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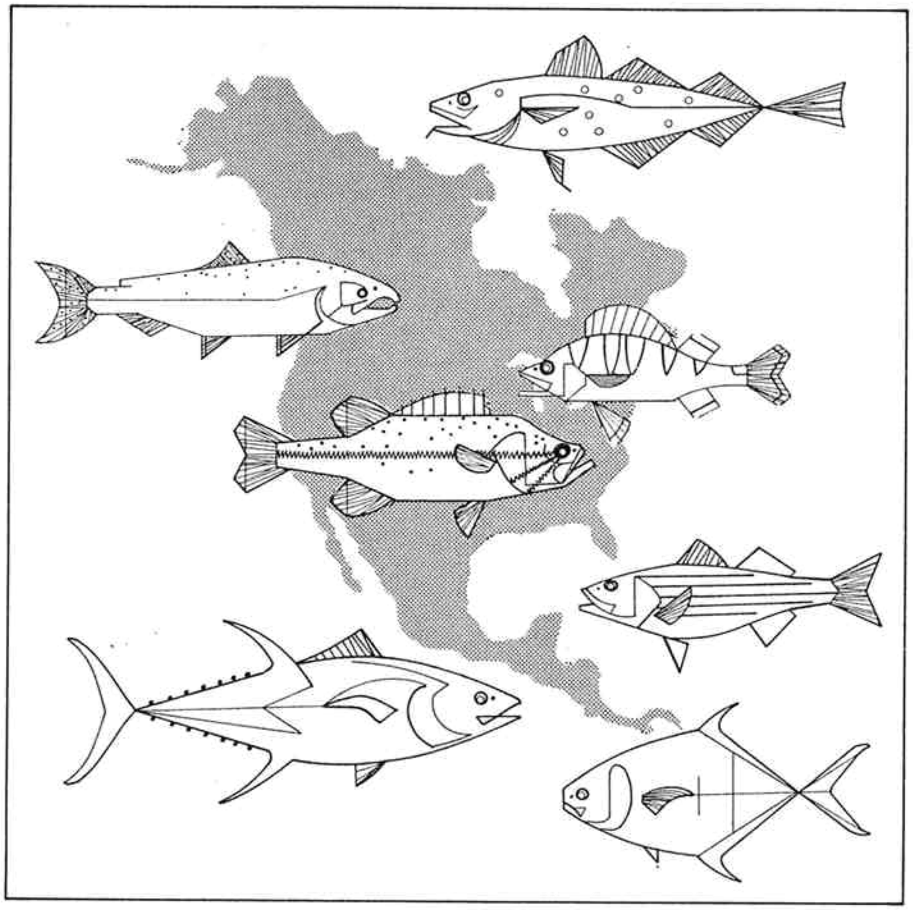

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Spawning and Nursery Habitats of Largemouth Bass in the Tidal Hudson River

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Abstract.—Spawning and nursery habitats of largemouth bass *Micropterus salmoides* in the freshwater portion of the Hudson River estuary were identified and characterized. The shoreline from Troy to Peekskill, New York, was classified by habitat (exposed shoreline, shallow shoreline, creek mouths, coves, and bays), and 15 adult males, radio-tagged in March, were tracked to nesting sites. Fish moved 1.6–64 km and spawned in areas protected from wind and wave action or in areas where tidal action was mitigated. Bays and coves were the habitats selected by most nesting radio-tagged bass. Nests of 114 untagged largemouth bass were visually located; 44% of these nests were in bays, 37% in creek mouths, 18% in coves, and only 1% along exposed shoreline. Habitat types selected by nesting largemouth bass amounted to less than 25% of the total shoreline habitat available. Water temperatures over the nests when the nests were first discovered ranged from 16.7 to 20.5°C, and depth of the nests at low tide ranged from 0.15 to 1.10 m. One nest was dewatered at low tide. Electrofishing catch rates for age-0 largemouth bass indicated that areas selected for nesting were also the primary nursery habitats. Suitable spawning and nursery habitats for largemouth bass in the Hudson River are limited and should be safeguarded to ensure the health of the local largemouth bass sport fishery.

Largemouth bass *Micropterus salmoides* is one of the most sought-after gamefish species in the USA. The Hudson River estuary, New York, has supported a rapidly growing largemouth bass fishery since the late 1970s, much of it centered around tournament fishing. This study was undertaken because anglers, conservationists, and state fisheries managers were concerned about the effect of increased fishing effort on the high-quality (53% of the largemouth bass in the electrofishing catch were 381 mm or larger), low-density largemouth bass population in the river.

Spawning and nursery habitats of largemouth bass in lacustrine environments are well documented (Kramer and Smith 1962; Robbins and McCrimmon 1974; Coble 1975; Heidinger 1975, 1976; Carlander 1977; Edwards et al. 1983), but little information is available in the literature concerning these habitats in large tidal rivers. Riverine populations of largemouth bass are known to spawn in backwater areas that are often nearly isolated from the main river (Schonhoff and Van Vooren 1985). These same slough and backwater areas can also serve as nursery habitat for age-0 largemouth bass (Montgomery and Fickeisen 1978). In 1984, R. M. Davis and others (Maryland Department of Natural Resources, unpublished) found low-density populations of age-0 largemouth bass in creek mouths and small embayments of the tidal Potomac River, and Odum et al. (1984) reported age-0 largemouth bass in the extreme shallows of tidal freshwater marshes with dense emergent vegetation. The majority of information on tidal largemouth bass populations resides in unpublished reports and internal documents.

The purpose of this study was to describe spawning habitat and movement of largemouth bass in the tidal portions of the Hudson River. We also identified and described the nursery habitat and relative abundance of age-0 largemouth bass in different habitats and years.

Study Area

The estuarine reach of the Hudson River extends from the mouth at New York City north to Troy, New York. The study area was restricted to a 180-km section of the river from the dam at Troy to Peekskill (Figure 1). Most radiotelemetry data were from fish tagged in the upper portion of the estuary (river km 160–210). River widths ranged from 200 to 1,000 m and a navigation channel was maintained for ship and barge traffic. Tidal areas of the river included an assortment of bays, mud flats, cove areas, and creek mouths up to the first tidal barrier. The majority of the study reach was fresh water with conductivities ranging from 100 to 1,600 μS/cm. The southern section

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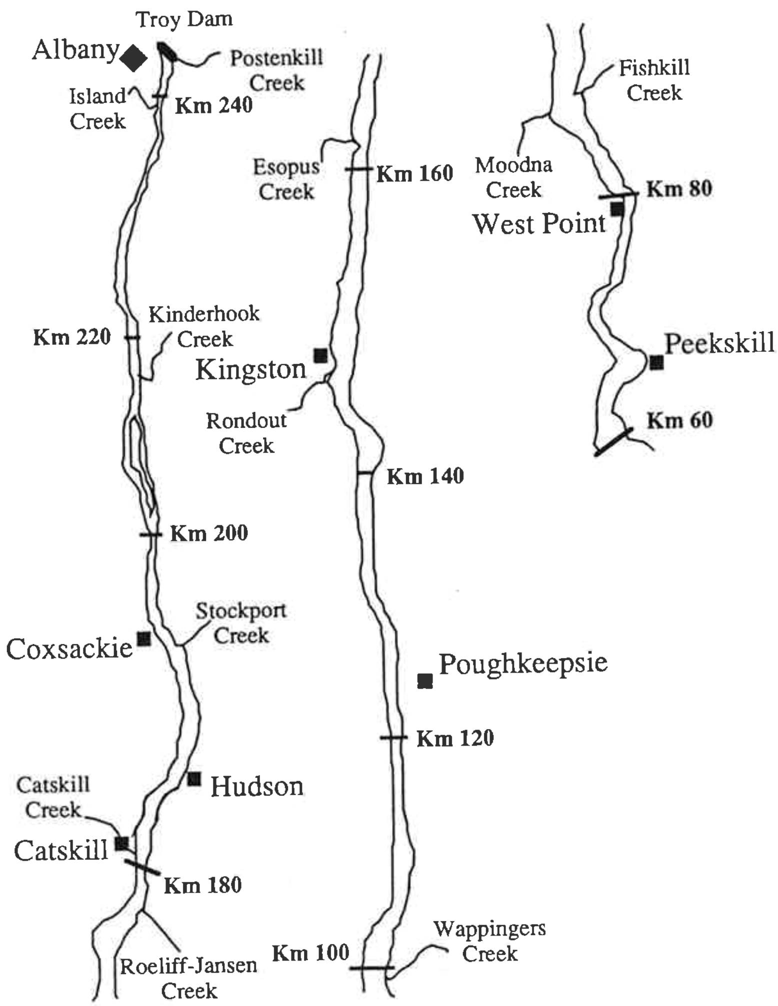

FIGURE 1.—Map of the study area and approximate river kilometer designations, including major creeks and cities.

of the study area, south of Poughkeepsie, occasionally experienced saltwater intrusions that raised conductivity to over 3,000 μS/cm. Tidal fluctuations averaged slightly more than 1 m and were the driving force for river currents. Substrates were predominately fine sands and silt with localized areas of bedrock, gravel, and bank stabilization material such as boulders and bricks. There were numerous islands formed by material dredged from the navigation channel.

Methods

We divided the river shoreline between the Troy dam and Peekskill into five major habitat types based on predominant physical characteristics through the use of National Oceanic and Atmospheric Administration (NOAA) maps and visual surveys with boats and airplanes.

Exposed shorelines were areas with steep dropoffs, little protection from wind and waves, and little or no vegetation.

Shallow shorelines were shallow expanses usually with light to moderate vegetation, little protection from wind and wave action, and predominantly sand–silt substrates.

Creek mouths were tidal portions of creeks entering into the Hudson estuary. Microhabitats associated with creek mouths included artificial structures to retain creek banks, unvegetated streambeds with gravel or clay or silt, boulders and rock ledges, and sloping shorelines of sand or clay. Moderate to dense amounts of submerged or floating and emergent plants were usually present out of the immediate stream channel. Sites were well protected from wind-induced wave action.

Coves were embayments with moderate protection from wind, waves, and current and a wide range of vegetation types and densities.

Bays were pond-like areas, still influenced by river and tidal action but well protected from wind and wave action. Many areas were marsh-like, usually connected to the river by an outlet or culvert pipe. In some, the full tidal effect was mitigated by elevation of the outlet or culvert pipe.

We divided these habitats into approximate 0.4-km shoreline units, numbered them on NOAA maps and determined the total length of shoreline made up of each habitat type. Sections within each habitat stratum were selected at random and visited to determine substrate composition, wind and wave action, vegetative cover, depth, and presence of current.

Radiotelemetry was used to track largemouth bass to nesting and spawning sites because high turbidity in the Hudson River estuary limited visual observation. Telemetry also allowed us to identify individual fish and assess movement patterns and homing tendencies. Radiotransmitters used in 1987 were 16 × 50-mm cylinders with rounded ends and a 294–309-mm antenna exiting the transmitter at the center of one end. Transmitters weighed 7.8–8.8 g in water and were less than 2% of the body weight of the fish. Transmitters used in 1988 were rectangular in shape, 20 × 40 × 10 mm, with 300-mm teflon-coated wire antennas; these transmitters weighed 5.1–6.4 g in water. All transmitters (purchased from Cedar Creek Bioelectronics Laboratory, University of Minnesota) were encased in biologically inert epoxy and supplied with lithium batteries rated at 60-d life expectancy. Each radio transmitted on an individual frequency between 53.042 and 53.952 MHz.

In the Hudson River, large numbers of largemouth bass and smallmouth bass *Micropterus dolomieu* congregate in five known wintering sites from late October to early April (Carlson 1992). These concentrations, located in Coxsackie Cove, Catskill creek, Esopus Creek, Rondout Creek, and Wappingers Creek, provide a unique opportunity to study seasonal movements. New York State Department of Environmental Conservation (DEC) personnel collected largemouth bass by electrofishing in three wintering sites March 24–27, 1987, and March 24–26, 1988. Male largemouth bass selected for radio-tagging ranged from 420 to 1,470 g. Sex of fish was determined by probing the urogenital opening (Benz and Jacobs 1986) and sex was confirmed in 1987 by visual examination of gonads when transmitters were implanted.

Immediately after capture, we anesthetized fish in a 76-L tub containing tricaine (MS-222). In 1987, the transmitter was inserted through a 20–30-mm incision along the ventral side of the body cavity anterior to the anus, and the antenna was loosely coiled into the body cavity by a modification of the methods suggested by Hart and Summerfelt (1975). The body cavity was closed with three or four sutures of 2.7-kg test monofilament fishing line. Prior to surgery, all transmitters, instruments, surgical gloves, materials, and containers were sterilized in 95% ethanol. Malachite green was applied to the sutured incision to prevent infection. Fish were returned to the holding tank until they revived and were released a short time later near the capture location.

Because of high mortality of internally radio-tagged largemouth bass in 1987, 10 adults from each wintering site were fitted with externally mounted transmitters in 1988 by the methods of Winter (1977). Two teflon-coated wires exiting from the transmitters were threaded through a needle and passed through the musculature slightly below the base of the dorsal fin and then through an oval piece of nalgene plastic. Neoprene pads (3.2 mm thick) provided a cushion between the fish and the transmitter and also added buoyancy to reduce the effects of transmitter weight. Transmitter, neoprene, and plastic pad were pulled tightly up against the fish and two overhand knots were tied in the teflon-coated wires to hold the transmitters in place.

Transmitters were checked before, during, and after attachment to insure proper operation. We tracked fish with a Cessna 172 airplane equipped with directional antennae and a scanning radio receiver and began tracking on the day following transmitter attachment. Largemouth bass were tracked 2 d each week and their locations were recorded on NOAA navigation charts. When water temperatures reached a point at which males generally begin prespawning activities (~13°C), we began to determine exact locations with a boat-mounted, directional Yagi antenna. We attempted to visually locate males guarding nesting sites and to describe the nesting habitat. Fish that remained in the same location for several days when the position was closely approached by boat or on foot were assumed dead. Attempts were made to recover the tags on these occasions. Fish that continued to transmit a signal after spawning were monitored by plane once per week to determine postspawning movements.

Physical variables measured at each site included habitat type, depth and distance of the nest from the shoreline at low tide, vegetative cover, and temperature of the water directly over the nest. Substrate was collected with a 50 × 32-mm core sampler and samples were sieved into various particle sizes according to the procedures of Welch (1948). Sieved samples were air-dried and weighed to give percent size composition by weight.

Relative preference for nesting in the five habitat types by radio-tagged largemouth bass was determined with methods reported by Bovee (1986) for habitat use analysis. Use by nesting fish and availability of habitat types were combined to develop preference values for nesting habitat:

$$P_i = U_i/A_i;$$

P_i = a normalized index of preference of habitat type i;
U_i = relative frequency (%) of fish observations at habitat type i;
A_i = relative frequency (%) of habitat type i available during the observation period.

After calculation, data were normalized to a scale from 0.0 to 1.0 by dividing the fractional preference values (U_i/A_i) for each habitat type by the highest preference value. In this case 0.0 indicates the least preferred habitat and 1.0 represents the most preferred. Habitat use by radio-tagged largemouth bass was compared to the distribution of habitat availability with chi-square analysis.

Nests of radio-tagged bass were observed at least twice per week to determine nest success. A nest observed to have fry in or rising above the nest was considered successful. Age-0 largemouth bass were collected with seines from the Troy dam south to Peekskill during summer 1987. Using habitat categories described previously, we selected seine sites randomly in proportion to the amount of each habitat present in the river. In addition, unpublished seine data from Consolidated Edison, Inc. (1974–1984), and DEC (1980–1987) were examined for relative abundance and distribution of age-0 largemouth bass.

We also collected age-0 largemouth bass at selected sites in 1987–1991 by direct current electrofishing from a boat with a 5.8-m hull cathode. We selected random sections of shoreline representative of each type of habitat. The segment of shoreline judged to be the most suitable habitat within the 0.4-km shoreline unit was electrofished for 15 min during daylight hours in August–October. Number and lengths of age-0 largemouth bass caught were recorded for each site. Scales were taken to determine ages of fish collected if age classification by length was not obvious. Catch rates (number of bass/hour) were calculated for each of the five habitats. Catch rates were compared between habitats and years with unpaired t-tests of data transformed by square-root (catch rate + 0.5) (Steele and Torrie 1980). All comparisons were made at the $\alpha = 0.05$ level.

Results

Although 24 largemouth bass were radio-tagged in 1987, only 4 fish were tracked to nesting sites. Six fish never moved from the wintering site and were either found dead or assumed dead, and eight fish were found dead 1.6–11.2 km from tagging locations. Signals from six transmitters were lost after 3–64 d. Signals from five of these bass remained near the release sites and the remaining fish was tracked for 17.6 km before the signal was lost.

During the first 2 weeks after the fish were radio-tagged in 1987 (March 24–April 2), water temperatures were 5–6°C and movements were restricted to less than 300 m. By April 9, five fish had moved out of their respective wintering sites and moved 1.6–3.2 km. By April 18, all 13 fish that exhibited movement had left the wintering sites and begun to disperse up and down the river. Fish generally traveled along the shoreline, except for one fish that crossed the river channel. Distance traveled ranged from 1.6 to 64 km. The fish that moved 64 km (Esopus Creek to Island Creek in Albany) returned to Coxsackie after spawning and remained there until signal failure on June 15. This fish was recaptured by electrofishing in March 1988 in Esopus Creek. A second fish moved across the river and south 2 km to nest (Catskill Creek to Roeliff-Jansen Creek), then moved 14.5 km north and then 4 km south near Hudson South Bay on June 5 when the signal failed. Subsequently, this fish returned to Catskill Creek where it was recaptured by electrofishing in March 1988.

Three of the four radio-tagged largemouth bass that nested in 1987 had moved to the general nesting area by May 1. The fourth fish moved to where it nested between May 5 and May 21. Distances between wintering sites and nesting sites of the four radio-tagged fish were approximately 1.6, 1.6, 6.4, and 64 km.

In 1988, 30 largemouth bass were radio-tagged and 11 were tracked to nesting sites. Of the remaining 19 fish, 7 were assumed dead, 4 were found dead, and signals were lost from 6 fish prior to spawning. Two fish were tracked through the spawning period but never nested. Because the sex of fish was not verified by examination of the gonads, these fish may have been females and could have moved in and out of their spawning area without being detected. The earliest a nesting radio-tagged fish left a wintering site was April 5, when water temperature was 8°C, whereas the latest a radio-tagged fish remained at a wintering site was May 23 (17°C). Time elapsed between departure from a wintering site to appearance at a nesting site was 2–39 d. The earliest radio-tagged largemouth bass nest was discovered on May 12 (16.7°C), the last on June 12 (20°C).

Distances between wintering sites and nesting sites of radio-tagged fish in 1988 ranged from 4.8 to 16.8 km (mean, 8.1 km; SD, 3.3). Three fish nested north of their wintering sites and eight nested south of theirs.

During both years, over 80% of the radio-tagged fish from the Coxsackie wintering site that nested used Stockport Creek and surrounding areas, including pools and backwaters north of the creek along the east shore of the river (km 195–210). Two fish returned to the Coxsackie wintering site after nesting and remained there through the end of tracking. One fish traveled about 16 km south and approximately 1 km up a small stream to Hudson South Bay, nesting well away from the river proper. All fish tagged at Coxsackie nested south of the wintering site.

In 1987 and 1988, largemouth bass radio-tagged at the Catskill Creek wintering site traveled both north and south. Nesting sites were more dispersed throughout the river than those of fish from the Coxsackie wintering site. None of the radio-tagged fish nested in Catskill Creek, but several untagged fish were observed nesting in the creek. One radio-tagged fish nested in an area that was dewatered during low tide. During each tidal cycle, this fish abandoned the nest as water depth dropped to about 15 cm, moved to a small nearby pool during low tide and returned when the nest site was reflooded. Some radio-tagged fish moved in and out of the creek mouth several times after spawning.

Two of the four largemouth bass radio-tagged in Esopus Creek during the study nested close to the creek mouth. One fish traveled approximately 0.3 km south of the creek mouth and nested in a large, shallow cove. The other fish moved out of the wintering site and nested in the large cove just north of the creek. One fish traveled about 10 km north before nesting and another traveled 64 km north before nesting. None of the fish radio-tagged in Esopus Creek nested in the creek itself; however, as with Catskill Creek, several untagged fish nested in the mouth of the creek.

TABLE 1.—Amount of shoreline habitat available in the study reach of the Hudson River, number and percentage of largemouth bass nests in different habitats as determined by radiotelemetry, and relative preference (P_i) for these habitats by largemouth bass in 1987 and 1988.

Habitat	Amount of habitat: km	Amount of habitat: %	Nests in habitat: Number	Nests in habitat: %	Relative preference
Exposed shoreline	285.5	63.0	1	6.7	0.01
Cove	60.0	13.2	6	40.0	0.22
Creek mouth	36.5	8.0	1	6.5	0.06
Bay	11.0	2.4	5	33.3	1.00
Shallow shoreline	60.5	13.3	2	13.3	0.07
Total	453.5		15		

Bays and coves were the habitats selected by most nesting radio-tagged largemouth bass (Table 1). Creek mouths and bays were the least abundant habitats in the river. About 63% of the near-shore habitat was classified as exposed shoreline but only one fish nested at an exposed site. The estimate of relative preference showed that bass selected bays (P_i = 1.00) and coves (P_i = 0.22) for nesting. Distribution of use, relative to availability of habitat, showed a significant difference between the two distributions (probability of a greater χ^2 = 0.001). Nests of 114 untagged largemouth bass were also located; 18% of these nests were in coves, 44% in bays, 37% in creek mouths, and 1% along exposed shoreline.

Earliest nesting activity was observed in small shallow bays, which tended to warm more quickly than the river. Water temperatures over the 15 nests when the nests were first discovered ranged from 16.7 to 20.5°C, (mean, 18°C; SD, 1.26). Depth at low tide for 14 of 15 nests ranged from 0.15 to 1.10 m (mean, 0.58 m; SD, 0.25). The 15th nest was above the low tide level. Distance of nesting sites from shore ranged from less than 0.5 m to 275 m. Water chestnut *Trapa natans*, spatterdock *Nuphar* spp., eurasian milfoil *Myriophyllum spicatum*, or other aquatic vegetation was present at 73% of radio-tagged largemouth bass nests. No aquatic vegetation was located near nests of other

TABLE 2.—Boat electrofishing catch rates (bass/h) for age-0 largemouth bass in the five habitat types in the Hudson River during 1987–1991.

Habitat	Number of sites	Hours fished	Number of bass	Bass/h
Exposed shoreline	224	56	126	2.25
Cove	61	15.25	85	5.57
Creek mouth	68	17	182	10.71
Bay	25	5.81	77	13.25
Shallow shoreline	53	13.25	43	3.24

radio-tagged fish, but two were adjacent to large rocks or structure and one was shaded by a large overhanging oak tree. In samples taken from 21 nesting sites, 58% (SD, 32) of the substrate was larger than 2 mm in size (rock and gravel), 21% (SD, 20) ranged from 2.0 to 0.25 mm (sand), and 21% (SD, 27) was less than 0.25 mm (fine sand and silt). Substrate of nests in bays was 47% (SD, 34) larger than 2 mm, 18% (SD, 11) 2.0–0.25 mm, and 36% (SD, 31) smaller than 0.25 mm. In creek mouth nests, the respective substrate distribution was 56% (SD, 31), 32% (SD, 26), and 12% (SD, 17); in cove nests, it was 65% (SD, 34), 15% (SD, 19), and 19% (SD, 29).

The presence of fry in or rising above the nest of radio-tagged bass was determined for 14 of the 15 nests. Two of the nests in bays and one nest in a cove produced fry; however, we observed no fry in the other 11 nests, which may have been unsuccessful.

Over 1987–1991, 431 electrofishing samples produced 513 age-0 largemouth bass. Catch rates were highest in bays, followed in descending order by creek mouths, coves, shallow shoreline, and exposed shoreline (Table 2). Catch rates in 1988, 1989, 1990, and 1991 were greater than those in 1987; however, differences between the last four years were not significant (Table 3).

Densities of age-0 largemouth bass were uneven along the length of the estuary. Catch rates in the northern section of the estuary (km 243–192) were

TABLE 3.—Boat electrofishing catch rates (bass/h) for age-0 largemouth bass in each year, 1987–1991.

Year	Number of sites	Hours fished	Number of bass	Bass/h
1987	79	19.75	15	0.8
1988	124	31.00	190	6.1
1989	77	19.13	62	3.2
1990	79	19.58	74	3.8
1991	72	17.85	172	9.6
Total	431	107.31	513	4.78

TABLE 4.—Catch rates of age-0 largemouth bass in four sections of the Hudson River (river km 35–243).

River segment	Electro-fishing 1987–1991 (bass/h)	Cornell seining 1987 (bass/haul)	DEC and Con Ed[a] seining 1974–1987 (bass/haul)
Segment 1 (km 243–192)	1.39	0.00	0.01
Segment 2 (km 192–141)	3.30	0.17	0.04
Segment 3 (km 141–67)	10.97	0.25	0.16
Segment 4 (km 67–35)	b	b	0.01
Number of samples	431	85	24,397

[a] New York Department of Environmental Conservation and Consolidated Edison, Inc.
[b] Not sampled below river km 90.

lowest among the three river segments we sampled (Table 4). Catch rates increased steadily in a southerly direction.

Discussion

The extent of mortality of the radio-tagged fish in 1987 was unexpected. Dummy transmitters had been placed in four largemouth bass in the laboratory with the same procedures. After being held for 59 d, all four fish healed well and appeared to accept transmitters. Transmitters were implanted surgically in 1987 because fish did not retain transmitters in stomachs during trials in the winter of 1986–1987 and because it was believed that abundant aquatic vegetation would entangle externally attached transmitters. Harsh environmental conditions may have contributed to high mortality. Snowmelt and exceptionally heavy spring rains after fish were returned to the river subjected the fish to cold, turbulent waters. Delayed healing of largemouth bass implanted with transmitters when water temperatures were low has been observed in Iowa (B. J. Schonhoff III, Iowa Department of Natural Resources, personal communication), and stress relating to handling of fish may also have been a factor. Because total annual mortality of adult largemouth bass in the Hudson River is relatively high, (42–65%: D. M. Green, unpublished data) some mortality would be expected even without implantation of transmitters. The postwinter and spawning periods may be particularly stressful times and some portion of the annual mortality would occur during these periods.

External radiotransmitters used in 1988 were much more successful. Thirteen of 30 tagged fish were tracked through the spawning season, and 11 were observed to spawn. The greater success can possibly be attributed to a combination of milder weather and the use of a less invasive tagging technique. One radio-tagged fish recaptured during a local tournament was in good condition with minimal damage from attachment of the transmitter.

Hudson River largemouth bass began to leave the wintering sites as water temperatures increased to approximately 10°C. Mesing and Wicker (1986) reported peak largemouth bass movement in Lakes Yale and Eustice, Florida, to be related to the spawning season and distances traveled by fish ranged from 2.5 to 3.0 km. Schonhoff and Van Vooren (1985) reported maximum distances traveled by radio-tagged largemouth bass in the Mississippi River to be about 6.4 km. In a conventional tag-and-recapture study on the St. Johns River in Florida, Moody (1960) found that most largemouth bass (62%) were recaptured within 16 km of their release points after periods of up to 5 months, although one fish moved 200 km. During our study, most fish traveled 3–16 km up and down the river shoreline and this may be an indication of an average spawning migration distance. Some fish did travel greater distances, overlapping various wintering sites. It is not known what percentage of fish return to the same wintering site each year or how many use more than one, although returns of marked fish in our current project on the Hudson indicate there may be little mixing between sites.

Location of nesting sites may determine spawning success in the Hudson River. Diverse habitats were used for nesting and the degree of protection from wind and wave action varied greatly. Mortality of eggs and fry in lakes has been attributed to wind-induced wave action (Miller and Kramer 1971). In the Hudson River, massive wakes from large ships pose a further threat to nests in unprotected areas. Only 10% of the shoreline was well protected (bays and creek mouths), but 40% of the radio-tagged fish nested in these protected habitats. These areas were also well vegetated, and vegetative cover or other structure is important in nest site selection (Kramer and Smith 1962; Emig 1966). Vegetation or structure was associated with 14 of the 15 nests built by radio-tagged fish.

The effect of tidal action on spawning and nest selection is uncertain. High recruitment has been associated with stable water levels in lakes, and reductions in water levels have been detrimental to nesting success (Van Geldern 1971). Whether daily tidal fluctuations also reduce nesting success is unknown, but catch rates for young were relatively low (Table 3). It is significant that most fish nested in areas where tidal action was somewhat mitigated.

Site-specific temperature differences may influence nest site selection. Earliest nesting activity was observed in small shallow bays that tended to warm more quickly than the river. Largemouth bass spawning has been observed in canals that were 1.0–2.7°C warmer than the lakes they fed into (Mesing and Wicker 1986). Largemouth bass have also been shown to actively select higher water temperatures in spring (Gibbons et al. 1972). Although not measured, water in bays, pools, and backwater areas probably warms faster than the main Hudson River, which may promote spawning in these areas.

Largemouth bass spawn successfully on a wide range of shallow-water substrates (Heidinger 1976), but not on silt bottoms (Bulkey 1975). Most bottom material in the nests of radio-tagged and untagged fish was composed of gravels; however, 21% of the material in the nests was silt. The material in only two nest sites consisted of more than 50% silt. Areas in which tidal currents are reduced also are the areas most subject to siltation. This serves to further reduce the quality of spawning habitat.

Largemouth bass hatched in protected habitats probably remain there for the first year of life. Catch rates for age-0 largemouth bass in the more protected habitat types (creek mouths and bays) were approximately four times higher than those in unprotected areas (exposed shoreline and shallow shoreline). Cove habitats were less protected than bays and creek mouths and catch rates in this habitat type were intermediate between protected and unprotected areas. Nearly all age-0 largemouth bass were found in areas with either submerged vegetation or some type of structure (dock pilings, logs, etc). Dense weed beds and heavily structured areas held the vast majority of young. Many age-0 largemouth bass were captured near shore in water less than 2.0 m deep.

Differences in the amount of suitable spawning and nursery habitats may explain the north-to-south gradient in age-0 largemouth bass catch rates (Table 4). The northern section of the study area was narrow, currents were swift, and much of the shoreline was modified by dikes and fill. Steeply sloping, exposed shorelines in this area supported little vegetation or structure, and suitable spawning areas away from the main river channel were limited. The lack of appropriate spawning habitat north of the Coxsackie wintering site may explain why 80% of the radio-tagged fish released there nested south of Coxsackie. In the central segment of the river (km 192–141), more cove, bay, and creek mouth habitats exist than in the northern section. Largemouth bass selected these habitats for spawning, and catch rates for age-0 largemouth bass indicate that these habitats also served as nursery areas. In the southern segment of the river, cove, bay, and creek mouth habitats were present in percentages similar to those of the central section. In addition, wide, shallow areas existed. These areas allow for the development of vast expanses of submerged and floating aquatic vegetation that reduce the negative effects of ship- and wind-induced wave action.

The Hudson River is a very dynamic system with daily cycles in water level and current. Commercial ships, barges, and large yachts also contribute to disruptive water forces. Areas largely or partially protected from these natural or anthropogenic forces are in limited supply, making up less than 25% of the shallow-water habitat of the river. Radio-tagged largemouth bass selected these protected areas as nesting sites and observations of nest sites of untagged bass also suggest that protected areas are selected for nesting. Young-of-the-year largemouth bass were also most abundant in these areas. The low-density largemouth bass population (less than 2 fish/hectare: Carlson 1992) in the Hudson River appears particularly vulnerable to any loss or alteration of habitats. These important spawning and nursery habitats for largemouth bass in the Hudson River estuary should be protected.

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