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# PRIMARY FACTORS AFFECTING STURGEON POPULATIONS IN THE SOUTHEASTERN UNITED STATES: FISHING MORTALITY AND DEGRADATION OF ESSENTIAL HABITATS

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## ABSTRACT

Atlantic and shortnose sturgeons are highly valued for their eggs (caviar) and flesh, but stocks of both species are depleted. The shortnose sturgeon is listed as an endangered species, and a long-term (multidecade) moratorium on fishing for Atlantic sturgeon is specified in the recently updated fishery management plan of the Atlantic States Marine Fisheries Commission. Thus, identification, protection, and enhancement of essential habitats are priority issues for management agencies. As anadromous (Atlantic) and nearly anadromous (shortnose) species, these sturgeons use a wide variety of habitats; variations occur latitudinally, seasonally, and among different life stages. Spawning habitats have been identified in two southeastern rivers for shortnose sturgeon, but to date no spawning sites have been verified for Atlantic sturgeon. Some life stages of both species (including young juveniles) concentrate in or are restricted to small portions of estuaries during summer. Deterioration of water quality (especially dissolved oxygen) appears to be degrading the nursery function of these summer refugia, creating a recruitment bottleneck. Protection of essential habitats, especially nursery/summer habitats, from human-caused dissolved-oxygen reductions and other impacts is critical. By-catch, primarily in riverine/estuarine gillnet and estuarine/marine trawl fisheries, appears to be the second major source of mortality for southern sturgeons. Reserves, or no-fishing zones, could protect populations by reducing or eliminating by-catch mortality. This protection would be especially valuable in high salinity foraging areas (used primarily during cool months) and during spawning migrations. Proposed management strategies aimed at conservation and restoration of sturgeon populations therefore focus on two areas: protection of essential habitats and establishment of reserves to provide protection from fishing gears that generate substantial sturgeon by-catch. Specific management recommendations were developed on a system-by-system basis.

Two anadromous or semianadromous sturgeon (Acipenseridae) species occur on the Atlantic coast of North America, shortnose (*Acipenser brevirostrum*) and Atlantic (*A. oxyrinchus oxyrinchus*) sturgeons (Vladykov and Greeley, 1963). Previously ranging southward to northern Florida, all known populations of these species in the South have been depleted or extirpated. The shortnose sturgeon was listed as an endangered species in the United States in 1967. North Carolina's fishery for Atlantic sturgeon was closed in 1991, South Carolina's in 1985, Georgia's in 1996, and Florida's (east coast) in 1983. A multidecade moratorium on the Atlantic sturgeon fisheries in all states was imposed in 1998 by the Atlantic States Marine Fisheries Commission (ASMFC, 1998).

Biologists have studied shortnose and Atlantic sturgeons in the Southeast for over two decades. In general these research efforts were initially focused on documenting the commercial fishery (e.g., Leland, 1968) but then expanded into the areas of artificial propagation (e.g., Smith et al., 1980), habitat associations (Hall et al., 1991), physiology (Jenkins et al., 1993), and sources of mortality (Collins et al., 1996). However, information in certain areas, including habitat utilization patterns, has been difficult to obtain because of the relative scarcity of these fishes in most systems. It now appears that the ecology of southern sturgeons differs from that documented for northern populations. Further, although the directed fisheries have been closed for up to 25 yrs, at least some populations in the South continue to decline. Fishing mortality is believed to be an important factor in at least some localities (Collins et al., 1996), and recent evidence suggests that degradation of essential habitat is another major factor in the declines (Rogers and Weber, 1995a). Here, we synthesize the habitat-use information collected in river systems and nearshore waters in Georgia, South Carolina, and North Carolina; integrate existing by-catch information; and provide management recommendations on a system-by-system basis.

## Methods

The methods used in the studies we synthesize have been described in previous publications and reports and will only be briefly mentioned here. The objectives of some studies included identifying essential habitats of various life stages, whereas other studies focused on other issues but produced information on habitat utilization. Habitat use was determined primarily by collection of specimens in gill nets, trammel nets, and trawls and through radio and acoustic telemetry studies. Salinity, temperature, dissolved oxygen (DO), and often substrate type were determined for most capture and telemetry locations. Study areas included most major rivers and sounds (Fig. 1).

In the St. Marys River (Georgia) during 1994–1995, and in the Satilla River (Georgia) during 1995 and 1998, stratified random trammel net surveys for sturgeons were conducted during summer (Rogers and Weber, 1995a). In the Altamaha River (Georgia), trammel nets were deployed during 1986–1994 in all seasons at river kilometers (rkm) 0–80. Side-scan sonar was used to survey areas of summer concentrations of both sturgeon species (Rogers et al., 1994). Shortnose sturgeon spawning locations were tentatively identified by telemetry studies and gill-net collections (Rogers and Weber, 1995b). Winter concentrations of subadult Atlantic sturgeon were located serendipitously during trawling intended to determine sea turtle abundance in the nearshore shipping channel (Rogers et al., 1994).

In the Ogeechee River (Georgia), both stratified random (1993–1994) and nonrandom trammel-net sampling were used to collect sturgeons. Shortnose sturgeon telemetry studies were conducted during 1994–1995 (Weber et al., in press). Nonrandom trammel net sampling and standardized hydrographic surveys were conducted during 1997–1998 (Rogers, unpubl. data).

Sturgeons have probably been studied more extensively in the Savannah River (Georgia/South Carolina) than in any other system in the region. Most research was directed toward shortnose sturgeon, but information on Atlantic sturgeon (especially juveniles) was also acquired. From 1985 through 1992, and again 1997 to present, sturgeons were captured by directed sampling and acquired from the by-catch of a network of commercial American shad (*Alosa sapidissima*) gill-net fishermen (Hall et al., 1991; Smith et al., 1993, unpubl. data). Radio and acoustic telemetry studies were conducted during 1985–1991 (Hall et al., 1991; Collins and Smith, 1993). Shortnose sturgeon brood fish from this river were spawned, and about 92,000 progeny of various ages were released into the river at several locations in a pilot stock-enhancement study conducted during 1984–1992 (Smith and Collins, 1996). In addition to the stock-enhancement work, cultured juveniles were used in other studies, such as delineation of environmental tolerances (salinity, temperature, and DO; Jenkins et al., 1993) and identification of optimal tagging techniques (Smith et al., 1990; Collins et al., 1994). Spawning and culture research on Savannah River strain shortnose sturgeon has been conducted since the mid-1980s at several locations, including U.S. Fish and Wildlife Service facilities (e.g., Orangeburg National Fish Hatchery, Bears Bluff National Fish Hatchery) and South Carolina Department of Natural Resources facilities (e.g., Marine Resources Research Institute, Waddell Mariculture Center). Nonrandom trammel-net sampling for sturgeons was conducted in the lower Savannah River during 1997–1998 (Collins, unpubl. data).

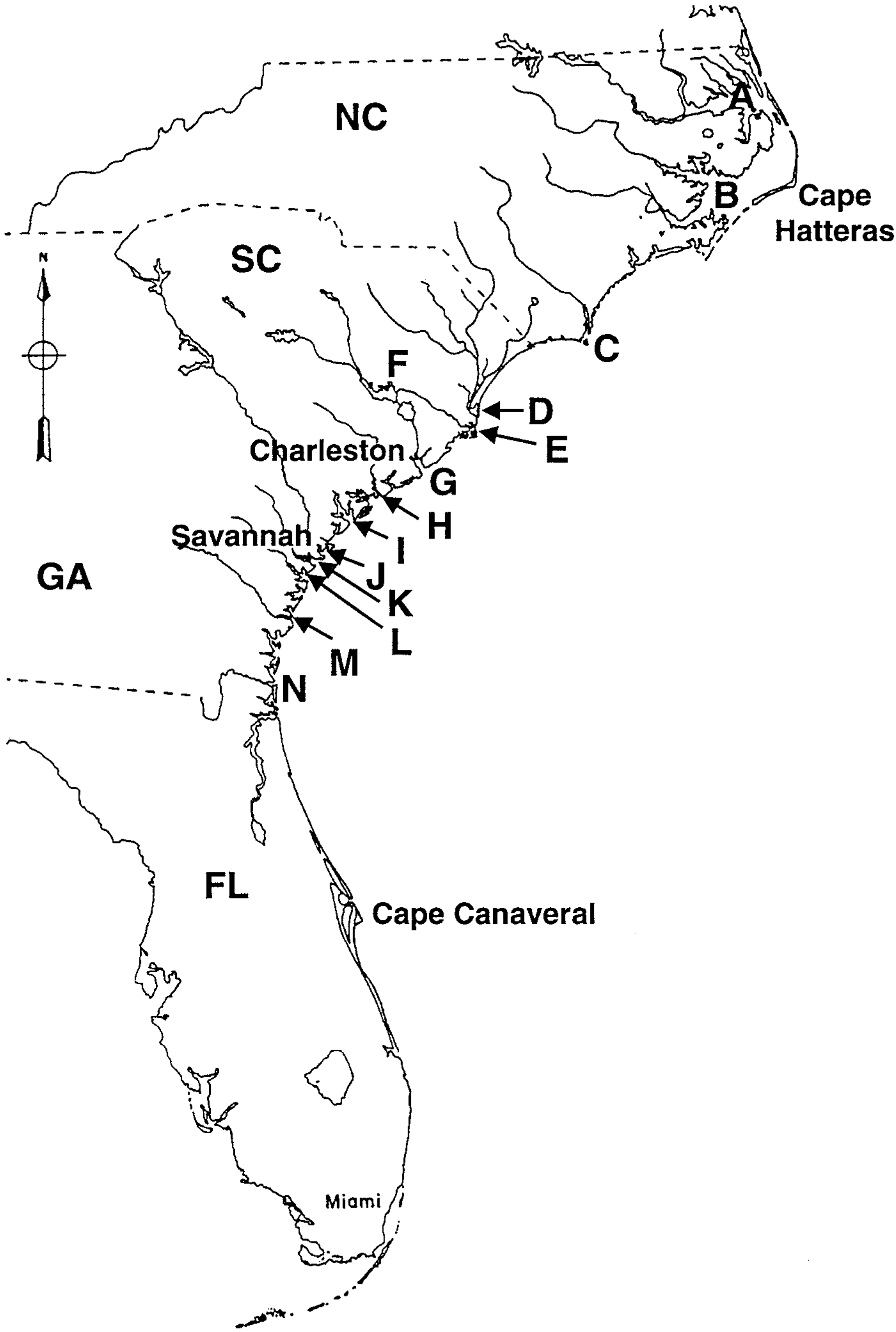


Figure 1. Sounds and river systems of North Carolina, South Carolina, and Georgia. Identifying letters correspond to those in Table 1.

In the St. Helena Sound system, a mark-recapture study of shortnose and juvenile Atlantic sturgeons has been under way since 1994 (McCord, 1998). Also, former commercial sturgeon fishermen have assisted in the capture of adult Atlantic sturgeon for an ongoing telemetry study that began in winter–spring 1997 in this river and in the nearby Combahee River (Collins et al., 1999). Starting in 1998, adult shortnose sturgeon have been captured and are being used in telemetry studies to identify movements and habitat use (Collins, unpubl. data).

In the Cooper River (South Carolina), adult shortnose sturgeon were captured during the spawning season in 1995–1998 below Pinopolis dam and fitted with radio transmitters to assess spawning and postspawning habitat use (Cooke, 1998). Information on Atlantic sturgeon was obtained incidentally from trawling operations designed to determine sea turtle abundance in the Charleston Harbor shipping channel during 1990–1991 (Van Dolah and Maier, 1993). In the Santee-Cooper Lakes, a reservoir/canal/river system formed by the damming of the Santee and Cooper rivers, shortnose sturgeon captured in 1998–1999 by commercial catfish trotline fishermen and by directed sampling with trammel nets were implanted with radio transmitters in an attempt to determine whether reproduction took place within the system (Collins, unpubl. data).

The primary sturgeon fishery in the southeast during 1970–1985 was in the Winyah Bay area. During 1978–1982 fisheries and biological data were collected in an effort to characterize that segment of the sturgeon fishery (Smith et al., 1984). The fishery was closed in 1985, but since then by-catch mortality and poaching have become concerns. During 1994–1996, sturgeon by-catch mortality in Winyah Bay's commercial shad gill net fishery was assessed (Collins et al., 1996).

In the lower Cape Fear River (North Carolina), a 1990–1992 gill-net survey and telemetry study investigated habitat use and distribution patterns of juvenile Atlantic and adult shortnose sturgeons (Moser and Ross, 1995). In 1996–1998 this survey was expanded upriver to document effects of low-elevation dams on sturgeon movements (Moser et al., 1998). Ancillary data on by-catch of sturgeon in the shad fishery were obtained throughout the surveys.

Little is known of sturgeon distribution in other North Carolina drainages. A data base of sturgeon captures by various agencies was compiled in 1997 and is being used to identify the rivers most likely to support sturgeon populations (Moser et al., 1998). In addition, a telemetry study is in progress in Albemarle Sound to document habitat use by juvenile Atlantic sturgeon (J. Hightower, North Carolina State University, pers. comm.).

## Results and Discussion

Adult shortnose sturgeon are especially vulnerable to passive fishing gears during their extensive up- and downriver spawning movements. In the Savannah River, for example, adults are common in the by-catch of the American shad gill-net fishery from the lowest point in the river at which fishing is allowed (about rkm 43) up to at least rkm 278 (the uppermost of several sturgeon spawning areas; Collins and Smith, 1993). By-catch of sturgeons in this river was as high as 102 fish $fisher^{-1}$ $yr^{-1}$, and immediate by-catch mortality of sturgeons in this gear type was 16%; another 20% of fish were injured (Collins et al., 1996). In addition to such accidental mortality, intentional mortality of shortnose sturgeon captured in the shad fishery is known to occur (McCord, 1998). In the Cooper River, for example, about 50 shortnose sturgeon (20–50% of the estimated annual spawning aggregation) were taken by a single team of poachers in 1995 (D. Cooke, S.C. Department of Natural Resources, pers. comm.). Total fishing mortality is therefore likely to be substantial in rivers containing both a sturgeon population and a shad fishery. Furthermore, sublethal effects of by-catch have been documented. Shortnose sturgeon may delay or even abort upstream spawning migration after gill-net capture (Moser and Ross, 1995). Valuable shortnose sturgeon spawners can be protected by establishment of no-fishing zones for set-net (anchored gillnet) fisheries from the mesohaline estuary (overwintering area) upriver to spawning areas.

Growth rates of juvenile Atlantic, and probably shortnose, sturgeon are greatest in spring and fall and much lower in winter and summer (McCord, 1998; unpubl. data), so the fish are probably inhabiting important foraging areas during cooler seasons. These areas appear to include a large portion of the estuary and, for Atlantic sturgeon, the nearshore continental shelf and shipping channels (Rogers et al., 1994). Marine and estuarine hook-and-line fisheries have little impact, but sturgeons (especially juvenile and subadult Atlantics) do occur in the by-catch of trawl fisheries in South Carolina and Georgia, especially the inshore/nearshore segment of the penaeid shrimp trawl fishery during cool months. The shrimp trawl fishery produced 39% of 97 reported recaptures of Atlantic sturgeon tagged in a Georgia study conducted before use of turtle excluder devices became mandatory (Collins et al., 1996). Use of turtle excluder devices is thought, but not proven, to reduce by-catch of sturgeons. In North Carolina, sturgeons are probably caught in shrimp trawls during much of the year because trawling is permitted in the sounds shoreward of the Outer Banks. Unfortunately, little is known about the magnitude of by-catch or by-catch-induced mortality in the inshore segment of the fishery, but the long tow times normally employed in this fishery suggest that mortality may be high. Marine/estuarine reserves, in the form of no-trawling zones in bays and sounds shoreward of established lines, are already in place in South Carolina and Georgia. If future studies verify that trawling causes significant sturgeon mortality, the mortality could be drastically reduced by extension of existing reserves seaward and by closure of the sounds to trawling in North Carolina.

No spawning sites of Atlantic sturgeon have been identified in the southeastern United States, but shortnose sturgeon spawning sites have been identified in two rivers and tentatively in another. Sites were characterized by deep, scoured channels with hard substrates to which the eggs may adhere. Spawning of shortnose sturgeon occurred at several widely separated locations with no obvious similarities in at least one river (Hall et al., 1991; Collins and Smith, 1993), but in other rivers, only a single spawning site is known (the base of the dam in the Cooper River; Cooke, 1998). Alternatively, spawning appears to be closely associated with a scarce and easily identifiable landform in some rivers. For example, in the Altamaha River, shortnose sturgeon appear to spawn at widely separated locations but only at limestone outcrops (Rogers and Weber, 1995b). This spawning habitat is similar to that used by Gulf sturgeon (*A. o. desotoi*) in the Choctawhatchee River (Florida/Alabama; J. Hightower, North Carolina State University, pers. comm.) and in the Suwanee River (Florida; Sulak and Clugston, 1998). In this case, designating known or probable spawning areas as essential habitat, and protecting or enhancing them, may help conserve existing sturgeon stocks (Table 1).

With rare exceptions, the fresh–brackish water interface area serves as the summer nursery habitat for Atlantic sturgeon and the summer habitat for all ages of shortnose sturgeon in the Southeast (Smith et al., 1993; McCord, 1998; Fig. 2). The essential nature of this habitat is illustrated by patterns of capture during summer for shortnose sturgeon in the Altamaha (Flournoy et al., 1992), Savannah (Hall et al., 1991; Smith and Collins, 1996), and Edisto (unpubl. data) rivers, where juvenile shortnose sturgeon have been captured only in the vicinity of the interface. Summer behavior of adults, however, may differ somewhat among rivers. In the Altamaha River, shortnose sturgeon oversummer in

Table 1. Initial management recommendations for *Acipenser brevirostrum* and *A. oxyrinchus* population segments in North Carolina, South Carolina, and Georgia. Some systems include more than one river. The option of restocking rivers with hatchery-produced fish is omitted from consideration because its present applicability is in doubt. Letters in parentheses correspond to locations in Figure 1.

| System | Initial Management Recommendations |
|---|---|
| Albemarle Sound (A) | Establish estuarine set-net fishery reserve. |
| Pamlico Sound (B) | None (Presence of sturgeon populations not verified.) |
| Cape Fear River (C) | (1) Establish riverine/estuarine reserve closed to set-net fishery.<br>(2) Provide access to upriver habitats through low-elevation dams.<br>(3) Reverse degradation of nursery habitat. |
| Winyah Bay (D) | (1) Establish riverine/estuarine reserves closed to set-net fishery in the bay and all four major rivers (except any river shown not to harbor sturgeon).<br>(2) Maintain continuous, adequate flow from dam on Great Pee Dee River during spawning season. |
| Santee River (E) | (1) Establish riverine/estuarine reserve closed to set-net fishery.<br>(2) Maintain continuous, adequate flow from dam during spawning season. |
| Santee-Cooper Lakes (F) | None (Spawning and nursery habitats not identified. No net fisheries.) |
| Cooper River (G) | (1) Protect *A. brevirostrum* spawning habitat at base of dam.<br>(2) Halt degradation of nursery habitat.<br>(3) Maintain continuous, adequate flow from dam during spawning season. |
| St. Helena Sound (H) | (1) Establish riverine reserve closed to set-net fishery for the Edisto River only.<br>(2) Expand estuarine reserve closed to trawl net fishery seaward during late fall through winter. |
| Port Royal Sound (I) | None (Presence of sturgeon populations not verified.) |
| Savannah River (J) | (1) Halt degradation of nursery habitat, especially the increased salinity and decreased DO from harbor deepening and point-source pollution.<br>(2) Establish riverine reserve closed to set-net fishery to first dam at river kilometer 300.<br>(3) Maintain continuous, adequate flow from dam during spawning season. |
| Ogeechee River (K) | (1) Halt degradation of nursery habitat.<br>(2) Establish riverine/estuarine reserve closed to set-net fishery. |
| Altamaha River (L) | (1) Halt degradation of nursery habitat.<br>(2) Establish riverine/estuarine reserve closed to set-net fishery.<br>(3) Protect apparent *A. brevirostrum* spawning habitat at limestone outcrops. |
| Satilla River (M) | (1) Reverse degradation of nursery habitat.<br>(2) Establish riverine/estuarine reserve closed to set-net fishery. |
| St. Marys River (N) | Reverse degradation of nursery habitat. |

a very few deep holes near the interface, which they rarely leave. This behavior has also been noted for juvenile Atlantic sturgeon in the Cape Fear River (Moser and Ross, 1995). In the Edisto River, however, telemetry results suggest that shortnose sturgeon follow the salt front upriver with flood tides and downriver with ebb tides. The narrow range of

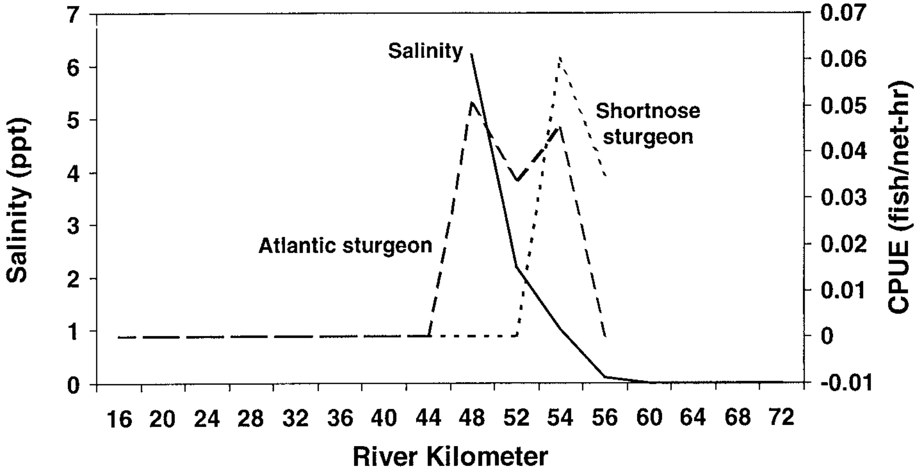


Figure 2. Catch per unit effort (fish net-hr$^{-1}$) for shortnose sturgeon and juvenile Atlantic sturgeon in relation to the fresh–brackish water interface in the Ogeechee River, Georgia. (One net-hr equals 91 m of trammel net fished for 1 hr.)

salinities (0.0–4.2 ‰, mean = 0.46‰, SD = 0.83, n = 83) detected indicates that shortnose sturgeon remained close to the interface during summer 1998. No telemetry results are available for the Savannah River in summer 1998, but the salinities at which shortnose sturgeon were captured (0.1–1.3‰, mean = 0.31‰, SD = 0.34, n = 17) suggest similar behavior. One reason for the different behavior of Altamaha River sturgeon may be the availability of physicochemical refugia created by freshwater springs identified there by side-scan sonar (Rogers et al., 1994). Similar refugia may be present in the Cape Fear River. Regardless of behavioral differences, the fresh–brackish water interface area must be considered a critical habitat for southern sturgeons, especially shortnose sturgeon.

Populations of both sturgeon species are reported as far south as the St. Johns River (Florida), but current information suggests that both species may have been extirpated from this river, as well as from the St. Marys River (Florida/Georgia; Rogers and Weber, 1995a; Kahnle et al., 1998; NMFS, 1998). Shortnose sturgeon appear to be extinct and Atlantic sturgeon scarce in the Satilla River (Rogers and Weber, 1995a), and both species are now rare in the Ogeechee River (Weber et al., in press). The status of sturgeons in most North Carolina rivers is not known, but some populations have probably been recently extirpated, and the Cape Fear River population of shortnose sturgeon is extremely small (Moser and Ross, 1995).

The recent extirpations and severe population depressions of these species in the south is probably not coincidental; mortalities related to the synergistic effects of low dissolved oxygen levels and high summer temperatures would tend to affect southern populations to a greater extent than those farther north. Summer water temperatures in southern estuaries commonly approach and sometimes exceed the maximum tolerable levels identified in the laboratory for early juvenile shortnose sturgeon (Jenkins et al., 1993), and drastically reduced growth rates of juvenile Atlantic sturgeon indicate that they are also severely stressed during summer (McCord, 1998). Summer dissolved oxygen lows in the nursery habitat, probably caused by eutrophication due to nonpoint- (primarily) and point-

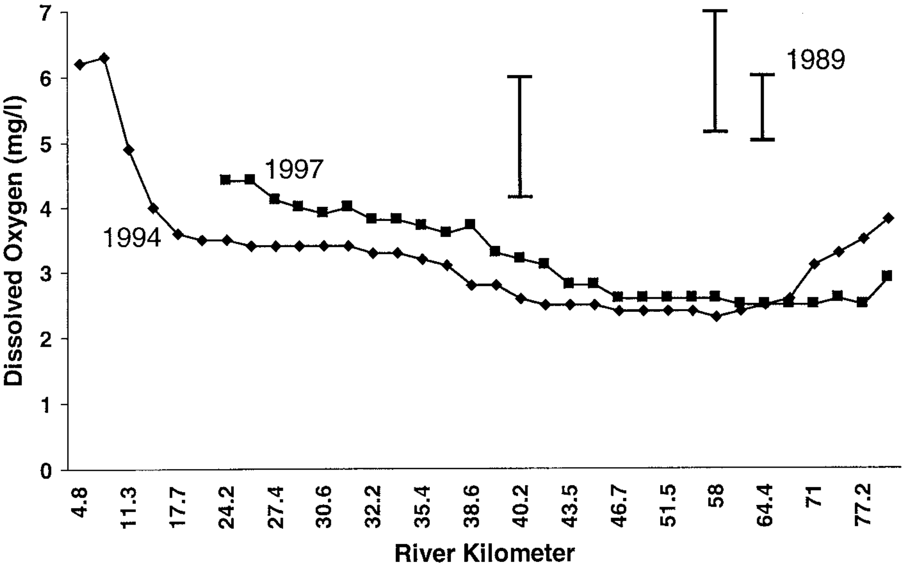


Figure 3. Summer dissolved oxygen ranges for three locations in fresh–brackish water interface area of the St. Marys River, Florida/Georgia, during 1989 compared to dissolved oxygen measurements from summer 1994 and summer 1997.

source pollution, are becoming increasingly common throughout the region (Leathery, 1998; Mallin et al., 1997). For example, DO levels during summer in the interface area of the St. Marys River were ≥ 4.2 mg $L^{-1}$ in 1985 but were as low as 2.5 mg $L^{-1}$ in both 1994 and 1997 (Fig. 3). At the Cape Fear River's interface, they were as low as 2.4 mg $L^{-1}$ in 1996 (Mallin et al., 1997). Such levels could easily kill fish already stressed by high temperatures, causing them to be "squeezed" between their thermal and DO requirements, as proposed by Coutant (1985) for striped bass. Thus, effective ecological functioning of the summer habitat may be especially critical for southern populations, and recent extirpations and year-class failures in the South could well be due to degradation of that habitat.

Because of decreasing sensitivity with age to salinity variations, low DO concentrations, and high temperatures (Jenkins et al., 1993, unpubl. data), degradation of summer habitat would probably compromise nursery functions before causing mortality of adults. In support of this hypothesis are skewed shortnose sturgeon length-frequency distributions observed in the Altamaha, Ogeechee, and Savannah Rivers. The fresh–brackish interface areas of all three rivers were sampled with identical (including mesh size) trammel nets in directed attempts to collect shortnose sturgeon. In the Altamaha River, where dissolved oxygen levels low enough to cause mortality of sturgeons have not been reported, 73% of shortnose sturgeon (n = 415) were ≤ 60 cm fork length (juveniles and young adults). In the Ogeechee River, where water quality in the vicinity of the interface is substantially poorer, only 36% of fish (n = 82) were in that size range. Water quality in the interface portion of the Savannah River is also comparatively poor, and only 34% of shortnose sturgeon (n = 32) captured in 1997–1998 were juveniles and young adults. The significantly greater abundance of young fish ($\chi^2$: P « 0.001) in the Altamaha River than

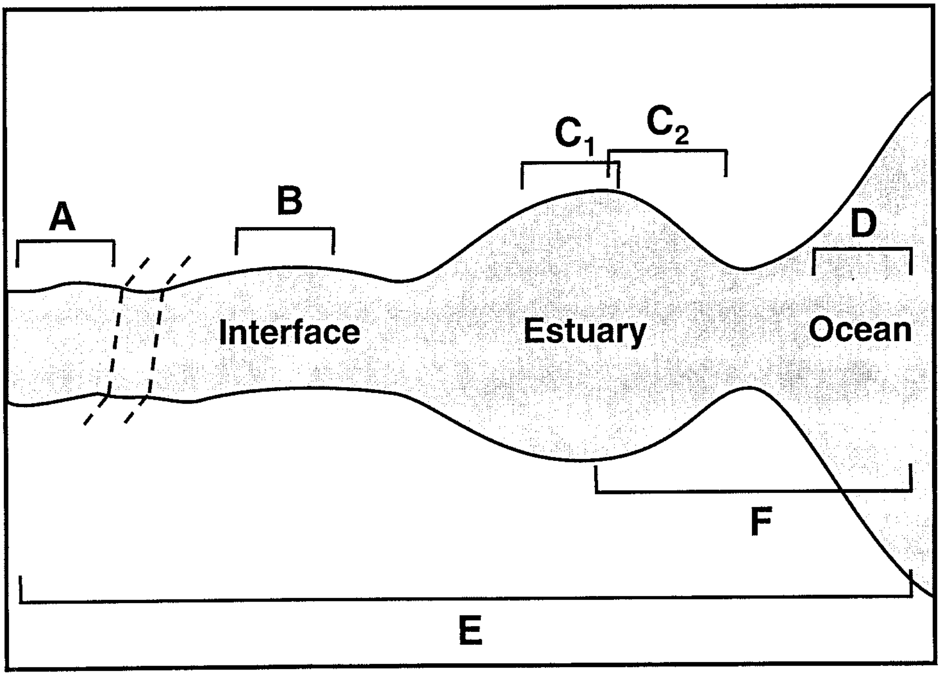


Figure 4. Generalized southern river system showing locations of essential habitats of Atlantic and shortnose sturgeons in relation to areas where sturgeons are likely to occur in the by-catch of commercial shrimp and shad fisheries. (A = upriver spawning habitat for both species; B = nursery habitat for both species and summer habitat for adult shortnose; $C_1$ and $C_2$ = late fall-winter habitat for adult shortnose and juvenile Atlantic, respectively; D = late fall–winter habitat for subadult Atlantic; E = area of potential threat from the shad fishery; F = area of potential threat from the shrimp fishery.)

in the Ogeechee and Savannah rivers may be a result of degradation of the summer habitat for these life stages in the latter two rivers.

Rivers north of the Ogeechee River in which the summer habitat is especially vulnerable at present include the Savannah River, the Cooper River, and a number of drainages in North Carolina including the Cape Fear River. In all cases, water quality (especially DO) is already low enough to be of concern, and major dredging projects through the nursery habitats are scheduled for several systems. In the Savannah River, water-quality models predict that planned channel deepening will reduce dissolved oxygen concentrations in the nursery habitat below its present minimally adequate level (GPA, 1998), and the predicted concentrations are likely to be lethal (Jenkins et al., 1993). In the Cooper River, water-quality change predictions have not yet been quantified, but the low adult population size (about 100–300 spawners annually; D. Cooke, S. C. Department of Natural Resources, pers. comm.) makes even a slight reduction in juvenile survival particularly deleterious. The Cape Fear River population of shortnose sturgeon is probably even smaller than that of the Cooper River, and deepening is scheduled to begin in 1998. Further, existing water quality problems in North Carolina systems have reportedly been exacerbated by substantial expansion of the hog farming industry, and low-DO events and harmful algal blooms have become more frequent there. Protection and restoration of the essential summer/nursery habitat, primarily through reduction of nutrient loading in the region's rivers, is critical if populations of sturgeons are to survive in the South.

Habitat-use patterns of most life stages of Atlantic and shortnose sturgeons have been identified in the South. Sturgeon management and recovery efforts in this region should incorporate this information into river-specific policies (Table 1) that focus on two goals: (1) establishing reserves to reduce fishing mortality and (2) protection of essential habitats. Marine, estuarine, and riverine reserves aimed at shad set-net and shrimp trawl fisheries could reduce or eliminate by-catch mortality during spawning migrations and during cool months when populations shift seaward. Exempting hook-and-line fisheries, which do not affect sturgeons, could increase popular support for these reserves. Protection and restoration of spawning and especially summer habitats are also critically needed management actions (Fig. 4).

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