nine tracking locations of the 05 female upstream of Fletchers, six locations (66.6%) were at night, a result that supports our hypothesis that the fish was upstream of Fletchers at night. It was difficult to locate the tag's signal upstream of Fletchers because of poor signal detection likely caused by large boulders that deflected the signal when the fish was partially under boulders.

Female 05 was never manually tracked or detected by the LFD remote station. This result and our daily tracking data show that she did not move farther upstream than Chain Bridge. All tracking show the female moved up- and downstream in the Fletchers–Chain Bridge reach for 6 d before departing and moving downstream. Her movement never localized at any small site, like when a female spawns. There was not likely any significant relationship between fish movements and tidal flow because river flow always dominated tidal influence.

The 06 tagged female was captured at rkm 63 on 22 March and tagged and released on 23 March (Figure 4). The female did not make a pre-spawning migration in April like the 05 female. Capture, handling, and internal tagging of this fish in late March, so near the pre-spawning migration time, likely caused it to abort the migration.

2007

Location of gill net sets in the Fletchers–Chain Bridge reach are shown in Figure 13. Information on the species captured is shown in Table 7. The dominant fish captured were benthic fishes, so nets were fishing well for sturgeon; but none were captured.

River conditions at LFD when gill nets were set at the Fletchers–Chain Bridge reach are shown in Figure 10B. Based on the occurrence of the 05 female at Flechers in 2006 (low flow and 15 ºC), our netting after the brief high flow spate on 16 April was done at a time when sturgeon could have been present. However, we captured zero sturgeon.

V. Spring D-net sampling for ELS

2004

We fished D-nets on 31 March and on 8 and 13 April at Chain Bridge (locations on Figure 1, inset map). We set eight nets for a total of 14 h 43 min and sampled 2,394 m^3 volume of water. We captured hundreds of eggs of other fish species that were spawning upstream. The eggs were likely eggs of (Catostomidae: white sucker *Catostomus commersoni,* quillback sucker, (or both) because ripe and running adults were captured at Chain Bridge. We captured no sturgeon ELS. River conditions during sampling are shown in Figure 9A.

2005

During 14–28 April, we fished D-nets (24 nets set for a total of 348 h 21 min) at Little Falls and Chain Bridge (Figure 2, inset map). Nets sampled a total water volume of 24,687 m^3. We captured hundreds of eggs and ELS, but we captured no sturgeon ELS. Many of the ELS captured were likely from quillback or white sucker spawning. River conditions during sampling were good for the sets at Fletchers (Figure 9B).

2006

Periodically during 15–28 April 2006 after the 05 female departed the Fletchers–Chain Bridge reach, we set 16 D-nets for a total of 196 h 18 min (locations on Figure 3, inset map). Nets sampled a volume of 17,370 m^3 of water. For 6 d after the 05 female departed, we set D-nets during low-river flows, which were optimal for capturing ELS (Figure 10). Many of the eggs and ELS captured were likely from spawning suckers. We captured no sturgeon ELS. Drift-net sampling was interrupted during 21–25 April by high river flow (Figure 10A). Sampling resumed during 26–28 April when water temperature was 18°C, 2 weeks after the tagged 05 female departed.

2007

Location of D-net sets is shown in Figure 13 and data on river conditions when netting was done is shown by Figure 10B. Netting was done when flow was low with low debris levels, so sampling for ELS was efficient. Seventeen D-nets were set on 8 d during 30 April–10 May (total net h, 245.05). Nets sampled 59,230 m^3 of water, the largest volume of water sampled any year. Many of the ELS captured were likely from spawning suckers. We concluded these species were the likely source of captured eggs because we have captured pre-spawning adults each year of the study. Like all previous years, we captured no sturgeon ELS.

V. Water quality, substrate, and invertebrate survey

Water quality.— Locations of the 14 stations sampled during May–December 2006 from Buoy 56 (rkm 139) to Buoy 6 (rkm 87) are shown in Figure 14. Data collected monthly at the stations are in Appendix 1. To show monthly trends in DO, salinity, and temperature along the length of the sample reach, we show data from three stations, i.e., the most upstream station (Buoy 56, Figure 15A), a middle-station (Buoy 26 at rkm 108, Figure 15B), and the lowermost station (Buoy 6, Figure 15C).

In the 2006 survey, water temperature was highest and DO was the lowest during the month of July (28.9 ^{o}C and 5.2 mg/L, respectively); the highest DO level, 10.0 mg/L, occurred in December. Generally there was little variation (< 0.5 mg/L, < 0.5 ^{o}C) in DO and temperature between samples taken at the surface or at the bottom, or in the channel or in shoals on the same day, showing water was well-mixed by tidal and river flow and wind. There was a trend for decreasing DO with increasing salinity during the summer months of June–August. When salinity was 7.4 ppt, DO was reduced by 2.5 mg/L compared to DO levels in fresh water at the same time. The freshwater:saltwater interface was typically near Aquia Creek (rkm 103), but moved upriver near Quantico (rkm 115) during June, August, and September. The freshwater:saltwater interface moved downriver in July due to high rainfall in the watershed.

Substrate & invertebrates in the foraging–wintering reach.— Substrate samples were collected at 57 tracking locations. The majority of the samples (46 samples or 80.7%) contained only mud, nine samples (15.8%) contained sand and mud, and three samples (two samples at Maryland Point and one near Craney Island) or 5.3%, contained gravel and mud. Thus, mud dominated substrate type in all areas used by the two sturgeon adults. Forty-seven of 57 samples contained live bivalve mollusks (range, 1–56; mean, 9.4) and one sample near Maryland Point contained four worms.

Discussion

Capturing adult shortnose sturgeon

During 2,814 h of anchored gill netting and 97 h of drift gill netting in summer–fall, we captured only one adult shortnose sturgeon and three juvenile Atlantic sturgeons. As found in the northeast, juvenile Atlantic sturgeons were in saline water and located slightly downstream of shortnose sturgeon (Buckley and Kynard 1985, Kieffer and Kynard 1993). Nets mostly captured benthic fishes, which indicated the nets fished well for sturgeons, so the low catch of shortnose sturgeon likely correctly reflects a low abundance. Multifilament netting avoided capturing American shad and striped bass as we only captured a few of these species.

With two telemetry-tagged fish guiding the selection of net set locations in 2006, we expected to capture additional fish. However, gillnetting captured no additional shortnose sturgeon. Our tracking and sampling results suggest 1) that shortnose sturgeons are very rare in the river, and perhaps, 2) shortnose sturgeon are often widely spatially separate except during some months, particularly when water quality is poor. If hypothesis #2 is correct, then concentrating netting effort near tagged fish in 2006 possibly biased the sets against capturing more sturgeon. Additional netting should be done with and without biasing the sets toward areas with tagged sturgeon.

Atlantic sturgeon status

What is the natal river of the juvenile Atlantic sturgeon we captured? Are they non-natal coastal migrants from another river or remnants of a Potomac River population? One juvenile weighed only 1.5 kg, which is small for a coastal migrant. Could they be the result of a rare spawning in the Potomac River by a few Atlantic sturgeons that spawn undiscovered in the Fletchers–Chain Bridge reach? We have no data to answer this question, but the small size of juveniles suggests the status of Atlantic sturgeon in the Potomac River needs study.

River reach of adult shortnose sturgeon

The total reach used by both females was 124 km (rkm 63 capture site of the 06 female to rkm 187 at Chain Bridge). This reach includes foraging and wintering concentration areas in the freshwater: saltwater reach and an upstream freshwater reach with potential spawning habitat.

Based on a tracking study of a small number of adult shortnose sturgeon in the Merrimack River (Kieffer and Kynard 1993), we would not expect much change in the size of the foraging–wintering concentration area with a slightly larger number of tracked adults. The two females we tracked likely identified correctly the summer–wintering and potential spawning reaches of shortnose sturgeon in the river.

The two females moved seasonally to different river reaches, but in some months, both used a common reach. The general pattern for both fish in 2006 follows. In May, both females moved to the saline part of the summering–wintering area (rkm 94–99) where salinity was 3.5–4.6 ppt. As water temperature increased in early June 2006, both fish's home range decreased towards the upstream freshwater part of the concentration area (rkm 121–139, salinity 0.1–1.3 ppt) and they remained there all summer (7 June–5 September). During July, home range was small (rkm 132–139), when water temperature was 30 ^{o}C and DO was 5.2–6.1 mg/L.

As water temperature decreased in the fall, the 05 female remained in fresh water, but the 06 female left the freshwater Craney Island reach and moved downstream to the saline reach that she occupied earlier in May (rkm 99, salinity 1.9–3.2 ppt). The 05 female repeated essentially her 2006 movement pattern later in 2007.

However, this pattern was different in 2007 for the 06 female, which wintered downstream farther (rkm 85) and in higher salinity (5.3 ppt in February) compared to the 05 female, who remained in fresh water. Because repeated tracking in 2007 did not locate the 06 female in the freshwater reach used by the 05 female, it seems that she did not shift her river reach use upstream to freshwater like she did in spring–summer 2006. This may be due to improved water quality in 2007. Unless there has been a failure of the 06 female's tag, it seems likely that she is between rkm 85 and 63 in saline water and in a much wider and more difficult reach to track (Figure 4).

Habitat use and seasonal movement

Movement tracks of the two tagged females during May–December 2006 show both used the same macro-habitat type (channel or channel edge) regardless of season. Fish were tracked in shoal habitat only twice, both locations during the winter (February). Adult shortnose sturgeon in other rivers use both channel and shoal habitats during foraging (Kynard et al. 2000). Thus, the restricted use of Potomac River sturgeons to channel habitat suggests shoals do not provide suitable habitat during most of the year. Although forage items were limited both in type and abundance, even in the channel areas frequented by adults, growth of the 05 female was good and as of July 2007, she was maturing eggs rapidly.

Seasonal movements of the two females show the likely size of the foraging–wintering concentration area for adult shortnose sturgeons. During the summer, fall, and winter, the total reach used by both fish in 2006 and 2007 was 78 km (rkm 141 near Craney Island to the capture site of the 06 female, rkm 63), and for 2007, the size may be slightly larger if the 06 female is slightly lower in the river than rkm 63. Tracking the two females has identified the Craney Island reach as the upper freshwater limit, but the downstream saline limit is still uncertain. It may be rkm 63, where the 06 female was captured, or it may be farther downstream.

If males were tracked, would the summering–wintering concentration areas be different than for females? Tracking Connecticut and Merrimack river adults found both sexes used common concentration areas during foraging and wintering (Kynard et al. 2000). There should be no difference between males and females for concentration area use.

The foraging–wintering reach used by the two Potomac River females was most similar to that of north-central populations (Delaware River to Merrimack River), not to southern populations. Merrimack River adults, which are estimated at < 100 adults, used only a 12 km reach for foraging–wintering (Kieffer and Kynard 1993). Although the total river reach used was small in the Merrimack River, the general characteristics of the reach, particularly for salinity, used by adults was the same in the Merrimack and Potomac rivers—fish used the lower freshwater and upper saline reach (freshwater: saltwater interface). Adults in north-central rivers remain mostly in fresh water with occasional visits to weakly saline water, particularly after spawning (Kynard 1997). This style of fresh and saline water use is the same as the use pattern of the 05 female in the Potomac River. This life-history style is different from adults in southern rivers that spend more time in saline water, particularly in the winter when fish use high salinity (Kynard 1997). The visits to weak salinity in May by the 05 female in 2 years and by the 06 female in 1 year are commonly made by adults in north-central rivers (Buckley and Kynard 1985, Kieffer and Kynard 1993). The use of fresh and salt water suggests the Potomac River females are either colonizers from a north-central river or remnants of the natal Potomac River population that uses salinity like north-central adults.

Tracked adults showed they were using the river all year, not just for a few months. Thus, it seems the fish are either natal to the Potomac River or colonizers that have selected concentration areas and established regular movements between areas of use, like natal shortnose sturgeon in other rivers (Kynard 1997). While we only tracked two Potomac River shortnose sturgeon, the data show the adults have life history movements typical of the species in other rivers with seasonal movements between foraging and wintering reaches, and when sexually mature, a spawning migration upstream to a rocky bottom reach with moderate velocity.

Spawning

Female 05, which contained late-stage eggs, moved upstream 65 km from her wintering site to the Fletchers–Chain Bridge reach in April 2006. Timing of the movement resulted in the female being present at the Fletchers–Chain Bridge reach when water temperature was within the range acceptable by spawning shortnose sturgeon (Kynard 1997, Kieffer and Kynard In press). Based on observations of many females in other rivers, the upstream movement by the 05 female was a pre-spawning migration of a female seeking spawning habitat and males. Gill netting captured no males, so it seems likely she did not find any males.

The pre-spawning migration style of the 05 female was a one-step spring migration from the wintering to the spawning area (Kynard 1997). This migration style is typically found in adult females that energetically and physically are able to pass rapids and distance and migrate to the spawning area in only the spring; thus, they do not need a two-step migration (fall, then spring) to traverse rapids and distance (Kynard et al. In press-a). Delaware River shortnose sturgeon winter only about 20 km downstream from the spawning reach and also have a one-step spring migration. The one-step migration style of the 05 female is life history information that eliminates any population with a two-step migration as the source of colonizers.

The use by both tagged sturgeons of foraging and wintering reaches far downstream from Washington, and the April pre-spawning migration by the 05 female to Washington suggest that the adult captured by J. Milner on 19 March 1876 in Washington, D.C. was a pre-spawning or spawning adult. The mid-April spawning migration of the 05 female to Washington suggests that spawners in the larger natal population was at the Washington spawning reach for several weeks to a month, a situation similar to Connecticut River shortnose sturgeon (Kieffer and Kynard In Press).

The absence of males in all our sampling regardless of year, season, or location, suggests that only females may be present or that males are very rare. If genetic analysis of our females finds they are colonizers from the Delaware River, then the absence (or scarcity of males) suggests females of a donor stream initiate colonization of nearby rivers. Colonization would seem like a good reproductive strategy for females as density of spawned ELS increases to a high level. The population of Delaware shortnose sturgeon likely exceeds 13,000 adults (Kynard 1997), but no information on abundance of ELS is available. If colonization is occurring, then it could be in the initial stages and it may take years for males to appear and successful spawning to occur. A pre-spawning migration is done by solitary adults (no schooling by the sexes; Kieffer and Kynard In Press), so males are not required for females to initiate a pre-spawning migration. Thus, pre-spawning migrations by females will occur whether males are present or not. In other rivers, a spawning female is accompanied by at least several males during the 24–48 h that spawning occurs (Kieffer and Kynard In Press, Kynard et al. In Press-b). A minimum abundance of 3:1 (males: females) seems typical.

Spawning habitat exists in the reach just downstream of LFD (Kynard et al. 2005) and in the Fletchers–Chain Bridge reach; thus, a lack of spawning habitat did not likely prevent the spawning of the 05 female. Although bottom water velocity was not measured for all of the Fletchers–Chain Bridge reach, a bottom velocity of 1 m/s on the channel shoulder and the lack of sediment debris on top of rocks in the channel suggested a bottom velocity acceptable to pre-spawning females was present at many channel or channel shoulder locations. Shortnose sturgeon spawn over a wide range of bottom velocities (0.3–1.3 m/s; Kieffer and Kynard In Press, Kynard et al. In Press-b). Although more data on bottom velocity is needed, the wide range of acceptable velocity, the multiple sites with 1 m/s velocity, and the widespread availability of a rocky bottom strongly suggest spawning conditions exist at many locations in the Fletchers–Chain Bridge reach. We encourage further study of the Fletchers–Chain Bridge reach as spawning habitat for shortnose sturgeon.

In other rivers, pre-spawning shortnose sturgeon swim upstream past a reach with habitat that appears physically acceptable for spawning only to spawn at another reach (Kynard 1997, Kynard et al. In press–a). Thus, besides the presence of acceptable habitat, the actual place is important to the selection of spawning site for some shortnose sturgeons. Thus, even if spawning habitat is present at Fletchers–Chain Bridge, only a female actually spawning at the Fletchers–Chain Bridge reach can reveal that a female will stop, find the site acceptable, and spawn there. So far, our efforts during the present study did not find evidence of successful spawning at LFD or at Fletchers–Chain Bridge.

The water temperature and period of stable river discharge during April 2006 was sufficient for the 05 female (or other females) to initiate and complete spawning. But all evidence indicates that spawning of the 05 female (or other female sturgeons) did not occur. Discharge remained stable from early March through 20 April when water temperatures were acceptable for spawning (Kieffer and Kynard In press). The evidence for a lack of spawning follows: first, we captured no ELS with a netting effort that has verified spawning by capturing eggs when only one or a few females spawned (Kieffer and Kynard 1996). Secondly, the D-netting effort was timed to have a good chance of capturing ELS, i.e., in the first few days after spawning (Kynard et al. In press–b). Thirdly, we captured no males with the female at Fletchers–Chain Bridge, an expectation if the female was near spawning because males are attracted to female pheromone (Kynard and Horgan 2002b). And fourth, the female never localized movements, a characteristic of spawning females (Kieffer and Kynard In press). Female shortnose sturgeon have a long-duration spawning style, i.e., females pause movement and spawn small batches of eggs several times/h at different sites, the entire spawning process lasting 24–48 h (Kynard et al. In press–b). Thus, although we collected evidence of a spawning migration in spring 2006, during four spring periods (2004–2007), we collected no evidence of successful spawning by shortnose sturgeon in the river. When females are rare, this situation is likely common because there will be years when no males or females are mature (Kieffer and Kynard In Press).

Water quality and forage

Water quality in the Potomac River provided minimal water temperature and DO conditions for adult shortnose sturgeon in summer and was acceptable other seasons. In the freshwater reach both tagged females used in summer 2006, water temperature was slightly higher than in the freshwater:saltwater reach, but the DO level was higher in freshwater reaches than in the saline reach. The slightly higher level of DO in fresh water compared to the saline reach may be the reason that both tagged females used the same freshwater reach in summer 2006. The 06 female is likely in the saline reach in summer 2007, a movement that may be related to the improved DO level in the saline reach (unpublished data).

Young juvenile shortnose sturgeons have no tolerance to salinity and remain in fresh water until they are about 10 months old (Jenkins et al. 1993). Within the Potomac River, this life history suggests that young juveniles spawned upstream at Fletchers-LFD would rear at the freshwater reach used by the tagged adults (like the situation for Connecticut River shortnose sturgeon; Kynard and Horgan 2002a). Our water quality sampling in the upstream part of the freshwater reach suggests that the DO and water temperature levels during summer in this reach would also be acceptable for juveniles. Based on our observations of adults and juveniles in lab tanks, high summer temperatures that exceed 27°C would likely cause sub-lethal effects (like reduced feeding and movement) by both life stages in the Potomac River. Temperature and DO conditions during summer, when river conditions for survival and growth are the most limiting for all life stages of shortnose sturgeon, provide an important clue as to the suitability of the Potomac River for the species.

In the freshwater reach we studied, Lippson (1979) reported large areas with sand bottom. We did not find sandy areas, and instead, mud dominated all areas. This suggests a major change has occurred in bottom composition during the past 30 years. The increase in the dominance of mud has likely had a major deleterious impact on available habitat and food for many fishes, including sturgeons. Previous studies found foraging juvenile and adult shortnose sturgeon did not use mud, or used it rarely, instead fish used a variety of mixed or hard substrates of sand–gravel (Kynard et al. 2000).

Is the river reach and habitat sufficient for a shortnose sturgeon population?

Can a shortnose sturgeon population complete all the stages of a life cycle in only about 100 km of river? Although recruitment has not been documented, shortnose sturgeon may do so in the Merrimack River in much less than 100 km (Kieffer and Kynard 1993, 1996). Whether Potomac River shortnose sturgeon are colonizers from the Delaware River (or other unknown donor river) or are the remnant of the natal Potomac River population, all information suggests there is sufficient river length and seasonal habitats to support a population. There is upstream spawning habitat, which provides rearing for eggs and free embryos, and there is foraging–wintering habitat in the freshwater:saltwater reach for year 1 and older juveniles and adults, which use similar habitat and concentration areas (Kynard et al. 2000). However, a major unanswered question on life history is whether there is rearing habitat for larvae and year-0 juveniles, the ontogenetic stages where year-class strength and future recruitment is established. These life stages would live downstream of the spawning area and upstream of the freshwater:saltwater interface, i.e., in the freshwater reach. Because other benthic species like suckers are abundant and spawn at the Fletchers–LFD area, it is likely that young suckers rear successfully. Research on spawning and food and habitats of sucker ELS could provide insight into the situation for young sturgeons.

River length is an important factor in the early life history of shortnose sturgeon (Kynard and Horgan 2002a). The dispersal of larvae must stop when fish are still in fresh water because they have no tolerance to salinity. Thus, distance between the spawning area and salt water is important to life history. Downstream dispersal by larvae is an adaptation evolved by each population to place larvae at the appropriate rearing reach upstream of salt water. If Potomac River shortnose sturgeon adults are colonizers from a donor river, the dispersal style of the larvae may not match the appropriate drift distance for the Potomac River because the spawning areas in the two rivers may not be the same distance upstream from salt water. If genetic studies show the two Potomac River females are from the Delaware River, then a laboratory study of Delaware River larval dispersal should be done to determine if there is a mis-match between their innate dispersal distance and the length of the freshwater reach available in the Potomac River. This may not be a problem because spawning occurs in the Delaware River at rkm 220, which is close to rkm 185–197 where spawning habitat is available in the Potomac River. The dispersal pattern of larvae from the Delaware or Potomac River shortnose sturgeon could be studied in the laboratory, as was done with Connecticut and Savannah River shortnose sturgeon (Kynard and Horgan 2002a, Parker 2007).

Status of Potomac River shortnose sturgeon

The major goal of the life history research was to understand the status and life history of shortnose sturgeon in the Potomac River. The data indicated the species is very rare and either a remnant of the natal Potomac River population or colonizers from another north-central river, most likely the Delaware River, the nearest river with a large shortnose sturgeon population and with similar life history traits (one-step spawning migration and use of salinity). We identified the river reaches used for summering and wintering, and potentially, for spawning. The long residence time and repeated seasonal use of these same summering–wintering reaches by the tagged Potomac River adults, suggest they are not coastal non-natal migrant adults that have entered the river to forage, then depart after a few months. Although the two females used slightly different river reaches relative to salinity, both homed to river reaches and use of river reaches were like the species in other rivers. If the fish are non-natal colonizers, their relative use of freshwater and saline reaches suggest they are not likely from distant southern rivers, where adults use highly saline water in winter more than the tracked Potomac River adults (Kynard 1997). The genetics study (Part II of this report) should provide the answer to the natal origin of the two females.

All data indicated shortnose sturgeon abundance is very low, with fewer adults present than in any river yet found with a sustaining population (Kynard 1997). Whether a population is building from colonizers or from a few natal remnant fish, it could take many years before a sustaining population is established with the presence of all year classes.

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Table 1. Information on fishes captured during gill netting for shortnose sturgeon in the Potomac River during 2004. Water temperature, salinity and dissolved oxygen were measured within 1 m of the river bottom. NM = not measured.

Common name	Scientific name	Number captured	Capture date(s)	Temperature (°C)	Salinity (‰)	Dissolved oxygen (mg/L)	Depth (m)
Little Falls (rkm 189); 7sets (147.0 h)							
Quillback sucker	*Carpiodes cyprinus*	1	1 Apr	11.2	NM	NM	1.5–4.0
Walleye	*Stizostedion vitreum*	1	1 Apr	11.2	NM	NM	1.5–4.0
Chain Bridge/Fletchers (rkm 184.5–187); 6 sets (141.6 h)							
Blue catfish	*Ictalurus furcatus*	2	1–8 Apr	10.2–11.2	NM	NM	5.5–6.1
Carp	*Cyprinus carpio*	1	8 Apr	10.2	NM	NM	5.5–6.2
Channel catfish	*Ictalurus punctatus*	1	8 Apr	10.2	NM	NM	5.5
Gizzard shad	*Dorosoma cepedianum*	3	1 Apr	11.2	NM	NM	3.1–6.1
Quillback sucker	*Carpiodes cyprinus*	15	1–8 Apr	10.2–11.2	NM	NM	3.1–6.2
Striped bass	*Morone saxatilis*	3	1–8 Apr	10.2–11.2	NM	NM	3.1–6.3
Craney Island (rkm 139); 2 sets (41.2 h)							
Goldfish	*Carassius auratus*	1	29 Jul	26.7	0	5.8	1.2
Aquia Creek (rkm 104); 4 sets (85.4 h)							
Blue catfish	*Ictalurus furcatus*	2	28 Jul	25.7–27.0	0	7.6	5.2
Roosevelt Island (rkm 163–179); 47 sets (747.0 h)							
Blue catfish	*Ictalurus furcatus*	18	3 Aug–23 Sep	19.7–27.5	0.1	7.7	2.1–4.9
Carp	*Cyprinus carpio*	54	4 Aug–5 Oct	19.0–28.4	0.1	7.7	1.8–4.0
Channel catfish	*Ictalurus punctatus*	26	3 Aug–23 Sep	19.7–28.4	0.1	8.7	1.8–10.1
Gizzard shad	*Dorosoma cepedianum*	7	1–22 Sep	19.7–28.4	0.2	6.8	2.7–4.6
Goldfish	*Carassius auratus*	2	1–2 Sep	27.5–28.4	0.2	6.0	3.7–4.6
Quillback sucker	*Carpiodes cyprinus*	10	5 Aug–23 Sep	19.7–28.4	0.2	6.9	1.8–4.9
Striped bass	*Morone saxatilis*	1	2 Sep	28.4	0.2	6.0	3.5
Walleye	*Stizostedion vitreum*	3	1 Sep	27.5	0.2	6.0	2.7–3.1

Table 2. Information on fishes captured in 100-m long anchored multifilament gill nets set for shortnose sturgeon in the Potomac River during 2005. Water temperature, salinity and dissolved oxygen were measured near the river bottom. NM = not measured; * = 50-m long gill net.

Common name	Scientific name	Number captured	Capture date(s)	Temperature (°C)	Salinity (‰)	Dissolved oxygen (mg/L)	Depth (m)
Little Falls (rkm 189); 35 sets (759.1 h)*							
Carp	*Cyprinus carpio*	7	5–18 Apr	NM	NM	NM	< 4.0
Gizzard shad	*Dorosoma cepedianum*	31	6–18 Apr	NM	NM	NM	< 4.0
Quillback sucker	*Carpiodes cyprinus*	3	7–18 Apr	NM	NM	NM	< 4.0
White sucker	*Catostomus commersoni*	1	6 Apr	NM	NM	NM	< 4.0
Chain Bridge (rkm 187); 12 sets (124.4 h)*							
Blue catfish	*Ictalurus furcatus*	8	23–27 Jun	25.0–27.9	0	NM	5.7–10.2
Channel catfish	*Ictalurus punctatus*	4	23–27 Jun	25.0–27.9	0	NM	4.8–10.2
Flathead catfish	*Pylodictis olivaris*	1	23–27 Jun	25.0	0	NM	9.0
Gizzard shad	*Dorosoma cepedianum*	4	23–27 Jun	25.0–27.9	0	NM	4.8–10.2
Fletchers (rkm 185); 9 sets (19.1 h)*							
Blue catfish	*Ictalurus furcatus*	4	20 Apr	NM	NM	NM	4.5–6.0
Carp	*Cyprinus carpio*	3	21–28 Apr	NM	NM	NM	2.4–7.2
Gizzard shad	*Dorosoma cepedianum*	3	21–26 Apr	NM	NM	NM	4.5–5.4
Quillback sucker	*Carpiodes cyprinus*	3	21–28 Apr	NM	NM	NM	2.4–7.2
Fort Belvior (rkm 142); 4 sets (9.1 h)							
Carp	*Cyprinus carpio*	2	8 Aug	30.2	0.1	6.9	10.8–12.3
Channel catfish	*Ictalurus punctatus*	8	8 Aug	30.2	0.1	6.9	10.8–13.5
Gunston Cove (rkm 140); 12 sets (124.4 h)							
Blue catfish	*Ictalurus furcatus*	4	8 Aug	29.3	0.1	6.3	8.1–9.2
Channel catfish	*Ictalurus punctatus*	1	8 Aug	29.3	0.1	6.3	8.4–8.9
Craney Island (rkm 139); 28 sets (60.0 h)							
Blue catfish	*Ictalurus furcatus*	9	5–12 Jul	28.2–28.9	0–0.2	NM	1.6–19.8
Carp	*Cyprinus carpio*	7	11–12 Jul	28.2–28.9	0.1–0.2	NM	1.6–2.1
Channel catfish	*Ictalurus punctatus*	7	11–13 Jul	27.8–28.2	0–0.2	NM	1.6–2.0
Gizzard shad	*Dorosoma cepedianum*	9	5–7 Jul	28.5–28.7	0–0.1	7.1	3.4–9.6
Shortnose sturgeon	*Acipenser brevirostrum*	1	20 Sep	26.9	0.1	5.2	22.4
Bouy 56 (rkm 137); 36 sets (529.3 h)							
Blue catfish	*Ictalurus furcatus*	7	Oct	17.0–26.4	0.1	6.0	7.5–21.6
Channel catfish	*Ictalurus punctatus*	6	Oct	14.3–27.1	0.1	8.4	6.6–21.0
Gizzard shad	*Dorosoma cepedianum*	12	Oct	17.0–26.4	0.1	6.6	6.3–15.6
Hog choker	*Trinectes maculatus*	1	29 Sep	23.8	0	6.0	11.4
Menhaden	*Brevoortia tyrannus*	2	23 Sep	26.5	0	5.4	9.3–10.8
Striped bass	*Morone saxatilis*	1	4 Oct	22.4	0	6.6	6.9–7.5

Cockpit Point (rkm 124); 20 sets (40.1 h)							
Blue catfish	*Ictalurus furcatus*	3	19–21 Jul	28.8–29.4	0	NM	1.3–8.4
Carp	*Cyprinus carpio*	1	19 Jul	29.4	0	NM	1.3–1.5
Channel catfish	*Ictalurus punctatus*	1	29 Jul	29.0	0	NM	4.5–4.8
Gizzard shad	*Dorosoma cepedianum*	7	26–29 Jul	29.0–30.2	0.1	7.5	5.7–6.3
Bouy 41 (rkm 115); 4 sets (87.7 h)							
Nothing caught			14–15 Nov	13.3	0.9	8.7	6.3
Aquia Creek (rkm 104); 12 sets (287.0 h)							
Blue catfish	*Ictalurus furcatus*	2	16–21 Jun	27.7	NM	NM	3.7–4.0
Carp	*Cyprinus carpio*	1	20 Jun	NM	NM	NM	3.5
Channel catfish	*Ictalurus punctatus*	5	16 Jun	27.7	NM	NM	4.0
Large mouth bass	*Micropterus salmoides*	2	20–21 Jun	NM	NM	NM	3.5–3.9
Longnose gar	*Lepisosteus osseus*	1	21 Jun	NM	NM	NM	3.5
Potomac Creek (rkm 99); 10 sets (147.0 h)							
Carp	*Cyprinus carpio*	5	14 Jun	27.7	0.1	NM	2.1–3.4
Channel catfish	*Ictalurus punctatus*	15	13–14 Jun	27.0–27.7	0.1	7.5	2.1–3.5
Gizzard shad	*Dorosoma cepedianum*	2	14 Jun	27.7	0.1	NM	3.4

Table 3. Characteristics of shortnose sturgeon at original capture and recapture sites in the Potomac River. The 05 and 06 sturgeon were fish captured in 2005 and 2006, respectively.

Sturgeon	Capture date	Capture site (rkm)	Fork length (cm)	Total length (cm)	Weight (kg)	Sex	Egg maturity
05 sturgeon	09/20/05	139	73.0	82.0	4.3	female	late
05 sturgeon	04/12/06	185	73.0	82.0	3.8	female	unknown
05 sturgeon	08/04/06	139	74.0	83.0	4.0	female	unknown
05 sturgeon	07/16/07	134	80.0	88.0	4.5	female	early
06 sturgeon	03/22/06	66	75.0	84.0	4.8	female	late

Table 4. Information on fishes captured during drifting a 150-m long gill net for shortnose sturgeon in the Potomac River in 2005. Water temperature, salinity, and dissolved oxygen were measured witnin 1 m of the river bottom. NM = not measured.

Common name	Scientific name	Number captured	Capture date(s)	Temperature (°C)	Salinity (‰)	Dissolved oxygen (mg/L)	Depth (m)
Gunston Cove (rkm 140); 1 set (1.2 h)							
Gizzard shad	*Dorosoma cepedianum*	1	17 Aug	NM	NM	NM	3.9–5.4
Craney Island (rkm 139); 2 sets (1.3 h)							
Carp	*Cyprinus carpio*	2	7 Sep	NM	NM	NM	3.5
Bouy 54 (rkm 132); 3 sets (4.1 h)							
Blue catfish	*Ictalurus furcatus*	2	6 Oct	22.8	NM	6.3	9–13.5
Channel catfish	*Ictalurus punctatus*	1	6 Oct	22.8	NM	6.3	9–13.5
Gizzard shad	*Dorosoma cepedianum*	75	6–24 Oct	16.0–22.8	NM	6.3	9–13.5
Possum Point (rkm 123); 6 sets (6.0 h)							
Blue catfish	*Ictalurus furcatus*	37	24–26 Aug	27.7–28.6	0.4–0.6	4.7–5.3	8.1–10.0
Channel catfish	*Ictalurus punctatus*	3	24–25 Aug	28.2–28.6	0.4–0.6	4.7–5.3	7.3–9.6
Gizzard shad	*Dorosoma cepedianum*	41	24–26 Aug	27.7–28.6	0.4–0.6	4.7–5.3	7.3–10.0
Quantico (rkm 115); 4 sets (2.9 h)							
Blue catfish	*Ictalurus furcatus*	5	18–Aug	29.2	0.5	4.5	6.7–8.9
Longnose gar	*Lepisosteus osseus*	1	19–Aug	28.9	0.8	5.0	5.6–6.4
Gizzard shad	*Dorosoma cepedianum*	8	18–19 Aug	28.9–29.2	0.5–0.8	4.5–5.0	5.6–7.4
Aquia Creek (rkm 104); 6 sets (5.8 h)							
Blue catfish	*Ictalurus furcatus*	3	11–12 Aug	29.3	1.1	6.5	3.2
Gizzard shad	*Dorosoma cepedianum*	13	11 Aug–1 Sep	26.9–29.4	1.1–1.2	6.5	3.1–3.9
Menhaden	*Brevoortia tyrannus*	13	11–12 Aug	29.3	1.1	6.5	3.2–3.6

Table 5. Information on fishes captured in 100-m long anchored multifilament gill nets set for shortnose sturgeon in the Potomac River during 2006. Water temperature, salinity and dissolved oxygen were measured near the river bottom. Underlined sampling areas show river km, number of nets set, and number of hours nets fished. NM = not measured; * = 50-m long gill net.

Common name	Scientific name	Number captured	Capture date(s)	Temperature (°C)	Salinity (‰)	Dissolved oxygen (mg/L)	Depth (m)
Little Falls (rkm 189)*; 16 sets (370.4 h)							
American shad	*Alosa sapidissima*	2	29 Mar	11.8	0.2	NM	< 2
Carp	*Cyprinus carpio*	1	29 Mar	11.8	0.2	NM	< 2
Quillback sucker	*Carpiodes cyprinus*	4	12–13 Apr	14.5	0.2	NM	< 2
Chain Bridge/Fletchers (rkm 184.5–187); 9 sets (213.5 h)							
American shad	*Alosa sapidissima*	3	17–18 Apr	18.2	0.2	8.2	10–12
Blue catfish	*Ictalurus furcatus*	7	11–17 Apr	18.2	0.2	8.2	10–12
Carp	*Cyprinus carpio*	14	11–18 Apr	18.2	0.2	8.2	10–12
Channel catfish	*Ictalurus punctatus*	5	17–18 Apr	18.2	0.2	8.2	10–12
Gizzard shad	*Dorosoma cepedianum*	18	11–18 Apr	18.2	0.2	8.2	10–12
Quillback sucker	*Carpiodes cyprinus*	4	17–18 Apr	18.2	0.2	8.2	10–12
White catfish	*Ameiurus catus*	1	17 Apr	NM	0.2	NM	10–12
Shortnose sturgeon	*Acipenser brevirostrum*	1	12 Apr	NM	NM	NM	NM
Craney Island (rkm 139); 19 sets (128.3 h)							
Blue catfish	*Ictalurus furcatus*	3	13–21 Jun	23.3–26.3	0.2	5.9–6.9	8–22
Carp	*Cyprinus carpio*	1	12 Sep	23.7	0.2	5.5	17
Channel catfish	*Ictalurus punctatus*	3	12 Jun–12 Sep	23.3–28.4	0.2	5.0–6.7	4–17
Gizzard shad	*Dorosoma cepedianum*	46	12–22 Jun	23.3–26.7	0.2	6.5–6.7	4–23
Longnose gar	*Lepisosteus osseus*	1	13 Jun	23.3	0.2	5.9	22
Menhaden	*Brevoortia tyrannus*	99	13–22 Jun	23.3–26.7	0.2	5.9–6.5	8–22
Quillback sucker	*Carpiodes cyprinus*	1	12 Jun	23.3	0.2	6.7	7
Shortnose sturgeon	*Acipenser brevirostrum*	1	4 Aug	31.9	0.1	6.6	13
Bouy 52 (rkm 133); 17 sets (30.7 h)							
Blue catfish	*Ictalurus furcatus*	2	15 Sep	22.3	0.2	5.9	12–13
Gizzard shad	*Dorosoma cepedianum*	1	15 Sep	22.3	0.2	5.9	12–13
Cockpit point (rkm 124); 18 sets (351.4 h)							
Blue catfish	*Ictalurus furcatus*	17	7 Jun– Sep 6	23.3–24.9	0.2–1.1	5.3–6.7	7–10
Carp	*Cyprinus carpio*	4	7–20 Jun	23.3–24.9	0.2–1.1	5.3–6.7	7–10
Channel catfish	*Ictalurus punctatus*	5	7–14 Jun	23.3–24.9	0.2–1.1	5.3–6.7	7–10
Gizzard shad	*Dorosoma cepedianum*	1	8–20 Jun	23.3–24.9	0.2–1.1	5.3–6.7	7–10
Longnose gar	*Lepisosteus osseus*	7	7–14 Jun	23.3–24.9	0.2–1.1	5.3–6.7	7–10
Menhaden	*Brevoortia tyrannus*	65	7–14 Jun	23.3–24.9	0.2–1.1	5.3–6.7	7–10
Maryland Point (rkm 99); 2 sets (43.3 h)							
Blue catfish	*Ictalurus furcatus*	1	25 Sep	21.9	3.9	7	14–16
Bouy 13 (rkm 94); 8 sets (192.8 h)							
American shad	*Alosa sapidissima*	2	22 May	NM	NM	NM	7
Channel catfish	*Ictalurus punctatus*	4	18 May	19.4	3.5	6.3	7
Croaker	*Micropogonias undulatus*	2	18–22 May	19.4	3.5	6.3	7
Menhaden	*Brevoortia tyrannus*	86	18–22 May	19.4	3.5	6.3	7

Table 6. Information on fishes captured when drifting a 150-m long gill net near the bottom for shortnose sturgeon in the Potomac River in 2006. Water temperature, salinity and dissolved oxygen were measured near the river bottom. Underlined sampling areas show river km, number of nets set, and number of hours nets fished. NM = not measured.

Common name	Scientific name	Number captured	Capture date	Temperature (°C)	Salinity (‰)	Dissolved oxygen (mg/L)	Depth (m)
Craney Island (rkm 139); 24 sets (26.9 h)							
Blue catfish	*Ictalurus furcatus*	7	28 Sep–1 Nov	12.2–21.7	0.1	6.0–9.0	10–23
Carp	*Cyprinus carpio*	2	2–10 Oct	18.9–20.4	0.1	6.1–7.1	14–23
Channel catfish	*Ictalurus punctatus*	4	11 Sep–3 Oct	20.4–23.7	0.1	5.5–6.1	13–20
Gizzard shad	*Dorosoma cepedianum*	2	25 Aug–18 Oct	16.8–27.8	0.1	6.0–7.5	10–17
White sucker	*Catastomus commersoni*	3	18–19 Oct	16.8–17.1	0.1	7.5	13–18
Bouy 52 (rkm 132); 14 sets (16.0 h)							
Blue catfish	*Ictalurus furcatus*	26	7 Jul–17 Aug	26.0–30.9	0.1	5.0–6.4	35–44
Carp	*Cyprinus carpio*	1	7 Jul	26.0	0.1	5.5	43
Channel catfish	*Pylodictis olivaris*	2	7 Jul–17 Aug	26.0–30.9	0.1	5.0–6.4	35–44
Flathead catfish	*Ictalurus punctatus*	2	21 Jul	26.9	0.1	6.0	35
Gizzard shad	*Dorosoma cepedianum*	14	7 Jul–17 Aug	26.0–30.9	0.1	5.0–6.4	35–44
Longnose gar	*Lepisosteus osseus*	1	17 Aug	27.6	0.1	6.2	37–44
Possum Point (rkm 123); 15 sets (12.5 h)							
Blue catfish	*Ictalurus furcatus*	14	7 Jun–29 Aug	24.2–30.2	0.7–1.1	5.3–6.8	9–14
Carp	*Cyprinus carpio*	2	18–29 Aug	27.2–28.1	0.7–0.9	5.7–6.7	8–11
Channel catfish	*Ictalurus punctatus*	5	7 Jun–29 Aug	24.2–30.2	0.7–1.1	5.3–6.8	8–14
Gizzard shad	*Dorosoma cepedianum*	9	7 Jun–28 Aug	24.2–30.2	0.7–1.1	5.3–6.8	7–14
Quantico (rkm 115); 5 sets (5.8 h)							
Atlantic sturgeon	*Acipenser oxyrinchus*	1	15 Aug	27.5	1.1	6.0	9
Blue catfish	*Ictalurus furcatus*	1	8 Jun–29 Aug	24.9–28.1	0.2–1.1	NM	6–9
Channel catfish	*Cyprinus carpio*	2	8 Jun–30 Aug	24.9–28.1	0.2–1.1	NM	9–11
Gizzard shad	*Ictalurus punctatus*	5	8 Jun–29 Aug	24.9–28.1	0.2–1.1	6.0	6–9
Menhaden	*Brevoortia tyrannus*	3	29–30 Aug	28.1	1.1	NM	6–10
Maryland Point (rkm 99); 19 sets (13.7 h)							
Atlantic sturgeon	*Acipenser oxyrinchus*	2	19–21 Sep	22.8	4.0	6.4	9–16
Blue catfish	*Ictalurus furcatus*	1	20 Sep	22.4	2.6	7.5	11–13
Hog choker	*Trinectes maculatus*	2	20–21 Sep	22.4	2.6	7.5	10–12
Menhaden	*Brevoortia tyrannus*	26	24 May–26 Sep	18.9–21.9	3.5–3.9	6.3–7.0	8–14
White catfish	*Ameiurus catus*	1	25 Sep	21.9	3.5	7.0	8–14
White perch	*Morone americana*	1	25 Sep	21.9	3.5	7.0	8–14
Bouy 13 (rkm 94); 1 set (1 h)							
Menhaden	*Brevoortia tyrannus*	20	23 May	18.9	3.5	6.3	7

Table 7. Information on fishes captured in 100-m long anchored multifilament gill nets set for shortnose sturgeon in the Potomac River during 2007. Underlined sampling areas show river km, number of nets set, and number of hours nets fished.

Common name	Scientific name	Number captured	Capture date	Depth (m)
Fletchers (rkm 185); 60 sets (1,097.1 h)				
American shad	*Alosa sapidissima*	2	11 Apr–1 May	4.0–16.0
Blue catfish	*Ictalurus furcatus*	12	9 Apr–8 May	6.0–23.0
Blueback herring	*Alosa aestivalis*	1	7 May	3.0–6.1
Carp	*Cyprinus carpio*	55	24 Apr–10 May	3.1–10.0
Channel catfish	*Ictalurus punctatus*	130	2 Apr–10 May	3.0–21.3
Gizzard shad	*Dorosoma cepedianum*	47	24 Apr–10 May	4.0–10.0
Largemouth bass	*Micropterus salmoides*	1	30 Apr	3.1–8.0
Muskellunge	*Esoz masquinongy*	1	9 Apr	4.0–6.0
Striped bass	*Morone saxatilis*	7	4 Apr–10 May	4.0–10.0
Quillback sucker	*Carpiodes cyprinus*	165	2 Apr–10 May	3.0–21.3
Walleye	*Stizostedion vitreum*	3	11–25 Apr	4.1–18.6
White catfish	*Ameiurus catus*	2	7–9 May	4.0–10.0
White perch	*Morone americana*	5	23–26 Apr	4.1–18.6
White sucker	*Catastomus commersoni*	2	2–11 Apr	3.6–10.0

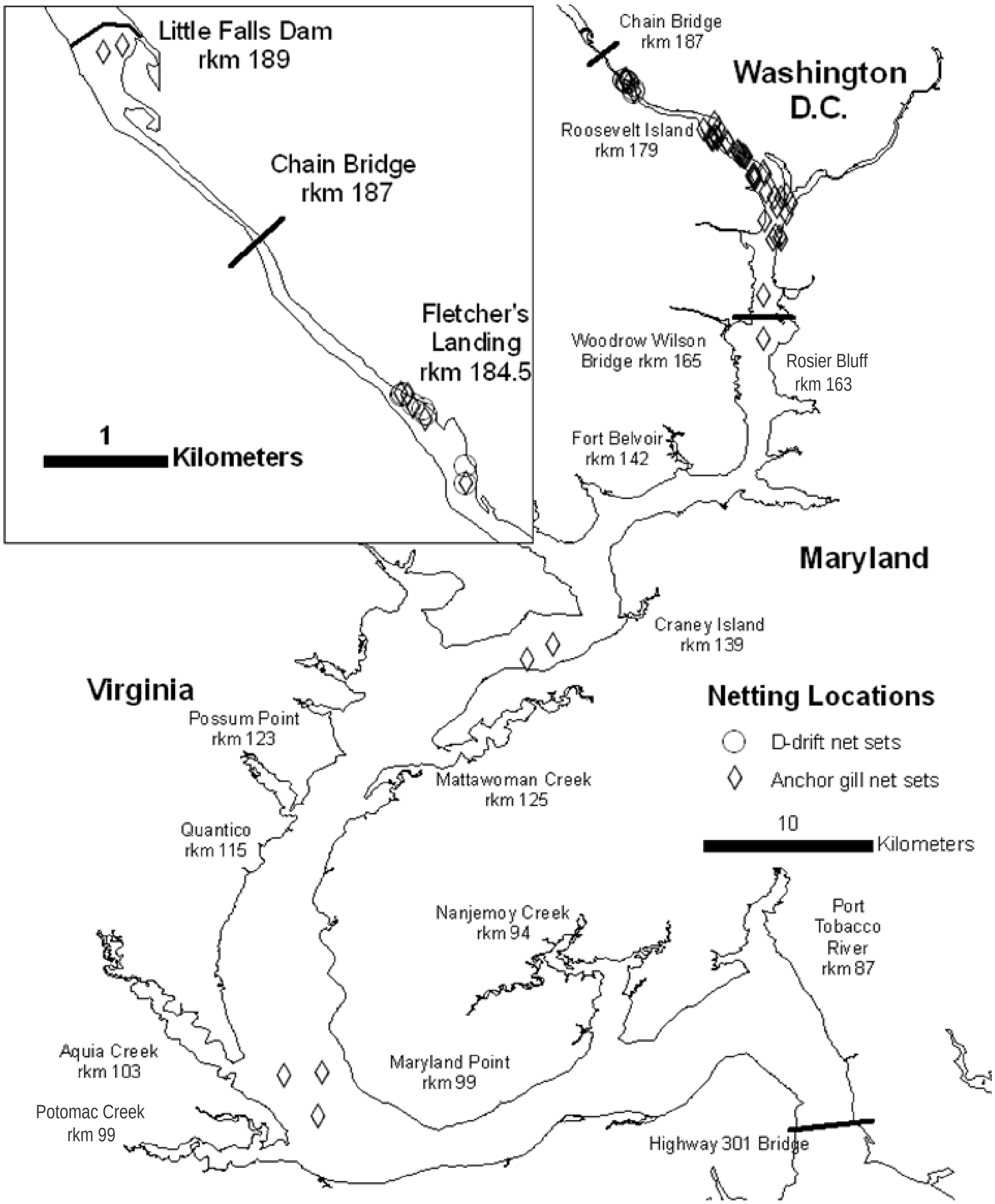

Figure 1. Map showing the study area and sampling locations for adults and early life stages during 2004. Inset map shows river reach sampled in spring with gill nets (for adults) and with D-nets (for early life stages) to evaluate spawning.

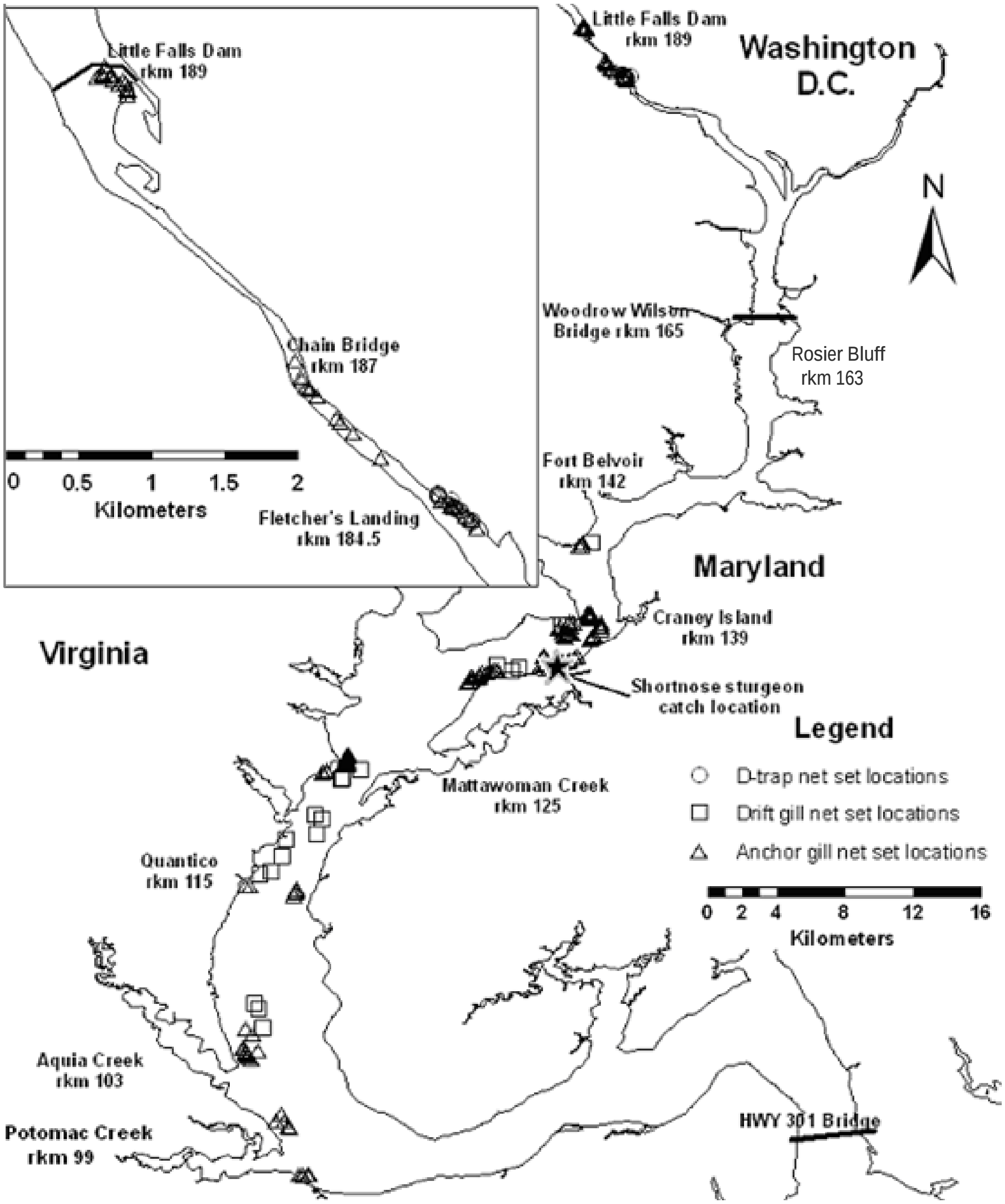

Figure 2. Map showing the study area for shortnose sturgeon during 2005. Inset Map shows the river reach sampled in the spring.

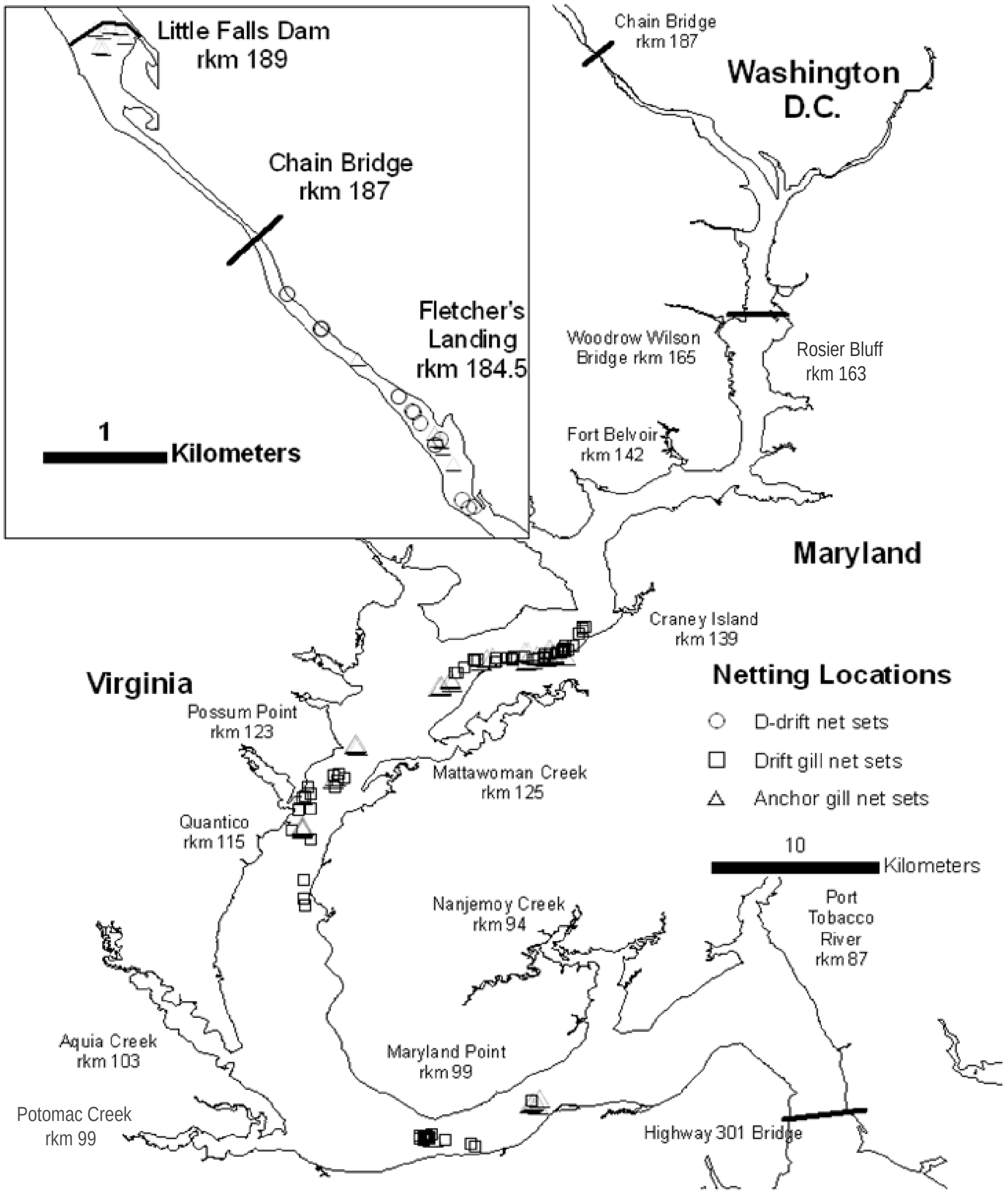

Figure 3. River reaches on the Potomac River sampled for shortnose sturgeon in 2006. D-drift nets were set at a potential spawning site to capture early life stages and verify spawning. Drift and anchor gill nets were set to capture adults for telemetry tagging. Inset map shows the most upstream reach studied from Little Falls Dam to Fletcher's Landing.

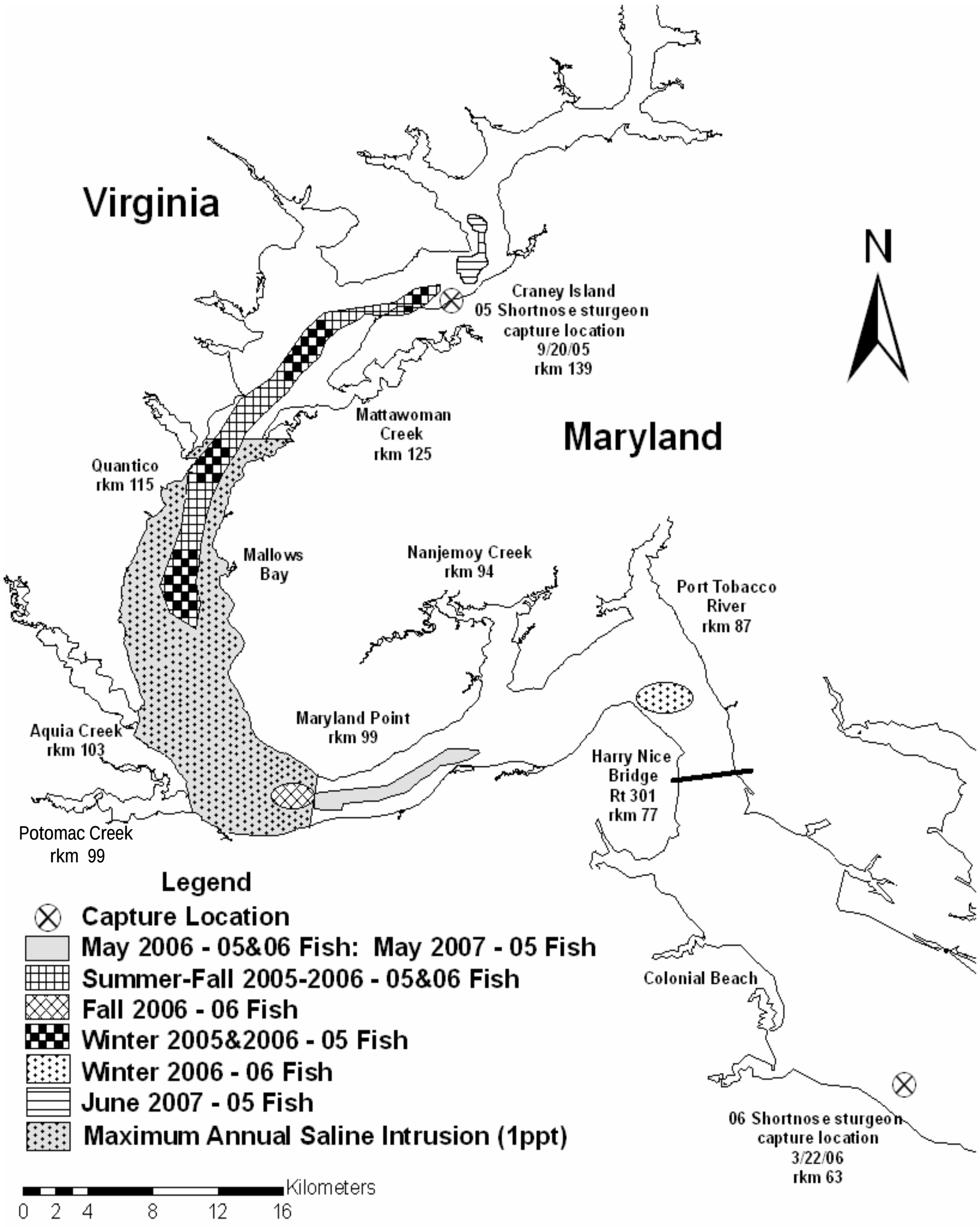

Figure 4. Summer-winter use of the Potomac River by two tagged female shortnose sturgeons (05 and 06 fish) in 2005–2007. A winter year is identified by the year a winter begins in December, but also includes January–March of the following year. The initial capture location of each female is also shown.

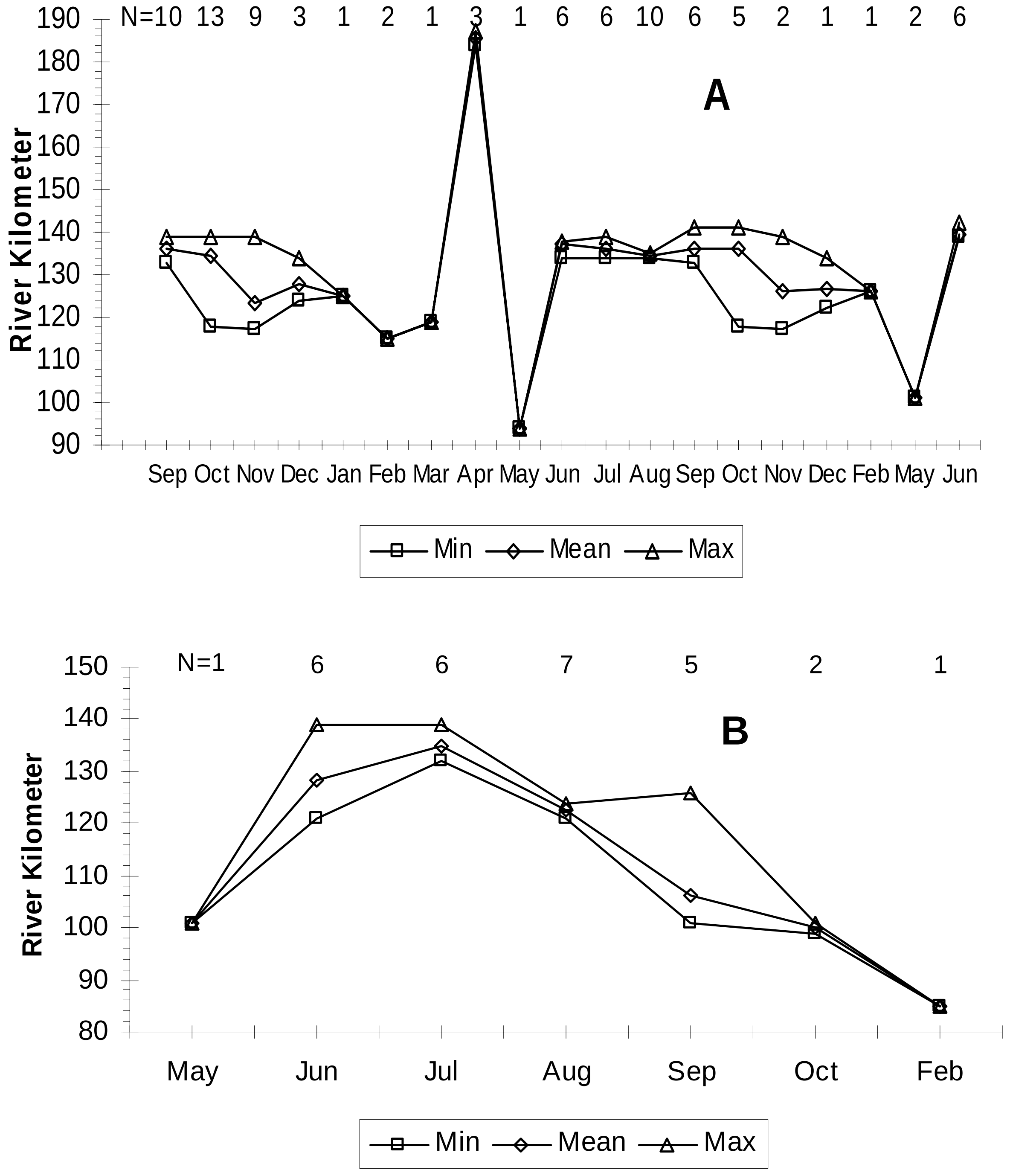

Figure 5. Monthly river reach and home range of two radio-tagged female shortnose sturgeons tracked in the Potomac River. Home range is the distance from the minimum (most downstream location) to the maximum (most upstream location) of fish each month. The 05 female (A) was captured and tagged at rkm 139 in September 2005 and tracked from September 2005 to June 2007. The 06 female (B) was captured and tagged at rkm 63 in March 2006 and tracked from May 2006 to February 2007. N = number of fish locations each month.

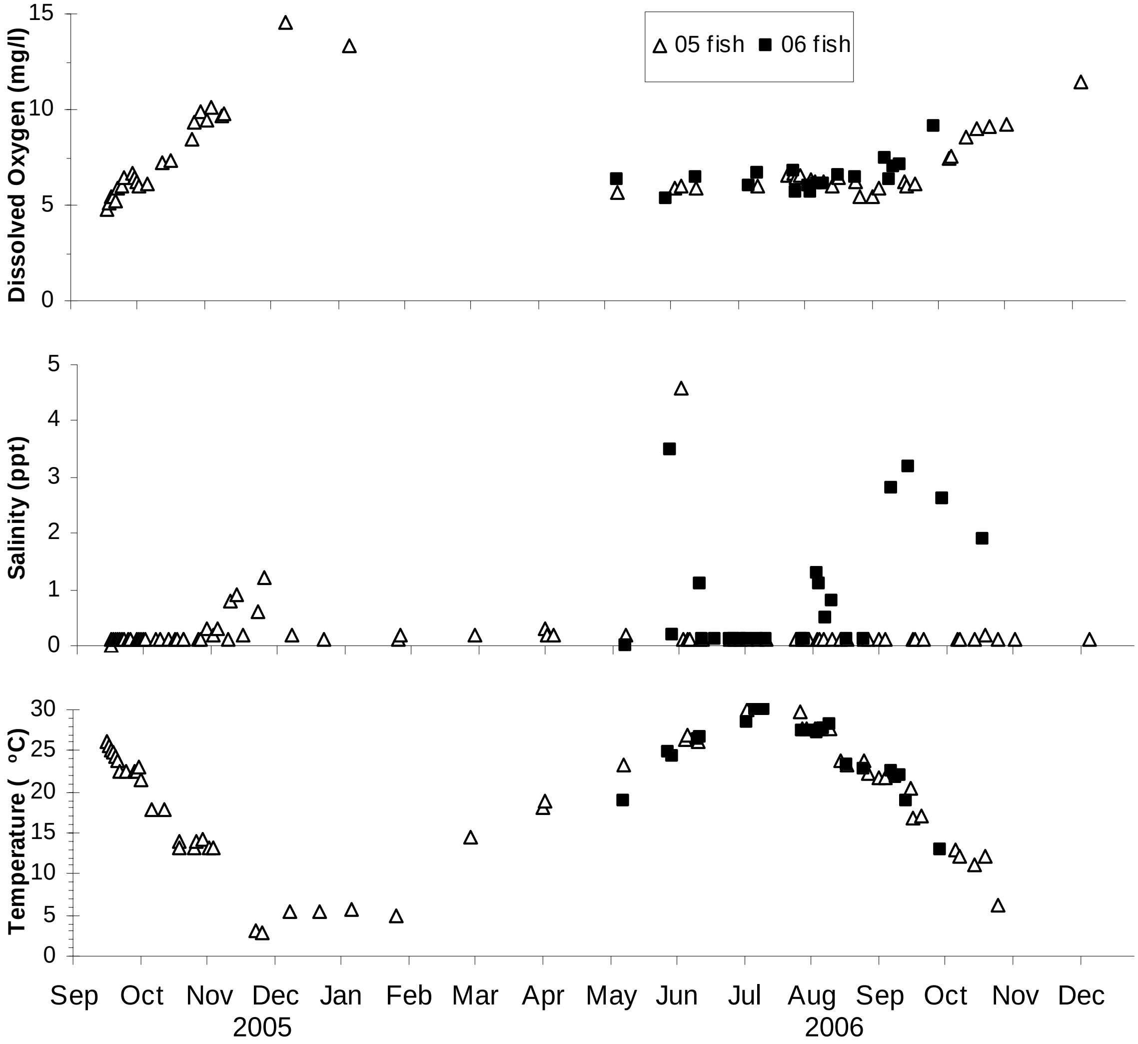

Figure 6. Water quality at monthly tracking locations of the 05 and 06 females.

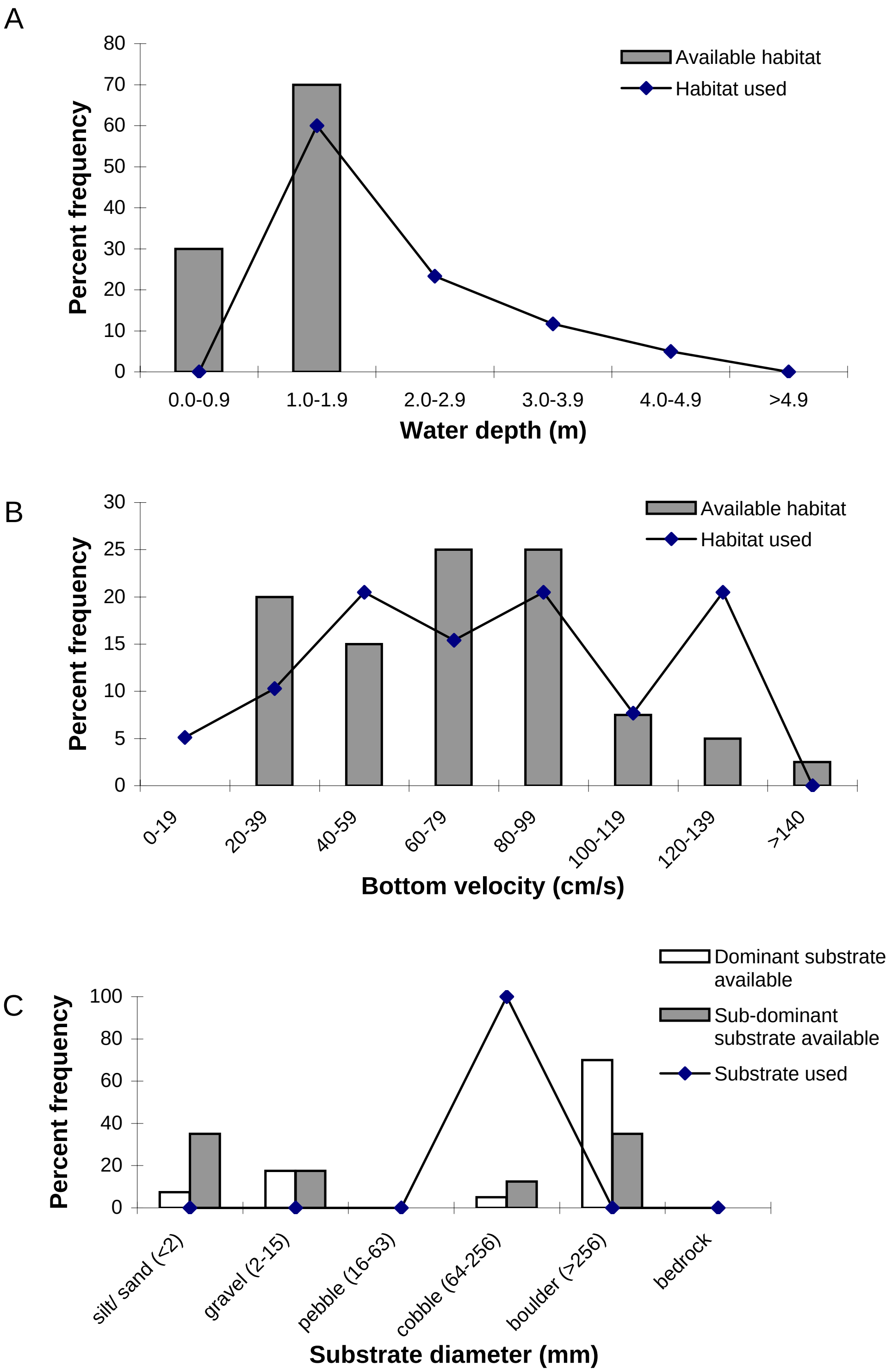

Figure 7. Characteristics of water depth, bottom velocity, and substrate type available for spawning of shortnose sturgeon at the Little Falls Dam area, Potomac River, and characteristics of these factors used (habitat use dategory) by shortnose sturgeons in the Connecticut River (Kieffer and Kynard unpublished data). River gauge height was 4.6 ft during sampling at Little Falls Dam.

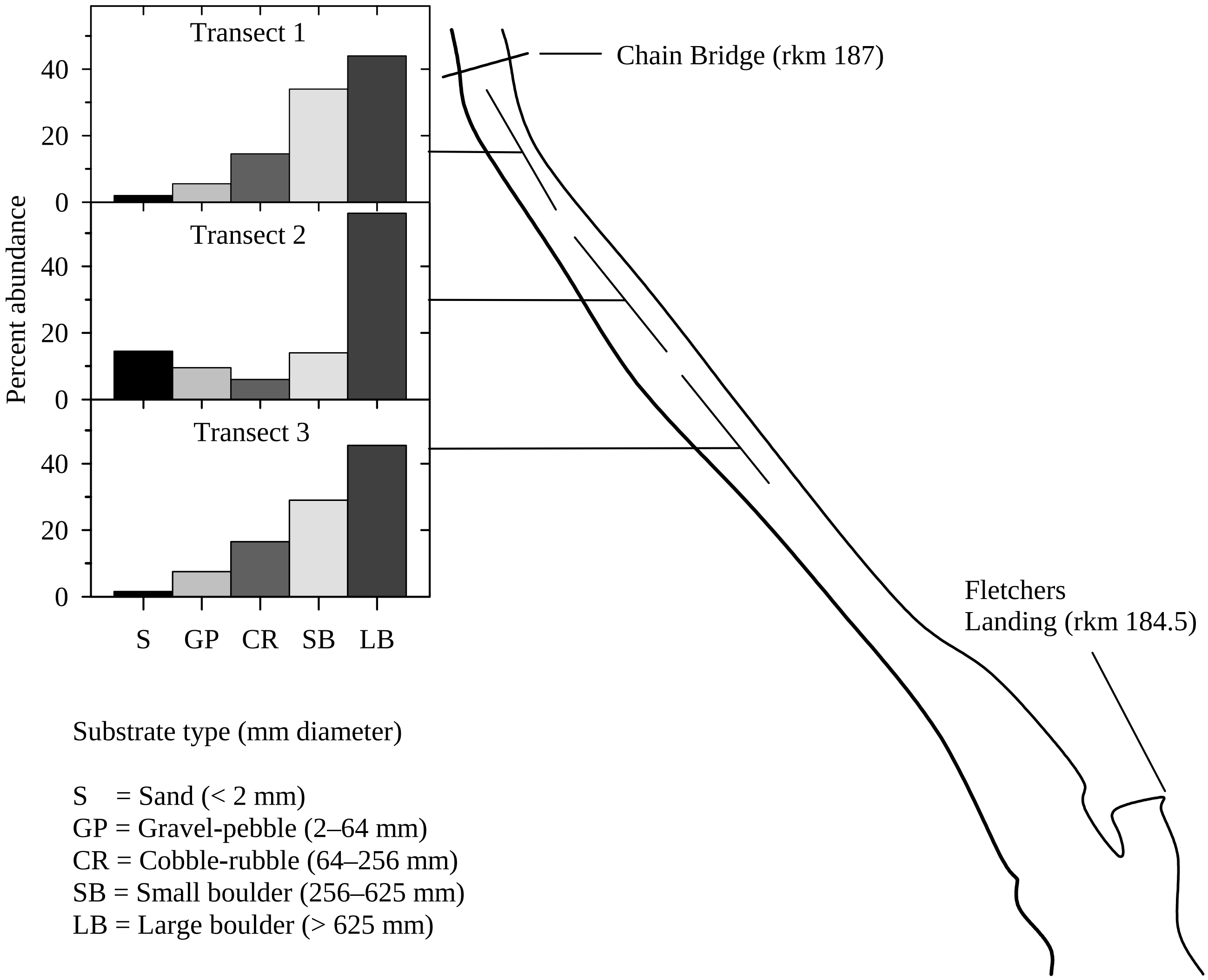

Figure 8. Bottom substrate type at three channel transects between Fletchers Landing and Chain Bridge. Each bottom transect was surveyed by underwater video and 10 video frames in each transect were classified for substrate composition

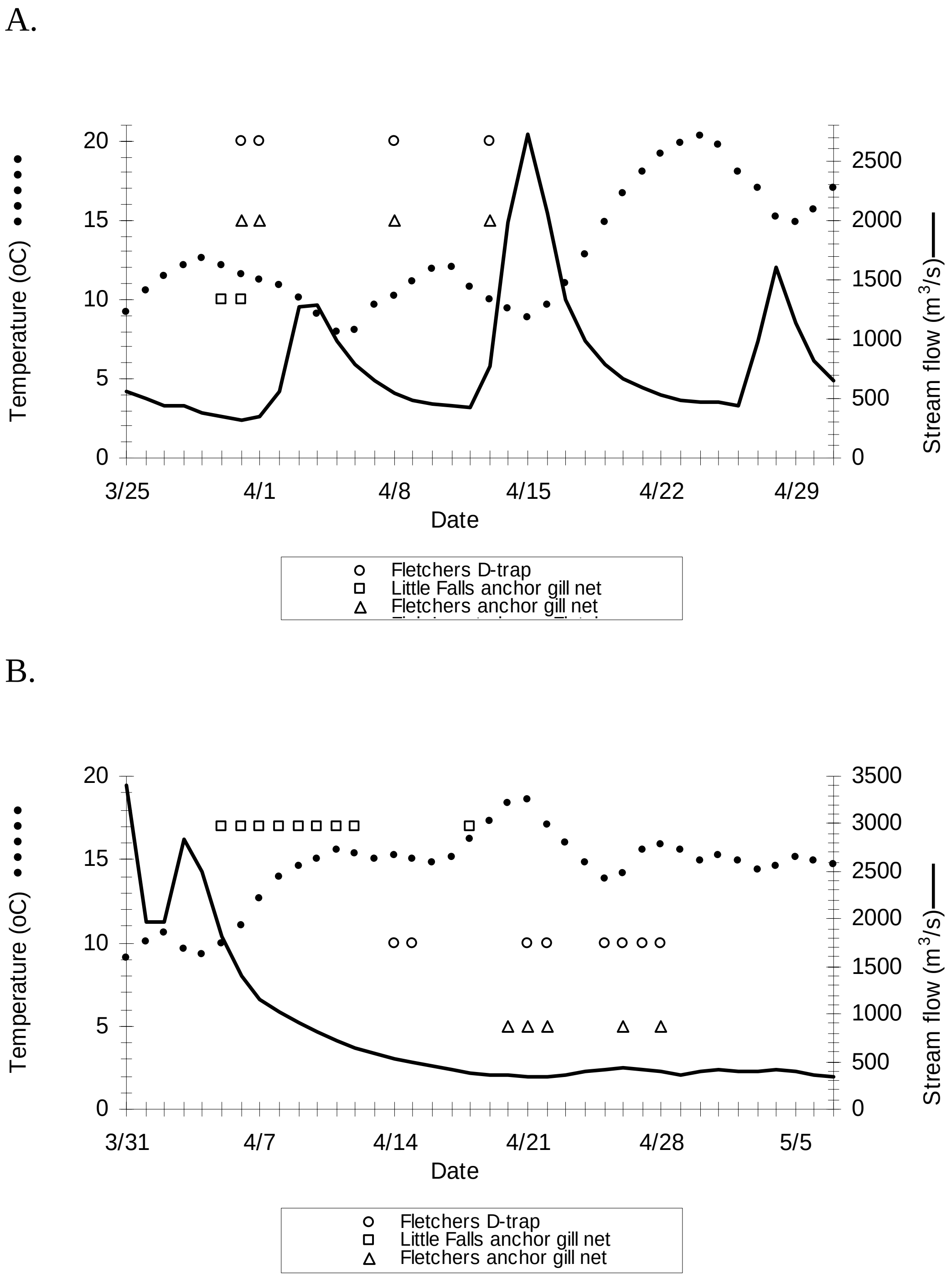

Figure 9. Mean daily river temperature and discharge along with capture activities for pre-spawning shortnose sturgeon (gill nets) and for early life stages (D-trap) in the Fletcher's Landing–Little Falls Dam reach of the Potomac River. Net locations are shown in Figures 1 and 2 inset. Upper panel shows spring 2004, lower panel shows spring 2005.

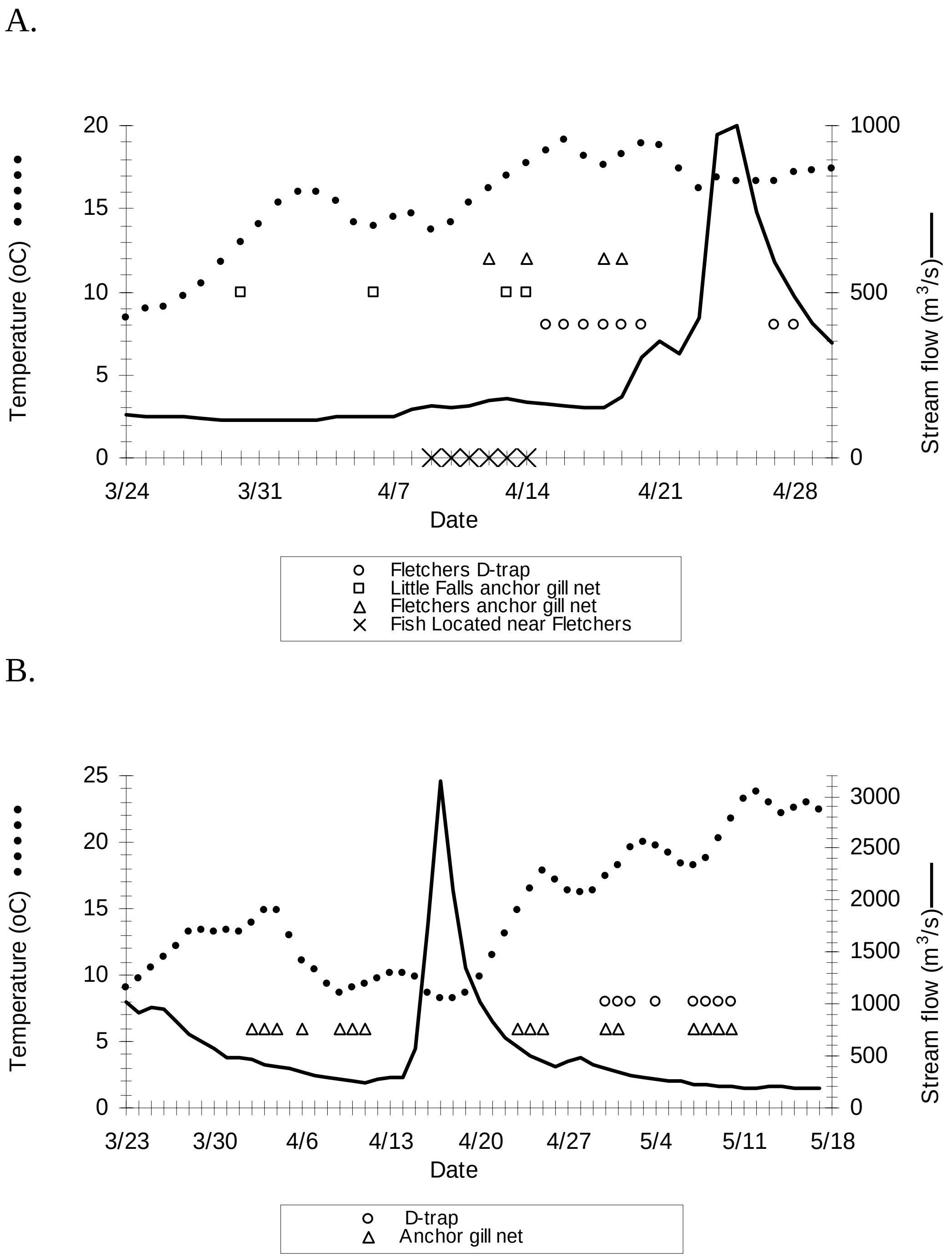

Figure 10. Mean daily river temperature and discharge along with capture activities for pre-spawning shortnose sturgeon (gill nets) and for early life stages (D-trap) in the Fletcher's Landing–Little Falls Dam reach of the Potomac River. Net locations are shown in Figures 3 and 2 inset map. Upper panel shows spring 2006, lower panel shows spring 2007.

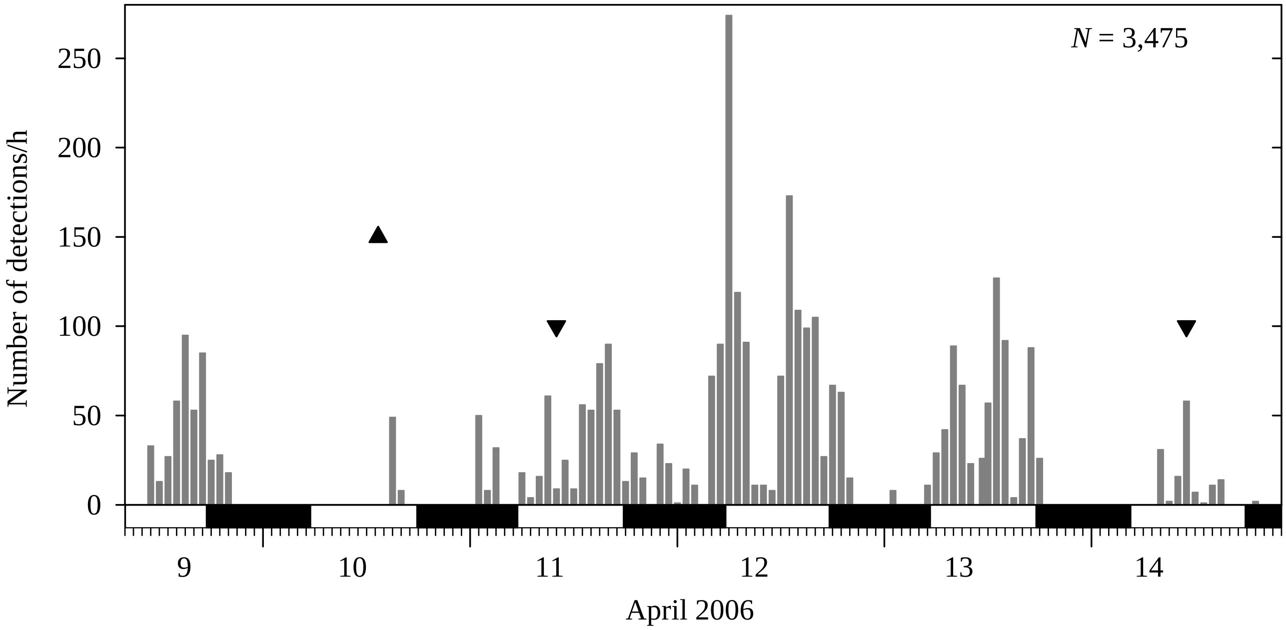

Figure 11. Frequency the 05 female was detected in the Potomac River by remote telemetry station at Fletcher's Landing (rkm 184.5) between 9–14 April 2006. Gray vertical bars indicate the number of times telemetry tag was logged per hour. Bar along x-axis indicates diel time (white = day and black = night). Triangles indicate fish located during boat-tracking surveys; up-pointing triangle = fish located at Chain Bridge (rkm 187) and down-pointing triangles = fish located near Fletcher's Landing.

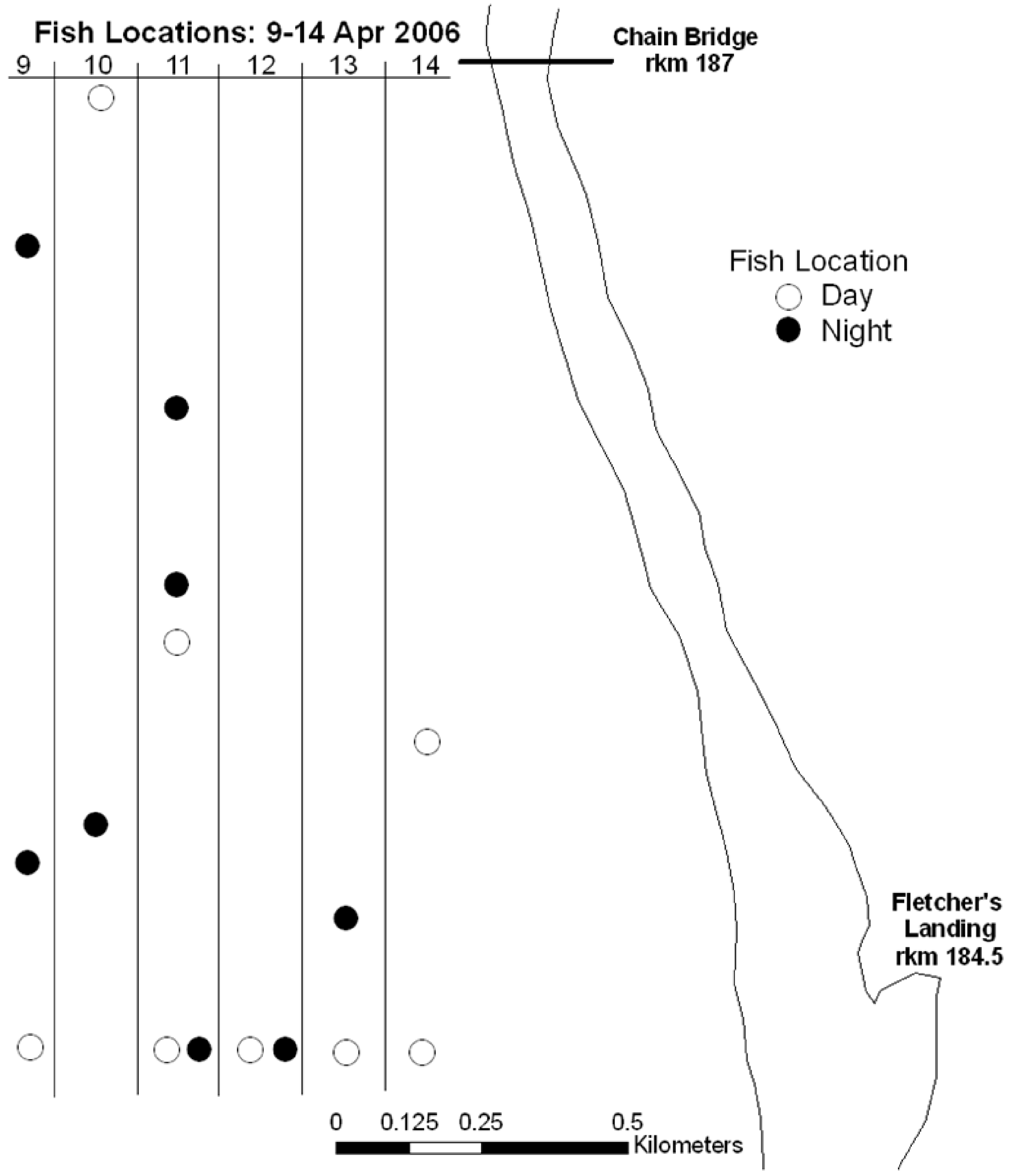

Figure 12. Manual tracking locations of the 05 female between Fletchers and Chain Bridge during the day and night of 9-14 April 2006.

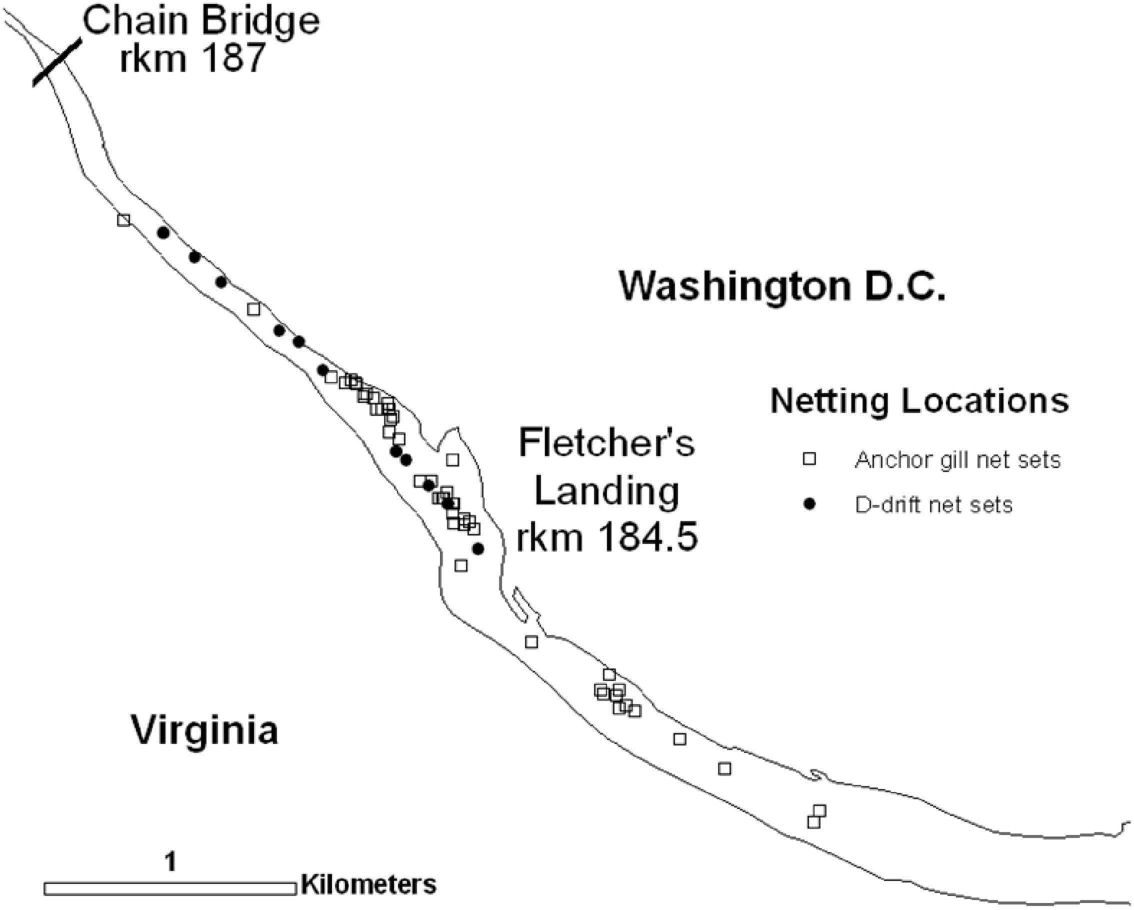

Figure 13. Sampling for shortnose sturgeon at the Fletcher's Landing-Chain Bridge reach of the Potomac River in spring 2007. Anchored gill nets were set to capture adults for telemetry tagging. D-drift nets were set at the potential spawning site identified by tracking a late stage female in 2006.

Figure 14. Location of the 14 buoy stations (buoy number and river km) sampled for water quality during May-December 2006.

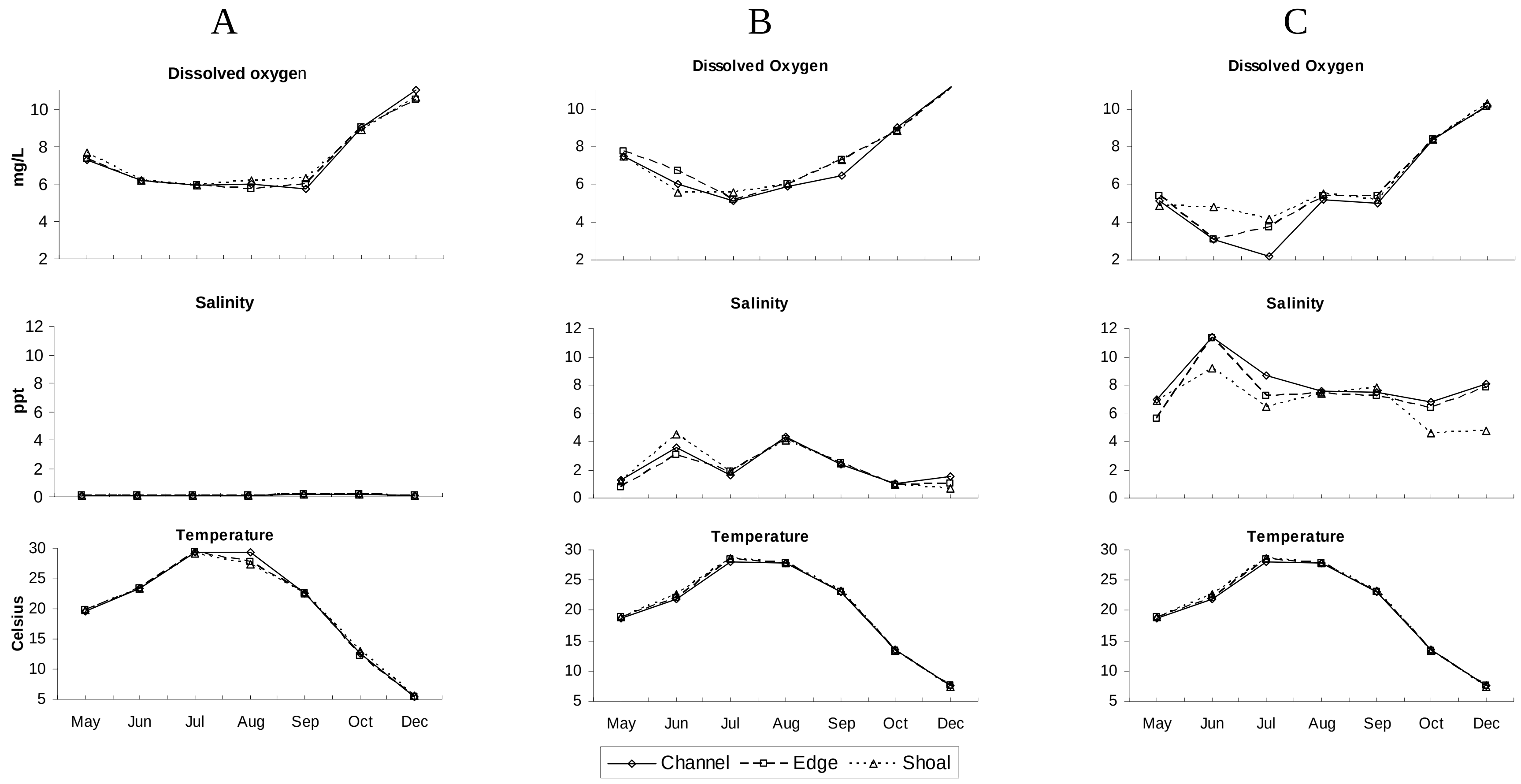

Figure 15. Water quality at the upstream station (A = Buoy 56), mid-station (B = Buoy 26), and lowermost station (C = Buoy 6) during May-December 2006. For each station, we present the data from three habitats: channel, channel edge and shoal.

Appendix 1. Water quality at 14 stations shown in Figure 14 during May–December 2006.

Date	5/16/2006				
Location		DO	Salinity	Temperature	Depth
38.36.684	Channel	7.3	0.1	19.9	75
77.08.415	Shoal	7.7	0.1	19.8	11
Bouy 56	Edge	7.3	0.1	19.7	37
	Channel	7.3	0.1	19.5	41
	Shoal	7.4	0.1	19.8	15
Bouy 54	Edge	7.2	0.1	19.7	27
38.35.699	Channel	7.3	0.1	19.6	23
77.11.976	Shoal	7.7	0.1	19.7	12
Bouy 52	Edge		0.1		
38.33.655	Channel	7.5	0.1	19.4	24
77.14.069	Shoal	8.1	0.1	19.5	14
Bouy 45	Edge		0.1		
38.32.655	Channel	7.6	0.2	19.3	28
77.15.491	Shoal	7.6	0.2	19.7	16
Bouy 43	Edge	7.5	0.2	19.3	11
38.29.788	Channel	7.2	0.2	19.3	25
77.16.710	Shoal	9.0	0.2	19.8	7
Bouy 41	Edge	7.4	0.2	19.7	16
38.28.213	Channel	7.5	0.4	19.2	27
77.16.493	Shoal	7.4	0.3	19.3	16
Bouy 40	Edge	7.5	0.3	19.3	20
38.25.612	Channel	7.4	0.7	19.2	24
77.16.251	Shoal	7.6	0.7	19.6	7
Bouy 32	Edge	7.5	0.8	19.2	16
38.23.064	Channel	7.5	1.3	19.2	21
77.15.434	Shoal	7.8	0.8	19.1	15
Bouy 26	Edge	7.5	1.2	19.1	16
Date	5/17/2006				
38.21.031	Channel	6.4	3.6	18.9	34
77.12.411	Shoal	6.9	2.7	19.1	13
Bouy 22	Edge	6.8	3.2	19.1	20
38.21.781	Channel	5.7	4.3	18.8	34
77.10.045	Shoal	5.8	4.5	18.8	10
Bouy 16	Edge	6.0	3.9	18.8	22
38.23.030	Channel	5.6	5.5	18.8	26
77.08.091	Shoal	6.0	4.3	19.1	7
Bouy13	Edge	5.3	5.7	18.7	22
38.23.797	Channel	4.8	6.6	18.7	40
77.04.855	Shoal	5.6	5.7	18.8	9
Bouy 8	Edge	5.1	6.3	18.7	15
38.24.688	Channel	5.1	7	18.7	90
77.02.436	Shoal	5.4	5.6	18.8	8
Bouy 6	Edge	4.9	6.9	18.9	50

Date	6/16/2006				
Location		DO	Salinity	Temperature	Depth
Buoy 56	Channel Surface	6.3	0.1	23.6	67
	Channel Bottom	6.2	0.1	23.4	67
	Edge Surface	5.9	0.1	23.5	44
	Edge Bottom	6.1	0.1	23.4	44
	Shoal	6.2	0.1	23.5	5
Buoy 54	Channel Surface	6.3	0.1	23.3	38
	Channel Bottom	6.7	0.1	23.1	38
	Edge Surface	6.2	0.1	23.2	20
	Edge Bottom	6.5	0.1	23.3	20
	Shoal	6.4	0.1	23.2	6
Buoy 52	Channel Surface	6.5	0.2	23.1	20
	Channel Bottom	6.3	0.2	23.2	20
	Edge Surface	6.5	0.2	23.1	15
	Edge Bottom	6.5	0.2	23.2	15
	Shoal	6.4	0.2	22.9	10
Buoy 46	Channel Surface	5.9	0.6	23.0	22
	Channel Bottom	6.0	0.8	23.3	22
	Edge Surface	6.0	0.4	23.0	14
	Edge Bottom	5.9	0.5	23.3	14
	Shoal	6.0	0.4	23.0	10
Buoy 45	Channel Surface	5.8	0.8	23.1	29
powerlines	Channel Bottom	5.9	1.2	23.1	29
	Edge Surface	6.2	1	23.1	17
	Edge Bottom	6.1	1.2	23.3	17
	Shoal	6.6	1.1	22.9	12
Buoy 41	Channel Surface	6.1	1.1	23.2	25
	Channel Bottom	5.4	1.9	22.7	25
	Edge Surface	5.9	1.6	22.9	13
	Edge Bottom	5.8	1.8	22.9	13
	Shoal	5.9	1.5	22.8	6
Buoy 40	Channel Surface	6.2	1.8	23.1	28
	Channel Bottom	6.3	2.7	23.1	28
	Edge Surface	6.1	1.8	23.1	28
	Edge Bottom	6.3	2.2	23.1	28
	Shoal	6.1	1.6	23.1	28
Buoy 32	Channel Surface	6.2	3.5	23.2	24
	Channel Bottom	5.9	3.2	22.9	24
	Edge Surface	6.2	3.8	22.9	19
	Edge Bottom	5.8	3.9	22.9	19
	Shoal	6.1	3.3	23.1	15
Buoy 26	Channel Surface	7.3	4.5	23.2	22
	Channel Bottom	6	3.6	22.8	22
	Edge Surface	6.7	4.9	22.9	19
	Edge Bottom	6.7	3.1	22.8	19
	Shoal	5.6	4.5	22.8	17
Buoy 22	Channel Surface	6.3	6.2	22.8	27
	Channel Bottom	5.5	6.8	22.6	27
	Edge Surface	5.5	6.5	22.7	18
	Edge Bottom	4.5	6.9	22.6	18
	Shoal	6.3	5.2	22.8	12
Buoy 16	Channel Surface	6.2	7.7	22.6	33
	Channel Bottom	4.2	8.5	22.4	33
	Edge Surface	4.1	8	22.4	19
	Edge Bottom	4.1	8.4	22.4	19
	Shoal	3.9	7.8	22.4	16
Buoy 13	Channel Surface	5.1	8.5	22.6	23
	Channel Bottom	3.5	9.8	22.2	23
	Edge Surface	4.6	8.4	22.5	17
	Edge Bottom	4.1	9.3	22.3	17
	Shoal	4.1	7.8	22.4	10
Buoy 8	Channel Surface	4.4	8.6	22.5	35
	Channel Bottom	3.3	10.5	22.1	35
	Edge Surface	3.7	9.1	22.4	27
	Edge Bottom	3.4	9.6	22.2	27
	Shoal	3.4	9.5	22.3	4
Buoy 6	Channel Surface	4.7	8.2	22.7	78
	Channel Bottom	3.1	11.4	21.9	78
	Edge Surface	4.5	9.3	22.4	50
	Edge Bottom	3.1	11.3	22.0	50
	Shoal	4.8	9.2	22.6	8

Date	7/19/2006				
Location		DO	Salinity	Temperature	Depth
Buoy 56	Channel Surface	5.5	0.1	29.5	63
	Channel Bottom	5.9	0.1	29.5	63
	Edge Surface	5.6	0.1	29.4	37
	Edge Bottom	5.7	0.1	29.5	37
	Shoal	5.9	0.1	29.3	12
Buoy 54	Channel Surface	5.6	0.1	29.4	37
	Channel Bottom	5.8	0.1	29.4	37
	Edge Surface	6.2	0.1	29.4	16
	Edge Bottom	6.1	0.1	29.3	16
	Shoal	6.2	0.1	29.3	12
Buoy 52	Channel Surface	5.8	0.1	29.2	22
	Channel Bottom	5.7	0.1	29.2	22
	Edge Surface	5.8	0.1	29.2	15
	Edge Bottom	5.9	0.1	29.2	15
	Shoal	6.1	0.1	29.2	10
Buoy 46	Channel Surface	6.5	0.1	29.2	23
	Channel Bottom	6.3	0.1	29.1	23
	Edge Surface	7.4	0.1	29.3	18
	Edge Bottom	6.3	0.1	28.9	18
	Shoal	7.1	0.1	29.1	14
Buoy 45	Channel Surface	6.5	0.1	29.1	30
powerlines	Channel Bottom	5.7	0.1	28.8	30
	Edge Surface	5.9	0.1	28.8	23
	Edge Bottom	5.8	0.1	28.7	23
	Shoal	6.0	0.1	28.8	9
Buoy 41	Channel Surface	5.2	0.1	28.7	25
	Channel Bottom	5.1	0.1	28.5	25
	Edge Surface	5.1	0.1	28.4	14
	Edge Bottom	5.2	0.1	28.2	14
	Shoal	5.4	0.1	28.4	5
Buoy 40	Channel Surface	5.2	0.1	28.8	30
	Channel Bottom	4.6	0.1	28.2	30
	Edge Surface	5.0	0.1	28.3	20
	Edge Bottom	5.1	0.1	28.3	20
	Shoal	5.3	0.1	28.9	8
Buoy 32	Channel Surface	5.6	0.4	29.0	20
	Channel Bottom	4.9	1.2	28.7	20
	Edge Surface	5.6	0.5	28.7	15
	Edge Bottom	5.3	1.1	28.7	15
	Shoal	5.8	0.8	28.8	7
Buoy 26	Channel Surface	5.3	1.4	28.8	21
	Channel Bottom	5.1	1.6	28.8	21
	Edge Surface	5.2	1.8	29.0	13
	Edge Bottom	5.2	1.9	29.0	13
	Shoal	5.6	1.9	29.3	6
Buoy 22	Channel Surface	5.3	1.7	28.9	25
	Channel Bottom	5.4	1.9	29.0	25
	Edge Surface	5.3	1.8	28.9	17
	Edge Bottom	5.2	2.2	29.1	17
	Shoal	5.1	2.5	29.2	12
Buoy 16	Channel Surface	4.8	3.6	29.1	23
	Channel Bottom	4.1	4.5	28.8	23
	Edge Surface	4.7	3.9	29.0	15
	Edge Bottom	4.3	4.4	28.9	15
	Shoal	4.2	4.5	28.9	9
Buoy 13	Channel Surface	4.5	4.8	29.0	28
	Channel Bottom	3.3	5.7	28.6	28
	Edge Surface	4.7	5	28.8	14
	Edge Bottom	4.7	5.3	28.8	14
	Shoal	4.6	5.2	28.8	6
Buoy 8	Channel Surface	4.7	5.4	28.8	32
	Channel Bottom	3	6.4	28.4	32
	Edge Surface	4.9	5.6	28.8	19
	Edge Bottom	3.9	5.9	28.6	19
	Shoal	4.6	5.8	28.6	9
Buoy 6	Channel Surface	5.3	5.4	28.7	110
	Channel Bottom	2.2	8.7	28.0	110
	Edge Surface	4.3	6.3	28.8	54
	Edge Bottom	3.7	7.2	28.5	54
	Shoal	4.2	6.5	28.7	11

Date	8/23/2006				
Location		DO	Salinity	Temperature	Depth
Buoy 56	Channel Surface	6.2	0.1	28.0	70
	Channel Bottom	6.0	0.1	27.8	70
	Edge Surface	6.0	0.1	27.8	23
	Edge Bottom	6.0	0.1	27.7	23
	Shoal	6.2	0.1	27.5	8
Buoy 54	Channel Surface	5.8	0.1	27.9	40
	Channel Bottom	6.1	0.1	27.5	40
	Edge Surface	6.2	0.1	27.6	21
	Edge Bottom	6.0	0.1	27.5	21
	Shoal	6.3	0.1	27.7	7
Buoy 52	Channel Surface	6.5	0.1	27.5	22
	Channel Bottom	6.4	0.1	27.4	22
	Edge Surface	6.3	0.1	27.6	16
	Edge Bottom	6.2	0.1	27.3	16
	Shoal	6.5	0.1	27.4	10
Buoy 46	Channel Surface	6.5	0.1	27.9	26
	Channel Bottom	6.4	0.1	27.6	26
	Edge Surface	6.3	0.1	27.6	20
	Edge Bottom	6.2	0.1	27.5	20
	Shoal	6.3	0.1	27.4	11
Buoy 45	Channel Surface	6.4	1.1	27.7	26
powerlines	Channel Bottom	6.6	1.4	27.7	26
	Edge Surface	6.6	1.3	27.7	17
	Edge Bottom	6.8	1.4	27.7	17
	Shoal	6.8	1.4	27.8	10
Buoy 41	Channel Surface	7.1	1.5	27.8	26
	Channel Bottom	7.1	2	27.7	26
	Edge Surface	7.1	1.7	27.8	21
	Edge Bottom	7.1	1.8	27.6	21
	Shoal	7.3	1.8	27.7	10
Buoy 40	Channel Surface	7.3	1.9	27.7	26
	Channel Bottom	7.0	2.8	27.8	26
	Edge Surface	7.2	2.1	27.8	18
	Edge Bottom	7.0	2.6	27.8	18
	Shoal	7.1	2.2	27.9	13
Buoy 32	Channel Surface	7.2	3.2	27.5	23
	Channel Bottom	6.3	3.7	27.8	23
	Edge Surface	7.7	2.5	27.8	18
	Edge Bottom	6.5	3.6	27.7	18
	Shoal	7	3.1	27.9	8
Buoy 26	Channel Surface	6.1	4.2	27.8	23
	Channel Bottom	5.9	4.3	27.6	23
	Edge Surface	6.4	4.1	28.0	20
	Edge Bottom	6	4.2	27.5	20
	Shoal	6	4.1	27.7	12
Buoy 22	Channel Surface	5.7	4.1	27.8	26
	Channel Bottom	5.6	4.7	27.6	26
	Edge Surface	5.4	4.8	27.6	16
	Edge Bottom	5.3	5	27.6	16
	Shoal	5.7	4.5	27.6	11
Buoy 16	Channel Surface	5.2	5.6	27.8	33
	Channel Bottom	5.2	5.8	27.7	33
	Edge Surface	5.2	5.5	27.8	16
	Edge Bottom	5	6	27.7	16
	Shoal	5.1	5.5	27.9	9
Buoy 13	Channel Surface	5	6.4	28.0	27
	Channel Bottom	4.8	6.9	27.9	27
	Edge Surface	4.7	6.4	27.9	17
	Edge Bottom	4.7	6.9	27.8	17
	Shoal	4.9	6.7	28.1	8
Buoy 8	Channel Surface	4.9	7.2	28.0	39
	Channel Bottom	4.8	8	27.8	39
	Edge Surface	5.6	7.3	28.1	29
	Edge Bottom	5	7.7	27.8	29
	Shoal	5.2	7.5	27.9	7
Buoy 6	Channel Surface	5.4	7.1	27.9	90
	Channel Bottom	5.2	7.6	27.8	90
	Edge Surface	6.6	7	28.4	35
	Edge Bottom	5.4	7.4	27.8	35
	Shoal	5.5	7.4	27.8	8

Date	9/18/2006				
Location		DO	Salinity	Temperature	Depth
Buoy 56	Channel Surface	6.1	0.2	22.6	78
	Channel Bottom	5.7	0.2	22.6	78
	Edge Surface	6.1	0.2	22.7	22
	Edge Bottom	6.0	0.2	22.6	22
	Shoal	6.3	0.2	22.6	9
Buoy 54	Channel Surface	6.3	0.2	22.9	39
	Channel Bottom	5.9	0.2	22.6	39
	Edge Surface	6.1	0.2	22.8	22
	Edge Bottom	6.2	0.2	22.6	22
	Shoal	5.9	0.2	22.9	13
Buoy 52	Channel Surface	6.2	0.2	22.9	22
	Channel Bottom	6.0	0.2	22.5	22
	Edge Surface	6.0	0.2	22.7	15
	Edge Bottom	6.1	0.2	22.6	15
	Shoal	6.1	0.2	23.2	10
Buoy 46	Channel Surface	6.4	0.2	22.5	23
	Channel Bottom	6.2	0.2	22.2	23
	Edge Surface	6.7	0.3	22.6	13
	Edge Bottom	6.5	0.3	22.3	13
	Shoal	7.1	0.3	22.9	10
Buoy 45	Channel Surface	6.1	0.3	22.3	28
powerlines	Channel Bottom	6.0	0.3	22.1	28
	Edge Surface	6.0	0.3	22.4	16
	Edge Bottom	5.9	0.3	22.3	16
	Shoal	6.3	0.4	23.1	12
Buoy 41	Channel Surface	6.2	0.6	22.7	25
	Channel Bottom	6.0	0.7	22.4	25
	Edge Surface	6.4	0.8	22.7	16
	Edge Bottom	6.5	0.8	22.5	16
	Shoal	6.7	0.8	22.9	7
Buoy 40	Channel Surface	6.4	0.9	22.7	28
	Channel Bottom	6.4	1	22.7	28
	Edge Surface	6.7	1	22.8	16
	Edge Bottom	6.6	1.2	22.7	16
	Shoal	6.9	1.1	23.2	7
Buoy 32	Channel Surface	6.6	1.3	22.7	23
	Channel Bottom	6.6	1.8	22.5	23
	Edge Surface	6.8	1.3	22.7	14
	Edge Bottom	6.8	1.6	22.6	14
	Shoal	6.9	1.4	22.9	9
Buoy 26	Channel Surface	6.6	1.9	22.5	20
	Channel Bottom	6.5	2.4	22.4	20
	Edge Surface	7.4	2.1	22.9	15
	Edge Bottom	7.3	2.5	23.0	15
	Shoal	7.3	2.5	23.5	7
Buoy 22	Channel Surface	7	2.9	22.6	24
	Channel Bottom	6.3	3.2	22.6	24
	Edge Surface	6.7	3.2	22.5	15
	Edge Bottom	6.8	3.3	22.6	15
	Shoal	7.1	3.5	23.3	5
Buoy 16	Channel Surface	7.4	3.7	23.4	35
	Channel Bottom	5.7	4.7	22.8	35
	Edge Surface	6.5	4.3	22.8	15
	Edge Bottom	6.2	4.6	22.7	15
	Shoal	6.5	4.4	23.1	7
Buoy 13	Channel Surface	6.6	4.7	22.9	30
	Channel Bottom	5.4	6.4	22.9	30
	Edge Surface	6.9	4.4	23.0	18
	Edge Bottom	5.5	5.9	23.0	18
	Shoal	7.3	4.9	24.4	5
Buoy 8	Channel Surface	6.6	5.6	23.4	26
	Channel Bottom	6.2	6	23.1	26
	Edge Surface	6.2	6.2	23.6	20
	Edge Bottom	6.2	6.3	23.5	20
	Shoal	6.4	6.4	23.5	8
Buoy 6	Channel Surface	6	6.3	23.4	106
	Channel Bottom	5	7.5	23.0	106
	Edge Surface	5.7	6.9	23.1	27
	Edge Bottom	5.4	7.2	23.1	27
	Shoal	5.2	7.8	23.2	9

Date	10/30/2006				
Location		DO	Salinity	Temperature	Depth
Buoy 56	Channel Surface	8.9	0.2	12.4	70
	Channel Bottom	9.0	0.2	12.2	70
	Edge Surface	8.9	0.2	12.6	35
	Edge Bottom	9.0	0.2	12.7	35
	Shoal	8.9	0.2	13.0	5
Buoy 54	Channel Surface	8.9	0.2	12.6	42
	Channel Bottom	9.0	0.2	12.2	42
	Edge Surface	8.7	0.2	12.7	22
	Edge Bottom	9.0	0.2	12.4	22
	Shoal	8.8	0.2	12.5	6
Buoy 52	Channel Surface	9.1	0.2	12.7	20
	Channel Bottom	9.2	0.2	12.4	20
	Edge Surface	9.0	0.2	12.5	13
	Edge Bottom	9.1	0.2	12.5	13
	Shoal	8.9	0.2	12.7	9
Buoy 46	Channel Surface	9.2	0.2	12.4	22
	Channel Bottom	9.3	0.2	12.3	22
	Edge Surface	9.2	0.2	12.4	14
	Edge Bottom	9.1	0.2	12.4	14
	Shoal	9.1	0.2	12.5	8
Buoy 45	Channel Surface	9.0	0.2	12.5	29
powerlines	Channel Bottom	9.3	0.2	12.4	29
	Edge Surface	9.1	0.2	12.7	13
	Edge Bottom	9.2	0.2	12.6	13
	Shoal	9.0	0.2	13.0	4
Buoy 41	Channel Surface	9.2	0.2	12.7	25
	Channel Bottom	9.2	0.2	12.7	25
	Edge Surface	8.9	0.2	12.8	16
	Edge Bottom	9.0	0.2	12.8	16
	Shoal	9.0	0.2	12.9	5
Buoy 40	Channel Surface	9.1	0.2	12.9	26
	Channel Bottom	9.1	0.2	12.7	26
	Edge Surface	9.1	0.2	12.9	15
	Edge Bottom	9.0	0.2	12.8	15
	Shoal	9.0	0.2	12.9	8
Buoy 32	Channel Surface	9.1	0.2	13.1	22
	Channel Bottom	9.0	0.4	12.9	22
	Edge Surface	8.9	0.3	13.2	13
	Edge Bottom	8.9	0.3	12.9	13
	Shoal	9	0.3	13.1	5
Buoy 26	Channel Surface	9	0.8	13.0	20
	Channel Bottom	9	1	12.7	20
	Edge Surface	8.8	0.9	13.2	15
	Edge Bottom	8.8	0.9	13.0	15
	Shoal	8.8	0.9	13.8	7
Buoy 22	Channel Surface	9	1.8	13.1	26
	Channel Bottom	9.1	1.9	12.7	26
	Edge Surface	8.8	1.7	13.1	15
	Edge Bottom	8.8	1.8	12.7	15
	Shoal	8.9	1.5	12.9	10
Buoy 16	Channel Surface	8.7	2.7	13.1	32
	Channel Bottom	8.9	3.1	13.0	32
	Edge Surface	8.7	2.8	13.0	17
	Edge Bottom	8.7	3	13.0	17
	Shoal	8.7	2.9	13.0	8
Buoy 13	Channel Surface	8.7	3.3	13.1	30
	Channel Bottom	8.5	3.5	13.1	30
	Edge Surface	8.8	3.2	13.2	15
	Edge Bottom	8.7	3.4	13.1	15
	Shoal	8.7	3.1	13.4	5
Buoy 8	Channel Surface	8.4	4.5	13.3	37
	Channel Bottom	8.5	5.1	13.7	37
	Edge Surface	8.4	4.7	13.4	22
	Edge Bottom	8.5	5	13.4	22
	Shoal	8.4	5.3	13.5	6
Buoy 6	Channel Surface	8.5	4.2	13.5	87
	Channel Bottom	8.4	6.8	13.6	87
	Edge Surface	8.5	4.2	13.3	40
	Edge Bottom	8.4	6.4	13.3	40
	Shoal	8.4	4.6	13.3	8

Date	12/15/2006				
Location		DO	Salinity	Temperature	Depth
Buoy 56	Channel Surface	10.9	0.1	5.5	70
	Channel Bottom	11.0	0.1	5.4	70
	Edge Surface	10.6	0.1	5.5	30
	Edge Bottom	10.5	0.1	5.4	30
	Shoal	10.6	0.1	5.6	6
Buoy 54	Channel Surface	10.7	0.1	5.7	40
	Channel Bottom	10.9	0.1	5.5	40
	Edge Surface	10.6	0.1	5.5	25
	Edge Bottom	10.6	0.1	5.5	25
	Shoal	10.7	0.1	5.2	6
Buoy 52	Channel Surface	10.6	0.1	5.7	25
	Channel Bottom	10.8	0.1	5.6	25
	Edge Surface	10.9	0.1	5.6	18
	Edge Bottom	10.9	0.1	5.6	18
	Shoal	10.9	0.1	5.5	10
Buoy 46	Channel Surface	10.7	0.1	6.0	26
	Channel Bottom	11.2	0.1	5.8	26
	Edge Surface	11.3	0.1	4.8	15
	Edge Bottom	11.2	0.1	4.5	15
	Shoal	11.2	0.1	4.6	9
Buoy 45	Channel Surface	10.9	0.1	6.1	28
powerlines	Channel Bottom	10.9	0.1	6.0	28
	Edge Surface	10.5	0.1	6.0	14
	Edge Bottom	11.0	0.1	5.8	14
	Shoal	11.1	0.1	5.6	10
Buoy 41	Channel Surface	10.6	0.1	6.0	28
	Channel Bottom	11.4	0.1	5.8	28
	Edge Surface	11.1	0.1	5.6	13
	Edge Bottom	10.9	0.1	5.6	13
	Shoal	10.7	0.1	5.7	6
Buoy 40	Channel Surface	10.8	0.1	5.8	31
	Channel Bottom	11.2	0.1	5.7	31
	Edge Surface	10.7	0.1	5.9	18
	Edge Bottom	11.3	0.1	5.8	18
	Shoal	11.3	0.1	5.6	10
Buoy 32	Channel Surface	11.1	0.1	6.2	23
	Channel Bottom	11.6	0.2	5.8	23
	Edge Surface	11.1	0.1	6.1	12
	Edge Bottom	11.4	0.2	6.0	12
	Shoal	11.1	0.1	6.1	6
Date	12/11/2006				
Buoy 26	Channel Surface	11.2	1	6.4	26
	Channel Bottom	11.2	1.5	6.6	26
	Edge Surface	11.2	0.8	6.5	16
	Edge Bottom	11.1	1	6.6	16
	Shoal	11.1	0.7	6.3	9
Buoy 22	Channel Surface	11	1.7	6.7	30
	Channel Bottom	10.9	2.6	6.9	30
	Edge Surface	11.1	1.5	6.8	20
	Edge Bottom	10.6	2.6	6.9	20
	Shoal	11	1.5	6.6	15
Buoy 16	Channel Surface	10.6	3.1	7.0	30
	Channel Bottom	10.5	4	7.1	30
	Edge Surface	10.5	3.4	7.1	16
	Edge Bottom	10.4	3.9	7.1	16
	Shoal	10.4	3.6	7.1	8
Buoy 13	Channel Surface	10.7	3.4	7.0	28
	Channel Bottom	10.1	7.2	7.6	28
	Edge Surface	10.6	3	6.9	16
	Edge Bottom	10.5	3.4	7.1	16
	Shoal	10.6	2.8	6.9	5
Buoy 8	Channel Surface	10.6	3.7	6.9	30
	Channel Bottom	9.7	7.6	7.7	30
	Edge Surface	10.5	4	7.0	20
	Edge Bottom	10.2	7.4	7.0	20
	Shoal	10.3	4	7.0	7
Buoy 6	Channel Surface	10.5	5.1	7.2	80
	Channel Bottom	10.2	8.1	7.6	80
	Edge Surface	10.3	4.8	7.4	40
	Edge Bottom	10.1	7.8	7.5	40
	Shoal	10.3	4.8	7.4	12