TENNESSEE VALLEY AUTHORITY

River Basin Operations

Water Resources

DENSITY, MOVEMENT PATTERNS, AND SPAWNING CHARACTERISTICS OF SAUGER (*Stizostedion canadense*) IN CHICKAMAUGA RESERVOIR, TENNESSEE - 1988

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EXECUTIVE SUMMARY

The State of Tennessee, responsible regulatory agency overseeing power plant compliance activities within the boundries of the state, listed the sauger as a species of "special concern" in Chickamauga Reservoir in 1986 due to apparent declining populations. The Tennessee Valley Authority along with the Tennessee Wildlife Resources Agency initiated an intensive sampling program for sauger in 1986 to determine the status of the population and define any potential impacts of Sequoyah (SQN) or Watts Bar (WBN) Nuclear Plant operation on sauger reproductive success. This report covers the results of that study thru 1988.

The study monitored sauger movement patterns during the late winter-early spring spawning period enabling location of the spawning site, addressed various environment conditions potentially impacting the spawn, monitored annual densities of sauger migrating to upper Chickamauga Reservoir, and discussed potential impacts of operation of SQN and WBN on sauger spawning success based on knowledge gained about factors influencing the sauger spawn. Due to the apparent continual decline in sauger densities, it is recommended population estimates be continued through the 1991 spawning season. SQN and WBN were not operational during the spawning periods sampled in these investigations, and therefore could not have contributed to the decline, however sampling in the vicinity of the plants during a spawning period when a plant(s) is operational is recommended.

INTRODUCTION

In 1986, apparent declining populations led the State of Tennessee to list the sauger as a sport fish species of "special concern" in Chickamauga Reservoir. That same year, TVA initiated an intensive program in cooperation with the Tennessee Wildlife Resources Agency (TWRA) to determine the status of the Chickamauga sauger population and to identify potential impacts of operation of Watts Bar (WBN) and Sequoyah (SQN) Nuclear Plants on this important sport fish.

Results of the 1986 and 1987 sauger studies on Chickamauga Reservoir revealed the occurrence of significant changes in the population (Hevel 1988). From spring 1986 to spring 1987 the estimated number of adult sauger migrating to the Watts Bar tailwater decreased from 18,000+ to approximately 3,000 fish. A shift in the length-frequency from mainly age 2 fish in 1986 to age 3 fish in 1987 indicated a large 1984 year class dominated the sauger population followed by a lower density 1985 year class.

Hevel (1988) noted that densities of adult sauger in upper Chickamauga Reservoir are dependent upon reproductive success rather than fishing mortality or other human influences. Water temperature fluctuations and stream flow during the spawning period appeared to have the greatest impacts on sauger reproductive success.

Movement patterns identified during 1986-87 revealed a concentrating of adult sauger in the vicinity of Watts Bar Dam during the pre-spawn period, a downstream migration to the Hunter Shoals area at Tennessee River Mile (TRM) 520 to 521 immediately preceding the spawn (especially by males) and a general dispersal of fish after the spawn. The Hunter Shoals area, approximately seven miles downstream of WBN, was the only spawning site identified during 1986-87 studies.

This report presents results from the third year of this investigation. Objectives of the work during 1988 were to (1) continue monitoring sauger population characteristics and various habitat parameters to determine factors influencing population cycles, (2) monitor adult sauger movement patterns over a larger portion of the pre- and post-spawn periods to better describe timing of the spawning migration and post-spawn dispersal patterns, (3) characterize the habitat components of the Hunter Shoals spawning site, and (4) discuss potential impacts of operation of WBN and SQN based on knowledge gained about factors influencing sauger spawning success.

DESCRIPTION OF STUDY AREA

The study area in 1988 was the 15-mile reach of the Tennessee River immediately downstream from Watts Bar Dam (figure 1), the reach identified in 1986 and 1987 sampling to have the highest sauger catch rates. This section of Chickamauga Reservoir is essentially riverine with substrate characterized by gravel, cobble, bedrock and Asiatic clam (Corbicula sp.) shells overlain by very little siltation except for deep pool areas (TRMs 525, 523, and 519). Flows in this reach are controlled by hydroelectric turbine discharges from Watts Bar Dam, only infrequently augmented by spillway releases. Water temperatures fluctuate in response to discharges from the dam and environmental influences such as cold fronts and solar heating. During extended periods of zero discharge, weather conditions have more pronounced impacts.

SQN is located in the lacustrine section of Chickamauga Reservoir with the diffuser discharge at TRM 483.4 (TVA 1985). Heated discharge water can be routed one of three ways: (1) to the diffuser pond and out the diffuser pipes (open mode); (2) through the cooling towers, then to the diffuser pond and out diffuser pipes (helper mode); or (3) through the cooling towers and recirculated to the intake (closed mode) with only blowdown discharged through the diffuser pipes. Heated water is discharged through the diffuser at a velocity of 3 m/s. The average temperature increase across the system at full 2-unit operation is 16.4°C. SQN Unit 1 operated intermittently from April through July, then at essentially full load the rest of 1988. SQN Unit 2 was not operational throughout the study.

WBN is located in the more riverine section of upper Chickamauga Reservoir two river miles below Watts Bar Dam at TRM 528. WBN did not operate during the 1988 sample period. Both WBN and SQN pumped water through the cooling towers when not producing electricity, but there was no thermal load. When WBN becomes operational it will be in the closed cycle cooling mode. Two natural draft cooling towers for heat dissipation at WBN will discharge at a rate of between 1.3 and 2.4 m^3/s (45 and 85 cfs) through multiport diffusers into the main channel at TRM 527.8 (TVA 1986). During periods of no releases from Watts Bar Dam, discharges from WBN will be stored in a holding pond. Maximum releases through the diffuser will be less than 5.0 m^3/s when operation of WBN is combined with releases from the blowdown holding pond during Watts Bar Dam discharge periods. The expected temperature difference between WBN discharge and that of the river varies from 10°C during winter and spring to 5°C during summer and fall. The near-field dilution will be at least 15 and the far-field mixing will depend on releases from Watts Bar Dam. At the long-term average release, maximum diffuser discharge represents 0.6 percent of reservoir flow.

MATERIALS AND METHODS

The Watts Bar tailwater area (TRMs 515 to 529.9) was sampled from February through June 1988, with experimental and standard gill nets. Experimental gill nets consisted of five 6.1 m panels (25.4, 38.1, 50.8, 63.5 and 76.2 mm bar mesh size), while standard gill nets were 30.4 m x 2.4 m with 38.1 mm bar mesh. Use of experimental gill nets was discontinued after early March because few juvenile sauger were being captured and standard nets were more successful in collecting adults. Nets were routinely set perpendicular to the shoreline with both ends weighted which facilitated placement at any point across the channel or overbank. Netting was conducted at night when sauger are typically most active. In the vicinity of Watts Bar Dam, nets were set in the spilling basin, out of the current, during hydroelectric generation periods. To avoid high water velocities, it was necessary to set nets at Hunter Shoals when water was not being discharged from Watts Bar Dam. Nets were usually fished in areas productive during 1986 and 1987. Set times were limited to two hours when possible to reduce catch mortality.

Netting data were recorded on a generalized fish survey form. Information noted for each net included: date, location, time net was fished, and total number of each fish species collected. For each sauger captured, additional data recorded were: total length (mm), weight (g), sex (when identification was possible), and notation on whether or not the specimen was "free-flowing". Fish were considered free-flowing when eggs or milt could be observed after applying slight pressure to the ventral surface of the fish anterior to the vent. If applying pressure resulted in no milt or eggs, determination of sex could not be made. Scales for age and growth information were taken from at least 10 sauger in each age group using the method described by Jearld (1983).

Prior to release, each sauger was tagged with a numbered disc reward tag attached approximately one to two cm above the lateral line and below the posterior insertion of the dorsal fin. Tags were attached by slipping a numbered disc tag onto a 76.2 mm nickel pin which was inserted through the musculature of the fish. An unmarked disc was threaded onto the sharp end of the pin, the pin was cut off approximately one cm passed the unmarked disc and the remainder bent back towards the unmarked disc. The tag was attached loosely to the fish to allow room for growth. Tag numbers were recorded and the fish were released into the same area in which they were captured. A reward ($5) was offered by TWRA for each tag returned by fishermen.

More detailed distribution and movement information was obtained by radio-tagging 31 adult sauger. Low frequency transmitters (48-49 Mhz), each with a unique frequency, were attached to fish near the spiny dorsal fin by the method described by Woodward and Tomljanovich (1987) and illustrated in figure 2. After tagging, fish were retained in a live well for a short period to ensure recovery. Radio frequency of the tag and the release location were recorded prior to release.

Transmitter-tagged fish were relocated by triangulation of radio signals received during boat and airplane searches. Whenever these signals were encountered the frequency, date, time, and river mile were recorded on a radio tracking form. Airplane tracking was done weekly during daylight hours. Boat tracking was conducted during daylight and nighttime hours in association with gill netting.

Sauger spawning habitat on Hunter Shoals was described using scuba divers to obtain visual recordings of the substrate. Scuba divers used an underwater video camera to make recordings of the substrate along three bank to bank transects at Hunter Shoals. Transects were selected to include the approximate upstream, middle, and downstream portions of the identified spawning area. Divers followed a cable marked in meters, making video recordings whenever the substrate composition changed noticeably. A video cassette recorder was used in the laboratory to playback the tape for assignment of habitat characterization codes suggested by Brusven (1977). These codes describe the substrate based on the dominant particle size, subdominant particle size, and degree (percent) substrate particles are imbedded.

Depth recordings and current velocity measurements were also made. Water depth was determined using a chart recorder. Velocity measurements were taken using a digital current meter along two transects perpendicular to flow on the spawning site. Measurements were taken at locations 25, 50, and 75 percent of the width of the river and at 5-foot (152.4 cm) depth intervals from the surface to the bottom.

In the laboratory, sauger scales were pressed onto cellulose acetate slides. A magnified scale image was projected from a microscope equipped with a drawing attachment onto a digitizing pad attached to a personal computer. Annuli were electronically marked using the pad, simultaneously entering the data into the computer.

Data Analysis

Analysis of gill netting data in 1988 included catch per unit effort (number/hour) by species and length-frequency of sauger. Comparisons between catch rates and various environmental factors (i.e., water temperatures and Watts Bar Dam discharge rates) were made using linear regression. Log transformations were done when relationships were curvilinear.

The Thompson and Juday mark and recapture census method (Lackey 1974) was used to estimate sauger population size. Although some assumptions for a closed system were violated, this estimate of the number of spawning adult sauger provided the best available measure of abundance. This multiple census method of estimation is based on the formula:

$$N = \frac{\Sigma C_t m_t}{\Sigma r_t}$$

where N = estimated population size,
C_t = total fish taken on day t,
m_t = total number of marked fish at the start of day t,
$\Sigma C_t m_t$ = summation of the daily products of C_t and m_t to day t,
r_t = number of recaptures in the sample C_t, and
Σr_t = total recaptures during the experiment to day t.

Age and growth analyses were accomplished using software developed by Frie (1982). The direct proportion technique was used to calculate the linear relationship between total length and scale radius and total length at each age class prior to capture. Data obtained from sauger collected in spring 1988 were compared with those for sauger collected in 1986 and 1987 and to the average growth of sauger from mainstream reservoirs.

Relative weights (W_r) were calculated as a measure of fish condition. Relative weight is based on a percentage comparison of the observed weight per unit length with an accepted standard weight per unit length. It is calculated using the formula:

$$W_r = \frac{W}{W_s} \times 100$$

where W is the observed weight and W_s is the standard weight for a given length. Standard weights of sauger for comparison with Chickamauga fish were generated from length-weight relationships for all available historical sauger data from Tennessee River mainstream reservoirs.

Exploitation rate of sauger by fishermen was calculated by dividing the number of tag returns by the number of marked fish in the population (Lackey and Hubert 1977). This technique assumes tagged fish are subject to fishing and natural mortality at the same rates as the untagged population. Comparisons were made between the 1988 results and 1986 and 1987 data.

RESULTS

A total of 34 species of fish, including 5,565 individuals, was collected during 841 hours of experimental and standard gill netting in late-winter and spring 1988 (table 1). Skipjack herring and gizzard shad, with a catch per net hour (c/h) of 1.35 and 1.33, respectively, were most abundant in netting samples. Next were yellow bass and sauger with catch rates of 0.85 fish per hour each and channel catfish with 0.61 fish per hour. Catch rates of all other species were less than 0.50 individuals per hour.

Sauger Population Dynamics

The sauger catch rate of 0.85 fish per net hour in 1988 was much lower than those obtained in 1986 and 1987 (2.14 and 3.05 fish per net hour, respectively). This considerably lower catch rate in 1988, while reflecting a decrease in sauger densities, was also biased by variations in periods sampled between years. Sampling in 1986 and 1987 was restricted to the high sauger density March-April spawning period, whereas sampling in 1988 was conducted from early February until early June, to better describe timing of pre- and post-spawn movement. The additional sampling was done when sauger densities in the study area were low, thus reducing overall catch rates. Collections of other species were similar all three years except for a much higher catch rate of channel catfish in 1987 (2.27 fish per net hour) over that in the other two years (0.39 fish per net hour in 1986 and 0.61 fish per net hour in 1988).

A population estimate of sauger in upper Chickamauga Reservoir during spring 1988 spawning migrations also revealed a reduction in sauger abundance. Only 1,251 sauger were estimated to be utilizing this area of the reservoir during spring 1988 compared to previous estimates of 18,381 and 2,861 in 1986 and 1987, respectively (table 2).

Sauger growth in Chickamauga Reservoir, for all three years, exceeded average growth of sauger in Tennessee River mainstream impoundments for age 4 fish and two of the three years for age 5 fish (figure 3). No 5 year old sauger were aged in 1987. Growth for age 2 and 3 sauger was similar to average growth of sauger from all mainstream reservoirs. Age 1 fish from 1986 and 1988 samples grew more slowly than those of the historical data base while 1987 age 1 fish exceeded the mainstream average.

Inspection of length frequency percentages reveals one dominant year class (1984) throughout the three spring sampling periods (figure 4). In 1986 age 2 fish were most numerous, in 1987 age 3 sauger dominated numbers, and in 1988 age 4 fish were most prevalent. Similarly, it can be seen that the large 1984 year class was followed by a small 1985 year class and a much reduced 1986 year class.

Age 4 sauger made up 38 percent of the sauger population in 1987 and 27 percent in 1986, while age 4 fish in 1988 accounted for 63 percent of the sauger population. Hevel (1988) reported 90 to 95 percent mortality of age 3 and 4 sauger from upper Chickamauga Reservoir in 1986 and 1987. The low overall abundance of sauger in 1988, coupled with projected high mortality of the older fish dominating the population suggests that without a strong year class of sauger produced in upper Chickamauga Reservoir in 1987 or 1988 the population may fall to a point where adequate reproduction to sustain the population is not possible. Assessment of the 1987 year class, which should first be available for collection during the 1989 spawning migration, will help determine the seriousness of the situation.

The relative health of individual sauger in upper Chickamauga Reservoir in 1988 was good. The mean relative weight (W_r) of 105 was on the higher end of the average range for sauger in Tennessee River mainstream impoundments (100±5). These results are only moderately higher than those obtained in spring 1986 (W_r = 96) and 1987 (W_r = 98).

Fishermen Harvest Rate

Fishermen recaptures indicate a low exploitation rate of sauger in Chickamauga Reservoir. The exploitation rate for 1988 was six percent compared to eight percent and five percent in 1987 and 1986, respectively. As mentioned previously, estimates of sauger densities varied during the three spawning seasons with 18,000+ in 1986, about 3,000 in 1987 and approximately 1,250 in 1988. Sauger densities apparently have little bearing on the rate at which they are exploited.

Estimated numbers of sauger harvested from 1977 through 1987 (TWRA unpublished data) reveal highest harvest occurred during the late 1970s followed by a decline reaching lowest levels by 1982 (table 3). The harvest rate then began a slow increase until 1986, followed by a slight reduction in 1987. Sauger population densities estimated during the present study overlap TWRA harvest estimates only during 1986 and 1987. The estimated harvest during each of these years exceeded estimated population densities. A majority of the sauger harvest occurs during the late winter-spring period in the upper reaches of Chickamauga Reservoir. It is possible expansion of numbers of sauger creeled from this limited area and time frame to the entire reservoir and complete year overestimated the total harvest. Conversely, the population estimate includes only fish which migrate to the upper reservoir area. Any sauger which do not migrate upstream to spawn in the Tennessee River section of Chickamauga Reservoir would not be included in the 1986-87 density estimates. Hevel (1988) conducted considerable netting sampling in the Hiwassee River section of the reservoir (only other major tributary) and from the mouth of the Hiwassee (TRM 500) upstream to Watts Bar Dam and did not locate any concentrations of sauger other than those near Watts Bar Dam and in the Hunter Shoals area.

Sauger Reproduction

Sauger Spawning Movement Patterns

Movement patterns of sauger prior to, during, and after the spawn were monitored with gill net catch rates throughout the sample period, recaptures of disc-tagged fish from netting samples and fishermen returns, and tracking of radio-tagged fish. Gill netting in 1988 was conducted during pre-spawn, spawn, and post-spawn periods in areas known to maintain sauger concentrations. Sauger catch rates generally increased along with water temperature until peak spawning in early April (figure 5). As in 1987 and 1986, there was a shift in the distribution of adult sauger from the vicinity of Watts Bar Dam downstream 8.9 river miles to the Hunter Shoals area (TRM 521) as the water temperature approached 11°C. Catch rates at Hunter Shoals remained high until water temperatures approached 19°C on May 2. Similar declines in catch rate occurred in 1987 by April 16 and by

April 30 in 1986. These declines indicate the end of the sauger spawn for the corresponding year. Comparison of discharge rates from Watts Bar Dam with catch rates in 1988 revealed no distinct relationship (figure 5), as discharge rates were only high during the pre-spawn period in February 1988.

Tag returns by fishermen in 1988 indicate sauger dispersed from Hunter Shoals and distributed throughout Chickamauga Reservoir after spawning. Some sauger concentrated at the Blythe Ferry area (TRM 499.5) immediately after the spawn, and some stayed below Watts Bar Dam through September (figure 6). Similar concentrations were not noted at the Blythe Ferry area in 1986 and 1987, but some fish did remain in the vicinity of the dam during both years. Only 3 percent of the sauger returned by fishermen had moved through a dam (Watts Bar) during 1988 compared to 14 percent moving through both upstream and downstream dams in 1986 and 1987.

Radio-tracking

Sauger radio-tagged in February, March, April, and May (table 4) provided more comprehensive information on the movement patterns of adult sauger during late winter, spring, and early summer 1988. Sex of sauger radio-tagged in the present study during the pre-spawn period could not be positively determined without dissection; however, previous studies of sauger spawning behavior have revealed distinctly different movement patterns of the two sexes. Saylor et al. (1983) and Hevel (1988) found that sexually mature male sauger arrive on the spawning grounds prior to mature females, and individual males remain there throughout the spawning season. Priegel (1970) reported similar male movement patterns for walleye with females appearing on the spawning grounds only when imminently ready to spawn. Therefore radio-tagged sauger that left the dam and moved downriver to the Hunter Shoals area and stayed during the spawning period are considered to be males in this report. Saylor et al. (1983) noted adult female sauger congregating in staging areas (i.e., deep pools not far from the spawning grounds) until spawning commenced. Random movements outside the Hunter Shoals spawning area and/or a tendency to remain in the immediate vicinity of Watts Bar Dam until peak spawning were considered indicative of female spawning behavior in the present study.

Pre-spawn sauger, those radio-tagged in February and March immediately below Watts Bar Dam, exhibited three different movement patterns. Some fish exhibited a typical male movement pattern moving from the dam to areas on or adjacent to Hunter Shoals during late March (figures 7 and 8). Another group of fish showed more random movements, typical of females, with only occasional sitings on or near the spawning grounds (figures 9, 10, and 11). Some of the latter fish made several passes through Hunter Shoals, also suggestive of spawning females. A third pattern involved four radio-tagged fish remaining in the vicinity of Watts Bar Dam or just downstream throughout the spawning period (figures 12 and 13).

Pre-spawn sauger respond to a strong instinct to migrate upstream, and have been found to pass through upstream dams (Cobb 1960). Three other sauger tagged during the pre-spawn period in the present study moved upstream through the navigation lock at Watts Bar Dam (figure 14). All of these fish migrated to the Fort Loudoun Dam tailwater area of upper Watts Bar Reservoir, one prior to and two after the late March-early April sauger spawning period. One of the latter fish moved downstream 18 river miles passing through the Hunter Shoals area prior to moving back upstream through Watts Bar Dam in late April. This sauger probably spawned in upper Chickamauga Reservoir prior to entering Watts Bar Reservoir. The sauger which moved through the dam and migrated to Fort Loudoun Dam tailwater prior to the spawning period probably spawned in upper Watts Bar Reservoir.

Ripe known-sex sauger (six males and four females) radio-tagged and released at Hunter Shoals during April gave general information on post-spawn dispersal patterns for males and females. Five males gradually left the shoal area for nearby downstream areas and distributed haphazardly following the spawning season (figure 15). The other male tagged April 5 moved through Watts Bar Dam to a point 50 miles upstream by April 13 (figure 16). Two female sauger tagged during the spawn moved upstream to Watts Bar Dam from the the Hunter Shoals area with one going through the dam over 40 river miles into Watts Bar Reservoir prior to returning to the shoal in mid April (figures 16 and 17). The other two females either lost their tags or died shortly after release as no movement was noted for these fish.

Throughout the 1988 sampling period, 23 percent of the sauger radio-tagged in upper Chickamauga Reservoir moved through Watts Bar Dam, proving that it is not a major barrier to upstream migration. Aerial scanning for radio-tagged fish was not done in 1987, therefore movement through dams to adjacent reservoirs was not monitored. No sauger were radio-tagged in 1986.

Environmental Influences on Spawning

Nelson (1968) reported sauger year class strength to be dependent upon magnitude of daily water level fluctuations during the incubation period in Lewis and Clark Lake, Nebraska. Sauger were spawning in less than two feet of water in the headwaters of Lewis and Clark Lake, and thus, years with water level fluctuations greater than three feet left a majority of the eggs exposed to the air for extended periods. Sauger in upper Chickamauga Reservoir spawned in water approximately 5 to 9 m deep (16 to 30 feet); therefore water level fluctuation is not a limiting factor in the Watts Bar tailwater area.

Two environmental factors Hevel (1988) reported to influence the onset and success of sauger spawning in upper Chickamauga Reservoir were changes in water temperature and variations in flows (i.e., discharges through Watts Bar Dam). He reported a positive correlation (0.01 level) between water temperature and percentage of sauger in spawning-ready condition in Watts Bar Dam tailwaters in 1986. The same year there was a significant (0.05 level) inverse correlation between Watts Bar Dam mean nighttime discharge rates in April and percent of sauger collected in spawning condition. Sauger generally spawn between sunset and sunrise (Nelson 1968, Scott and Crossman 1973, and Robison and Buchanan 1988); therefore discharges during this time period were considered most important. However, neither water temperatures nor night discharge rates correlated with sauger gravidity rates in 1987. During the present study, percentage of free-flowing adult sauger was again highly correlated (significant at the 0.01 level) with water temperature, but not with April night discharges from Watts Bar Dam (figure 18). It is apparent water temperature does influence sauger readiness to spawn, and thus timing of spawning, during most years. Conversely, discharge rates from Watts Bar Dam generally have limited direct influence on the onset of sauger spawning.

A closer inspection of the progression of percent gravid sauger through the sample period during spring 1988 reveals when most sauger reached a spawning-ready state (figure 19). Approximately 25 percent of the adult sauger were free-flowing through March 28 in 1988. On March 29, over 80 percent were in a free-flowing condition. There was no sharp water temperature increase between the two dates (11.1 to 11.5°C) or on any date previous suggesting the triggering factor was not a rapid rise in water temperature. Discharges through Watts Bar Dam during this time were at a constant and low level also indicating limited influence on inception of spawning.

Hassler (1953) and Koenst and Smith (1976) suggested a slow increase in water temperature was necessary to produce strong sauger year classes. Gradual warming trends in water temperature are known to produce strong year classes of walleye in Lake Erie (Busch 1975). Hevel (1988) indicated a gradual rise in water temperature in spring 1987 produced more sustained sauger spawning activity than fluctuating temperatures during spring 1986 in upper Chickamauga Reservoir. Water temperature variations in 1986 postponed the spawn to a point where temperatures approached lethal levels for sauger eggs (Hevel 1988). Water temperatures during 1988 maintained a slow rise through mid-April with over 50 percent of the population remaining in spawning readiness from March 29 to April 13 supporting the theory of positive impacts of gradually rising water temperatures on sustained sauger spawning activity.

Water quality measurements taken in 1988 revealed little change in either dissolved oxygen levels, conductivity, or pH throughout spring sampling (table 5). Therefore, no correlations were attempted between sauger gravidity and these parameters.

Scott and Crossman (1973) reported that sauger thrive and reproduce best in turbid environments. They theorized turbidity prevents excessive egg adhesion and thereby reduces potential for suffocation. The headwater areas of reservoirs on the Tennessee River are typically somewhat turbid, especially during spring. However, Tennessee has been in a severe drought during the 1980s and water clarity in the Tennessee River has been unusually high. The population decline during this period may be a result of the drought. Similar declines in sauger densities have been noted in other Tennessee River and tributary impoundments during the 1980s (Saylor et al. 1983, Woodward and Tomljanovich 1987, and Buchanan 1989). When spring rainfall returns to more normal levels it will be possible to monitor the effects of increased turbidity on sauger reproductive success.

Spawning Habitat Description

Hevel (1988) pinpointed an area a few hundred meters above Hunter Shoals as the site most used by sauger for spawning. This is a transition area from deep pool (9 m depth) to shoal (5 m depth). Current velocities near the bottom during zero discharge at Watts Bar Dam range from 4.27 cm/s (0.14 ft/sec) in the pool to 6.83 cm/s (0.224 ft/s) on the shoal. The optimal velocity for sauger spawning, incubation of eggs, and survival of larvae ranges from 9.1 to 61.0 cm/s (0.3 to 2.0 ft/s), while zero velocities are thought to be unsatisfactory (Crance 1986). Brusven's (1977) substrate characterization codes revealed the spawning site consists mainly of small, loosely-imbedded gravel with some areas dominated by large gravel, small and large cobble, and small boulders (table 6). Corbicula shells were numerous over large portions of the habitat and, due to size, were considered as small gravel substrate. Crance (1986) reported cobble/rubble (64 - 250 mm) substrates to be optimal for sauger spawning. Most spawning sauger in the Hunter Shoals vicinity, as evidenced by collection of free-flowing females in gill nets, were captured over large cobble substrate at mid-stream in the old river channel.

DISCUSSION

Harvest estimates indicate the sauger population in Chickamauga Reservoir declined from peak densities in the late 1970s to lowest levels in the early 1980s. Harvest gradually increased through 1986, showing a slight downturn in 1987. Population estimates over the 1986-88 period reveal adult sauger densities have dropped from an estimated 18,000+ in 1986 to less than 1,300 in 1988. Fishermen exploitation rates remained similar over the 1986-88 study period (five to eight percent) indicating fishing mortality is not a major cause of decreasing sauger abundance. The primary reasons for the declining abundance from 1986 through 1988 were the weakness of the 1985 and 1986 year classes and high mortality of older age classes. Fluctuations in water temperature during the 1986 sauger spawning period delayed both sauger maturation and spawning activity to a point where water temperatures approached lethal levels for sauger eggs and likely reduced survival. Gradual warming during the 1987 spawning season produced more sustained spawning activity at lower temperatures. However, because yearling sauger are generally not collected during spring sampling in reservoir headwaters, the first definitive information on success of the 1987 sauger spawn will be provided by sampling in 1989.

Sauger congregate below Watts Bar Dam in pre-spawning condition from early February until late March. As the water temperature approaches 11°C a majority of the adult male sauger move downstream to the Hunter Shoals spawning area and remain there until the water temperature warms to 19°C by early May. Females wait until imminently ready to spawn, move onto the spawning area, spawn, and leave the area, all over a period of only a few hours. Spawning activity is highest at the end of March and continues about two weeks into April, depending on water temperature. After spawning ceases, sauger generally disperse haphazardly both upstream and downstream.

Water temperature, especially a gradual rise, was the only condition which correlated with progression of spawning maturity and time of the spawn. The operation schedule of Watts Bar Dam is a major influencing factor on water temperatures in the sauger spawning area of upper Chickamauga Reservoir. More consistent releases from the dam result in less variation in downstream water temperatures. High turbidity could not be evaluated as a factor influencing spawning because the Tennessee River Valley experienced a severe drought during the three years of study and turbidity was consistently low. Reduced turbidity is considered unfavorable for sauger reproductive success and may be the major factor affecting the population decline. When spring rainfall returns to more normal levels it will be possible to monitor effects of turbidity on sauger reproductive success.

Scott and Crossman (1973) and Robison and Buchanan (1988) report sauger spawn over gravel to cobble size substrate in 2 to 12 feet (0.6 to 3.7 m) of water. Detailed study of the Hunter Shoals spawning area found a substrate composed mainly of small gravel, but including areas of larger gravel and cobble. Most sauger spawning activity occurred in the transitional area between a 9 m deep pool and the 5 m deep shoals on the upstream side of Hunter Shoals over large cobble substrate.

Inter-reservoir movement of adult sauger was again documented in 1988. Only 3 percent of the disc-tagged sauger returned by fishermen had traversed through a dam (Watts Bar); however, 23 percent of the radio-tagged sauger in 1988 passed through Watts Bar Dam, with some individuals moving back downstream through the dam. This level of inter-reservoir movement supports the theory of considerable integration of reservoir sauger populations proposed by Hevel (1988). From this, it is evident key spawning areas in one reservoir may supply or supplement sauger year classes in other reservoirs. This could either magnify or reduce impacts from operation of TVA facilities. In the case of WBN and SQN, any negative effects these plants might have upon sauger spawning success in upper Chickamauga Reservoir have the potential of negatively impacting populations in a number of both upstream and downstream reservoirs. Conversely, if sauger spawn in adjacent reservoirs, movement into Chickamauga could mitigate any adverse impacts caused by either plant. However, spawning sites in adjacent reservoirs have not been searched for to date. Tennessee Tech University will be conducting a study similar to the present investigation during spring 1989 in upper Watts Bar Reservoir.

SQN and WBN were not operational (no thermal loading) during 1986, 1987, and 1988 sauger spawning seasons and could not have had any impacts on the success of the sauger spawn during these years. The sauger spawning area near Hunter Shoals is over 35 river miles upstream from the discharge at SQN. The main concerns of SQN operation on the success of the sauger spawn in upper Chickamauga Reservoir involve attraction of fish to the diffuser area. This attraction could detour movement of fish from the spawning shoals and the altered temperature regime could upset the synchrony of the spawning readiness of the sauger if the fish did continue on to the spawning site. SQN operated intermittently in 1988 after the major spawning run had occurred. Assuming the plant remains operational, sampling in 1989 and 1990 should provide more concrete data concerning impacts of SQN on sauger migrations.

WBN has a higher potential for adverse impacts as this plant is located seven river miles above the spawning area. However, discharge from WBN will seldom exceed 2.4 m^3/s and never over 5 m^3/s (maximum of 0.6 percent of the flow past the plant). Water temperature fluctuations caused by plant operation will not influence conditions at Hunter Shoals due to the rapid dilution of the heated water. The potential for WBN to influence sauger distribution is again mainly diversion of adults to the diffuser area instead of the spawning site and possibly altering the rate which sauger become ready to spawn as a result of the localized increase in water temperature. Once WBN becomes operational, sampling in the vicinity of the diffuser during the pre-spawning and spawning periods will have to be completed to evaluate the impacts of plant operation on the sauger spawn.

Recommendations

If 1989 sampling does not show a reversal in the trend of a declining sauger population, i.e., the 1987 year class appears in low densities on the spawning area, then production of the 1988 year class should be sampled in 1990 to evaluate its strength. Mark and recapture techniques would again be used to estimate adult sauger densities. Continued use of TWRA reward tags would allow additional detail concerning inter-reservoir movement and harvest rates of sauger. Gill net sampling in the vicinity of the SQN diffuser during the 1990 spawning migration, assuming the plant is operational, would determine if plant operation diverts migrating fish from the spawning site.

Once WBN goes on line, netting throughout sauger pre-spawn, spawn, and post-spawn periods should be conducted at Watts Bar Dam, the WBN diffuser, and Hunter Shoals to determine affects of plant operation on the spawning migration. Monitoring of water temperatures at the three sample areas using continuous reading devices would reveal the extent of plant influence on water temperature.

A return to a normal rainfall pattern for the Tennessee Valley in spring 1989 would tend to stabilize discharges from Watts Bar Dam and increase turbidity levels. If discharges can be maintained continuously throughout the 1989 spawning season with minimum flows of approximately 2000 cfs, temperature reversals would be minimized resulting in optimal conditions for a successful 1989 year class. Sampling in 1991 would verify this projection. Measurements should be taken in 1990 and 1991 to define turbidity levels during the spawning periods.

Although beyond the constraints of this project, if the sauger population continues to decline, supplemental stocking of fry or fingerling sauger may be necessary to sustain the population until favorable conditions exist to produce strong year classes. Without a boost to the population or a return to adequate spawning conditions, the sauger population in Chickamauga Reservoir and possibly those in other upper Tennessee River reservoirs are in jeopardy. Determination of when supplemental stocking is necessary and how many are required would be the responsibility of TWRA.

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Table 1. Species list, number collected, catch per hour, and relative abundance (%) of fish encountered during spring gill netting at upper Chickamauga Reservoir, 1988 (Total effort consisted of 841.2 hours).

Common Name	Number Collected	Catch per hour	Relative Abundance (%)
Spotted gar	1	0.00	0.02
Longnose gar	59	0.07	1.06
Shortnose gar	1	0.00	0.02
Skipjack herring	1138	1.35	20.43
Gizzard shad	1120	1.33	20.13
Threadfin shad	2	0.00	0.04
Mooneye	204	0.24	3.67
Golden shiner	1	0.00	0.02
White sucker	1	0.00	0.02
Northern hogsucker	2	0.00	0.04
Smallmouth buffalo	16	0.02	0.29
Spotted sucker	218	0.26	3.92
Black redhorse	4	0.00	0.08
Golden redhorse	10	0.01	0.13
Blue catfish	92	0.11	1.65
Channel catfish	514	0.61	9.24
Flathead catfish	12	0.01	0.22
White bass	343	0.41	6.16
Yellow bass	719	0.85	12.92
Striped bass	8	0.01	0.14
Rock bass	11	0.01	0.20
Warmouth	3	0.00	0.05
Bluegill	9	0.01	0.16
Redear sunfish	8	0.01	0.14
Smallmouth bass	1	0.00	0.02
Spotted bass	7	0.01	0.13
Largemouth bass	1	0.00	0.02
White crappie	6	0.01	0.11
Black crappie	16	0.02	0.29
Yellow perch	20	0.02	0.36
Sauger	713	0.85	12.81
Walleye	12	0.01	0.22
Freshwater drum	281	0.33	5.05
Totals	5565	6.62	100.00

Table 2. Estimated population densities of sauger in upper Chickamauga Reservoir during spring 1986, 1987, and 1988.

YEAR	POPULATION ESTIMATE	CONFIDENCE INTERVAL
1986	18,381	10,482 - 58,905
1987	2,861	2,506 - 3,254
1988	1,251	1,066 - 1,515

Table 3. Estimated numbers of sauger harvested from Chickamauga Reservoir in 1977-87 and estimated population densities for 1986-88.

Year	Estimated Harvest	Population Density
1977	15,295	
1978	55,661	
1979	66,053	
1980	19,722	
1981	17,824	
1982	2,560	
1983	6,045	
1984	11,473	
1985	12,312	
1986	22,293	18,381
1987	16,396	2,861
1988	------	1,251

Table 4. Release dates, locations, radio frequencies (mhz), lengths, weights, and sex (when known) of radio-tagged sauger from the Tennessee River below Watts Bar Dam (TRM 529.9) and Hunter Shoals (TRM 521.3).

Frequency	Release Date	River Mile	Length	Weight	Sex
49.033	02/01/88	529.9	447	974	Unk
49.040	"	"	503	1487	"
49.050	"	"	447	1016	"
49.090	"	"	476	1274	"
49.111	"	"	461	985	"
49.131	"	"	493	1548	"
49.139	"	"	437	1042	"
49.151	02/03/88	"	-	-	"
49.180	"	"	470	983	"
49.191	"	"	482	1179	"
49.212	03/02/88	"	470	954	"
49.219	"	"	460	1148	"
49.231	"	"	470	1100	"
49.241	"	"	463	1023	"
49.269	"	"	483	1147	"
49.291	"	"	460	1129	"
49.310	"	"	458	1324	"
49.330	"	"	517	-	"
49.340	03/16/88	"	491	1274	"
49.361	"	"	480	1117	"
49.351	04/06/88	521.3	491	1420	F
49.370	"	"	456	929	M
49.391	"	"	446	956	M
49.419	"	"	460	995	M
49.459	"	"	475	1036	F
49.500	"	"	465	1058	M
49.543	"	"	487	1242	M
48.562	04/07/88	"	493	1420	F
49.562	"	"	484	1110	M
49.582	04/08/88	"	466	1120	F
49.600	05/04/88	"	453	720	M

Table 5. Water chemistry near the substrate at collection locations in upper Chickamauga Reservoir on sample dates during spring 1988.

Sample Date	D.O. (mg/1)	Conductivity (ohms/cm)	pH	Water temperature (°C)
2-01-88	11.4	.160	7.7	6.4
2-02-88	11.4	.159	7.5	6.9
2-04-88	12.3	.169	7.8	6.7
2-08-88	12.3	.165	8.3	5.8
2-09-88	12.7	.165	8.2	5.8
3-01-88	12.3	.177	6.8	7.5
3-02-88	11.9	.172	7.8	7.3
3-03-88	-*	-	-	-
3-16-88	-	.173	8.7	8.9
3-17-88	12.0	.175	8.0	9.0
3-22-88	12.6	.181	7.6	10.2
3-28-88	12.2	.185	8.5	11.2
3-29-88	12.1	.194	7.2	11.9
3-30-88	11.1	.176	7.8	11.7
4-04-88	-	-	-	-
4-05-88	10.6	.177	7.8	12.8
4-06-88	10.0	.177	8.0	12.4
4-07-88	10.0	.176	7.9	11.8
4-13-88	9.4	.169	7.1	13.3
5-02-88	6.6	.166	7.8	16.7
5-03-88	6.4	.166	7.9	16.8
5-04-88	6.9	.172	7.5	16.8
5-05-88	6.8	.167	7.9	16.5
5-10-88	6.0	.170	7.3	17.3
5-12-88	7.2	-	-	18.7

*Measurement not taken

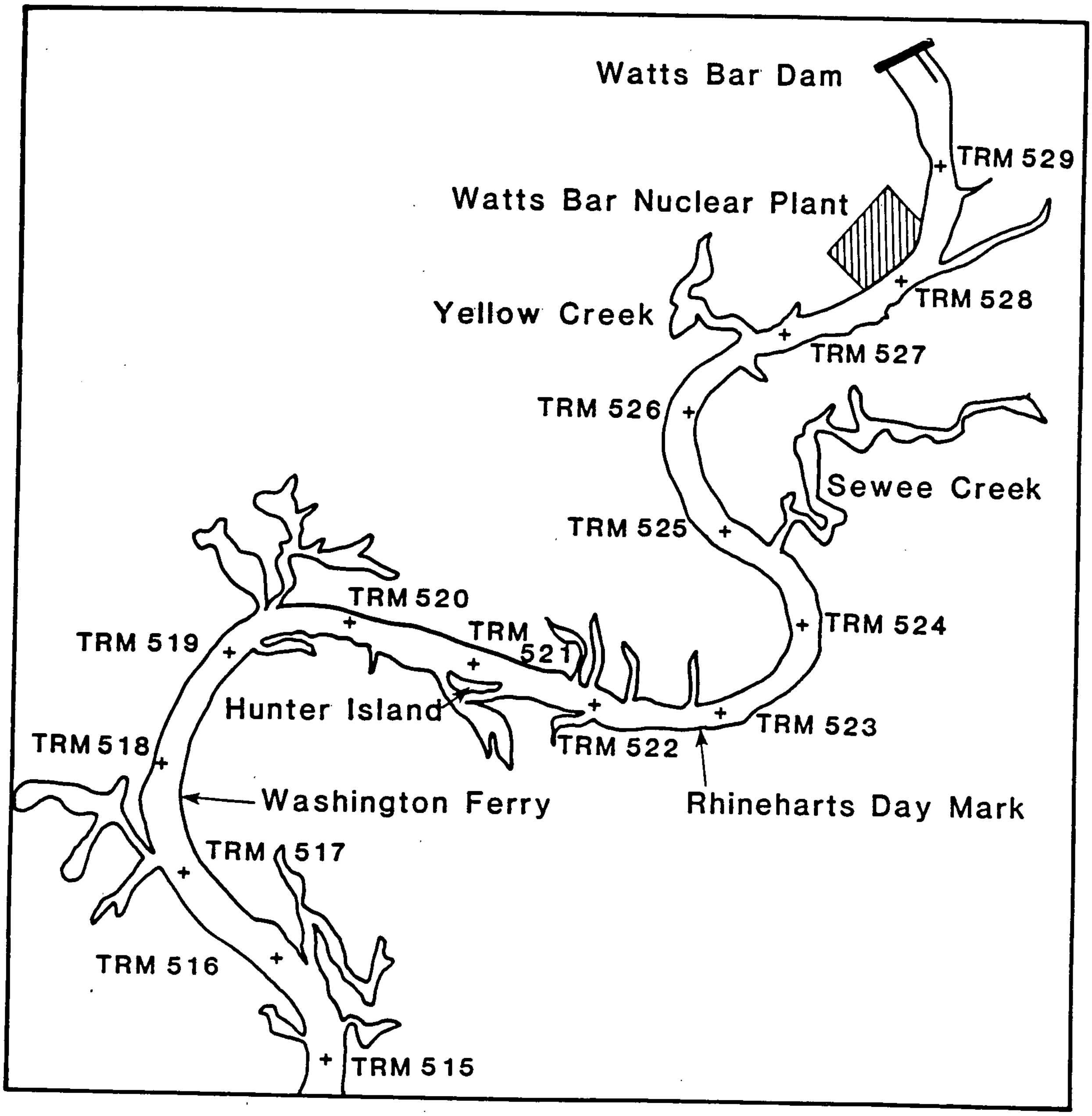


Figure 1. Location of Study Site (TRM 515.0-529.9) in the Watts Bar Tailwater area (Chickamauga Reservoir) of the Tennessee River.

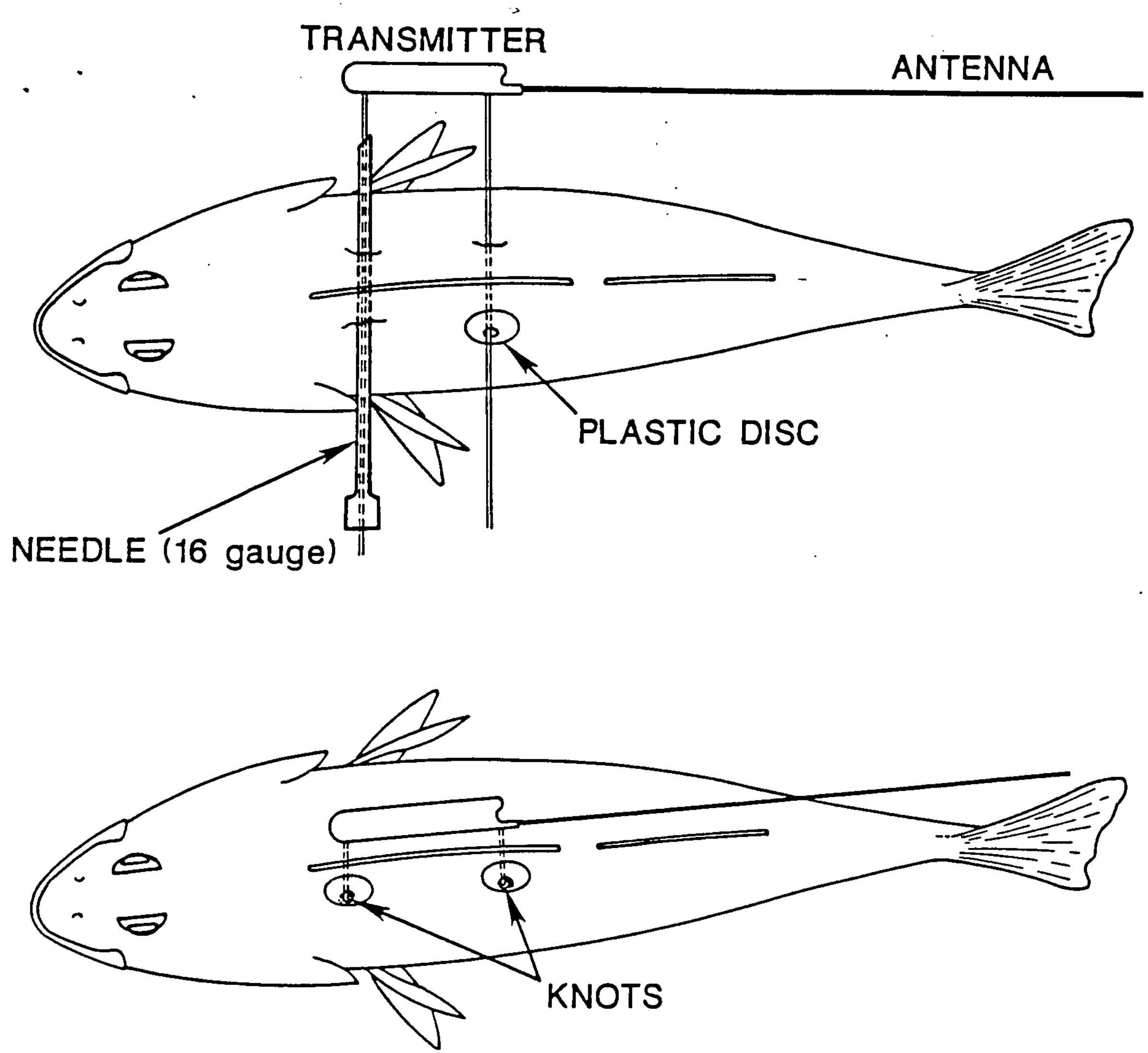


Figure 2. Method of attachment of radio tags from Hevel (1988).

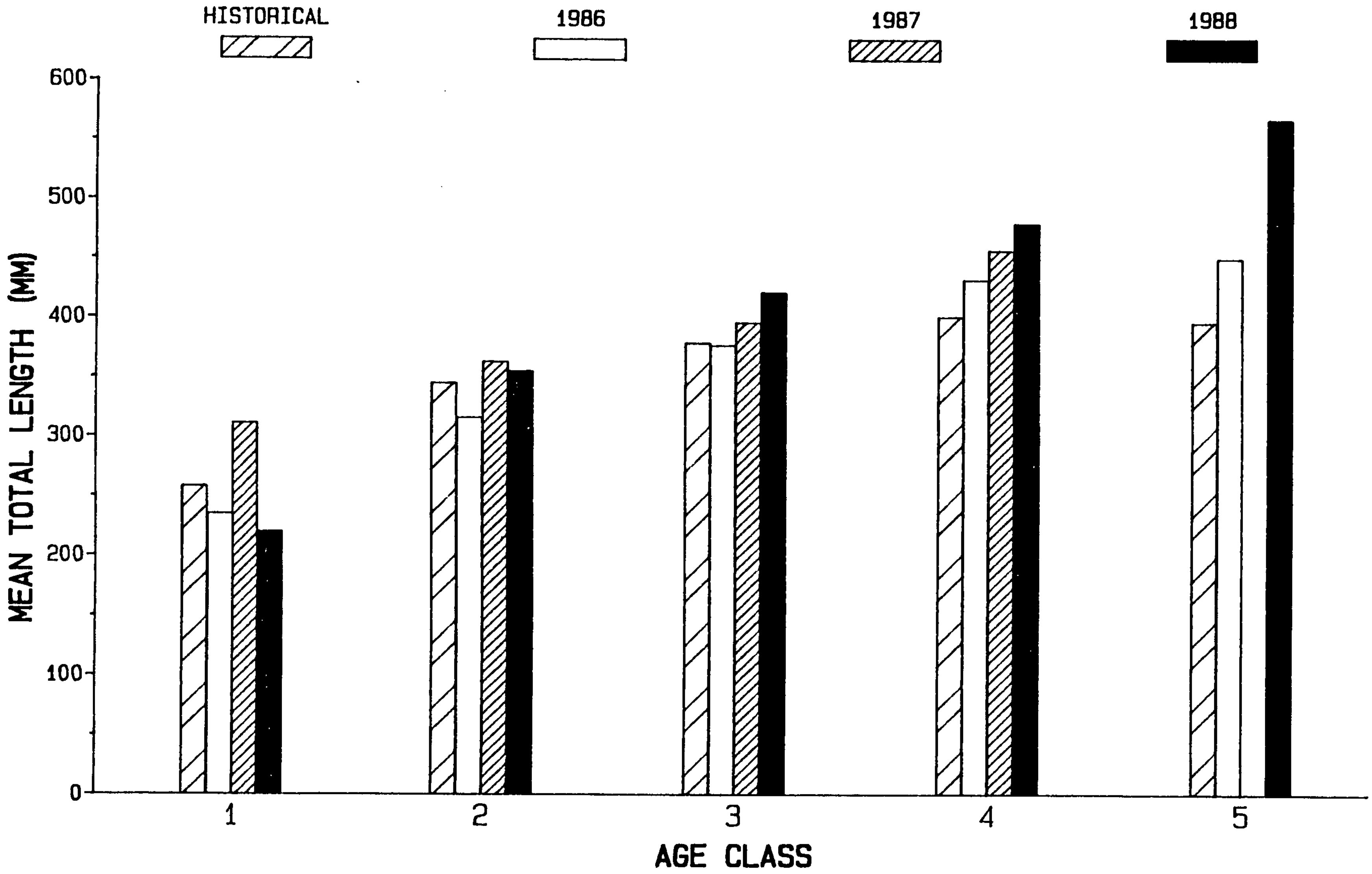


Figure 3. Comparison of mean total lengths of sauger at each age class for Tennessee River mainstream reservoirs (historical) and those collected from upper Chickamauga Reservoir during spring 1986, 1987, and 1988.

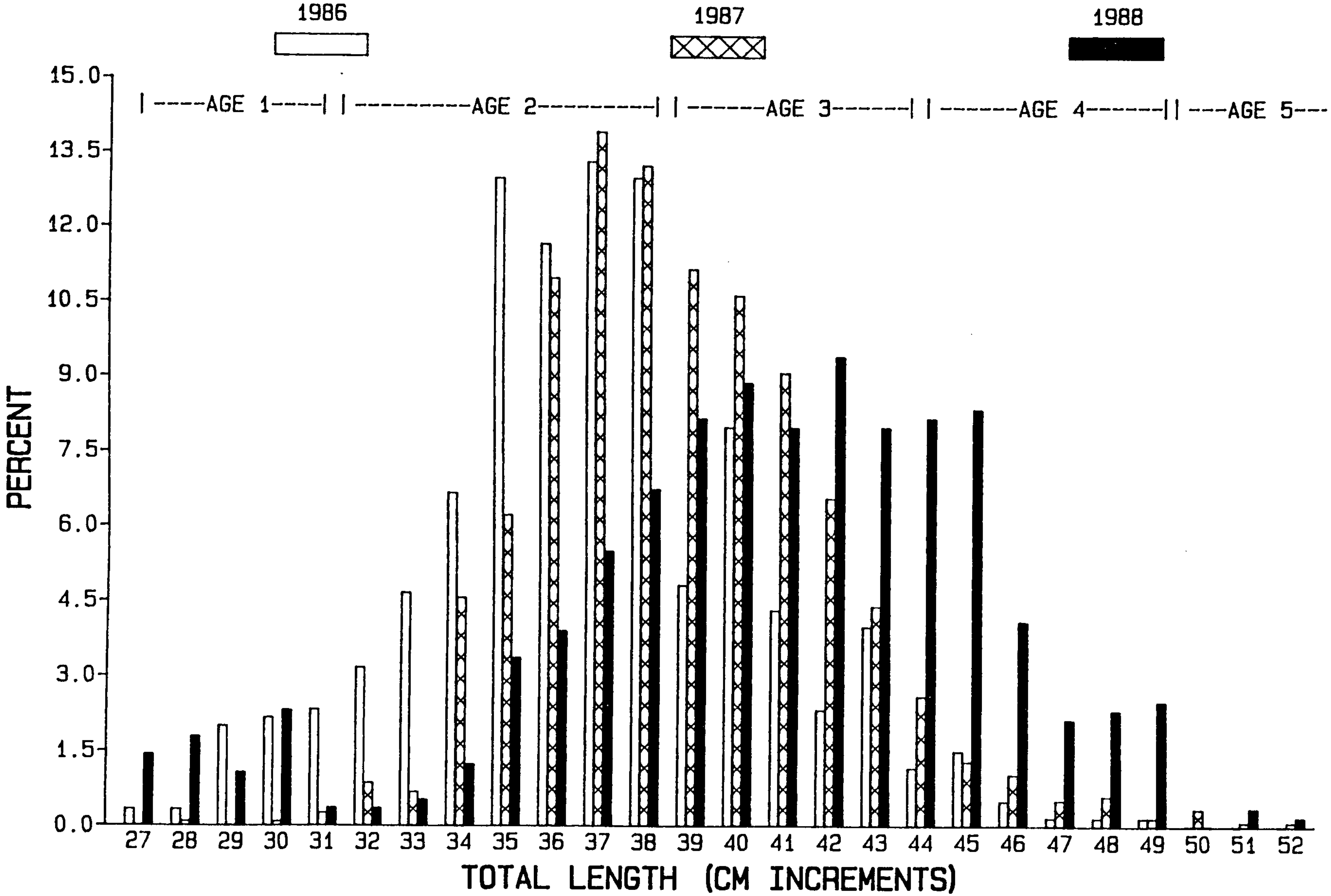


Figure 4. Annual percent length frequency and approximate age groupings of sauger captured with gill nets in upper Chickamauga Reservoir during spring 1986, 1987, and 1988.

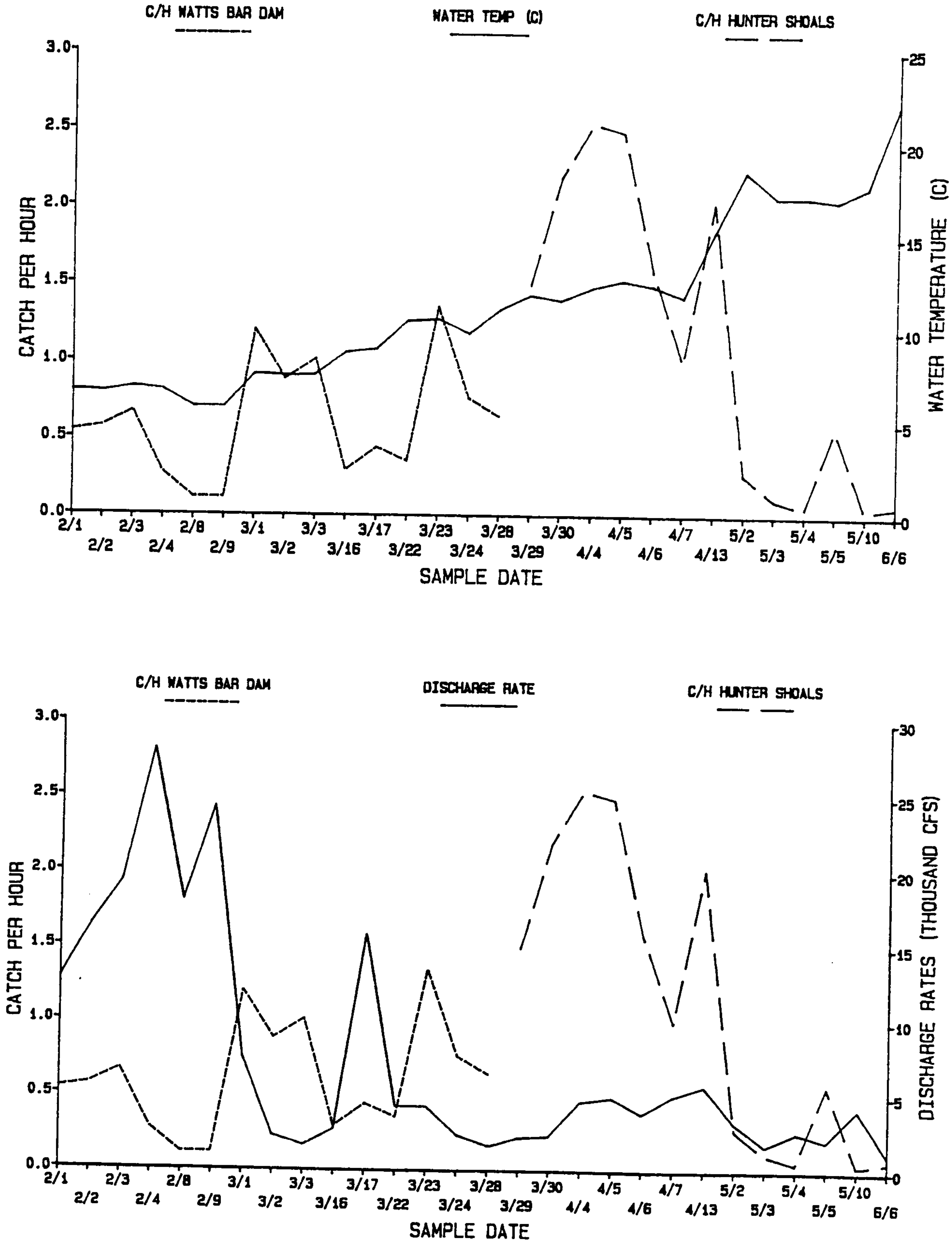


Figure 5. Comparison of sauger catch rates at two sites in upper Chickamauga Reservoir with water temperature and Watts Bar Dam discharge rates throughout the 1988 sampling period.

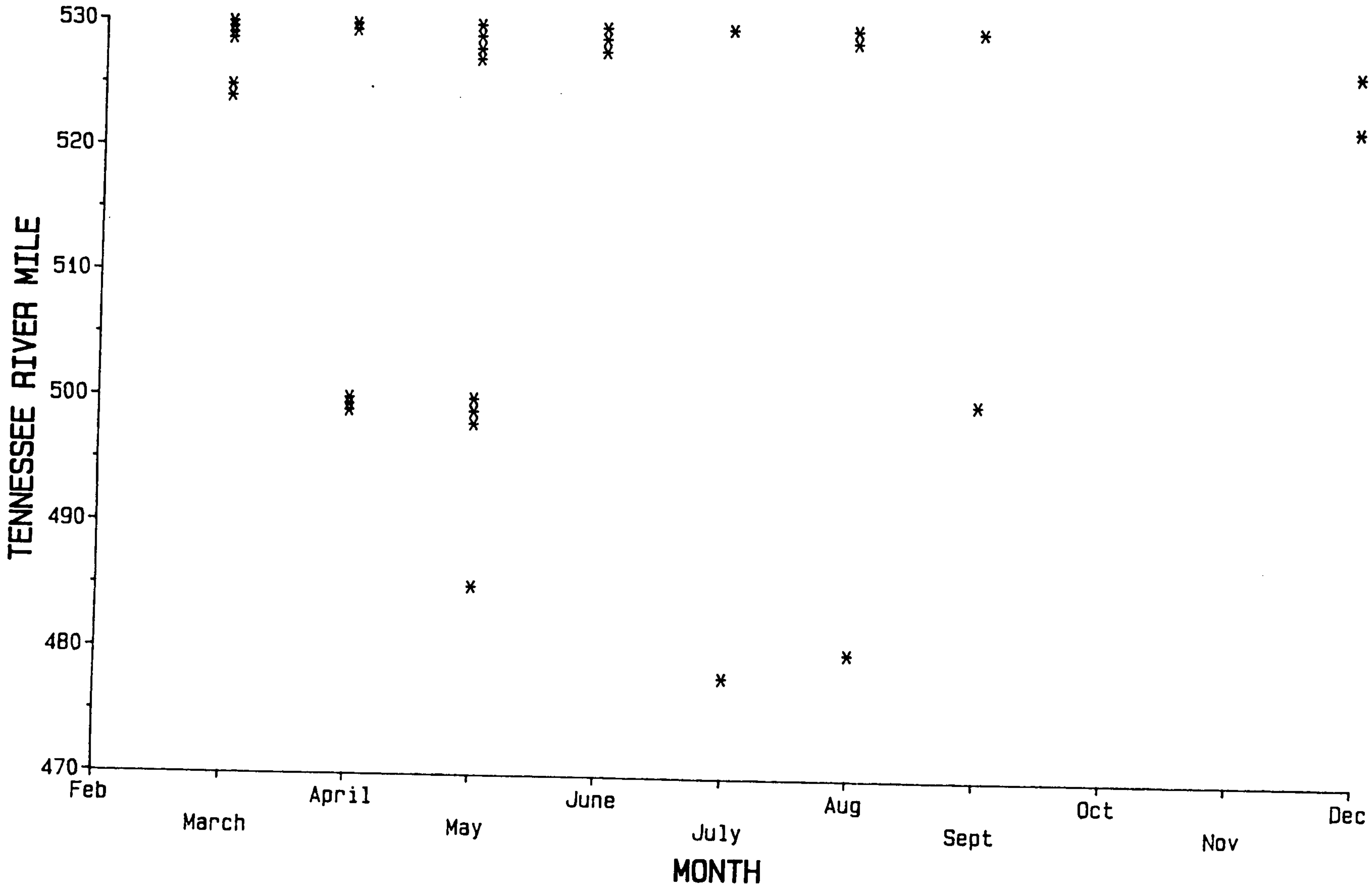


Figure 6. Distribution of disc-tagged sauger when caught by fishermen during 1988.

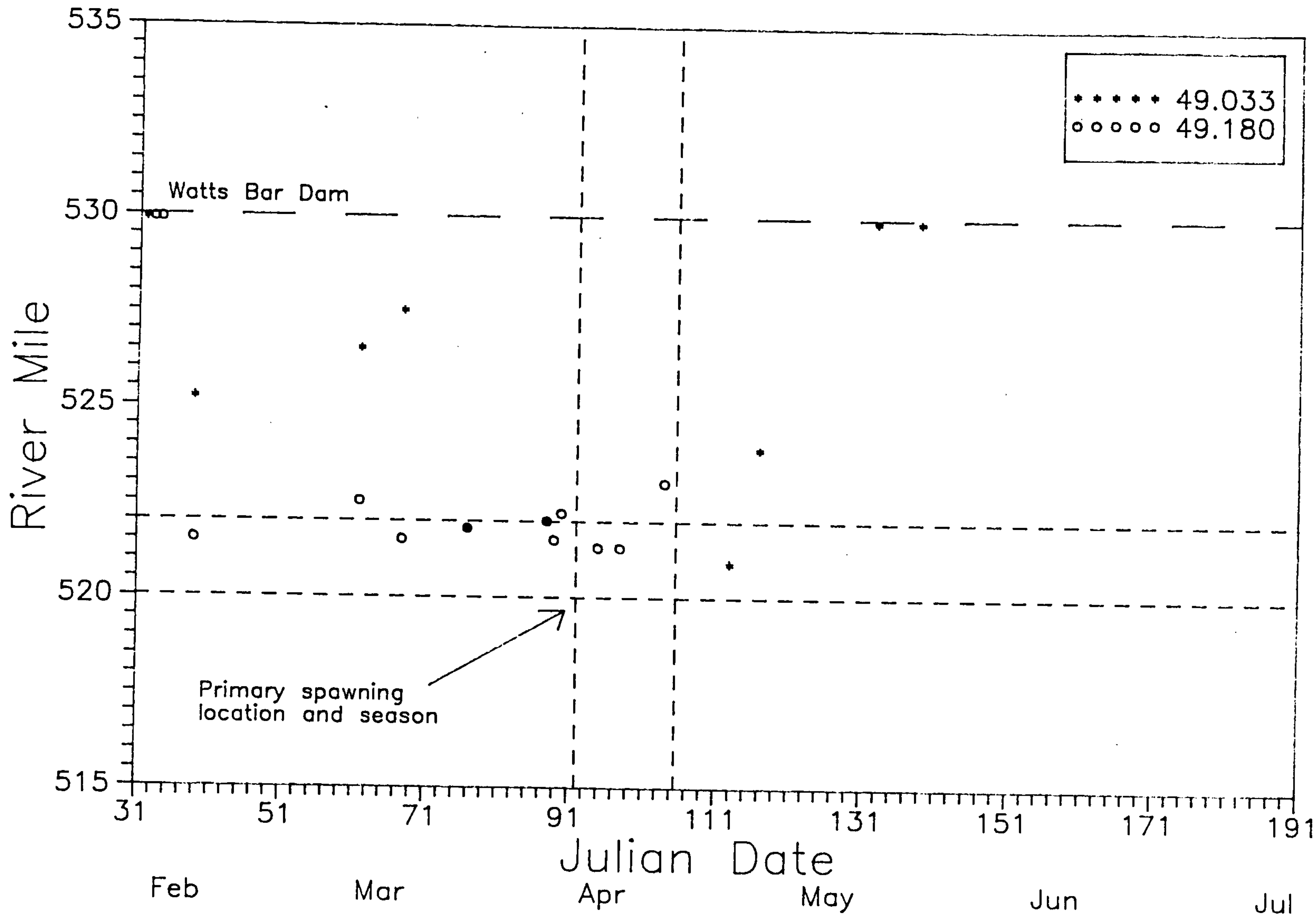


Figure 7. Locations of radio-tagged sauger released below Watts Bar Dam during February 1988 which exhibited male spawning movement patterns.

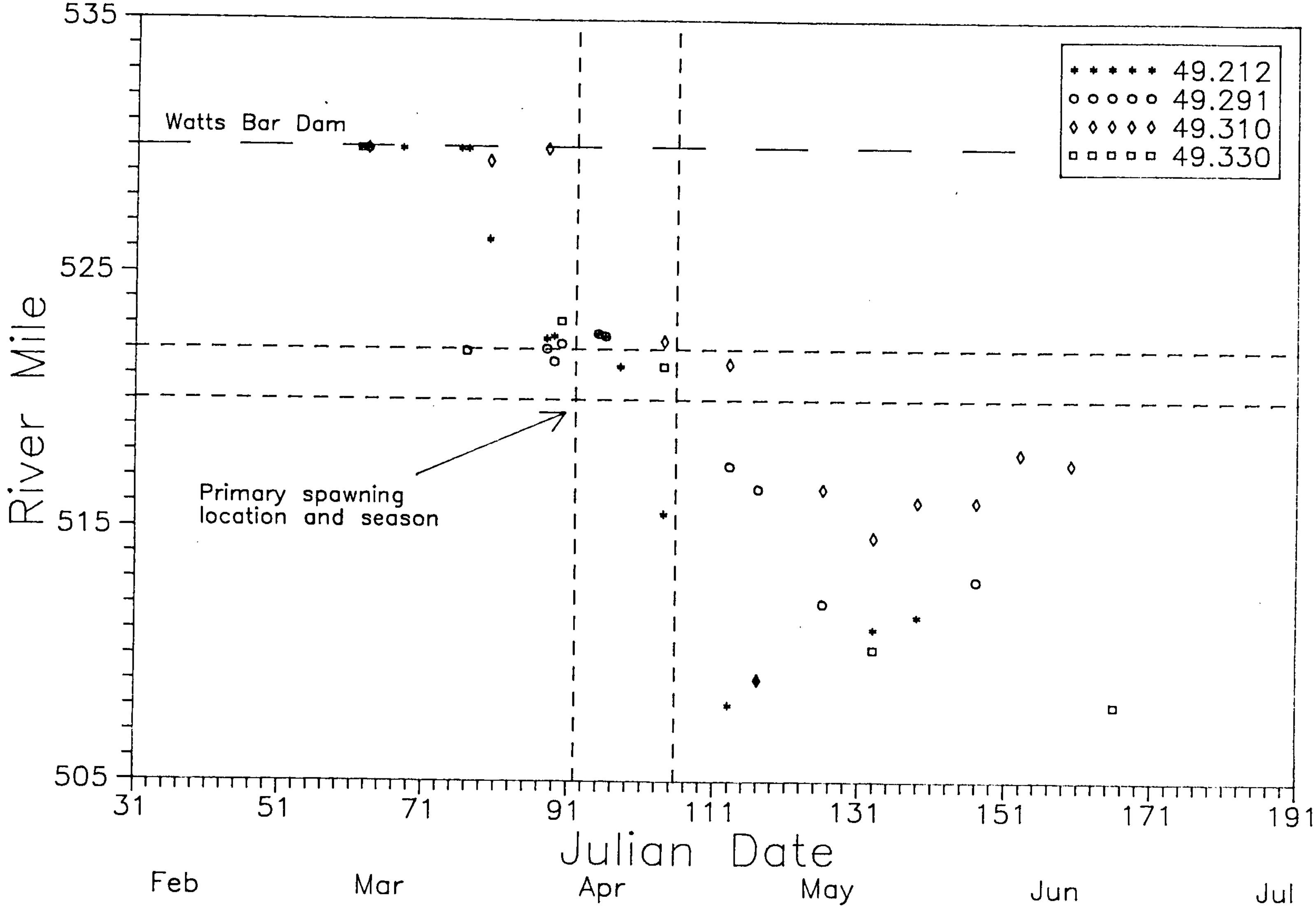


Figure 8. Locations of radio-tagged sauger released below Watts Bar Dam during March 1988 which exhibited male spawning movement patterns.

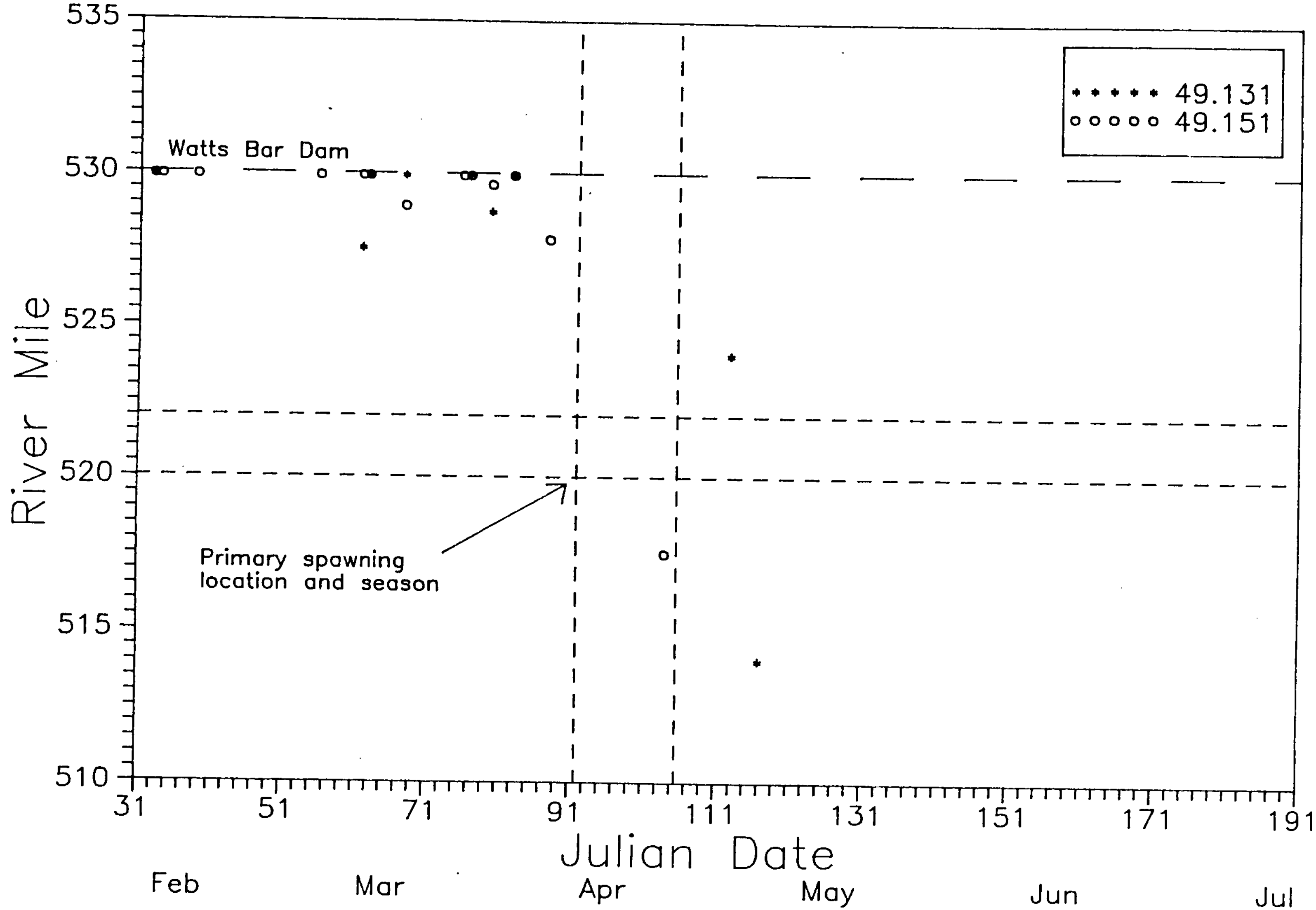


Figure 9. Locations of radio-tagged sauger released below Watts Bar Dam during February 1988 that exhibited female spawning movement patterns.

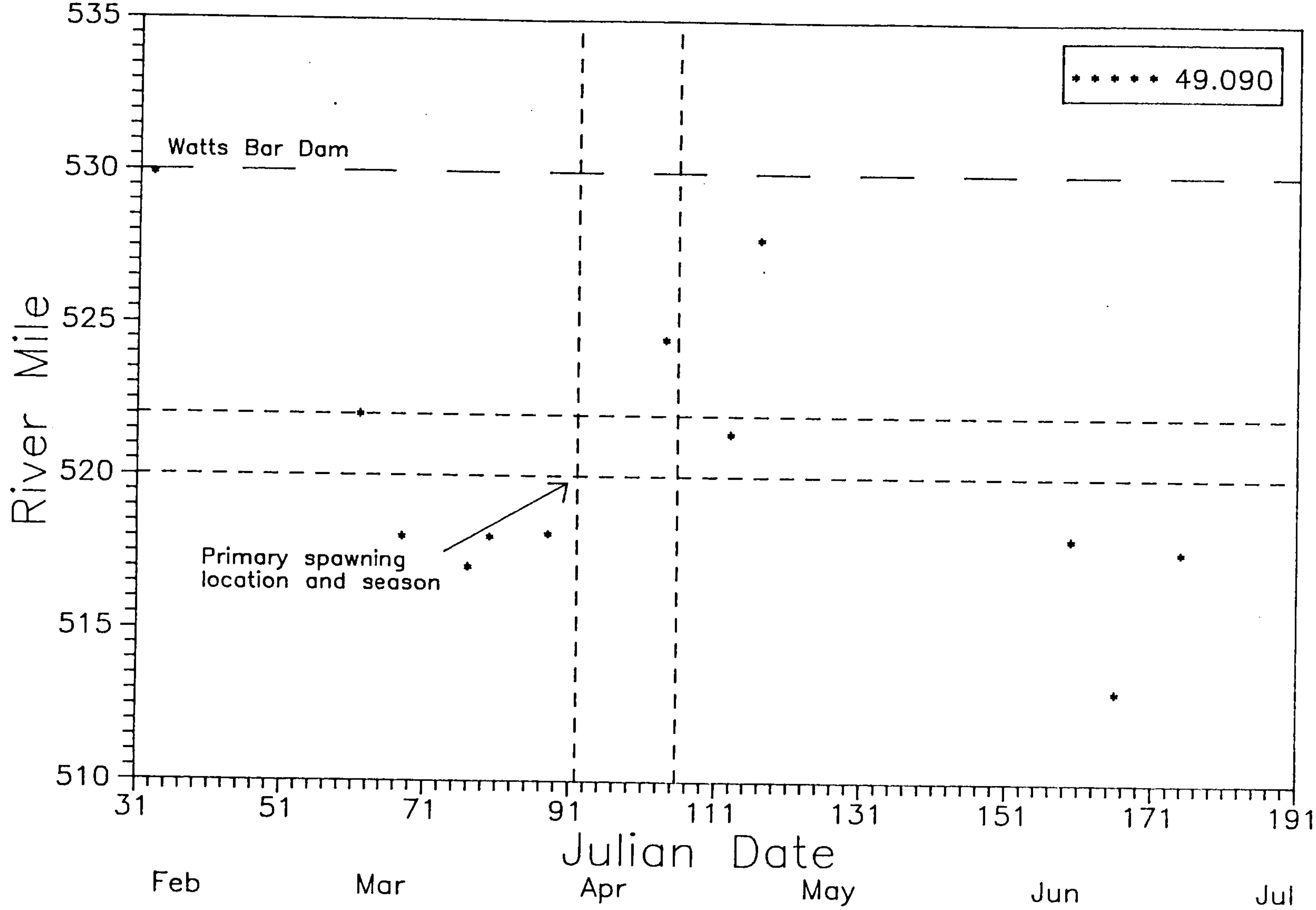


Figure 10. Locations of radio-tagged sauger (presumed female) released below Watts Bar Dam during February 1988 that moved downriver prior to the spawning season, but passed through the spawning vicinity during peak spawning activity.

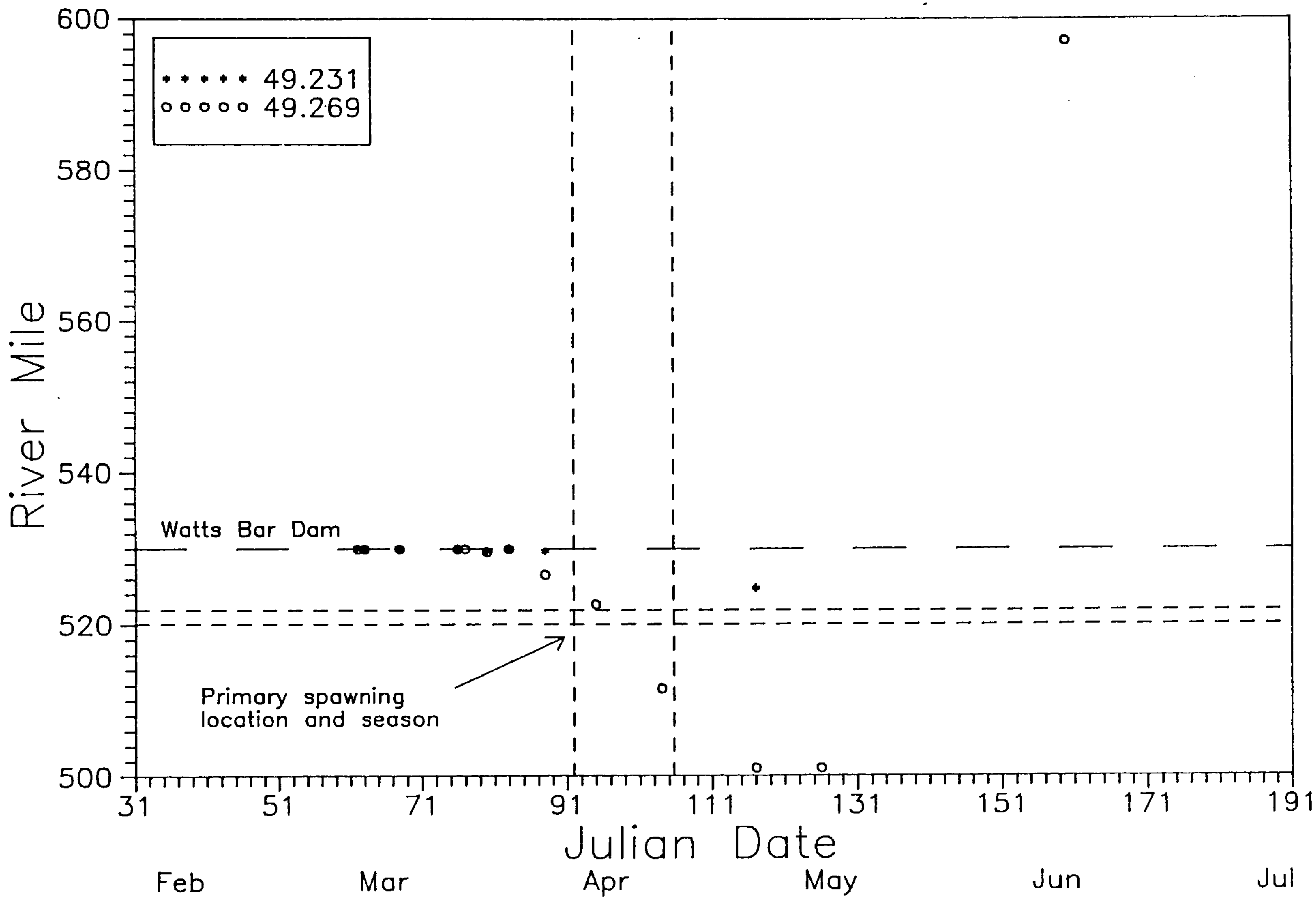


Figure 11. Locations of radio-tagged sauger released below Watts Bar Dam during March 1988 that exhibited female spawning movement patterns.

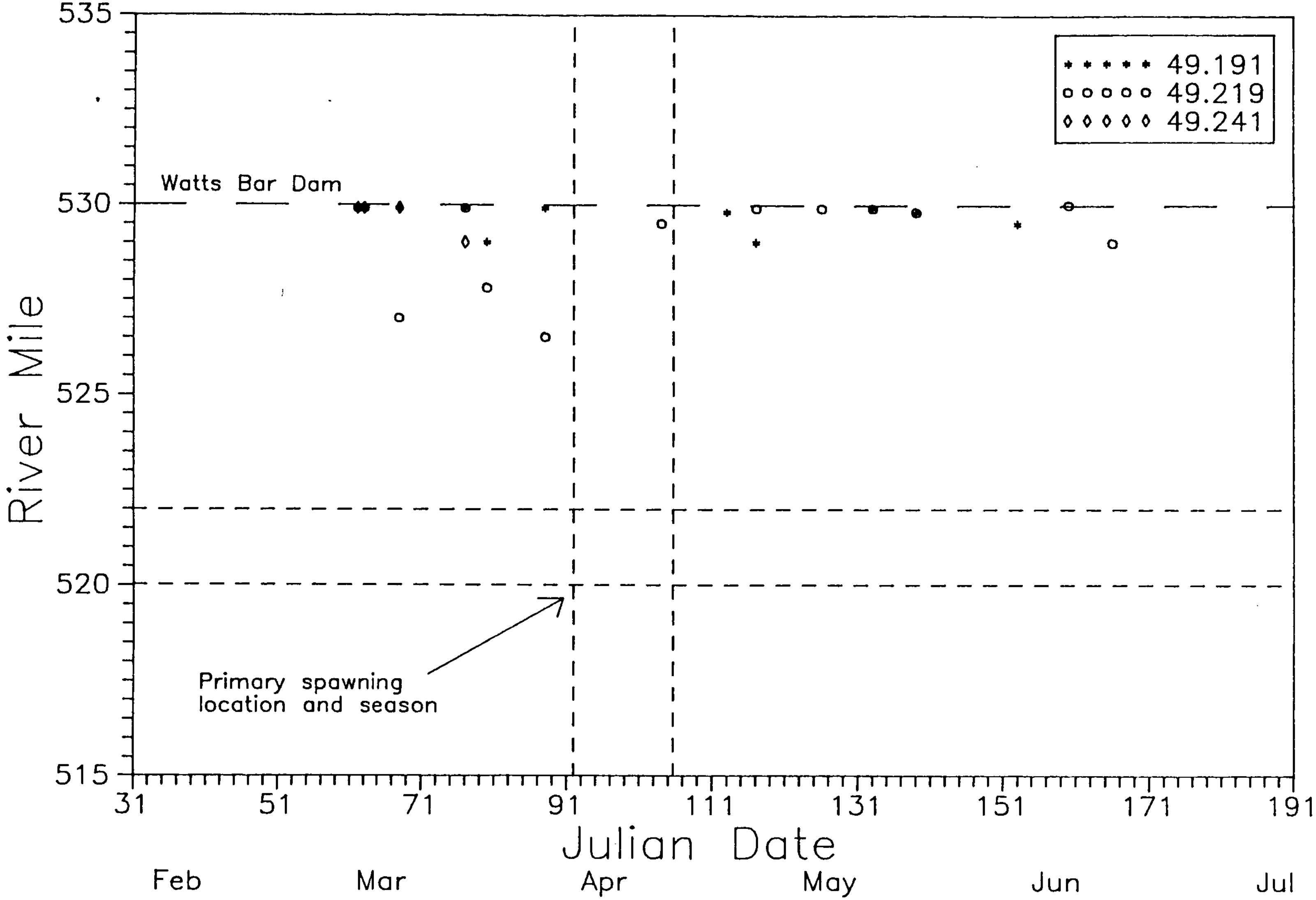


Figure 12. Locations of radio-tagged sauger released below Watts Bar Dam during March 1988 that remained at Watts Bar Dam throughout the study period.

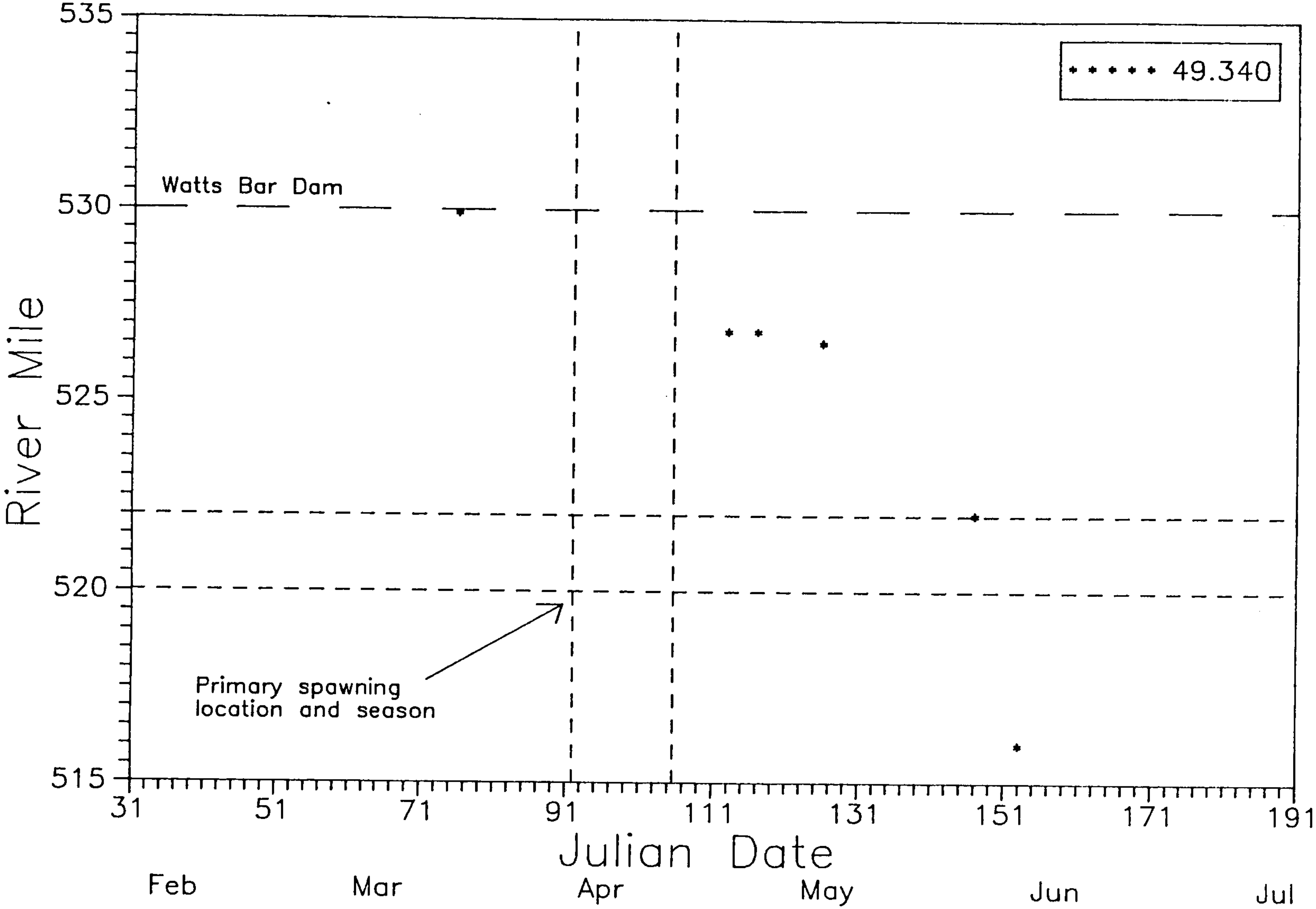


Figure 13. Locations of a radio-tagged sauger released below Watts Bar Dam during March 1988 that showed a gradual movement downstream. Apparently not associated with spawning activity.

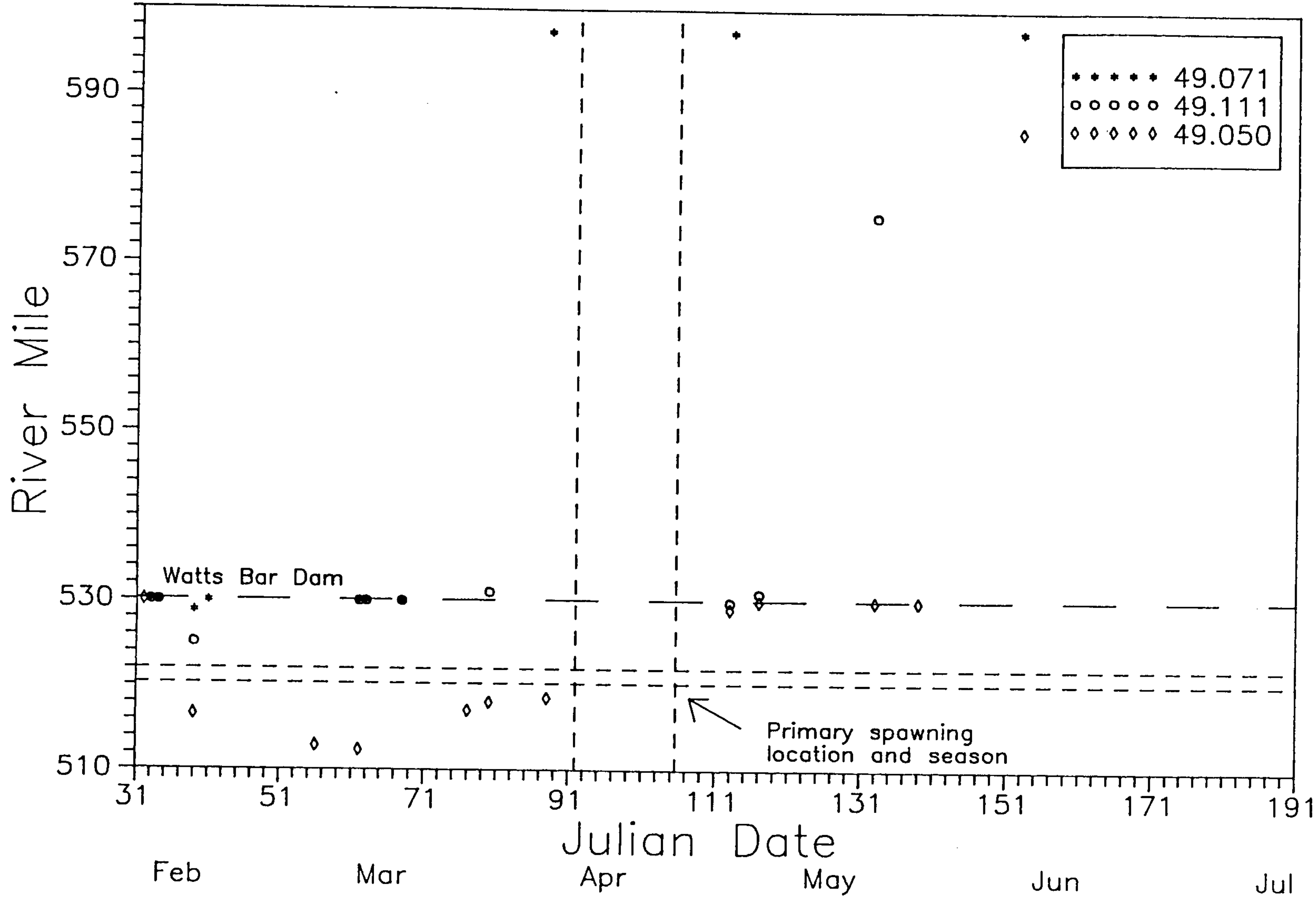


Figure 14. Locations of radio-tagged sauger released below Watts Bar Dam during February 1988 that moved upstream through the dam into Watts Bar Reservoir.

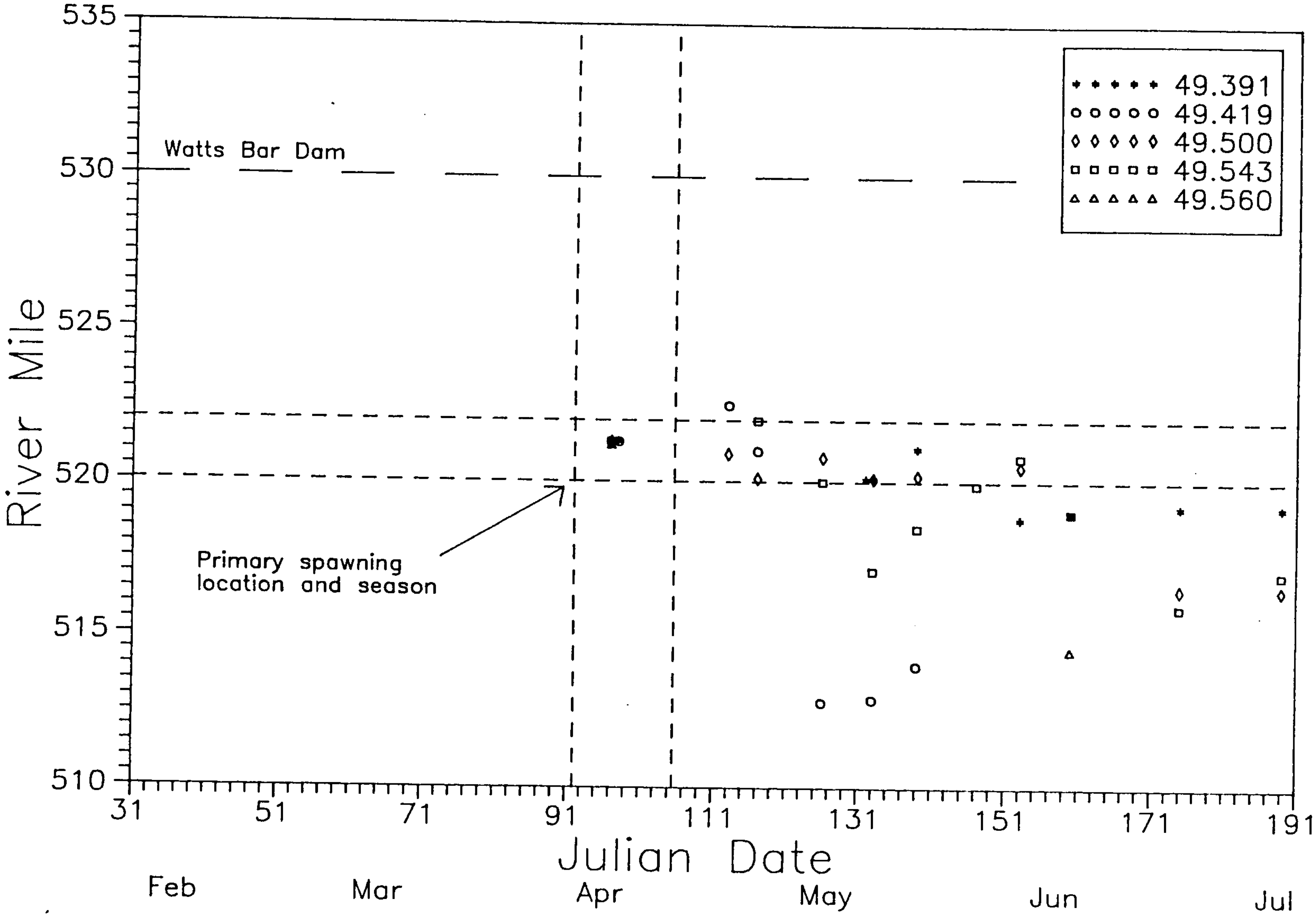


Figure 15. Locations of radio-tagged male sauger released on the Hunter Shoals spawning grounds during April 1988, showing post-spawn dispersal.

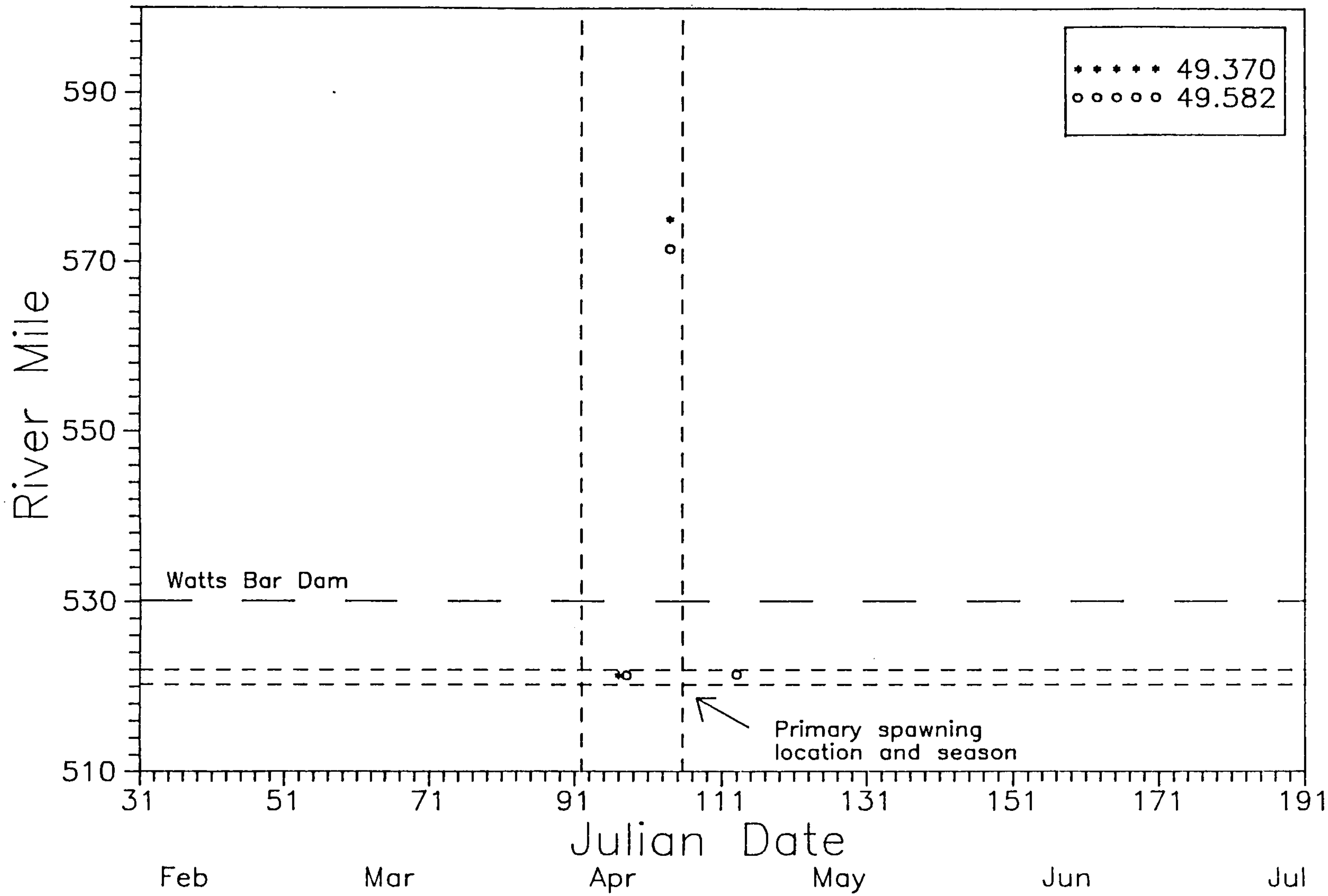


Figure 16. Locations of radio-tagged sauger released on the Hunter Shoals spawning grounds during April 1988 that moved upstream through Watts Bar Dam into Watts Bar Reservoir (Fish 49.582, female; Fish 49.370, male).

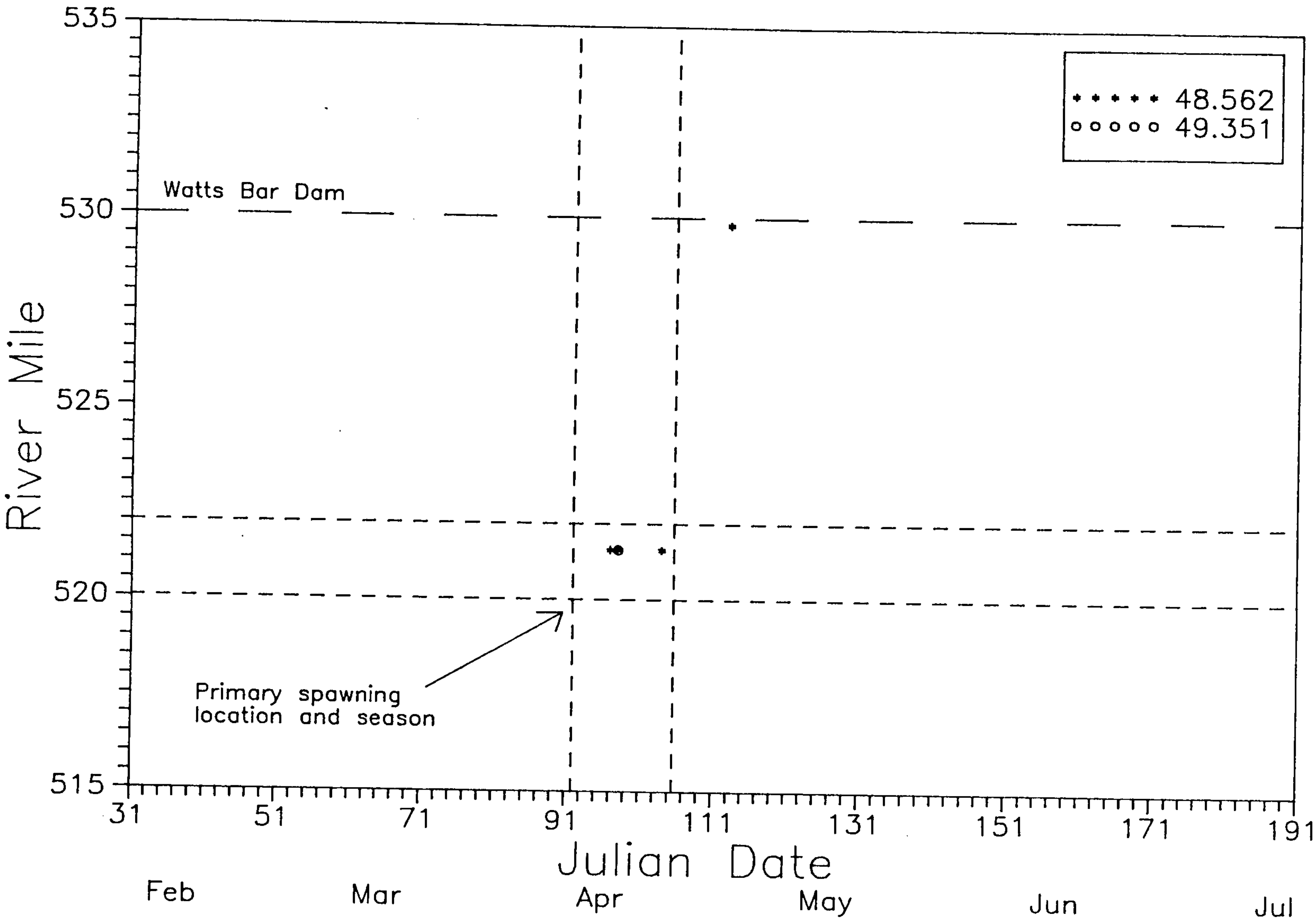


Figure 17. Locations of radio-tagged female sauger released on the Hunter Shoals spawning grounds during April 1988 showing post-spawning distribution.

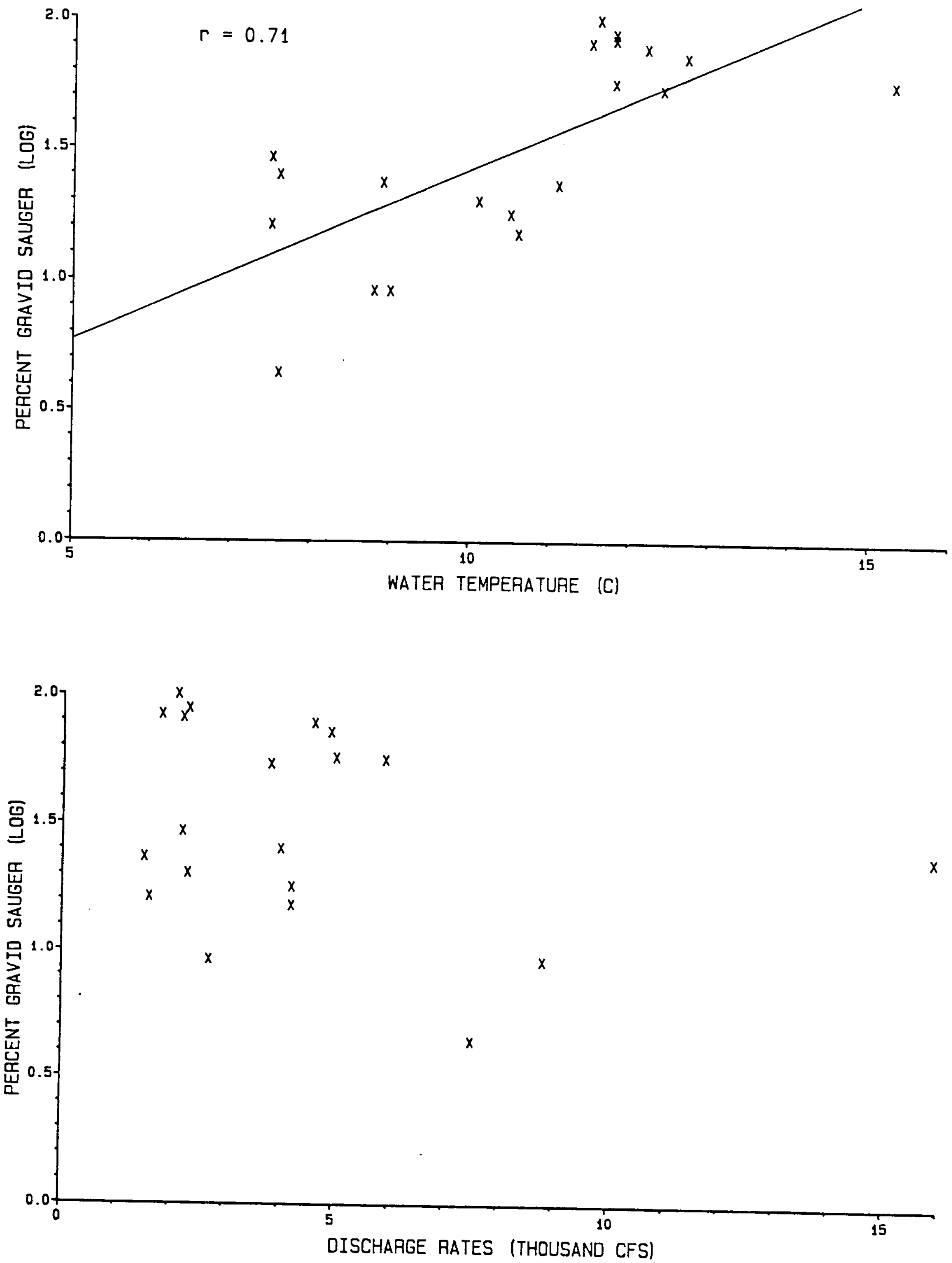
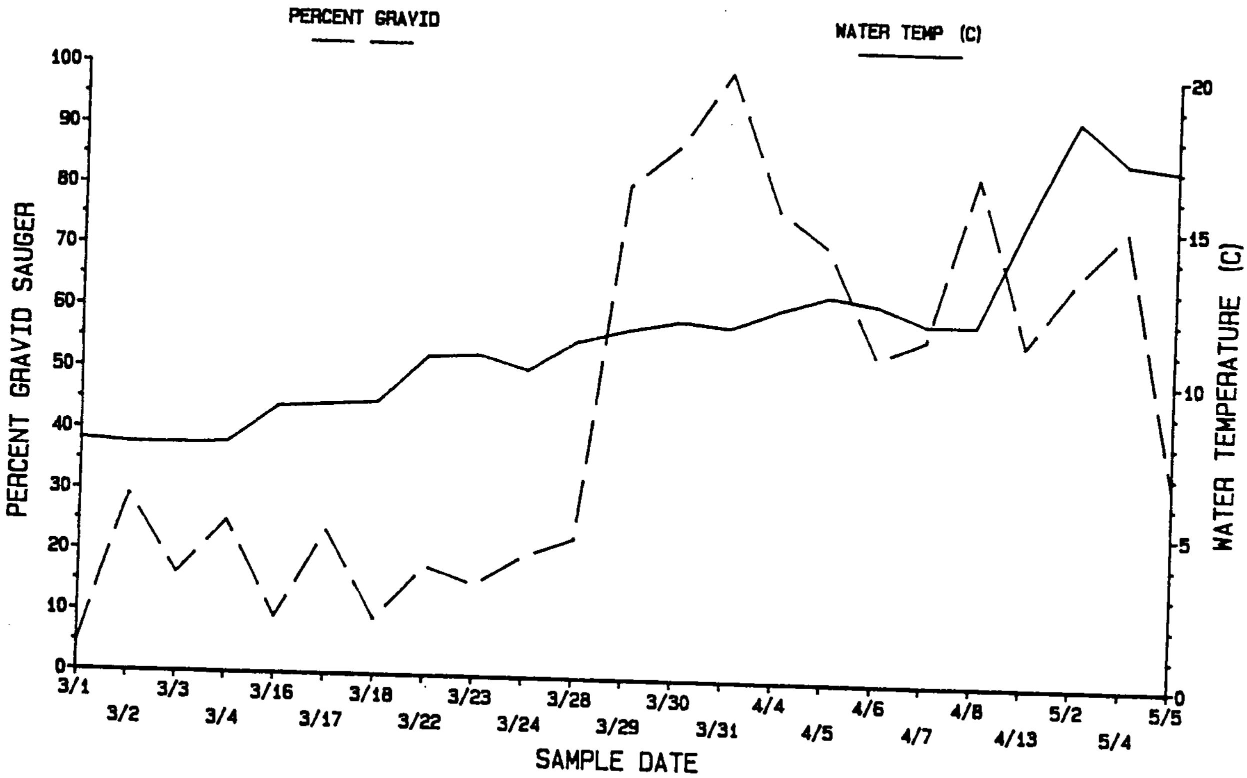


Figure 18. Relationships of water temperature and Watts Bar Dam discharge rates with percent gravid (spawning ready) sauger collected from upper Chickamauga Reservoir during spring 1988.



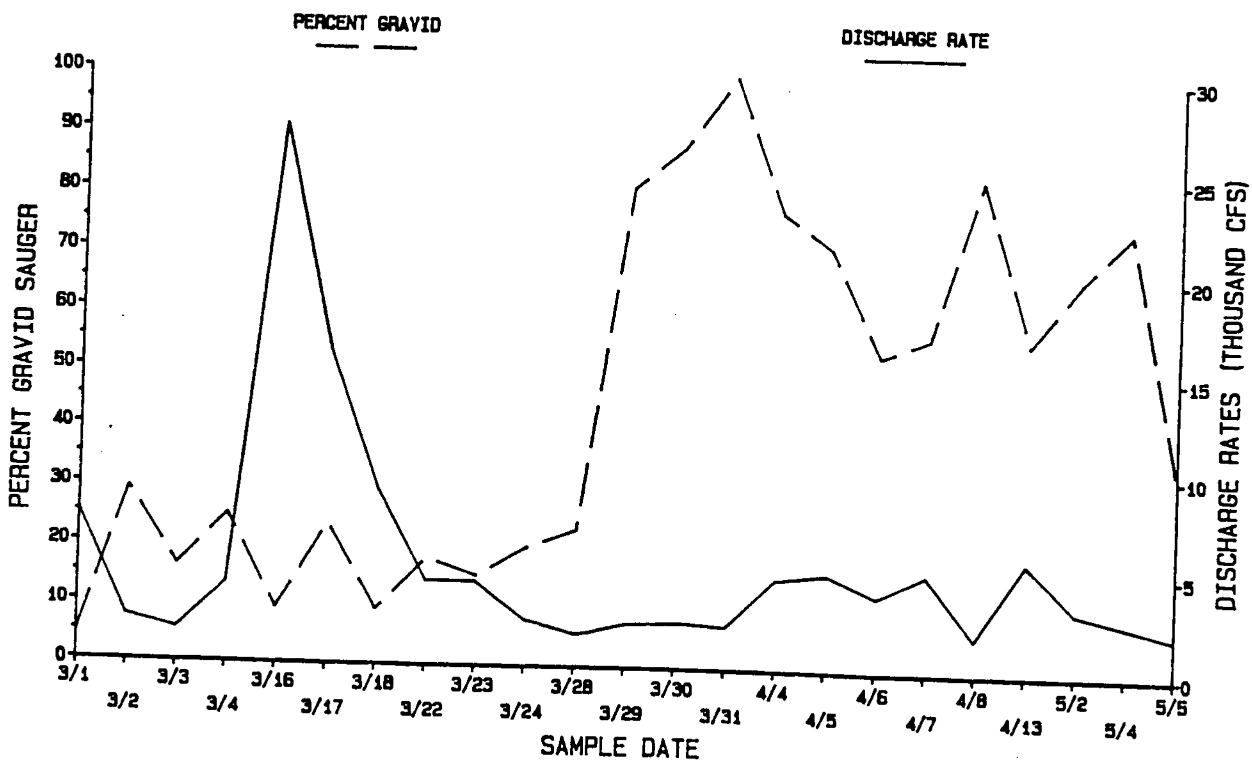


Figure 19. Comparisons of water temperatures and discharge rates with percent gravid (spawning ready) sauger collected from upper Chickamauga Reservoir during spring 1988.