MOVEMENTS, DISTRIBUTION AND HABITAT PREFERENCES OF STRIPED BASS IN ROBERT S. KERR RESERVOIR, OKLAHOMA

By

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Chapter I

Introduction

This thesis is comprised of two manuscripts written for submission to North American Journal of Fisheries Management and Transactions of the American Fisheries Society. Chapter I is an introduction to the rest of the thesis. The manuscripts are complete as written and require no supporting material. The manuscripts are contained in Chapters II and III and are titled `Striped Bass Distribution, Movements, and Site Fidelity in Robert S. Kerr Reservoir, Oklahoma' and `Habitat Preferences of Striped Bass in Robert S. Kerr Reservoir, Oklahoma: A GIS Approach', respectively.

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Chapter I

Introduction

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Chapter II

Striped Bass Distribution, Movements, and Site Fidelity in Robert S. Kerr Reservoir, Oklahoma

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Striped Bass Distribution, Movements and Site Fidelity in Robert S. Kerr Reservoir, Oklahoma.

Abstract.-We conducted a telemetry study to determine the seasonal and summer diel distribution and movement patterns of small (<2.7 kg) and large (≥2.7 kg) striped bass Morone saxatilis in Robert S. Kerr Reservoir, Oklahoma. We surgically implanted 22 fish with ultrasonic telemetry tags, and systematically searched the entire reservoir for tagged fish twice monthly. In addition, we placed a remote receiver on Kerr Lock and Dam, immediately below the reservoir to monitor striped bass movement out of the reservoir. Between January 1993 and March 1994 125 locations of 15 different fish were made. Large and small striped bass accounted for 61 and 64 locations, respectively. The remote receiver recorded two fish on separate occasions in the tailwater below the reservoir. Striped bass exhibited limited seasonal distribution and movements. Spring movements (i. e., distances and rates of movement) were significantly greater than those in summer (P=0.0397; P=0.0213, respectively), but not different from those in winter 1993, autumn, or winter 1994. In summer, large fish moved greater distances (P=0.0064) and were more active (P=0.490) during diel tracking than small fish. Striped bass displayed strong fidelity to the Illinois River throughout the study with 63% percent of all fish locations occurring in this tributary. The mean percent occurrence of

individual fish in the Illinois River was 66%. Because of their limited movements and distribution, and fidelity to the Illinois River, this population is highly susceptible to overfishing.

Striped bass Morone saxatilis in inland reservoirs exhibit two patterns of seasonal distribution and movement. In one pattern, herein termed indirect, striped bass move upstream to spawn in reservoir tributaries in spring and downstream to disperse throughout the main body following spawning (Combs and Peltz 1982; Braschler et al. 1988; Hampton et al. 1988; Farquhar and Gutreuter 1989; Poarch 1989). They remain in this area until the water temperature rises above a critical level (25-27 °C) in the summer, forcing them to seek out spatially-restricted thermal refuge habitats (Summers 1982; Coutant 1985; Zale et al. 1990; McDaniel et al. 1991). In another pattern, herein termed direct, striped bass move to refuge habitats following spawning and do not disperse into the reservoir (Cheek et al. 1985; Lamprecht and Shelton 1986). In autumn, when the water temperature falls below the critical level, fish from both groups usually disperse out of the refuge habitats to other areas of the reservoir until the following spring.

Although several studies have documented seasonally restricted spatial distributions of striped bass, few have reported evidence of site fidelity by individual fish. Fidelity describes an animals tendency to return to a previously used area or to remain in a location for extended periods (White and Garrott 1990), which typically indicates that resources are clumped in these areas. Lamprecht and Shelton (1986) described repeated use of the Thurlow Dam tailwater and Alabama River, Alabama, by individual striped bass over consecutive years. Individual striped bass repeatedly used restricted areas of Lake Whitney, Texas, and remained there for months at a time (Farquhar and Gutreuter 1989).

Tolerance of extreme environmental conditions and movements among habitats by striped bass may be dependent on fish size. Coastal stocks of striped bass exhibit size-related movements (Merriman 1937; Vladykov and Wallace 1938; Raney et al. 1954; Chapoton and Sykes 1961; Moore and Burton 1975; Mansueti 1961; Massmann and Pacheco 1961). Large striped bass (≥2.7 kg), (Chapoton and Sykes 1961) migrate long distances along the Atlantic coast, whereas small fish (<2.7 kg) usually remain near their natal rivers (Fay et al. 1983; Coutant 1985). Documentation of size-related differences in striped bass movements and the factors that influence them in inland waters is limited. Six large striped bass, tagged in the Arkansas River near Tulsa, Oklahoma, moved between 191-1,800 km downstream through navigation locks and dams (Pers. Comm. Alexander Zale).

Robert S. Kerr Reservoir, Oklahoma, supports a relatively small population of striped bass, compared with populations in other regional reservoirs (Peterson 1990). Throughout much of the year anglers in the reservoir have reported difficulty locating striped bass, except in the tributary arms. We used ultrasonic telemetry to track striped bass movements in Kerr Reservoir. Our specific objectives were to determine seasonal and summer diel distribution and movements of striped bass in the reservoir, and if movements or distribution patterns differed between small (<2.7 kg) and large (≥2.7 kg) striped bass.

Study Site

Kerr Reservoir is a mainstream reservoir of the Arkansas River located in east central Oklahoma. The 18,000 ha reservoir is bounded by four hydroelectric dams, and it is used mainly for navigation, power generation, and recreation. The reservoir consists of an upper riverine portion (Upper River), a lower lacustrine portion (Main Lake), and two large tributaries, the Illinois River and Canadian River (Table 1). The Illinois River arm is an Ozarkian river that is 15 km long with gravel and mud substrate, low conductivity and discharge, and high water clarity. The Canadian River is a shallow turbid river that is 25 km long with a shifting sand substrate, intermediate conductivity, and moderate discharge. The Upper River has a relatively narrow deep channel upriver (the channel is maintained for navigation) that spreads out below the confluence of the tributaries as it enters the Main Lake. It has low water clarity and high conductivity and discharge. The Main Lake is a lacustrine habitat with low water clarity and a large proportion of shallow, mud bottomed areas with submerged tree stumps.

Methods

We used ultrasonic telemetry to track the movements of small (<2.7 kg) and large (≥2.7 kg) striped bass in Kerr Reservoir. Fish were collected between October 1992 and May 1993 from the Illinois River (N=12) by electrofishing and from the Canadian River (N=10) with gillnets (Table 2). We surgically implanted these 22 fish with temperature-sensing ultrasonic tags (Model CTT-83-2, Sonotronics, Tucson, Arizona) and an external anchor tag. Each ultrasonic tag had a unique aural code, consisting of a series of pulses and pauses, that allowed for identification of individual fish. Small fish ranged from 1.2-2.9 kg in mass ($\bar{x}$ =1.98 kg) and from 435-529 mm (SL) in length ($\bar{x}$ =484 mm). Large fish ranged from 3.3-15 kg in mass ($\bar{x}$ =6.0 kg) and from 464-920 mm (SL) in length ($\bar{x}$ =626.6 mm). Striped bass captured, but not selected for implantation (N=37), were tagged only with an external anchor tag. These fish ranged from 0.12-8.3 kg in mass ($\bar{x}$ =2.7 kg) and from 317-765 mm (SL) in length ($\bar{x}$ =508 mm).

We systematically searched the entire reservoir by boat twice monthly, except for July and August 1993 when only the Illinois River and surrounding area was searched. In addition, the Canadian River could not be searched on several occasions because of low water. We determined our search pattern by overlaying a 2000 m by 2000 m grid system on a map of Kerr Reservoir (Figure 1, Appendix A). We chose this grid size because the range of the ultrasonic tags (1000 m) allowed us to search an entire cell from one location. At the center of each grid cell, we lowered a directional hydrophone (model DH-2, Sonotronics) into the water and slowly rotated it in a complete circle at each transmitter frequency. Precise fish locations were determined by maneuvering the boat toward and around a detected signal until it could be heard with equal volume in all directions. In addition to the regular monthly tracking, we tracked tagged fish in the Illinois River at 6-hour intervals for 48 hours in August 1993 to determine summer diel movement patterns.

We recorded striped bass movement out of the reservoir with a remote receiver (Model USR-18, Sonotronics), hydrophone, and laptop computer placed on the Robert S. Kerr lock wall immediately below the reservoir. The receiver, in conjunction with the computer, recorded the frequency, time, date, and temperature of tags in the vicinity. A tag was recorded only if a fish was located within range of the hydrophone long enough for the receiver to hear three pulses in a row without a pause.

We grouped data by seasons to facilitate analyses. The timing and duration of these seasons was based on striped bass biology and environmental characteristics of Kerr

Reservoir. The seasons were spring (May to mid-July), summer (mid-July to mid-October), autumn (mid-October through December), and winter (January through April). We characterized the spring season as the time when the mean reservoir temperature ranged from 14 °C to 22 °C and fish moved into potential spawning habitat. The summer season began when the water temperature rose above 22 °C and striped bass moved to restricted refuge habitats. This season lasted until the water temperature dropped below 25 °C. The autumn season was characterized by a dispersal of striped bass from their refuge habitat when the water temperature ranged from 14 to 22 °C. The winter season included the time between autumn and the beginning of the spawning season when the temperature ranged from 5 to 14 °C.

Distance moved between successive locations and rates of movement were computed for all seasons. The shortest distance over water between successive locations as measured using geographic information system (GIS) software (GRASS 4.0). We then calculated rates of movement by dividing the distance by the number of days elapsed between successive locations.

We used a repeated measures split-plot analysis of variance (AOV) to compare mean distances moved and mean rates of movement by size classes and seasons (Steele and Torrie 1960). A split-plot design was appropriate because we repeatedly sampled the same individuals over time, thus the variances due to the individuals and the variance of the treatment variables (i. e., size and seasons) must be accounted for (Maceina et al. 1994). We transformed all movement data with a rank transformation (Conover and Iman 1981) because untransformed data failed to meet the assumption of homogeneity of variances. Our null hypotheses were distances moved and rates of movement by striped bass did not differ among size classes or seasons. If a significant difference was found, we compared the means with Duncan's Multiple Range test.

We chose the T-square sampling procedure over a nearest-neighbor method to determine seasonal spatial dispersion patterns of striped bass because we did not have an exact distribution map of every individual during each sampling period (Diggle, Besag and Gleaves 1976; Krebs 1989). Spatial dispersion patterns were assessed by measuring the distance from random points to the nearest fish, and then from that fish to its nearest neighbor. The nearest neighbor must be located in an area more than 90° from the original fish. This requirement is tested by drawing a straight line from the random point to the nearest fish and then drawing another line perpendicular to the first. The nearest neighbor then must lie on the opposite side of the perpendicular line from the random point. We calculated a T-square statistic for each survey of the reservoir using the measurements for all fish located during that particular survey. Small T-square values (0-1.2) indicate a regular distribution, medium values (1.2-1.29) indicate a random pattern, and large values (>1.29) indicate an aggregated distribution. All values that fell within a season were then averaged to get a mean dispersion statistic for each season. We used a one-way AOV to test for differences in dispersion among seasons. If a significant difference was found, we compared the means with Duncan's Multiple Range post-hoc test.

Results

Locational Statistics

We obtained 125 individual striped bass locations from January 1993 to March 1994 (Table 2, Appendix B). Small and large striped bass accounted for 64 and 61 locations, respectively. Thirteen of these locations (10%) were from two fish tagged in the Canadian River and the remaining 112 locations were from fish tagged in the Illinois River. Seven fish were never relocated, and one fish (384-I) died after being at large for 97 days. The number of locations per individual fish ranged from 3-18.

Anglers caught seven fish that had been tagged in the Illinois River. Of these, two had transmitters and five had only anchor tags. One transmittered fish was released and the other fish (357-I), caught in August 1994, was reported to weigh 4.5 kg, a 2.6 kg increase in weight since it was tagged in October 1992 (Table 2).

Movements

The mean distances moved by striped bass were significantly different among seasons (P=0.0397, F=2.66, df=4) (Figure 2). Striped bass moved the furthest in spring ($\bar{x}$ =12,204 m, SD=19,450 m), which was significantly greater than summer (P≤0.05) when they moved the least ($\bar{x}$ =2,291 m SD=9,092) (Figure 2). A second peak occurred in autumn ($\bar{x}$ =7,891 m, SD=17,566) but was not significantly different from the other seasons. Striped bass movements were intermediate during both winter 1993 ($\bar{x}$ =3,472 m, SD=5,709) and winter 1994 ($\bar{x}$ =6,904 m, SD=13,569).

The seasonal mean rates of movement by striped bass paralleled the pattern for distances moved (Figure 2). The greatest rates occurred in the spring ($\bar{x}$ =302 m/day, SD=325 m/day), and they were significantly greater (P<0.05) than summer ($\bar{x}$ =107 m/day SD=238 m/day). Autumn rates ($\bar{x}$ =227 m/day, SD=443), although high, were not significantly different from other seasons. Winter 1993 ($\bar{x}$ =133 m/day, SD=146) and winter 1994 ($\bar{x}$ =175 m/day, SD=300) were intermediate to all other seasons.

Overall, large and small striped bass did not differ in distances moved (P<0.9845, F=0.00, df=1) or rates of movement (P<0.8591, F=0.03, df=1) (Table 3). Seasonally, in summer, large fish moved greater distances (P<0.0064, F=12.45, df=1) and at greater rates (P<0.0490, F=5.17, df=1) in summer than small fish (Table 3).

Diel rates of movement differed between small and large striped bass (P<0.0334, F=28.44, df=1), but not among time periods (Figure 3). Large fish moved at greater rates ($\bar{x}$ =47.63 m/hr, SD=39.77) than small fish ($\bar{x}$ =13.28 m/hr, SD=12.38), but distance moved by small and large fish did not differ significantly (P<0.0959, F=8.95, df=1). In general, the activity of large fish peaked at night when they moved the greatest distances ($\bar{x}$ =604.29 m, SD=563.25) at the greatest rates ($\bar{x}$ =71.56 m/hr, SD=43.36) and was lowest during daylight hours when distance moved was lowest ($\bar{x}$ =295.67 m, SD=236.95) and rates were least ($\bar{x}$ =29.02 m/hr, SD=25.79). Small striped bass moved at similar rates during day ($\bar{x}$ =13.69 m/hr, SD=14.58) and night ($\bar{x}$ =12.07 m/hr, SD=2.36), but small sample size makes this comparison tenuous.

On two separate occasions, fish tagged with transmitters were recorded by the remote receiver in the tailwater of Kerr Dam. One fish was recorded on 13 January 1993; however, we failed to identify this fish because two tags were tuned to the same frequency and neither fish was ever relocated. Another fish moved in and out of the tailwater between 25 December 1993 and 25 January 1994. We failed to identify this fish because the tag frequency had shifted in the cold water and the recorded frequency did not match any of our frequencies.

Distribution and Site Fidelity

Striped bass showed a high degree of fidelity to the Illinois River throughout the study (Table 2, Figure 4) (Appendix C). Sixty-three percent of all locations occurred in this tributary and only during autumn 1993 were more fish located in another area of the reservoir than in the Illinois River. Overall, about two-thirds of the individual fish locations occurred in the Illinois River (Table 2). Additionally, the number of locations in the Illinois River exceeded 60% for 10 and 70% for six of the 15 fish located during the study. For all seasons combined, the Upper River was the second most used strata (20%) followed by the Main Lake (11%) and the Canadian River (7%).

Further evidence of site fidelity was exemplified by two fish. Fish 366-I was located in a tree stump field in the Main Lake during the winter of 1993. It then moved into the Canadian River where it remained until mid-October. We next located this fish in another area of the Main Lake where it remained until early December. It then returned to the same stump field it was found at during the previous winter and remained there for the rest of the study. Fish 357-I was caught by an angler in the Illinois River in early August 1994 next to the same log-pile it was located at during the summer of 1993. Another fish (3335-I) stayed in a stump field near the mouth of the Illinois River for the majority of the study. Several other fish (e. g., 357-I, 447-I, and 2444-I) left the Illinois River for short periods of time but returned to the river.

Striped bass were aggregated during all seasons. Fish were more tightly clumped in winter 1994 (4.64) ($P<0.0001$, $F=20.47$, $df=4$) than in all other seasons. Fish were less tightly clumped during autumn (2.07), followed by summer (1.80), winter 1993 (1.68), and spring (1.57).

Discussion

Our findings indicate that striped bass in Kerr Reservoir exhibited limited seasonal distribution during all seasons. We originally believed that the low catch rates reported by anglers and from electrofishing (Deppert and Mense 1979) in Kerr Reservoir after the thermal refuge season occurred because striped bass dispersed from the Illinois River into other parts of the reservoir. We found that some striped bass dispersed from this tributary for a short time following the refuge season, but most returned by winter. Following winter, fish moved upstream into the Upper River and Illinois River presumably to spawn, but returned directly from spawning habitat to the Illinois River for the summer refuge season. This direct pattern of distribution and movements is similar to that described by Cheek et al. (1985) and Lamprecht and Shelton (1986).

The strong fidelity displayed by striped bass in Kerr Reservoir to the Illinois River may have been mediated by its temperature regime and habitat structure. This tributary provided a cool water refuge during summer because of the hypolimnetic discharge, but during autumn and both winters water temperatures were cool enough throughout the reservoir for striped bass to disperse out from this tributary. Yet, fish were tightly clumped in the Illinois River during all these seasons. Most fish locations were concentrated in an area near the confluence of the Illinois River and Upper River strata, whereas in summer striped bass used areas further upstream in the Illinois River. Lamprecht and Shelton (1986) reported striped bass using winter holding sites in the Alabama River and they characterized these as being within 10 m of shore and at the edge of the current. Furthermore, they reported striped bass remained in these areas for the entire winter (approximately December to March) and one fish used the same site in consecutive winters. Striped bass in Kerr Reservoir were often located near shore and in slack water or near submerged cover (e. g., tree stumps and root-wads) and could be using the Illinois River as a winter holding site similar to fish in the Alabama River.

Seasonal movements by striped bass (i. e., rates and distances moved) in Kerr Reservoir were similar to those reported for this species by Cheek et al. (1985) and Hampton et al. (1988) who found movement rates to be highest in spring and lowest in summer. Cheek et al. (1985) reported similar rates for spring and winter, but these were significantly higher than those for summer and fall. Hampton et al. (1988) reported a significantly higher rate of movement in spring (April-June) than during either the `feeding' (i. e., summer) or winter seasons. Likewise, Braschler et al. (1988) reported the highest movement rates from April through mid-May; however, they only tracked fish from January to July. In contrast, striped bass in the Ohio River reportedly moved most during winter and least in summer (Henley 1991). The maximum movement rates for striped bass in Kerr Reservoir were less than the minimum rates for all studies listed above regardless of the season, indicating that striped bass in Kerr Reservoir move substantially less than other inland populations.

We found no differences in distances or rates of movement for small and large striped bass when all seasons were combined (Table 3). However, large fish did move more than small fish in summer. Our inability to detect differences among seasons may have been confounded by fish growth and small sample size. Many of the small striped bass we tagged were near our size-class cutoff, and probably grew into the large size class during the study, which limited our ability to detect a difference between the two size classes. This is supported by the growth of fish 357-I which was classified as small at the beginning of the study but when caught in August 1994 had grown into the large size class. Although pronounced differences in seasonal movements by different-sized striped bass have been documented for coastal stocks (Chapoton and Sykes 1961), correspondingly small differences have been reported for inland stocks except for those reported by Jacks (1990). Large striped bass in Lake Texoma reportedly migrated to deep cool-water areas in summer whereas small fish continued to use the entire reservoir (Matthews et al. 1989). Small striped bass (1.8-4.9 kg) in Old Hickory Reservoir, Tennessee, moved less than larger fish and remained in the lower end of Old Hickory Reservoir for most of the year, whereas large fish made annual migrations and used the cooler upper end of the reservoir during summer (Poarch 1988). The high degree of site fidelity exhibited by striped bass in Kerr Reservoir suggests that movements by small and large-sized individuals in this system are not distinctly different during most seasons.

Summer diel movements for striped bass in Kerr Reservoir were similar to those reported for this species in the Tallapoosa River, Alabama (Lamprecht and Shelton 1986). Large striped bass in Kerr were most active nocturnally and more active than small striped bass who moved little during all time periods. Lamprecht and Shelton (1986) reported that striped bass activity was greatest at night with peaks occurring near dawn and dusk and were relatively quiescent during daylight hours. In contrast, Hampton et al. (1988) reported peak activity between 0800 and 1200 hours with a secondary peak in the afternoon (1400-1800 hours). Similarly, Henley (1991) reported striped bass were most active during diurnal periods and least active during nocturnal periods.

We found large striped bass were more active than small fish; however, Coutant's thermal niche hypothesis (Coutant 1985) suggests small striped bass should be more active than large fish, especially during summer. This apparent exception to Coutant's predictions may be a function of temperature. During the August diel tracking period, temperatures ranged from 16-27 °C in the Illinois River and often were below 20 °C in sections of the River. Therefore, temperature apparently did not limit movements of large or small striped bass within this thermal refuge.

Management Implications

Critical summer refuge habitats for striped bass in Kerr Reservoir were limited to the Illinois and Canadian rivers. The volume of these critical habitats presumably determines the carrying capacity of the reservoir for striped bass (Coutant 1985) and may explain their low population size in this system. Coutant (1985) stated the availability of potential prey species for striped bass in refuge habitats is important in determining the condition of individual fish located in these areas. Zale et al. (1990) found that striped bass ceased feeding above 27 °C and died from malnutrition if water temperature remained above this level for extended periods. The condition of striped bass declined in the St. Johns River during summer when they were forced into refuge areas where prey was not available (McDaniel et al. 1991). Coutant (1985) reported striped bass would not leave cool hypolimnion areas to feed on shad located a few meters above them in warmer water. We observed that prey species, including shad (Dorosoma sp.), skipjack herring (Alosa chrysochloris), and rainbow trout (Onchoryncus mykiss), were usually abundant in the Illinois River throughout summer. The availability of prey fish is reflected in the trophy size striped bass landed in the reservoir, including the last three state records. Because of the strong fidelity of striped bass to the Illinois River, high angling pressure in this tributary, and angler interest in pursuing trophy size fish, the Kerr population is susceptible to overfishing. To protect this population, future studies should focus on determining population size and age structure and angling pressure to prevent overharvest of this population.

In summary, striped bass in Kerr Reservoir made limited seasonal migrations compared to other inland populations. Large fish moved greater distances at faster rates than small fish in summer and during diel tracking in August. Striped bass were most aggregated during winter 1994 and least in the spring. Finally, striped bass displayed site fidelity to the Illinois River throughout the study.

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Table 1.-Physical and chemical habitat of strata in Robert S. Kerr Reservoir, Oklahoma.

	Water depth(m)	Secchi depth (cm)	Conductivity (µS/cm)	pH	Discharge (m^3/s)[a]
Strata	Mean(range)	Mean(range)	Mean(range)	Mean(range)	Mean(range)
Upper River	3.2(0.3-5.5)	33(5-122)	596(245-1144)	8.1(7.4-8.8)	9,387(2,097-5,440)[b]
Illinois River	1.5(0.3-3.0)	107(10-290)	195(108-391)	7.8(7.0-9.2)	1,495(280-3,114)
Canadian River	1.4(0.3-3.5)	53(15-155)	408(171-563)	8.1(7.5-8.9)	6,477(1,012-14,120)
Main Lake	2.4(0.3-6.5)	36(8-104)	455(54-859)	8.1(6.6-9.0)	-

[a] USGS discharge data.

[b] Discharge data is from the Arkansas River 80 km upriver of Kerr Reservoir.

Table 2.-Locational statistics for striped bass ultrasonically tagged in Robert S. Kerr Reservoir, Oklahoma. A `C' following the fish number indicates the fish was tagged in the Canadian River and an `I' indicates the fish was tagged in the Illinois River; NF indicates the fish was never found.

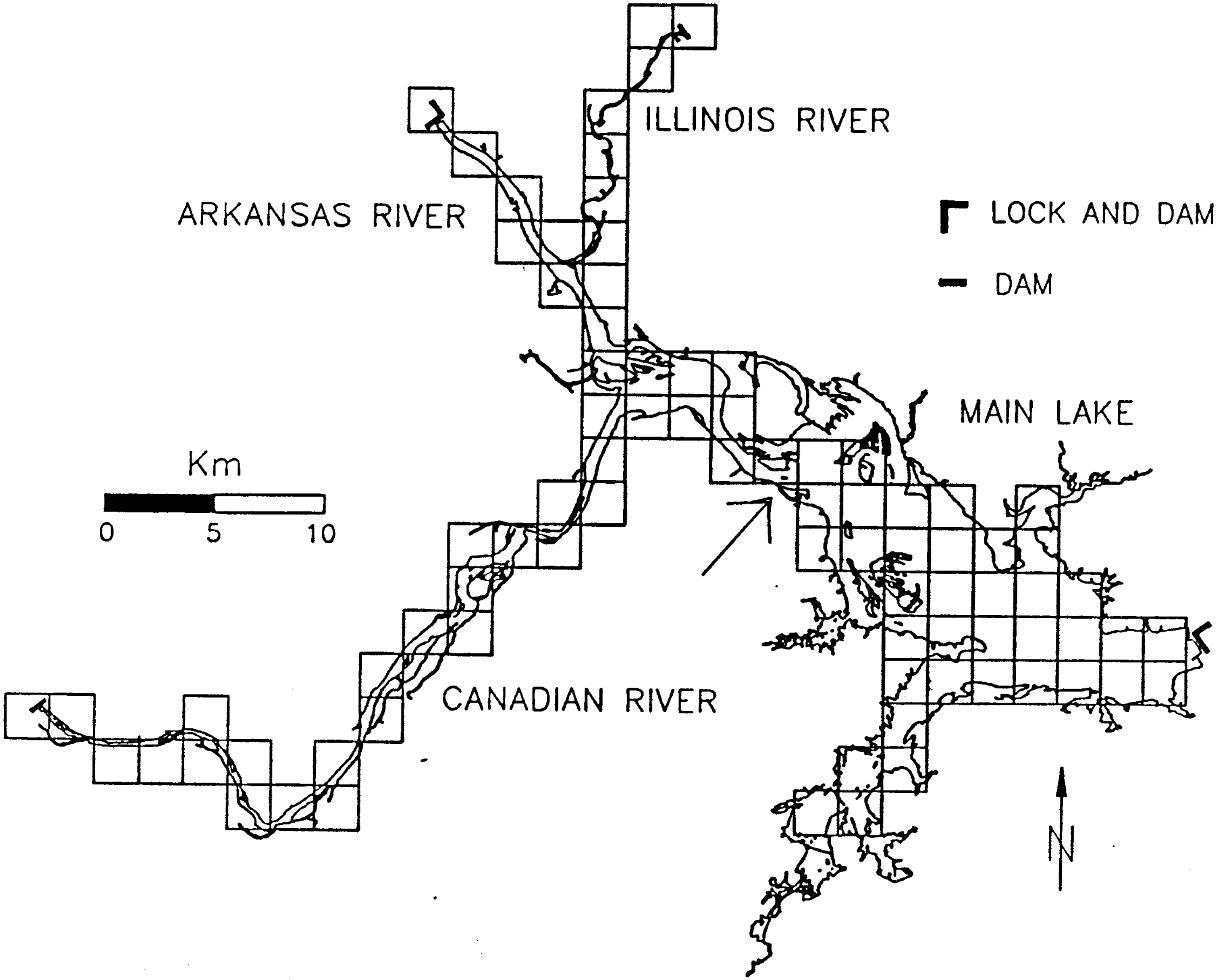
		Standard	Days	Number of locations (%)			
Fish number	Weight (kg)	length (mm)	at large	Main Lake	Canadian River	Upper River	Illinois River
2345-I	1.2	410	121	1(33.3)	0	1(33.3)	1(33.3)
3335-I	1.2	438	367	0	0	1(5.6)	17(94.4)
2633-I	1.4	460	311	0	0	2(16.7)	10(83.3)
97-C	1.8	465	NF	-	-	-	-
357-I	1.9	474	472	0	2(20.0)	1(10.0)	7(70.0)
456-C	1.9	435	NF	-	-	-	-
2363-I	2.3	500	261	1(16.7)	3(50.0)	0	2(33.3)
348-I	2.4	480	376	0	0	3(50.0)	3(50.0)
366-I	2.9	495	459	6(66.7)	3(33.3)	0	0
276-C	2.9	513	NF	-	-	-	-
384-I	3.3	533	97	2(100.0)	0	0	0
249-C	3.3	465	NF	-	-	-	-
258-C	3.5	464	310	0	0	3(37.5)	5(62.5)
2354-I	4.1	635	394	1(12.5)	0	2(25.0)	5(62.5)
2444-I	4.8	629	414	0	0	5(29.4)	12(70.6)
447-I	5.0	648	479	0	0	5(31.2)	11(68.8)
465-C	5.2	605	NF	-	-	-	-
555-C	6.3	635	NF	-	-	-	-
88-C	6.5	670	NF	-	-	-	-
2336-C	7.0	645	NF	-	-	-	-
267-C	8.2	670	269	0	0	2(40.0)	3(60.0)
339-I	15.0	920	367	0	1(25.0)	0	3(75.0)

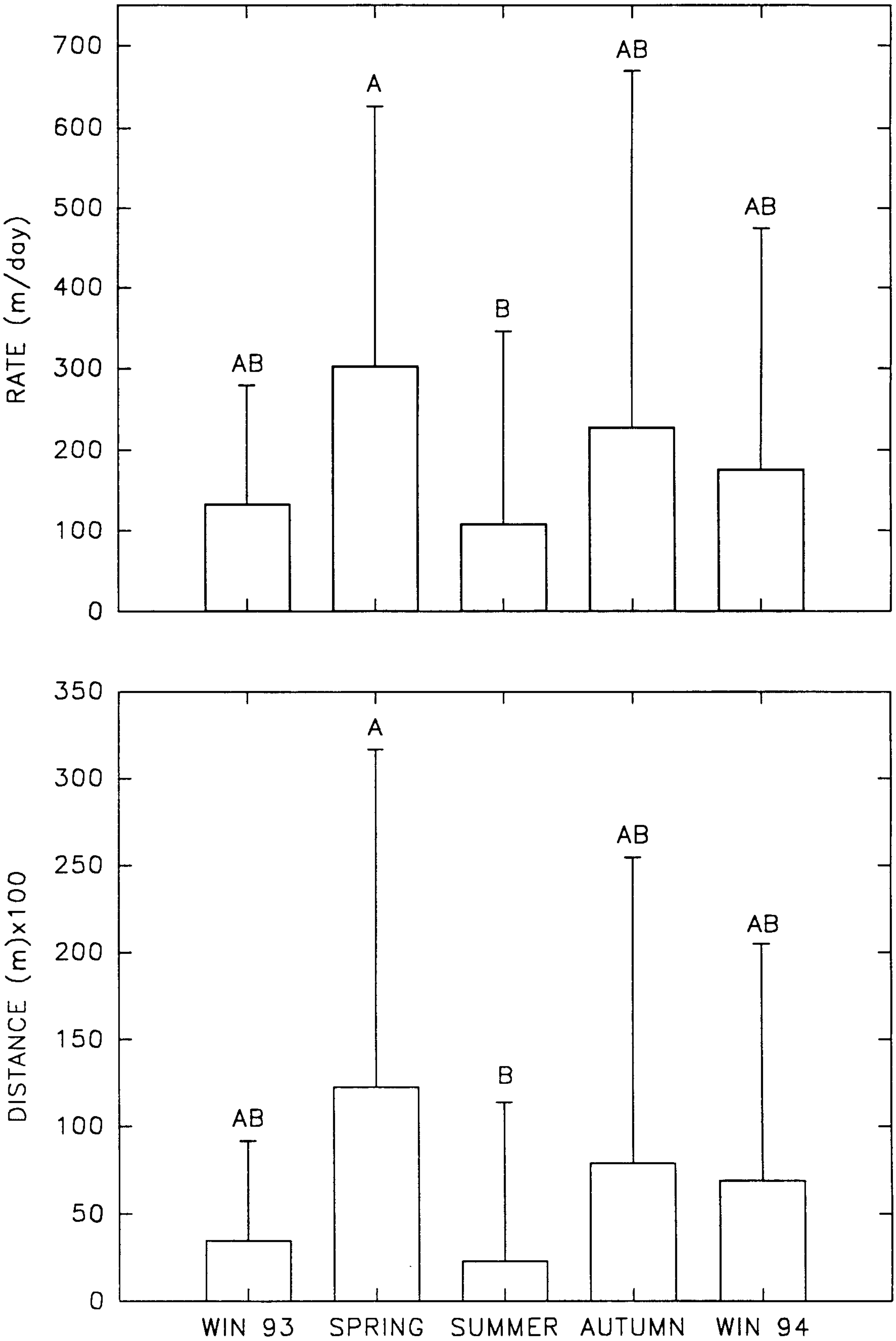
Table 3.-Seasonal mean distances (m) and rates of movement (m/day) (SD in parentheses) for small (<2.7 kg) and large (≥2.7 kg) striped bass in Robert S. Kerr Reservoir, Oklahoma. An asterisk indicates a significant difference ($P \leq 0.05$) between large and small striped bass.

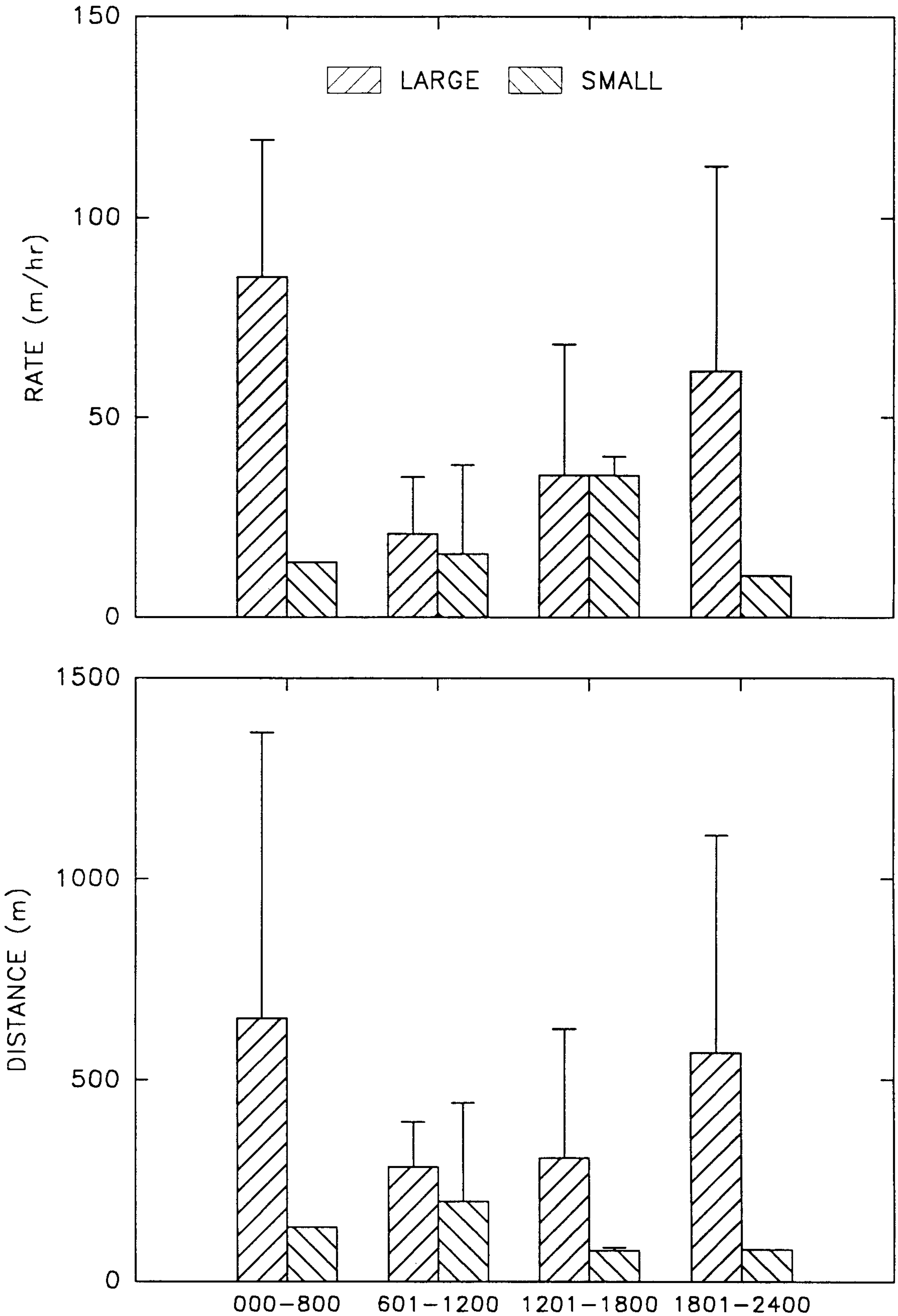
	Large			Small		
		Distance (m)	Rates (m/day)		Distance (m)	Rates (m/day)
	N	Mean(SD)	Mean(SD)	N	Mean(SD)	Mean(SD)
Winter 1993	12	2,545(3,198)	92(132)	23	4,167(7,042)	163(153)
Spring	8	13,094(20,479)	335(403)	12	11,477(19,454)	274(263)
Summer	14	5,028(12,430)*	141(295)*	17	818(1,376)	71(161)
Autumn	14	9,295(18,897)	266(474)	6	2,915(5,027)	103(172)
Winter 1994	13	4,241(6,198)	187(345)	6	15,340(28,400)	169(125)
Overall	61	6,350(3,474)	193(345)	64	5,461(12,631)	156(190)

FIGURE CAPTIONS

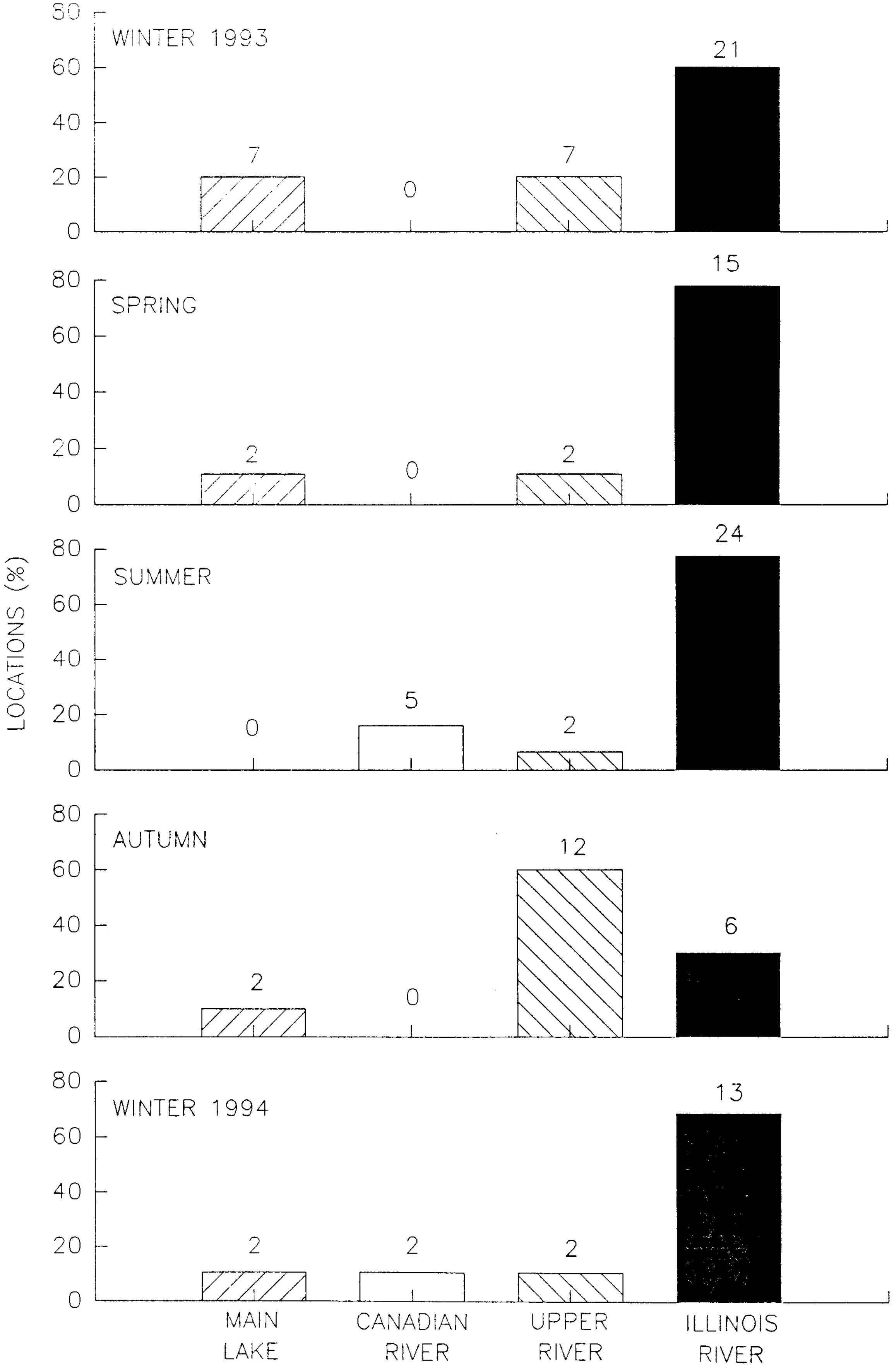
1. Habitat strata of Robert S. Kerr Reservoir, Oklahoma with 2000 m by 2000 m grid overlay. The arrow identifies the break between the Upper River and Main Lake strata.
2. Mean distances (m) and rates of movement (m/day) by striped bass during each season in Robert S. Kerr Reservoir, Oklahoma. Error bars represent +1 SD.
3. Mean rates of movement (m/day) for striped bass during six hour time periods in Robert S. Kerr Reservoir, Oklahoma. Error bars represent +1 SD.
4. Percent frequency of striped bass locations for each habitat strata by season in Robert S. Kerr Reservoir, Oklahoma. Numbers above each bar are number of locations.


ILLINOIS RIVER
ARKANSAS RIVER
LOCK AND DAM
DAM
MAIN LAKE
Km
0
5
10
CANADIAN RIVER
N


RATE (m/day)
700
600
500
400
300
200
100
0
A
AB
B
AB
AB
DISTANCE (m)x100
350
300
250
200
150
100
50
0
A
AB
B
AB
AB
WIN 93
SPRING
SUMMER
AUTUMN
WIN 94



150
100
50
0
RATE (m/hr)
LARGE
SMALL
1500
1000
500
0
DISTANCE (m)
000-800
601-1200
1201-1800
1801-2400


WINTER 1993
SPRING
SUMMER
AUTUMN
WINTER 1994
LOCATIONS (%)
0
20
40
60
80
7
0
7
21
2
0
2
15
0
5
2
24
2
0
12
6
2
2
2
13
MAIN LAKE
CANADIAN RIVER
UPPER RIVER
ILLINOIS RIVER

Chapter III

Habitat Preferences of Striped Bass in Robert S. Kerr Reservoir, Oklahoma: a GIS Approach

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Abstract.-We used ultrasonic telemetry and geographic information systems (GIS) technology to determine striped bass Morone saxatilis seasonal habitat preferences, map available habitat and evaluate the error of these maps, and predict striped bass seasonal distribution patterns in Robert S. Kerr Reservoir, Oklahoma. We found that striped bass used cooler water temperatures than were available (ambient) in the reservoir during all seasons. Optimal temperature ranges for striped bass were lowest in winter 1994 (6.00-6.50 °C) and highest in summer (19.85-24.99 °C), whereas available temperatures ranged from 3.67-14.20 °C and 15.70-30.87 °C during these same seasons. The aerial extent of optimal habitat ranged from 3,820 ha in summer to the entire reservoir in autumn and winter 1994. The mean error for seasonal temperature maps ranged from -0.25 °C in winter 93 to 0.68 °C in summer. When both suitable and optimal habitat were present striped bass preferred areas with optimal habitat over suitable habitat. However, striped bass preferred the Illinois River in all seasons, regardless of the quality of the habitat in that tributary, and varied their preference of other areas of the reservoir among seasons. Using this information, we were able to predict striped bass seasonal distribution in Kerr Reservoir; however, our predictions need to be verified. This

information should enable anglers to locate striped bass more efficiently and precisely. Consequently, an effective management plan is needed for this species in Kerr Reservoir to prevent overexploitation.

Inland populations of striped bass Morone saxatilis exhibit consistent habitat preferences among reservoir environments. Adults select riverine habitats with swiftly flowing, turbulent waters in spring for spawning (Crance 1984). Typically, after spawning striped bass disperse to lacustrine habitats (Combs and Peltz 1982; Summers 1982; Braschler et al. 1988; Farquhar and Gutreuter 1989; Henley 1991) or move directly to spatially restricted, and sometimes isolated thermal refuge habitat areas (Cheek et al. 1985). Coutant (1985) proposed a thermal niche for adult striped bass which states that temperature tolerance decreases with increasing age. This niche is defined by the upper avoidance temperature of 25 °C and the minimum dissolved oxygen concentration of 2 mg/L that striped bass can tolerate. As a result, striped bass summer habitat can be limited to restricted areas of a reservoir (i. e., metalimnion, tailwater, or spring fed tributaries) by high water temperatures and low levels of dissolved oxygen (Coutant and Carroll 1980; Matthews et al. 1985; Cheek et al. 1985; Coutant 1985; Moss 1985; Phalen et al. 1988; Matthews et al. 1989).

Cheek et al. (1985) suggested using water temperature and dissolved oxygen data to predict the seasonal distribution of striped bass based on demonstrated habitat preferences. The use of such predictions has benefited the management of some inland stocks (Zale et al. 1990), the process of which can be greatly facilitated with the use of geographic information system (GIS) technology. Wildlife researchers have used GIS extensively to analyze available habitat data to find areas of suitable habitat (e. g., Johnson et al. 1990; Herr and Queen 1993), but few have used GIS in a comparable way with fisheries data. Hubbs (1988) mapped areas of suitable spawning habitat for lake trout Salvelinus namaycush and muskellunge Esox masquinongy in Dale Hollow Reservoir, Tennessee. He did not, however, include estimates of the error with his maps. Because all maps contain uncertainty (Berry 1994), estimates of that uncertainty should be provided with a map just as variance estimates are given with mean values.

In this paper we describe the seasonal habitat preferences of striped bass in Robert S. Kerr Reservoir, Oklahoma with the aid of GIS technology. This reservoir has a small population of striped bass (Peterson 1990) dominated by large-sized individuals. Striped bass anglers typically catch fish in the tributaries but have difficulty locating them in other portions of the reservoir. Our objectives were to use GIS technology in conjunction with telemetry to determine striped bass habitat use, to map available habitat and evaluate the error of these maps, and to use this information to predict striped bass seasonal distribution.

Study Site

Kerr Reservoir is a mainstem reservoir of the Arkansas River located in east central Oklahoma. The 18,000 ha reservoir is bounded by four hydroelectric dams, and is used mainly for navigation, as part of the McClellan-Kerr navigation system, power generation, and recreation. The reservoir consists of an upper riverine portion (Upper River), a lower lacustrine portion (Main Lake), and two large tributaries, the Illinois River and Canadian River (Figure 1). The Illinois River arm is an Ozarkian river with gravel and mud substrate, low conductivity, high water clarity, and is 15 km long (See Table 1, Chapter II). Flow in the river is dependent on a peaking hydropower facility that releases water from the hypolimnion of Tenkiller Lake. The Canadian River arm is a shallow turbid river with a shifting sand substrate, moderate ranges of conductivity, and is 25 km long. River flow is regulated by a peaking hydropower facility that has a hypolimnetic release from Eufaula Reservoir. The Upper River has a maintained navigation channel, low water clarity and high conductivity. The Main Lake is lacustrine with low water clarity and vast areas that are shallow and mud-bottomed with submerged tree stumps.

Methods

Habitat use.-We used ultrasonic telemetry to determine the distribution and habitat use of striped bass in Kerr Reservoir. Fish were collected between October 1992 and May 1993 from the Illinois River (N=12) by electrofishing and from the Canadian River (N=10) with gillnets (Table 1). We surgically implanted each of these 22 fish with a temperature-sensing ultrasonic tag (Model CTT-83-2, Sonotronics, Tucson, Arizona) and an external anchor tag. Each ultrasonic tag had a unique aural code, consisting of a unique series of pulses and pauses, that allowed for identification of individual fish. Tagged fish ranged from 1.2-15.0 kg in mass ($\bar{x}$ =4.18 kg) and from 435-920 (SL) mm ($\bar{x}$ =562 mm).

We systematically searched the entire reservoir by boat twice monthly, except for July and August 1993 when only the Illinois River and surrounding area was searched. In addition, the Canadian River could not be searched on several occasions because of low water. We determined the search pattern by overlaying a 2000 m by 2000 m grid system on a map of Kerr Reservoir, which was developed by digitizing the reservoir outline from 1:24,000 U. S. Geological Survey (USGS) topographic maps into a raster-based GIS application program (GRASS 4.0) (Figure 1). We chose this grid size because the range of the telemetry tags (1000 m) allowed us to search an entire cell from one location. At the center of each grid cell, we lowered a directional hydrophone (model DH-2, Sonotronics) into the water and slowly rotated it in a complete circle at each transmitter frequency. Precise fish locations were determined by maneuvering the boat toward and around a detected signal until it could be heard with equal volume in all directions. Habitat use was measured at each fish location. We measured current velocity at 0.6 of total depth and water temperature and dissolved oxygen profiles at 1 m intervals from the surface to bottom.

Available habitat.-We defined physical habitat strata in Kerr Reservoir prior to initiating the telemetry study. To stratify the reservoir, we collected physical habitat data at points along transects run across the reservoir from the top of the system to the bottom. Habitat data collected included depth profiles of water temperature, dissolved oxygen, and conductivity, water clarity (secchi depth) and mean water column current velocity. These data were classified with cluster analysis (SAS 1985) into areas of similar physical habitat. The resulting analysis identified eight strata. We overlaid the 2000 m by 2000 m grid map on the habitat strata map of Kerr Reservoir to create a stratified sampling surface. We then randomly selected a minimum of two but not more than 30% of the grid cells within each habitat strata as available habitat sampling points (Appendix A). At each selected cell center we measured water temperature and dissolved oxygen at 1 m intervals from surface to bottom and determined mean water column current velocity. To reduce the number of strata and facilitate analyses, we reanalyzed the previously collected data with additional data collected while measuring available habitat. This analysis grouped the eight strata into four (i. e., Illinois River, Canadian River, Upper River, and Main Lake). All subsequent analyses were performed using these four strata.

GIS procedures and habitat criteria.-We developed seasonal habitat maps of the reservoir for temperature, dissolved oxygen, and current velocity by interpolating map surfaces with GIS software (Star and Estes 1990). Using available habitat data collected during each sampling trip, we calculated the mean water column measurements for each habitat variable and randomly selected 20% of these values to serve as check points. With the remaining data points (80%), we interpolated a habitat map of the entire reservoir using an inverse distance weighted square interpolation algorithm at a resolution of 100 m^2. We repeated this procedure three times, resampling the same data, and averaged the three interpolated surfaces to obtain a mean surface for each sampling trip. All interpolated surfaces within a season were averaged to create a mean seasonal habitat map for each variable. Map error was estimated as the mean difference between coincident check points and their interpolated values. We compared the coefficient of variation of these error estimates to assess relative variability among seasonal maps.

Seasonal habitat maps were reclassified into optimal, suitable, and unsuitable using parameters defined by striped bass habitat use in the reservoir. We determined ranges of optimal, suitable and unsuitable striped bass habitat, using Thomas and Bovee's (1993) terminology from the frequency histogram of habitat use for all variables specific to a season. We defined the middle 50% of the distribution as optimal habitat and reclassed areas of the seasonal habitat maps in this range. Areas on the habitat maps in the interval for striped bass habitat use between 5-25% and 75-95%, were reclassed as suitable habitat. Anything outside of these ranges was considered unsuitable. We used a Boolean operator (i. e., logical `and') to combine multiple habitat variables in a single season (e. g., temperature and current velocity in the spawning season). We overlaid striped bass locations onto corresponding seasonal habitat maps to test our predictions of striped bass seasonal distribution.

Habitat preference.-We estimated preference of individual fish for each habitat stratum with Johnson's Rank Preference Index (Johnson 1980), a nonparametric test that ranks the use of habitat strata relative to their availability and tests the null hypothesis that all strata are used equally. We ranked the habitat strata from most used (I) to least used (IV) based on the number of times a fish was located in each strata during a season. We ranked the availability of strata from largest (I) to smallest (IV) based on surface area. If no fish were located in a stratum during a season, it was excluded from the analysis. The difference between the rank of use and availability for each individual fish was computed for all individuals within a season. These ranks were averaged across individuals for each strata. The lowest resulting rank represented the most preferred stratum and the highest rank the least preferred. This index also tests for differences in preference among strata with a multiple comparison method similar to the Least Significant Difference (LSD) commonly used with analysis of variance.

We used a one-sided chi-square analysis to determine if areas of optimal habitat were occupied in equal proportion to areas of suitable habitat (Conover 1971). Using the 2000 m by 2000 m grid cell map, we counted the number of cells occupied and unoccupied by striped bass for suitable and unsuitable habitat and constructed a 2 X 2 contingency table.

Results

Habitat use

Striped bass temperature use varied with season, but paralleled the available temperature in the reservoir (Figure 2). The lowest optimal temperature range for striped bass occurred in winter 1994 (6.00-6.50 °C) and was highest in summer 19.85-24.99 °C. Suitable temperature ranged from 4.19-5.99 and 6.51-11.85 °C in winter 1994 to 17.62-19.84 and 25.00-27.98 °C in summer. Concurrently, available reservoir temperature in winter 1994 ranged from 3.67-14.20 °C and in summer ranged from 15.70-30.87 °C (Appendix D and E).

Optimal levels of dissolved oxygen use by striped bass in summer ranged from 4.70-7.45 mg/L and suitable levels ranged from 2.50-4.69 and 7.46-11.58 mg/L. Available dissolved oxygen for summer ranged from 3.68-10.47 mg/L. Optimal current velocities in spring ranged from 0.13-1.13 m/s and suitable velocities ranged from 0-0.12 and 1.14-2.14 m/s. Available current velocity in spring ranged from 0-2.05 m/s.

Habitat suitability and map error

The size and distribution of optimal and suitable habitat, with respect to temperature, dissolved oxygen, and velocity, in the reservoir varied among seasons, and no unsuitable habitat was predicted from our analysis. In winter 1993, suitable habitat totaled 108 ha and occurred in the Illinois River near the confluence with the Upper River (Figure 3). Optimal winter habitat totaled 17,759 ha and included most of the reservoir. Optimal habitat in spring (temperature and velocity) accounted for 1,693 ha and covered the Illinois River, much of the Upper River, the first few kilometers of the Canadian River, and a portion of a minor tributary in the Main Lake (Figure 4). Suitable habitat equaled 17,085 ha. Optimal habitat in summer (temperature and dissolved oxygen) totaled 3,820 ha and was confined to the Illinois River and a few kilometers at the upper end of the Canadian River (Figure 5). In addition, a small area of optimal habitat occurred at the division between the Upper River and Main Lake strata; however, this area is probably an anomaly of the interpolation and data collection procedures. Suitable habitat totaled 14,958 ha. The entire reservoir was classified as optimal for both autumn and winter 1994 (Figure 6 and 7).

The mean temperature error for seasonal habitat maps ranged from -0.25 °C in winter 93 to 0.68 °C in summer (Table 1). A negative difference indicates the interpolated surface underestimated the actual values at the check points and positive differences signifies over-estimation. The spring temperature map was the most precise (CV=227.94%) and winter 1994 was the least precise (CV=1,255.56%). For dissolved oxygen the measured mean at check points was 7.00±1.27 (SD) mg/L, whereas the interpolated level at those check points was 7.04±0.99 (SD) mg/L, and the mean error for the summer dissolved oxygen was -0.04±0.94 (SD) mg/L. Equivalent measurements for velocity in the spring yielded a real mean of 0.39±0.35 (SD) m/s, an interpolated mean of 0.48±0.36 (SD) m/s, and an error of -0.09±0.30 (SD) m/s.

Habitat preference

Striped bass preferred the Illinois River over the other habitat strata during all seasons (Table 2). During winter 1993 the Upper River was the second most preferred stratum and the Main Lake was preferred least. Striped bass preferred the Canadian River second in spring, summer, and winter 1994. The Main Lake was the least preferred strata in every season except summer when it was excluded from the analysis.

Striped bass occupied optimal habitat in greater proportion than suitable habitat in seasons when both were available (Table 3). In winter 1993, 97.5% of all cells contained optimal habitat and 3.5% contained suitable habitat. Striped bass used 12.3% of all cells and 9.9% of these cells were classified as optimal habitat and 2.5% as suitable habitat. In spring, 29.6% of all cells in the reservoir were classified as optimal habitat and 70.4% as suitable habitat. Striped bass used 11.1% of all cells and 7.4% of these contained optimal habitat and 3.7% contained suitable habitat. During summer, 45.7% of all cells contained optimal habitat and 54.3% contained suitable habitat. Striped bass occupied a total of 8.6% of the cells in the reservoir and 7.4% contained optimal habitat and 1.2% contained suitable habitat. In autumn and winter 1994 only optimal habitat was present, thus we did not calculate a chi-square value.

Discussion

Our findings showed that striped bass used areas of Kerr Reservoir that had cooler temperatures in spring (13-25 °C) and summer (17-28 °C) than ambient temperatures available during these seasons (12-29 °C and 15-31 °C, respectively). Coutant and Carroll (1980) reported striped bass in summer were located in temperatures ranging from 20-24 °C and concentrated in areas with temperatures ranging from 22-23 °C although reservoir temperatures reached 29 °C. During spring, they found striped bass in water temperatures ranging from 14-25 °C with most fish concentrating in water ranging from 18-21 °C. Cheek et al. (1988) reported available temperatures in Watts Bar Reservoir, Tennessee, during summer ranged from 20-29.5 °C, but striped bass concentrated in the tributary arms where temperatures ranged from 20-25 °C. Cheek et al. (1988) found that striped bass generally used ambient water temperatures in spring, autumn, and winter. Coutant and Carroll (1980) did not track fish in winter but during October striped bass used ambient water temperatures. Mean water temperatures used by striped bass in Kerr Reservoir were lower than the mean ambient temperature during every season (Figure 2).

Striped bass in Kerr Reservoir preferred the Illinois River over all other strata throughout the study. Such intensive use of a restricted area during all seasons has not been reported for other inland reservoir populations. Combs and Peltz (1980) found striped bass in Keystone Reservoir, Oklahoma, in tributaries in spring and restricted areas of the Main Lake in summer, but fish dispersed throughout the reservoir in autumn and winter. Cheek et al. (1988) reported striped bass concentrating in tributaries of Watts Bar Reservoir, Tennessee, beginning in the late spring and lasting through the summer. However, in autumn they dispersed from the tributaries to the main water body for the winter. Preference by striped bass for the Illinois River in summer is expected because of the cooler water from the hypolimnetic release from Tenkiller Lake, but their continued preference for this tributary in autumn and winter is atypical for inland populations. Possible reasons for their fidelity to this tributary include the availability and easier detection of forage fish because of high water clarity (See Table 1, Chapter II).

Because the striped bass population size in Kerr Reservoir is small and their distribution is limited, we collected fish for tagging from areas of the reservoir (i. e., the Illinois and Canadian Rivers) that would maximize our catch efficiency. We do not believe, however, that use of the Illinois River was high because most of the tagged fish were collected from that area. For example, of the two fish from the Canadian River that were found after tagging, both were located in or near the Illinois River (Table 1). Furthermore, all fish located in the Canadian River originated from the Illinois River. Thus, we believe the distribution of striped bass in Kerr Reservoir would not differ from the one we described regardless of where our fish were originally tagged.

We predicted areas of Kerr Reservoir that would contain striped bass using available habitat data. Similarly, Hubbs (1988) collected physicochemical data to assess spawning habitat in Dale Hollow Reservoir for lake trout (Salvelinus namaycush) and muskellunge (Esox masquinongy). He queried the spatial data base to find areas that met published spawning habitat criteria for the two species (e. g., temperature, depth and substrate). In addition, he classified the habitat as high, medium or low quality. Identifying the potential distribution of fish species is one application of GIS in fisheries. Giles and Nielson (1992) list policy decisions (e. g., controlling human use of fisheries resources), citing access locations, and risk analyses as other potential uses of GIS technology in fisheries. We believe that GIS technology can be especially useful in managing reservoir fisheries by allowing biologist to increase sampling efficiency and to identify and monitor available habitat (Wilde and Fisher, in press).

Although the accuracy of our predicted habitat maps was relatively good (as indicated by the small mean errors), the precision was low (coefficient of variation ranging from 500-1,200%). Using a stratified random sampling design instead of another more appropriate design to collect available habitat data in the reservoir may have increased the variability in the final interpolated habitat maps. A systematic sampling design for collecting available habitat data probably would have reduced the amount of error in the interpolation process. When a large number of random habitat collection points were closely grouped in one area, as occurred in some parts of the reservoir (Appendix A), other areas were under-represented, which affected the precision of the interpolated map. Interpolated values in the under-represented areas become strongly influenced by points from a different area. This was especially true in the heterogeneous environment of Kerr Reservoir. For example, we often interpolated a surface based on several points in the Main Lake, but only one point in the Upper River and occasionally no points in the Illinois River, which was physicochemically very different from the Main Lake. As a result, the Main Lake strongly influenced the interpolated values in the tributaries and increased the error in the interpolated surface. We believe that our procedure of creating three interpolated surfaces for each sampling trip based on randomly selected data points and averaging them to produce a final map for a tracking period compensated for the inadequacies of our sampling design. However, use of a systematic sampling design should decrease the variability of interpolated maps. We recommend using a systematic sampling scheme to collect data on ambient water conditions to improve the precision of the interpolation.

To summarize the striped bass seasonal habitat preferences in Kerr Reservoir we developed a conceptual model of striped bass movements and habitat use based on Wootton's model (1990). His model involved three basic habitat types: spawning, feeding, and refuge habitat, and he hypothesized that fish periodically move between these habitat types to optimize the benefits and costs during different life stages. Our model for the Kerr Reservoir population (Figure 8) centers on the predominant use of the Illinois River, but shows the seasonal habitat preferences for variables deemed important in the literature. In spring, striped bass in Kerr Reservoir moved into riverine habitat with current for spawning when reservoir temperatures reached 12 °C. Spawning habitat was located in the Illinois and Upper River strata where current velocities ranged from 0-2.14 m/s and mean temperature ranged between 15 and 20.5 °C. Afterwards, striped bass moved directly into summer refuge habitat because reservoir temperatures rose quickly in spring. These refuge areas, located in the Illinois River and upper end of the Canadian River, provided suitable water temperature (17 to 28 °C) in summer when water temperatures were unfavorably high for striped bass in other parts of the reservoir. Striped bass dispersed from summer refuge habitat when reservoir temperatures fell below critical levels, but most fish soon returned to the Illinois River as water temperatures continued to drop in winter. In winter, fish congregated in the Illinois River near the confluence with the Upper River. Striped bass remained in this habitat until spring arrived when they again moved to their spawning habitat.

In summary, GIS and telemetry were effective tools for determining striped bass habitat preferences and mapping available habitat in Robert S. Kerr Reservoir. We created maps of available seasonal habitat using GIS technology and habitat data (i. e., temperature, dissolved oxygen, and current velocity) collected throughout the reservoir, and classified these maps into optimal, and suitable habitat for striped bass. We found the Illinois River provided optimal habitat for striped bass in every season and fish preferentially used optimal habitat areas over suitable areas in all seasons when both habitat types were present. This information can be an effective management tool for reservoir fisheries managers. To better manage this population, further study needs to be conducted on the effects that biotic factors (e. g., forage fish availability, distribution and movements) and abiotic factors (e. g., pH and conductivity) have on the distribution and habitat preferences of striped bass.

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Table 1.-Seasonal error of interpolated temperature maps in Robert S. Kerr Reservoir, Oklahoma.

Season	N	Mean of observed data points (SD)	Mean of interpolated data points (SD)	Mean difference (SD)	Coefficient of variation (SD/mean*100)
Winter 1993	68	8.57(2.65)	8.39(2.65)	0.18(0.91)	505.55
Spring	50	20.96(4.69)	20.28(4.15)	0.68(1.55)	227.94
Summer	65	24.69(4.02)	24.94(3.70)	-0.25(2.13)	-852.00
Autumn	33	11.54(3.51)	11.45(3.39)	0.09(1.03)	1144.44
Winter 1994	24	7.89(3.36)	7.98(2.91)	-0.09(1.13)	-1255.56

Table 3.- Seasonal habitat strata preferences for striped bass in Robert S. Kerr Reservoir, Oklahoma. An asterisk indicates the strata was excluded from analysis because no locations were made in that strata. Rank prefernces with different letters are significantely ($P \leq 0.05$) different.

Strata	Mean difference between use and availability	Rank preference
	Winter 1993	
Illinois River	-1.455	1[a]
Upper River	0.182	2[b]
Canadian River*	-	-
Main Lake	1.273	3[c]
	Spring	
Illinois River	-2.292	1[a]
Upper River	0.708	3[b]
Canadian River	-0.292	2[c]
Main Lake	1.875	4[d]
	Summer	
Illinois River	-1.591	1[a]
Upper River	1.364	3[c]
Canadian River*	0.227	2[b]
Main Lake	-	-

Table 3.-Continued.

Strata	Mean difference between use and availability	Rank Preference
	Autumn	
Illinois River	-0.944	1[a]
Upper River	-0.611	2[a]
Canadian River*	-	-
Main Lake	1.556	3[b]
	Winter 1994	
Illinois River	-2.250	1[a]
Upper River	-0.750	3[bc]
Canadian River*	-0.125	2[b]
Main Lake	1.625	4[c]

Table 4.-Frequency of use of optimal and suitable habitat by striped bass in Robert S. Kerr Reservoir, Oklahoma.

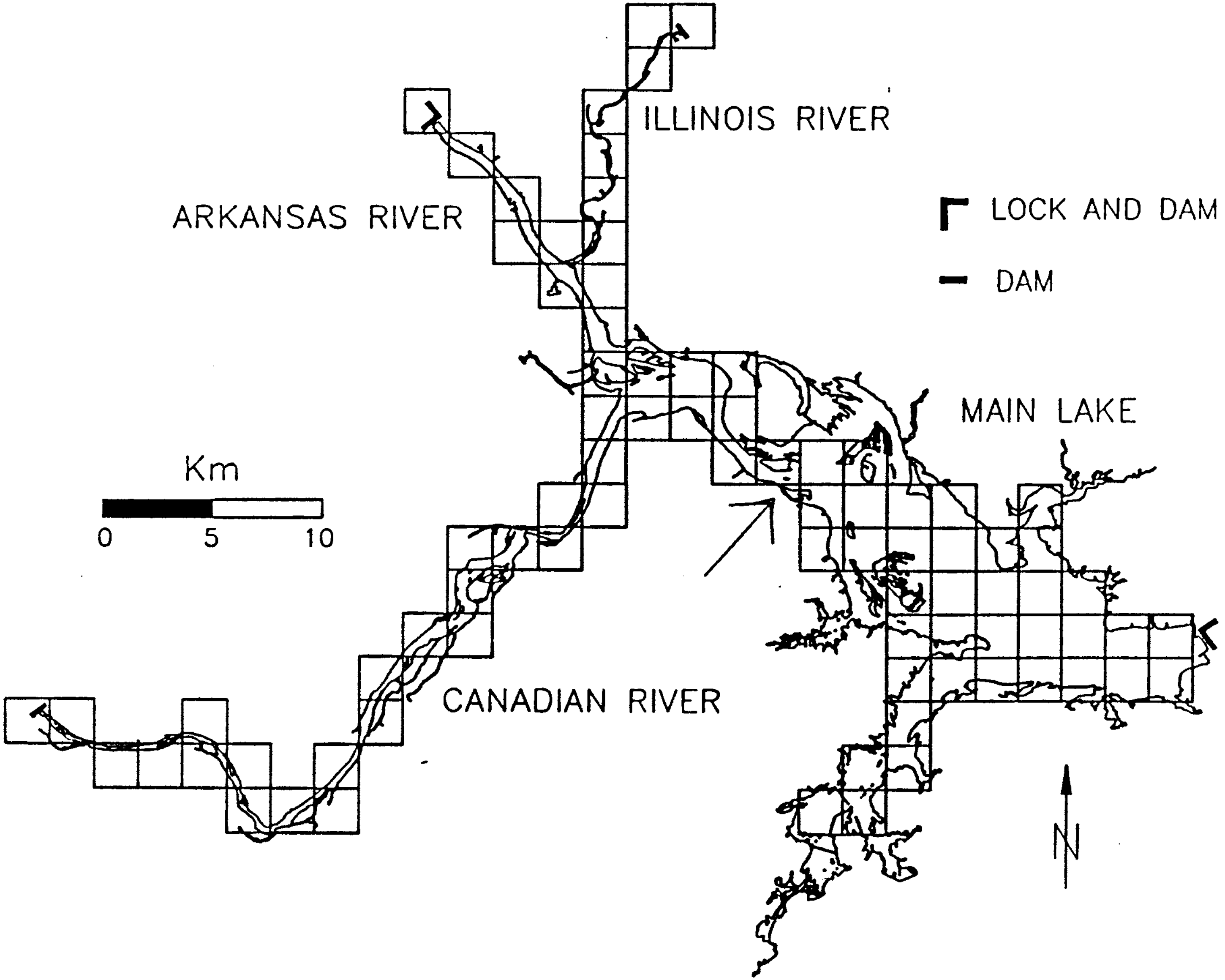
Cells	Optimal habitat (frequency)	Suitable habitat (frequency)	Total	
		Winter 1993		
Occupied	8	2	10	$\chi2=2.58$
Unoccupied	71	0	71	df=1
Total	79	2	81	$P \leq 0.005$
		Spring		
Occupied	6	3	9	$\chi2=2.225$
Unoccupied	18	54	72	df=1
Total	24	57	81	$P \leq .014$
		Summer		
Occupied	6	1	7	$\chi2=3.816$
Unoccupied	31	43	74	df=1
Total	37	44	81	$P \leq .001$

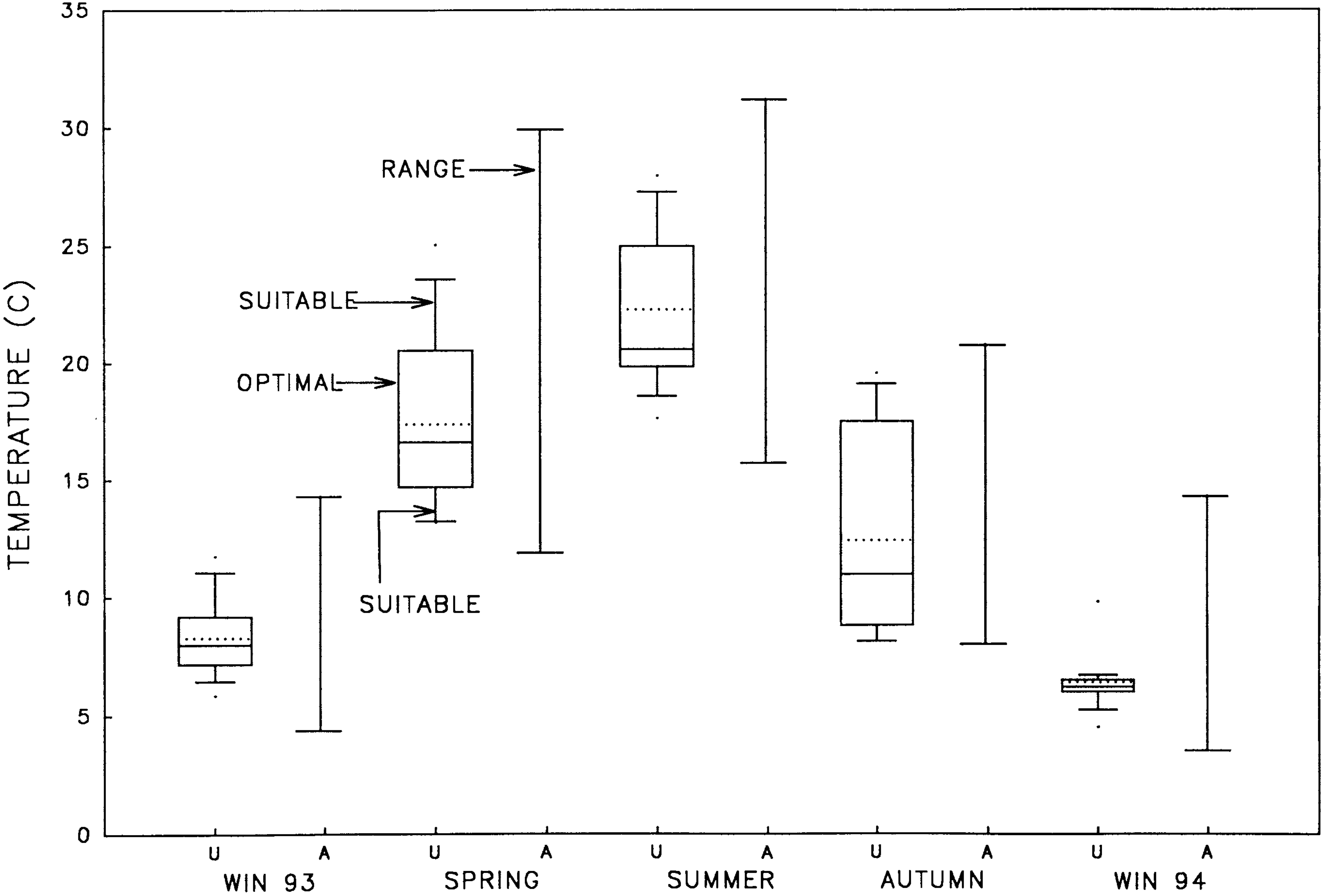
FIGURE CAPTIONS

1. Habitat strata of Robert S. Kerr Reservoir, Oklahoma, with 2000 m by 2000 m grid overlay. The arrow identifies the break between the Upper River and Main Lake strata.
2. Used (U) and available (A) (ambient) seasonal temperature in Robert S. Kerr Reservoir, Oklahoma. Bars on used habitat represent 25-75th percentile, lower lines represent 5-25th percentile and upper lines represent 75-95th percentile, dashed and solid lines in bars represent means and medians, respectively and small dots indicate the range.
3. Winter distribution of optimal (gray areas) and suitable (white areas) habitat in Robert S. Kerr Reservoir, Oklahoma. Triangles represent striped bass locations.
4. Spring distribution of optimal (gray areas) and suitable (white areas) habitat in Robert S. Kerr Reservoir, Oklahoma. Triangles represent striped bass locations.
5. Summer distribution of optimal (gray areas) and suitable (white areas) habitat in Robert S. Kerr Reservoir, Oklahoma. Triangles represent striped bass locations.
6. Autumn distribution of optimal (gray areas) and suitable (white areas) habitat in Robert S. Kerr Reservoir, Oklahoma. Triangles represent striped bass locations.

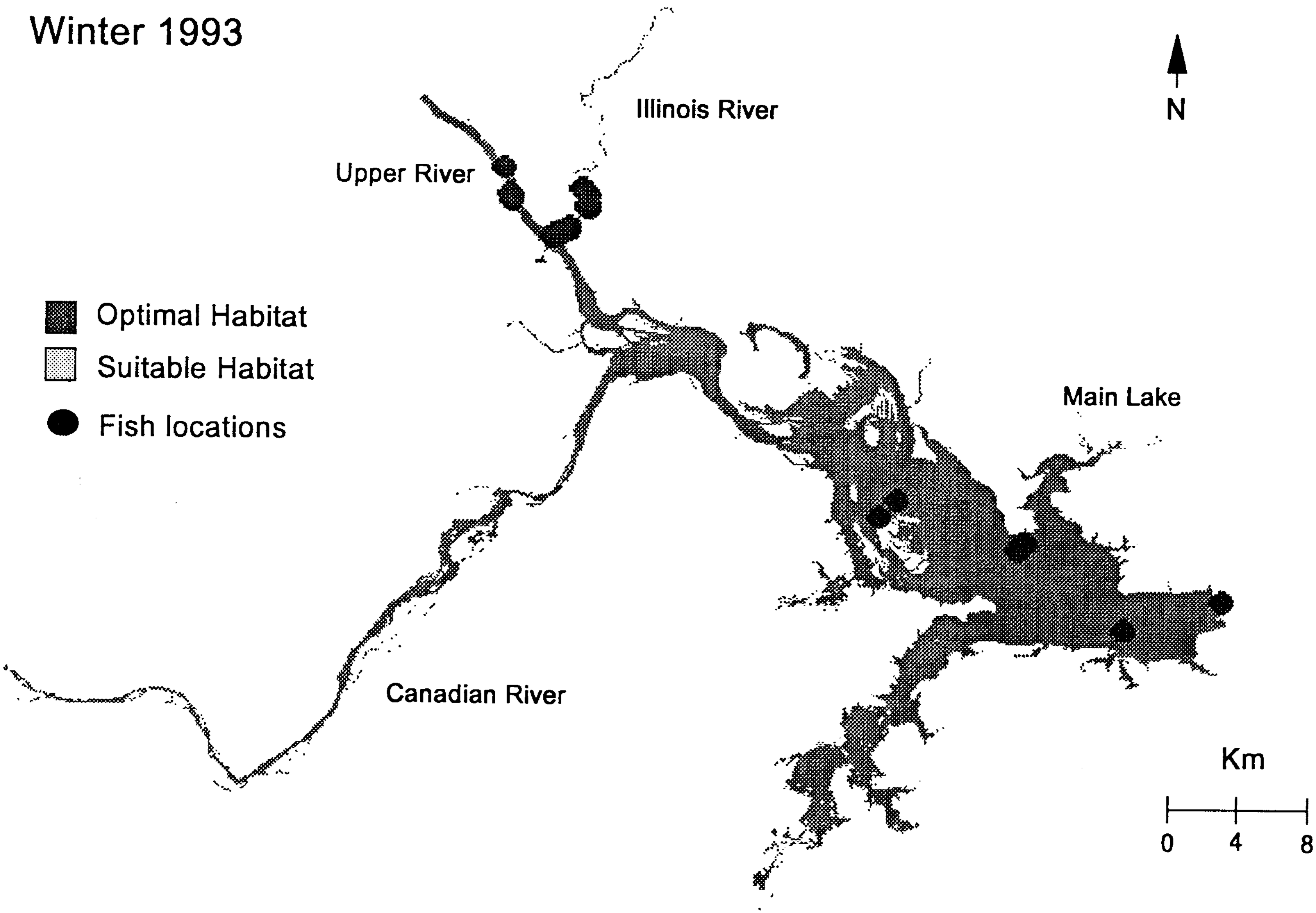
7. Winter 1994 distribution of optimal (gray areas) and suitable (white areas) habitat in Robert S. Kerr Reservoir, Oklahoma. Triangles represent striped bass locations.

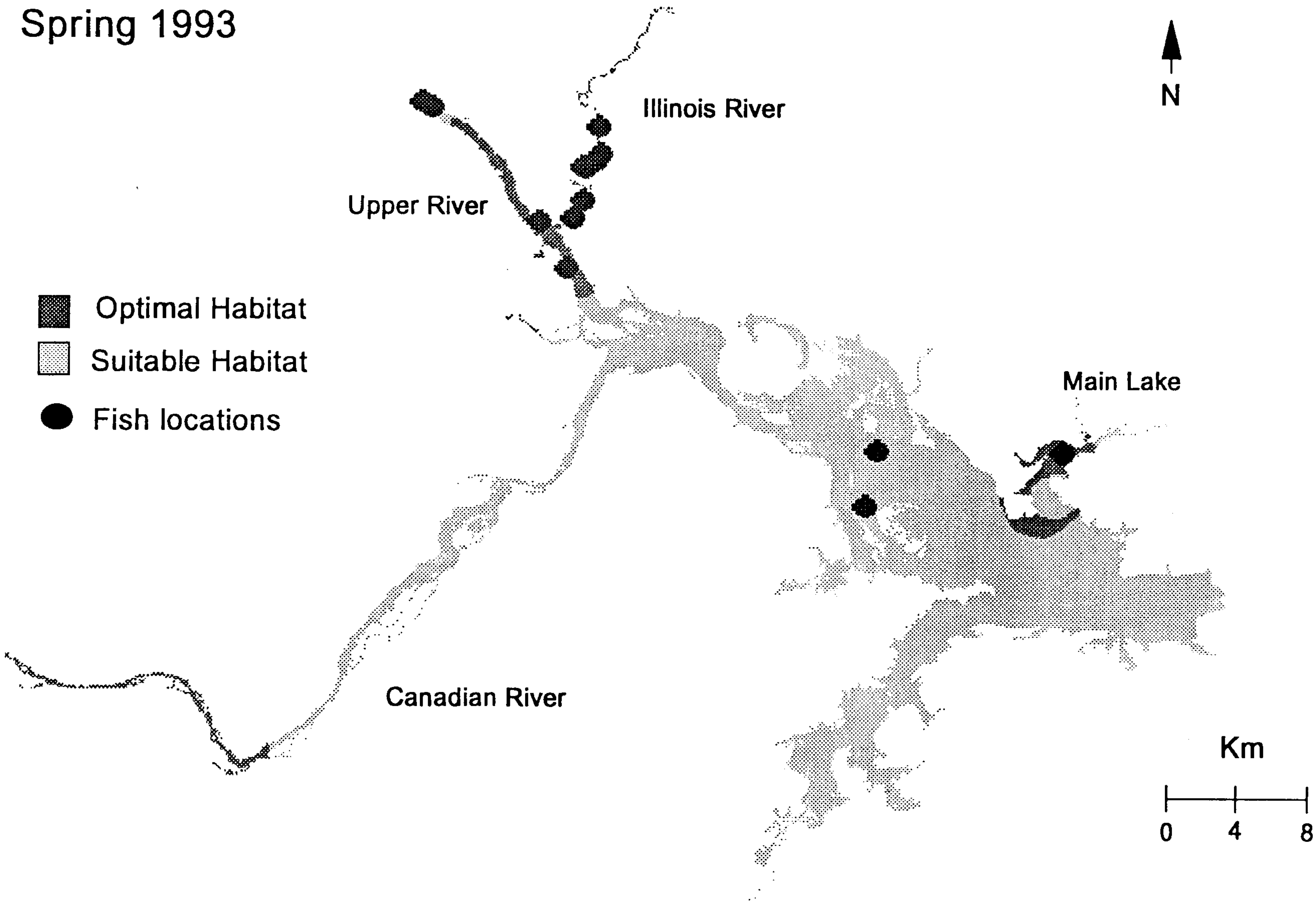
8. Summary diagram of striped bass preferences for selected habitat parameters in Robert S. Kerr Reservoir, Oklahoma.

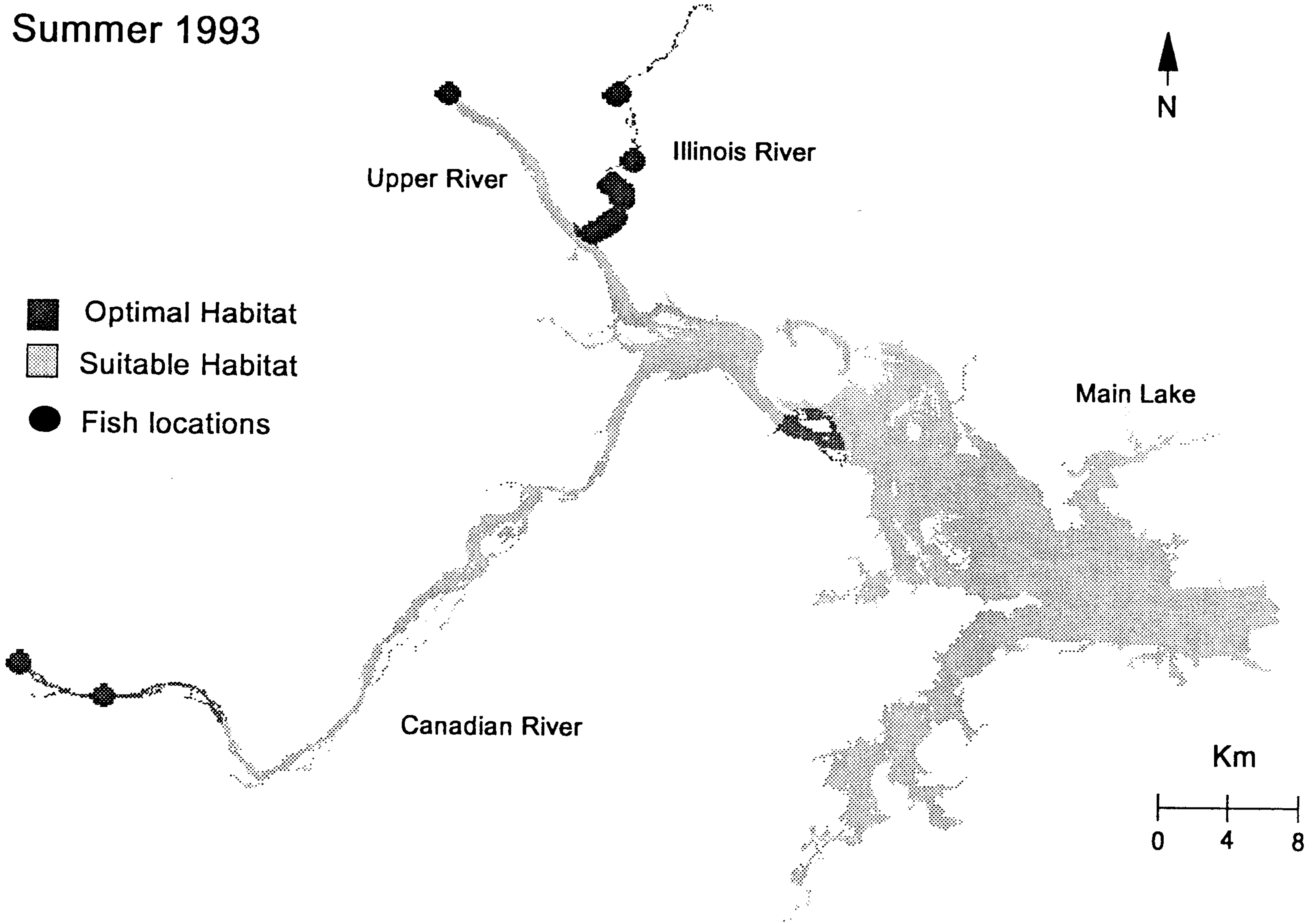

ILLINOIS RIVER
ARKANSAS RIVER
LOCK AND DAM
DAM
MAIN LAKE
Km
0
5
10
CANADIAN RIVER
N

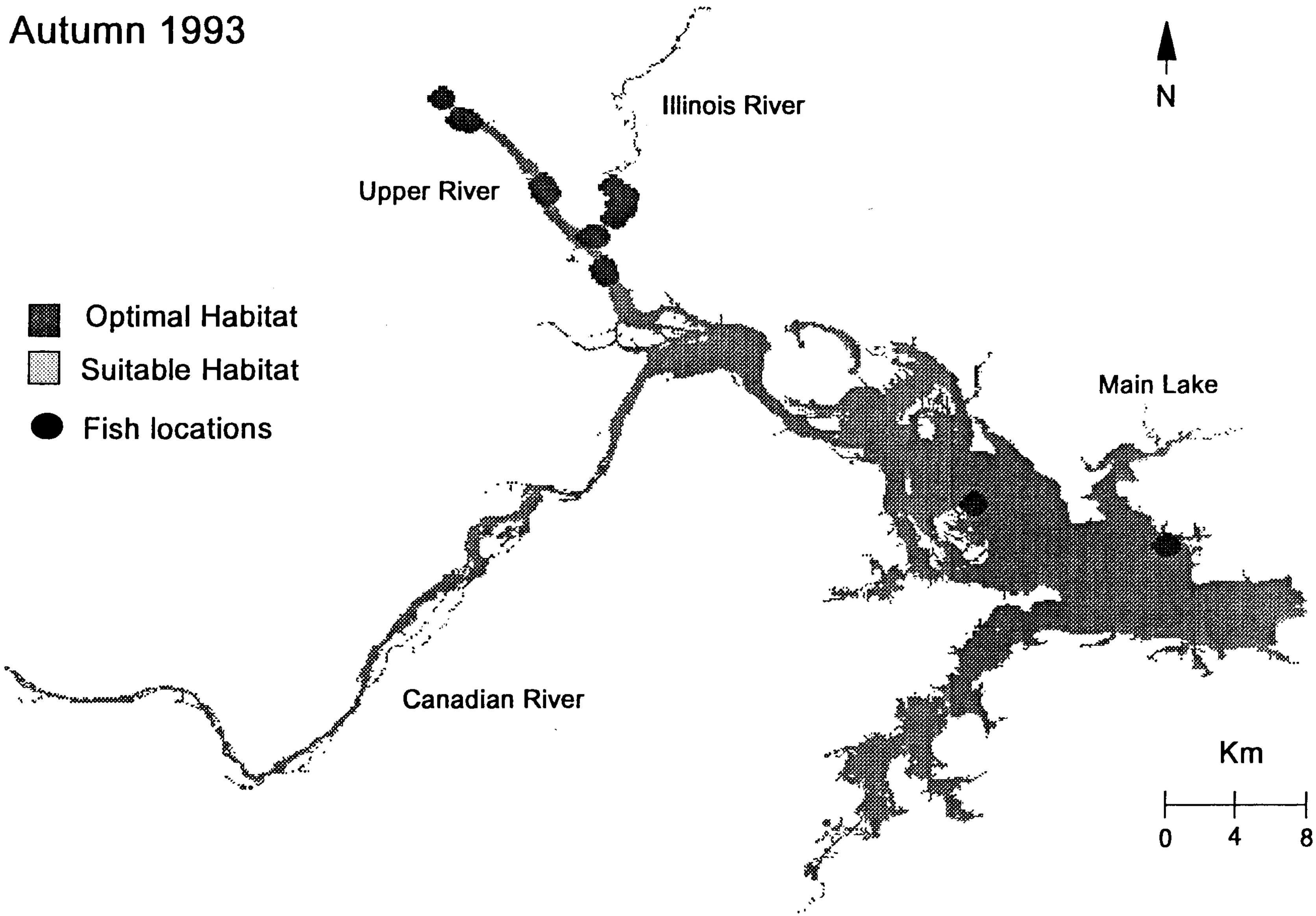


TEMPERATURE (C)
35
30
25
20
15
10
5
0
RANGE
SUITABLE
OPTIMAL
SUITABLE
U
A
U
A
U
A
U
A
U
A
WIN 93
SPRING
SUMMER
AUTUMN
WIN 94

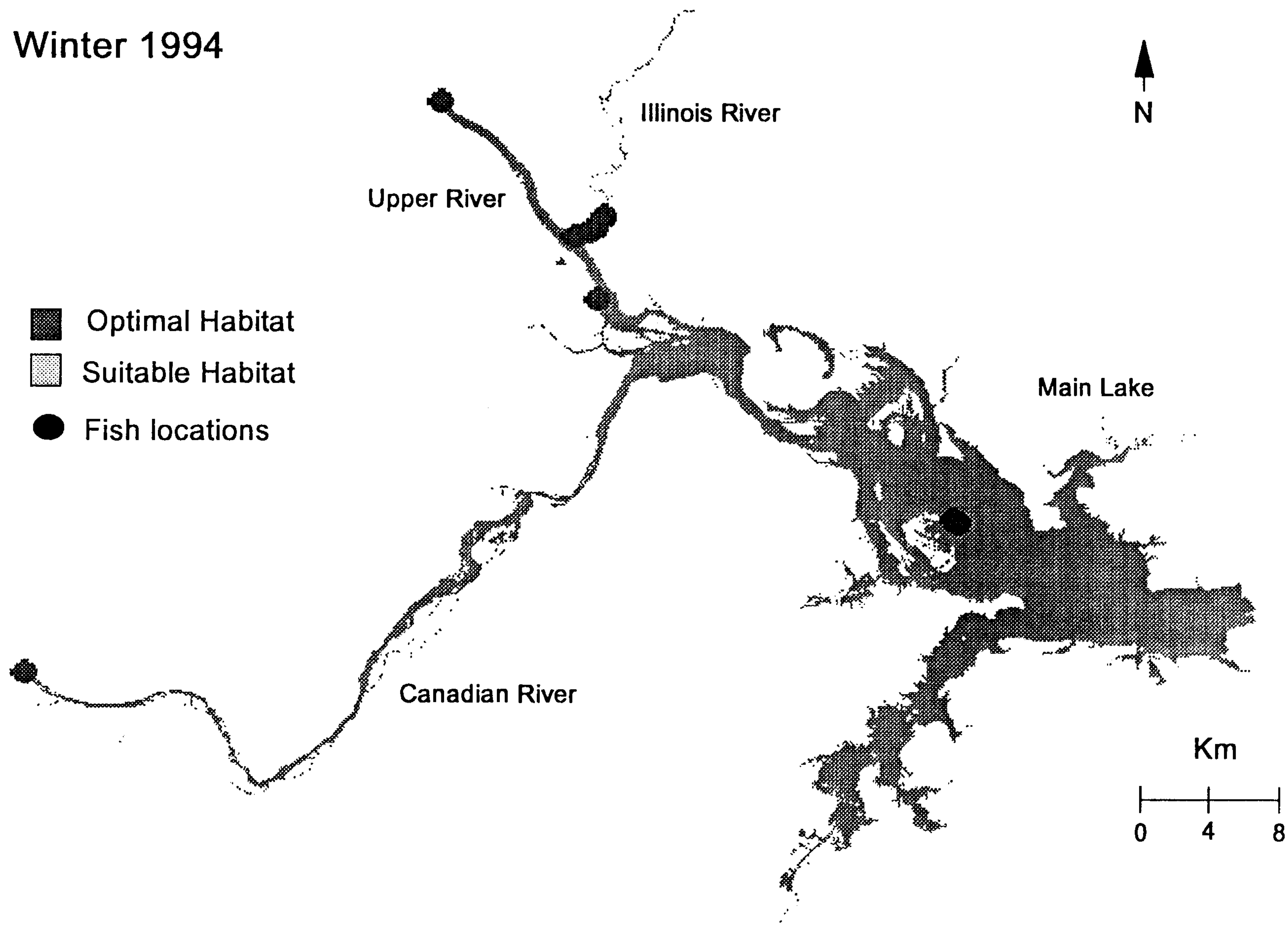

Winter 1993
Illinois River
N
Upper River
Optimal Habitat
Suitable Habitat
Fish locations
Main Lake
Canadian River
Km
0
4
8

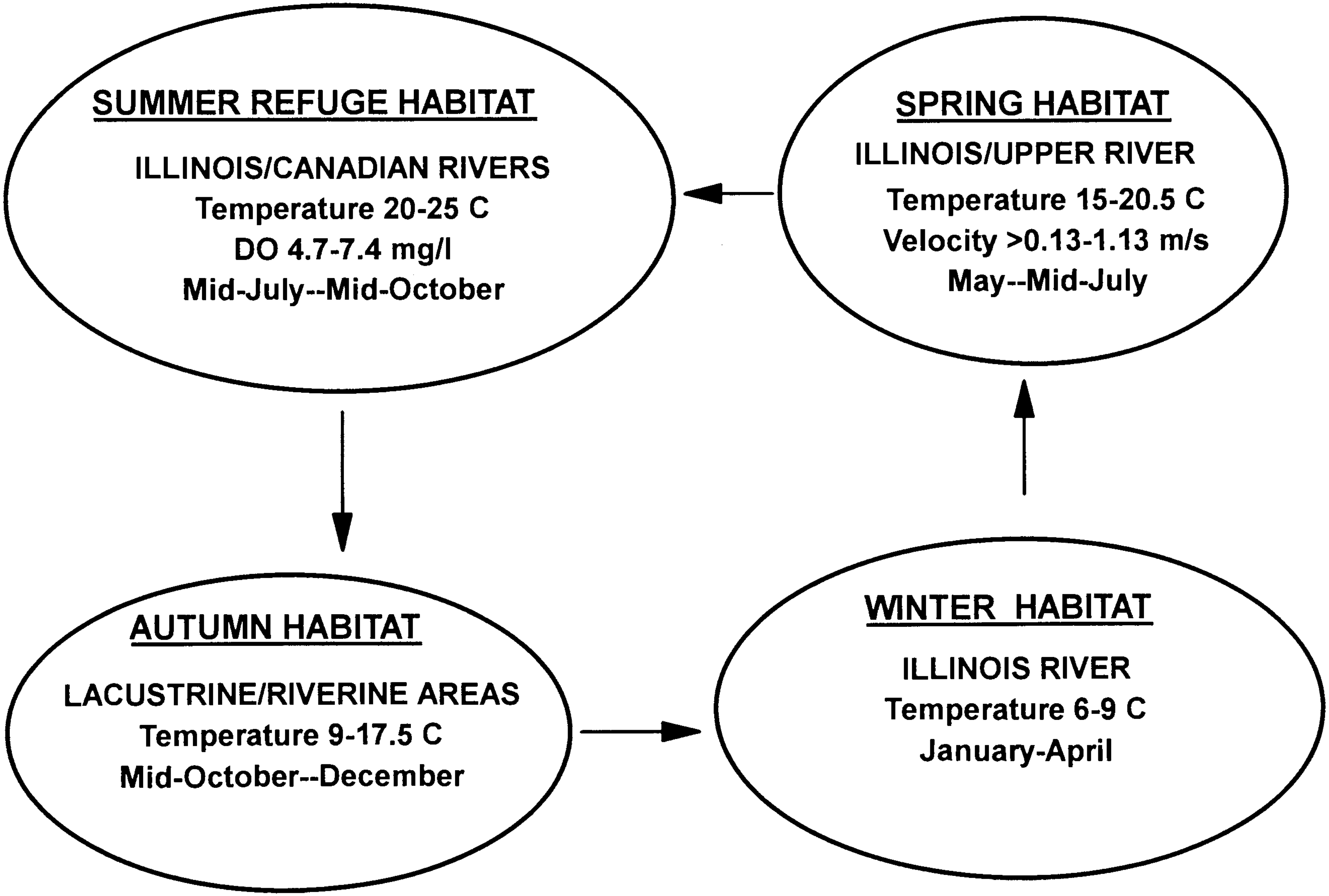

Spring 1993
Illinois River
Upper River
Optimal Habitat
Suitable Habitat
Fish locations
Main Lake
Canadian River
N
Km
0
4
8


Summer 1993
N
Illinois River
Upper River
Optimal Habitat
Suitable Habitat
Fish locations
Main Lake
Canadian River
Km
0
4
8



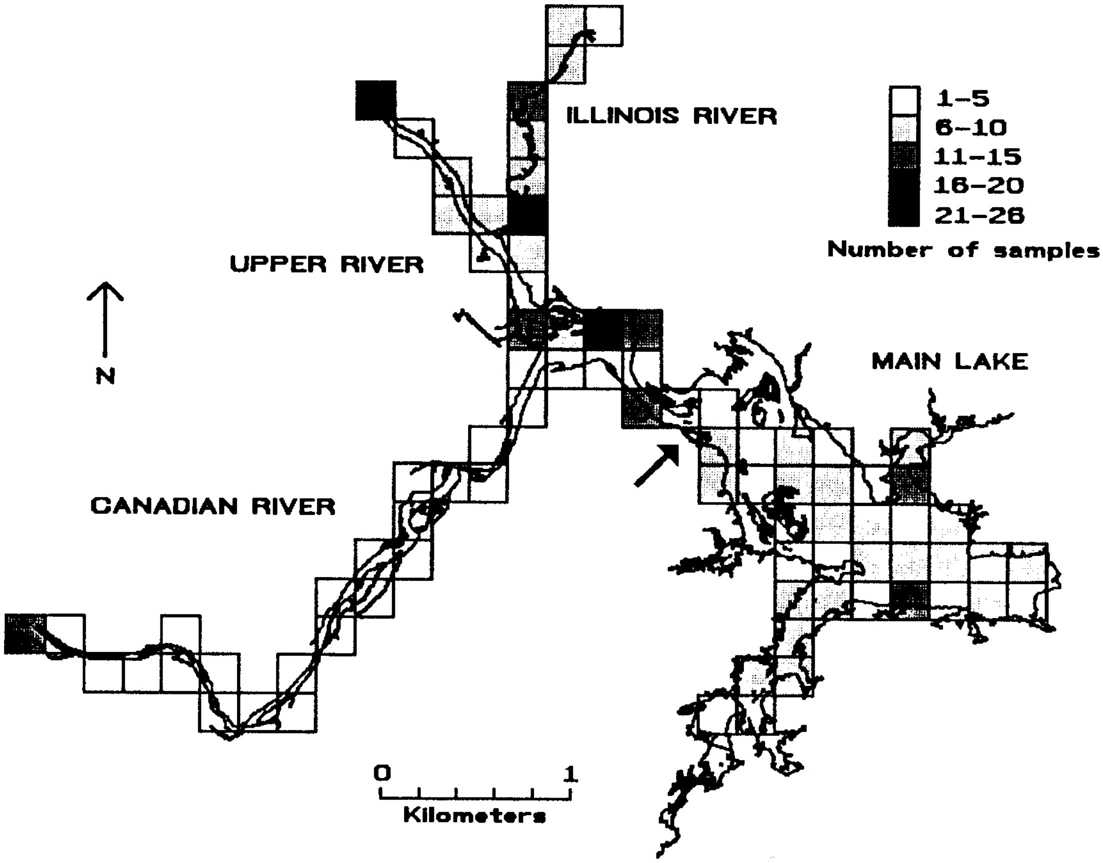
Autumn 1993
Illinois River
N
Upper River
Optimal Habitat
Suitable Habitat
Fish locations
Main Lake
Canadian River
Km
0
4
8


Winter 1994
Illinois River
N
Upper River
Optimal Habitat
Suitable Habitat
Fish locations
Main Lake
Canadian River
Km
0
4
8


SUMMER REFUGE HABITAT
ILLINOIS/CANADIAN RIVERS
Temperature 20-25 C
DO 4.7-7.4 mg/l
Mid-July--Mid-October
SPRING HABITAT
ILLINOIS/UPPER RIVER
Temperature 15-20.5 C
Velocity >0.13-1.13 m/s
May--Mid-July
AUTUMN HABITAT
LACUSTRINE/RIVERINE AREAS
Temperature 9-17.5 C
Mid-October--December
WINTER HABITAT
ILLINOIS RIVER
Temperature 6-9 C
January-April

APPENDIX A

Sampling Frequency for Individual Habitat Cells


ILLINOIS RIVER
1-5
6-10
11-15
16-20
21-26
Number of samples
UPPER RIVER
N
MAIN LAKE
CANADIAN RIVER
0
1
Kilometers

APPENDIX B

Location and Habitat Use Statistics for Individual Striped Bass

Appendix B.-Locations and vital statistics for individual striped bass implanted with ultrasonic transmitters in Robert S. Kerr Reservoir. Standard error in parentheses.

Tag #: 258-C

Date located	Distance moved since last location	Strata	Coordinates Northing	Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg\L)
06/23/93	46,598	IR	310569	3931964	0.34	15.65(0.01)	-
07/19/93	1,734	IR	310171	3930366	0.09	23.46(2.42)	6.23(0.74)
11/10/93	2,954	UR	309900	3928400	0.05	-	-
12/06/93	1,426	IR	309615	3929795	0.04	-	-
12/13/93	302	UR	309325	3929825	-	8.99(0.02)	10.53(0.05)
01/20/94	974	IR	310134	3930323	0.09	6.38(0.13)	-
01/28/94	275	IR	309850	3930270	0.07	6.20(0.12)	-
03/17/94	4,009	UR	310250	3932175	0.16	11.84(0.20)	12.12(0.03)

Appendix B. (Continued)

Tag #: 267-C

Date located	Distance moved since last location	Strata	Coordinates Northing	Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg\L)
12/06/93	50,259	UR	307516	3931813	0.34	-	-
12/13/93	5,844	IR	310250	3932175	-	10.33(0.00)	9.69(0.17)
01/20/94	12,164	UR	303425	3936383	0.12	4.19(0.40)	-
01/28/94	10,667	IR	310410	3930930	0.12	6.50(0.00)	-
02/03/94	793	IR	309940	3930250	0.14	6.70(0.12)	-

Appendix B. (Continued)

Tag #: 267-C

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg\L)
12/06/93	50,259	UR	307516	3931813	0.34	-	-
12/13/93	5,844	IR	310250	3932175	-	10.33(0.00)	9.69(0.17)
01/20/94	12,164	UR	303425	3936383	0.12	4.19(0.40)	-
01/28/94	10,667	IR	310410	3930930	0.12	6.50(0.00)	-
02/03/94	793	IR	309940	3930250	0.14	6.70(0.12)	-

Appendix B. (Continued)

Tag #: 267-C

Date located	Distance moved since last location	Strata	Coordinates Northing	Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg\L)
12/06/93	50,259	UR	307516	3931813	0.34	-	-
12/13/93	5,844	IR	310250	3932175	-	10.33(0.00)	9.69(0.17)
01/20/94	12,164	UR	303425	3936383	0.12	4.19(0.40)	-
01/28/94	10,667	IR	310410	3930930	0.12	6.50(0.00)	-
02/03/94	793	IR	309940	3930250	0.14	6.70(0.12)	-

Appendix B. (Continued)

Tag #: 339-I

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg\L)
08/02/93	1,460	IR	310254	3930472	0.00	24.31(1.61)	7.45(0.62)
08/26/93	1,153	IR	310016	3930341	0.09	21.42(2.14)	6.34(0.42)
09/02/93	1,475	IR	310672	3931620	0.02	25.59(0.88)	11.32(1.75)
10/14/93	51,135	CR	285620	3909320	-	20.51(0.08)	6.28(0.02)

Appendix B. (Continued)

Tag #: 348-I

Date located	Distance moved since last location	Strata	Coordinates Northing	Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg\L)
01/18/93	1,383	IR	309763	3930218	0.19	7.52(0.01)	10.44(0.01)
03/09/93	544	IR	309336	3929940	0.12	8.77(0.04)	11.56(0.02)
03/24/93	272	IR	309565	3929827	0.09	8.00(0.01)	11.95(0.05)
06/23/93	8,896	UR	303604	3936153	0.44	25.48(0.00)	-
09/02/93	291	UR	303340	3936360	0.23	27.97(0.01)	6.27(0.07)
10/23/93	8	UR	303350	3936362	0.16	17.48(0.00)	7.50(0.00)

Appendix B. (Continued)

Tag #: 357-I

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg|L)
01/11/93	429	IR	309943	3930960	0.07	8.20(0.00)	10.62(0.01)
01/18/93	2,625	IR	309343	3930017	0.00	7.45(0.02)	10.46(0.00)
02/08/93	2,074	IR	310600	3931397	-	8.26(0.01)	11.49(0.01)
03/09/93	5,136	UR	307300	3931800	0.53	7.31(0.01)	12.11(0.03)
03/24/93	2,594	IR	309087	3929838	0.41	9.19(0.03)	11.58(0.09)
07/14/93	8,940	IR	310334	3936457	0.14	20.62(0.03)	10.11(0.63)
07/27/93	209	IR	310462	3936509	0.14	17.62(0.01)	3.83(0.00)
08/03/93	216	IR	310325	3936375	0.12	16.97(0.02)	8.32(0.19)
01/27/94	57,941	CR	285661	3909346	0.04	6.70(0.21)	-
02/10/94		CR	285700	3909300	0.00	-	-

Appendix B. (Continued)

Tag #: 366-I

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg|L)
02/07/93	11,394	ML	324200	3917600	0.05	6.92(0.49)	11.70(0.03)
03/08/93	1,158	ML	323487	3916781	0.05	7.03(0.14)	11.89(0.02)
04/18/93	445	ML	322833	3916625	0.11	12.17(0.18)	10.97(0.01)
07/13/93	51,155	CR	288244	3907800	0.05	24.73(-)	6.24(-)
09/03/93	1,186	CR	289200	3907800	-	24.99(0.01)	6.59(0.30)
10/14/93	3,957	CR	285646	3909353	0.02	20.56(0.63)	6.37(0.03)
11/18/93	63,522	ML	332900	3915100	0.11	11.00(0.00)	-
12/07/93	8,101	ML	325023	3917121	0.23	8.41(0.00)	10.49(0.02)
01/14/94	1,158	ML	325711	3916422	0.09	5.00(0.00)	-

Appendix B. (Continued)

Tag #: 384-I

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg\L)
01/06/93	431	ML	329482	3915278	0.16	5.70(0.00)	11.04(0.04)
01/17/93	46	ML	329559	3915338	0.04	5.06(0.03)	12.07(0.07)

Appendix B. (Continued)

Tag #: 447-I

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg|L)
03/09/93	3,724	UR	307200	3931900	0.36	7.24(0.01)	12.07(0.01)
03/24/93	2,725	IR	309091	3930023	0.09	9.20(0.01)	12.37(0.07)
04/09/93	552	UR	308619	3930341	0.31	11.06(0.01)	10.71(0.00)
05/13/93	2,884	IR	310481	3931381	0.11	13.13(0.33)	5.19(0.19)
05/17/93	3,339	IR	311126	3933371	0.05	13.30(0.03)	8.40(0.06)
06/01/93	125	IR	311032	3933259	0.65	13.21(0.01)	8.00(0.05)
06/17/93	4,015	IR	310309	3936458	0.30	15.07(0.01)	-
08/03/93	6,538	IR	310575	3931915	0.00	20.60(-)	5.47(-)
08/26/93	588	IR	310141	3932208	0.02	19.85(0.74)	6.79(0.33)
11/10/93	1,097	IR	310575	3931350	0.04	-	-
11/21/93	5,314	UR	307400	3932300	0.27	11.30(0.12)	-
12/06/93	393	UR	307543	3931905	0.28	-	-

Tag #: 447-I(continued)

Date located	Distance moved since last location	Strata	Coordinates		Velocity (m\s)	Temperature (°C)	D. O. (mg|L)
			Northing	Easting			
12/14/93	10	UR	307550	3931913	-	8.15(0.00)	10.64(0.03)
01/20/94	3,526	IR	309938	3930234	0.04	6.20(0.12)	-
01/28/94	778	IR	309160	3930040	0.14	6.38(0.13)	-
02/03/94	88	IR	309230	3929990	0.16	6.00(0.00)	-

Appendix B. (Continued)

Tag #: 2345-I

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg/L)
04/08/93	18,707	ML	323325	3919312	0.21	10.63(0.00)	10.89(0.01)
05/13/93	18,451	IR	310034	3930496	0.05	17.08(0.17)	6.10(0.05)
06/02/93	9,469	UR	303538	3936169	1.28	20.69(0.00)	8.07(0.03)

Appendix B. (Continued)

Tag #: 2354-I

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg\L)
03/09/93	1,690	IR	309333	3929940	0.09	8.62(0.01)	11.49(0.01)
03/24/93	31	IR	309565	3929827	0.09	8.00(0.01)	11.95(0.05)
04/09/93	858	UR	308619	3930341	0.23	11.06(0.01)	10.69(0.01)
07/19/93	888	IR	309377	3929937	0.11	24.67(0.32)	6.81(0.04)
09/10/93	5,242	IR	311133	3933355	0.09	18.46(0.01)	-
09/24/93	3,001	IR	310678	3931489	0.74	19.85(0.00)	2.47(0.01)
11/10/93	4,355	UR	310000	3928000	0.18	-	-
01/14/94	12,1076	ML	325555	3916655	0.55	6.00(0.00)	-

Appendix B. (Continued)

Tag #: 2363-I

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg\L)
01/11/93	2,716	IR	309886	3931824	0.00	8.21(0.02)	10.49(0.01)
01/18/93	3,224	IR	308657	3929754	0.24	7.51(0.00)	10.47(0.01)
04/08/93	28,859	ML	331500	3919217	0.00	11.93(0.01)	9.79(0.01)
07/13/93	68,086	CR	285623	3909339	0.45	22.83(0.02)	3.59(0.07)
08/03/93	17	CR	285630	3909345	0.12	24.25(0.05)	3.68(0.27)
09/03/93	30	CR	285666	3909366	0.33	25.20(0.04)	4.24(0.07)

Appendix B. (Continued)

Tag #: 2444-I

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg\L)
02/21/93	1,774	IR	309372	3930182	0.18	7.28(0.01)	11.26(0.01)
03/09/93	2,743	UR	307300	3931600	-	-	-
03/24/93	2,409	IR	309090	3929992	0.07	9.22(0.02)	12.10(0.06)
04/09/93	8,190	UR	303926	3935900	0.70	10.89(0.00)	10.61(0.01)
06/23/93	8,588	IR	309542	3929890	0.00	16.23(0.03)	-
07/02/93	380	IR	309651	3930258	0.00	16.80(0.41)	6.21(0.42)
07/19/93	515	IR	310166	3930366	0.09	23.01(2.19)	6.18(0.67)
09/02/93	424	IR	310420	3930660	0.05	27.98(0.24)	11.58(0.06)
09/20/93	798	IR	309854	3930163	0.17	20.59(0.02)	-
10/07/93	359	IR	310180	3930400	0.00	19.72(0.01)	4.72(0.02)
10/23/93	387	IR	310350	3930733	0.12	18.97(0.02)	6.60(0.03)
11/21/93	4,297	UR	307410	3932310	0.36	11.00(0.00)	-

Tag #: 2444-I(continued)

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg\L)
12/06/93	453	UR	307543	3931905	0.30	-	-
12/14/93	10	UR	307550	3931913	-	8.17(0.00)	10.70(0.04)
01/20/94	3,615	IR	309957	3930357	0.07	6.00(0.00)	-
01/28/94	198	IR	309810	3930230	0.09	6.30(0.12)	-
02/03/94	54	IR	309840	3930260	0.11	5.80(0.12)	-

Appendix B. (Continued)

Tag #: 2633-I

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg\L)
01/11/93	2,632	IR	309886	3931824	0.00	8.21(0.02)	10.49(0.07)
02/22/93	2,817	IR	309454	3930027	0.11	6.18(0.01)	11.22(0.02)
03/09/93	2,837	IR	310668	3931856	0.19	6.56(0.00)	11.61(0.07)
03/09/93	456	IR	310464	3932064	0.03	8.73(0.12)	11.34(0.11)
05/13/93	3,076	IR	311310	3933644	0.04	16.72(0.15)	7.43(0.03)
05/17/93	1,019	IR	310559	3932928	0.02	13.67(0.06)	8.28(0.02)
06/01/93	484	IR	311032	3933259	0.51	13.24(0.02)	8.10(0.09)
07/14/93	78	IR	311000	3933202	0.30	20.53(0.00)	9.21(0.74)
08/03/93	124	UR	310864	3933275	0.00	19.93(0.06)	6.51(0.06)
09/10/93	300	IR	311125	3933325	0.41	18.69(0.01)	-
09/24/93	3,028	IR	310688	3931577	0.12	19.94(0.00)	2.52(0.01)
10/23/94	10,445	UR	304080	3935360	0.04	17.60(0.08)	7.13(0.02)

Appendix B. (Continued)

Tag #: 3335-I

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	Velocity (m\s)	Temperature (°C)	D. O. (mg\L)
02/21/93	1,817	IR	310645	3931373	0.28	7.11(0.00)	11.27(0.03)
03/09/93	132	IR	310642	3931247	0.38	6.44(0.15)	11.38(0.03)
03/24/93	90	IR	310579	3931255	0.53	7.28(0.00)	11.70(0.02)
04/09/93	4,008	UR	309782	3928128	0.28	11.37(0.01)	10.67(0.02)
05/13/93	5,203	IR	311162	3934973	0.07	17.50(0.06)	8.12(0.01)
05/17/93	2,548	IR	309622	3932688	0.02	13.56(0.02)	8.21(0.15)
07/19/93	4,541	IR	309438	3929897	0.11	25.00(0.62)	7.10(0.05)
08/02/93	54	IR	309454	3929918	0.00	28.21(0.54)	7.73(0.17)
08/26/93	54	IR	309500	3929900	0.07	26.86(0.54)	8.23(0.42)
09/02/93	297	IR	310220	3932220	0.05	25.20(0.23)	12.47(0.64)
09/20/93	222	IR	309409	3929954	0.17	20.39(0.00)	-
09/24/93	2,480	IR	310633	3931878	0.05	19.83(0.02)	2.89(0.02)

Tag #: 3335-I(continued)

Date located	Distance moved since last location	Strata	Coordinates Northing	Coordinates Easting	velocity (m\s)	Temperature (°C)	D. O. (mg\L)
10/07/93	412	IR	310360	3932160	0.07	19.65(0.02)	4.70(0.00)
10/23/93	602	IR	310816	3931733	0.43	19.67(0.01)	5.72(0.02)
12/06/93	605	IR	310678	3931191	0.34	10.84(0.01)	9.13(0.05)
01/20/94	1,248	IR	309892	3930296	0.04	6.13(0.13)	-
01/28/94	1,024	IR	310450	3930990	0.11	6.50(0.00)	-
02/03/94	1,148	IR	309770	3930180	0.11	6.00(0.00)	-

VITA

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Candidate for the Degree of

Master of Science

Thesis: DISTRIBUTION, MOVEMENTS AND HABITAT PREFERENCES OF STRIPED BASS IN ROBERT S. KERR RESERVOIR, OKLAHOMA

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