

Movement, Home Range, and Site Fidelity of Bluegills in a Great Plains Lake

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Abstract.—Little is known about the distribution, movement, and home ranges of bluegills *Lepomis macrochirus* in lentic environments. Therefore, the objectives of this study were to evaluate the seasonal and diel differences in movement rates, site fidelity, and home range of bluegills in a shallow, natural Great Plains lake. A total of 78 bluegills (200–273 mm total length) were implanted with radio transmitters in March and May 2000. Of these fish, 10 males and 10 females were randomly selected and located every 2 h during one 24-h period each month from April to September 2000. Bluegill movement peaked during midsummer; however, there was little difference in diel movements, suggesting relatively consistent movement throughout the 24-h period. Home range estimates (which included the 24-h tracking plus an additional six locations from the same fish located once per day for six consecutive days each month) ranged up to 172 ha, probably because only about half of the bluegills exhibited site fidelity during any month sampled. Bluegill movement did not appear to be strongly linked with water temperature, barometric pressure, or wind speed. These results suggest that bluegills move considerable distances and that many roam throughout this 332-ha shallow lake. However, diel patterns were not evident. Sampling bluegills in Great Plains lakes using passive gears (e.g., trap nets) may be most effective during the summer months, when fish are most active. Active sampling (e.g., electrofishing) may be more effective than the use of passive gears in spring and fall, when bluegills are less active.

Bluegills *Lepomis macrochirus* are a popular sport fish in North America and their population dynamics (i.e., recruitment, growth, mortality) have received substantial attention in the literature. However, bluegill movement, home range, and site fidelity are not well understood, particularly for lentic systems. Studies on bluegills in lotic systems have suggested that most fish are sedentary, few fish moving long distances (Gunning and Shoop 1963; Gatz and Adams 1994). Other species of *Lepomis* have also shown restricted movement in streams (e.g., Gerking 1953; Smithson and Johnston 1999). However, similar information does not exist for lentic bluegill populations.

Diel and seasonal movements may be related to several factors, including feeding, predator avoidance, spawning, and environmental biotic and abiotic conditions (Matthews 1998), all of which probably apply to bluegills. Bluegills are sight feeders and feed during diurnal periods (Keast and Welsh 1968; Werner and Hall 1974). Feeding activity may account for diel distribution of fishes;

thus, diel movement may be a function of foraging (Helfman 1981; Keast and Fox 1992).

Reports on the effects of environmental variables (e.g., barometric pressure, water temperature, wind speed) on warmwater fish movement have been mixed. Movement rates may either increase with rising or steady barometric pressure (e.g., Markham et al. 1991; Guy et al. 1992; Jones and Rogers 1998) or have little influence on fish movement (Warden and Lorio 1975; Guy et al. 1994). Increased wind speed was related to decreased movement of crappies *Pomoxis* spp. in South Dakota lakes (Guy et al. 1992, 1994). In addition, fish movement increases as metabolism (based on water temperature) increases throughout the summer (Hergenrader and Hasler 1967), up to an optimum temperature (i.e., 27–29°C for bluegills; Coutant 1977), and then movement decreases if temperatures are above optimum.

Bluegill home ranges may be influenced by fish size (Minns 1995), food density (Fish and Savitz 1983), and social hierarchies (Fish and Savitz 1983). In addition, sexual and seasonal differences can affect home range; for example, male bluegills will guard nests after spawning, thus reducing home range size during this period. Larger bluegills may exhibit site fidelity, remaining in the same area for an extended period of time (Ball 1943). Fish and Savitz (1983) found bluegill home

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ranges of 0.15–0.75 ha lasting for 1–3 months and a negative relation between bluegill size and home range size for fish <190 mm total length (TL). In Tennessee streams, Gatz and Adams (1994) found linear home ranges of up to 17 km for bluegills, whereas linear home ranges for bluegills in Louisiana streams were typically less than 38 m (Gunning and Shoop 1963). To our knowledge, no one has investigated seasonal home ranges or home range size of bluegills in lentic habitats over a longer periods (e.g., 6 months).

The objectives of our study were to evaluate diel and seasonal differences in movement rates and distribution of bluegills in a shallow, natural lake of the Great Plains. We hypothesized that bluegill movement rates would decrease during the nocturnal period, because of presumed reduced feeding, and increase with and up to their optimum water temperature of 29°C (Coutant 1977). We also hypothesized that male bluegill home ranges would be reduced and site fidelity would be increased from early to midsummer because of nest-guarding during spawning. Finally, we wanted to evaluate whether wind speed and barometric pressure influenced bluegill movement and distribution.

Methods

Study site.—Pelican Lake is a 332-ha, shallow, windswept (mean depth = 1.2 m) natural prairie lake in the Valentine National Wildlife Refuge of north-central Nebraska. Vegetation is dispersed throughout the lake, submergent vegetation covering approximately 23% of lake area in midsummer and emergent vegetation covering 14% (Paukert and Willis 2002). The fish community primarily includes bluegills, largemouth bass *Micropterus salmoides*, yellow perch *Perca flavescens*, northern pike *Esox lucius*, and common carp *Cyprinus carpio*.

Transmitter implantation and tracking.—We surgically implanted (see Paukert and Willis (2002) 33 female and 27 male bluegills with 3.2-g radio transmitters from 8 to 17 March 2000. Transmitters expelled from or collected from fish that died among our original implants were subsequently implanted into an additional 4 females and 14 males on 22–23 May 2000. Therefore, a maximum of 60 fish had transmitters at any given sampling time.

We randomly selected up to 10 male (211–260 mm TL) and 10 female bluegills (229–271 mm TL) and located these fish every 2 h for one 24-h period on 21 April, 15 May, 20 June, 22 July, 14

August, and 9 September 2000. We recorded and stored their coordinates using a global positioning system (Timble GeoExplorer 3, Sunnyvale, California) and differentially corrected these data in the laboratory. We estimated that we were within 5 m of the actual fish location; we had little evidence of fish being scared by the boat (Paukert and Willis 2002). We classified the 24-h period into four diel periods: dawn (2 h before to 2 h after sunrise), daytime, dusk (2 h before sunset to 2 h after sunset) and night. Because of transmitter expulsion, delayed mortality, or loss of radio contact, the same fish were not necessarily tracked each month. However, it was not uncommon for the same fish to be tracked for multiple months.

Barometric pressure and wind speed were recorded from the Miller Field, Valentine, Nebraska weather station (National Oceanic and Atmospheric Administration), approximately 40 km north of Pelican Lake. Hourly values closest to each fish location were used for wind speed and barometric pressure. Water temperature was recorded every 2 h by a temperature logger 0.5 m below the lake surface in the middle of the lake.

Statistical analysis.—A repeated-measures (with individual fish as the repeated variable) analysis of variance (ANOVA) was used to test differences in mean bluegill movement rates (m/h) among diel periods, months, and between sexes using individual fish as the experimental unit. In all analyses, movement rate variances were heterogeneous, so a mixed model was used (Proc MIXED in SAS; Littell et al. 1996). We specified the covariance structure as first-order autoregressive because we assumed the within-subjects correlation to be less correlated with observations that were farther apart in time (Littell et al. 1996). Because the same fish was not necessarily tracked each month, we specified that the autoregressive covariance structure pertains to the submatrices for each unique fish within each diel period, month, and sex; that is, subject = fish identification number (diel period \times month \times sex) (SAS; Littell et al. 1996). When there was a significance difference in the ANOVA, a least-squares means procedure was used to identify where these differences occurred. Spearman's rank correlations were used to relate environmental variables (i.e., barometric pressure, water temperature, wind speed) with movement rate for each of the 6 months. In these analyses we used a Bonferroni correction ($\alpha = 0.05/6 = 0.008$) to account for spurious correlations (Sokal and Rohlf 1995).

We used the minimum convex polygon (MCP) method to estimate home range size. An additional

TABLE 1.—Analysis of variance table comparing movement rates (m/h) between sexes and among months and periods for bluegills located every 2 h for 24 h in Pelican Lake, Nebraska, from April to September 2000.

Source	df	F	P
Period	3, 384	1.47	0.222
Sex	1, 384	7.03	0.008
Month	5, 384	9.96	0.001
Period × Sex	3, 384	0.34	0.793
Period × Month	15, 384	1.20	0.266
Sex × Month	5, 384	0.67	0.648
Period × Month × Sex	15, 384	0.97	0.488

six consecutive daily contacts (during the same week as the 24-h tracking) from the same fish each month (from a concurrent study; Paukert and Willis 2002) were included in our analysis. The addition of the six daily locations was used to distribute the observations throughout a longer period of about 1 week. Therefore, the home range analysis was conducted with the 8–10 locations from the 24-h tracking and the additional six consecutive daily locations, which were all the locations for each fish each month. We calculated two MCPs for each fish each month: one that included all points (for comparisons with other studies) and one with 50% of the observations. The 50% MCP was calculated because it most likely resembles a core occupation area and it removes outliers that can substantially influence the home range estimate (White and Garrot 1990). In our home range analyses, sample sizes were very similar (i.e., within 1–2 observations) across individuals and months, thus minimizing the effects of sample size on our estimator (White and Garrot 1990). A repeated-measures ANOVA was used to compare home range size with sex and month as the main effects. Spearman's rank correlations were used to relate home range size with movement rates and fish length.

To test for site fidelity, we used mean squared distance (MSD) from the center of activity, which is analogous to Schoener's r^2 (Schoener 1981; Hooge et al. 1997). In this analysis, we calculated a MSD for each individual each month and compared this MSD to 1,000 randomly generated paths for each fish each month. If actual movements were lower than the lower bound of the 95% confidence interval of the 1,000 random MSDs, the individual fish exhibited site fidelity (Spencer et al. 1990; Hooge et al. 1997). We then used logistic regression to determine whether the proportion of individuals exhibiting site fidelity was dependent on month or sex. Home range estimates and site fidelity were calculated using ArcView (ESRI

1999) and the Animal Movement extension (Hooge et al. 1997).

Results

Bluegill Movement Patterns

Bluegill movement was highly variable throughout the study, ranging from near 0 m/h to 1,104 m/h (mean = 57 m/h) but was influenced by sampling month and bluegill sex. However, bluegill mean monthly movement was not related to fish length for males ($r = -0.14$, $df = 52$, $P = 0.32$), females ($r = 0.03$, $df = 54$, $P = 0.84$), or all fish combined ($r = 0.03$, $df = 108$, $P = 0.74$). Bluegill movement differed across months ($F_{5, 384} = 9.96$, $P < 0.001$), but there was no difference among diel periods. On average, females moved (mean = 67 m/h, $SE = 5$) more than males (mean = 49 m/h, $SE = 5$; $F_{1, 384} = 7.03$, $P = 0.008$), regardless of diel period or month (Table 1). Mean monthly movement rates ranged from a mean of 30 m/h ($SE = 9.0$) in September to a mean of 100 m/h ($SE = 10$) in July (Figure 1). The least-squares means comparison indicated that July had the highest mean monthly movement rate, followed by June and August; April, May, and September had the lowest mean monthly movement rates. However, movement rates did not differ among diel periods ($F_{3, 384} = 1.47$, $P = 0.22$). Bluegill movement was consistent across diel periods but peaked in mid-summer for both males and females.

Environmental Relationships

Barometric pressure and wind speed had little influence on bluegill movement rates. Although movement rate was positively related to barometric pressure for all months combined ($r = 0.32$, $df = 804$, $P < 0.001$), June was the only individual month with a significant relationship ($r = 0.37$, $df = 140$, $P < 0.001$; Table 2). Mean movement rates for each month were not directly related to water temperature for males ($r = 0.37$, $df = 4$, $P = 0.47$) or females ($r = 0.43$, $df = 4$, $P = 0.40$). Movement

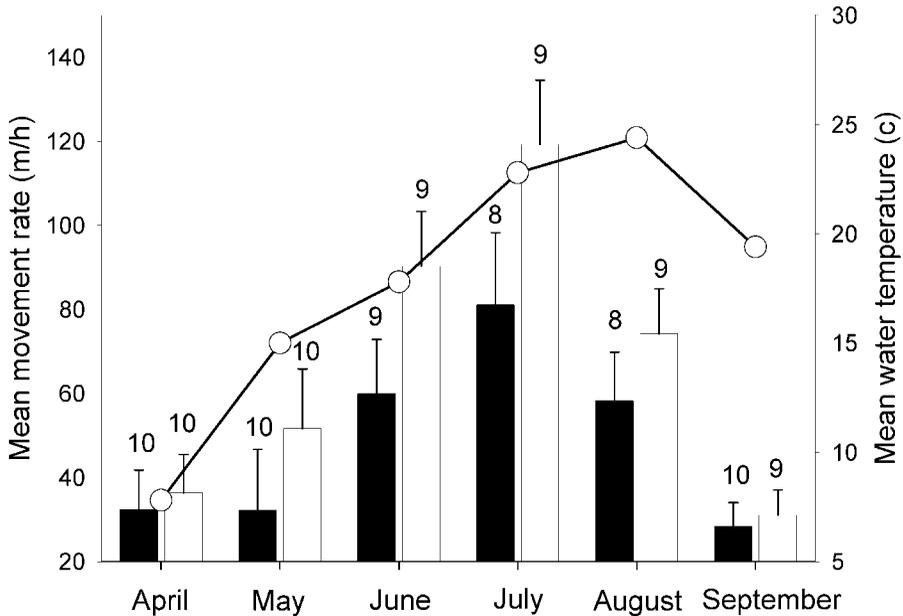


FIGURE 1.—Mean movement rates and +1 SE for male (black bars) and female (white bars) bluegills located every 2 h for 24 h each month from April to September 2000 in Pelican Lake, Nebraska. The black line with white circles represent mean water temperature for the period (month). The number of fish used to calculate the mean movement rate is displayed above each vertical bar.

rates peaked in July when water temperature averaged 22.8°C; movement decreased in August, although water temperatures averaged 24.4°C (Figure 1).

Home Range and Site Fidelity

Minimum convex polygon home ranges ranged from 0.13 to 172 ha across all months and sexes but did not differ between sexes ($F_{1,23} = 0.01, P = 0.91$) or among months ($F_{1,32} = 1.32, P = 0.29$). The core home range (i.e., 50% MCP) did not differ between sexes and ranged from less than 0.01 ha to 27.2 ha ($F_{1,15} = 2.34, P = 0.15$). Bluegills had larger core home ranges in July than in May,

June, and September ($F_{5,23} = 2.78, P = 0.04$). The largest core home range occurred in April (mean = 2.9 ha; Figure 2); however, April had the lowest proportion of bluegills exhibiting site fidelity ($\chi^2 = 10.17, P = 0.001$; Figure 2). Movement rates were positively related to both the MCP home range ($r = 0.58, df = 104, P < 0.001$) and the 50% MCP ($r = 0.27, df = 104, P = 0.005$); home range size increased with increasing bluegill movement. Fish length was not related to either home range ($r = -0.02, df = 104, P = 0.82$) or core home range size ($r = -0.02, df = 104, P = 0.82$).

Discussion

Bluegills in Pelican Lake did not exhibit movement rate differences among diel periods throughout the 6-month study. In contrast, other centrarchids (e.g., crappies) have exhibited diel movement patterns that peaked during the crepuscular periods and were lowest during daytime (Guy at al. 1992, 1994). Although we did not measure feeding activity, increased movement is often related to increased feeding (Emery 1973; Helfman 1981). Bluegills typically feed during the diurnal periods (Keast and Welsh 1968; Keast and Fox 1992) but may exhibit nighttime feeding as well (Sarker 1977; Keast 1978). Therefore, we suggest

TABLE 2.—Spearman’s rank correlations between bluegill movement rates (m/h) and barometric pressure and movement rates and wind speed at Pelican Lake, Nebraska, 2000, where N = number of bluegill locations.

Month	N	Barometric pressure		Wind speed	
		r	P	r	P
Apr	136	0.155	0.071	-0.259	0.002
May	157	0.102	0.202	-0.136	0.089
Jun	142	0.373	0.001	-0.160	0.056
Jul	123	0.149	0.101	-0.216	0.017
Aug	111	0.128	0.181	-0.024	0.801
Sep	137	-0.131	0.126	0.082	0.342
Overall	806	0.342	0.001	-0.146	0.001

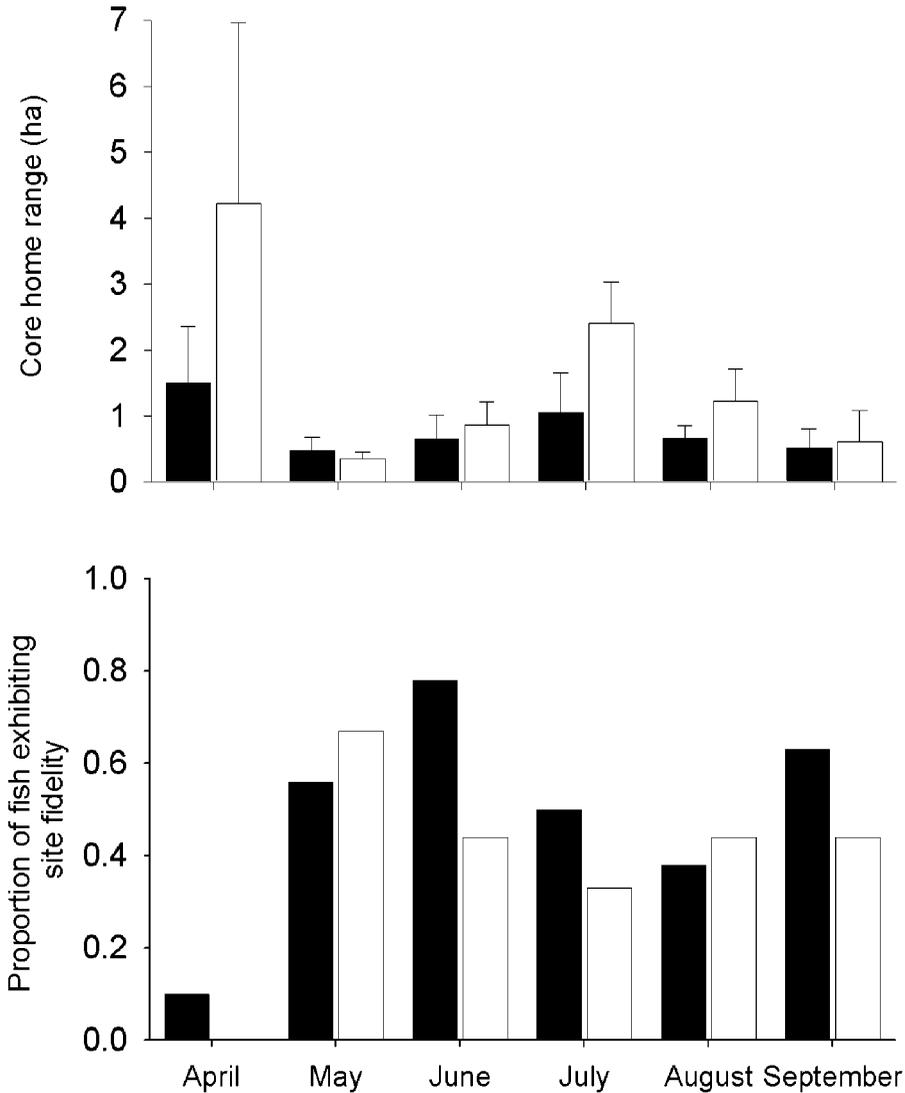


FIGURE 2.—Mean and +1 SE monthly core (i.e., 50% minimum convex polygon) home ranges (top panel) and site fidelity proportions (bottom panel) for male (black bars) and female (white bars) bluegills in Pelican Lake, Nebraska. Bluegills were located once every 2 h and daily for 6 d each month from April to September 2000.

that bluegills in Pelican Lake may feed during both the diurnal and nocturnal periods.

Bluegill movement in Pelican Lake peaked in midsummer, but this relationship could not be attributed directly to water temperature. Fish movement typically is a function of water temperature (Hergenrader and Hasler 1967) up to the optimum temperature for that species (i.e., 27–29°C for bluegill; Coutant 1977), beyond which movement may then decline (Mesing and Wicker 1986). However, we observed our highest movement rates at about 23°C. Either bluegills in Pelican Lake ex-

hibited lower optimum temperatures or other factors influence movement.

We found little evidence that bluegill movement was related to environmental factors (i.e., barometric pressure and wind speed). Although some studies have suggested increased movement with increased (Guy et al. 1992) or steady (Markham et al. 1991; Jones and Rogers 1998) barometric pressure, our study supports other findings indicating limited influence of barometric pressure on movement patterns (Warden and Lorio 1975; Guy et al. 1994). In general, as wind speed increased,

movement rates decreased for Pelican Lake bluegills during each month sampled, except September. Many of these relationships were nonsignificant or weak; however, the trend was consistent. For crappies in South Dakota lakes, Guy et al. (1992, 1994) also suggested that increased wind speed was related to decreased movement. In the shallow environment of Pelican Lake, increased wind may cause extensive wave action and a more turbid environment, which could reduce bluegill feeding (Gardner 1981), thus reducing movement rates.

Our home range estimates for bluegills were larger than the few estimates we found in the literature. Fish and Savitz (1983) reported that bluegill home ranges were less than 1 ha, whereas only 8.5% of the home ranges in Pelican Lake were less than 1 ha. Our estimates of the mean core area home range was about 4.5 times larger than the mean primary occupation area reported by Fish and Savitz (1983). However, minimum convex polygon home ranges tend to overestimate home range size with few observations (Schoener 1981), which may have occurred in our study. Nonetheless, we had similar observations for each fish each month, so comparisons between sexes and among months within our study are valid. Bluegill home range was highest in April, which was most likely related to the low proportion of fish exhibiting site fidelity during that month. Other than April, bluegill home range peaked in July, probably because bluegill movement rate and home range were positively related.

Bluegill home range was not related to fish length, which is unlike other studies (Fish and Savitz 1983; Minns 1995). However, we utilized a limited range of fish lengths. If home range does increase with fish length (Minns 1995), we would expect larger home ranges in these larger bluegills. Fish may have larger home ranges when prey availability is reduced (Charnov et al. 1976) or have smaller home ranges because of social dominance (Fish and Savitz 1983). Because invertebrate abundance was high in Pelican Lake (1,377 benthic macroinvertebrates per square meter, 1,178 zooplankton per liter; Paukert and Willis 2002) and because we implanted some of the largest bluegills in the lake, we do not believe that larger home ranges can be attributed to reduced prey availability or subdominant fish being tagged. Nonetheless, home range size of bluegills was the largest reported for this species, which warrants further consideration.

Site fidelity was typically low, about half of the

fish exhibiting site fidelity. In June, 80% of the males exhibited site fidelity, which would be consistent with spawning activity when males guard the nest. However, turbid conditions in Pelican Lake (Secchi disk transparencies typically <1 m) prohibited direct observations of nest building or guarding. The low numbers of fish exhibiting site fidelity throughout the study, coupled with the larger home ranges, suggest that these fish may roam considerably. Because the habitat was relatively homogeneous in this lake (Paukert and Willis 2002), it would not appear that the roaming would be a function of habitat selection. Clearly more research is needed to determine the mechanism for site fidelity of bluegills in lentic environments.

Our results suggest that bluegill movement in Pelican Lake was considerable, with some movement rates over 1,000 m/h in this shallow, natural lake. However, diel patterns in movement rates were not evident. Our estimates of bluegill home range were some of the largest reported in the literature, probably because Pelican Lake fish typically roamed throughout the lake and did not exhibit site fidelity.

Management Implications

Bluegill sampling in shallow, natural lakes of the Great Plains using passive gears (e.g., trap nets; Hubert 1996) may be most efficient during midsummer (i.e., June) when these fish are most active. However, sampling with active gears (e.g., electrofishing; Reynolds 1996) may be more effective than passive gears during spring and summer when bluegills are less active. Increased site fidelity in late spring and summer, particularly for males, suggests that spawning activity may be most prevalent during this time and may bias sampling towards more males. Biologists need to consider sex and monthly differences in bluegill movement and site fidelity when sampling in lentic systems.

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References

- Ball, R. C. 1943. A tagging experiment of the fish population of Third Sister Lake, Michigan. *Transactions of the American Fisheries Society* 74:360–369.
- Charnov, E. L., G. H. Orians, and K. Hyatt. 1976. Ecological implications of resource depression. *American Naturalist* 110:247–259.
- Coutant, C. C. 1977. Compilation of temperature preference data. *Journal of the Fisheries Research Board of Canada* 34:739–745.
- Emery, A. R. 1973. Preliminary comparisons of day and night habits of freshwater fish in Ontario lakes. *Journal of the Fisheries Research Board of Canada* 30:761–774.
- ESRI. 1999. Getting to know ArcView GIS. ESRI, Redlands, California.
- Fish, P. A., and J. Savitz. 1983. Variations in home range of largemouth bass, yellow perch, bluegills, and pumpkinseeds in an Illinois Lake. *Transactions of the American Fisheries Society* 112:47–153.
- Gardner, M. B. 1981. Effects of turbidity on feeding rates and selectivity of bluegills. *Transactions of the American Fisheries Society* 110:446–450.
- Gatz, A. J., Jr., and S. M. Adams. 1994. Patterns of movement of centrarchids in two warmwater streams in eastern Tennessee. *Ecology of Freshwater Fish* 3:35–48.
- Gerking, S. D. 1953. Evidence for the concepts of home range and territory in stream fishes. *Ecology* 34:347–365.
- Gunning, G. E., and C. R. Shoop. 1963. Occupancy of home range by longear sunfish, *Lepomis m. megalotis* (Rafinesque) and bluegill, *Lepomis m. macrochirus* Rafinesque. *Animal Behaviour* 11:325–330.
- Guy, C. S., Neumann, R. M., and D. W. Willis. 1992. Movement patterns of adult black crappie, *Pomoxis nigromaculatus*, in Brant Lake, South Dakota. *Journal of Freshwater Ecology* 7:137–147.
- Guy, C. S., D. W. Willis, and J. J. Jackson. 1994. Biotelemetry of white crappies in a South Dakota glacial lake. *Transactions of the American Fisheries Society* 123:63–70.
- Helfman, G. S. 1981. Twilight activities and temporal structure in a freshwater fish community. *Canadian Journal of Fisheries and Aquatic Sciences* 38:1405–1420.
- Hergenrader, G. L., and A. D. Hasler. 1967. Seasonal changes in swimming rates of yellow perch in Lake Mendota as measured by sonar. *Transactions of the American Fisheries Society* 96:373–382.
- Hooge, P. N., B. Eichenlaub, and E. Solomon. 1997. The animal movement program. U.S. Geological Survey, Alaska Biological Science Center, Anchorage.
- Hubert, W. A. 1996. Passive capture techniques. Pages 157–192 in B. R. Murphy and D. W. Willis, editors. *Fisheries techniques*, 2nd edition. American Fisheries Society, Bethesda, Maryland.
- Jones, M. S., and K. B. Rogers. 1998. Palmetto bass movements and habitat use in a fluctuating Colorado irrigation reservoir. *North American Journal of Fisheries Management* 18:640–648.
- Keast, A. 1978. Feeding interrelations between age-groups of pumpkinseed (*Lepomis gibbosus*) and comparisons with bluegill (*L. macrochirus*). *Journal of the Fisheries Research Board of Canada* 35:12–27.
- Keast, A., and M. G. Fox. 1992. Space use and feeding patterns of an offshore fish assemblage in a shallow mesotrophic lake. *Environmental Biology of Fishes* 34:159–170.
- Keast, A., and L. Welsh. 1968. Daily feeding periodicities, food uptake rates, and dietary changes with hour of day in some lake fishes. *Journal of the Fisheries Research Board of Canada* 25:1133–1144.
- Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS system for mixed models. SAS Institute, Cary, North Carolina.
- Markham, J. L., D. L. Johnson, and R. W. Petering. 1991. White crappie summer movements and habitat use in Delaware Reservoir, Ohio. *North American Journal of Fisheries Management* 11:504–512.
- Matthews, W. J. 1998. Patterns in freshwater fish ecology. Chapman and Hall, New York.
- Mesing, C. L., and A. M. Wicker. 1986. Home range, spawning migrations, and homing of radio-tagged Florida largemouth bass in two central Florida lakes. *Transactions of the American Fisheries Society* 115:286–295.
- Minns, C. K. 1995. Allometry of home range size in lake and river fishes. *Canadian Journal of Fisheries and Aquatic Sciences* 52:1499–1508.
- Paukert, C. P., and D. W. Willis. 2002. Seasonal and diel habitat selection by bluegills in a shallow natural lake. *Transactions of the American Fisheries Society* 131:1131–1139.
- Reynolds, J. B. 1996. Pages 221–254 in B. R. Murphy and D. W. Willis, editors. *Fisheries techniques*, 2nd edition. American Fisheries Society, Bethesda, Maryland.
- Sarker, A. L. 1977. Feeding ecology of the bluegill, *Lepomis macrochirus*, in two heated reservoirs of Texas III. Time of day and patterns of feeding. *Transactions of the American Fisheries Society* 106:596–601.
- Schoener, T. W. 1981. An empirically based estimate of home range. *Theoretical Population Biology* 20:281–325.
- Smithson, E. B., and C. R. Johnston. 1999. Movement patterns of stream fishes in a Ouachita Highlands stream: an examination of the restricted movement paradigm. *Transactions of the American Fisheries Society* 128:847–853.
- Sokal, R. R., and F. J. Rohlf. 1995. *Biometry*, 3rd edition. Freeman, New York.
- Spencer, S. R., C. S. Cameron, and R. K. Swihart. 1990. Operationally defining home range: temporal de-

- pendence exhibited by hispid cotton rats. *Ecology* 71:1817–1822.
- Warden, R. L., and W. J. Lorio. 1975. Movement of largemouth bass (*Micropterus salmoides*) in impounded waters as determined by underwater telemetry. *Transactions of the American Fisheries Society* 104:696–702.
- Werner, E. E., and D. J. Hall. 1974. Optimal foraging and the size selection of prey by the bluegill sunfish (*Lepomis macrochirus*). *Ecology* 55:1042–1052.
- White, G. C., and R. A. Garrot. 1990. Analysis of wildlife radio-tracking data. Academic Press, San Diego.