AN ABSTRACT OF THE THESIS OF

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Title: Spring movements, regional fidelity, and spawning habitat of sauger (Stizostedion canadense) in Melvern Reservoir, Kansas, and the Global Positioning System for aquatic surveys.

Abstract approved: David R. Edds

In 1988-1991, the Kansas Department of Wildlife and Parks stocked sauger fry in Melvern Reservoir to provide a brood source and sport fish. In 1989-1991, fall electroshocking indicated that stocking had been successful, with the 1991 survey showing three year classes of sauger. However, during spring-time electroshocking in 1992, sauger were not found; thus, this sequestered brood resource could not be utilized. To locate sauger spawning areas, I monitored movements and habitat use of adult sauger with ultrasonic telemetry, the Global Positioning System (GPS), and a Geographic Information System (GIS) in the spring of 1993. Horizontal movements were greatest in March prior to the spawn. During the spawn, sauger exhibited high fidelity toward two reservoir shoals, where they spawned on a clay/silt, pebble, and cobble substrate. These spawning grounds were associated with a geologic district unique to one region of the reservoir. Male sauger generally occupied deeper waters than females, with both sexes inhabiting open water habitats during the pre- and post-spawn periods, and moving near shore during the spawn. After the spawn, tagged sauger were located in coves where large schools of young-of-year gizzard shad, Dorosoma cepedianum, were seen, possibly being used as prey. Barometric pressure and inflow best explained change in water depth occupied by sauger; male depths were also associated with day of year, precipitation, pool level change, and reservoir discharge, whereas female depths were further explained by water temperature. The change from expansive pre-spawn movements to minimal activity during the spawn was moderately explained by barometric pressure. It can be concluded that sauger in Melvern Reservoir responded to stimuli similar to those found in rivers during spring. Furthermore, sauger populations in such confined systems allow easily-accessed stocks for (1) sport fishing, (2) artificial propagation, (3) in situ genotype reserves for conservation of riverine populations, and (4) glochidial-host sources for threatened and endangered mussel species.

The Global Positioning System (GPS) is a superior surveying technology that quickly provides highly accurate reproducible spatial data, even in remote reference-free areas. During episodes of night-time sauger tracking, fog and darkness precluded recognition of individual coves; however, GPS coordinates of sauger found in these coves were later plotted with GIS, which proved valuable for accurate

coding of reservoir regions to fish fixes, and essential in deriving data on fish movements.

Herein, I review the fundamentals, limitations, and strengths of GPS. This technology is a satellite-based navigation system that relies on radio signals having intrinsic error sources such as signal deflection, refraction, and intentional degradation by the U.S. Department of Defense. Accuracy is measured as the spatial divergence from a known location, and precision is expressed with the root mean square statistic. Either basic GPS (BGPS) or differential GPS (DGPS) can be used, depending on the spatial resolution needed and time allowed for a survey. DGPS requires more time, data processing, and personnel training, yet is more accurate than BGPS due to correction of signal errors.

SPRING MOVEMENTS, REGIONAL FIDELITY, AND SPAWNING HABITAT OF SAUGER (*Stizostedion canadense*) IN MELVERN RESERVOIR, KANSAS, AND THE GLOBAL POSITIONING SYSTEM FOR AQUATIC SURVEYS

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PREFACE

The following synthesis presents a procedure and outcome for which the ultimate goal was to find spawning male sauger in Melvern Reservoir. Achieving this goal identified unique spring movements and areas where sauger spawned, and provided evidence suggesting that this species may offer a fish well adapted to high-fluctuating water regimes characteristic of altered ecosystems, such as impounded river drainages.

This thesis includes two chapters that will be submitted to different scientific journals, each is written in the style specified by its respective periodical. Chapter 1 describes spring movements, regional fidelity, and spawning habitat of sauger (Stizostedion canadense) in Melvern Reservoir, and will be submitted to the Transactions of the American Fisheries Society as a feature article. Chapter 2 discusses fundamentals, limitations, and strengths of the Global Positioning System (GPS) for aquatic surveys, and will be submitted to Fisheries as a review article for that journal's "Environment" section.

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CHAPTER 1

Spring Movements, Regional Fidelity, and Spawning Habitat of Sauger (*Stizostedion canadense*) in Melvern Reservoir, Kansas

Abstract. - I assessed spring movements of sauger, *Stizostedion canadense*, with respect to environmental factors, habitats, regions, and geologic districts in Melvern Reservoir, Kansas, during spring, 1993. No previous sauger studies had been conducted in lacustrine systems lacking large river inflow. I monitored movements of 20 adult sauger (377 to 477 mm) with ultrasonic telemetry, the Global Positioning System (GPS), and a Geographic Information System (GIS); 254 fish fixes were made from 5 February through 21 June. Movements were greatest in March prior to the spawn, ranging up to 2.8 km/d; one male traveled at least 11.4 km in five days. Sauger displayed fidelity toward mainstem shoals, where they spawned on clay/silt, pebble, and cobble substrate; spawning grounds were associated with a geologic district unique to one region of the reservoir. Male sauger inhabited deeper water than females; both sexes were found in pelagic habitats during the pre- and post-spawn periods, but were in or near littoral zones during the spawn. Spring habitat use of Melvern Reservoir sauger was associated with stimuli similar to those found in rivers during spring. In multiple regression analysis barometric pressure and reservoir inflow best explained change in water depth occupied by sauger; male depths were also a function of day of year, precipitation, pool level change, and reservoir discharge, whereas female depths were further associated with water temperature. Sauger populations in such confined systems

provide a popular sportfish, easily-accessed stocks for artificial propagation, and in situ genotype reserves for conservation of riverine populations.

The sauger, Stizostedion canadense, has a native distribution throughout large rivers of the Mississippi River drainage, from Montana and Pennsylvania to northern Louisiana (Lee et al. 1980). Sauger are nocturnal spawners (Scott and Crossman 1973) renowned for far-reaching migrations of up to 380 km (Collette et al. 1977); these mass movements typically occur up rivers or into lotic systems from reservoirs (Becker 1983; Cross and Collins 1995), though Priegel (1969) reported spawning on the shores of Lake Winnebago, Wisconsin. Spawning generally occurs over hard bottoms in tributary streams, in tailwaters of dams, or in the lotic environment upstream from reservoirs on large rivers (Becker 1983). At these locations sauger scatter demersal adhesive eggs over rocks, rubble, gravel, sand, or combinations of these (Priegel 1969; Nelson 1978; Medlin 1990; Siegwarth 1993). Peak spawning activity lasts 5-10 d and spawning on the whole lasts approximately two weeks (Nelson et al. 1967; Nelson 1968; Scott and Crossman 1973) between April and May, depending on geographic location (Nelson 1968; Priegel 1969; Fitz and Holbrook 1978; Nelson 1978; Rawson and Scholl 1978).

In Kansas, sauger occur in the Missouri River and rarely in the Kansas River Basin westward to the Blue River. Historically, they were confined to large, rather turbid rivers, seldom entering tributaries. Early spring reproductive migrations are known immediately downstream from the Kansas River dam at Lawrence; young-of-the-year (YOY) have been found in pools along sandbars in the Missouri River (Cross and Collins 1995).

In 1988-1991 the Kansas Department of Wildlife and Parks (KDWP) stocked sauger fry into Melvern Reservoir to provide an additional sportfish and to establish a brood source of sauger to be used in artificial propagation of "saugeye", a walleye (♀) x sauger (♂) hybrid. Successful stocking was indicated by fall electrofishing in 1989, 1990, and 1991 with catch per unit effort, CPUE, of about 25 fish/h (J. Stephen, KDWP, personal communication). Spring electrofishing in 1992 yielded no sauger; thus, this sequestered brood resource could not be utilized in the KDWP saugeye production program. Fall 1992 surveys showed five year classes of sauger, with YOY present from natural reproduction.

Studies on sauger have been conducted in major river systems (Gebken and Wright 1972; Rawson and Scholl 1978; Pitlo 1992), impoundments of large rivers (Nelson 1968; Fitz and Holbrook 1978; Hickman et al. 1989), and lakes with large rivers flowing into them (Fish 1932; Priegal 1969). Melvern Reservoir, lacking large river inflow, is a lacustrine environment unique for sauger. Behavior of sauger in this system may provide insight into reproductive strategies of this species in other aquatic ecosystems.

The purpose of this study was to locate sauger spawning areas in Melvern Reservoir; specific objectives were to (1) monitor and describe movements from February through June, (2) determine use of reservoir regions and habitat during this period, (3) describe spawning ground characteristics, and (4) seek environmental explanations for spring activity patterns.

STUDY SITE

Melvern Reservoir is a multipurpose impoundment located on the Marais des Cygnes River in east-central Kansas (dam, 38°30'N, 95°42'W; Figure 1). Draining a watershed of 90,400 ha, this reservoir at multipurpose pool, 316 m above mean sea level (MSL), has 163 km of shoreline and a surface area of 2800 ha. Maximum and mean depth are 23 m and 7 m, respectively (Todd and Willis 1985). Dam construction began in 1967 and finished in 1970; the reservoir was operational by 1972. The headwater region of the watershed is predominantly row crop farmland with riparian mixed-hardwood forest, and tallgrass prairie and sparse mixed-hardwoods border the reservoir. In spring, reservoir Secchi-disk water transparencies vary from 15 cm at the upper end to 45 cm at the lower end (Willis 1987).

Melvern Reservoir receives water from the Marais des Cygnes River and rainfall-dependent flows from eight ephemeral tributaries. From January through May, 1990-1993, mean total inflow was 8.1 m^3/s (U.S. Army Corps of

Engineers, Kansas City District office). Upstream from the reservoir, a log jam more than 100 m in length alters the lotic nature of the Marais des Cygnes River (Figure 1); water seeps through the log jam into a downstream slough. Before meeting the log jam, this river has an annual mean discharge of 3.0 m^3/s ($\underline{N}=25$); no flow was recorded at times from 1976 to 1989 (Geiger et al. 1991; 1995).

METHODS

Implanting Transmitters. - On 21, 26, and 27 October 1992, KDWP personnel collected 71 adult sauger by electrofishing Melvern Reservoir; all fish were transported to KDWP Milford Fish Hatchery and held in a raceway. Fish were sexed by inserting a serological pipette into the urogenital opening and extracting eggs or milt. On 19 and 20 December 1992, 10 each of the largest male and female sauger (Table 1) were implanted with individually-coded ultrasonic transmitters (Sonotronics Co., Tucson, Arizona; 20 g in air; 16 x 60 mm) with surgical procedures adapted from Hart and Summerfelt (1975), Pitlo (1978), and McKinley et al. (1992). All sauger had relative weights representative of healthy fish (Table 1). Tagged fish were separated by sex into 1363 L aerated tanks and periodically observed for two days to verify initial success of surgery. On 23 December 1992, tagged sauger were transported to Melvern Reservoir, acclimated to lake water, and released into a cove in the mid-lower reservoir region (Figure 1).

Ultrasonic tags (20-300 Khz) were selected due to Melvern Reservoir's high water conductivity (> 300 μmhos/cm) and maximum depth, where radio signals (40-200 Mhz) would be degraded (Winter et al. 1973; Stasko and Pincock 1977). Tags had a theoretical life span of 392 d and contained information instructing anglers to contact KDWP if a fish was caught or found dead. Posters explaining the study were posted at the reservoir marina and all boat ramps (Appendix A).

Tracking Fish. - Ice cover prevented tracking until 5-8 February and again until 5 March, after which day-time tracking was conducted at least weekly through 21 June 1993. Night-time tracking (2000 to 0400 hours) was conducted on 23 and 24 March and 1, 2, 16, 17, and 25 April. All tracking sessions started at the causeway or marina (Figure 1), whichever was not used the previous period, and progressed clockwise around the reservoir. A boat with a bow-mounted directional hydrophone followed a continuous transect 100-500 m offshore. Signals could be received from approximately 500-1000 m, with greater reception on waveless days. Every 300-400 m the boat was stopped and the hydrophone was lowered 0.25 m below the boat's keel and slowly rotated in all directions. Upon hearing a signal from a tagged sauger, pursuit for the strongest signal commenced. When the strength of the signal remained constant while rotating the hydrophone 360°, a marker buoy was placed in the water to designate fish location. Time, date, and fish identification number were recorded with initial buoy placement.

Universal Transverse Mercator (UTM) coordinates for fish locations were obtained with a MAGELLAN NAV PRO 5000 hand-held Global Positioning System (GPS) receiver. This unit was programmed to collect 15 position fixes and compute an average, which was recorded as a fish's location. Without using a control receiver, geopositioning with a single remote GPS unit has a maximum error of 100 m of true location (Puterski et al. 1992; Chapter 2), a degree of accuracy deemed adequate for documenting fish locations on a water body the size of Melvern Reservoir.

Geographic and Environmental Variables. - Manipulation of spatial data was performed using the IDRISI Geographic Information System (GIS; Clark University 1992). A KURTA digitizer and TOSCA digitizing software were used with the GIS to encode and integrate maps of various geographic features, upon which fish fixes were plotted. Six 1:24,000-scale U.S. Geological Survey topographic maps were used to plot the Marais des Cygnes River main channel and Melvern Reservoir multipurpose pool contour. A 1:50,000-scale mineral resource map and a 1:40,000-scale areal geology map provided locations of gravel quarries and geologic districts (sensu Nelson et al. 1992) based on stratigraphic and test-hole data collected prior to impoundment of the reservoir (O'Conner et al. 1955) (Table 2; Figure 1 and 2). Maps were digitized with the UTM cartographic projection (Snyder 1982), compatible with UTM coordinates provided by GPS. Mean water temperature, air temperature, wind speed, discharge, inflow, barometric pressure, and total precipitation and change in reservoir pool elevation were calculated for the seven days prior to each tracking period; data were obtained from the Melvern Reservoir and Kansas City District offices of the U.S. Army Corps of Engineers, and the National Oceanic and Atmospheric Administration Climate Analysis Center, Washington, D.C.

Activity. - Sauger activity was characterized in four ways: horizontal movement, water depth, habitat, and region. Horizontal movement was described with a Minimum Displacement Index (MDI) derived from Euclidian distance (m) per unit time for successive fixes of individual fish (Figure 3). This type of activity characterization is conservative because fish do not always move on a continuous straight-line; they may move erratically based on environmental, behavioral, or physiological factors. Water depth was described as the depth of water column inhabited by sauger, and was measured with an ULTRA EAGLE II (Eagle Electronics, Inc.) sonic depth finder. Habitat was coded for each fish location as: open, cove, shore, dam, or beach. Regions were assigned to fish locations after using GIS to overlay fish fixes on eight reservoir zones (Figure 1) to identify any fidelity to areas by sauger during pre-spawn, spawn, and post-spawn periods. No tagged fish were located west of the causeway, thus this headwater region was omitted from analyses.

Spawning Habitat. - Spawning activity was documented with night-time tracking, electrofishing (Smith Root SR-18 DC-pulsed work barge), and fyke netting with a 25 m lead. Spawning habitat was characterized along transects by depth and substrate type (Appendix C) using the depth finder and a Ponar dredge (modified Wentworth scale; Cummins 1962), or with meter square quadrats when habitat was exposed at lower pool levels. Substratum categories and depth were averaged for each spawning site.

Analysis. - Analyses were performed using the Statistical Analysis System (SAS; SAS Institute 1985) at a significance level of $P < 0.05$. The MDI data for both sexes, and depth scores for males, were heteroscedastic (Bartlett's test) and their sample means were non-normally distributed ($N < 51$, Shapiro-Wilk W-test; $N > 50$, Kolmogorov D-test) (SAS; Proc UNIVARIATE, NORMAL option). Logarithmic and square root transformations did not alleviate the violations of parametric assumptions. These data were rank transformed and used in parametric analyses (Conover and Iman 1981); ranking was smallest to largest starting with 1, and averaged in case of ties. In a randomized complete block design, this type of ranking used with the parametric analysis of variance (ANOVA) compares to the nonparametric Friedman test in robustness and power, but takes advantage of both between and within block information (Conover and Iman 1981; Sokal and Rohlf 1995).

An unbalanced fixed effects model was assumed due to repeated sampling of experimental units across treatments, i.e., tagged sauger tracked repeatedly over time. Effects of day of year and sex on water depth and MDI were tested using a split-plot ANOVA with repeated measures (ANOVAR; Cody and Smith 1987; Maceina et al. 1994). Univariate ANOVAR was used with sexes lumped, or separated in cases where a significant sex effect was found; comparisons of means were made using least squares means and the PDIFF option (SAS; Proc GLM), after applying the standard Bonferroni adjustment on $\underline{P}$ values, where $\underline{P}'$ to reject < $\underline{P}$/K, and K is the number of comparisons (Rice 1989). Depth scores derived from night observations were analyzed separately from those obtained during the day. Use of reservoir regions and habitats by tagged sauger were analyzed using Model-I contingency tables with the chi-square test of independence (Sokal and Rohlf 1995) (SAS; Proc FREQ, TABLES option); sexes were analyzed together because they exhibited similar distribution patterns, generally occurring in the same regions and habitats.

Stepwise multiple regression was used to examine the relationship between environmental factors and sauger depth and movement (SAS; Proc STEPWISE, MINR option). Mallow's C_p statistic, R^2 increase, bounds on condition number derived from eigenvalues, and variables' nominal P values were used as criteria for selecting a regression model (Mallows 1964; Myers 1990). Sexes were analyzed together, or separately in cases where a significant sex effect was found with split-plot ANOVAR.

RESULTS

From 5 February to 21 June, 188 fixes (99 ♂, 89 ♀) were made during the day and 66 (32 ♂, 34 ♀) were made at night. Number of fixes per fish ranged from 6 to 20, with a mean of 14. Male fixes plotted with GIS demonstrated high fidelity with a north shore shoal, whereas females exhibited less clustering (Figure 4). This fidelity coincided with spawning behavior documented throughout April. There was a 45% total mortality rate of tagged fish with 30% occurring after the spawn; 15% was attributed to harvest by anglers and 30% to unknown causes (Table 1). A tagged male and female sauger survived 16 and 28 months, respectively, before capture by KDWP personnel for brood stock (Table 1). Incision areas on these two fish were represented by clean scars, and the fish had grown 20 mm and 58 mm, respectively.

Activity

Horizontal movements of individual fish ranged from 10 m/d to 2.8 km/d, with one male (#2) traveling at least 11.5 km in five days (17 to 22 March) (Appendix B). There was no significant interaction between sex and MDI scores (ANOVAR; $\underline{P} = 0.28$), but there was a significant effect of day of year on MDI (ANOVAR; $\underline{P} = 0.0001$). Greatest movements by sauger occurred during March (Figure 5); March movements exhibited significant differences with those of later months (Table 3).

Depth of water at tagged fish locations differed significantly between sexes (ANOVAR; $\underline{P} = 0.04$; Figure 6). Water depth occupied by male tagged sauger varied from < 0.6 to 20.7 m, whereas females inhabited depths from < 0.6 to 17.9 m. In April and June, males were in shallower water than in February and March (Table 3; Figure 6); April night-time mean depths were also shallower than March means (30%, $\underline{P}' < 0.008$). Females were shallower in May than in March (Table 3; Figure 6); March and April night-time mean depths exhibited no significant differences.

Habitat use by tagged sauger was not random ($\chi^2 = 93.4$, df = 16, $\underline{P} < 0.001$). In February and March respectively, 61% and 64% of fish fixes were in open water habitats; but in April, 59% were in shore habitats (Figure 7). In May and June, 44% and 46% of tagged sauger were found in coves; in May, 38% were in open water, whereas in

June, 38% were located in shore habitats (Figure 7). The rip-rapped dam was used infrequently from February through May (≤ 6%), and the sandy beach habitat was occupied only in April (6%).

Tagged sauger used different reservoir regions throughout the study period (χ^2 = 97.3, df = 28, $\underline{P}$ < 0.001). In February, 83% of fish fixes were in the north mid-lower area of the reservoir (Figure 7). Sauger were more evenly distributed among regions in March, and in April 63% were found in the northern lower sector (Figure 7). Sauger dispersed thereafter, showing affinity for the north mid-lower region in May and June (44 and 50%, respectively).

Environmental Variables

Multiple regression of the dependent variables water depth and MDI was performed using the independent variables inflow, discharge, precipitation, pool elevation change, wind, air temperature, water temperature, barometric pressure, and day of year. To investigate environmental factors associated with variation in sauger activity, regression was performed on data for the entire study period and on specific intervals encompassing pre-spawn and spawn periods.

For the period of February to June 1993, tagged male sauger water depth (WD) was best explained by the model:

$$WD = -48.23 - 48.33\ PC + 0.001\ IN + 0.001\ DI + 0.44\ BP$$

($\underline{R}^2 = 0.44$; df = 91; $\underline{P} < 0.0001$)

and female WD was best explained by the model:

$$WD = 5.98 + 0.03\ IN + 0.02\ BP - 0.27\ WT$$

($\underline{R}^2 = 0.37$; df = 86; $\underline{P} < 0.0001$)

where PC = pool elevation change, IN = inflow, DI = discharge, BP = barometric pressure, and WT = water temperature.

For the pre-spawn and spawn periods, 5 March to 30 April, male WD was best accounted for by the following model:

$$WD = 108.12 - 0.89\ DY - 28.23\ PC + 3.66\ PR$$

($\underline{R}^2 = 0.50$; df = 60; $\underline{P} < 0.0001$)

and female WD corresponded to the model:

$$WD = 0.87 + 0.07\ IN + 0.04\ BP$$

($\underline{R}^2 = 0.20$; df = 51; $\underline{P} < 0.0045$)

where DY = day of year, and PR = precipitation.

Barometric pressure and inflow appeared in three of these four regression models, and pool change in two; remaining variables occurred in one model only. Variation in sauger movements was not well explained by multiple regression analysis, with $\underline{R}^2 = 0.11$ using all independent variables.

Spawning Habitat

Shallow night-time fish fixes were used as initial electrofishing sites. CPUE ranged from 26 to 68 fish/h through April for one north shore shoal (SHOAL; Figure 1). Electrofishing was only successful 20 to 50 m offshore at a depth of 1 to 2 m. Fyke net CPUE ($fish \cdot net^{-1} \cdot 24\ h^{-1}$) peaked at this site on 15 April, with eight ripe and two spent females; water temperatures were 8.9 °C and 7.8 °C at net set and check times, respectively. Four ripe females were partially-spent; four others were full and freely exuded eggs from the urogenital opening without applying abdominal pressure. On the same day, eight ripe females were collected in nets set on the next down-reservoir north point; however, this area was electrofished through April and only five males were collected on 2 and 8 April. Nets on 6 and 30 April had five "green" and two spent females, respectively. Reservoir pool level and water temperature began to rise 13 April before peak collections (Figure 8).

Four tagged male sauger were found within a 5-m^2 area on 17 April at 0220 hours. Water temperature was 7.8 °C and pool level was approximately 0.6 m above multipurpose elevation (Figure 8); these fish were < 0.6 m deep and < 3 m from shore. This area (FOUR; Figure 1) was electrofished on 26 April at multipurpose pool, resulting in a CPUE of 36 fish/h at > 20 m offshore; no fish were captured inshore. Sauger electrofished at the SHOAL and FOUR sites were all male. Both sites were low-gradient flats. The SHOAL site had a mean depth of 1.8 m, and averaged 3.9 m offshore at 50 m. The FOUR area had a mean depth of 1.6 m and averaged 1.8 m at 50 m. Substrate at the SHOAL site was predominantly pebble and clay/silt, whereas the FOUR site was dominated by pebble and cobble (Figure 9).

DISCUSSION

This study suggests that sauger in Melvern Reservoir exhibit distinct pre-spawn, spawn, and post-spawn activities, including migration to specific spawning grounds. Sauger showed fast and far-reaching movements in March prior to spawning, a behavior similar to extensive upstream spawning migrations by this species in rivers (e.g., Nelson 1969; Fitz and Holbrook 1978; Pitlo 1985; St. John 1990). Although large-scale movements had been anticipated, I hypothesized their direction to be upstream toward the Marais des Cygnes River in search of suitable spawning grounds; however, no tagged sauger were located upstream from the causeway. Prior to existence of the now extensive log jam (Figure 1), some walleye made upstream spring migrations (D. Gabelhouse, Nebraska Fish and Game Commission, personal communication). Downstream from this log jam, the river is a backwater lacking the appreciable current associated with large rivers. Reasons why tagged sauger avoided headwater areas are not known, however

Mississippi River sauger avoid backwater habitats and exclusively occupy areas alongside the main river channel or fast-flowing tributaries of the river (Freiermuth 1987; Pitlo 1992; Siegwarth 1993). Although the log jam is likely a migratory deterrent it is plausible that the slack-water, heavily-silted reservoir headwater may also act as a barrier for sauger seeking hard-bottomed substrate for spawn sites.

In February, sauger were located mostly in either the reservoir mainstem or a large north bay, whereas in March they were broadly distributed in the reservoir. In this study, male and female sauger inhabited different water depths. It is unknown where in the water column tagged fish occurred, but inferences can be made regarding use of shallow and deep water areas. In February and March, both sexes inhabited deep pelagic habitats; association with the mid-upper mainstem region in March appears related to either the LOTER district or the river channel. Reasons for sauger occupying these habitats are unknown, but may be due to prey availability. Sauger have been shown to prey upon gizzard shad (Dorosoma cepedianum) (Vanicek 1964; Minton et al. 1981; McBride and Tarter 1983), which school in pelagic habitats of reservoirs (Matthews et al. 1988). Sauger are known to increase consumption of shad in winter months (McGee et al. 1977; Fitz and Holbrook 1978; Wahl and Nielsen 1985), though McGee et al. (1977) noted sauger switching from threadfin shad (D. petenense) to pelagic freshwater drum (Aplodinotus grunniens) during February in Watts Bar Reservoir, Tennessee. Priegel (1969) reported use of freshwater drum by several size-classes of sauger in Lake Winnabago, and Wahl and Nielsen (1985) found freshwater drum in the stomachs of Ohio River sauger. Though food habits were not analyzed in this study, sauger likely feed on freshwater drum and gizzard shad which both inhabit Melvern Reservoir river channel and LOTER areas during winter.

In April, the majority of tagged sauger exhibited fidelity toward a north shore in the lower reservoir region, where spawning grounds were identified. In contrast to earlier months, males inhabited shallow water of shore habitats, whereas females did not occupy shallow shore areas until mid-April, the period of peak spawning. The pattern observed in Melvern Reservoir was similar to those documented by Nelson (1968), Scott and Crossman (1973), and St. John (1990), where males arrived at spawning grounds first and stayed two to four weeks. Females typically do not appear until later, and stay only long enough to ovulate (< 1 to 3 d) before returning to deeper habitats (Hokanson 1977; St. John 1990).

Sauger dispersed after the spawn, but continued to show some affinity toward the north mid-lower reservoir region in May and June. The SHALE district of this area (Figure 2) may provide a habitat preferred by sauger, however it is uncertain what biotic or abiotic factors might influence this occurrence. In May 1993, tagged males were found in deep pelagic and cove environments, whereas females were located in shallower water of cove and shore habitats. Siegwarth (1993) reported that Mississippi River sauger exhibited extensive downstream post-spawn movements, occupying slack-water areas bordering the main and side channels of the river. The many coves of Melvern Reservoir provide slack-water habitat that may be selected during post-spawn periods. It is unknown why there was differential use of shallow water by sexes during the post-spawn period (Figure 6).

In June, both male and female sauger inhabited shallow areas of coves, shores, and pelagic zones; a few diurnal observations were made in very shallow areas < 1 m, where sauger were continuously moving. Prey availability may again explain why fish were in these localities during the post-spawn period. Spawning of gizzard shad in reservoirs takes place in shallow water of protected bays and inlets (Pflieger 1975), and occurs in Melvern Reservoir from the beginning of May through June (Willis 1987). In June of 1993, schools of young gizzard shad were observed at the surface in many shallow coves, which may have drawn sauger to these areas.

In Melvern Reservoir, there appears to be no distinct relationship between sauger occurrence and turbidity. Throughout the study, one tagged female (#11) inhabited the more turbid upper end of the reservoir (Figure 4), however no tagged sauger were found in the most turbid headwater region; the majority of tagged sauger resided in the less turbid lower regions (Figure 4). Several investigators have noted the presence of sauger in areas of high turbidity (Smith and Snell 1891; Scott and Crossman 1973; Nelson 1978). The decline or lack of sauger populations have been attributed to high water transparencies (Nelson and Walburg 1977; Hickman et al. 1989). In contrast, Crance (1987) reported that sauger have adapted well to reservoirs where Secchi readings of 5 to 10 m are common. Apparently sauger are suited to a variety of water clarities and, even though they are negatively phototaxic, they are active diurnal and nocturnal predators in turbid waters (Ali and Anctil 1968; Swenson 1977). Sauger may have an advantage in perturbed ecosystems where eutrophication and high turbidities commonly occur (Leach et al. 1977; Momot et al. 1977).

River systems are the evolutionary origin of sauger (Balon et al. 1977), and it is likely that spawning sauger in Melvern Reservoir respond to stimuli similar to those found in rivers during the spring. Throughout the study, change of water depth inhabited by male and female sauger was related in part to inflow and barometric pressure; depth occupied by males was also associated with pool elevation change and reservoir discharge, whereas female depths were further explained by water temperature. Sauger moved from deep water in the pre-spawn period to shallower water during the spawn period in April (Figure 6). During this time, water depth inhabited by males was most associated with precipitation, pool elevation change, and day of year, but female depths were best explained by inflow and barometric pressure.

Hydrostatic pressure, measured here by barometric pressure, may be a stimulus governing use of different water column depths. This pressure may signal sauger of environmental events important to their feeding and spawning behavior, such as warming trends or varying light intensities of incoming storm systems (Collette et al. 1977; Ryder 1977). Tesch (1959) suggested that ovulation of pikeperch (Stizostedion lucioperca) is directly stimulated by changes in atmospheric pressure.

Increases in reservoir inflow, pool level, and precipitation may simulate spring flows or flooding of river systems, noted to be associated with spawning behavior in riverine populations of sauger (Nelson 1968; Gebken and Wright 1972; Benson 1973). As a non-guarding open-substrate spawner (Balon et al. 1977), the ability of sauger to respond quickly to fluctuating water regimes may be critical for reproductive success and thus adaptive for this r-selected species, enabling it to exploit flooded areas for spawning. For riverine populations of walleye, Spangler et al. (1977) reported a positive relationship between flow rate and year-class strength, and Pitlo (1989) showed that spawning usually occurs within two weeks of peak river discharges associated with spring floods. Walburg (1972) reported that 80% of the variation in sauger year-class strength in Lewis and Clark Lake, South Dakota, could be explained by reservoir elevation change, exchange rates, and water temperature. In the same lake, Nelson (1968) showed that fluctuations in abundance of 1956-1965 sauger year-classes were closely related to power peaking operations at Fort Randall Dam. In the Tennessee River, Hickman et al. (1989) attributed decreased sauger populations in 1985-1989 to below average night-time flows during the spawning season.

Day of year was considered a variable that indirectly measured day-length, as photoperiod is an important environmental factor in the reproductive cycle of many fishes (Peter 1983; Bye 1984; Stacey 1984). Day of year was a variable that, in concert with precipitation and pool elevation change, helped explain water depth inhabited by male sauger during pre-spawn and spawn periods. Aside from day-length, factors such as lunar phase, water chemistry, and hormone levels also vary with day of year and may trigger male sauger to seek shallower areas for staging and spawning (Bye 1984; Stacey 1984). Intrinsic mechanisms governing sauger spawning migrations are not well understood, but there is evidence that changes in day-length and temperature cycles set limits on the length of the spawning season by affecting ova maturation and viability (Hokanson and Biesinger 1977; Ryder 1977). Percids spawn during periods of rising temperatures that enhance gamete viability, and females migrate toward spawning grounds at temperatures near their lower spawning threshold (Hokanson 1977). Shoreward migrations, especially of females, may be related to the ripening of gonads, with shores providing the warmer temperatures preferred for spawning.

Successful reproduction and survival of sauger have been considered dependent on large river habitats (Nelson 1968) or reservoirs having large rivers flowing into them (Hackney and Holbrook 1978). However, the use of littoral habitat in lacustrine systems for reproduction was demonstrated by Priegel (1969) and in the present study. Spawning activity was observed throughout April in Melvern Reservoir, and was estimated to have peaked in mid-April with water temperatures ranging from 7.2 to 8.3 °C. Evidence supporting this peak are 1) ovulating females, 2) four tagged males within a small area at the same time, and 3) highest electrofishing and fyke net CPUE. Temperatures during this peak were similar to those reported for spawning sauger by Nelson (1968), Priegel (1969), Gebken and Wright (1972), and Siegwarth (1993).

As evidenced by documented natural reproduction in 1992 and observations made here, suitable spawning habitat exists for sauger in Melvern Reservoir. In 1994 and 1995, large spring aggregations of ripe sauger persisted at the SHOAL site (J. Stephen, KDWP, personal communication; personal observation). This area appears to be preferred by spawning sauger over other areas in Melvern Reservoir. Such fidelity can be attributed to four factors. First, suitable spawning substrate (pebble and cobble) is available at the SHOAL area, similar to substrata reported by Fish (1932), Nelson et al. (1967), Priegel (1969), Nelson (1978), Saylor et al. (1983), Pitlo (1985), and Medlin (1990). Second, this spawning ground borders and slightly invades the HITER geologic district, found only in the northern lower reservoir region at higher elevations (Figure 2); substrate characterizing this district is comprised of gravel, pebble, and cobble-sized minerals, all intermixed with clay (Table 2). Third, locations of pre-impoundment commercial gravel quarries close to the SHOAL area (Figure 1) suggest that HITER minerals could have been deposited outside the district's natural range to lower elevations now below multipurpose pool, possibly explaining why pebble and cobble was found more than 50 m offshore. Even though other geologic districts are described as having hard substrates with silt, sand, clay, or gravel (Table 2), I believe that fidelity of spawning sauger to the SHOAL site is an effect of the HITER district, as a reflection of past quarrying activities and/or wave action "pulling" substrate inside the multipurpose boundary.

Though not mentioned as spawning substrate in literature reports, I found substantial amounts of clay at the spawning grounds, which could be important in egg viability and larvae survival. Swenson (1977) reported that red-clay turbidity and inshore walleye densities in Lake Superior were highly correlated, but was unable to statistically attribute the association with feeding behavior. Sauger may select spawning grounds with clay because of related turbidities that reduce excessive egg "clumping" caused by their adhesiveness, thereby minimizing suffocation and allowing proper development (Scott and Crossman 1973). Clay may offer a colloidal medium for food required by larval sauger (e.g., copepods, rotifers, cladocerans), or provide optimal chemistry for egg development at the sediment-water interface (Auer and Auer 1990). However, the significance of clay to spawn site selection or successful sauger reproduction is not understood, and studies on chemical suitability of substrates for proper egg development should be conducted. Moreover, it is unknown whether sauger return to natal areas for spawning, as do many salmonids. Factors affecting spawn site selection and hatching success should be studied. Data explaining such variables would be valuable for identifying, creating, or augmenting critical spawning grounds for this species.

Maintaining adequate pool levels is likely a critical determinant in maximizing sauger reproduction and recruitment in Melvern Reservoir. If spawning occurred at the FOUR area on 17 April, eggs were likely desiccated the following day due to falling pool levels (Figure 8). Benson (1973) reported that prior to 1966, sauger in the Missouri River between Lake Francis Case and Lewis and Clark Lake spawned during maximum high water power release periods, but eggs became exposed within 12 hours during minimum low water power release intervals. When these operations were eliminated during spawning, young sauger abundance was increased tenfold (Benson 1973). Restricted downstream discharge optimizing sauger spawning ground availability during periods of peak spawning should be implemented.

Sauger in reservoirs provide populations of sportfish and, in lacustrine systems like Melvern Reservoir, may allow easily-accessed brood fish for artificial propagation; in contrast, large aggregations of male sauger were notably absent in river spawning studies (Pitlo 1992). Therefore, confined systems such as Melvern Reservoir may prove valuable as in situ genotype reserves for conservation of riverine populations, maintaining genetic variation and long-term stability (Nelson and Soule 1987). Sauger are endemic to large central North American rivers and may offer a percid that is best adapted to high-fluctuating water regimes characteristic of altered ecosystems, such as impounded river drainages. Additionally, the sauger is an important host to glochidia of at least 12 mussel species (Hart and Fuller 1974; Appendix D); as a prolific mussel disperser it should be considered integral when managing for ecosystem diversity. Where local populations of sauger have been extirpated, management for these indigenous diurnal and nocturnal predators that are adaptable to a range of turbidities, could be enhanced by construction of littoral artificial pebble/cobble reefs. As applied here, a GIS approach to analyzing distribution of organisms in synchrony with historical watershed spatial data can be enlightening when studying reservoir ecology.

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TABLE 1. - Sex, length, weight, number of locations, and fate of tagged sauger tracked 5 February to 21 June 1993 in Melvern Reservoir, Kansas. Abbreviations for fate of individuals are U, unknown; UM, unknown mortality; FM, fishing mortality; and HB, harvested for brood stock.

Tagged Fish (Sex, No.)	Total length (mm)	Weight (g)	Relative Weight (Wr)[a]	Number of times located	Fate of fish	
					Date	Outcome
♂ 1	431	756	102	11		U
♂ 2	416	582	88	16	Apr 8, 1994	HB
♂ 3	436	668	87	10	Apr 16-25, 1993	UM
♂ 4	403	538	90	11	May 16, 1993	FM
♂ 5	400	500	85	13		U
♂ 6	416	588	88	20		U
♂ 7	394	479	86	6	Apr 17-25, 1993	UM
♂ 8	377	456	94	19		U

TABLE 1. - Continued.

Tagged Fish (Sex, No.)	Total length (mm)	Weight (g)	Relative Weight $(Wr)^a$	Number of times located	Fate of fish	
					Date	Outcome
♂ 9	383	481	94	12		U
♂ 10	379	460	93	16		U
♀ 11	456	918	105	16		U
♀ 12	429	744	102	10	Jun 2-10, 1993	UM
♀ 13	477	1017	99	14	May 18, 1993	FM
♀ 14	440	768	97	17	Jun 10-15, 1993	UM
♀ 15	427	714	99	15	Jun 10-15, 1993	UM
♀ 16	436	758	98	15		U
♀ 17	436	810	105	15	Apr 3, 1995	HB
♀ 18	422	692	100	--	< Feb, 1993	UM

TABLE 1. - Continued.

Tagged Fish (Sex, No.)	Total length (mm)	Weight (g)	Relative Weight (Wr)[a]	Number of times located	Fate of fish	
					Date	Outcome
♀ 19	430	762	103	14		U
♀ 20	406	668	109	11	May 26, 1993	FM

[a]Relative weight (Wr; Anderson and Gutreuter 1983) derived from sauger standard weight (Ws; Guy et al. 1990).

TABLE 2. - Character and vertical position of five geologic districts in the Melvern Reservoir watershed, Kansas (modified from O'Conner et al. 1955). District titles are ALLUV, stream valley alluvium; LOTER, low terrace complex; SHALE, Tecumseh shale; HITER high terrace complex; and LIME, Topeka limestone.

Geologic District	Description
ALLUV	Deposits of stream-laid gravel, sand, silt, and clay, comprising the Marais des Cygnes River Valley flood plain; lowest district elevation.
LOTER	Deposits similar to ALLUV; present intermittently and adjacent to ALLUV but higher.
SHALE	Shale complex of clay, silt, and sand, intermixed with sandy silty limestone strata; above LOTER and ALLUV elevations.

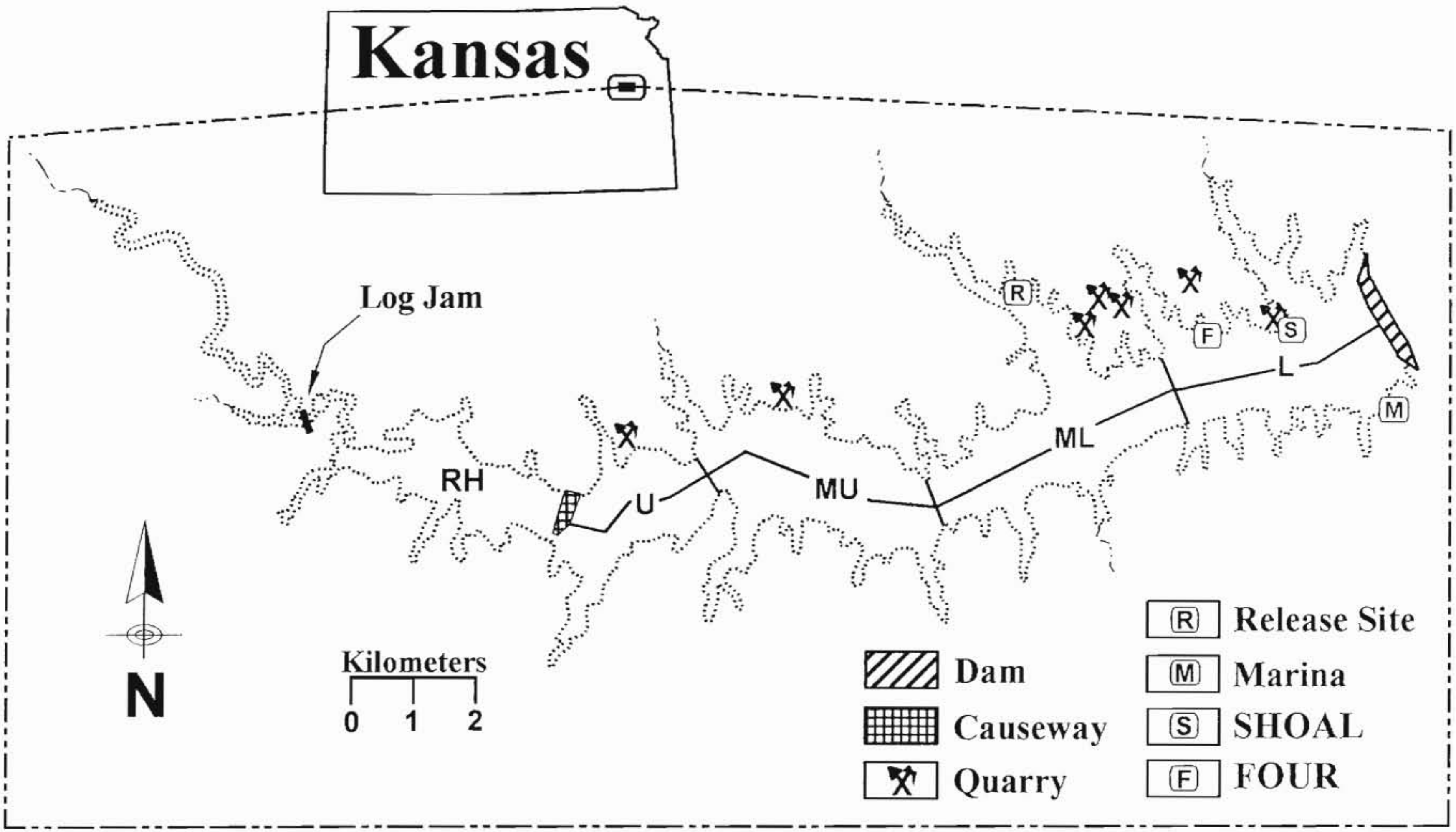
TABLE 2. - Continued.

Geologic District	Description
HITER	Deposits of sand, gravel, chert (ranging up to about 30 cm in diameter), larger calcareous material variable in size (centimeters to meters), matrix interstices filled with brownish-red clay; 18-49 m above ALLUV elevation.
LIME	Large fractured limestone bedrock, intermixed with clay-type shale; elevation similar to HITER.

TABLE 3. - Proportion of day-time MDI (upper diagonal) and depth (lower diagonal) means, within a month, significantly different from those of other months for Melvern Reservoir sauger tracked February through June, 1993. Sample size is given in parentheses; due to sex effect for depth, proportions are presented separately (♂/♀). Standard Bonferroni criterion for tablewide significance is _P_ < 0.003.

	Feb (7)	Mar (72)	Apr (34)	May (31)	Jun (26)
Feb (7/2)	-	0.00	0.00	0.00	0.00
Mar (43/36)	0.00/0.00	-	0.20	0.20	0.10
Apr (18/16)	0.67/0.00	0.67/0.00	-	0.00	0.00
May (10/21)	0.00/0.00	0.07/0.27	0.00/0.00	-	0.00
Jun (14/12)	1.00/0.00	0.80/0.00	0.00/0.00	0.08/0.00	-

FIGURE 1. - Melvern Reservoir, Kansas, showing landmarks and region abbreviations: RH, reservoir headwaters; U, upper; MU, mid-upper; ML, mid-lower; and L, lower.



Kansas
Log Jam
RH
U
MU
ML
L
R
F
S
M
N
Kilometers
0 1 2
Dam
Causeway
Quarry
Release Site
Marina
SHOAL
FOUR

FIGURE 2. - Location of geologic districts mapped in the Melvern Reservoir watershed, Kansas. District titles modified from O'Conner et al. (1955) are ALLUV, stream valley alluvium; LOTER, low terrace complex; SHALE, Tecumseh shale; HITER high terrace complex; and LIME, Topeka limestone. The Marais des Cygnes River channel and reservoir boundary at multipurpose pool are abbreviated RIVER and BOUND, respectively. Polygon cropping denoted with the symbol X.

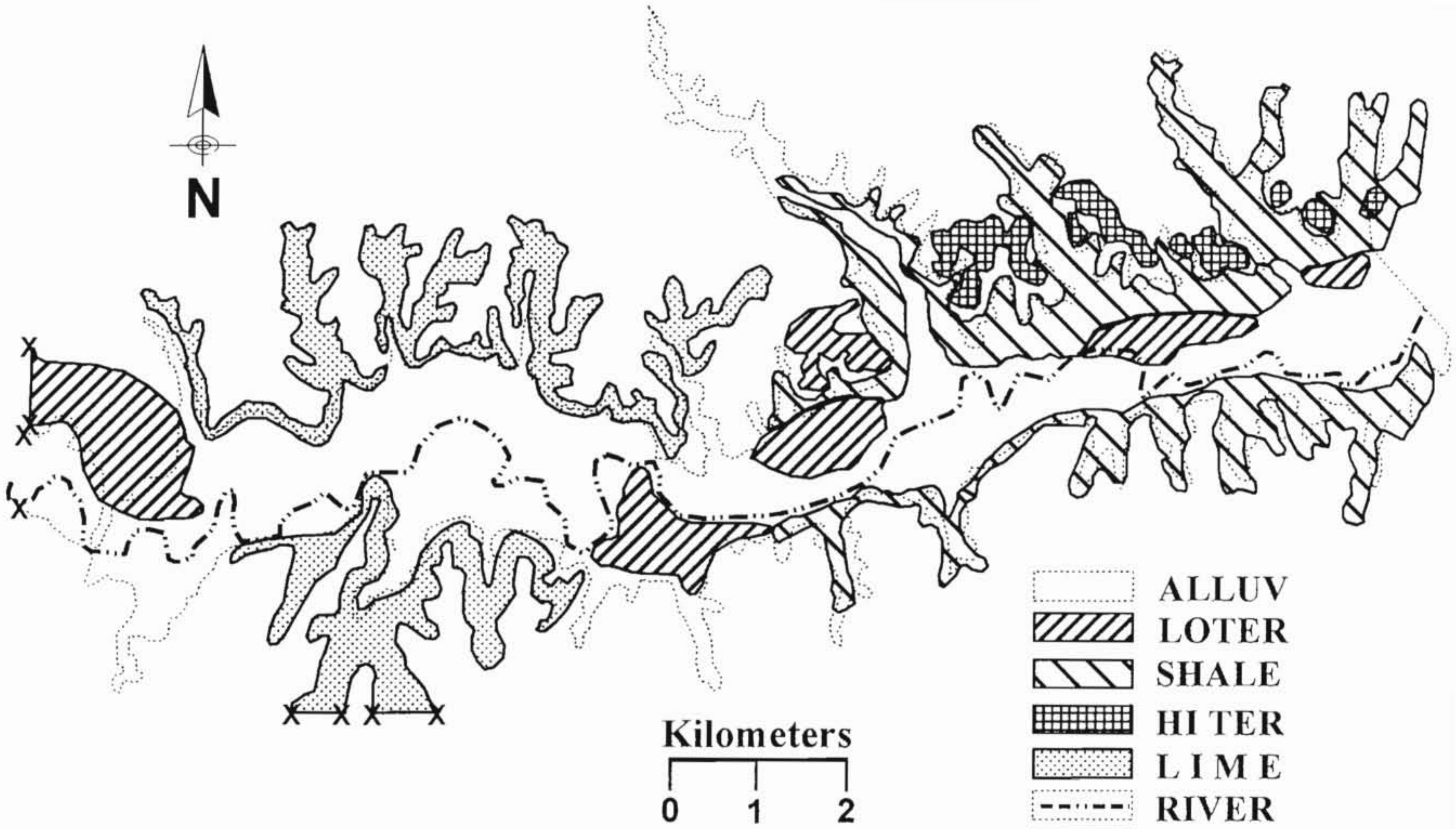
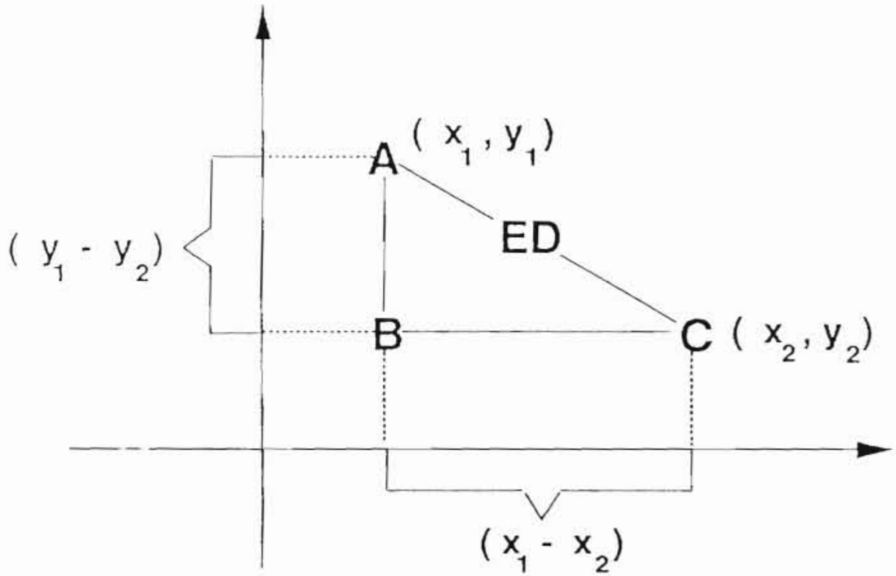

N
Kilometers
0
1
2
ALLUV
LOTER
SHALE
HI TER
L I M E
RIVER
BOUND

FIGURE 3. - Minimum Displacement Index (MDI) derived from the Pythagorean theorem's Euclidian distance (ED) divided by time expiration (TE), representing the minimum distance moved by an organism over a given time interval. Symbols describing ED are: (x_1, y_1) and (x_2, y_2) = first and second Cartesian coordinate pairs, representing two consecutive organism fixes (A and C).

Minimum Displacement Index (MDI):
MDI = ED / TE

ED = Euclidian Distance



$$(AC)^2 = (AB)^2 + (BC)^2$$

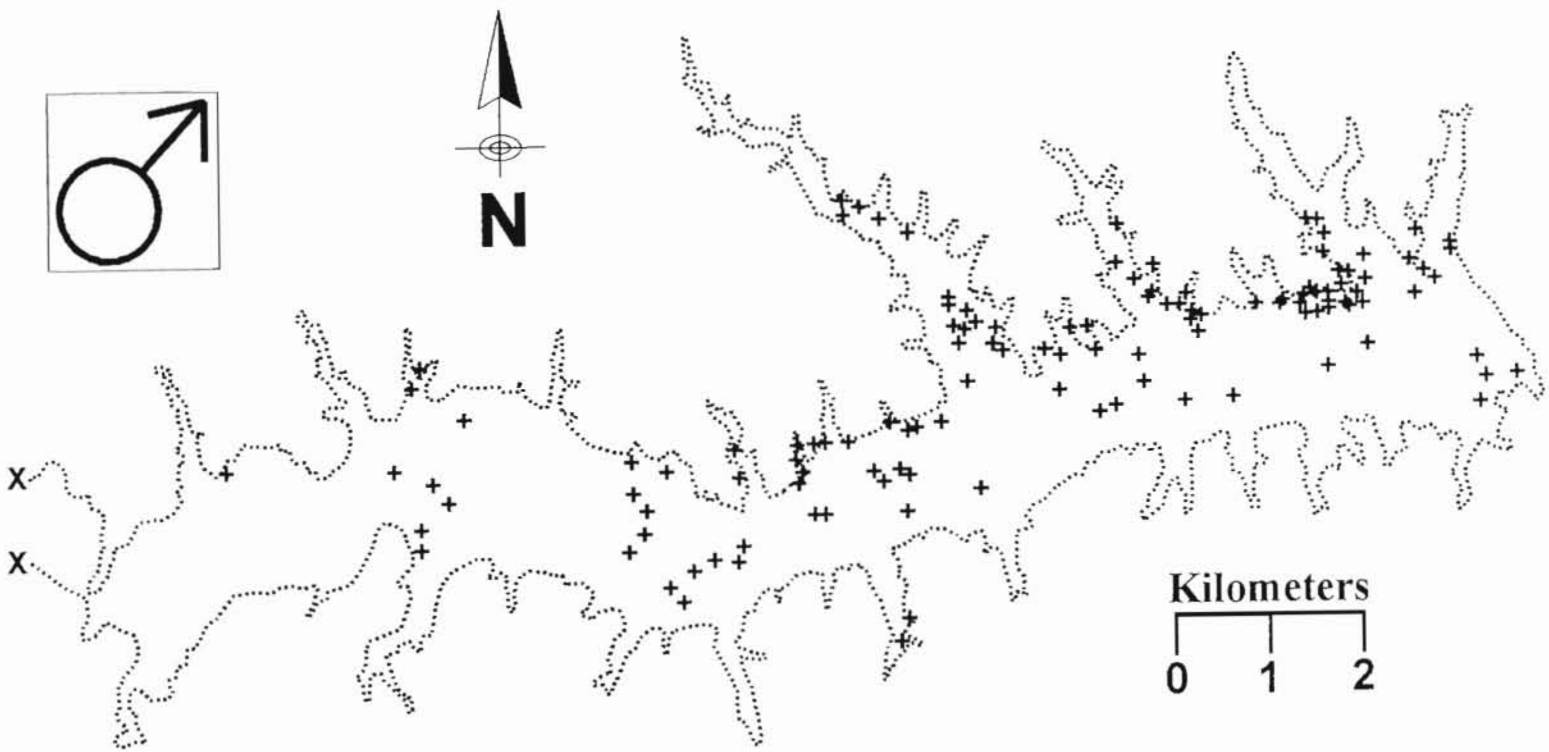
$$(AC)^2 = (y_1 - y_2)^2 + (x_2 - x_1)^2$$

$$AC = \sqrt{(y_1 - y_2)^2 + (x_1 - x_2)^2}$$

$$AC = ED$$

TE = Time Expiration

FIGURE 4. - Locations of male and female sauger found by ultrasonic telemetry in Melvern Reservoir, Kansas, from 5 February through 21 June, 1993; ♂ N=131, ♀ N=123. Polygon cropping denoted with the symbol X.


N
X
X
Kilometers
0
1
2

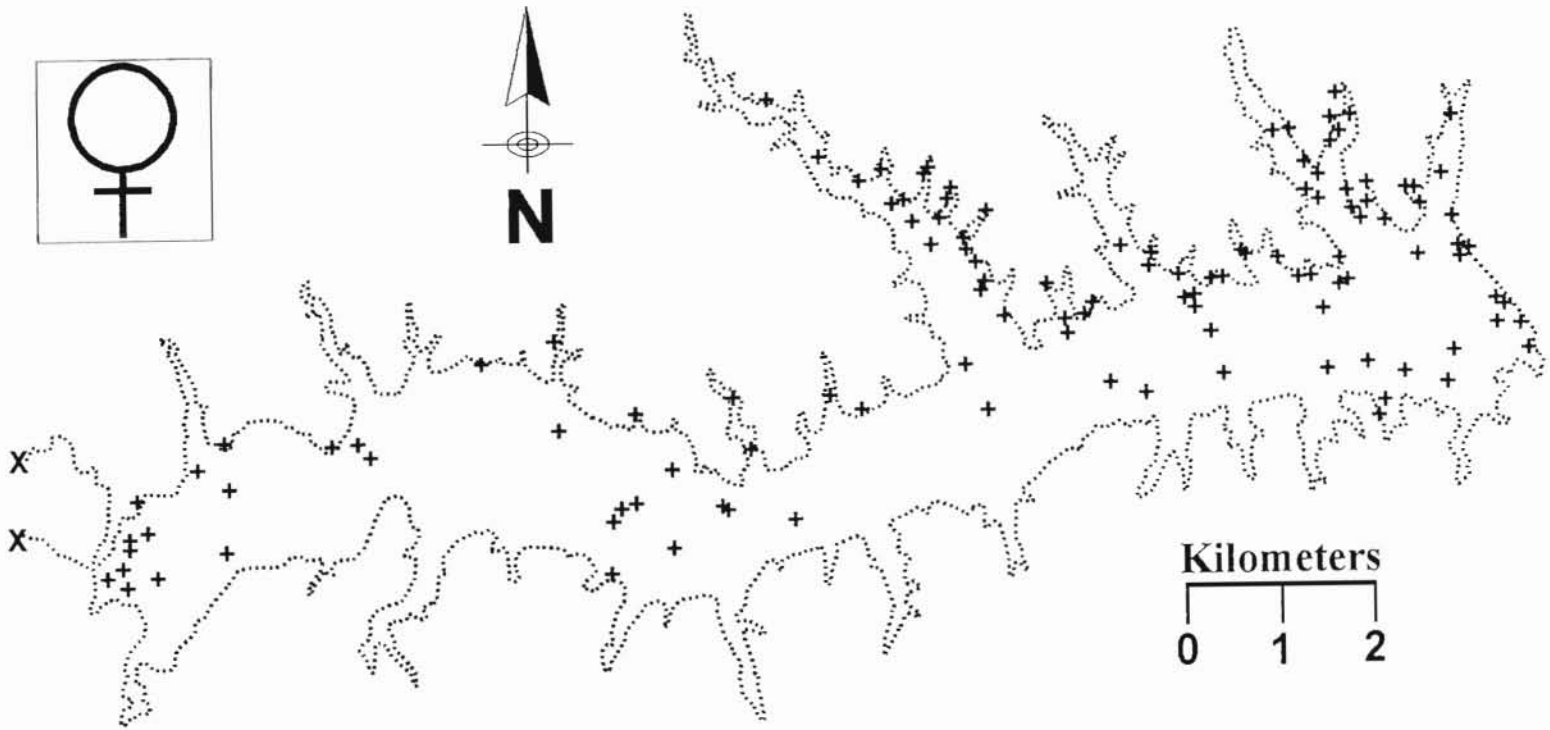
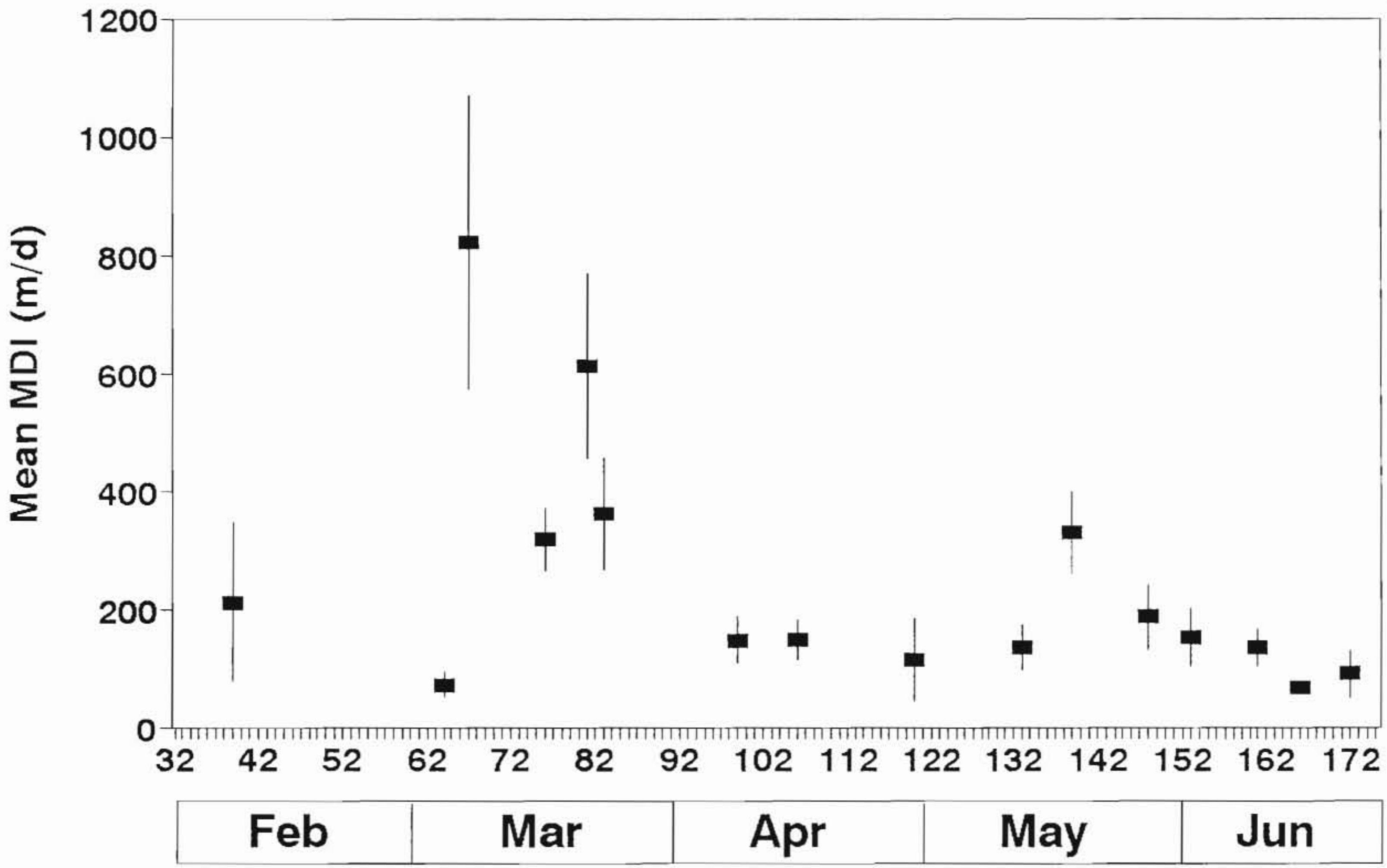
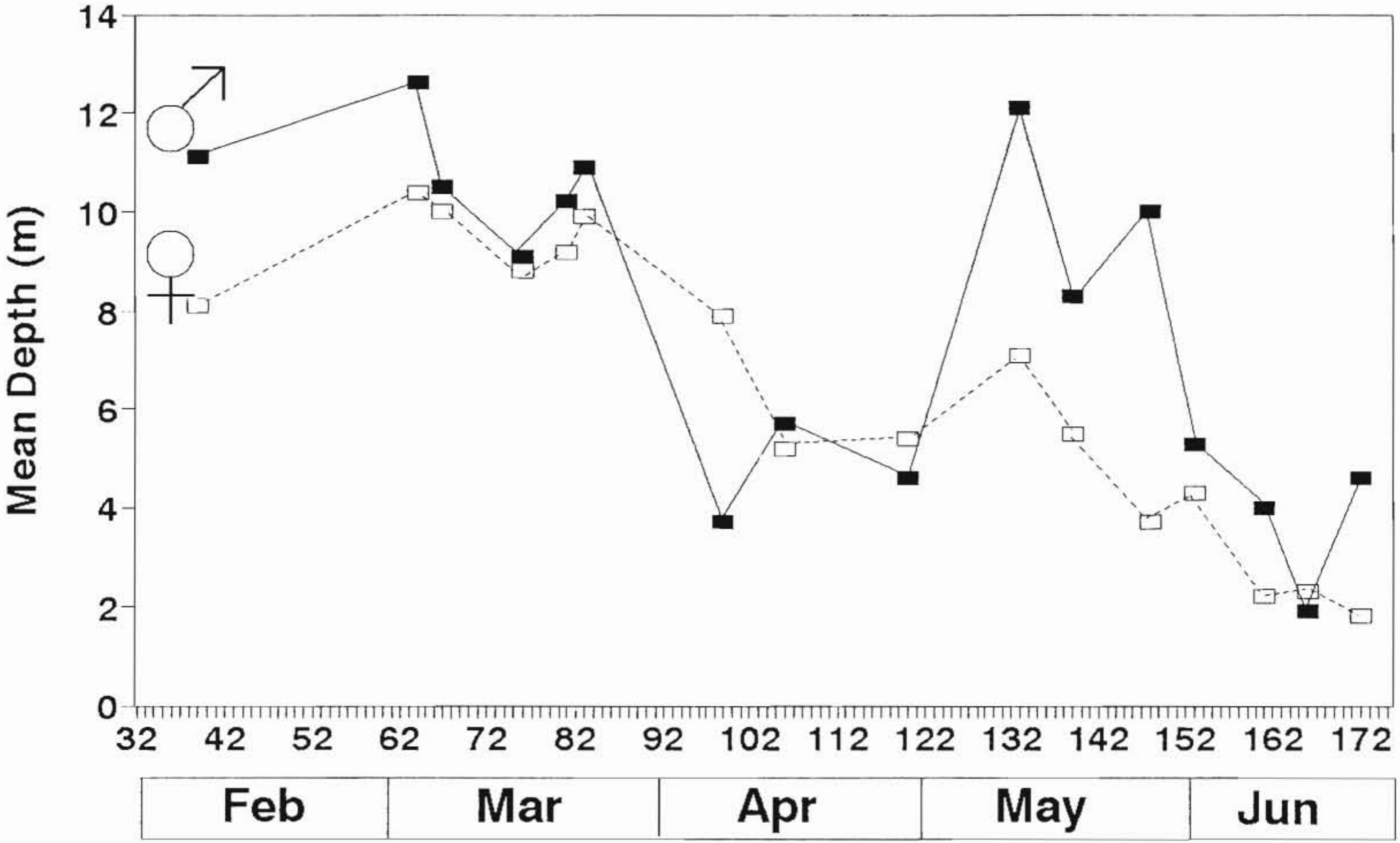

N
Kilometers
0
1
2
X
X

FIGURE 5. - Mean Minimum Displacement Index (MDI) exhibited by ultrasonic-tagged sauger in Melvern Reservoir, Kansas, from 5 February through 21 June, 1993; x-axis represents day of year.



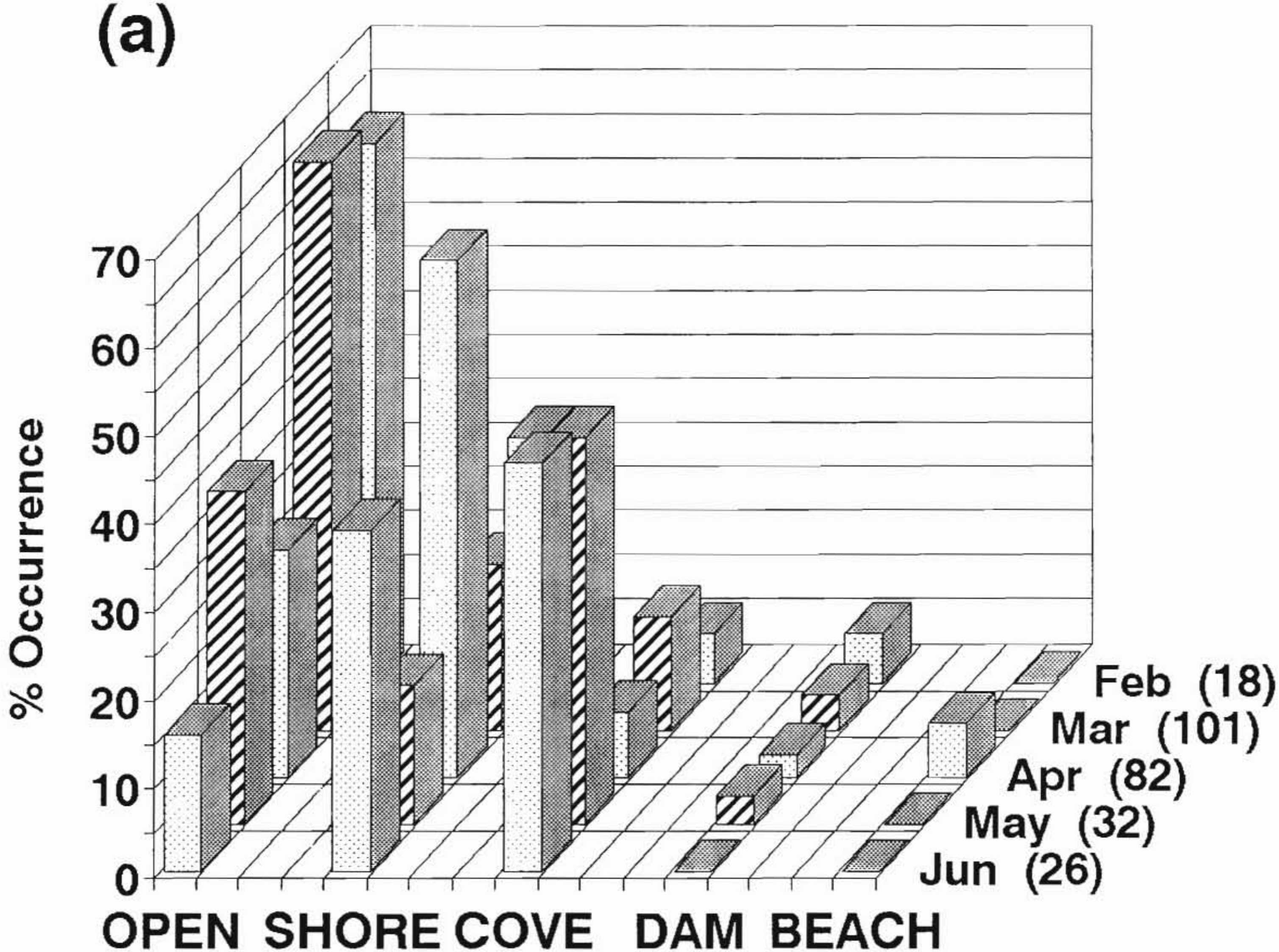
Mean MDI (m/d)
1200
1000
800
600
400
200
0
32
42
52
62
72
82
92
102
112
122
132
142
152
162
172
Feb
Mar
Apr
May
Jun

FIGURE 6. - Mean depth of water inhabited by male and female ultrasonic-tagged sauger in Melvern Reservoir, Kansas, from 5 February through 21 June, 1993; x-axis represents day of year.



Mean Depth (m)
14
12
10
8
6
4
2
0
32
42
52
62
72
82
92
102
112
122
132
142
152
162
172
Feb
Mar
Apr
May
Jun

FIGURE 7. - Habitat (a) and reservoir regions (b) occupied by ultrasonic-tagged sauger in Melvern Reservoir, Kansas, from 5 February through 21 June, 1993, with sample size in parentheses; each region divided into south (S) and (N) halves.


(a)
% Occurrence
0
10
20
30
40
50
60
70
OPEN
SHORE
COVE
DAM
BEACH
Feb (18)
Mar (101)
Apr (82)
May (32)
Jun (26)

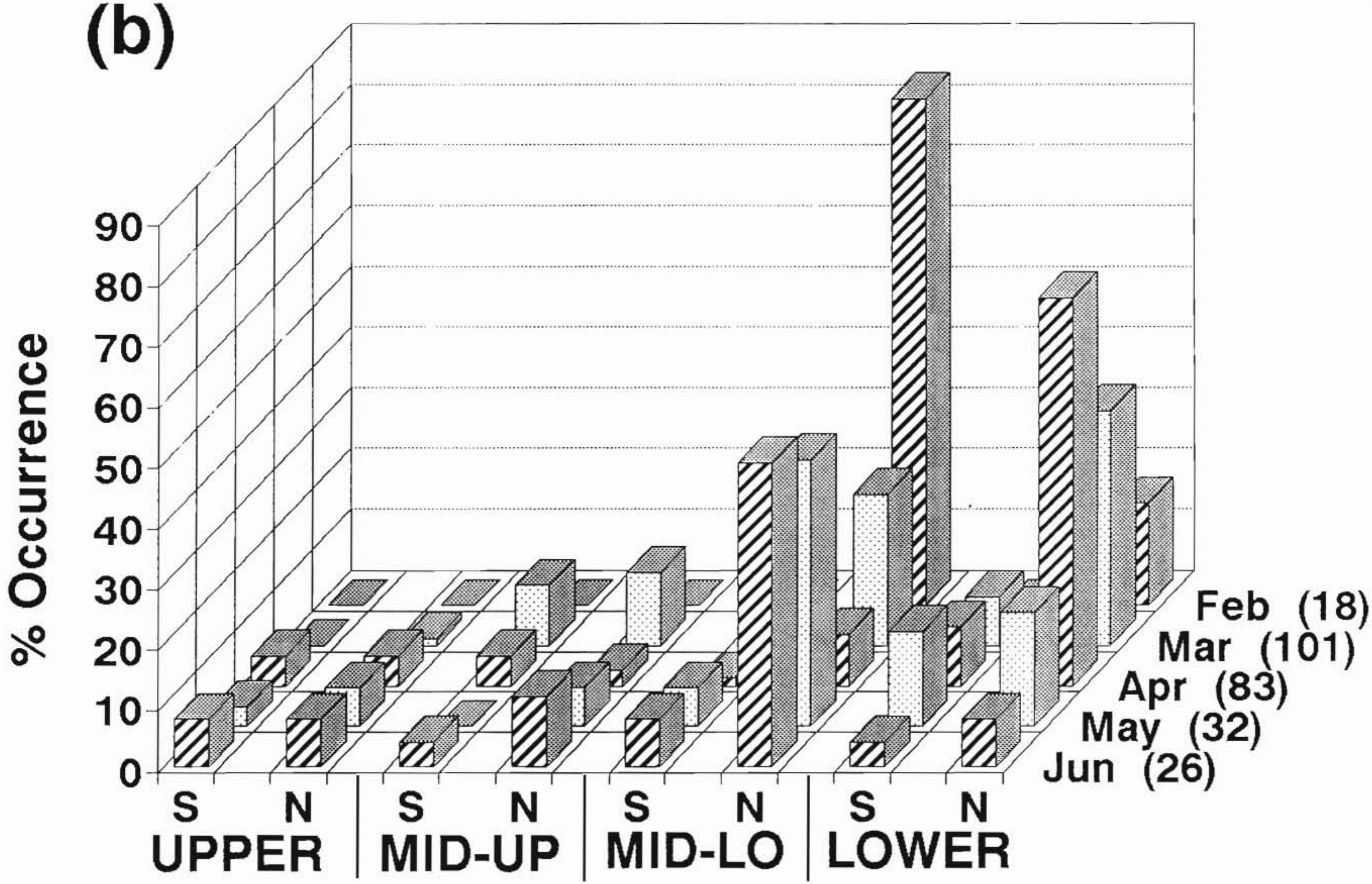
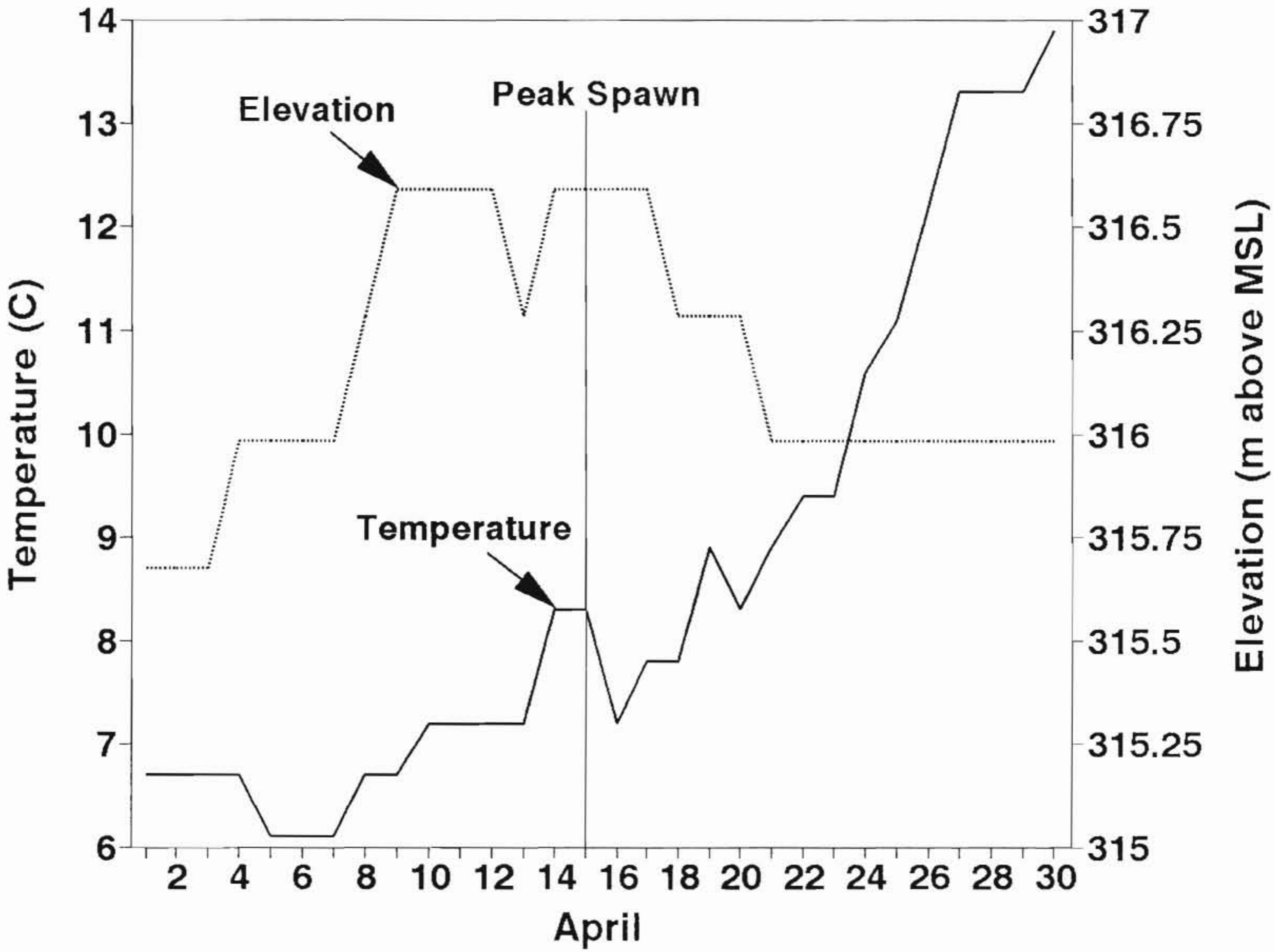
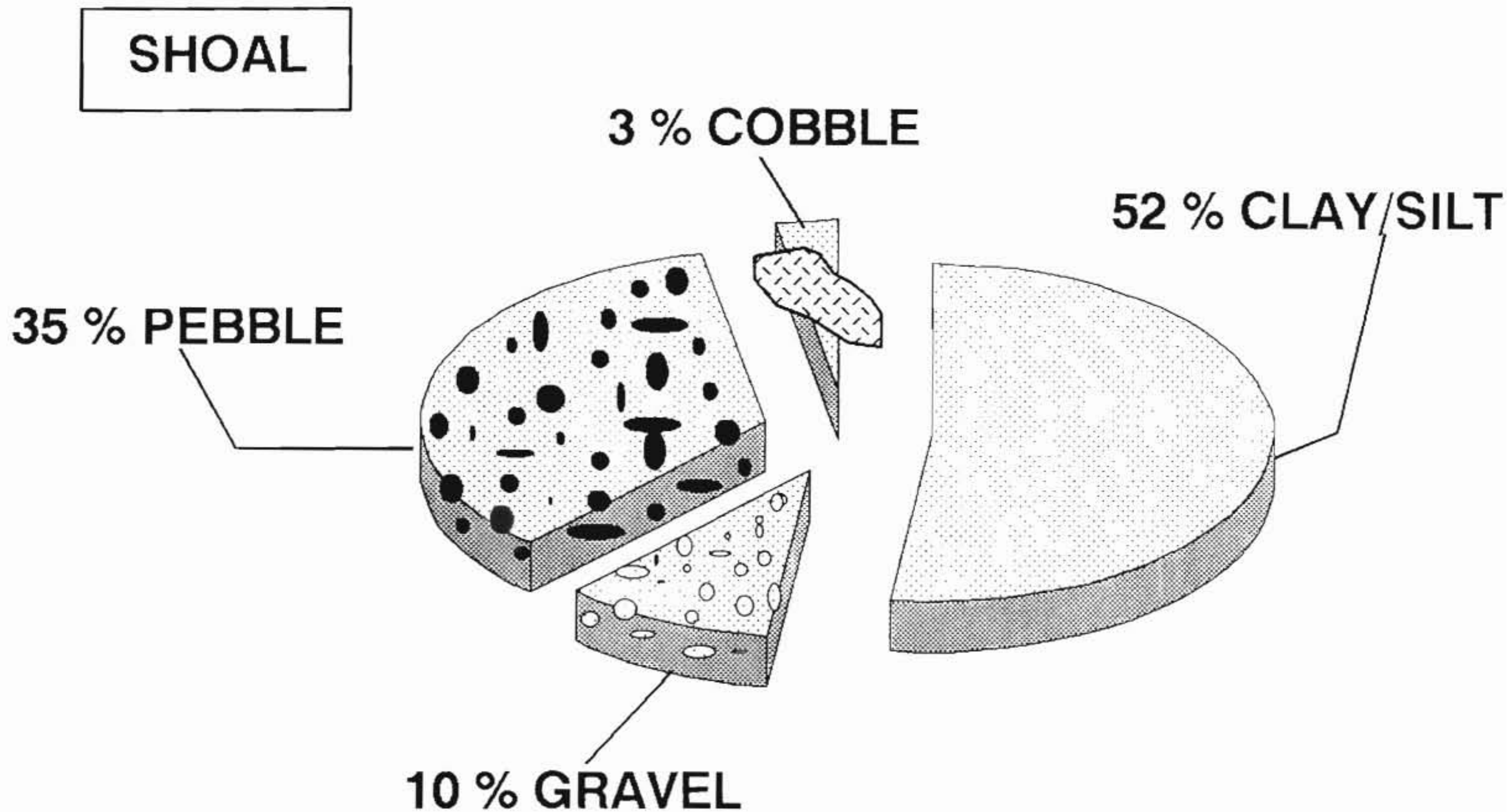

(b)
% Occurrence
0
10
20
30
40
50
60
70
80
90
Feb (18)
Mar (101)
Apr (83)
May (32)
Jun (26)
S
N
S
N
S
N
S
N
UPPER
MID-UP
MID-LO
LOWER

FIGURE 8. - Temperature and reservoir elevation (m above mean sea level; MSL) of Melvern Reservoir, Kansas, during April 1993. Vertical line represents date of estimated peak in spawning sauger activity.

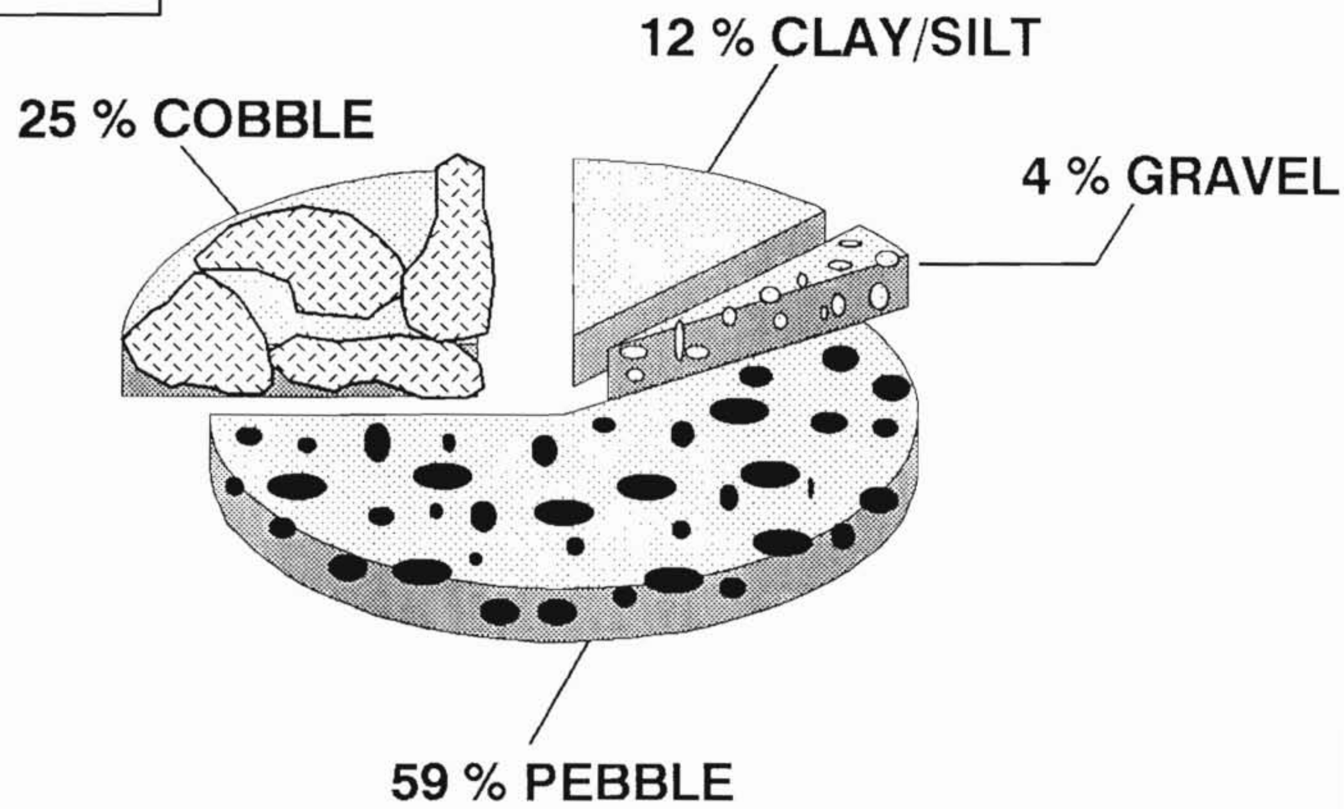


Peak Spawn
Elevation
Temperature
Temperature (C)
Elevation (m above MSL)
April
14
13
12
11
10
9
8
7
6
317
316.75
316.5
316.25
316
315.75
315.5
315.25
315
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

FIGURE 9. - Substrate composition for the two spawning grounds found near Melvern State Park in Melvern Reservoir, Kansas, in the spring of 1993.


SHOAL
3 % COBBLE
52 % CLAY/SILT
35 % PEBBLE
10 % GRAVEL

FOUR



APPENDIX A

ATTENTION WALLEYE AND SAUGER ANGLERS

Sauger were stocked in Melvern Reservoir to provide a source of male fish that could be hybridized with female walleye (at Milford Fish Hatchery) to produce saugeye for lakes and impoundments statewide.

Attempts to capture male sauger in the spring of 1992 were unsuccessful. To locate sauger during the spring, the Kansas Department of Wildlife and Parks has contracted Emporia State University to conduct a sauger tracking study using ultrasonic telemetry. Jay Jeffrey, a graduate student at ESU, has implanted transmitters in 20 sauger.

A fish with a transmitter can be identified by suture marks on the belly and a hole punched in the soft dorsal fin. Ideally, we want fish with transmitters to remain in the reservoir for the duration of the study (until December 1993), so performing catch and release of these implanted sauger would be desirable. **If you harvest a sauger that contains a transmitter, please contact the Kansas Department of Wildlife and Parks research office, Emporia (316-342-0658).**

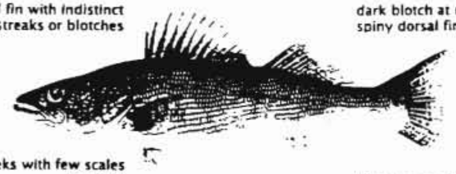
If you have any questions related to the study itself, you can contact Jay Jeffrey, Division of Biological Sciences, Emporia State University, 316-341-5453.

Identification of Walleye, Sauger, and Saugeye

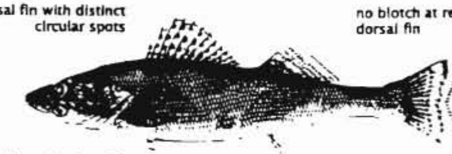
The Kansas Department of Wildlife and Parks has experimentally stocked sauger and saugeye (a hybrid of the walleye and sauger) in federal reservoirs where walleye have not flourished. The sauger is native to large rivers like the Kansas and Missouri. Both sauger and saugeye are better adapted to high flow and turbid water than the walleye; saugeye establish fishable populations below impoundments when flushed. Saugeye have also been stocked as an additional predator in small lakes with stunted crappie.

It is important that anglers be able to identify what type of perch (the family of fishes that includes walleye and sauger) they catch because length limits on walleye, sauger, and saugeye can differ in a given body of water. This poster portrays the key characteristics needed to identify these three fish.

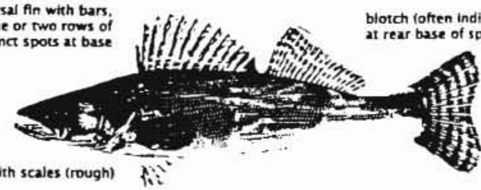
WALLEYE



SAUGER



SAUGEYE (hybrid)



KANSAS WILDLIFE & PARKS

Artwork by Joseph R. Tomelleri

APPENDIX B

Appendix B. - Day and night-time tracking data for sauger in Melvern Reservoir during 5 February through 21 June 1993. Designations for heading codes are: A, fish number; B, fish sex, 1=male, 2=female; C, month; D, day of year; E, time; F, easting (UTM); G, northing (UTM); H, Euclidian distance (m); I, Minimum Displacement Index (MDI; m/d); J, water depth; K, region; L, habitat; M, water temperature; N, reservoir discharge; O, reservoir inflow; P, reservoir elevation; Q, reservoir elevation change; R, precipitation; S, air temperature; T, wind; and U, barometric pressure. Period denotes missing value.

Day-time Tracking

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	1	2	36	1704	258006	4264782	.	.	.	.	.	.	24.9	4.9	316.1	0.61	0.15	1.83	14.00	278
1	1	2	39	1222	258066	4264809	66	22	8.2	3	1	3.3	12.8	8.7	316.0	0.12	0.00	3.67	14.64	203
1	1	3	64	1502	257781	4264297	586	23	12.2	3	1	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
1	1	3	67	1300	257670	4264367	131	44	9.1	3	1	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
1	1	3	83	1519	262320	4266520	207	13	14.4	1	4	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
1	1	4	99	1134	260850	4265925	270	17	5.2	1	2	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
2	1	2	36	1720	259463	4265523	.	.	.	3	3	.	24.9	4.9	316.1	0.61	0.15	1.83	14.00	278
2	1	2	39	1436	262342	4266286	2978	993	9.8	3	1	3.3	12.8	8.7	316.0	0.12	0.00	3.67	14.64	203
2	1	3	64	1100	262775	4266490	479	19	12.5	1	1	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
2	1	3	67	1246	257212	4264645	5861	1954	7.0	3	3	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
2	1	3	76	1115	251568	4264349	5652	628	2.4	7	2	4.4	20.0	3.1	315.3	0.34	0.00	-0.61	13.84	222
2	1	3	81	1100	262800	4266779	11492	2298	10.0	1	4	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
2	1	3	83	1455	261797	4266893	395	198	5.1	1	5	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
2	1	4	99	1253	262132	4266141	436	27	2.6	1	2	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
2	1	4	106	1415	262034	4266009	164	23	5.8	1	2	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
2	1	4	120	1027	262195	4266127	200	14	5.3	1	2	13.9	4.9	9.6	316.0	0.16	2.77	11.44	11.26	88
2	1	6	153	1120	256325	4264577	6071	184	1.6	3	3	20.0	49.1	2.1	316.5	0.77	1.27	16.17	13.84	166
2	1	6	161	1100	257011	4264600	686	86	1.6	3	3	21.1	22.5	11.6	316.2	0.13	5.21	17.28	11.26	78
2	1	6	166	1310	256975	4264382	221	44	1.8	3	2	23.3	14.2	5.9	316.0	0.18	2.95	20.06	9.17	125
2	1	6	172	1033	256950	4264275	110	18	0.8	3	2	23.9	14.2	8.7	316.0	0.13	1.02	20.78	14.48	141
3	1	2	39	1406	260258	4265307	.	.	15.8	1	1	3.3	12.8	8.7	316.0	0.12	0.00	3.67	14.64	203

3	1	3	64	1233	260656	4265114	442	18	14.3	2	1	2.8	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
3	1	3	67	1142	256439	4263627	4471	1490	10.1	6	1	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
3	1	3	76	1150	253400	4263636	3039	338	7.6	6	4	4.4	20.0	3.1	315.3	0.34	0.00	-0.61	13.84	222
3	1	3	81	1712	253649	4264045	479	96	6.7	6	1	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
3	1	3	83	1045	253771	4264912	858	429	7.2	5	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
3	1	4	99	1225	261860	4266175	662	41	3.5	1	2	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
3	1	4	106	1235	262827	4266152	967	138	19.2	1	1	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
4	1	2	36	1636	258546	4265961	.	.	.	3	4	.	24.9	4.9	316.1	0.61	0.15	1.83	14.00	278
4	1	3	64	1417	258576	4265301	661	24	14.0	3	4	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
4	1	3	67	1406	258453	4265809	523	174	11.9	3	4	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
4	1	3	81	1433	259335	4265591	909	65	6.1	3	2	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
4	1	3	83	1329	259472	4265209	457	229	11.6	3	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
4	1	4	99	1110	260350	4266175	1897	119	1.2	1	5	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
4	1	4	106	1513	260746	4265896	484	69	3.4	1	2	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
5	1	2	39	1500	263155	4266566	.	.	11.3	1	9	3.3	12.8	8.7	316.0	0.12	0.00	3.67	14.64	203
5	1	3	64	1130	262995	4266299	311	12	14.6	1	1	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
5	1	3	67	1616	262905	4266375	118	39	11.6	1	1	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
5	1	3	76	1529	258403	4265995	4518	502	9.8	3	4	4.4	20.0	3.1	315.3	0.34	0.00	-0.61	13.84	222
5	1	3	81	1345	260003	4266396	1649	330	9.9	1	4	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
5	1	4	99	1213	261915	4266149	2024	112	3.0	1	2	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
5	1	4	106	1306	263501	4265355	219	31	2.5	2	2	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
5	1	5	139	1527	255357	4264466	8192	248	11.6	5	2	17.8	21.4	22.8	318.4	0.15	2.03	13.39	10.14	130
5	1	6	161	1047	255383	4264129	338	15	8.4	5	1	21.1	22.5	11.6	316.2	0.13	5.21	17.28	11.26	78
5	1	6	172	1053	257820	4264875	2549	232	5.6	3	2	23.9	14.2	8.7	316.0	0.13	1.02	20.78	14.48	141
6	1	2	36	1530	258805	4265648	.	.	.	.	.	.	24.9	4.9	316.1	0.61	0.15	1.83	14.00	278
6	1	2	39	1106	258919	4265607	121	40	9.8	3	5	3.3	12.8	8.7	316.0	0.12	0.00	3.67	14.64	203
6	1	3	64	1537	257229	4263972	2351	94	12.5	4	1	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
6	1	3	67	1226	257130	4263964	99	33	10.0	4	1	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151

6	1	3	76	1432	260028	4265065	3100	344	13.6	4	1	4.4	20.0	3.1	315.3	0.34	0.00	-0.61	13.84	222
6	1	3	81	1301	262022	4265462	2033	407	20.7	2	1	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
6	1	3	83	1556	262386	4265710	440	220	18.7	1	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
6	1	4	106	1428	261986	4266150	2076	90	3.4	1	2	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
6	1	4	120	1036	261796	4265962	6359	454	4.4	1	2	13.9	4.9	9.6	316.0	0.16	2.77	11.44	11.26	88
6	1	5	133	1248	257973	4266698	3893	299	8.7	3	4	16.7	4.9	135.5	318.7	2.55	12.29	14.83	10.62	103
6	1	5	139	1105	261327	4266040	3418	570	12.3	1	1	17.8	21.4	22.8	318.4	0.15	2.03	13.39	10.14	130
6	1	5	148	1337	258033	4264362	3697	411	13.2	4	1	18.9	56.6	2.7	317.1	0.89	0.33	14.28	11.91	155
6	1	6	153	1407	255654	4264341	2379	476	11.3	5	1	20.0	49.1	2.1	316.5	0.77	1.27	16.17	13.84	166
6	1	6	161	1030	253490	4264276	2165	271	7.0	6	1	21.1	22.5	11.6	316.2	0.13	5.21	17.28	11.26	78
6	1	6	172	1013	253382	4265375	1104	100	7.5	5	3	23.9	14.2	8.7	316.0	0.13	1.02	20.78	14.48	141
7	1	3	64	1525	257928	4264380	.	.	13.1	3	1	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
7	1	3	76	1220	256106	4263536	2008	167	8.8	6	1	4.4	20.0	3.1	315.3	0.34	0.00	-0.61	13.84	222
7	1	3	81	1600	255732	4263279	454	91	7.3	6	1	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
7	1	3	83	1212	256366	4263504	673	337	7.4	6	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
8	1	2	36	1509	258494	4265644	.	.	.	.	.	.	24.9	4.9	316.1	0.61	0.15	1.83	14.00	278
8	1	2	39	1305	258318	4264909	756	252	11.9	3	1	3.3	12.8	8.7	316.0	0.12	0.00	3.67	14.64	203
8	1	3	64	1626	253400	4263777	5047	202	6.1	6	4	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
8	1	3	67	1500	261550	4266048	8460	2820	10.7	1	1	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
8	1	3	76	1700	263445	4265122	2109	234	10.4	2	1	4.4	20.0	3.1	315.3	0.34	0.00	-0.61	13.84	222
8	1	3	81	1330	260217	4265549	3256	651	9.6	1	1	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
8	1	3	83	1344	260169	4266262	227	114	10.4	1	4	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
8	1	4	99	1145	260750	4265950	1401	88	4.0	1	2	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
8	1	4	106	1524	260795	4265763	192	27	5.2	1	2	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
8	1	4	120	1043	261894	4265940	418	30	4.1	1	2	13.9	4.9	9.6	316.0	0.16	2.77	11.44	11.26	88
8	1	5	133	1300	257725	4266825	4262	328	7.3	3	4	16.7	4.9	135.5	318.7	2.55	12.29	14.83	10.62	103
8	1	5	139	1414	257300	4266975	451	75	3.4	3	5	17.8	21.4	22.8	318.4	0.15	2.03	13.39	10.14	130
8	1	6	161	1411	258050	4263000	4045	184	0.6	4	6	21.1	22.5	11.6	316.2	0.13	5.21	17.28	11.26	78

8	1	6	166	1414	257981	4262728	281	56	0.9	4	6	23.3	14.2	5.9	316.0	0.18	2.95	20.06	9.17	125
9	1	2	36	1551	258839	4265782	.	.	.	3	5	.	24.9	4.9	316.1	0.61	0.15	1.83	14.00	278
9	1	3	67	1326	257932	4264416	1640	53	11.6	3	1	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
9	1	3	81	1137	262816	4266749	5413	387	10.7	1	4	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
9	1	3	83	1643	263150	4266617	359	180	12.4	1	9	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
9	1	4	106	1543	259821	4265606	3691	160	2.7	3	3	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
9	1	5	133	1206	261114	4265155	1422	53	20.4	2	1	16.7	4.9	135.5	318.7	2.55	12.29	14.83	10.62	103
9	1	5	139	1445	257998	4263990	3327	555	5.5	4	1	17.8	21.4	22.8	318.4	0.15	2.03	13.39	10.14	130
9	1	6	153	1131	256925	4264483	1181	84	3.0	3	3	20.0	49.1	2.1	316.5	0.77	1.27	16.17	13.84	166
9	1	6	166	1302	257434	4264650	536	41	2.9	3	2	23.3	14.2	5.9	316.0	0.18	2.95	20.06	9.17	125
10	1	2	36	1636	258540	4265961	.	.	.	.	.	.	24.9	4.9	316.1	0.61	0.15	1.83	14.00	278
10	1	2	39	1135	258410	4266066	167	56	11.0	3	4	3.3	12.8	8.7	316.0	0.12	0.00	3.67	14.64	203
10	1	3	64	1321	258558	4265740	358	14	14.3	3	4	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
10	1	3	67	1354	258642	4265848	137	46	12.5	3	4	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
10	1	3	76	1407	258730	4264222	1628	181	10.8	4	1	4.4	20.0	3.1	315.3	0.34	0.00	-0.61	13.84	222
10	1	3	81	1613	255563	4263990	3175	635	10.5	5	1	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
10	1	3	83	1135	255485	4263778	2601	1301	10.6	5	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
10	1	4	99	1242	262176	4266049	423	26	6.7	1	2	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
10	1	4	106	1441	261775	4266125	408	58	3.6	1	2	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
10	1	5	139	1406	257359	4266900	4979	151	8.5	3	6	17.8	21.4	22.8	318.4	0.15	2.03	13.39	10.14	130
10	1	5	148	1112	257526	4266919	168	19	6.1	3	6	18.9	56.6	2.7	317.1	0.89	0.33	14.28	11.91	155
10	1	6	161	1109	257089	4264680	2281	175	2.4	3	3	21.1	22.5	11.6	316.2	0.13	5.21	17.28	11.26	78
11	2	3	64	1428	258553	4265170	.	.	14.0	3	4	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
11	2	3	67	1106	253894	4265122	4659	1553	6.1	5	2	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
11	2	3	81	1636	255360	4264657	1538	110	7.8	5	3	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
11	2	3	83	1120	255731	4263373	612	306	1.3	6	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
11	2	4	99	1550	251555	4263350	4176	261	4.5	8	1	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
11	2	4	106	1703	250686	4263417	872	125	3.1	7	1	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80

11	2	5	133	1451	251527	4264400	1425	53	3.0	7	2	16.7	4.9	135.5	318.7	2.55	12.29	14.83	10.62	103
11	2	5	139	1603	250689	4263439	1275	213	3.7	7	1	17.8	21.4	22.8	318.4	0.15	2.03	13.39	10.14	130
11	2	5	148	1253	250760	4263383	90	10	5.9	8	1	18.9	56.6	2.7	317.1	0.89	0.33	14.28	11.91	155
11	2	6	153	1032	250750	4263877	494	99	1.3	7	2	20.0	49.1	2.1	316.5	0.77	1.27	16.17	13.84	166
11	2	6	161	942	250510	4263086	827	103	0.9	8	2	21.1	22.5	11.6	316.2	0.13	5.21	17.28	11.26	78
11	2	6	166	1344	250847	4263524	553	111	3.4	7	1	23.3	14.2	5.9	316.0	0.18	2.95	20.06	9.17	125
11	2	6	172	940	250682	4263041	510	85	0.6	8	2	23.9	14.2	8.7	316.0	0.13	1.02	20.78	14.48	141
12	2	3	76	1500	258696	4265976	.	.	11.6	3	5	4.4	20.0	3.1	315.3	0.34	0.00	-0.61	13.84	222
12	2	3	83	1544	261973	4265738	3286	469	13.8	1	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
12	2	4	106	1644	252525	4264350	9471	412	4.0	7	2	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
12	2	5	133	1430	254575	4265350	3482	129	6.8	5	3	16.7	4.9	135.5	318.7	2.55	12.29	14.83	10.62	103
12	2	5	139	1358	258125	4267000	3915	653	3.6	3	6	17.8	21.4	22.8	318.4	0.15	2.03	13.39	10.14	130
12	2	5	148	1206	257225	4264850	2331	259	1.7	3	3	18.9	56.6	2.7	317.1	0.89	0.33	14.28	11.91	155
12	2	6	153	1143	257548	4264725	346	69	1.6	3	2	20.0	49.1	2.1	316.5	0.77	1.27	16.17	13.84	166
13	2	2	39	1555	260053	4266323	.	.	7.0	1	5	3.3	12.8	8.7	316.0	0.12	0.00	3.67	14.64	203
13	2	3	64	1150	263261	4266343	3208	128	8.5	1	9	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
13	2	3	67	1600	263336	4266326	77	26	9.4	1	9	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
13	2	3	76	1624	261937	4266802	1478	164	9.1	1	4	4.4	20.0	3.1	315.3	0.34	0.00	-0.61	13.84	222
13	2	3	81	1417	259321	4265974	2744	549	1.7	3	3	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
13	2	3	83	1410	261545	4266218	3036	1518	5.7	1	3	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
13	2	4	99	1343	263606	4265847	544	34	17.1	2	9	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
13	2	4	106	1334	262887	4266738	1145	164	7.5	1	5	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
13	2	5	133	1114	262204	4266844	626	23	7.6	1	5	16.7	4.9	135.5	318.7	2.55	12.29	14.83	10.62	103
14	2	2	36	1651	258770	4264735	.	.	.	.	.	.	24.9	4.9	316.1	0.61	0.15	1.83	14.00	278
14	2	3	64	1116	263085	4267064	4903	175	6.1	1	4	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
14	2	3	67	1322	262398	4265257	1933	644	11.6	2	1	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
14	2	3	76	1605	261926	4267013	1818	202	3.9	1	4	4.4	20.0	3.1	315.3	0.34	0.00	-0.61	13.84	222
14	2	3	81	1652	255710	4264130	6852	1370	9.8	5	1	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217

14	2	3	83	1431	262025	4265146	619	310	8.4	2	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
14	2	4	99	1350	263594	4265631	2038	127	3.4	2	10	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
14	2	4	106	1500	261037	4266047	2591	370	1.2	1	2	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
14	2	5	133	1124	262050	4267375	399	15	1.5	1	6	16.7	4.9	135.5	318.7	2.55	12.29	14.83	10.62	103
14	2	5	139	1046	262225	4267650	326	54	6.6	1	6	17.8	21.4	22.8	318.4	0.15	2.03	13.39	10.14	130
14	2	5	148	1013	262392	4267774	208	23	5.3	1	6	18.9	56.6	2.7	317.1	0.89	0.33	14.28	11.91	155
14	2	6	153	1312	262096	4267795	297	59	4.7	1	6	20.0	49.1	2.1	316.5	0.77	1.27	16.17	13.84	166
14	2	6	161	1313	262076	4267554	242	30	4.3	1	6	21.1	22.5	11.6	316.2	0.13	5.21	17.28	11.26	78
15	2	3	64	1600	256191	4263768	.	.	12.2	5	1	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
15	2	3	67	1204	256232	4263746	47	16	13.0	5	1	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
15	2	3	83	1154	255375	4263790	281	18	8.7	5	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
15	2	4	99	1045	260350	4266261	2571	161	9.1	1	5	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
15	2	4	106	1353	262323	4266708	2023	289	9.1	1	5	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
15	2	4	120	1102	260704	4265817	1034	74	7.4	1	1	13.9	4.9	9.6	316.0	0.16	2.77	11.44	11.26	88
15	2	5	133	1149	261051	4265110	788	61	17.9	2	1	16.7	4.9	135.5	318.7	2.55	12.29	14.83	10.62	103
15	2	5	139	1116	261199	4266308	1207	201	7.7	1	3	17.8	21.4	22.8	318.4	0.15	2.03	13.39	10.14	130
15	2	5	148	1413	262525	4264705	2080	231	2.7	2	3	18.9	56.6	2.7	317.1	0.89	0.33	14.28	11.91	155
15	2	6	153	1337	262752	4265120	473	95	13.3	2	2	20.0	49.1	2.1	316.5	0.77	1.27	16.17	13.84	166
16	2	2	36	1611	258665	4265902	.	.	.	.	.	.	24.9	4.9	316.1	0.61	0.15	1.83	14.00	278
16	2	2	39	1121	258927	4265638	372	124	9.1	3	5	3.3	12.8	8.7	316.0	0.12	0.00	3.67	14.64	203
16	2	3	64	1252	260920	4265502	1998	80	14.0	1	1	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
16	2	3	67	1047	254622	4264489	6379	2126	7.0	5	1	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
16	2	3	76	1333	256898	4263646	2427	270	9.7	4	1	4.4	20.0	3.1	315.3	0.34	0.00	-0.61	13.84	222
16	2	3	81	1120	262400	4266775	6330	1266	13.1	1	5	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
16	2	3	83	1354	260749	4265849	642	321	10.1	1	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
16	2	4	99	1530	252872	4264219	5726	358	6.9	5	1	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
16	2	5	133	1313	257700	4267021	3037	89	3.4	3	6	16.7	4.9	135.5	318.7	2.55	12.29	14.83	10.62	103
16	2	5	139	1330	258001	4266545	563	94	3.7	3	4	17.8	21.4	22.8	318.4	0.15	2.03	13.39	10.14	130

17	2	3	67	1436	259502	4265490	.	.	11.6	3	3	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
17	2	3	81	1155	263164	4266654	3843	275	12.5	1	9	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
17	2	3	83	1510	262550	4266600	427	214	13.8	1	5	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
17	2	4	99	1303	262248	4266709	2117	132	4.7	1	5	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
17	2	5	133	1226	259773	4265775	2857	84	6.9	3	3	16.7	4.9	135.5	318.7	2.55	12.29	14.83	10.62	103
17	2	5	148	1120	257101	4267169	3014	201	1.3	3	5	18.9	56.6	2.7	317.1	0.89	0.33	14.28	11.91	155
17	2	6	153	1215	256597	4267707	737	147	0.7	3	5	20.0	49.1	2.1	316.5	0.77	1.27	16.17	13.84	166
17	2	6	161	1206	258150	4267087	1672	209	1.4	3	6	21.1	22.5	11.6	316.2	0.13	5.21	17.28	11.26	78
17	2	6	166	1230	258345	4266750	389	78	1.2	3	6	23.3	14.2	5.9	316.0	0.18	2.95	20.06	9.17	125
17	2	6	172	1200	258375	4266825	81	14	3.0	3	6	23.9	14.2	8.7	316.0	0.13	1.02	20.78	14.48	141
19	2	3	64	1338	258273	4266581	.	.	10.4	3	5	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
19	2	3	67	1543	262134	4265985	3907	1302	11.0	1	1	3.3	15.9	40.0	315.8	0.55	1.30	2.28	13.03	151
19	2	3	76	1240	256475	4264325	5897	655	6.8	3	3	4.4	20.0	3.1	315.3	0.34	0.00	-0.61	13.84	222
19	2	3	81	1215	261789	4267120	6004	1201	7.3	1	5	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
19	2	3	83	1614	263140	4265018	338	169	15.1	2	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
19	2	4	99	1330	263825	4265625	8804	550	9.8	2	10	8.9	10.0	37.3	316.4	0.74	3.12	2.78	14.96	138
19	2	4	120	1112	260622	4266065	357	17	6.0	1	2	13.9	4.9	9.6	316.0	0.16	2.77	11.44	11.26	88
19	2	5	133	1401	256275	4264825	4520	348	9.4	3	3	16.7	4.9	135.5	318.7	2.55	12.29	14.83	10.62	103
19	2	5	139	1341	257925	4266750	2535	423	4.9	3	6	17.8	21.4	22.8	318.4	0.15	2.03	13.39	10.14	130
19	2	5	148	1356	260320	4264906	3023	336	5.2	2	1	18.9	56.6	2.7	317.1	0.89	0.33	14.28	11.91	155
20	2	3	64	1357	257483	4266932	.	.	7.9	3	4	3.3	15.4	35.5	315.9	0.55	3.53	-0.61	13.03	196
20	2	3	76	1515	258623	4266138	1389	116	11.7	3	5	4.4	20.0	3.1	315.3	0.34	0.00	-0.61	13.84	222
20	2	3	81	1510	258537	4266289	174	35	12.0	3	5	4.4	6.9	2.8	315.4	0.15	1.27	-1.11	20.76	217
20	2	3	83	1302	258500	4266375	301	151	12.3	3	6	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.31	248
20	2	4	106	1554	259508	4265625	2690	117	6.3	3	3	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
20	2	4	120	1300	250331	4263347	1389	99	2.9	8	.	13.9	4.9	9.6	316.0	0.16	2.77	11.44	11.26	88
20	2	5	139	1015	263675	4265825	13572	714	8.1	2	9	17.8	21.4	22.8	318.4	0.15	2.03	13.39	10.14	130

Night-time Tracking

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	1	3	83	0415	262207	4266346	4950	.	1.8	1	5	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.308	248
1	1	4	91	2328	260626	4266075	1751	219	2.3	1	2	6.7	2.8	11.1	315.6	0.27	3.45	5.72	14.3201	121
1	1	4	107	0228	260350	4266400	690	43	0.6	1	6	7.8	16.6	18.6	316.3	0.12	2.26	5.89	18.1817	88
1	1	4	115	2237	260675	4266150	410	51	0.6	1	2	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251
2	1	3	82	0154	261950	4266529	886	.	4.1	1	5	5.6	4.3	3.0	315.4	0.12	1.27	0.61	20.7561	231
2	1	4	92	0003	261698	4266100	799	80	2.4	1	2	6.7	3.3	14.6	315.6	0.27	3.45	5.50	18.3426	113
3	1	3	82	2100	253108	4264367	630	.	6.7	5	1	5.6	4.3	3.0	315.4	0.12	1.27	0.61	20.7561	231
3	1	4	92	0115	261888	4266836	8342	834	3.0	1	5	6.7	3.3	14.6	315.6	0.27	3.45	5.50	18.3426	113
4	1	3	82	0033	259881	4265006	800	.	15.1	4	1	5.6	4.3	3.0	315.4	0.12	1.27	0.61	20.7561	231
4	1	4	91	0038	262225	4266059	2881	320	1.1	1	2	6.7	2.8	11.1	315.6	0.27	3.45	5.72	14.3201	121
4	1	4	107	0228	260500	4266025	278	17	0.6	1	5	7.8	16.6	18.6	316.3	0.12	2.26	5.89	18.1817	88
4	1	4	115	2324	261982	4266322	1511	189	1.5	1	5	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251
5	1	3	83	0016	259572	4265812	726	.	4.7	3	3	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.308	248
5	1	4	92	0215	263799	4265409	4246	472	5.8	2	10	6.7	3.3	14.6	315.6	0.27	3.45	5.50	18.3426	113
5	1	4	106	0117	263390	4265544	1594	114	1.7	2	2	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
6	1	3	83	0210	261799	4266201	765	.	17.7	1	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.308	248
6	1	4	91	2310	260010	4266786	1882	235	8.7	1	4	6.7	2.8	11.1	315.6	0.27	3.45	5.72	14.3201	121
6	1	4	106	2343	262134	4266236	171	11	2.6	1	2	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
6	1	4	115	2128	255962	4263432	6779	753	8.9	6	1	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251
7	1	4	91	2050	255318	4263598	1052	.	1.7	6	1	6.7	2.8	11.1	315.6	0.27	3.45	5.72	14.3201	121
7	1	4	107	0346	255842	4263118	711	44	1.7	6	1	7.8	16.6	18.6	316.3	0.12	2.26	5.89	18.1817	88
8	1	3	82	0056	260350	4266125	591	.	3.0	1	5	5.6	4.3	3.0	315.4	0.12	1.27	0.61	20.7561	231
8	1	4	91	0050	262148	4266048	1991	221	2.6	1	2	6.7	2.8	11.1	315.6	0.27	3.45	5.72	14.3201	121
8	1	4	107	0220	260310	4266105	593	37	1.1	1	5	7.8	16.6	18.6	316.3	0.12	2.26	5.89	18.1817	88
8	1	4	115	2334	262018	4266339	1724	216	2.6	1	5	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251
9	1	4	91	2140	256364	4264312	7167	.	7.5	3	3	6.7	2.8	11.1	315.6	0.27	3.45	5.72	14.3201	121

9	1	4	107	0225	259685	4265799	236	15	1.7	3	3	7.8	16.6	18.6	316.3	0.12	2.26	5.89	18.1817	88
9	1	4	115	2346	262175	4266102	2508	314	1.8	1	2	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251
10	1	3	82	2120	253284	4265163	2563	.	6.4	5	3	5.6	4.3	3.0	315.4	0.12	1.27	0.61	20.7561	231
10	1	4	91	0007	261753	4266069	6674	742	3.3	1	2	6.7	2.8	11.1	315.6	0.27	3.45	5.72	14.3201	121
10	1	4	107	0137	261575	4266100	202	13	2.9	1	2	7.8	16.6	18.6	316.3	0.12	2.26	5.89	18.1817	88
10	1	4	115	2357	262280	4266139	706	88	0.8	1	2	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251
11	2	3	82	2206	255162	4263148	1522	.	1.4	6	1	5.6	4.3	3.0	315.4	0.12	1.27	0.61	20.7561	231
11	2	4	107	0417	250625	4263233	194	8	1.3	8	1	7.8	16.6	18.6	316.3	0.12	2.26	5.89	18.1817	88
11	2	4	115	2057	250941	4263101	342	43	1.1	8	1	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251
12	2	3	83	0229	261837	4266080	368	.	3.4	1	2	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.308	248
12	2	4	107	0404	252743	4264373	219	9	4.6	5	1	7.8	16.6	18.6	316.3	0.12	2.26	5.89	18.1817	88
12	2	4	115	2032	251319	4264115	1447	181	3.1	7	1	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251
13	2	3	82	2326	258514	4266394	910	.	3.5	3	6	5.6	4.3	3.0	315.4	0.12	1.27	0.61	20.7561	231
13	2	4	92	0226	263908	4265395	2502	250	.	2	10	6.7	3.3	14.6	315.6	0.27	3.45	5.50	18.3426	113
13	2	4	107	0057	262750	4266879	197	13	1.4	1	5	7.8	16.6	18.6	316.3	0.12	2.26	5.89	18.1817	88
13	2	4	115	0042	262825	4266925	88	11	7.5	1	5	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251
14	2	3	83	0400	262582	4264875	6912	.	1.5	2	3	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.308	248
14	2	4	92	0255	263175	4267625	2733	304	0.9	1	5	6.7	3.3	14.6	315.6	0.27	3.45	5.50	18.3426	113
14	2	4	107	0206	260937	4266017	104	7	1.6	1	2	7.8	16.6	18.6	316.3	0.12	2.26	5.89	18.1817	88
14	2	4	115	0030	261656	4267440	1594	199	4.4	1	5	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251
15	2	3	82	2150	255139	4263637	1098	.	9.3	6	1	4.4	4.3	3.0	315.4	0.12	1.27	0.61	20.7561	231
15	2	4	91	2246	257821	4266722	3818	424	2.9	3	4	6.7	2.8	11.1	315.6	0.27	3.45	5.72	14.3201	121
15	2	4	107	0023	262324	4266687	21	1	7.6	1	5	7.8	16.6	18.6	316.3	0.12	2.26	5.89	18.1817	88
15	2	4	115	2307	261713	4266043	888	111	3.6	1	2	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251
16	2	3	82	0137	261250	4266250	1264	.	2.4	1	3	5.6	4.3	3.0	315.4	0.12	1.27	0.61	20.7561	231
16	2	4	91	2230	258197	4266325	2596	288	9.9	3	4	6.7	2.8	11.1	315.6	0.27	3.45	5.72	14.3201	121
16	2	4	107	0315	259688	4265688	6973	436	3.9	3	2	7.8	16.6	18.6	316.3	0.12	2.26	5.89	18.1817	88
16	2	4	115	2209	259965	4264998	744	93	8.6	4	1	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251

17	2	3	83	0254	262839	4266286	491	.	5.5	1	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.308	248
17	2	4	92	0226	263908	4265395	2545	283	.	2	10	6.7	3.3	14.6	315.6	0.27	3.45	5.50	18.3426	113
17	2	4	106	2350	262121	4266235	491	35	3.9	1	2	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
17	2	4	115	0017	262375	4266956	764	85	2.9	1	6	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251
19	2	3	83	0327	263199	4265351	2262	.	10.1	2	1	5.6	2.9	3.0	315.4	0.12	1.27	0.89	19.308	248
19	2	4	91	2115	255221	4263757	8019	1002	9.1	6	1	6.7	2.8	11.1	315.6	0.27	3.45	5.72	14.3201	121
19	2	4	106	0035	263251	4266259	855	57	15.5	1	9	7.8	15.6	25.2	316.4	0.12	2.26	5.78	16.09	80
19	2	4	115	2220	260776	4265743	2528	281	7.6	1	1	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251
20	2	3	82	2307	258700	4266600	351	.	1.6	3	6	5.6	4.3	3.0	315.4	0.12	1.27	0.61	20.7561	231
20	2	4	92	0133	261511	4267420	3187	319	1.6	1	4	6.7	3.3	14.6	315.6	0.27	3.45	5.50	18.3426	113
20	2	4	107	0228	260325	4266125	958	64	0.6	1	4	7.8	16.6	18.6	316.3	0.12	2.26	5.89	18.1817	88
20	2	4	115	2109	251583	4263949	9009	1126	4.1	7	1	13.3	29.3	4.5	315.8	0.48	0.89	8.50	17.5381	251

APPENDIX C

Appendix C. - Substrate composition of two north shore areas near Melvern State Park, Melvern Reservoir, Kansas. Designations for heading codes are: S-T-#, site-transect-sample number; A, clay/silt; B, sand; C, gravel; D, pebble; E, cobble; and F, boulder. Surveys were conducted on 16 and 19 July, and 12 November 1993 using the modified Wentworth scale (Cummins 1962, Hynes 1970) to estimate percent occurrence of each substratum category.

S-T-#	A	B	C	D	E	F	S-T-#	A	B	C	D	E	F
FOUR-1-1	10	0	0	50	40	0	SHOAL-3-1	70	0	10	10	10	0
FOUR-1-2	15	0	5	40	40	0	SHOAL-3-2	50	0	0	50	0	0
FOUR-1-3	30	0	0	50	20	0	SHOAL-3-3	20	0	40	40	0	0
FOUR-1-4	50	0	10	10	30	0	SHOAL-3-4	0	0	0	100	0	0
FOUR-1-5	20	0	20	50	10	0	SHOAL-3-5	40	0	50	10	0	0
FOUR-1-6	0	0	0	70	30	0	SHOAL-3-6	0	0	0	100	0	0
FOUR-1-7	0	0	0	80	20	0	SHOAL-3-7	20	0	40	40	0	0
FOUR-1-8	0	0	0	80	20	0	SHOAL-3-8	0	0	10	90	0	0
FOUR-1-9	0	0	0	80	20	0	SHOAL-3-9	40	0	40	20	0	0
FOUR-1-10	0	0	0	80	20	0	SHOAL-3-10	30	0	60	10	0	0
SHOAL-1-1	0	0	5	95	0	0	SHOAL-3-1	0	0	0	100	0	0
SHOAL-1-2	0	0	5	95	0	0	SHOAL-4-2	50	0	50	0	0	0
SHOAL-1-3	95	0	0	5	0	0	SHOAL-4-3	50	0	50	0	0	0
SHOAL-1-4	100	0	0	0	0	0	SHOAL-4-4	0	0	0	0	100	0
SHOAL-1-5	90	0	0	10	0	0	SHOAL-4-5	70	0	30	0	0	0
SHOAL-1-6	95	0	0	5	0	0	SHOAL-4-6	50	0	0	50	0	0
SHOAL-1-7	100	0	0	0	0	0	SHOAL-4-7	0	0	0	100	0	0
SHOAL-1-8	95	0	0	5	0	0	SHOAL-4-8	5	0	5	90	0	0
SHOAL-1-9	0	0	0	50	50	0	SHOAL-4-9	0	0	0	100	0	0
SHOAL-1-10	95	0	0	5	0	0	SHOAL-4-10	0	0	0	100	0	0
SHOAL-2-1	0	0	0	100	0	0	SHOAL-5-1	0	0	0	100	0	0
SHOAL-2-2	0	0	0	100	0	0	SHOAL-5-2	50	0	0	50	0	0
SHOAL-2-3	100	0	0	0	0	0	SHOAL-5-3	100	0	0	10	0	0
SHOAL-2-4	100	0	0	0	0	0	SHOAL-5-4	0	0	0	100	0	0
SHOAL-2-5	100	0	0	0	0	0	SHOAL-5-5	60	0	40	0	0	0
SHOAL-2-6	100	0	0	0	0	0	SHOAL-5-6	70	0	10	20	0	0
SHOAL-2-7	100	0	0	0	0	0	SHOAL-5-7	90	0	5	5	0	0
SHOAL-2-8	100	0	0	0	0	0	SHOAL-5-8	90	0	10	0	0	0
SHOAL-2-9	100	0	0	0	0	0	SHOAL-5-9	80	0	20	0	0	0
SHOAL-2-10	95	0	0	5	0	0	SHOAL-5-10	95	0	5	0	0	0

APPENDIX D

Appendix D. Species of freshwater mussels using sauger as a glochidial host. References summarized from Hart and Fuller (1974).

Mussel	Reference(s)
Amblema plicata	Coker et al. 1921, Howard 1914, Surber 1913, Wilson 1916.
Megalonaias gigantea	Howard 1914.
Quadrula metanevra	Coker et al. 1921, Howard 1914.
Plethobasus cyphyus	Surber 1913, Wilson 1916.
Actinonaias carinata	Coker et al. 1921, Pearse 1924.
Lampsilis orbiculata	Coker et al. 1921, Surber 1913, Wilson 1916.
L. ovata (including *L. ventricosa*)	Coker et al. 1921, Wilson 1916.
L. radiata luteola	Coker et al. 1921, Corwin 1920, 1921.
Ligumia recta	Pearse 1924.
Ellipsaria lineolata	Surber 1913.
Truncilla donaciformis	Surber 1913, Wilson 1916.
T. truncata	Wilson 1916.

CHAPTER 2

The Global Positioning System for Aquatic Surveys

ABSTRACT. The Global Positioning System (GPS) is a superior surveying technology that quickly provides highly accurate reproducible spatial data, even in remote reference-free areas. Fundamentals, limitations, and strengths of the technology are reviewed. GPS is a satellite-based navigation system that relies on radio signals having intrinsic error sources such as signal deflection, refraction, and intentional degradation by the U.S. Department of Defense. Data errors are classified as random, blunder, or systematic. Accuracy is measured as the spatial divergence from a known location, and precision is expressed with the root mean square statistic. Basic or differential GPS (BGPS and DGPS, respectively) is used depending on the spatial resolution needed and time allowed for a survey. DGPS requires more time, data processing, and personnel training, yet is more accurate than BGPS due to correction of signal errors. Preliminary planning and training are essential for fisheries scientists preparing to conduct aquatic surveys.

The Global Positioning System (GPS) has emerged as a superior one-person, all-weather, all-day surveying method that quickly provides highly accurate, reference-free spatial data (Wassef and El-Maghraby 1991; Puterski et al. 1992; August et al. 1994). This technology relies on known positions of satellites and travel time of their radio signals to determine a receiver's coordinates by triangulation. Currently, 24 satellites orbit the Earth at an approximate altitude of 17,700 kilometers, this distance allows invulnerability of satellite signals to varying weather patterns and electrical interferences. Use of GPS during field reconnaissance ensures reproducible geo-positional accuracy of spatial data (e.g., fish fixes, sampling stations, critical aquatic and riparian habitats) (Beck et al. 1989; Strange 1989).

Conventional field survey techniques rely on benchmarks that correspond to mapped coordinates. For example, compass triangulation uses azimuths and their intercept(s), which must first be derived from visual landmarks. However, locations of habitats and organisms often do not have natural or anthropogenic features that can be used as reference points. Even if present, reference points may be obscured by sight-altering conditions, such as those found at night, in dendritic coves, and in fog or rainfall.

Loran-C is another popular benchmark-free sea and air navigation system having accuracies under 300 m, however its accuracy degrades with electrical interferences of powerlines and storms, and is limited to locations with Loran signal-transmitting stations (Hurn 1989; Puterski et al. 1992; McClane 1993). Rapidly evolving GPS receivers and software offer greater research utility with a stable technology (Long et al. 1991; Soler et al. 1992; August et al. 1994) that is well established in cost-effective environmental surveys (Graham 1993; Kruczynski and Jasumback 1993; Rutchey and Vilcheck 1994). GPS has been applied to aquatic field surveys, reducing field time, inaccuracy, and labor and cost per feature identified, while increasing collection of accurate in situ biological data (McClane 1993; Jensen et al. 1995; Chapter 1).

Aquatic habitats are quickly and most accurately delineated using GPS coupled with a Geographic Information System (GIS) (Puterski et al. 1992; Welch et al. 1992). However, preliminary planning and training is paramount to the success of such projects, otherwise biological phenomena may remain unknown and poorly documented. In order to transcend less efficient survey techniques, it is important to understand theory, error sources, accuracy and precision, and current limitations and strengths of GPS. The following discussion presents fundamental GPS information for aquatic ecologists.

Theory

By measuring distances between an unknown location on the surface of the Earth and known positions of orbiting satellites, it is possible to derive coordinates for the unknown location by triangulation (Figure 1); also termed "ranging." Distances are determined by matching coded satellite radio signals with a receiver-generated code sequence, both of which are synchronized in time. When this matching occurs, a receiver and satellite are said to be in "lock." The time between satellite signal transmission and arrival at receiver, multiplied by the speed of light, is used to calculate distances (velocity times travel-time equation; Kennie and Petrie 1990). Not only do satellite-emitted signals contain time, but they also carry data discerning satellite location and accuracy of the satellite's clock; diagnostics used in monitoring satellite "health." A GPS almanac containing satellites' orbits and positions is stored in all satellites and may be downloaded to a receiver. This almanac "tells" the receiver where to start looking for respective satellites at the time of the survey. At least three satellite locks are needed to solve for an unknown location.

There are two modes of GPS positioning: basic (BGPS) and differential (DGPS). Both modes are subject to errors intrinsic to satellite geo-positioning (see section below). In the autonomous BGPS mode, ranging is conducted solely between satellites and a remote receiver, with no corrective computation for error. Using BGPS, deviation from the true location may range to 100 m (Georgiadou and Doucet 1990; Puterski et al. 1992; Hurn 1993). In DGPS mode, positioning is contingent upon information from a second receiver located at a stationary known location, called a base station. This base station logs GPS error over time, and when time-synchronized with a field file, can correct the remotely-collected data (Figure 2). Postprocessing of base station and field files is performed with special computer software, where degree of correction depends on the quality of the base station receiver and DGPS software used. Field differential (field DGPS) uses a second hand-held receiver in place of the base station, with the second receiver left at a fixed known or unknown location. Field DGPS relies on receivers' positional fixes, not "raw" GPS signals, to differentially correct a field file. Software is used to smooth, synchronize, and average fixes from each of the receivers before correction. Although less accurate and precise than DGPS, field DGPS does not demand a lot of time, real-time data storage, or much receiver memory.

U.S. coastal regions and some inland urban areas have beacon networks that emit pre-corrected signals, eliminating the need for postprocessing and providing real-time quality-assured spatial data (Wethington and Paiva 1989; MacKay 1990; Hurn 1993). Private enterprises offer this capability for interior mainland regions. If available, this is clearly the positioning mode of choice since inexpensive GPS receivers able to receive these signals (RTCM SC-104 standard; Hurn 1993) are currently available.

Factors Affecting Accuracy

Many factors affect GPS accuracy, and some may leave a GPS operator with nothing more than digital garbage. Two major sources of GPS error are selective availability (SA) and multipath phenomena. SA is a U.S. Department of Defense (DOD) intentional GPS signal degradation. Signals from the DOD-owned satellites are "tweaked" to artificially create false clock and orbit information; this phenomenon is known as SA, or a spike. A spike's degrading power varies with the DOD alteration. Locations derived under the influence of a spike may be corrected using DGPS where the degree of correction is again base station, receiver, and software dependent. The effect of spikes during times of international war is of concern as this technology is key to national security, and if needed DOD could completely shut down the system. Otherwise, spiked surveys using BGPS still provide coordinates within 100 m of true location

(Georgiadou and Doucet 1990; Puterski et al. 1992).

Multipath involves time errors created by deflection(s) of a radio signal before arrival at a GPS receiver, causing it to arrive from two or more nonlinear paths (Puterski et al. 1992; Hurn 1993). This phenomenon may occur where obstructions exist, such as buildings, forest canopy (Wilkie 1989), dams (personal observation), or large ocean waves. This error source is best remedied by adjusting a receiver's settings and using a multipath-resistant antenna.

Ionospheric and tropospheric properties can interfere with GPS radio signals, inhibiting their travel speed to a receiver (e.g., signal refraction by charged particles). However, DOD regularly uploads satellites with corrective data regarding the current atmospheric state (Kennie and Petrie 1990), though atmospheric distortions may still contribute to total GPS error, with DGPS again alleviating their effect. Another source of error is "cycle slip," which occurs when a lock between receiver and satellite is interrupted, thus losing its synchronized code match; this can happen with heavy air traffic or with multipath conditions. This error source is also termed "loss of lock." During a BGPS survey, data collection typically has to be repeated when a cycle slip occurs. For high accuracy DGPS surveys, data editing and increased on-site sampling can eliminate cycle slip problems.

Current hand-held GPS receivers are commonly designed to track 6 to 8 satellites simultaneously. These numbers increase geometric quality which is expressed as, and inversely proportional to, the Position Dilution of Precision (PDOP). Lower PDOPs represent "visible" satellite configurations that are spread across the horizon and are typical of more accurate position fixes. High PDOPs depict satellite positions that are close in relation to each other and often are associated with poor accuracy fixes. The enhanced tracking capabilities of today's receivers also allow the use of algorithms to correct time errors associated with atmospheric effects and clock inaccuracies. Multipath remains an error source not cured by a receiver's algorithms or DGPS, therefore preliminary evaluation should be conducted of a receiver's antenna in varied obstructive environments.

Measuring Accuracy and Precision

Simply stated, GPS accuracy is measured by comparing known reference coordinates to those generated by a receiver. When receiver coordinates approach those of the reference, the distance/error between the two coordinate pairs has decreased; and accuracy has increased. Precision may be expressed in several ways, however horizontal deviation from a reference is commonly expressed with the root mean square (RMS) statistic, a composite value for more than one pair of Cartesian coordinates. The RMS is derived from the square root of the average of error vectors (Figure 3; Willmott 1984; Magellan Systems Corporation 1992). Thus, precision within and among surveys may be inspected using RMS (Figure 4).

Estopinal (1992) described three categories of survey errors: systematic, random, and blunder. Systematic GPS errors are inaccuracies that occur in the same direction, where the error form repeats itself over time. Data exhibiting this pattern are often spiked or from unhealthy satellites. Random errors are unpredictably variable and come from unidentified experimental error(s) including atmospheric, multipath, or Doppler effects (Puterski et al. 1992). Blunder errors are gross inaccuracies caused by carelessness such as pushing the wrong button, not having an external antenna turned "on", or recording data when a receiver displays a message analogous to "do not use data." Systematic and random errors are best minimized by double checking receiver settings, updating its almanac, and using DGPS. Blunder errors should and can be eliminated through careful quality-assurance measures which should include RMS monitoring.

Researchers should acquire knowledge for measuring GPS accuracy and precision, and recognize potential sources of error. These skills are extremely important for those designing and monitoring GPS aquatic field surveys.

Limitations and Considerations

Accuracy required to meet specific study objectives is the first important consideration in surveying design. This level of accuracy will determine the types of GPS instruments used and, if coupling with a GIS, will determine the required resolution of the GIS reference system. Logistics based on data acquisition rates must be thoroughly calculated based on the number of sampling stations to be surveyed within a day (see below). Harris and Bennett (1988) mentioned examples where they were forced to revisit survey sites, or not visit pre-planned sites, due to time and technical restrictions. Not unlike other aspects of field research, time and technical delays do arise even with the best planning.

Some technical considerations are 1) if batteries go "dead," so does the survey, 2) incorrect receiver initialization stops or inhibits survey speed, 3) an out-of-date almanac stops or inhibits survey speed, 4) memory of a receiver or linked data logger limits the amount of spatial data that may be collected when using DGPS, and 5) when using DGPS, base station and field data need to be converted to a compatible format for computer postprocessing.

Knowledge of a receiver's capabilities and setup options are invaluable for understanding what types of spatial data the receiver is generating. For instance, if GPS data will be applied to a GIS it is necessary to select the same model of the Earth's shape for both systems, otherwise locations may be mismatched in excess of 100 m (Puterski et al. 1992).

Two precautions noted by Blair (1989) are 1) before adopting GPS technology, claims for its accuracy and flexibility should be verified, and 2) tests on specific GPS instruments should be conducted to assure yourself, colleagues, and clients of GPS accuracy. Harris and Bennett (1988), Blair (1989), and Puterski et al. (1992) detailed preliminary planning, design, and execution procedures for applying GPS as a survey method.

GPS is not a "turnkey" operation (Wells et al. 1986). Advanced skills are needed for aquatic GPS surveys just as they are for conventional surveys. In fact, aquatic GPS surveyors need expertise in aquatic science and research design and analysis, in addition to cartography, geodesy, surveying, microcomputers, applied GIS, and DGPS theory and accuracy assessment. There are significant monetary, training, and practice investments with this technology, however time spent surveying without GPS is also cost-cumulative, with greater person hours in the field. Contention for applied or basic research funds may be dependent upon aquatic-survey efficiency; being GPS-equipped may make the difference in acquiring that dream research project or underbidding corporate competitors.

Strengths

To conduct systematic aquatic or terrestrial surveys in large reference-free ecoregions (e.g., wetlands, deserts, estuaries, flood plains), a survey grid can be established using GPS to reference grid points (e.g., buoys, posts, flags), thus creating unique survey sectors based on coded grid structures (Figure 5). If desired, DGPS technology allows sub-meter accuracies on a regular basis, and if cost and time are irrelevant, more precise forms of DGPS (see Puterski et al. 1992) have been documented to measure at the cm and mm-level (e.g., Meehan et al. 1987; Blewitt 1989; Rocken et al. 1990). When tracking more than four satellites with a PDOP < 5 at a fixed point, range of speed at which GPS data are collected for BGPS (< 100 m), DGPS (< 7 m), and precise DGPS (< 1 m) are as follows: 10-30 s, 10-15 min, and 20+ min, respectively (Magellan Systems Corporation 1992; C. Smith, Ashtech Inc., personal communication; personal observation).

If GPS survey details are documented, results are highly reproducible. Once receivers are initialized and set up for a specific use, field technicians can be taught to use these units without an understanding of GPS complexities. Technicians will likely prefer using hand-held digital units rather than assessing locations from unwieldy maps such as U.S. Geological Survey or National Wetlands Inventory maps. Also, several receivers have substantial memory for non-GPS data logging (e.g., water chemistry, site number, species, time).

The Future

To best conserve and steward our aquatic resources, efficient use of field time is essential. Increasing prevalence of the American Fisheries Society in the political arena may demand court-defensible data that portrays locations of threatened and endangered fishes, habitats, and ecosystems. The quickest and most accurate delineation of aquatic resources is through the use of GPS and GIS.

When mapping field observations, a pencil lead with a diameter of 0.9 mm makes a mark on a 1:24,000-scale map that accurately depicts a feature with a spatial error no less than 21.6 m; sub-meter accuracies obtained with DGPS can be digitally encoded with GIS, losing this spatial error. Thus, our aquatic resources will be best defended when using data derived from DGPS, the most meticulous and objective survey tool we can use. Murphy et al. (1995) reported the highest demand by fisheries biologists for continued education was in computer science, and the collection, analysis, and presentation of field data. Those organizations involved in aquatic conservation and research, should train their personnel in these areas with regard to GPS.

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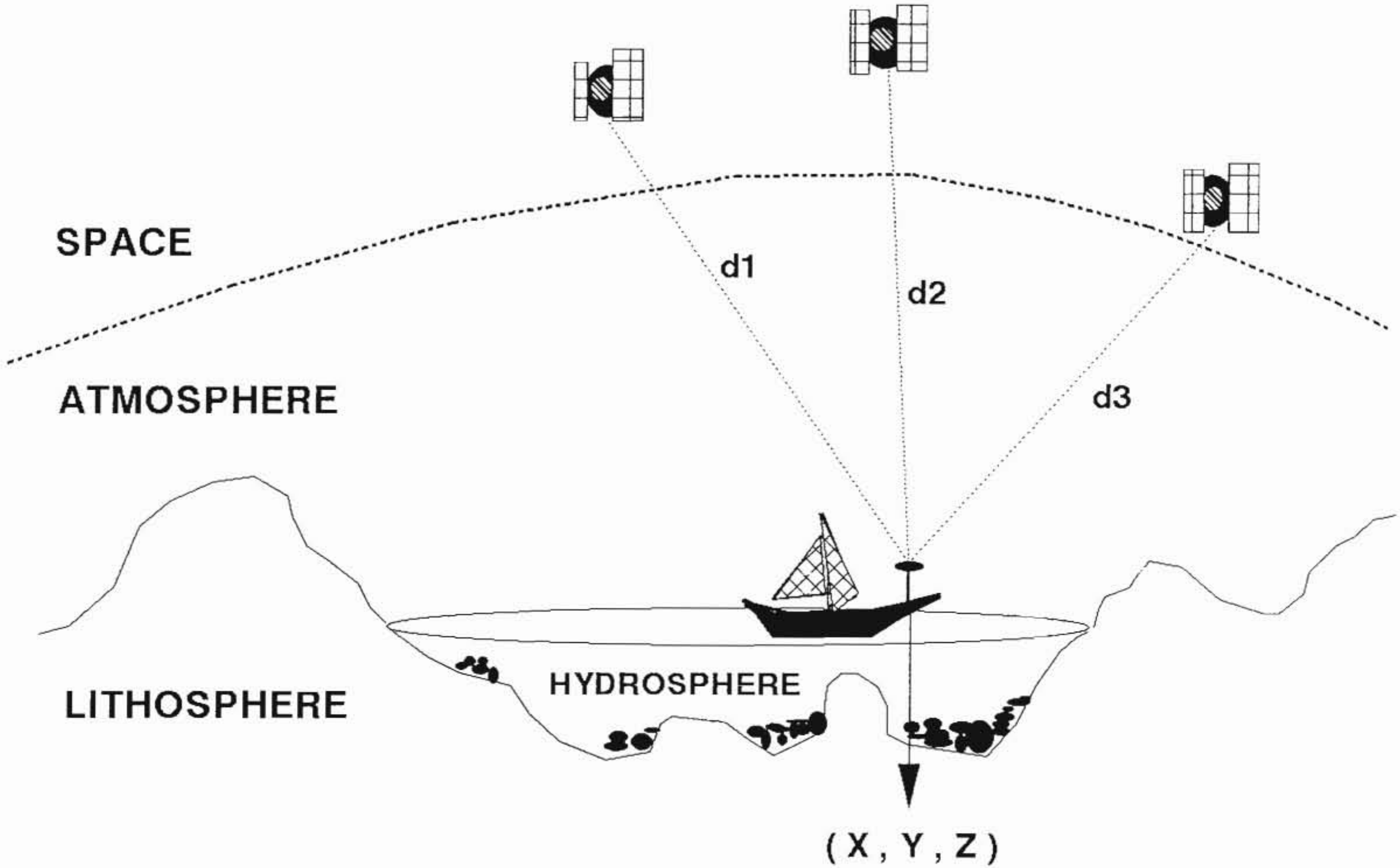
Figure 1. Triangulating an unknown location on Earth by measuring distances to known positions of orbiting satellites. Earth-based receiver provides horizontal and vertical coordinates: X and Y represent horizontal coordinates commonly expressed as geodetic (latitude/longitude) or Universal Transverse Mercator (UTM), and Z represents the vertical height typically measured as the distance above mean sea level.



SPACE
d1
d2
d3
ATMOSPHERE
HYDROSPHERE
LITHOSPHERE
(X , Y , Z)

Figure 2. Differential GPS theory, where a base station records satellite error, then corrections are applied to field data via computer software.

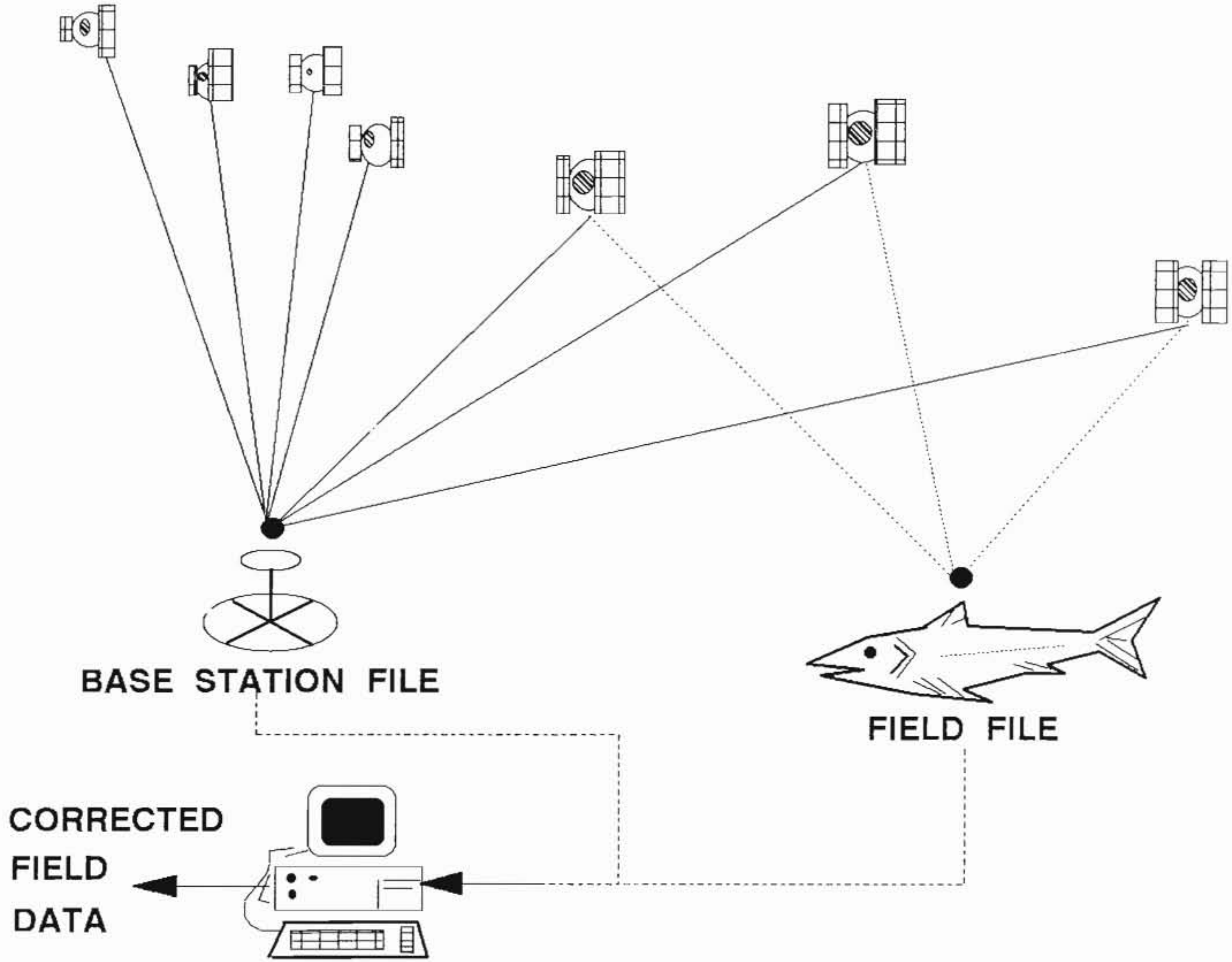
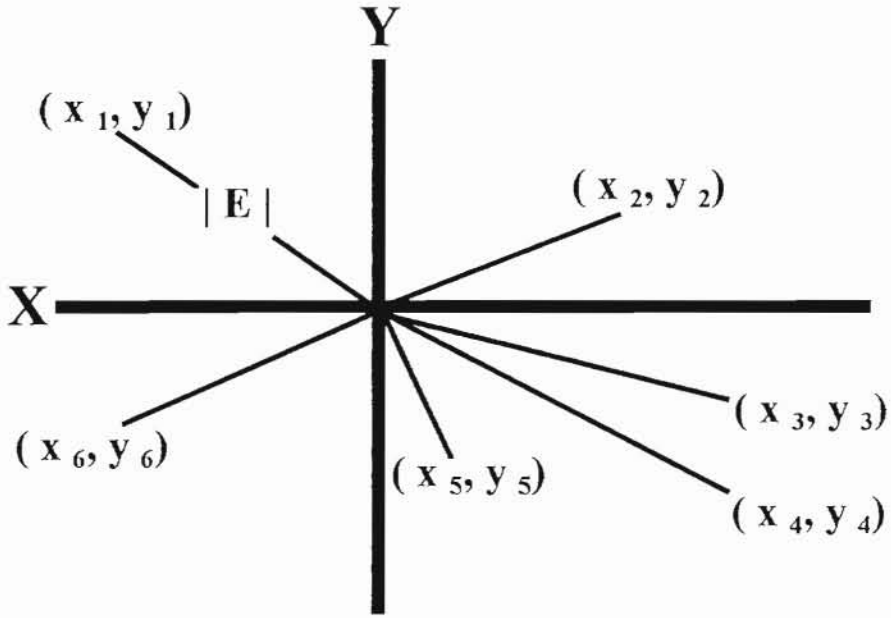

BASE STATION FILE
FIELD FILE
CORRECTED
FIELD
DATA

Figure 3. Derivation of the root mean square (RMS) statistic, a measure of precision for GPS coordinates.



Origin (0,0) = Known Location

| E | = Absolute Error = Euclidian Distance (ED)

$$ED = \sqrt{(y_1 - 0)^2 + (x_1 - 0)^2}$$

$$RMS = \sqrt{\sum ED \cdot n^{-1}}$$

Figure 4. Accuracy of a hand-held Magellan NAV PRO 5000 GPS receiver, measured using a first order National Geodetic Survey benchmark (NGS; LYON, PID:JF1376) near Emporia, Kansas. Precision is expressed by the root mean square (RMS) statistic. Differential (DGPS) and basic (BGPSa) surveys were collected on 10 September 1993; second basic survey (BGPSb) was conducted on 24 March 1994.

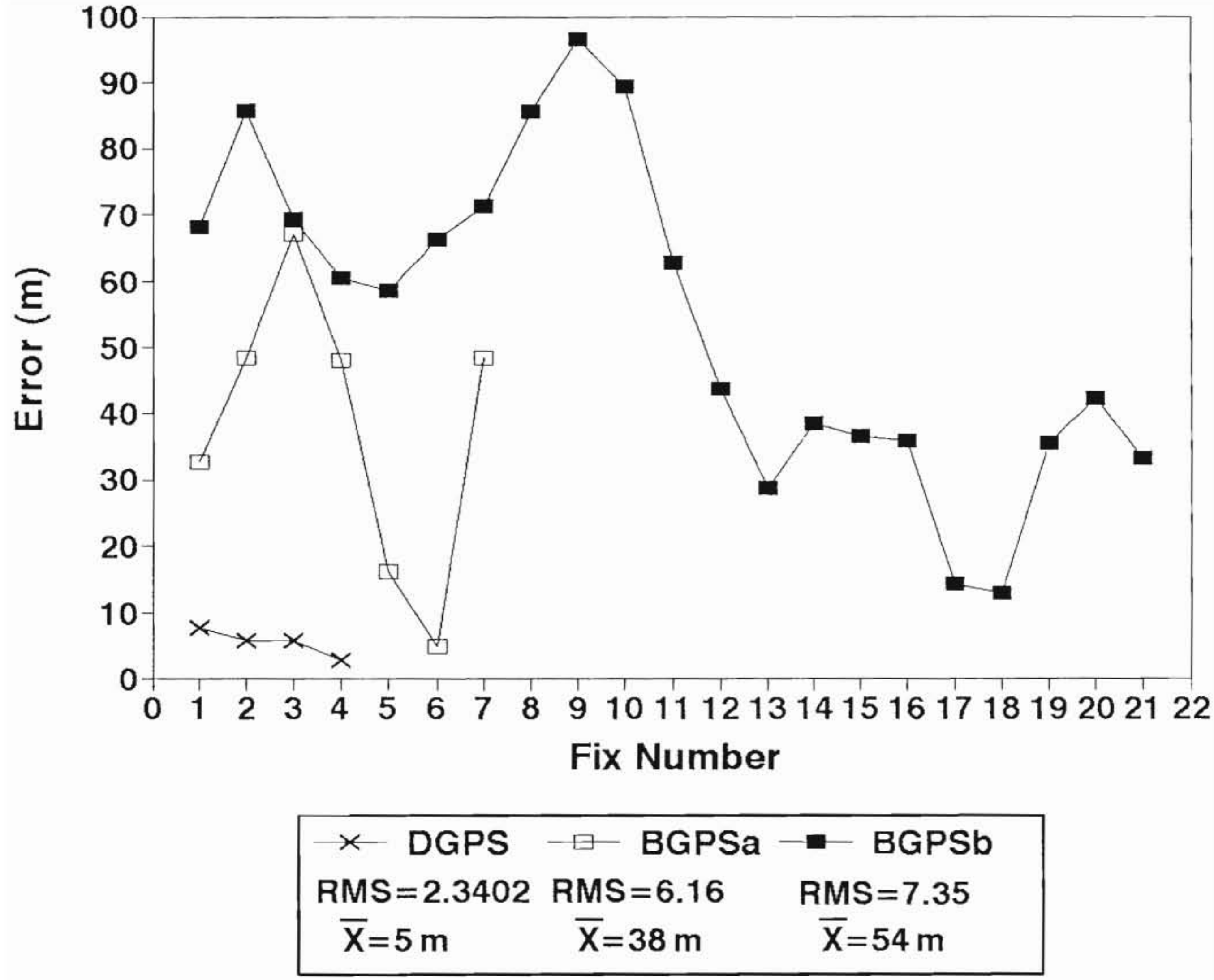
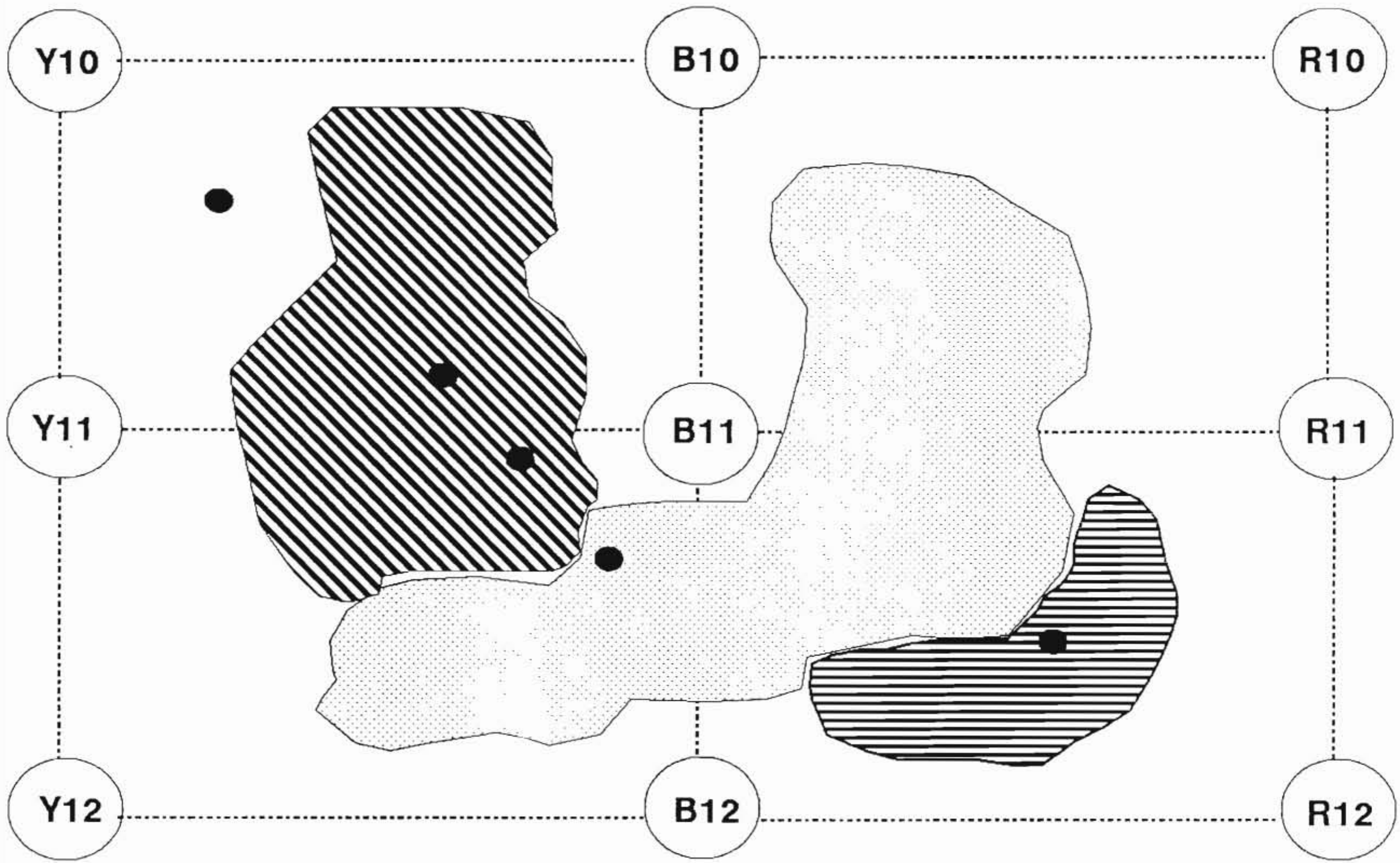

100
90
80
70
60
50
40
30
20
10
0
Error (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Fix Number
DGPS
BGPSa
BGPSb
RMS=2.3402
RMS=6.16
RMS=7.35
X̄=5 m
X̄=38 m
X̄=54 m

Figure 5. Theoretical grid delineating survey sectors based upon points derived from DGPS. Marked grid points identify sectors where numbers differentiate yellow (Y), blue (B), and red (R) transects. Polygons and filled circles represent habitat coverages and fish observations, respectively.


Y10
B10
R10
Y11
B11
R11
Y12
B12
R12

VITA SYNOPSIS

Jay D. Jeffrey was born in Lincoln, NE, on 15 April 1968. As an Army "brat", he was socially educated at Nurnberg, Germany; San Antonio, TX; San Francisco, CA; Ft. Leonard Wood, MO; El Paso, TX; Wahiawa, HI; and Ft. Riley, KS. He graduated in 1986 from Junction City High, KS. In May 1991, he received the Bachelor of Science degree concentrating on Fisheries and Wildlife Biology from Kansas State University, Manhattan. During his stay at Kansas State, he worked as a fisheries and wildlife research assistant in the Division of Biology with Drs. H.E. Klaassen, F.E. Wilson, and R.J. Robel; as a fisheries technician for the Kansas Department of Wildlife and Parks (KDWP) at Milford Fish Hatchery; as a biologist aide for the Natural Resources Division of Ft. Riley; and as a fisheries technician for the Idaho Fish and Game Commission. He also served as Vice-president for the Student Chapter of The Wildlife Society. After graduating, he worked six months for the Iowa Department of Natural Resources as a fisheries technician before working a four-month stint for a private firm as an avian ecologist in Florida.

He attended Emporia State University from August, 1992, to December, 1995, and during this time served as a Biology of Animals laboratory teaching assistant and graduate research assistant, and as the 1992/1993 student representative on the ESU Graduate Student Advisory Council. He again worked for KDWP as a fisheries and wildlife research technician, and was contracted by that agency to develop guidelines for personnel using the KDWP Threatened and Endangered Species database. He also worked for a private firm in Wyoming, supervising amphibian surveys, conducting surveys for black-footed ferrets, and performing field reconnaissance for montane environmental impact assessments. Lastly, for the Nature Conservancy, he conducted small mammal surveys throughout southeastern Wyoming.

Also while attending ESU, he served as Vice-chair and Chair of the American Fisheries Society (AFS) North Central Division (NCD) Student Affairs Committee, co-founding an annual student travel grant, and the electronic mail AFS-Student Affairs Network; for Kansas, he created and chaired the AFS Kansas Chapter Student Affairs Committee; and, in 1992, was the AFS Kansas Chapter representative at the annual AFS NCD executive committee meeting. Aside from two ESU division seminars, he gave presentations at the 1993 Great Plains Limnological Conference, 1993 Midwest Fish and Wildlife Conference, the 1993 and 1994 Kansas Chapter AFS annual meetings, and at the 1994 Southwestern Association of Naturalists annual meeting. Honors received include: 1993 AFS NCD Student Travel Grant award, 1993 AFS Kansas Chapter

Otto Tiemer Student Scholarship award, 1994 AFS Kansas Chapter Best Student Paper award, and 1993 AFS "honorable mention" Skinner Memorial award.

I, Jay D. Jeffrey, hereby submit this thesis to Emporia State University as partial fulfillment of the requirements for an advance degree. I agree that the Library of the University may make it available for use in accordance with its regulations governing materials of this type. I further agree that quoting, photocopying, or other reproduction of this document is allowed for private study, scholarship (including teaching) and research purposes of a nonprofit nature. No copying which involves potential financial gain will be allowed without written permission of the author.

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10 Jan. 1996

Date

Spring movements, regional fidelity, and spawning habitat of sauger (Stizostedion canadense) in Melvern Reservoir, Kansas, and the Global Positioning System for aquatic surveys.

Title of Thesis

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