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Movement and Distribution of Esocids and Forage Fishes In A Power Plant Cooling Reservoir

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MOVEMENT AND DISTRIBUTION OF ESOCIDS AND FORAGE FISHES IN A POWER PLANT COOLING RESERVOIR

BY

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MOVEMENT AND DISTRIBUTION OF ESOCIDS AND FORAGE FISHES IN A POWER PLANT COOLING RESERVOIR

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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MOVEMENT AND DISTRIBUTION OF ESOCIDS AND FORAGE FISHES IN A POWER PLANT COOLING RESERVOIR

Abstract

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One muskellunge (*Esox masquinongy*) and 2 northern pike (*E. lucius*) were surgically implanted with untrasonic transmitters and tracked in a South Dakota cooling reservoir from June 1979 to June 1980. The fishes inhabited the intake area of the reservoir during the summer (temperature range, 27.5 - 31.5^0 C) and the discharge area during the winter (temperature range, 4.5 - 21.5^0 C). In the spring and fall, the fishes were located throughout the reservoir (temperature range, 12.0 - 28.5^0 C). Highest rates of movement for the esocids were recorded during the spring (675 - 1,100 m/day). The lowest rates were recorded during late summer and fall (130 - 390 m/day). The muskellunge inhabited deeper water (4.5 m, average) than the northern pike (3.9 m, average) during the summer. Both esocid species inhabited the 0.5 - 3.0 m depth during the winter. Tracks made over a 24 hour period indicated greater distances moved by the muskellunge (2,063 m) than northern pike (487 m). Both the muskellunge and northern pike were most active during daylight periods, but they also moved at night. Echogram recordings indicated that forage fishes were distributed throughout the reservoir during the spring, summer, and fall, and were concentrated in the discharge area during winter.

ACKNOWLEDGMENTS

I would like to thank the United States Fish and Wildlife Service, South Dakota Game, Fish and Parks Department, and South Dakota State University for their financial assistance in this project. Further appreciation is extended to Montana-Dakota Utilities Company, Northwestern Public Service Company, and Otter Tail Power Company for the use of their cooling reservoir in which the study was completed. I would like to thank Nay Thomas, Big Stone Power Plant Supervisor, for his help and concern throughout the study.

The following people were instrumental in the collection of fish, data, and completion of field work: Dr. Robert Benda, Terry Margenau, Gordon Sloane, James Wahl, Robert Krska, Steve Johnson, and the South Dakota Department of Game, Fish and Parks personnel located at Webster, South Dakota. Their aid and assistance is very much appreciated. Dr. W. Lee Tucker, South Dakota Agricultural Experiment Station Statistician, is thanked for his patience and guidance through the several statistical tests made on the data. I would like to thank Alice Ann Molengraaf for her understanding in the typing of this thesis. And finally, a very special thank you to my adviser, Dr. Richard L. Applegate, for without his guidance, patience, understanding, and push I would not have made it through the rigors of research and graduate school.

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INTRODUCTION

Demand has caused electrical production to double in the last few decades (Mihursky and Kennedy 1967). To meet this demand, utility companies are building more fossil and nuclear fueled power plants. In 1973 there were 46 power plants in the United States utilizing ponds, lakes, or reservoirs as cooling water sources (Meredith 1973). It has been predicted that 20% of the power plants built in the United States by the year 2000 will have artificial cooling reservoirs (Metz 1977).

Cooling reservoirs have multiple-use potentials (Metz 1977). One possible use is rearing fish for food or sport purposes. Cooling reservoirs have thermally modified environments that may restrict the fish species stocked. The ability of fish to survive in a power plant cooling reservoir may depend on thermal preference or tolerance (Holland et al. 1974; Neill and Magnuson 1974; Nyman 1975a; Wrenn 1975; Reutter and Herdendorf 1976; Kelso 1977; Richards and Ibara 1978), genetic make-up (Nyman 1975b), season of year (Alabaster 1963; Barkley and Perrin 1971; Romberg et al. 1974), migratory behavior (Romberg et al. 1974), and the availability of forage species (Barkley and Perrin 1971; Spigarelli et al. 1973; Stauffer et al. 1974; Schaich and Coutant 1980).

Objectives of the present study were to determine the seasonal distribution and movement of muskellunge (*Esox masquinongy*), northern pike (*E. lucius*), and forage fishes in a South Dakota power plant cooling reservoir.

STUDY AREA

The cooling reservoir of the Big Stone Power Plant, a coal-fired 440-MW steam electric facility owned jointly by Montana-Dakota Utilities Company, Northwestern Public Service Company, and Otter Tail Power Company, is in northeastern South Dakota. At a water level of 341.1 m above mean sea level, the reservoir has a surface area of 145 ha, maximum depth of 10.0 m, and mean depth of 4.9 m. Eighteen forage fish species have been identified in the reservoir (Wahl 1980). Muskellunge fry and fingerlings were stocked in 1979 and 1980.

Cooling water is withdrawn on the east side of a T-shaped dike and heated water is released on the west side (Fig. 1). Mean water temperature at the surface of the intake area is about 29.0^0 C (temperature range, 27.5 - 31.5^0 C) during June through August and about 7.0^0 C (temperature range, 3.0 - 14.0^0 C) December through March; in the discharge area the respective temperatures are about 37.0^0 C (temperature range, 32.0 - 41.0^0 C) and about 19.0^0 C (temperature range, 10.0 - 28.0^0 C) (Fig. 2).

The entire shoreline is protected by riprap. Dense summer stands of Potamogeton spp. are present along the shore to a depth of 3 m. Aquatic vegetation was present in all 3 areas but heaviest concentrations were in the intake area.

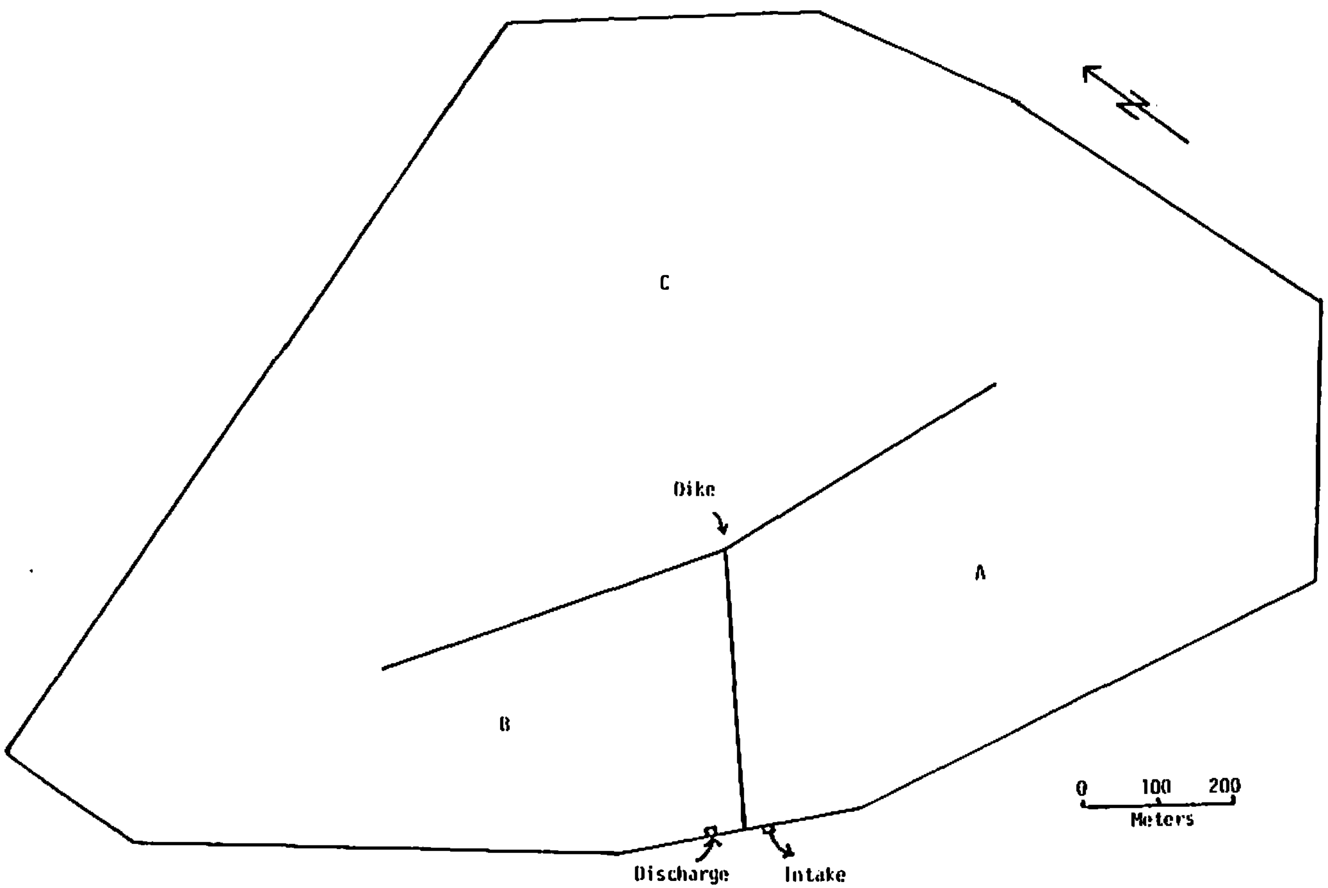

Fig. 1. Big Stone Power Plant cooling reservoir, South Dakota, showing intake area (A), discharge area (B), and mixing area (C).

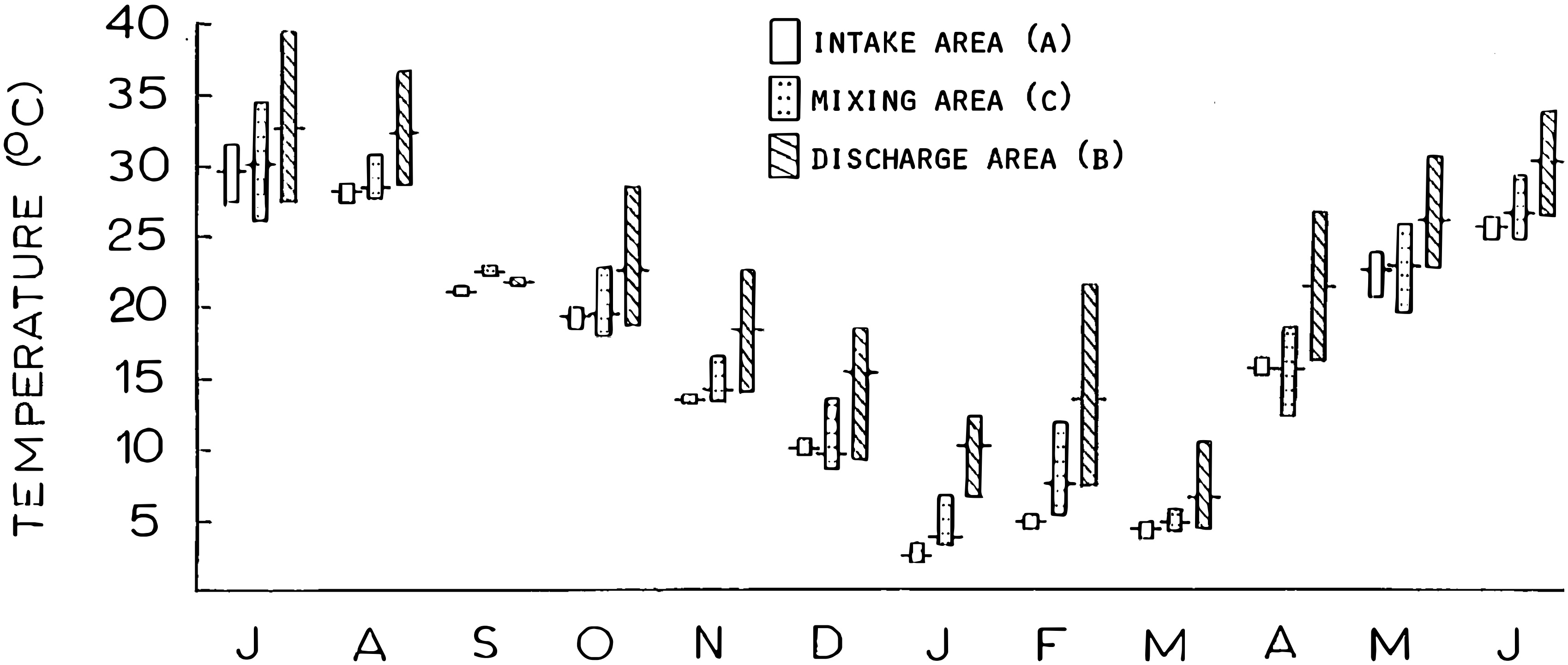

Fig. 2. Maximum, minimum, and mean temperatures in the Big Stone Power Plant cooling reservoir, South Dakota, 14 July 1979 - 25 June 1980.

MATERIALS AND METHODS

Five muskellunge (447 mm to 472 mm total length - TL) and 5 northern pike (524 mm to 945 mm) were surgically implanted with ultrasonic transmitters using methods described by Hart and Summerfelt (1975) and Crossman (1977) (Appendix Table 1). Each fish was anesthetized in a 15.0 mg/l quinaldine solution, and a 25.0 mm incision was made in the abdomen, anterior to the pelvic fins. Each transmitter was rinsed in 100% ethyl alcohol and then in a 15% terramycin solution, before being placed in the fish. The incision was sutured with 4-0 braided silk. Sutures consisted of 5 surgeon's overhand knots placed about 5.0 mm apart. The incision was treated with terramycin powder before the fish was placed in a recovery tank. Operation time per fish averaged 17 minutes. After recovery (15 - 20 minutes) fish were released into the cooling reservoir.

Ultrasonic transmitters and tracking equipment were manufactured by Donald L. Brumbaugh, Tucson, Arizona. Each 16.0 x 60.0 mm transmitter had a frequency output of 75 kHz, a life expectancy of 12 months, and weighed 8.0 g in water. The number of pulses per minute was used to differentiate between transmitters. The receiver had a frequency range of 65 to 85 kHz.

One muskellunge and 2 northern pike survived and retained active transmitters for 12 months. They were tracked from June 1979 to June 1980 (Appendix Table 1). Seasons of the year were determined by esocid distribution in the Big stone Power Plant cooling reservoir and were defined as: summer (June - August), fall (September -

November), winter (December - March), and spring (April - May). The seasonal distribution of the esocids was determined by locating the fishes 2 days each week during the winter and 3 - 5 days each week during the remaining seasons. Fish locations were determined by triangulation with a sextant and were plotted on a map of the reservoir. Diurnal movement was determined by tracking each fish for at least 2, 24 hour periods. A YSI Model 54 Oxygen-Temperature Meter was used to record temperatures at fish locations and a Lowrance LRG-505 White-line Graph Recording Sonar was used to record the depth of water at fish locations.

A formula developed by Neu et al. (1974) was used with chi square to analyze seasonal preference or avoidance of water depths by each fish in the area occupied during that season. The hypothesis was that esocids would utilize each depth category in proportion to its occurrence in the cooling reservoir. The formula was as follows:

$$\bar{p}_i - z_{(1 - a/2k)}\sqrt{\bar{p}_i(1 - \bar{p}_i)/n} \leq p_i \leq \bar{p}_i + z_{(1 - a/2k)}\sqrt{\bar{p}_i(1 - \bar{p}_i)/n} \quad \text{(Neu et al. 1974).}$$

The statistic p_i is the proportion of esocid occurrence in the i^{th} depth category and n is the number of locations at each depth.

A paired Student's t-test was used to analyze the 24 hour tracking data:

$$t = \frac{\bar{d}}{s_d} \quad \text{(Zar 1974)}$$

where d equals the mean difference between the 2 samples and s_d equals the standard deviation of $\bar{d}$:

$$s_d = s^2 \frac{(n_1 + n_2)}{n_1 \, n_2} \qquad \text{(Zar 1974)}$$

Day and night depth, rate of movement, and temperature data were compared to evaluate diurnal-nocturnal trends.

A Lowrance LRG-505 White-line Graph Recording Sonar was used to monitor forage fish distribution. Four transects were recorded once every 2 weeks in each of the 3 areas (Fig. 3). The transducer was mounted on a boat and placed approximately 30 cm underwater. Water temperatures were taken at 1 m depth intervals every other week at 10 stations in the reservoir with a temperature meter.

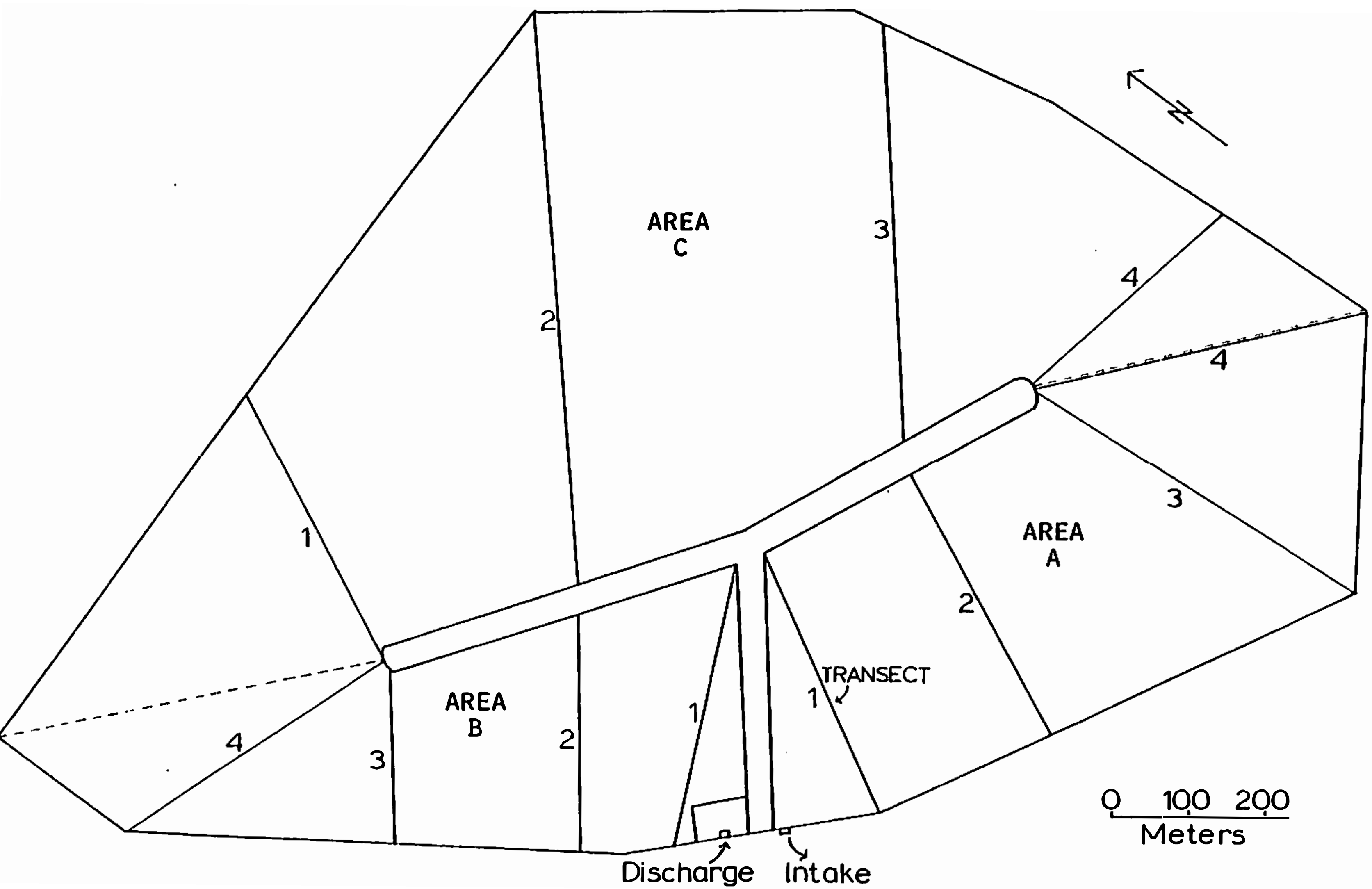

Fig. 3. Big Stone Power Plant cooling reservoir, South Dakota, with area divisions and sonar transects used in forage fishes movement study. A = intake area; B = discharge area; C = mixing area.

RESULTS AND DISCUSSION

The entire cooling reservoir was used by the esocids during the year (Figs. 4 and 5). The intake area was utilized by all 3 fishes during the summer and by the 2 northern pike in the fall. The muskellunge moved from the intake area to the mixing area as temperatures decreased in the fall. Both northern pike and the muskellunge were located in the discharge area during the winter. As temperatures increased in the spring, the fishes moved to the mixing area and then to the intake area.

Movement and Distribution of Muskellunge

The muskellunge was located in the mixing area during early and mid summer; in late summer the fish was located in the intake area (Fig. 6). The mean temperature for muskellunge locations during the summer was 30.0^0 C. The fish moved an average of 346 m/day during this period with the maximum movement (616 m/day) occurring in July (Fig. 7). The muskellunge may have increased movement in response to the warmer water coming from the discharge area into other areas of the reservoir. As water temperatures cooled in August, muskellunge movement decreased (262 m/day).

The muskellunge primarily inhabited the 3.1 - 7.0 m depth (77%) in the summer but also inhabited the 0.0 - 3.0 m depth (19%) (Fig. 8; Appendix Table 2). The fish inhabited water that was deeper than depths reported in other studies; muskellunge usually inhabited water 2.0 m in depth or less during the summer (Crossman 1977; Minor and Crossman 1978; Dombeck 1979).

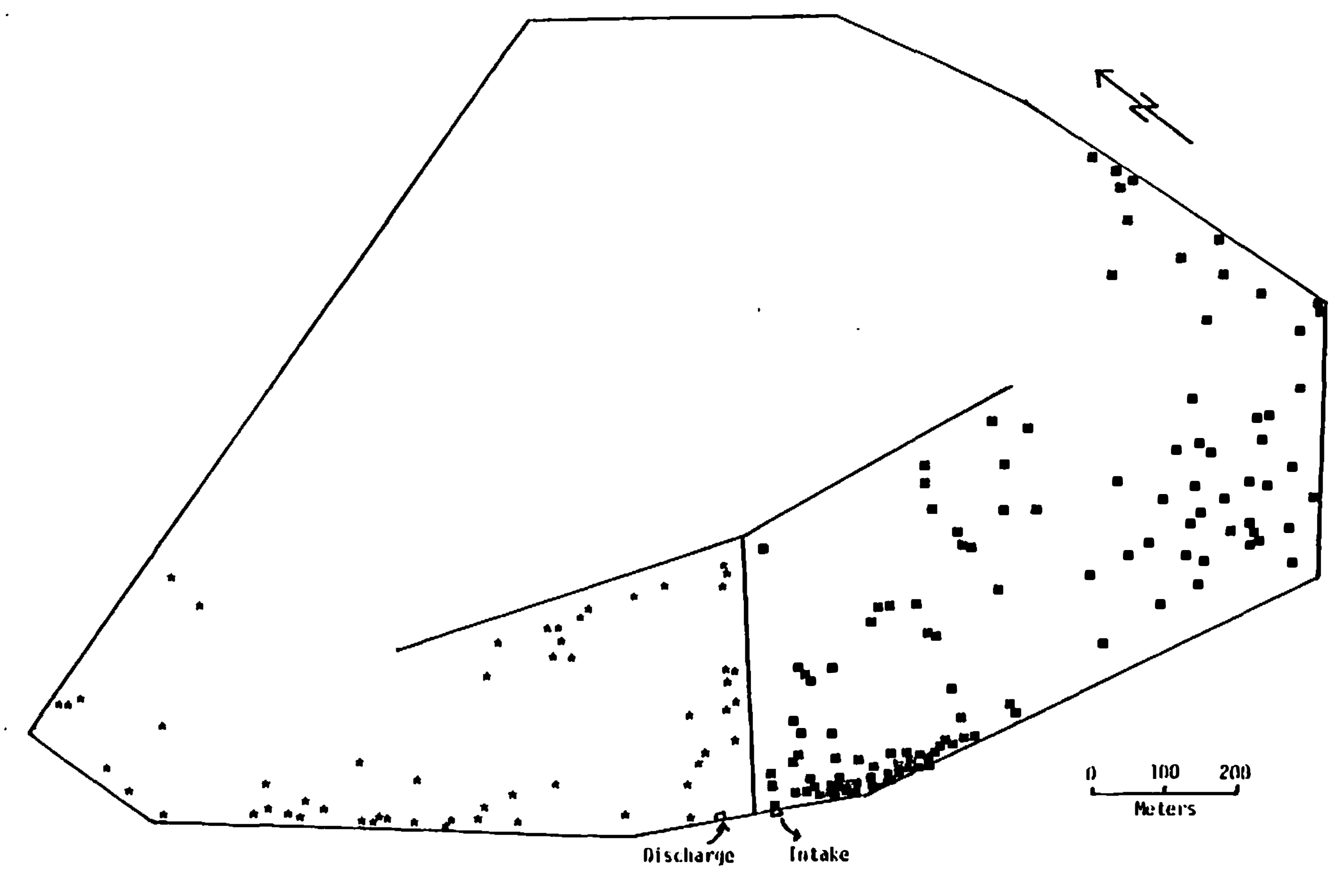

Fig. 4. Locations of a muskellunge (Esox masquinongy) and 2 northern pike (E. lucius) in Big Stone Power Plant cooling reservoir, South Dakota, on various days during summer 1979 and winter 1980. ■ - summer (9 July - 31 August 1979); ★- winter (2 December 1979 - 30 March 1980).

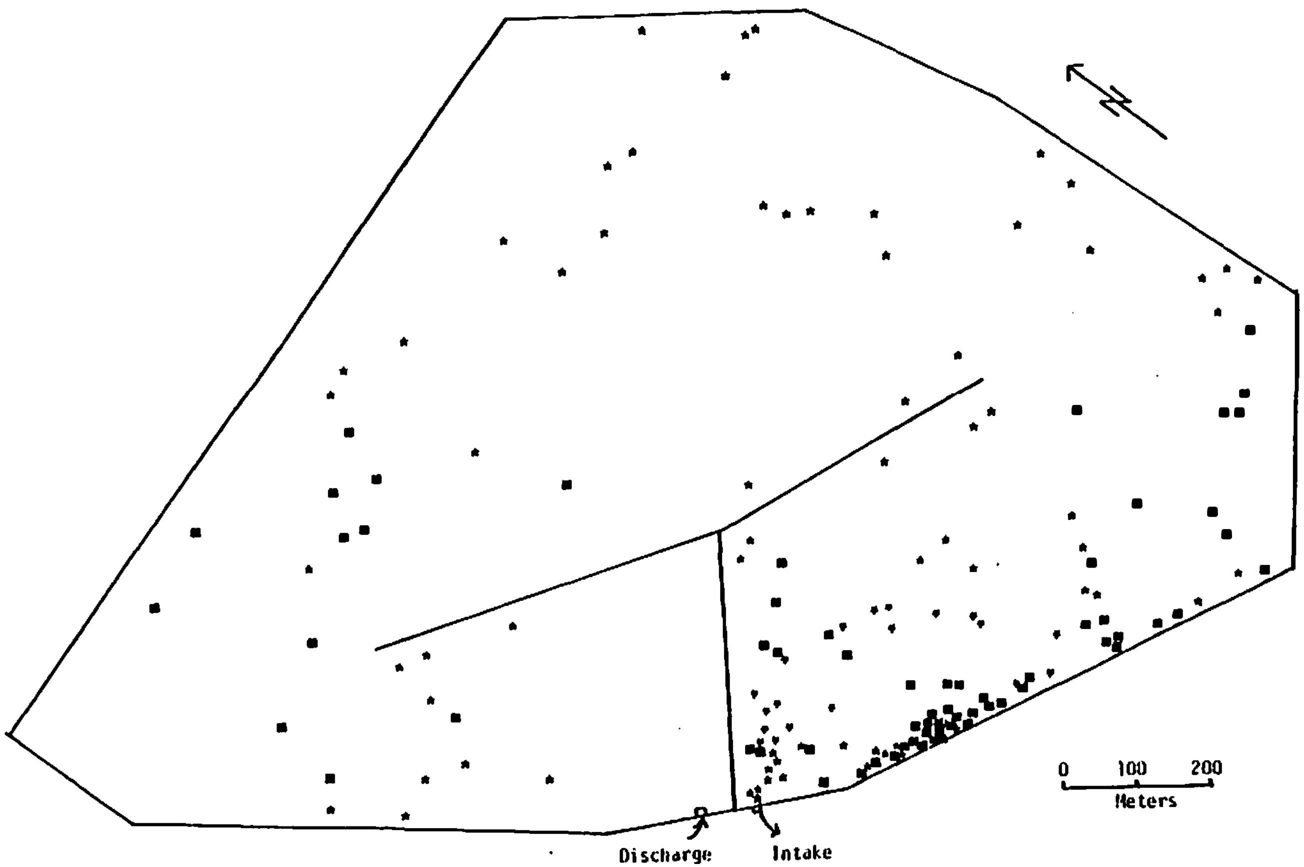

Fig. 5. Locations of a muskellunge (Esox masquinongy) and 2 northern pike (E. lucius) in Big Stone Power Plant cooling reservoir, South Dakota, on various days during fall 1979 and spring 1980. ■ - fall (1 September - 17 November 1979); ★ - spring (4 April - 12 June 1980).

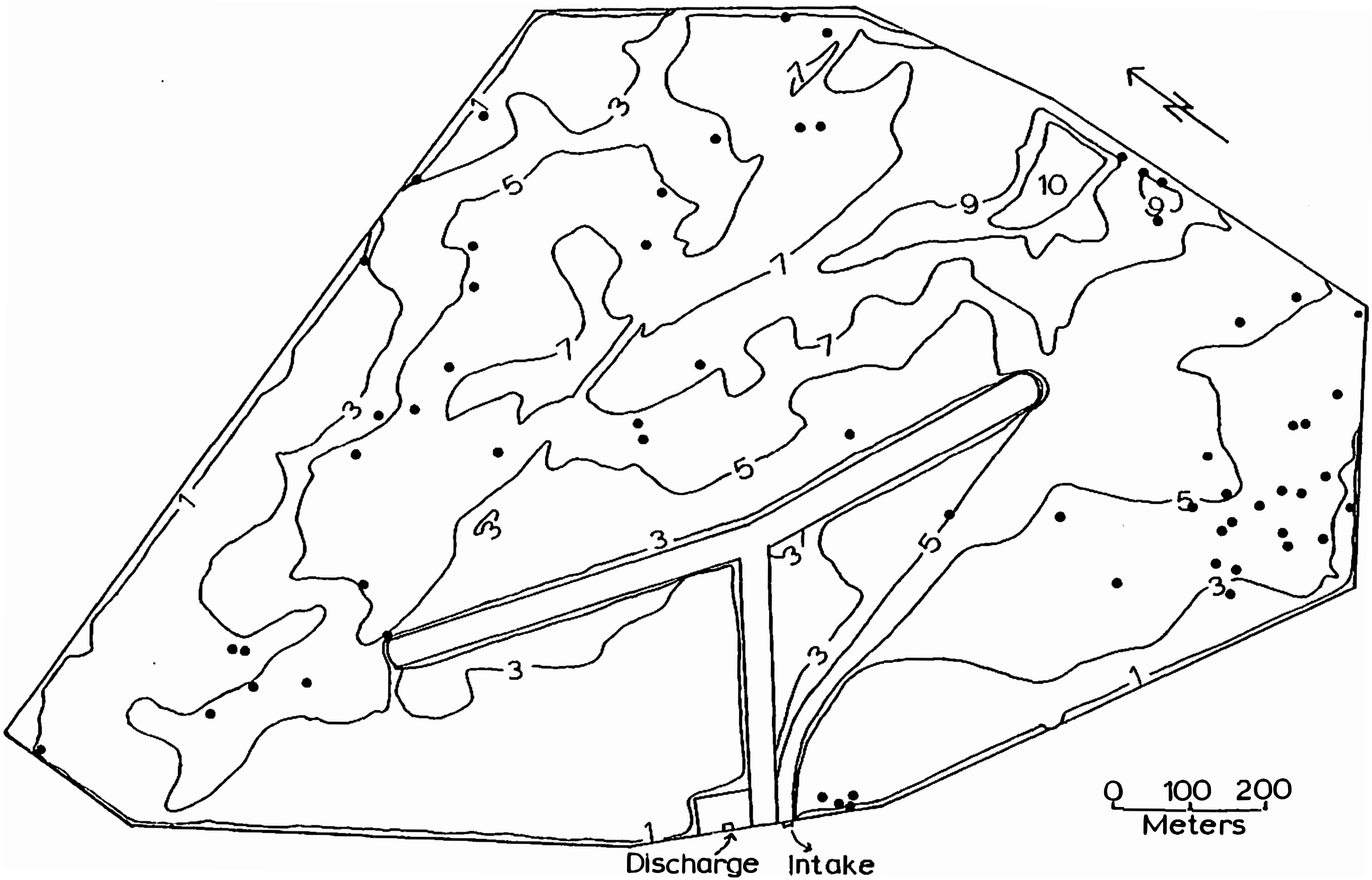

Fig. 6. Distribution of an ultrasonic tagged muskellunge (*Esox masquinongy*), 22 May - 31 August 1979, in Big Stone Power Plant cooling reservoir, South Dakota.

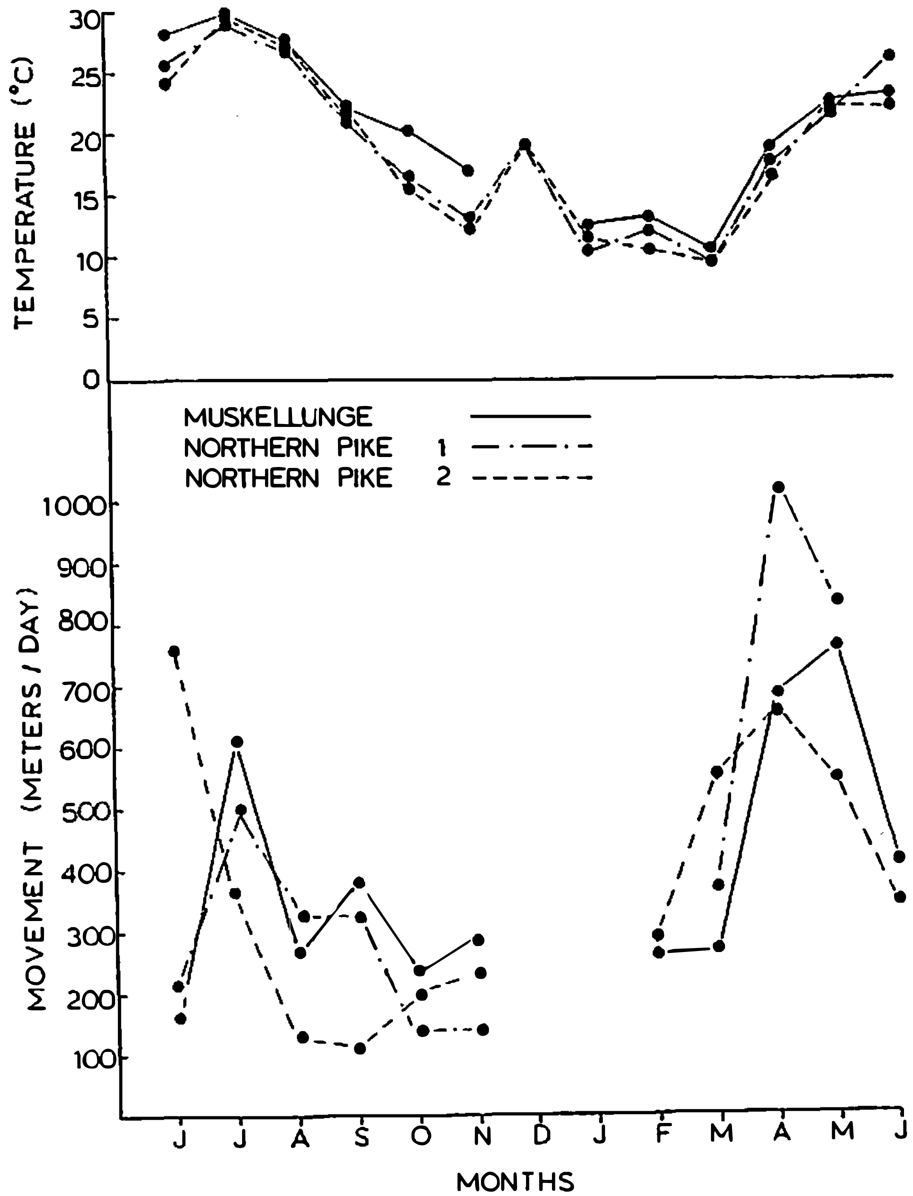

Fig. 7. Movement (m/day) and average temperature at each location for ultrasonic tagged muskellunge (*Esox masquinongy*) and northern pike (*E. lucius*), Big Stone Power Plant cooling reservoir, South Dakota, 1 June 1979 - 12 June 1980.

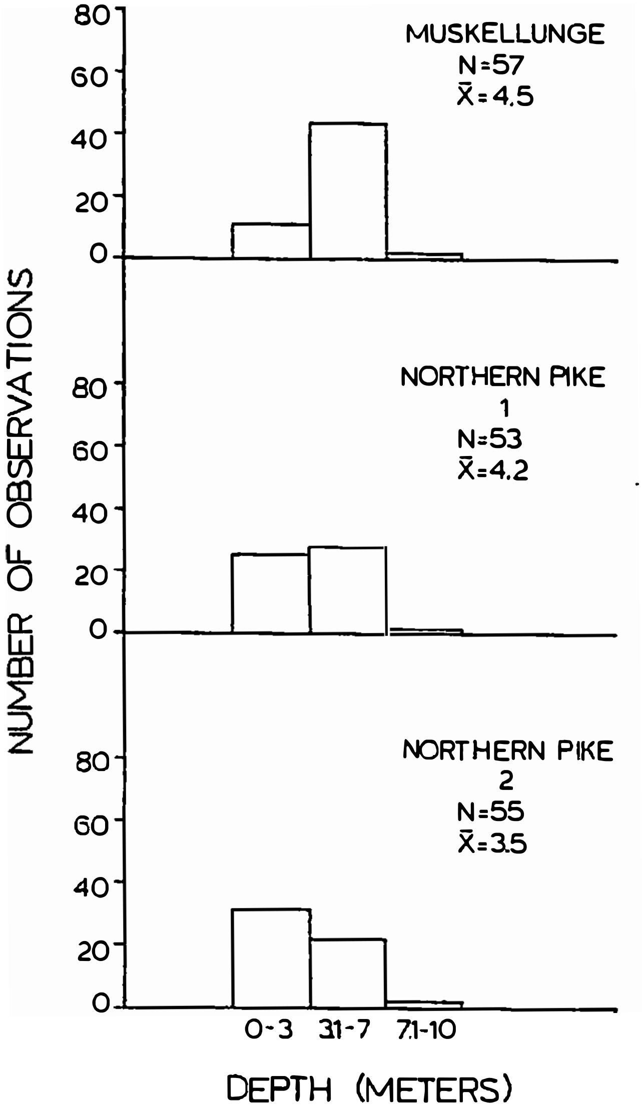

Fig. 8. Depth occupied by ultrasonic tagged muskellunge (*Esox masquinongy*) and northern pike (*E. lucius*) during the summer, in Big Stone Power Plant cooling reservoir, South Dakota, 1 June - 31 August 1979 and 1 - 12 June 1980.

The muskellunge increased movement in September ($\bar{x}$ = 380.0 m/day) (Fig. 7). The power plant was shut down for 20 days and the muskellunge moved from the intake area to the mixing area (Fig. 9). The fish remained in the mixing area until winter; temperatures ranged from 13.7 to 22.4^0 C. In the fall the fish was located in the 3.1 - 7.0 m depth (61%) and the 0.0 - 3.0 m depth (39%) (Fig. 10; Appendix Table 2). Minor and Crossman (1978) observed increased movement of muskellunge during the fall at temperatures of 8.0 - 15.0^0 C. Dombeck (1979) reported similar movement patterns between 4.0 - 12.0^0 C.

The muskellunge remained in the discharge area during the winter (mean temperature, 12.8^0 C) (Fig. 11) and moved an average of 269.0 m/day. Minor and Crossman (1978) and Dombeck (1979) found that muskellunge exhibit reduced movement rates in the winter. Winter temperatures in these 2 studies were about 3.0 - 4.0^0 C.

A condition referred to by McNeely and Pearson (1974) as overflow, occurred in the discharge area during the winter. Warm water occurred in the upper 1 m and cooler water was below 1 m. The fish remained in the discharge area during the winter in water depths of 0.5 - 3.0 m (Fig. 12; Appendix Table 2). Several muskellunge were captured with a gill net pulled as a seine in the discharge area. Most of the age-I fish (440 - 575 mm, TL) were captured near the top of the net. This indicated habitation of the upper warm water stratum or at least along the mixing zone of the 2 layers. The age-II fish were too large to become gilled (700 - 785 mm, TL) and swam freely within the confines of the net. These fish, however, exhibited no ill effects when

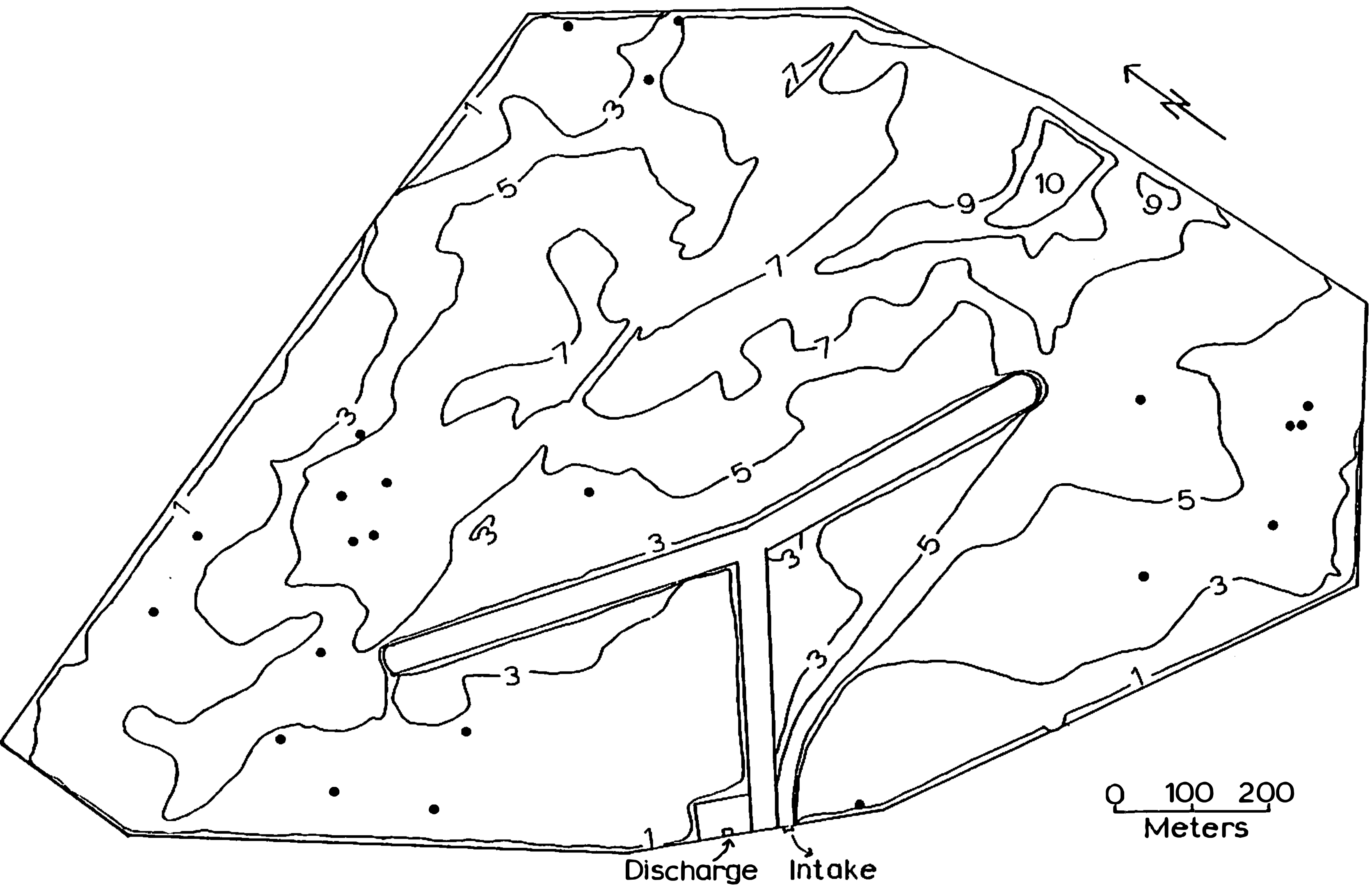

Fig. 9. Distribution of an ultrasonic tagged muskellunge (*Esox masquinongy*), 1 September - 17 November 1979, in Big Stone Power Plant cooling reservoir, South Dakota.

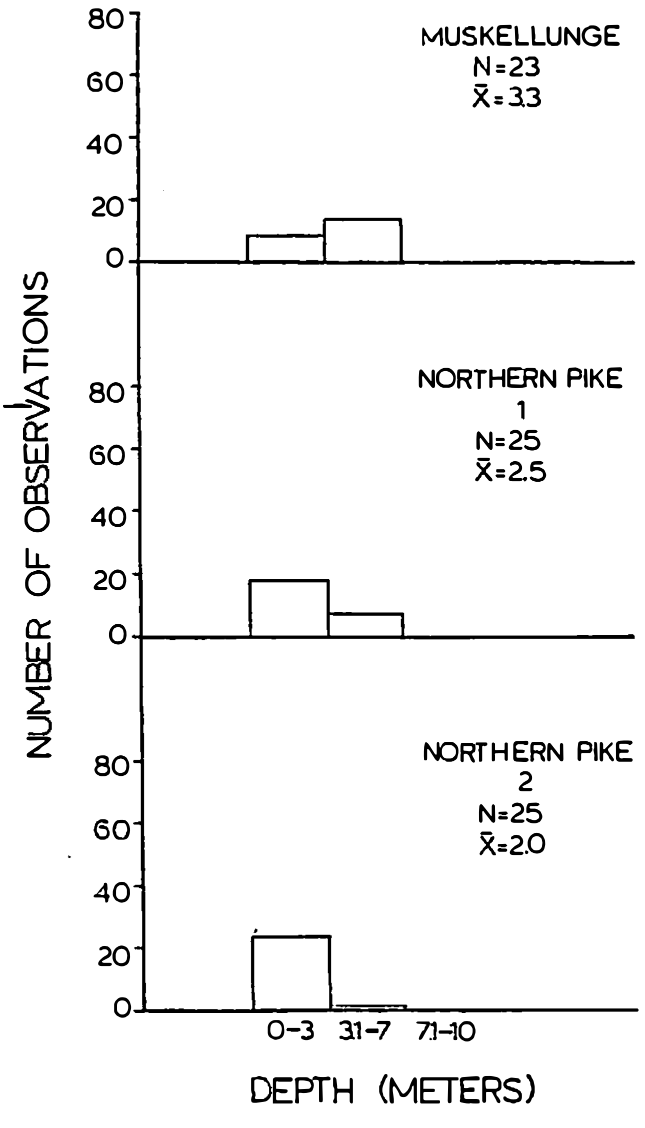

Fig. 10. Depth occupied by ultrasonic tagged muskellunge (*Esox masquinongy*) and northern pike (*E. lucius*) during the fall, in Big Stone Power Plant cooling reservoir, South Dakota, 1 September - 12 November 1979.

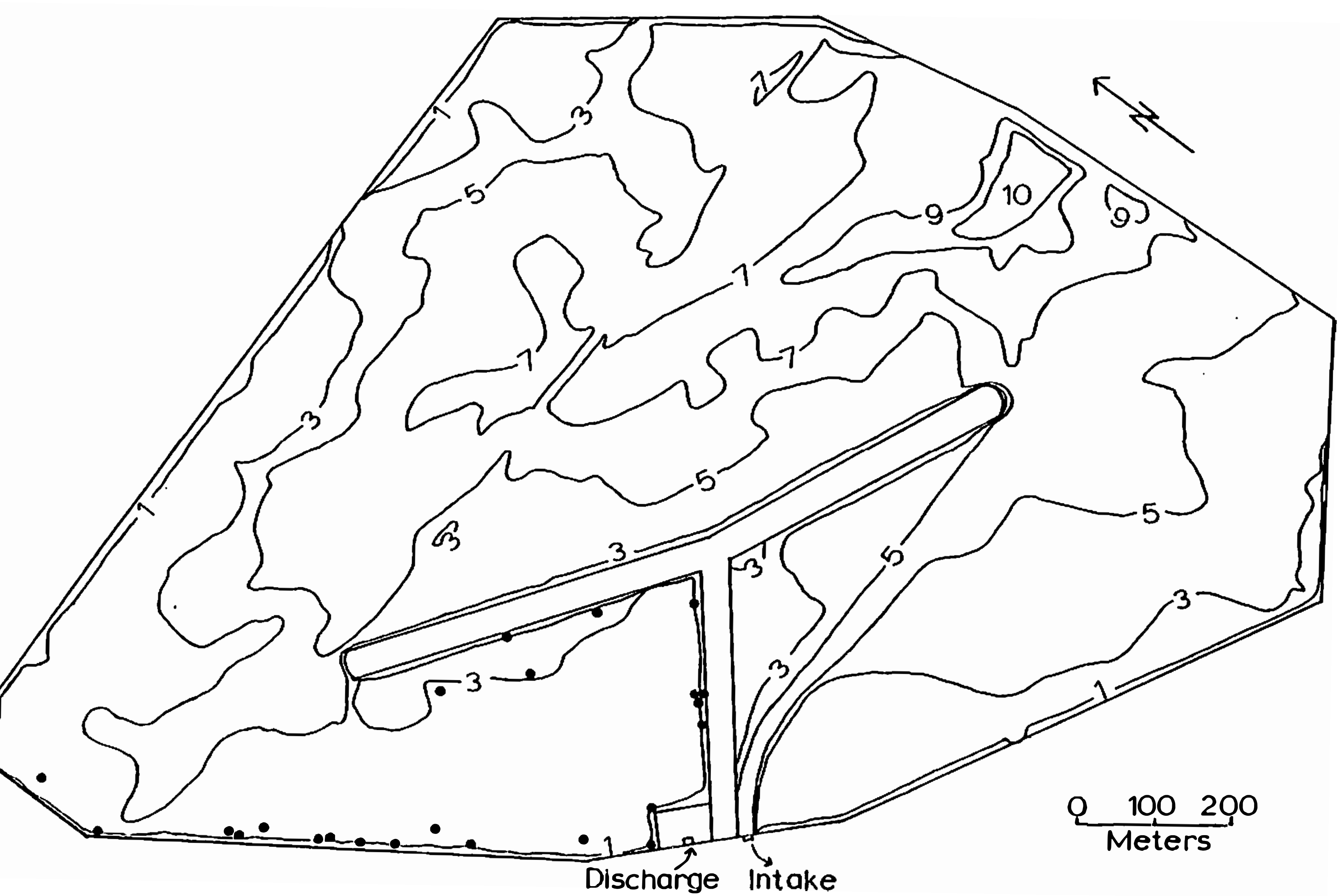

Fig. 11. Distribution of an ultrasonic tagged muskellunge (*Esox masquinongy*), 1 January - 30 March 1980, in Big Stone Power Plant cooling reservoir, South Dakota.

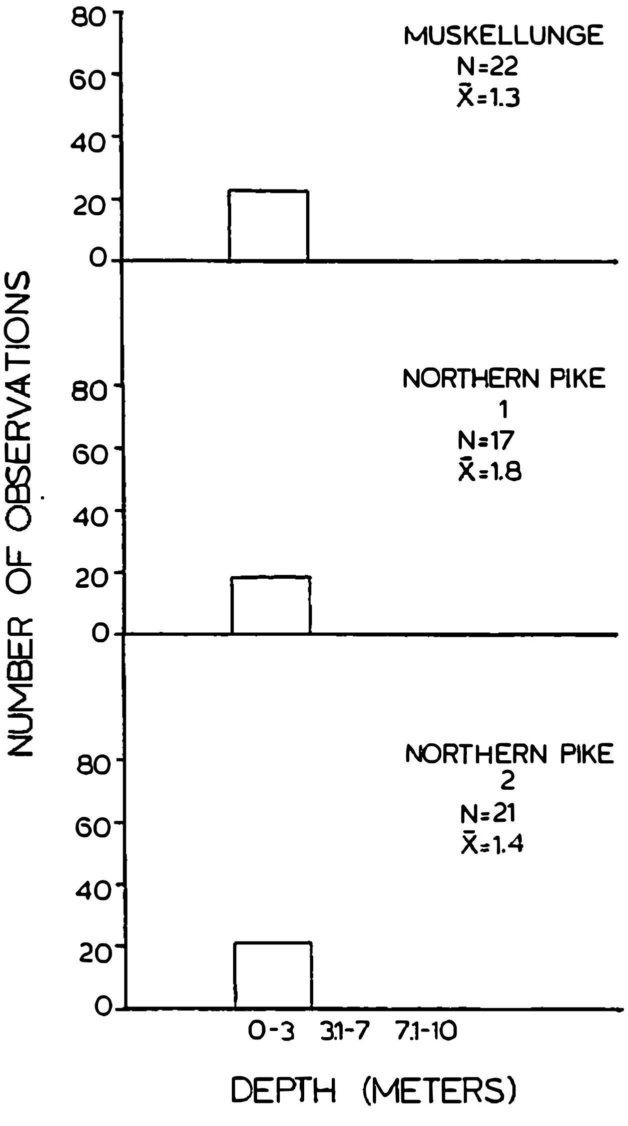

Fig. 12. Depth occupied by ultrasonic tagged muskellunge (<u>Esox masquinongy</u>) and northern pike (<u>E</u>. <u>lucius</u>) during the winter, in Big Stone Power Plant cooling reservoir, South Dakota, 2 December 1979 - 31 March 1980.

placed in containers filled with warm surface water. Higher water temperature in the discharge area was regarded as the primary reason for fish attraction (Alabaster 1963). Concentrations of forage fishes in heated discharge areas may also attract predatory fish (Barkley and Perrin 1971; Stauffer et al. 1974; Schaich and Coutant 1980). Richards and Ibara (1978) observed that brown bullheads (Ictalurus nebulosus) entered a heated discharge area in early winter and became "temperature trapped"; the bullheads remained in the warm water until spring.

The muskellunge began increasing movement rates at temperatures of 12.0 - 19.0^0 C; the fish moved an average of 730 m/day during the spring (Fig. 7). It moved from the discharge area on 19 April 1980. Temperatures averaged 24.0^0 C in the area. Most muskellunge locations in the spring were in the 3.1 - 7.0 m depth (69%) (Fig. 13). Utilization of the 0.0 - 3.0 m (17%) and 7.1 - 10.0 m depth (14%) also occurred (Appendix Table 2). Movement rates of muskellunge have been reported to increase as water temperatures increase in the spring (Minor and Crossman 1978; Dombeck 1979). Minor and Crossman (1978) reported muskellunge to have had an average movement rate (outside home range territory) of 301 m/day.

The muskellunge moved across the mixing area in May (775 m/day) (Fig. 14). Temperatures in the mixing area averaged 22.7^0 C (Fig. 2). The intake area was occupied by June. The muskellunge moved into this area about 45 days earlier than in 1979. Temperatures in the mixing area in June 1979 and June 1980 were similar. The muskellunge may have been selecting cooler water temperatures as it got older and larger. Schaich and Coutant (1980) noticed ontogenetic changes in

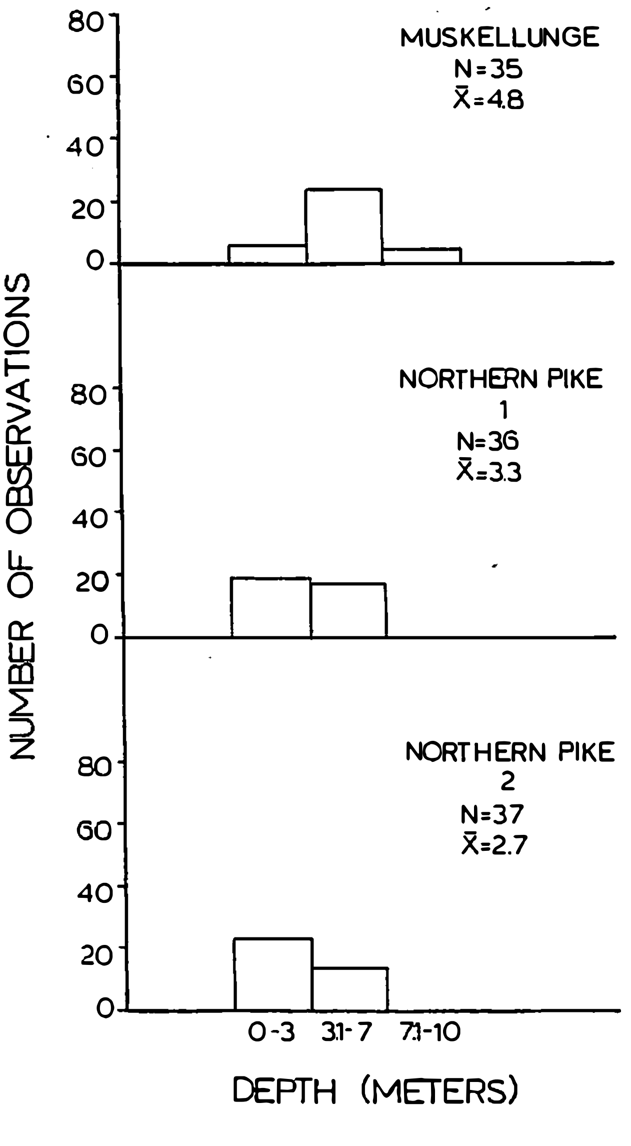

Fig. 13. Depth occupied by ultrasonic tagged muskellunge (*Esox masquinongy*) and northern pike (*E. lucius*) during the spring, in Big Stone Power Plant cooling reservoir, South Dakota, 4 April - 31 May 1980.

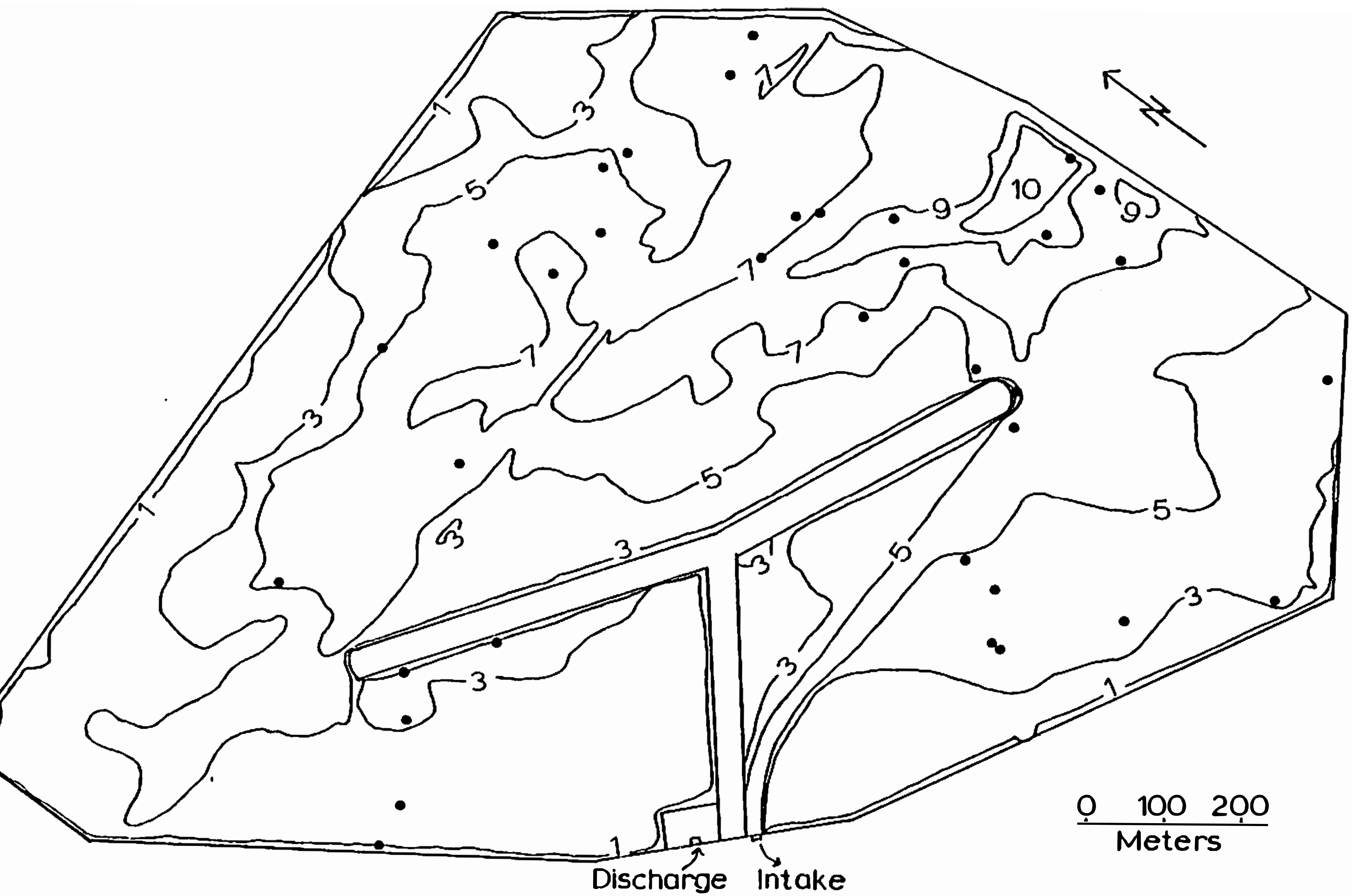

Fig. 14. Distribution of an ultrasonic tagged muskellunge (Esox masquinongy), 4 April - 31 May 1980, in Big Stone Power Plant cooling reservoir, South Dakota.

striped bass (*Morone saxatilis*); older fish appeared to prefer cooler temperatures than younger fish.

Movement and Distribution of Northern Pike

The movement and distribution of northern pike were similar to those of the muskellunge. The northern pike were located in the intake area during the summer (Figs. 15 and 16). Northern pike 1 movement rates (500 m/day) were greater than northern pike 2 (375 m/day) in July (Fig. 7). Both fish utilized all of the intake area and did not become sedentary until September. The fish were usually not located in areas of vegetation. Carbine and Applegate (1946), Malinin (1970), Diana et al. (1977), and Diana (1979) found northern pike to be mostly sedentary and closely associated with vegetation.

Casselman (1978) determined the upper lethal temperature to be 29.4^0 C for northern pike; however, Scott (1964) reported 33.0^0 C as the lethal temperature. Casselman also reported the optimum northern pike growing temperature (for length) to be 21^0 C. As temperatures increased above this optimum, growth rates decreased up to 28.0^0 C, where growth stopped altogether.

During the summer northern pike 1 and 2 were located in 0.0 - 3.0 m depth (47% and 56%, respectively) and 3.1 - 7.0 m depth (51% and 40%, respectively). Deeper areas (7.1 - 10.0 m) were utilized little by northern pike 1 and 2 (2% and 4%, respectively) (Fig. 8; Appendix Tables 3 and 4). Temperatures in the non-vegetated and vegetated areas averaged 29.4^0 C. In this study, movement and selection of habitat by northern pike appeared to be in response to

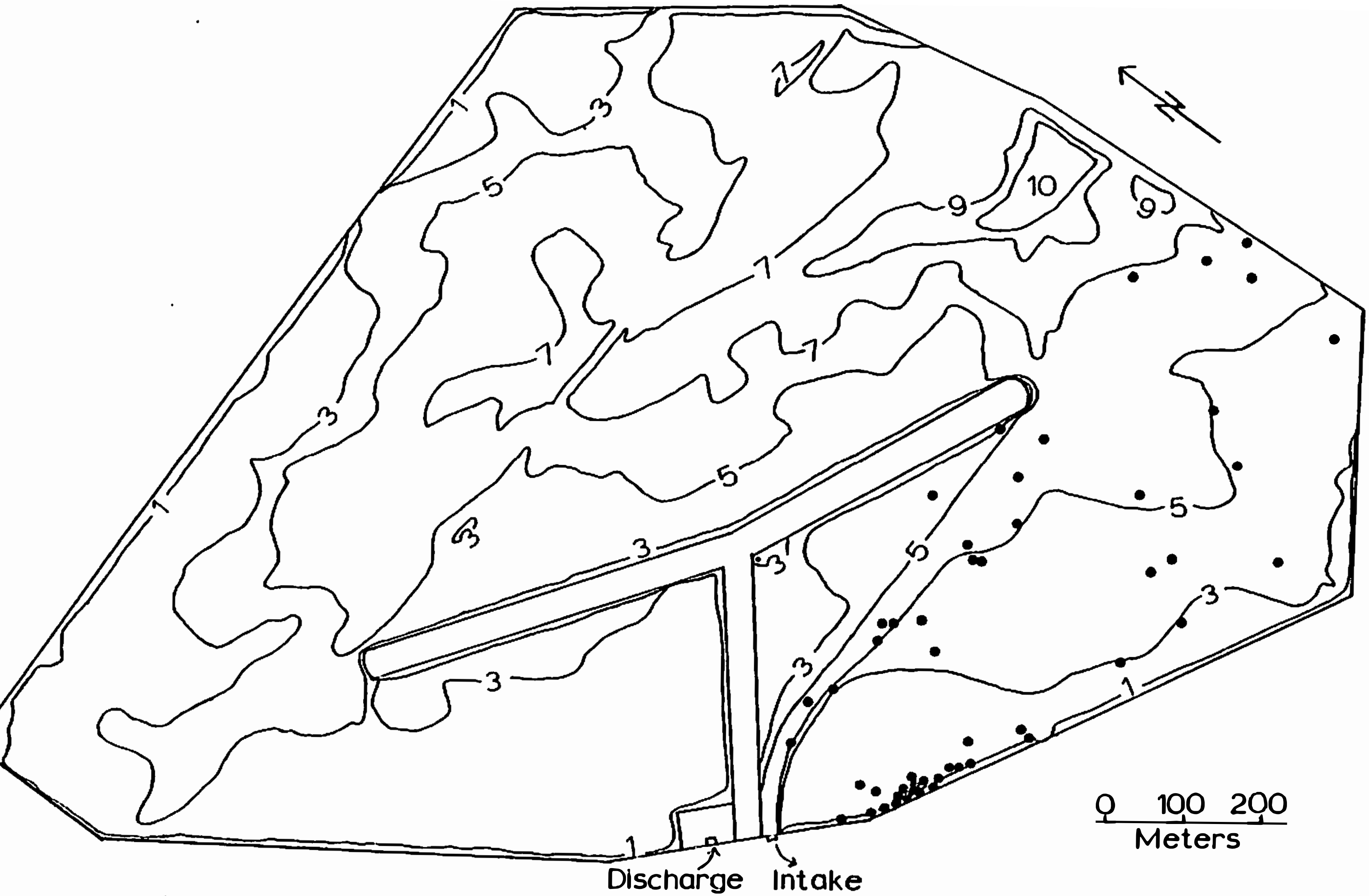

Fig. 15. Distribution of ultrasonic tagged northern pike (Esox lucius) 1, 21 June - 31 August 1979, in Big Stone Power Plant cooling reservoir, South Dakota.

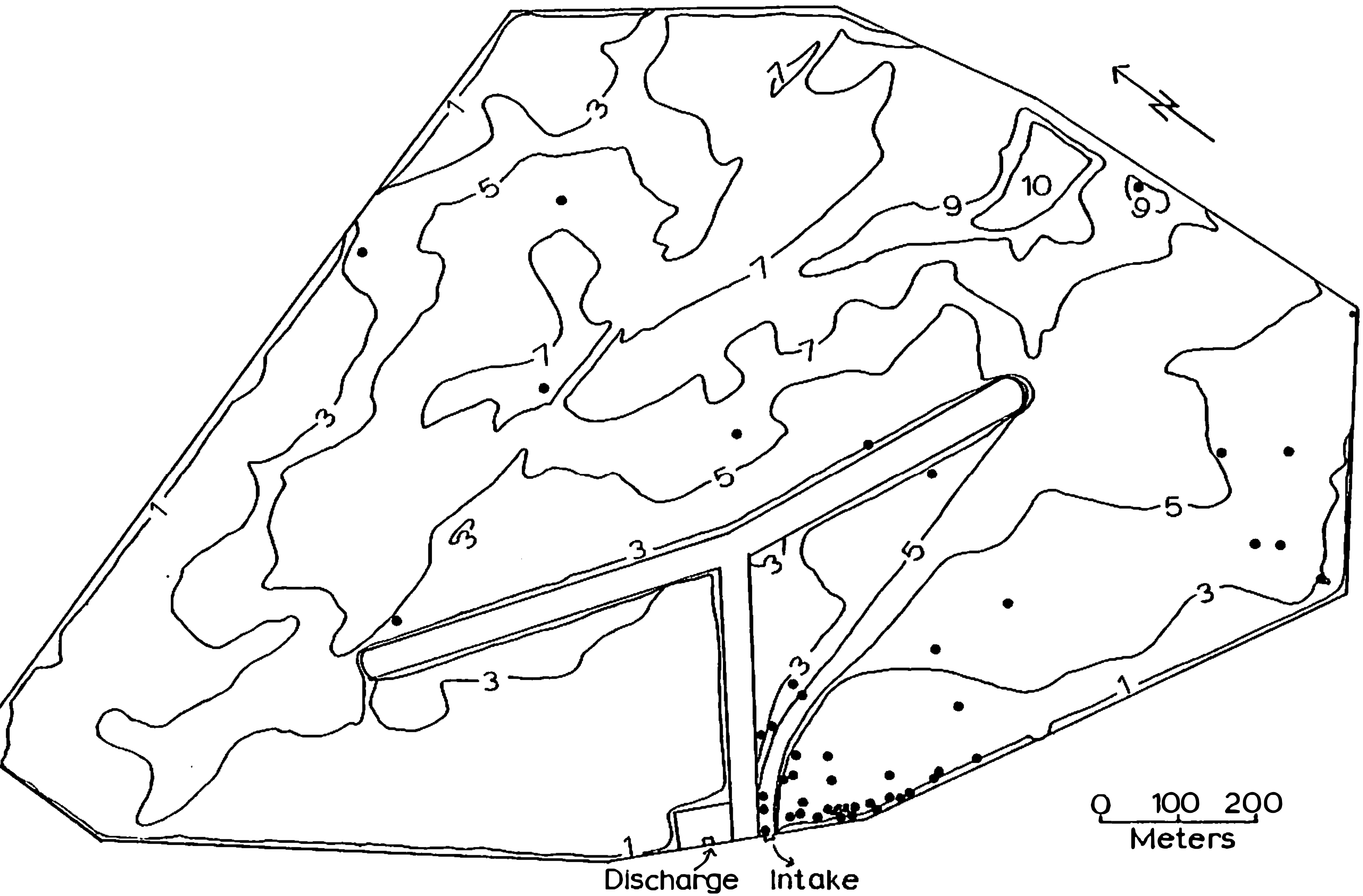

Fig. 16. Distribution of ultrasonic tagged northern pike (*Esox lucius*) 2, 13 June - 31 August 1979, in Big Stone Power Plant cooling reservoir, South Dakota.

water temperature. Diana et al. (1977) explained summer locations of northern pike in Lac Ste. Anne, Alberta, as selections of depth, distance from shore, vegetation, or bottom type. Schaich and Coutant (1980) observed striped bass following specific isotherms in the water column during the summer.

Northern pike 1 was located in 3.4 m of water in September (21.4^0 C) (Fig. 17). As water temperatures cooled in October (17.2^0 C), it moved into shallower water (2.1 m) and began to occupy vegetated areas. Figure 7 depicts the reduction of movement in October. Northern pike 2 remained along the southwestern shore of the intake area (Fig. 18) in September and October. It inhabited vegetated areas and moved extensively among them. Northern pike 1 began to utilize the 0.0 - 3.0 m depth more during the fall (72%). Northern pike 2 continued to utilize the shallow vegetated areas (96%) (Appendix Tables 3 and 4). Neither northern pike was located in the 7.1 - 10.0 m zone during the fall (Fig. 10).

The lowest movement of northern pike in the Big Stone cooling reservoir (less than 200 m/day) were recorded in the fall (Fig. 7). Moen and Henegar (1971) found northern pike movement varied with different factors including season; they observed low movement rates of tagged northern pike in the fall.

The northern pike moved into the discharge area between 17 November and 2 December 1979 (Figs. 19 and 20). Water temperatures ranged from 9.8^0 C in the intake area to 14.1^0 C in the mixing area. Temperatures in the discharge area ranged from 18.2^0 C to 23.0^0 C and

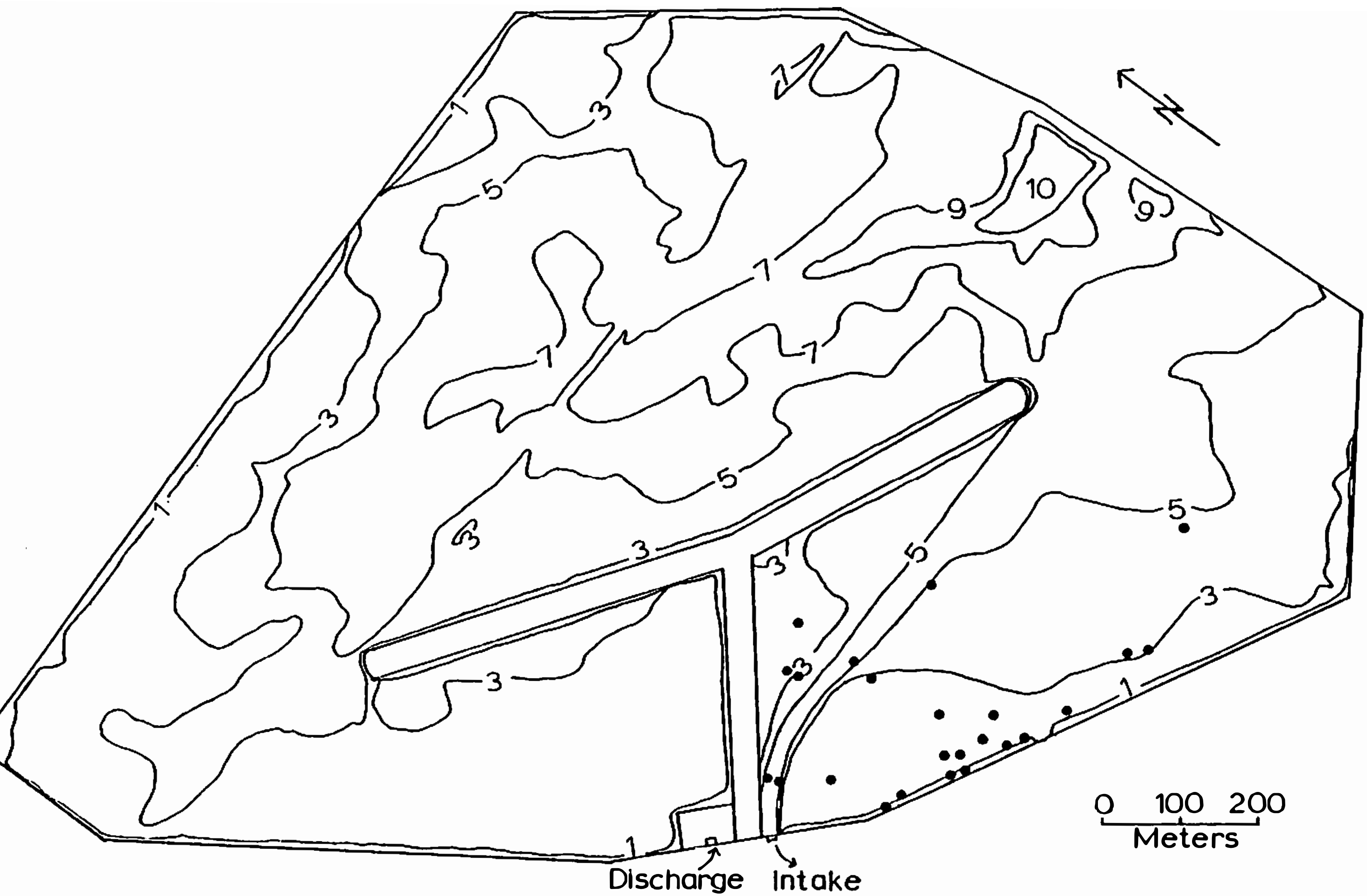

Fig. 17. Distribution of ultrasonic tagged northern pike (*Esox lucius*) 1, 1 September - 17 November 1979, in Big Stone Power Plant cooling reservoir, South Dakota.

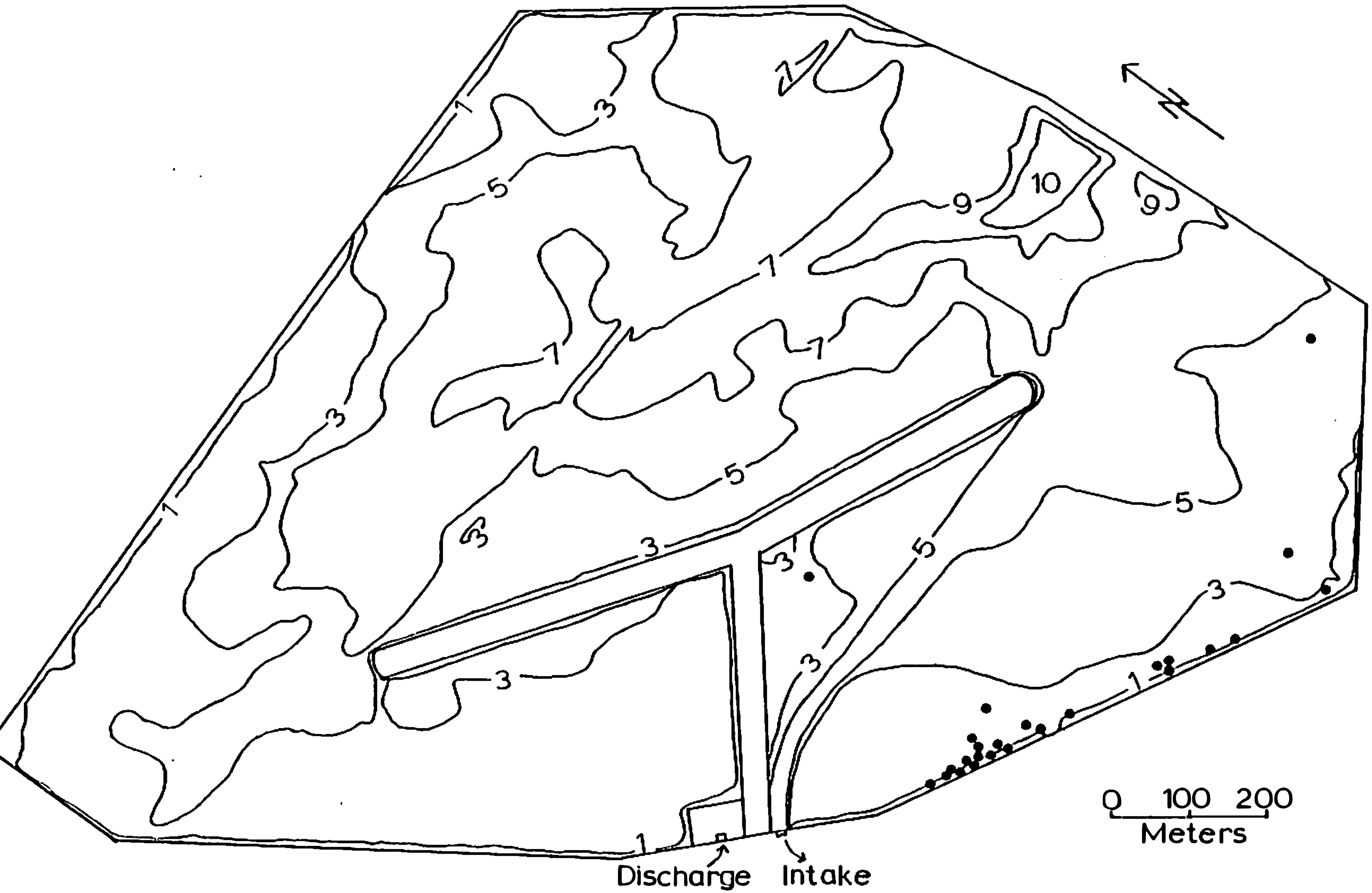

Fig. 18. Distribution of ultrasonic tagged northern pike (*Esox lucius*) 2, 1 September - 17 November 1979, in Big Stone Power Plant cooling reservoir, South Dakota.

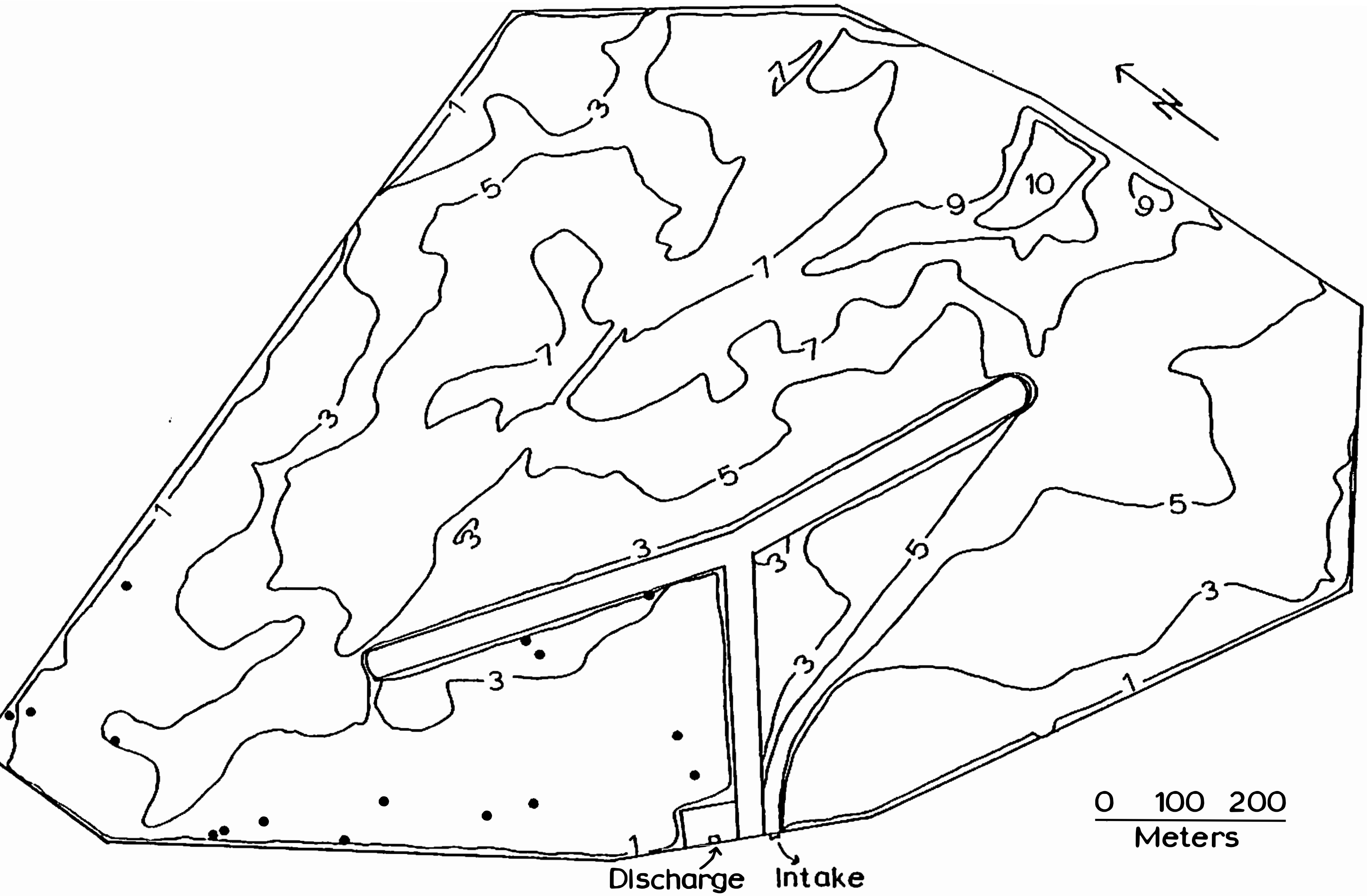

Fig. 19. Distribution of ultrasonic tagged northern pike (*Esox lucius*) 1, 2 December 1979 - 31 March 1980, in Big Stone Power Plant cooling reservoir, South Dakota.

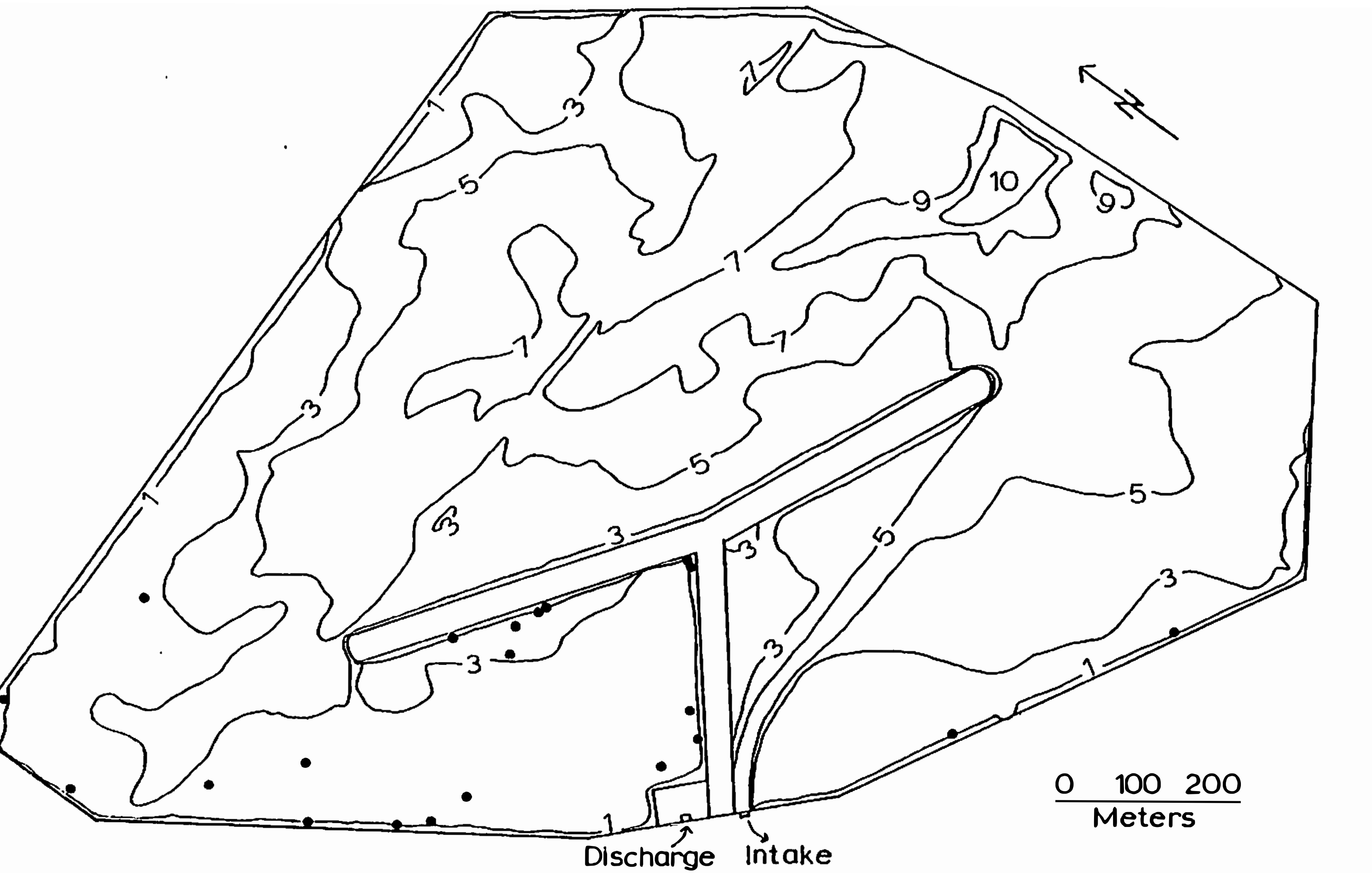

Fig. 20. Distribution of ultrasonic tagged northern pike (*Esox lucius*) 2, 2 December 1979 - 31 March 1980, in Big Stone Power Plant cooling reservoir, South Dakota.

were within the optimum range for northern pike. Echograms made during the same period indicated a major migration of forage fishes from the intake and mixing areas to the discharge area. Movement of the northern pike to the discharge area in late November may have been in response to the forage fishes usage of the area as well as their own temperature preference.

Malinin (1969) stated that "food plays an important, if not the most important, role in the selection of a sector and in the movements of fish." He found bream (*Abramis brama*) movement during summer dependent mainly on the food base. Even though radio-tagged northern pike were present in the discharge of a Minnesota power plant, Ross and Diana (1981) felt that these fish were neither confined nor attracted to the thermally altered water.

Barkley and Perrin (1971) reported that the presence of threadfin shad (*Dorosoma petenense*) in the outfall of a steam plant during the winter attracted predatory fish. They noticed that large predators moved into the area to feed even at low dissolved oxygen levels. Hanson (1973) reported large concentrations of northern pike during the winter in a warm water discharge of a reservoir in Missouri. Northern pike were found in a discharge canal during the winter along with high concentrations of spottail shiners (*Notropis hudsonius*) in Lake Wabaum, Alberta (Ash et al. 1974).

Both northern pike were rarely found more than 75 m from the shore. The average temperature for locations during this period was 13.3^{0} C. Both northern pike were found only in the 0.0 - 3.0 m depth

(100%) during the winter (Fig. 12; Appendix Tables 3 and 4). Winter observations in the present study indicated that both fish were located in the upper warm water strata. Movement from January through March was associated with discharge plume movement. A change in the plume location resulted in a change in the location of northern pike. Both fish remained on the outer perimeter of the plume except during the coldest portion of the winter. At that time, they were located inside the plume. Winter movement rates for northern pike 2 averaged 425 m/day; northern pike 1 averaged 375 m/day (Fig. 7). Little is known of the winter activity of northern pike. Diana (1979) reported northern pike to be sedentary in both the summer and winter. Diana et al. (1977) observed most daily winter movements of Lac Ste. Anne northern pike to be 199 m or less. Ross and Diana (1981) reported the mean distance moved between daily locations during the winter in a power plant discharge to be 251 m.

Spring was a period of increased activity (Figs. 21 and 22). Both northern pike remained in the discharge area until 5 April 1980. Movement rates were between 525 - 1,100 m/day. Temperatures were between 17.0 - 19.0^0 C (Fig. 7). Northern pike 2 was recorded moving 622.5 m/hour (12.0^0 C) on 12 April 1980. Casselman (1978) reported that temperatures between 14.0 and 19.0^0 C were optimum for northern pike activity. Carbine and Applegate (1946) observed that northern pike moved 16.1 km in 22 hours (727 m/hour) during the spring, 15 April 1946; no temperatures were recorded.

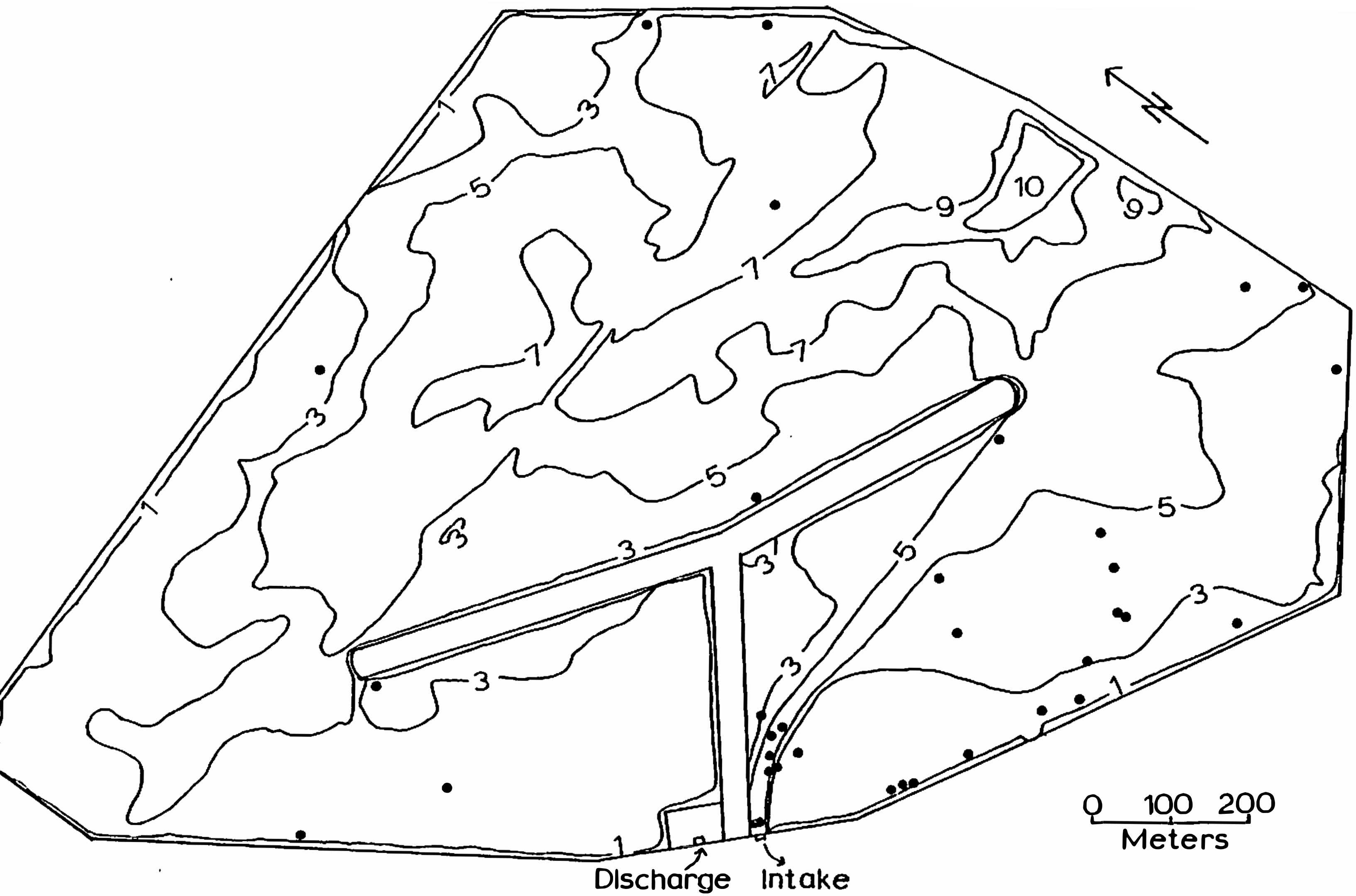

Fig. 21. Distribution of ultrasonic tagged northern pike (Esox lucius) 1, 4 April - 6 June 1980, in Big Stone Power Plant cooling reservoir, South Dakota.

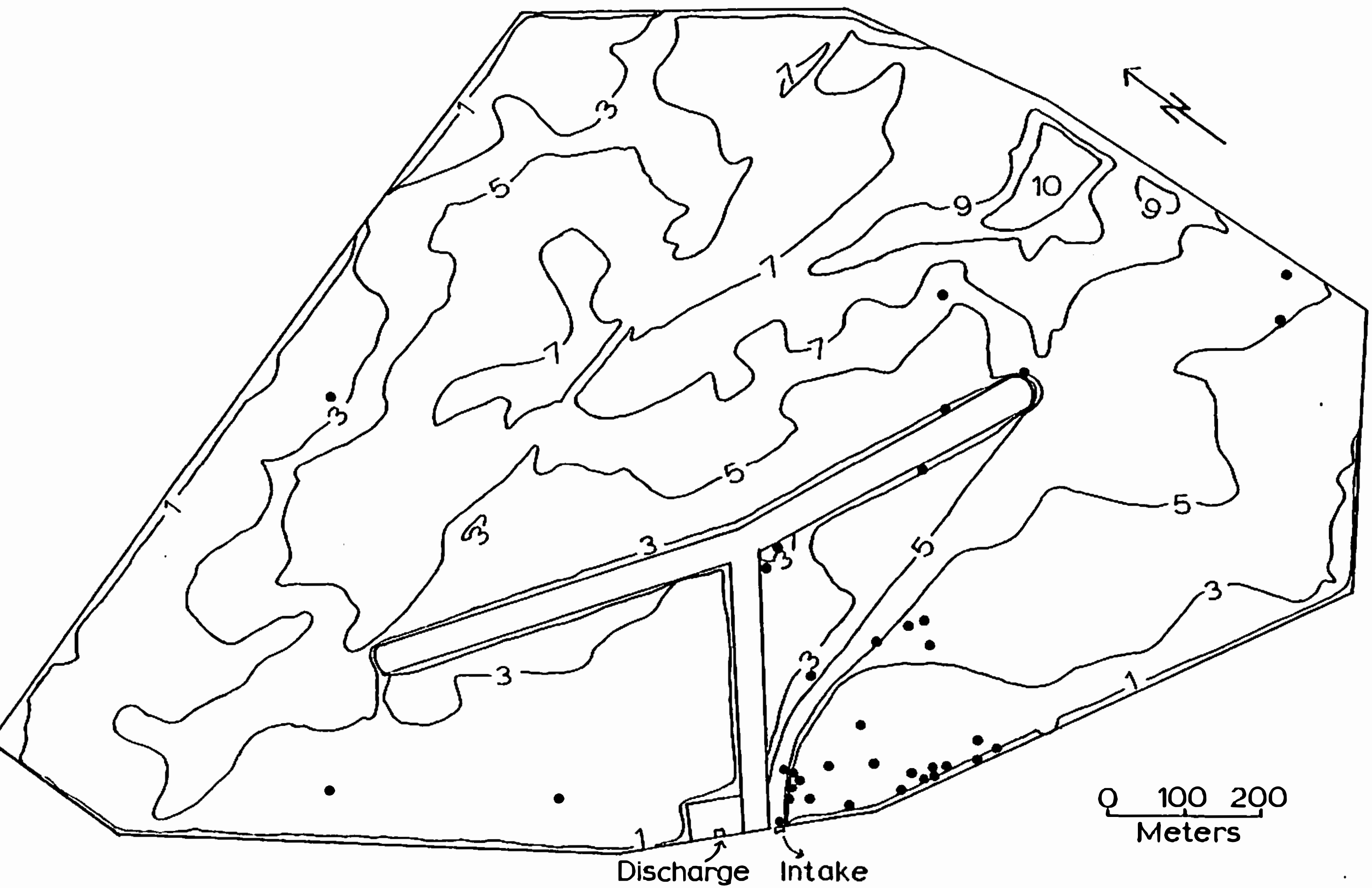

Fig. 22. Distribution of ultrasonic tagged northern pike (*Esox lucius*) 2, 4 April - 31 May 1980, in Big Stone Power Plant cooling reservoir, South Dakota.

The intake and mixing areas were inhabited by both northern pike during the remainder of April and May. Northern pike 1 and 2 locations were primarily in 0.0 - 3.0 m depth during the spring (53% and 62%, respectively). Neither fish was found in water deeper than 7.1 m (Fig. 13). Movement rates declined after spring temperatures reached 23.0^0 C (Fig. 7) and both fish moved to the intake area. Summer temperatures in the intake area averaged 26.0^0 C (Fig. 2). Northern pike 1 had tag failure on 6 June 1980. June locations averaged 24.4^0 C in temperature and 3.8 m in depth. Movement decreased (405 m/day) as temperature increased (Fig. 7). Distribution for June 1980 was similar to June 1979 distribution (Fig. 23).

Diurnal Movement of Esocids

In a 24 hour period, the muskellunge moved greater distances ($\bar{x}$ = 2,063 m) than northern pike 1 ($\bar{x}$ = 325 m) or 2 ($\bar{x}$ = 650 m) (Table 1). All 3 esocids were active during the 24 hour period, however most activity occurred during periods of light. Fishes were tracked in water 2.8 - 6.0 m deep with few underwater structures. Water temperatures ranged from 17.5 - 32.0^0 C.

Diurnal Movement of Muskellunge

The muskellunge was tracked for three 24 hour periods during the summer and fall of 1979 (Figs. 24, 25, and 26). Movement of the muskellunge averaged 2,063 m/day. Night movement was observed during all muskellunge tracks, especially on 2 September 1979. The fish

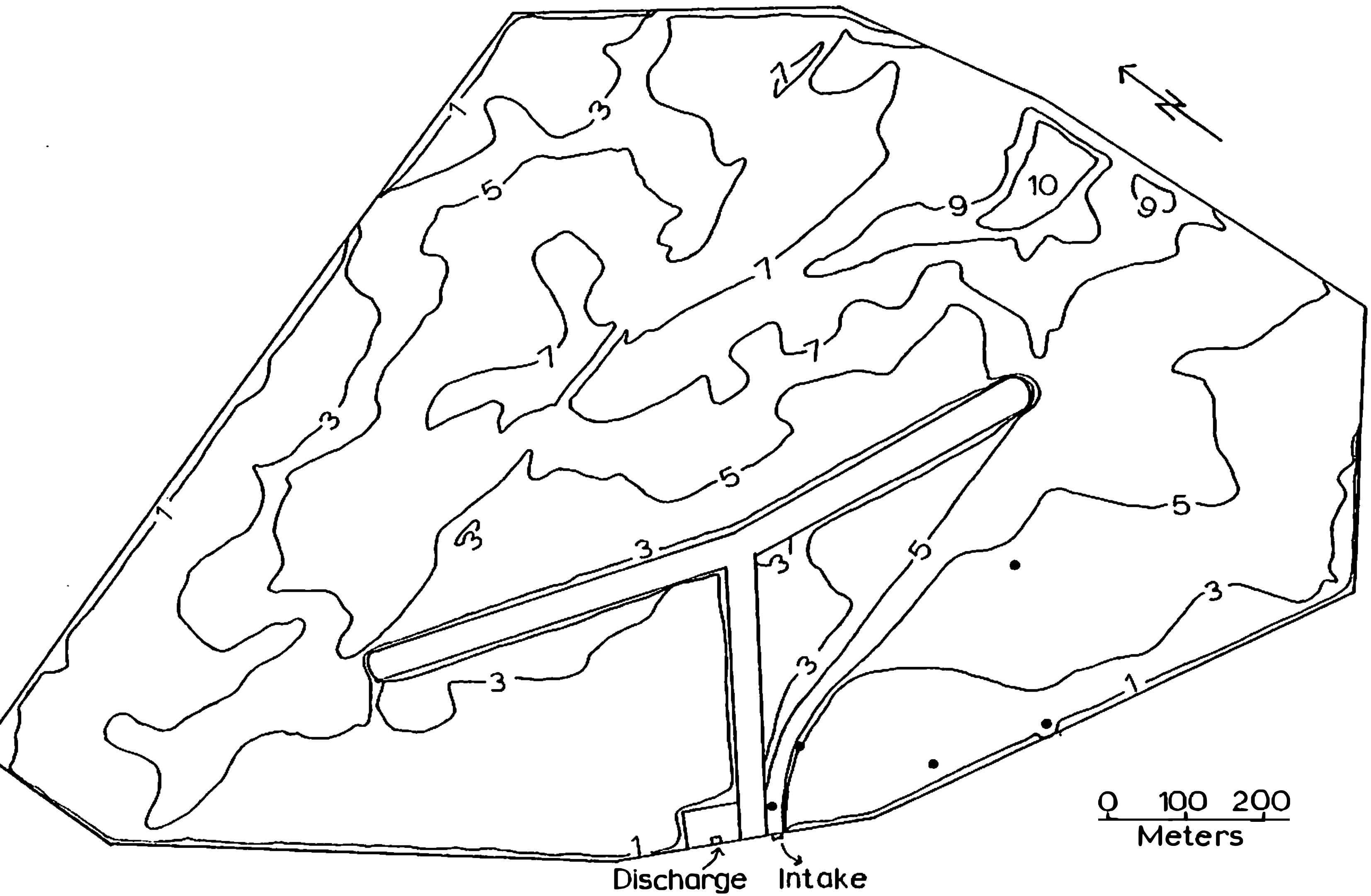

Fig. 23. Distribution of ultrasonic tagged northern pike (*Esox lucius*) 2, 1 - 12 June 1980, in Big Stone Power Plant cooling reservoir, South Dakota.

Table 1. Summary of 24 hour movement data of muskellunge and northern pike in Big Stone Power Plant cooling reservoir, South Dakota.

Fish	Date	Distance Traveled (Total m) % Day	% Night	Rate of Movement (Average m/hr) Day	Night	Temperature (C)	Depth (m)
Muskellunge	7/11/79	86.4	13.6	99.3	73.4	29.9	6.0
		(2,018)		(86.3)			
Muskellunge	8/15 - 16/79	97.4*	2.6	193.7	22.7	25.5	3.6
		(1,902)		(108.2)			
Muskellunge	9/1 - 2/79	60.0	40.0	130.7	211.2	28.4	4.3
		(2,270)		(170.9)			
Northern Pike 1	9/22/79	100.0	0.0	81.5	0.0	17.5	2.8
		(155)		(40.7)			
Northern Pike 2	7/22/79	58.9	41.1	48.1	83.7	32.0	5.3
		(560)		(65.9)			
Northern Pike 1	5/3 - 4/80	57.6	42.4	57.9	77.8	26.5	6.1
		(495)		(67.8)			
Northern Pike 2	5/21 - 22/80	70.9	29.1	73.1	107.5	25.2	5.1
		(740)		(90.3)			

* Significantly ($P < 0.05$) greater.

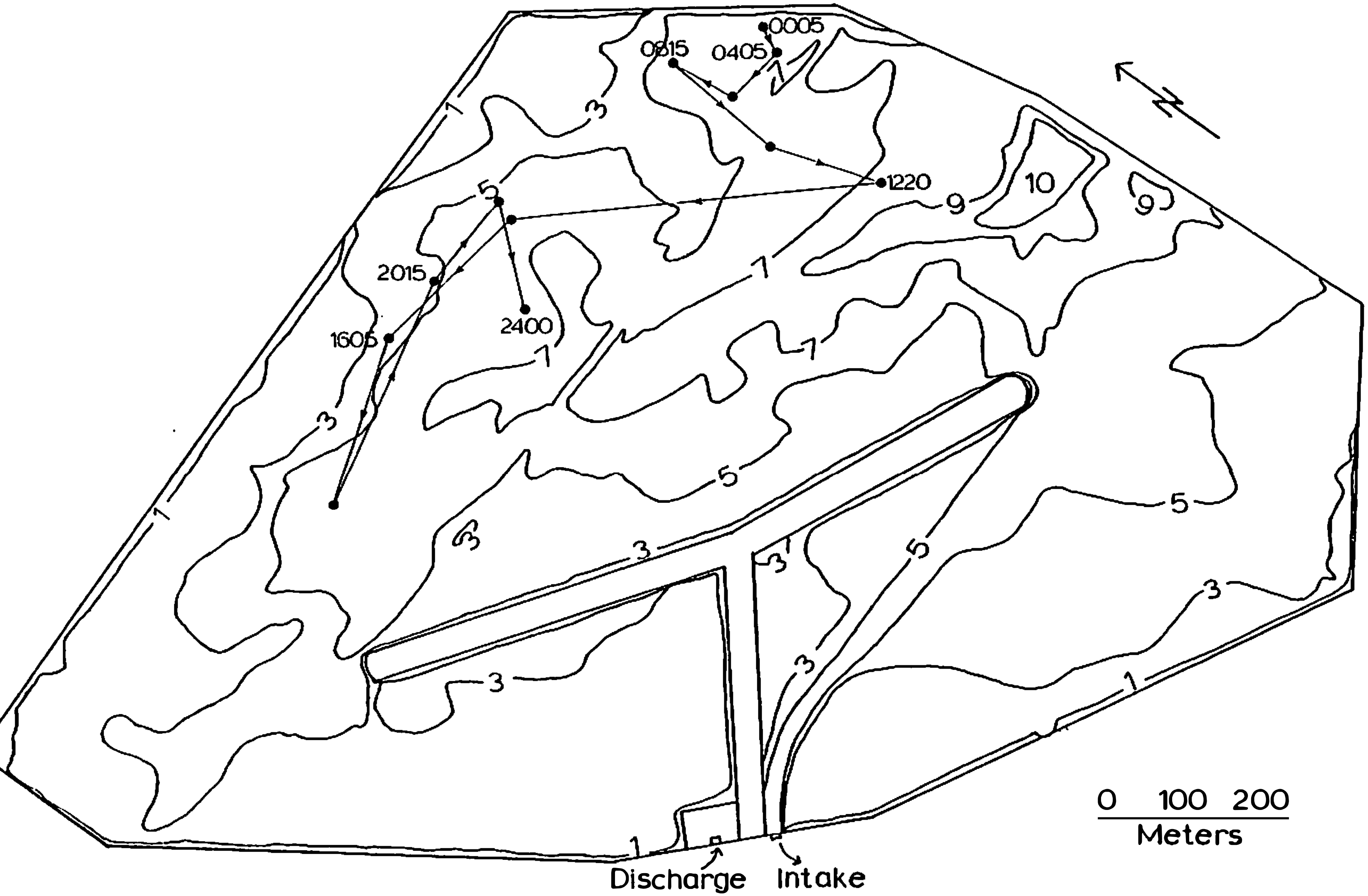

Fig. 24. Movement of an ultrasonic tagged muskellunge (Esox masquinongy), 0005 hours to 2400 hours, 11 July 1979, in Big Stone Power Plant cooling reservoir, South Dakota.

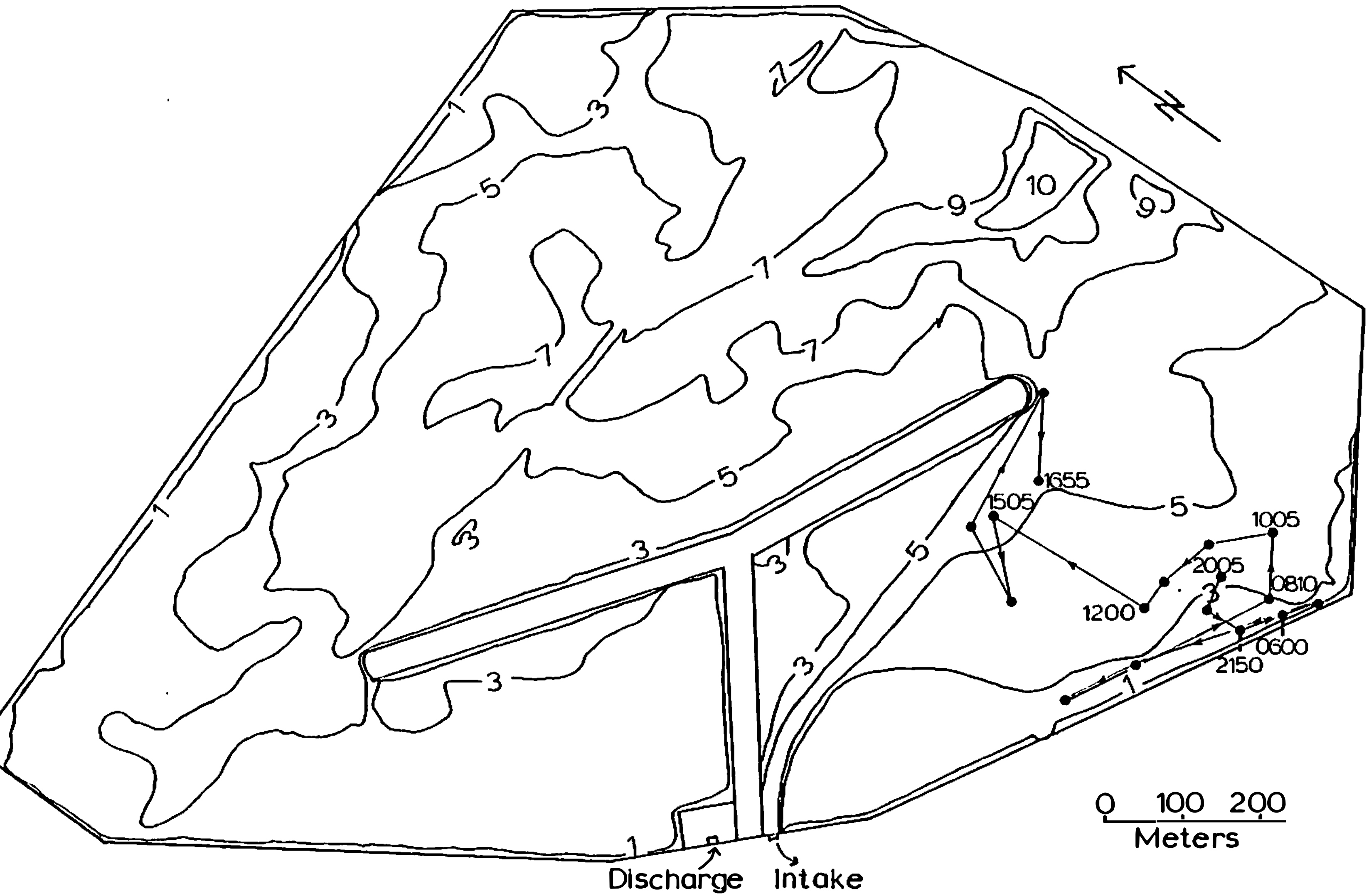

Fig. 25. Movement of an ultrasonic tagged muskellunge (Esox masquinongy), 2005 hours to 1655 hours, 15 - 16 August 1979, in Big Stone Power Plant cooling reservoir, South Dakota.

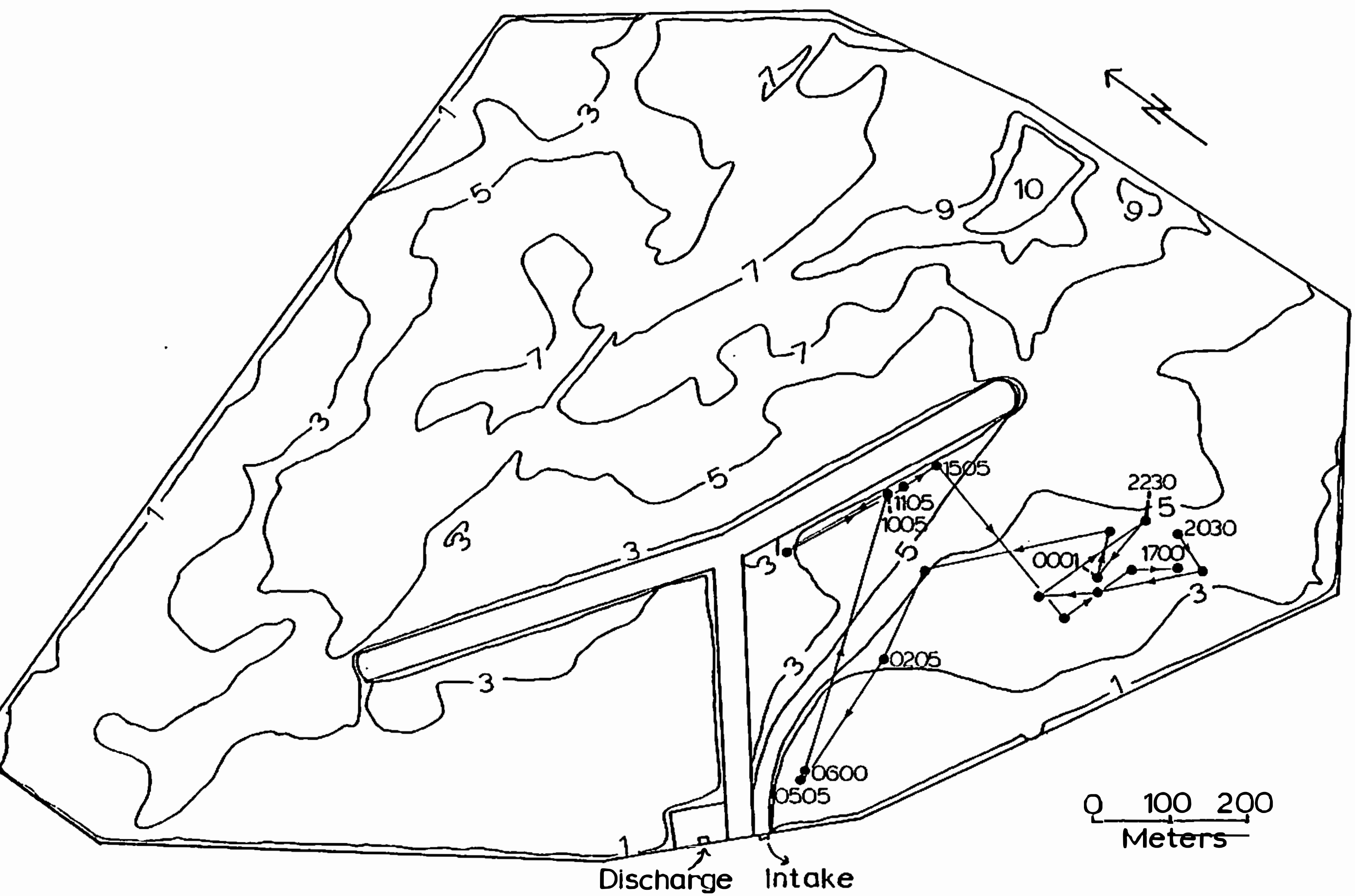

Fig. 26. Movement of an ultrasonic tagged muskellunge (Esox masquinongy), 2030 hours to 1700 hours, 1 - 2 September 1979, in Big Stone Power Plant cooling reservoir, South Dakota.

moved 2,270 m, 910 m (40.0%) of which were during the night. There was little increase in movement during early morning and evening hours by the muskellunge. Except for the track in September, movement rates were higher during the day than at night (Table 1). Most movement was occuring at temperatures above 28.0^0 C. The average depth inhabited during that period was 4.6 m. There was no significant ($P < 0.05$) difference in the water temperature inhabited at day and night. The fish moved a significantly greater distance during the day in the 15 - 16 August 1979 track ($P < 0.05$; t calc. = 2.86, df = 22), but not in the other 2 tracks. Depths of water at night locations ($\bar{x}$ = 5.0 m) were greater than those at day ($\bar{x}$ = 3.7 m).

Dombeck (1979) regarded temperature as one of the major parameters influencing muskellunge behavior. He did not observe decreases in muskellunge activity until temperatures exceeded 25^0 C. High movement rates of the esocids at temperatures above 25^0 C in the Big Stone cooling reservoir, may have been due to acclimation to the warm water or the fish may have been seeking more favorable (cooler) temperatures in the presence of temperatures above their optimum range. Crossman (1977) reported that muskellunge in Nogies Creek, Ontario, increased movement during the early morning and evening hours. He observed more movement at night than expected. Movement of muskellunge in Nogies Creek was reduced during the daylight hours.

The muskellunge moved from deep to shallow water at night in 1 of 3 tracks (2 September 1979). Crossman (1977) did not observe movement from deep to shallow water at night.

Diurnal Movement of Northern Pike

Northern pike were tracked for four 24 hour periods during the summer and fall of 1979 and spring of 1980 (Figs. 27, 28, 29, and 30). Distance traveled (m/hr) by northern pike 1 and 2 were less than those observed for the muskellunge ($\bar{x}$ = 325 and 650 m/day, respectively) (Table 1). Most movement occurred during the day (72%), however differences between day and night distance traveled were not significant. There was no significant difference in the water temperature occupied by the fish at day and night.

Northern pike 1 (monitored 22 September 1979) and 2 (monitored 21 - 22 May 1980) utilized different depths of water during day and night periods. Deeper water was occupied during the day ($\bar{x}$ = 3.4 m) by northern pike 1 when compared to night depths ($\bar{x}$ = 2.1 m); the opposite was true of northern pike 2 (day: $\bar{x}$ = 4.6 m; night: $\bar{x}$ = 6.3 m). The northern pike in Big Stone cooling reservoir were normally active during the early morning and late evening periods, however they moved during all periods in a 24 hr monitoring period.

Diana et al. (1977) observed the daily movement of Lac Ste. Anne northern pike (77%) was between 0 - 779 m/day. The northern pike were associated with vegetation and in 0.0 - 3.9 m of water 95% of the time during the summer.

Diana (1979) found northern pike to be significantly less active at night than during the day, but he did not find any significant differences in activity during daylight periods. Malinin (1969; 1970), Emery (1973), and Casselman (1978) reported that most

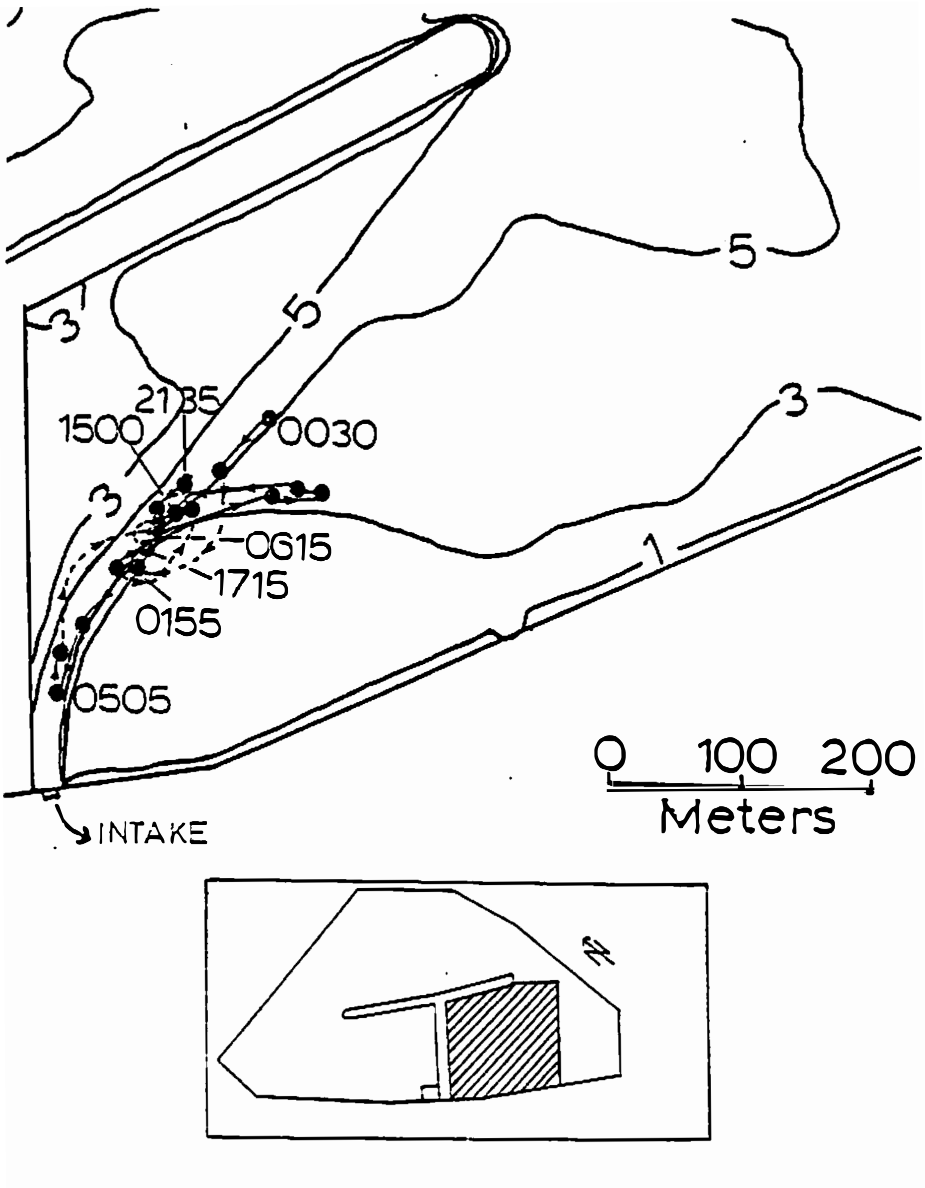

Fig. 27. Movement of ultrasonic tagged northern pike (Esox lucius) 2, 0030 hours to 2200 hours, 22 July 1979, in Big Stone Power Plant cooling reservoir, South Dakota.

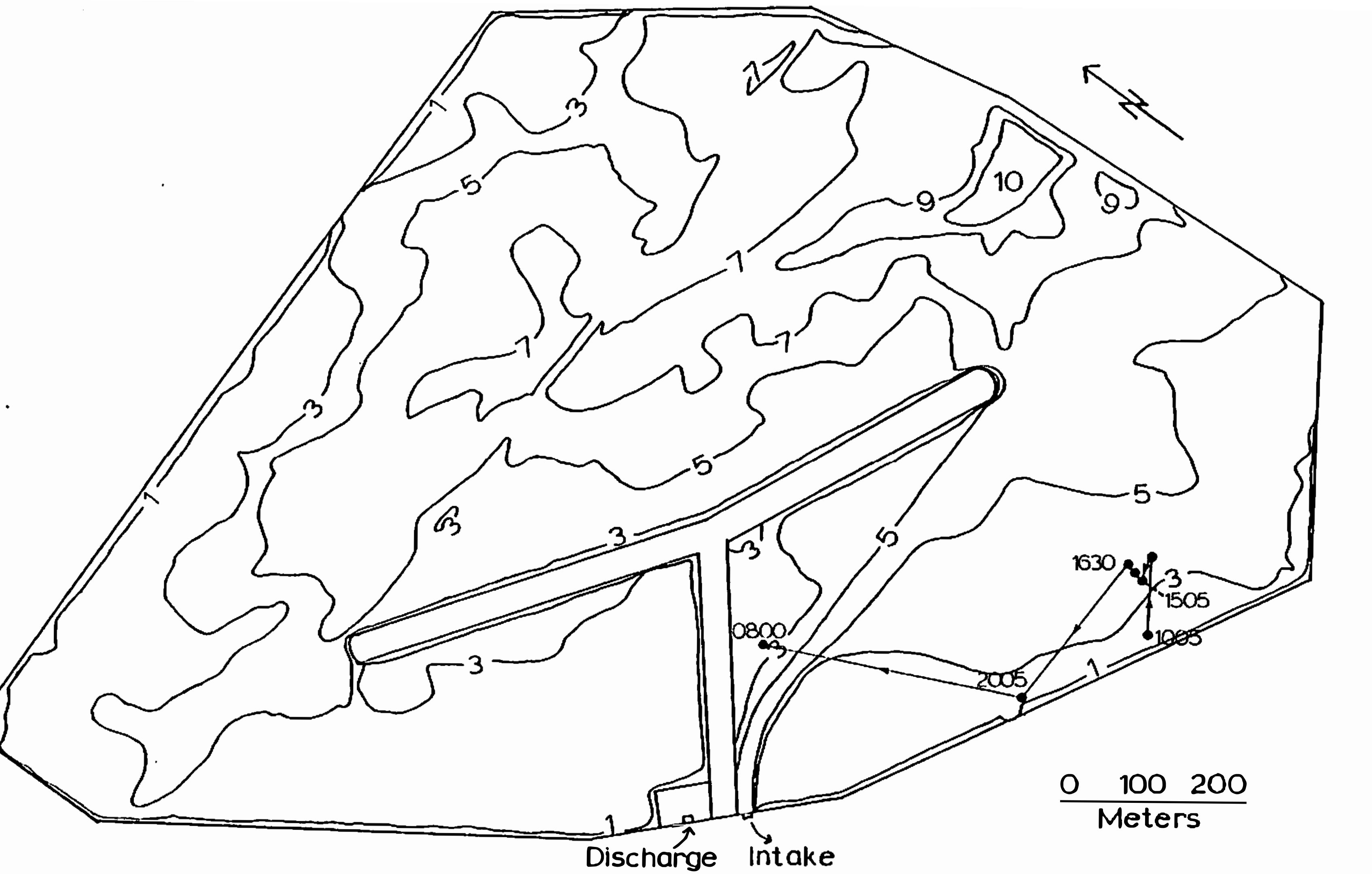

Fig. 28. Movement of ultrasonic tagged northern pike (*Esox lucius*) 1, 1005 hours to 0800 hours, 21 - 22 September 1979, in Big Stone Power Plant cooling reservoir, South Dakota.

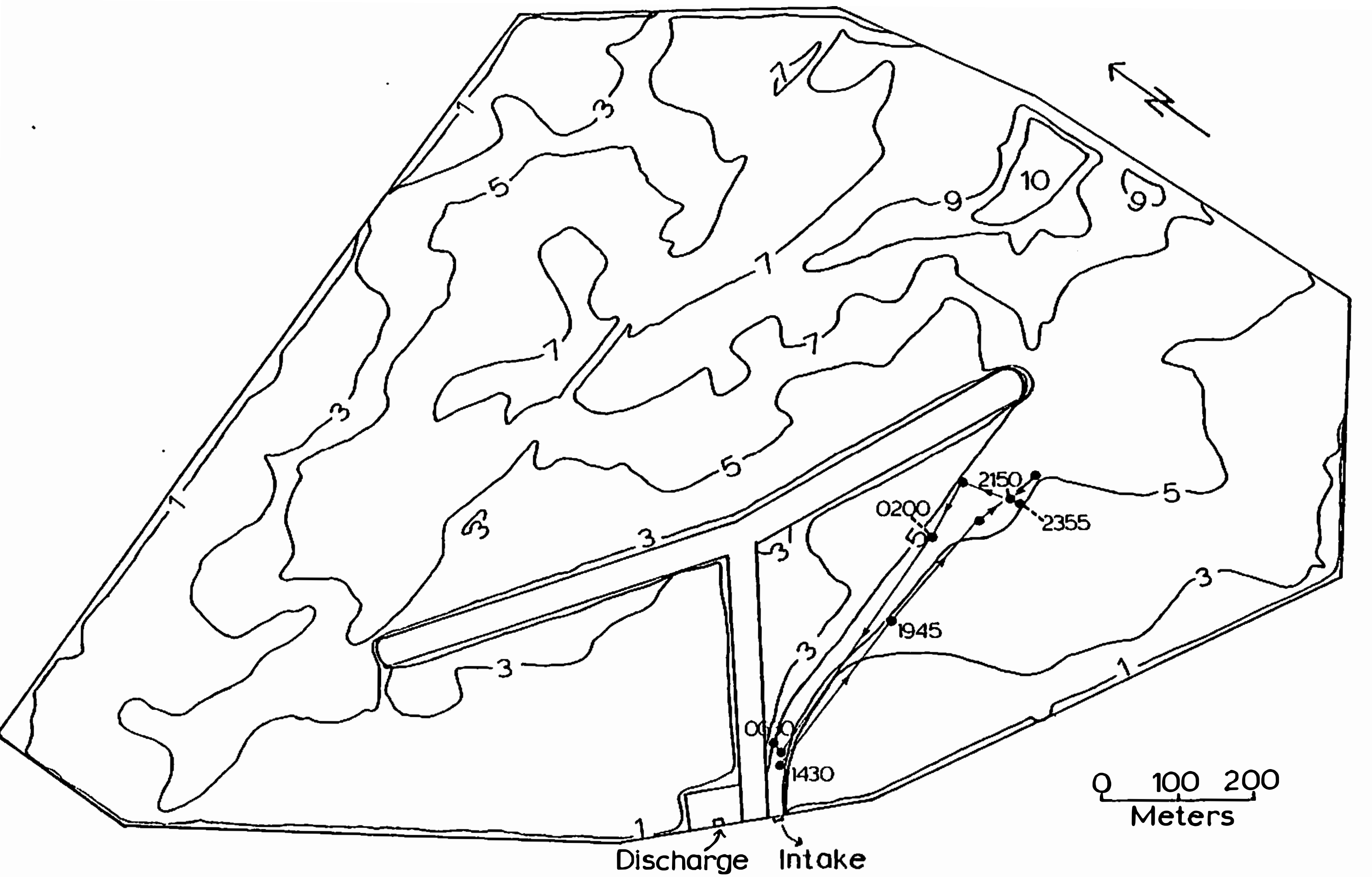

Fig. 29. Movement of ultrasonic tagged northern pike (Esox lucius) 1, 1430 hours to 1200 hours, 3 - 4 May 1980, in Big Stone Power Plant cooling reservoir, South Dakota.

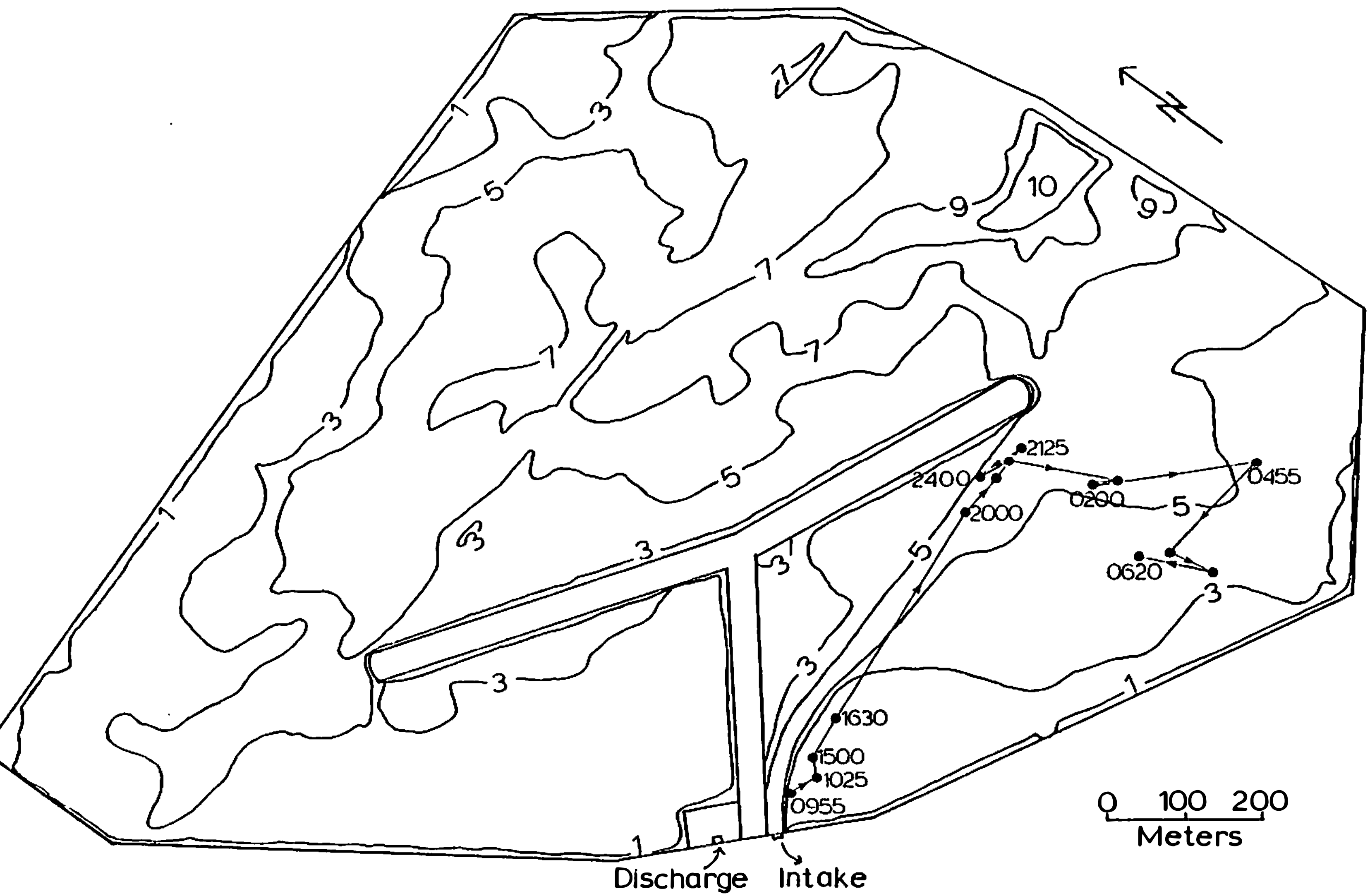

Fig. 30. Movement of ultrasonic tagged northern pike (Esox lucius) 2, 0955 hours to 0620 hours, 21 - 22 May 1980, in Big Stone Power Plant cooling reservoir, South Dakota.

northern pike movement occurred in the early morning or late evening. This would seem to be the best time of the day for a sight feeder like the northern pike to be active. Aggregations of forage fishes would be forming or breaking down during these periods and northern pike could utilize this time to capture prey (Emery 1973; Dobler 1977). Casselman (1978) found northern pike in aquaria moved spontaneously and independently of forage, which was always present. He suggested that other factors may be involved which influence movement.

Movement and Distribution of Forage Fishes

Water temperature appeared to have a major influence on the distribution of forage fishes in the Big Stone Power Plant cooling reservoir. Fishes inhabited the discharge area during the summer. Echograms indicated that concentrations of fishes in the discharge area were located on or near the bottom (1.8 - 2.8 m) (Fig. 31, A); fishes were not located in water deeper than 2.8 m. Forage fishes in the intake and mixing areas, during the summer, were characterized by being divided into 2 separate groups (Fig. 31, B). The first group was located between 0.9 - 2.7 m (average temperature 32.0^0 C); the second group was between 4.6 - 5.5 m (temperature 29.0^0 C). Few fishes were observed in the area nearest the intake entrance. Fishes were also located in stands of Potamogeton spp. (Fig. 31, C).

The power plant was shut down in September and forage fishes dispersed throughout the entire water column (Fig. 32, A). Temperatures increased in October (18.9 - 20.3^0 C; Fig. 7) and fishes resumed the segregated patterns observed during the summer (Fig. 32, B).

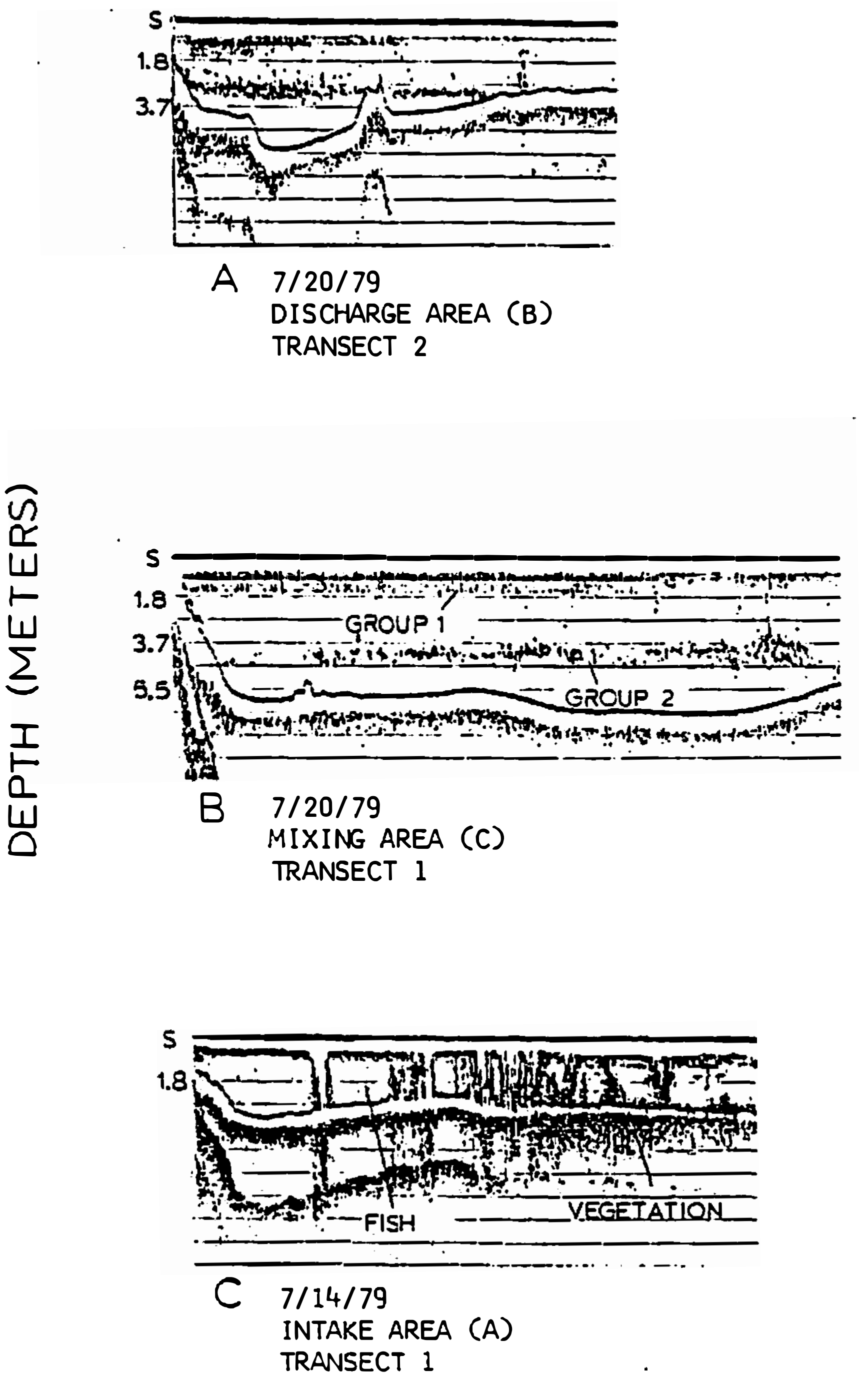

Fig. 31. Echograms illustrating characteristic summer concentrations of fish found in Areas A, B, and C, Big Stone Power Plant cooling reservoir, South Dakota.

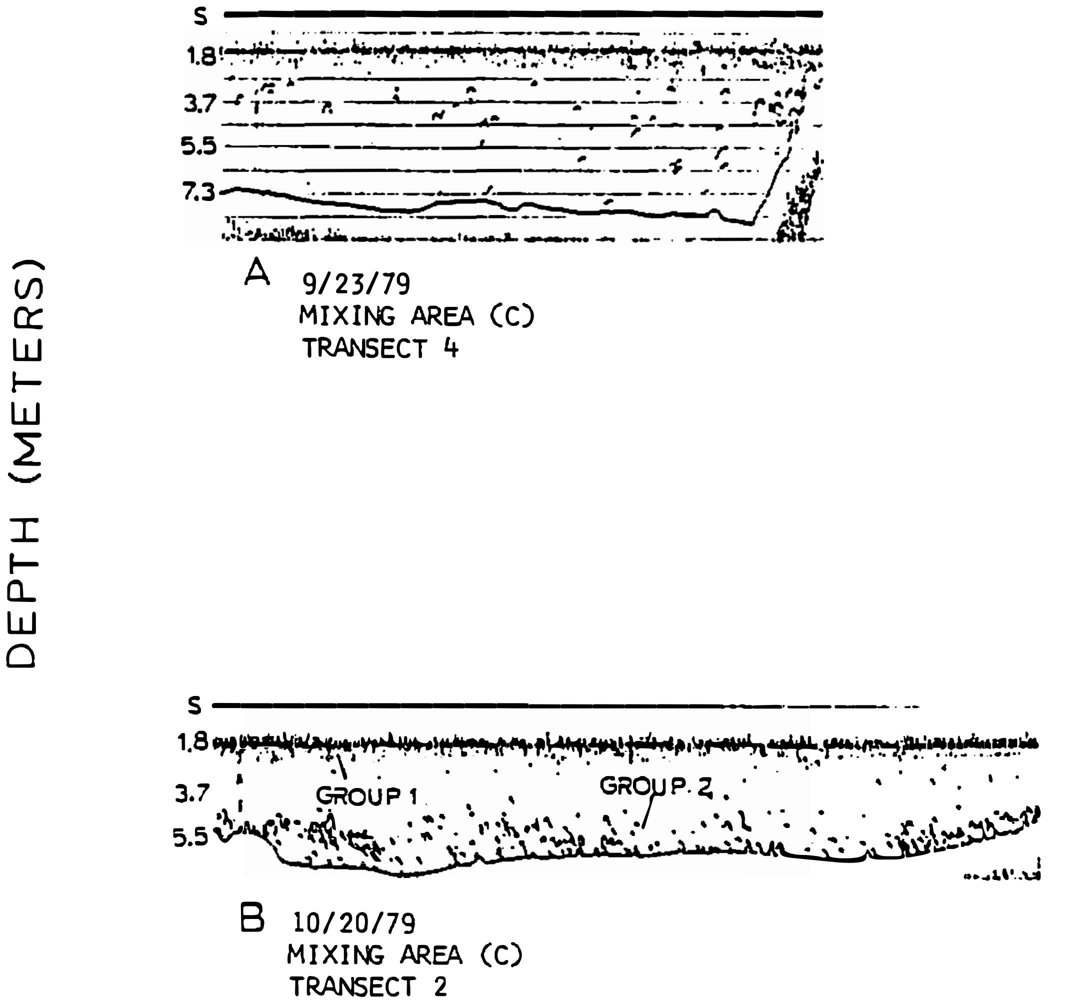

Fig. 32. Echograms of fish concentrations during (A) and after (B) power plant shut down in September, Big Stone Power Plant cooling reservoir, South Dakota.

Between 15 November and 1 December 1979, fishes moved from the intake and southern end of the mixing areas to the northern end of the mixing and discharge areas (9.8 - 14.0^{0} C; Fig. 33, A and B). January echograms revealed high concentrations of fishes in the discharge area and few in the remainder of the reservoir.

Forage fishes began to leave the discharge area and moved to the mixing and intake areas by 7 March 1980. Most fishes were in the upper 2 m (6.4^{0} C; Fig. 33, C). The power plant was not in operation from 13 - 28 March 1980 and water temperatures became uniform at 3.0^{0} C. Fish continued to move from the discharge area to the 2 other areas.

Temperatures increased in April and May and most of the fish had moved from the discharge area by 4 April 1980. Fish in the intake and mixing areas were located in the upper 3 m (14.0^{0} C); temperatures decreased to 10.0 - 11.0^{0} C below 4 m. By the end of April, temperatures had warmed in the deeper areas and fish began to utilize these areas (Fig. 34). Fish were distributed throughout all depths in the reservoir during May.

Temperatures in the Big Stone Power Plant were similar to those reported in other small cooling reservoirs (Brezina et al. 1970; McNeely and Pearson 1974; Neill and Magnuson 1974). Intense thermal stratification was present in the discharge area and portions of the mixing area. Most of the intake area was not thermally stratified because of its distance from the heat source and wind action.

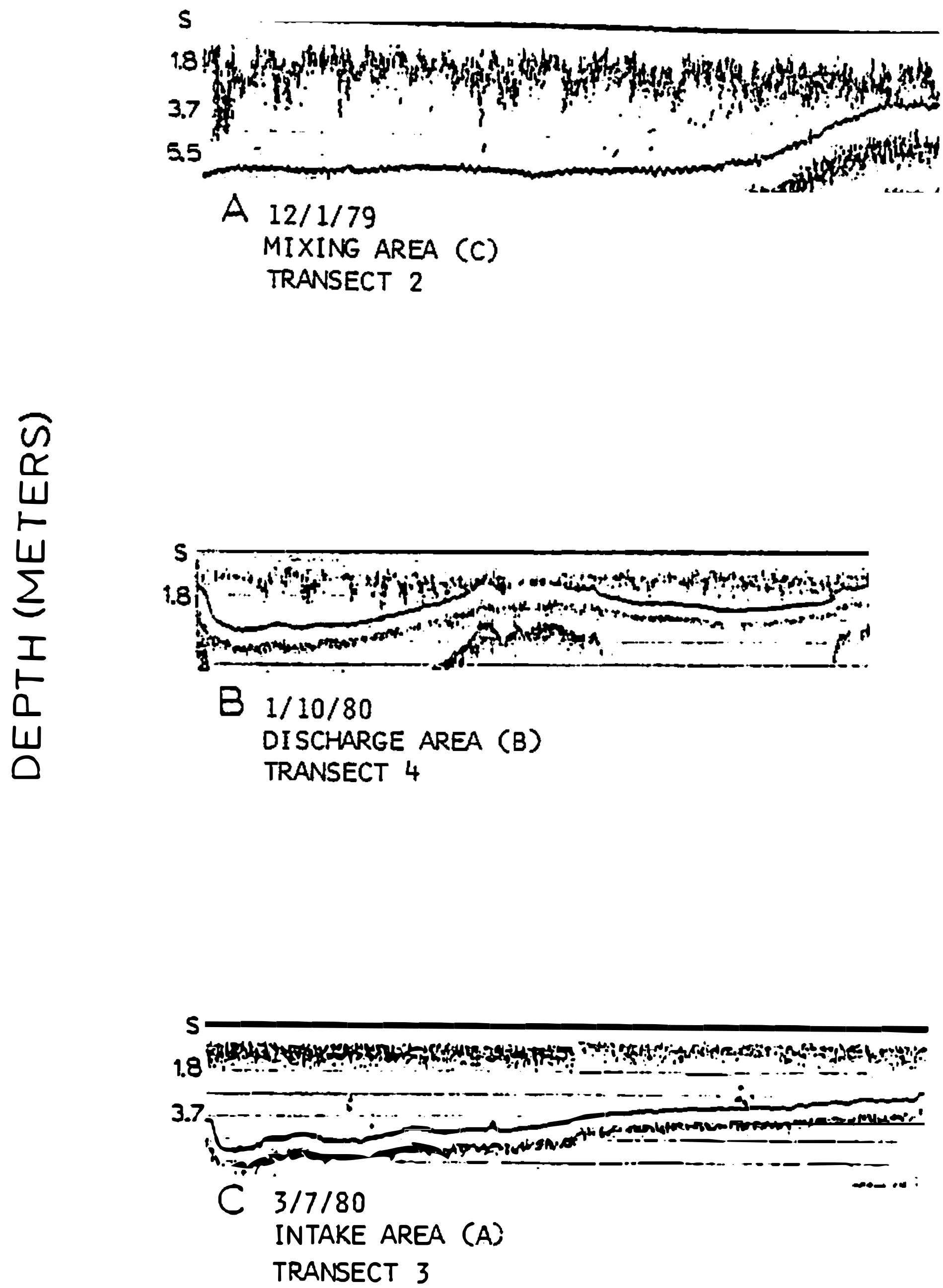

Fig. 33. Echograms illustrating changed concentrations of fish during early, middle, and late winter, Big Stone Power Plant cooling reservoir, South Dakota.

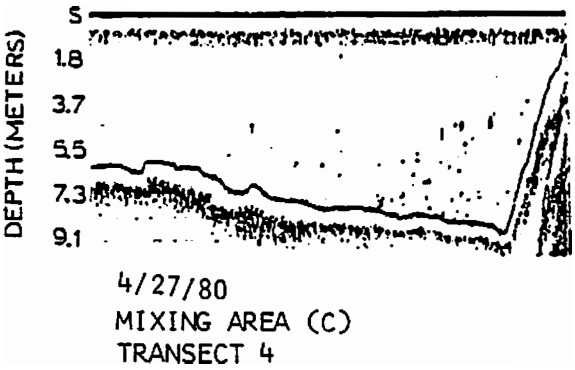

Fig. 34. Echogram illustrating utilization of deeper zones of the reservoir by fishes in early spring, Big Stone Power Plant cooling reservoir, South Dakota.

Bluegills, carp (*Cyprinus carpio*), and black bullheads (*Ictalurus melas*) were collected from all areas of the reservoir during the summer (Krska 1980). White suckers (*Catostomus commersoni*) were found to enter thermally altered water for short periods and then retreat to unaltered water (Kelso 1977). Smith (1971) suggested that fish found in thermally altered reservoirs were acclimated to withstand short durations of exposure to heated water. Holland et al. (1974) stated that bluegills present in thermally altered water had higher thermal tolerances than those found in natural water. It has been suggested that fish attraction to the discharge area during the late spring, summer, and fall may be caused by currents produced at the outfall (Kelso 1976).

Kelso and Minns (1975) found segregated pelagic populations of fishes in the summer near a thermal discharge. Separation of populations was thought to have been a function of temperature preference. Segregation of the fishes near discharge outfalls was thought to be caused by the plume and its configuration and unrelated to habitat (Kelso 1976).

Reutter and Herdendorf (1976) felt that attraction to the discharge area would be greatest in winter when the difference in a fish temperature preferendum and the ambient lake temperature was the greatest. Fishes are more prevalent in the discharge area during the winter than at any other time of the year (Dryer and Benson 1956; Alabaster 1963; Barkley and Perrin 1971).

Hall and Werner (1977) noticed that fish in a Michigan lake began to disperse from winter concentration sites as the water began to warm. They hypothesized that increasing prey availability and higher temperatures were the primary reasons for fish dispersion. In the Big Stone Power Plant cooling reservoir, however, fishes began to emigrate from the discharge area as water temperatures lowered. This action may have been in response to what Richards and Ibara (1978) termed "temperature trapping" of fishes in the discharge area. Once temperatures became uniform the fishes were able to leave the area.

SUMMARY

Both northern pike and the muskellunge exhibited seasonal movement within the Big Stone Power Plant cooling reservoir. The seasonal distribution of the tagged esocids indicated that these fishes were inhabiting areas of the reservoir where temperatures were most compatible for survival and growth. The esocids inhabited the intake area of the cooling reservoir during the summer, where temperatures were compatible for their survival (temperature range, 27.5 - 31.5^0 C) and they inhabited the discharge area during the winter, where temperatures were more favorable for their growth (range, 4.5 - 21.5^0 C).

Forage fish species exhibited seasonal movements similar to those of the esocids, but fishes were present throughout the reservoir during the spring, summer, and fall. Winter echograms indicated a concentration of fishes in the discharge area probably because of favorable temperatures for growth and concentration of forage.

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APPENDIX

Appendix Table 1. Summary of ultrasonic tagged muskellunge (*Esox masquinongy*), and northern pike (*E. lucius*) released in Big Stone Power Plant cooling reservoir, South Dakota.

Fish	Tag Number	Length (mm)	Weight (gr)	Date of Release	Expiration Date	Number of Days Tracked	Number of Observations
Muskellunge	40	460	530	5/22/79	5/31/79	9	1
Muskellunge	50	447	589	5/22/79	6/12/80	386	211
Muskellunge	61	472	610	5/22/79	5/31/79	9	1
Muskellunge	65	457	530	5/22/79	5/24/79	2	0
Muskellunge	92	455	510	5/22/79	5/31/79	9	4
Northern Pike	46	659	1,900	6/21/79	6/6/80	350	183
Northern Pike	53	605	1,325	6/13/79	6/12/80	364	193
Northern Pike	63	524	1,000	10/19/79	4/5/80	169	24
Northern Pike	88	623	1,425	6/20/79	8/4/79	44	53
Northern Pike	118	945	5,897	6/22/79	7/21/79	30	20
						TOTAL	691

Appendix Table 2. Chi square comparison of the number of observed and expected locations of ultrasonic tagged muskellunge (*Esox masquinongy*) in relation to the amount of area within each depth category, in Big Stone Power Plant cooling reservoir, South Dakota, 22 May 1979 - 12 June 1980.

Depth category (m)	Proportion of total area	Number of locations in each depth category	Expected number of locations in each depth category	Chi square calculation	Proportion of locations observed in each depth category	Confidence interval on proportion of occurrences (p_i) (95% confidence interval) in each depth category
Summer						
0.0 - 3.0	0.53	11	30	12.03	0.19	$0.07 \leq p_i \leq 0.32$
3.1 - 7.0	0.36	44	21	25.19	0.77	$0.64 \leq p_i \leq 0.91$
7.1 -10.0	0.11	2	6	2.67	0.04	$0.00 \leq p_i \leq 0.09$
				Σ39.89*		
Fall						
0.0 - 3.0	0.53	9	12	0.75	0.39	$0.15 \leq p_i \leq 0.64$
3.1 - 7.0	0.36	14	8	4.50	0.61	$0.36 \leq p_i \leq 0.85$
7.1 -10.0	0.11	0	3	0.00	0.00	—
				Σ 5.25		
Winter						
0.0 - 3.0	0.53	22	12	8.33	1.00	p_i
3.1 - 7.0	0.36	0	8	0.00	0.00	—
7.1 -10.0	0.11	0	2	0.00	0.00	--
				Σ 8.33*		
Spring						
0.0 - 3.0	0.53	6	18	8.00	0.17	$0.02 \leq p_i \leq 0.32$
3.1 - 7.0	0.36	24	13	9.31	0.69	$0.50 \leq p_i \leq 0.87$
7.1 -10.0	0.11	5	4	0.25	0.14	$0.00 \leq p_i \leq 0.29$
				Σ17.56*		

* Significant ($P < .05$) with 2 df.

Appendix Table 3. Chi square comparison of the number of observed and expected locations of ultrasonic tagged northern pike (Esox lucius) 1 in relation to the amount of area within each depth category, in Big Stone Power Plant cooling reservoir, South Dakota, 21 June 1979 - 6 June 1980.

Depth category (m)	Proportion of total area	Number of locations in each depth category	Expected number of locations in each depth category	Chi square calculation	Proportion of locations observed in each depth category	Confidence interval on proportion of occurrences (p_i) (95% confidence interval) in each depth category
Summer						
0.0 - 3.0	0.53	25	28	0.32	0.47	$0.31 \leq p_i \leq 0.64$
3.1 - 7.0	0.36	27	19	3.37	0.51	$0.34 \leq p_i \leq 0.67$
7.1 - 10.0	0.11	1	6	4.17	0.02	$0.00 \leq p_i \leq 0.06$
				Σ 7.86*		
Fall						
0.0 - 3.0	0.53	18	13	1.92	0.72	$0.51 \leq p_i \leq 0.94$
3.1 - 7.0	0.36	7	9	0.44	0.28	$0.07 \leq p_i \leq 0.50$
7.1 - 10.0	0.11	0	3	0.00	0.00	–
				Σ 2.36		
Winter						
0.0 - 3.0	0.53	17	9	7.11	1.00	p_i
3.1 - 7.0	0.36	0	6	0.00	0.00	–
7.1 - 10.0	0.11	0	2	0.00	0.00	–
				Σ 7.11*		
Spring						
0.0 - 3.0	0.53	19	19	0.00	0.53	$0.33 \leq p_i \leq 0.73$
3.1 - 7.0	0.36	17	13	1.23	0.43	$0.27 \leq p_i \leq 0.67$
7.1 - 10.0	0.11	0	4	0.00	0.00	–
				Σ 1.23		

* Significant ($P < .05$) with 2 df.

Appendix Table 4. Chi square comparison of the number of observed and expected locations of ultrasonic tagged northern pike (Esox lucius) 2 in relation to the amount of area within each depth category, in Big Stone Power Plant cooling reservoir, South Dakota, 13 June 1979 - 12 June 1980.

Depth category (m)	Proportion of total area	Number of locations in each depth category	Expected number of locations in each depth category	Chi square calculation	Proportion of locations observed in each depth category	Confidence interval on proportion of occurrences (p_1) (95% confidence interval) in each depth category
Summer						
0.0 - 3.0	0.53	31	29	0.14	0.56	$0.40 \leq p_1 \leq 0.72$
3.1 - 7.0	0.36	22	20	0.20	0.40	$0.24 \leq p_1 \leq 0.56$
7.1 -10.0	0.11	2	6	2.67	0.04	$0.00 \leq p_1 \leq 0.10$
				Σ 3.01		
Fall						
0.0 - 3.0	0.53	24	13	9.31	0.96	$0.87 \leq p_1 \leq 1.00$
3.1 - 7.0	0.36	1	9	7.11	0.04	$0.00 \leq p_1 \leq 0.13$
7.1 -10.0	0.11	0	3	0.00	0.00	–
				Σ16.42*		
Winter						
0.0 - 3.0	0.53	21	11	9.09	1.00	p_1
3.1 - 7.0	0.36	0	8	0.00	0.00	–
7.1 -10.0	0.11	0	2	0.00	0.00	–
				Σ 9.09*		
Fall						
0.0 - 3.0	0.53	23	19	0.84	0.62	$0.43 \leq p_1 \leq 0.81$
3.1 - 7.0	0.36	14	13	0.08	0.38	$0.19 \leq p_1 \leq 0.57$
7.1 -10.0	0.11	0	4	0.00	0.00	–
				Σ 0.92		

* Significant ($P < .05$) with 2 df.