Movement and behavior of the muskellunge determined by radio-telemetry. No. 113 1979

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MOVEMENT and BEHAVIOR of the MUSKELLUNGE DETERMINED by RADIO-TELEMETRY

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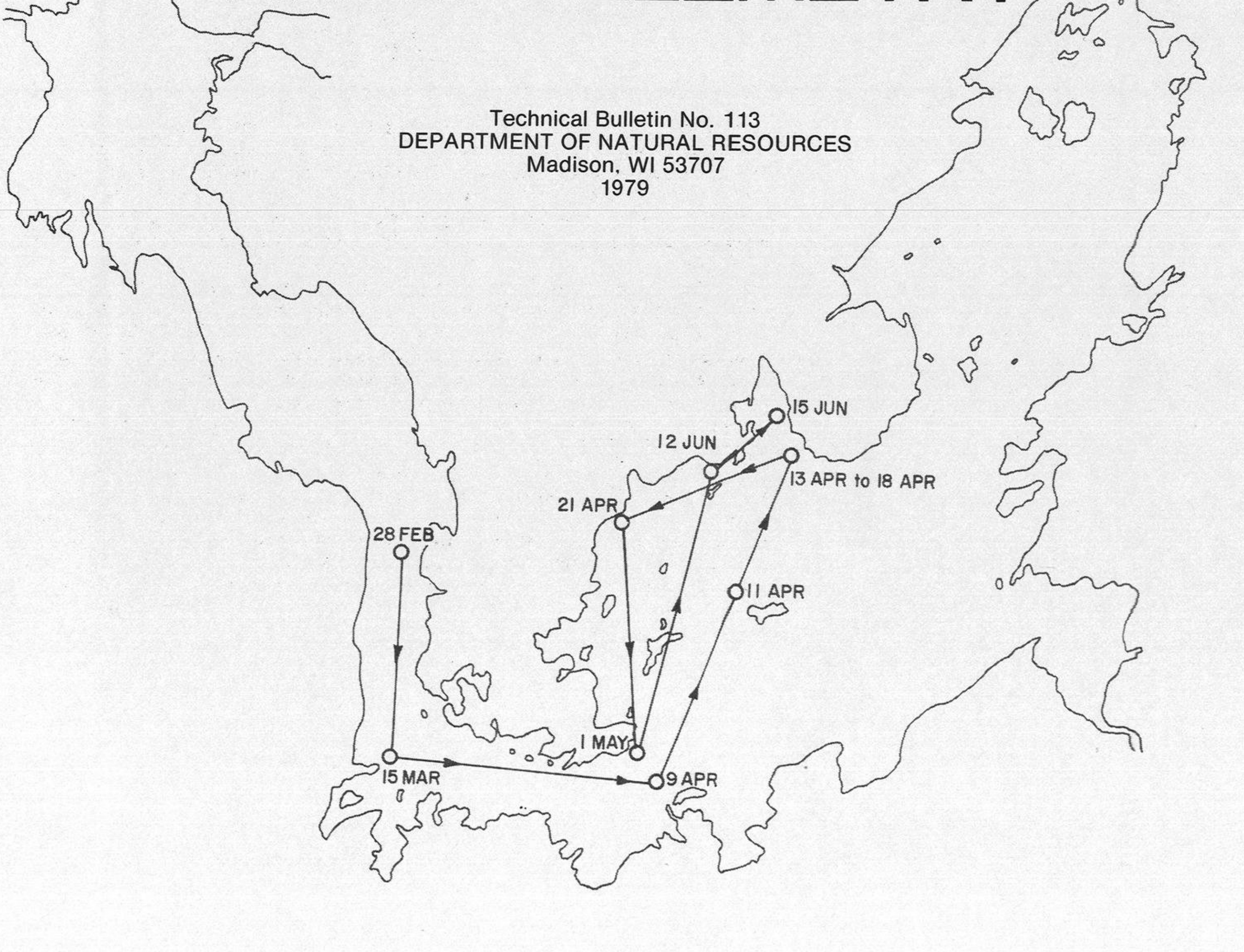

ABSTRACT

External radio-transmitters were placed on 18 muskellunge in Moose Lake and Black Lake, Sawyer County, Wisconsin. Movements of the transmitter-tagged muskellunge were monitored for 14 months, during both the open water season and through the ice. Black Lake is predominantly a muskellunge, largemouth bass, panfish lake with an area of 52 ha, while Moose Lake is predominantly a muskellunge and walleye lake with an area of 676 ha.

Peak movements and activities occurred in spring and fall when water temperatures were 4-12°C. During the summer months tagged fish occupied waters less than 2 m in depth at temperatures of 24-27°C. Greatest average swimming velocity of muskellunge observed was 50.8 m/minute. During winter months a tagged fish moved out of waters with low oxygen levels in the north bay of Black Lake to areas with a more abundant supply of oxygen. The monthly home range size of the muskellunge varied from 0.2 to 2.7 ha in Black Lake and from 2.3 to 27.7 ha in Moose Lake.

Four spawning areas were identified and spawning activities were observed. Muskellunge moved onto spawning grounds when water temperatures reached 8-10°C and remained on spawning grounds until temperatures reached about 14°C. Spawning occurred at night in depths less than 1 m over muck/sand bottoms with much debris and dead vegetation. Spawning areas were also approximately 1.5°C warmer than adjacent waters.

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by
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INTRODUCTION

The muskellunge (*Esox masquinongy* Mitchill) is a key link in our recreational economy and of great interest to the biologist and sportsman alike. Since muskellunge populations are always relatively low (Oehmcke et al. 1968), precise management of the muskellunge is desirable. At present the literature contains little basic behavioral information on the muskellunge, resulting in much speculation concerning its habits. Biologists need to know the carrying capacity of our lakes and rivers for muskellunge to aid in management decisions such as stocking and harvest quotas, to identify spawning areas, and to determine precise spawning behavior and the effects of physical and biological factors on the activity patterns and movements of this species.

Various tagging and mark-recapture studies such as those by Williamson (1940), Crossman (1956), and Johnson (1963) presented much of the movement information on the muskellunge known today. Two studies concurrent with this one (Crossman 1977; Minor and Crossman 1978) have resulted in home range and movement information on the muskellunge in Ontario. Yet, knowledge about the life history of the species remains incomplete because of inadequate methods of studying movement at all times of the year. Data on the winter movements and spawning activities of the muskellunge remain sparse. This study was an attempt to more completely describe behavior and movement of the muskellunge through the use of underwater telemetry.

Since its beginnings in the late 1950's (Trefthen 1956; Johnson 1960), underwater telemetry has been widely used in fishery research throughout North America and other parts of the world. Stasko (1975a) provides a bibliography of recent research.

The objectives of this study on muskellunge were to: (1) assess the applicability of telemetry techniques for the study of this species; (2) determine the extent of movement and size of home range; (3) describe seasonal movements and activities; and (4) identify and describe spawning areas.

STUDY AREA

This study was conducted in two lakes, Moose Lake and Black Lake, located in the Chequamegon National Forest in Sawyer County in the heart of northwestern Wisconsin's native muskellunge range (Fig. 1). Moose Lake is a reservoir, controlled by a concrete droplog dam with a head of 4 m, that was first filled to its present level in 1912. Prior to 1912 smaller log dams were built and the reservoir was used as a holding pond for logs later transported down the Chippewa River.The water level of the lake is drawn down 2.1 m from about November 15 to the time of ice breakup in the early spring.

Moose Lake has a surface area of 676 ha with a maximum depth of 6 m and 57 km of highly irregular shoreline including islands. Three major rivers enter it, Little Moose, Big Moose and the West Fork of the Chippewa, and several minor streams. It is approximately 12 km long and in most places less than 2 km wide (Fig. 2). It is generally shallow with 14% of its area less than 1 m deep and only 0.5% over 6.5 m in depth. It has a pH of 6.9, total alkalinity of 22 ppm, a conductivity of 78 micromoles/cm^3 and a secchi disc reading of 1.1 m during the summer. The original river channels are sand and gravel with scattered boulders of assorted sizes and muck in deep holes. The bays are generally muddy and strewn with rocks, logs and stumps. Vegetation is generally sparse, the predominant group being the pondweeds, *Potamogeton* spp.; burreeds, *Sparganium* spp.; cattails, *Typha* sp.; reed grass, *Phragmites* sp.; and rushes, *Scirpus* spp. Moose Lake is a Class A muskellunge lake and has one of the best naturally reproducing muskellunge populations in the state (Department of Natural Resources 1970). Other major fish species include: walleye, *Stizostedion vitrium* (Mitchill); black crappie, *Pomoxis nigromaculatus* (LeSueur); rockbass, *Ambloplites rupestris* (Rafinesque); yellow perch, *Perca flavescens* (Mitchill); white sucker, *Catastomus commersoni* (Lácepede); and redhorse, *Moxostoma* spp. Moose Lake has several resorts, many seasonal and permanent dwellings and a U.S. Forest Service campground.

Black Lake has a surface area of 52 ha with a maximum depth of 5.2 m and approximately 5 km of shoreline (Fig. 3). It has two small inlets and one outlet, Fishtrap Creek, which is tributary of the East Fork of the Chippewa River. The original water level of Black Lake has been raised 1.8 m by a concrete roller dam. It was used as a holding lake for logs during the logging era of the late 1800's and early 1900's.

Black Lake is about 1.7 km long and is divided into two basins. The north bay makes up about 30% of the total area. This area of the lake is nearing extinction due to the heavy growth of

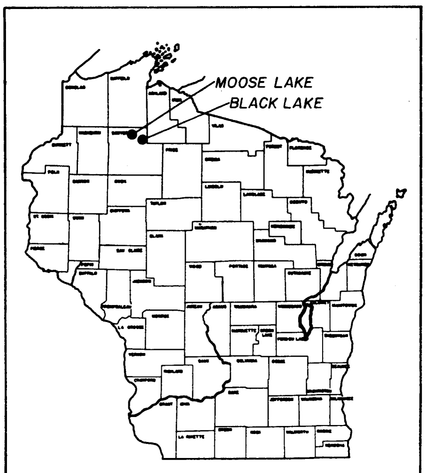

FIGURE 1. *Location of Moose Lake and Black Lake.*

both emergent and submergent aquatic vegetation, adding detritus to the bottom, and the marsh vegetation encroaching on the shoreline. The north bay has a small stream flowing into it and is largely encircled by a sphagnum and tamarack marsh producing a spongy unstable shoreline. By early summer this portion of the lake is choked with vegetation.

The remaining 70% of Black Lake is made up of a south basin which is much deeper, containing the bulk of the open water and the outlet. It has a

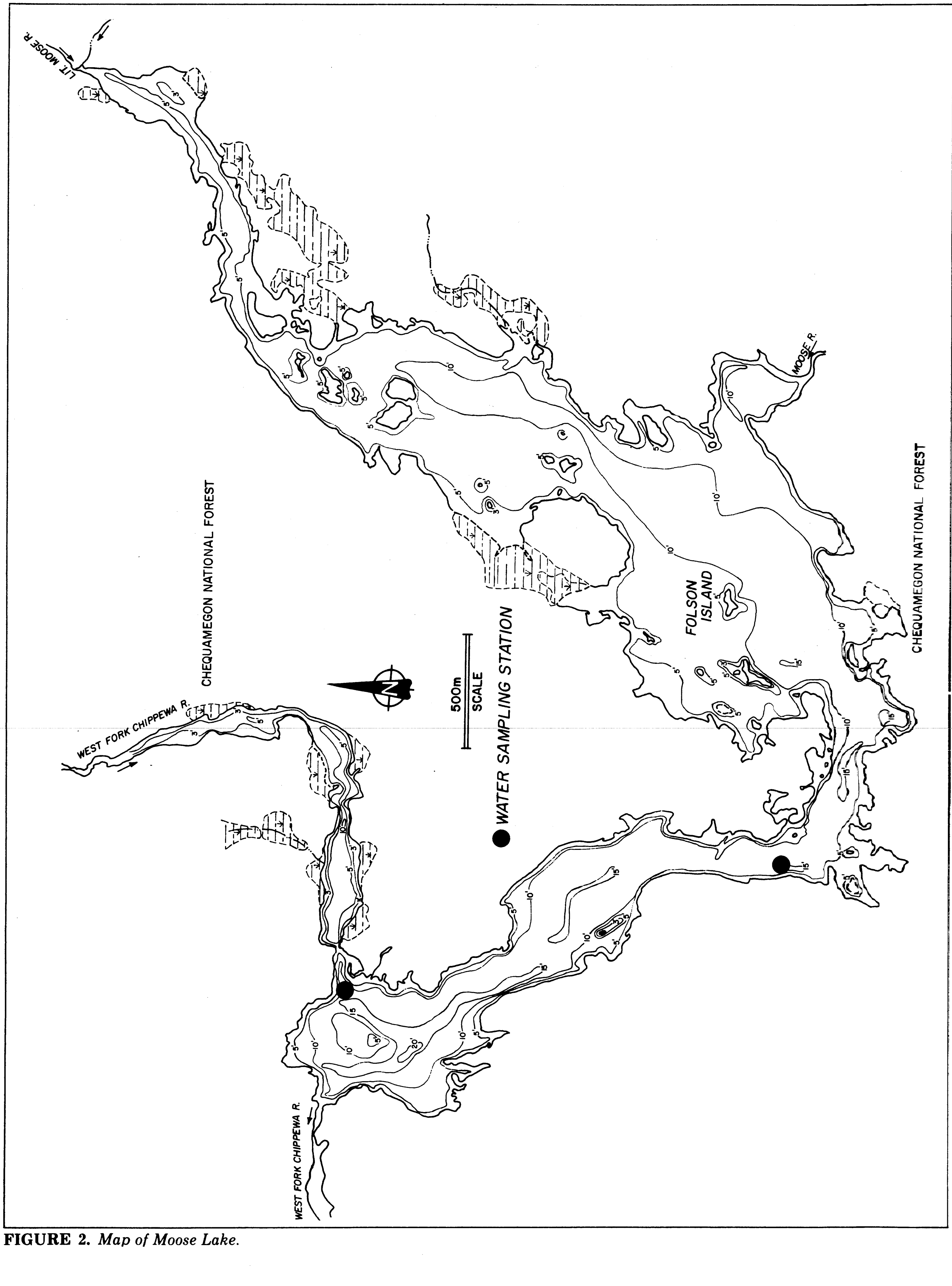

FIGURE 2. *Map of Moose Lake.*

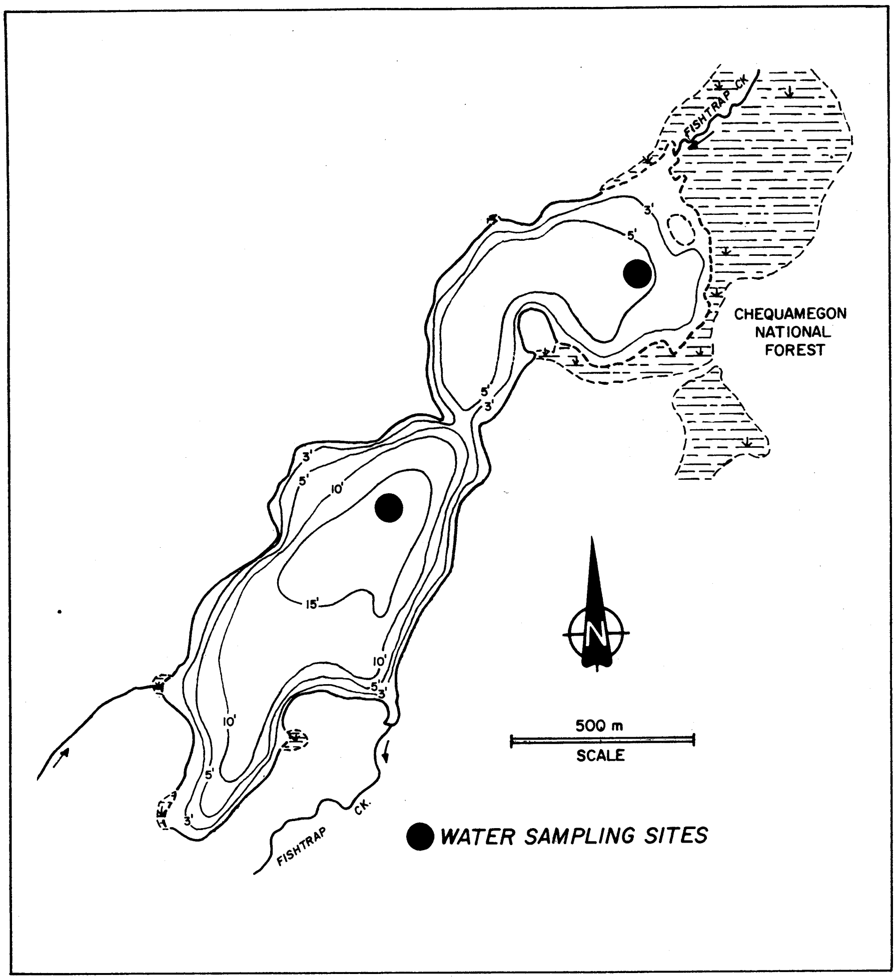

FIGURE 3. *Map of Black Lake.*

pH of 7.5, total alkalinity of 31 ppm, a conductivity of 90 micromoles/ $cm^3$and a secchi disc reading of 1.2 m. The bottom is strewn with logs and is mostly muck except along much of the shoreline where a strip generally less than 20 m of sand and/or gravel prevails. Vegetation is generally abundant in Black Lake except for the deeper areas of the south basin. Most of the shoreline is lined with emergent vegetation consisting of bulrushes; cattail; reed grass; arrowhead, *Sagittaria* sp.; and pickerelweed, *Pontederia* sp. Patches of water lilies, *Nuphar* sp. and *Nymphaea* sp.; and water shield, *Brasenia* sp. are particularly common in the north bay and scattered along the shoreline of the southern basin. Submergent vegetation growing to 1 to 2 m depths includes pondweeds; hornwort, *Certophylum* sp.; wild celery, ***Vallisneria* sp.; bladderwort, *Utricularia* sp.; milfoil,** *Myriophyllum* sp.; mare's tail, *Hippuris* sp.; and *Elodea* sp.

Black Lake is a Class A muskellunge lake. Other species of fish include: largemouth bass, *Micropterus salmoides* (Lacepede); yellow perch; black crappie; sunfishes, *Lepomis* spp.; and white sucker. Small panfish are very abundant indicating the possibility of stunted growth due to over population. Both Black Lake and Moose Lake become thermally stratified in summer and winter.

MATERIALS and METHODS

RADIO-TELEMETRY EQUIPMENT

The radio-telemetry equipment used in this study was designed and constructed by the Cedar Creek Bioelectronics Laboratory of the University of Minnesota. Radio-transmitters consisted of the radio circuitry, crystal and battery encased in Scotchcast no. 5 (Trademark of the 3M Company) plus a 30 cm whip antenna and a teflon-coated attachment wire (Fig. 4). A 53MHz receiver and a diamond-shaped bidirectional loop antenna were used to receive the radio signals (Fig. 5). For a detailed description of transmitter and receiver construction and circuitry see Cochran and Lord (1963) and Winter (1976). The receiver and antenna could easily be carried by the tracker on foot, skis or in a boat.

Three types of radio-transmitters were used in this study. Transmitters with a calculated life span of 90 days weighed 16 g in water, were 5.5 cm long and 1.5 cm in diameter. Temperature-sensitive transmitters, 300-day and 180-day, weighed 34 g in water and were 8 cm by 1.5 cm. Curves for the temperature-sensitive transmitters were calibrated in the laboratory by plotting pulse rate per minute against the temperature of the water, since there is a direct relationship between pulse frequency and temperature.

Based on the results of a preliminary study testing the effects of external and internal transmitters on muskellunge survival, external transmitters were used in this study (Append. A). Holt et al. (1977) reported successful use of external transmitters on walleye. Winter (1977) found that external transmitters caused no mortality or fungal infection and did not prevent fast escape, feeding and long movements of largemouth bass.

CAPTURE OF MUSKELLUNGE AND TRANSMITTER TAGGING PROCEDURE

Muskellunge were captured using fyke nets with 1.2 by 1.8 m front frames with 2.5 cm mesh and 15 m leads (Fig. 6). The lead was run perpendicularly from the shoreline to the hoop net which was placed in 1 to 2 m of water.

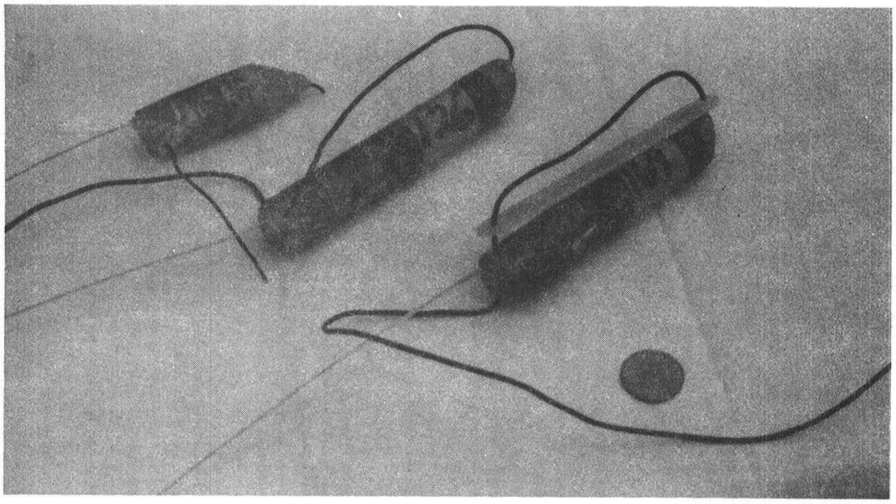

FIGURE 4. *Radio-transmitters placed on muskellunge used in study.*

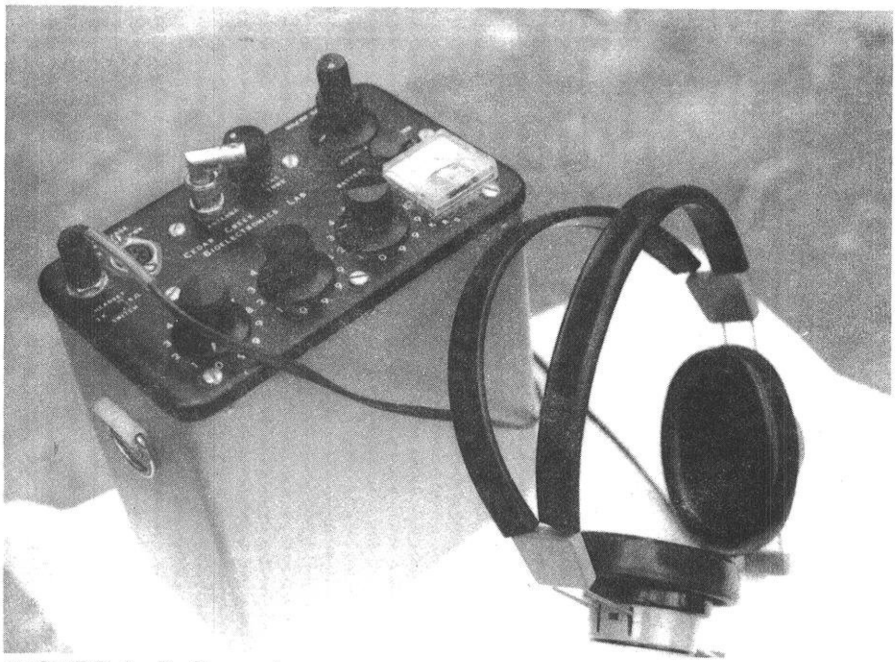

FIGURE 5. *Radio-receiver.*

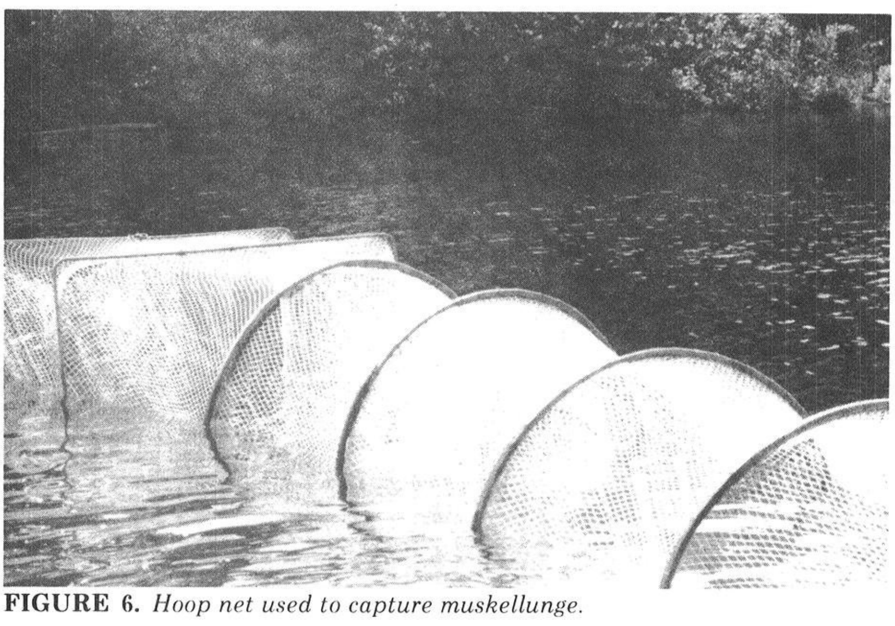

FIGURE 6. *Hoop net used to capture muskellunge.*

Various sizes of muskellunge were easily captured.

Fish selected for tagging with external radio-transmitters were weighed and placed in a 1.5 by 0.5 by 0.7 m portable tank where they were measured and tagged (Fig. 7). These fish ranged in length from 70 to 107 cm and in weight from 1.8 to 10.1 kg (Table 1). Muskellunge were very docile when placed in the tank with enough water to cover the gills but leaving the dorsal surface out of the water. The fish were easily tagged without the use of an anesthetic. Should a muskellunge begin to tense up it would simply be left alone until it relaxed, usually after about 30 seconds, and the procedure could be continued. The larger muskellunge, over 85 cm, were more docile and easier to tag than the smaller individuals.

Transmitters were attached externally to the back beside the dorsal fin. The basic procedure described by Winter (1977) was used with minor modification. A surgical needle was used to pass the teflon-coated attachment wire, connected to the transmitter, underneath the dorsal fin's supporting tissue. On the opposite side of the fish the wire was passed through a plastic washer. The wire was then brought back through a second hole in the washer, then back through the subdorsal tissue of the fish and through a hole in the posterior end of the transmitter. The wire could then be securely knotted to hold the unit tightly in place (Fig. 8). The end result was a continuous loop so when the attachment wire breaks, the entire unit falls off the fish. It is important that the anterior end of the transmitter be offset fusiform-shaped and that the attachment wire should come out the most anterior part of the transmitter. This reduced drag and prevented weeds from getting hooked on the unit (Fig. 9). The muskellunge were released immediately after tagging. The entire transmitter attachment procedure took from 3 to 5 minutes.

TRACKING

Muskellunge were tracked from a fiberglass or aluminum outboard boat or from shore during the open water season. During winter, skis proved to be the most efficient means of transportation for the tracker.

Field tests showed the maximum distance a transmitter signal could be picked up was 1.8 km, and the average range was 1.3 km when the transmitter was placed at a depth of 1 m and the average range was 0.8 km at a depth of 10 m, the maximum depth of water in this study. No noticeable decrease in range was observed through 60 cm of ice covering the lakes during winter months. Each transmitter had a different frequency and the channels were dialed on the receiver similar to a radio. This enabled the tracker to identify the individual fish being tracked.

Transmitter-tagged muskellunge were tracked both day and night in all types of weather and at all times of the year. At times fish were tracked continuously for up to 20 hours, especially immediately after release or at times of increased activity. During periods of continuous tracking fish locations were recorded at 15-minute intervals. A random number table was used to determine tracking schedules during periods of less intense tracking. Locations of fish were determined by triangulation, visual landmarks, and by use of a range finder.

A grid was established on each lake (Fig. 10). The Moose Lake grid was divided into 60 m intervals and the Black Lake grid was divided into 30 m intervals. An observed animal location (fix) was recorded and numbered according to its respective grid square based on the X-Y coordinate system encompassing the entire lake.

Activity of the fish was recorded at the time of each fix when it could be accurately determined. When a transmitter is turned or moving in any direction an increase or decrease in signal intensity is noted. When changes in signal intensity were observed the fish was recorded as being active at the time the fix was recorded. If the signal intensity was constant the fish was considered resting. If the tracker was unable to determine if the fish was resting or active, the activity was recorded as unknown. Activity should not be confused with movement which is a form of activity resulting in a change in location.

At the time each fix was recorded the following environmental parameters were recorded: water temperature and light intensity at 1 m of depth, wind direction, wind velocity, percent cloud cover, cloud type, movement of the barometer (up, down or steady), barometric pressure and solunar period. For fish tagged with temperature-sensitive transmitters, the water temperature at the fish's position was also recorded.

Two water quality monitoring stations were selected on each lake where water temperature, oxygen content, and conductivity profiles were monitored on a biweekly basis throughout the tracking period (Figs. 2 and 3).

FIGURE 7. *Portable tank for holding muskellunge during tagging.*

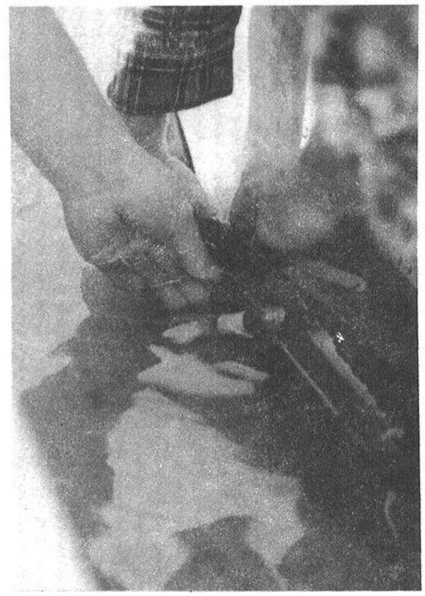

FIGURE 8. *Tagging Procedure.*

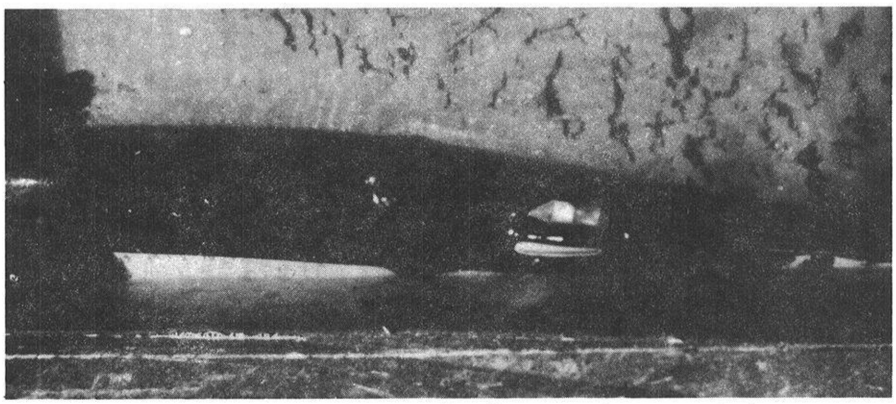

FIGURE 9. *Muskellunge with external radio-transmitter attached.*

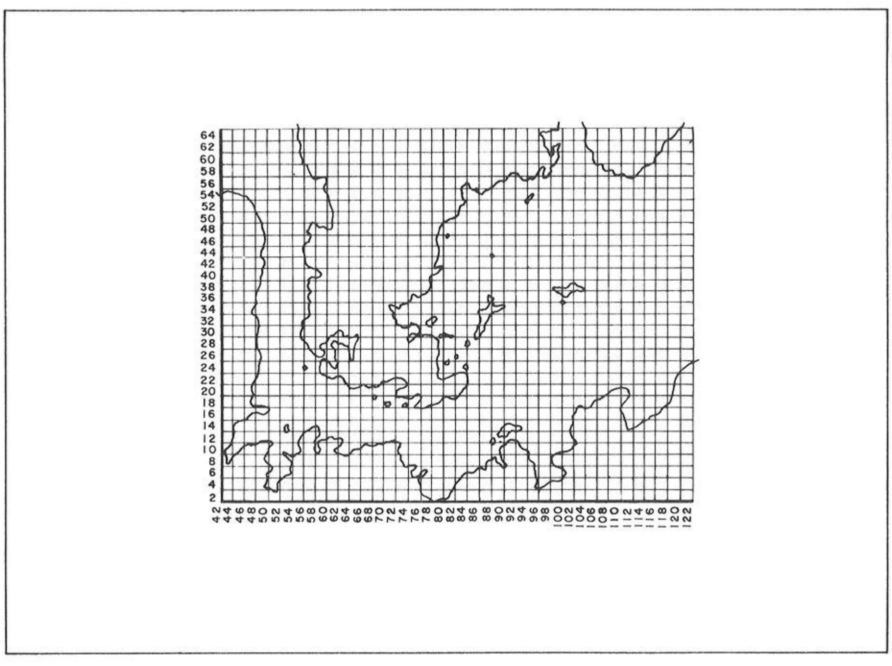

FIGURE 10. *Grid-square system used on Moose Lake.*

TABLE 1. *Summary of radio-tracked muskellunge and mean home range sizes in Moose Lake and Black Lake.*

Fish No.	Length (cm)	Weight (kg)	No. Fixes	First Day Tracked	Last Day Tracked	No. Days	Mean Home Range (ha)
Moose L.							
1	86	4.1	292	26 Jun 76	5 Sep 76	72	15.1
2	104	5.4	193	26 Jun 76	3 Sep 76	70	12.3
3	88	5.0	166	3 Sep 76	4 Nov 76	63	27.7
4	88	3.6	221	3 Sep 76	14 Dec 76	103	22.0
5	104	10.1	126	29 Sep 76	8 Mar 77	161	4.4
6	84	3.6	45	14 Oct 76	15 Feb 77	125	2.5
7	107	7.7	160	16 Oct 76	29 Jun 77	226	5.2
8	90	4.5	43	23 Oct 76	29 Apr 77	189	3.3
9*	94	5.9	52	21 Jun 77	2 Aug 77	43	3.6
10*	71	2.3	58	7 Jul 77	20 Aug 77	45	2.3
11*	79	3.6	53	9 Jul 77	12 Aug 77	35	2.9
Black L.							
12	80	2.7	208	8 Sep 76	18 Dec 76	102	1.4
13	79	2.9	210	8 Sep 76	24 Apr 77	229	1.5
14	71	1.8	80	13 Sep 76	15 Oct 76	33	2.7
15	74	2.3	100	14 Sep 76	21 Nov 76	69	1.7
16	70	2.0	84	22 Oct 76	27 Apr 77	188	1.5
17	104	7.7	70	14 Sep 76	9 Oct 76	26	1.2
18	80	3.2	107	23 Oct 76	27 Apr 77	187	0.2

*Temperature-sensitive transmitter.

ANALYSIS OF DATA

The Cedar Creek Bioelectronics Laboratory computer programs (Cedar Creek Software Library) and the Cyber 74 computer were used to analyze home range, intensity of use, and geometric center of activity on a monthly basis for each muskellunge tracked.

Home range is defined as the area over which an animal habitually travels while engaged in its usual activities (Smith 1966). In this study, home range or area utilized includes all observations made on each individual muskellunge excluding long movements between home ranges. The home range size was determined by a grid square method (Siniff and Tester 1965; Rongstad and Tester 1969). Black Lake was partitioned into 30 m squares and Moose Lake into 60 m squares (because of its larger size) on an X-Y coordinate system. The computer summed the grid squares and number of fixes in each square to determine home range, intensity of use, and the construction of map overlays. When a home range boundary cut across a point of land, the land was excluded from the home range calculation. The home range calculation is slightly biased since the whole area of a grid square is added even though only a portion of a square was used. However, studies such as this one simply delimit an area that approaches the maximum area utilized by an individual animal.

RESULTS

A total of 2,268 fixes were obtained on 18 muskellunge over a 14-month period; 859 of these fixes were on 7 fish in Black Lake and 1,409 fixes were on 11 fish in Moose Lake. This represents a total of 55 muskellunge-months of tracking. Muskellunge that were tracked ranged from 70 to 107 cm in length and from 1.8 to 10.1 kg in weight (Table 1).

SEASONAL MOVEMENTS

Muskellunge studied showed peak movement in the fall, followed by minimum movement during the winter months. Peak movement was again noted in spring followed by intermediate movement during the summer.

The general movements of fish No. 5 in Moose Lake from the date of capture, 26 September 1976 to 31 October 1976 are shown in Figure 11. This 4.1 kg fish traversed half the length of the lake (6 km) four times in less than one month. These long movements in the fall were typical of all fish tracked in Moose Lake. The same fish remained within a radius of 0.4 km during the winter, from 14 December 1976 to 8 March 1977.

The spring movements of fish No. 7 are shown in Figure 12. This 7.7 kg muskellunge left its winter range about 15 March 1977 and arrived on its spawning grounds on 13 April where it remained until 18 April. After spawning, fish No. 7 moved about almost constantly until 27 June when its transmitter expired after 225 days of transmitting.

The summer movements of muskellunge studied were intermediate between the fall and winter extremes. No. 2, a 5.4 kg fish, remained within a 0.8 km radius in the vicinity of the mouth of Big Moose River (Fig. 13). This fish would move about 0.8 km up Big Moose River approximately once a week during July and August. It would spend about 24 hours in the river each week where the water was about 1 m deep over a rock-gravel substrate and abundant wild celery. This muskellunge was also visually observed swimming and resting in this area on four different occasions. Fish No. 1 moved about within a distance of 2 km from 26 June to 5 September 1976 (Fig. 14).

The seasonal movements of the tracked muskellunge in Black Lake were less pronounced than those in Moose Lake, possibly because of its

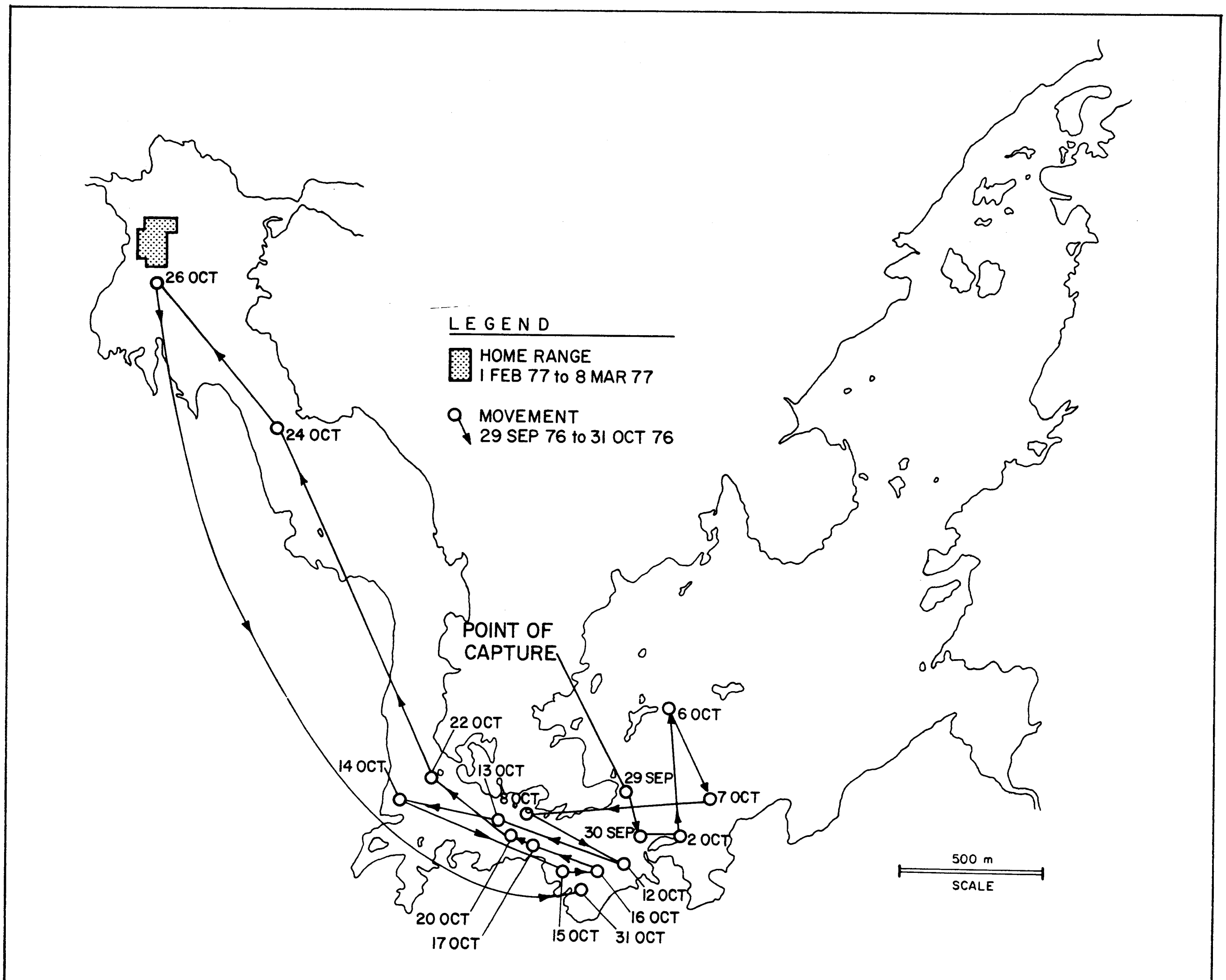

FIGURE 11. *Fall and winter movements of fish No. 5 in Moose Lake.*

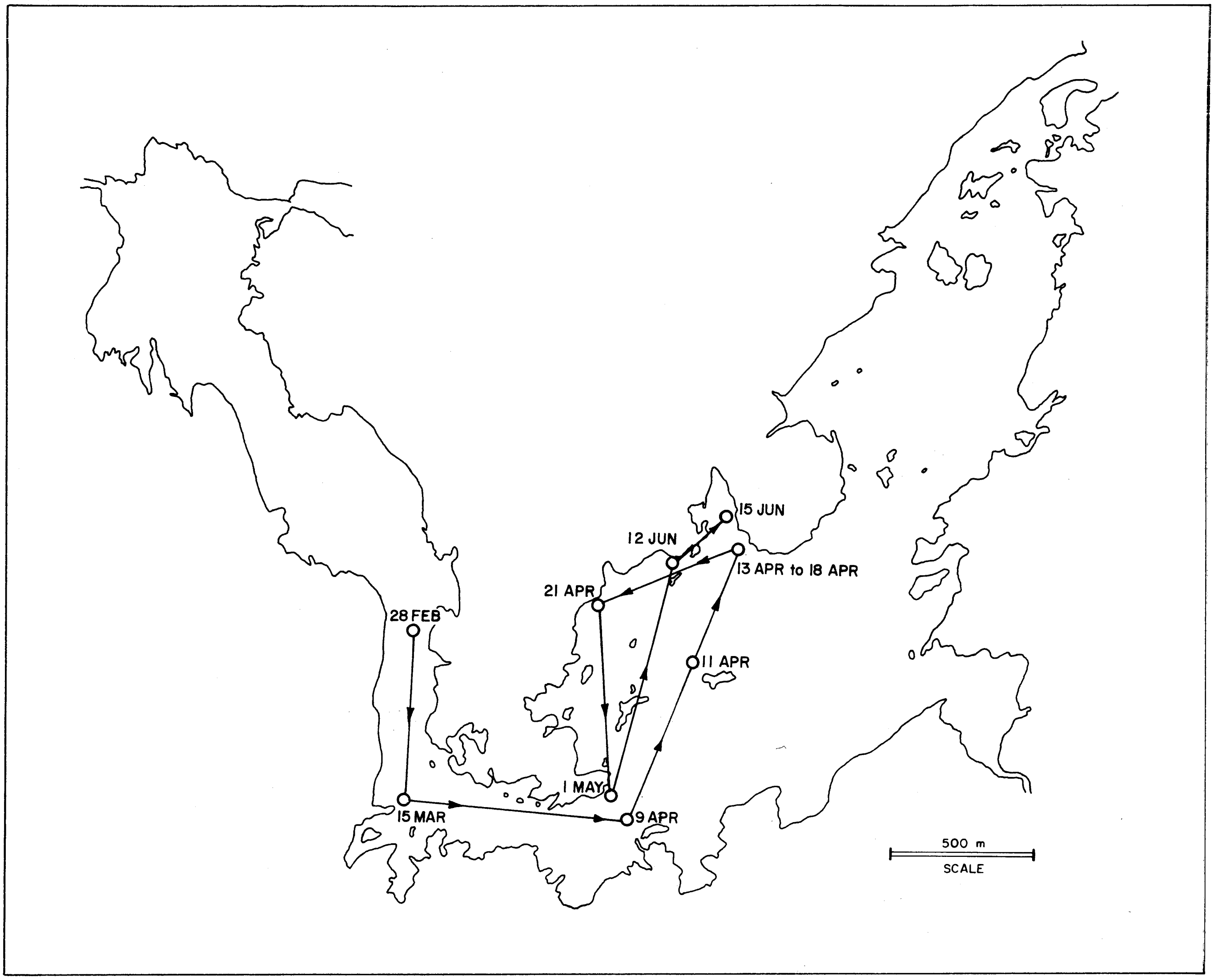

FIGURE 12. *Spring movements of fish No. 7 in Moose Lake from 15 Mar 77 to 15 Jun 77.*

difference in size. However, the basic pattern remained the same with peak movement in the fall and minimum movement during the winter.

On 5 November 1976, fish No. 12 in Black Lake was detected swimming rapidly in open water and an attempt was made to determine its velocity. Figure 15 shows the route and the exact time each fix was made for a 2-hour period. The average swimming velocity was 8.6 m/minute over the entire 2-hour period while the greatest average velocity over a 3-minute period was 50.8 m/minute.

FACTORS AFFECTING MOVEMENT AND ACTIVITY

Activity of radio-tagged muskellunge was found to be related to water temperature. Percent activity is used here to compare the number of times a fish was observed active versus resting. The tracker was unable to determine if the fish was active or resting for 5% of the fixes where the activity was recorded as unknown. The activity level of fish tracked in both lakes showed a rapid rise at 3-4°C and remained high until water temperatures reached 25°C when it decreased (Fig. 16).

Table 2 shows the mean water temperature at 1 m for each month. The greatest amount of activity was observed in the months of April and October, while the least was observed during the winter months with intermediate activity in summer. Water temperatures taken at 1 m (because fish usually inhabited water less than 2 m when summer stratification occurred) showed the highest mean water temperature at 25°C. Yet, during the summer months the fish were often observed in shallow areas where the mid-afternoon water temperatures sometimes exceeded 27°C.

Three muskellunge in Moose Lake were tagged with temperature sensitive transmitters during the time of stratification in the summer of 1977. The tagged muskellunge were never observed in water less than 21°C (Table 3). This indicates that the tracked muskellunge were never observed below the epilimnion whose lower limit in Moose Lake rarely exceeded 3 m. Table 3 also indicates low activity in water temperatures above 27°C.

Behavior indicating the ability to respond to insufficient oxygen levels was displayed by fish No. 18. This muskellunge remained fairly quiescent in north bay from 5 December 1976 to 20 February 1977 when he moved into the south basin of Black Lake. By 20 February the oxygen level in north bay had dropped to 0 ppm but ranged from 4.1-9.0 in the south basin. This fish remained in the south basin where oxygen levels were higher and did not return to north bay until 25 March when oxygen levels were 3.5 ppm.

The water level fluctuation of Moose Lake had no apparent effect on the movement or activities of the tracked muskellunge. The water level is gradually drawn down 2.1 m annually from 15 October to 15 November and remains at that level throughout the winter until the time of ice out in the spring.

No correlation was found between activity and the other environmental parameters which were monitored.

HOME RANGE

The monthly home range size of the 11 Moose Lake radio-tagged muskellunge for the entire tracking period ranged from 2.3-27.7 ha between individual fish (Table 1). In Black Lake monthly home range size ranged from 0.2-2.7 between individuals.

Analysis of home range size on a monthly basis showed that muskellunge tracked in Moose Lake had the largest home range in October, September and May. Intermediate home range sizes were observed during summer months and the smallest during winter months (Fig. 17). Black Lake muskellunge also showed large home ranges in the fall and smallest during the winter.

The fall home ranges of fish Nos. 13 and 14 in Black Lake are illustrated in Figure 18. Figure 19 shows the overlapping home ranges of fish Nos. 12 and 15 in Black Lake in the fall. Overlapping home ranges in October were also noted in Moose Lake between fish Nos. 6, 7 and 8. On several occasions Nos. 7 and 8 were observed within 10 m of each other.

The fall, winter, and spring home range of fish No. 7 in Moose Lake is shown in Figure 20. Disjointed home ranges typified this tagged muskellunge's movements, where one area was intensively utilized followed by movement to another area which was also intensively utilized. On occasion, other tracked muskellunge would also move back and forth between intensively utilized areas. Fish No. 7 greatly increased its spring home range which included its spawning grounds (Fig. 20).

The home range of fish No. 1 in Moose Lake increased from 6.1 ha in June to 14.4 in August (Fig. 14). This 4.1 kg fish was the most active fish tracked during the summer season. The summer home range of fish No. 2 (Fig. 13) was located near the mouth of Big Moose River. Part of this home range included the Big Moose River.

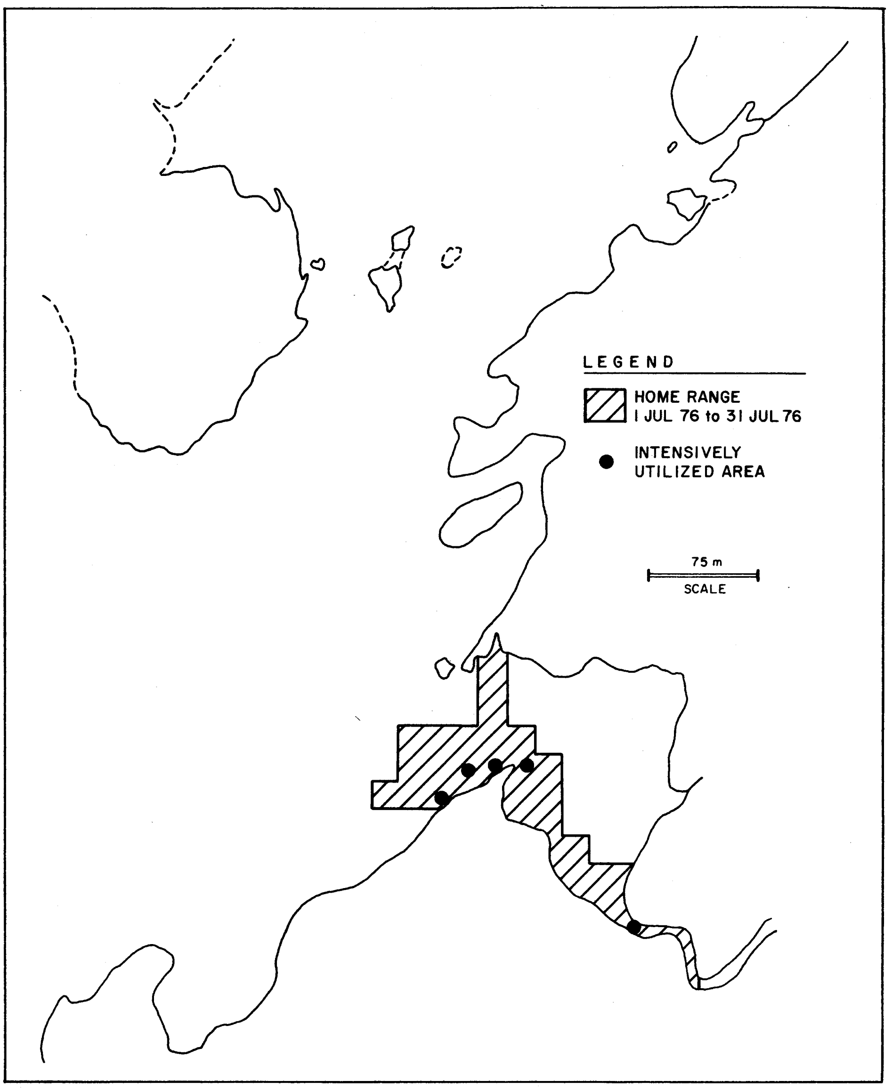

FIGURE 13. *Home range of fish No. 2 from 1 Jul 76 to 31 Jul 76 on Moose Lake.*

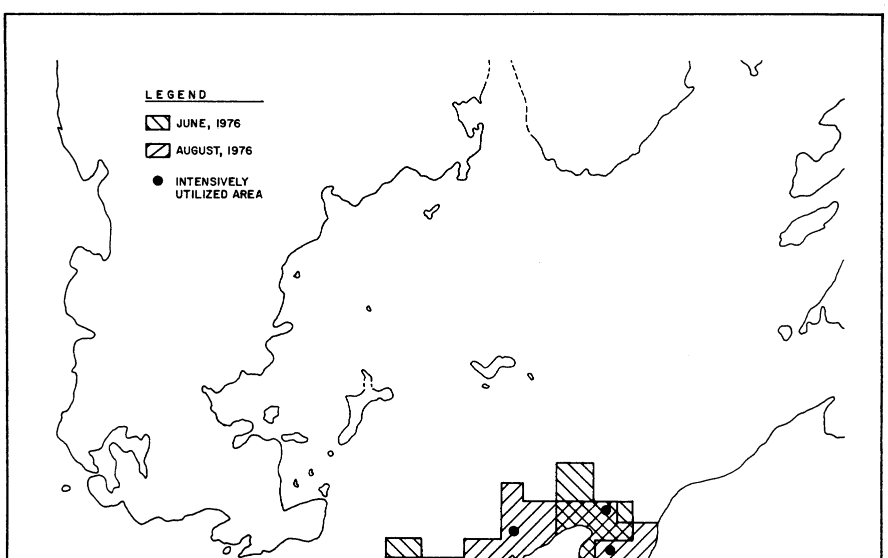

FIGURE 14. *Home range of fish No. 1 in June and August, 1976.*

TABLE 2. *Mean monthly water temperature (°C) at 1 m.*

Month	Moose Lake	Black Lake
Jan	0.6	0.6
Feb	0.6	0.6
Mar	0.6	0.6
Apr	8.9	10.0
May	18.9	19.1
Jun	22.8	24.4
Jul	23.9	25.0
Aug	23.9	24.4
Sep	18.3	17.8
Oct	10.6	10.6
Nov	0.6	0.6
Dec	0.6	0.6

TABLE 3. *Percent activity at various water temperatures of muskellunge tagged with temperature-sensitive radio transmitters in Moose Lake.*

Fish No.	22-24°C	25-27°C	+27°C
9	50%	41%	21%
10	73%	43%	0%
11	50%	54%	-

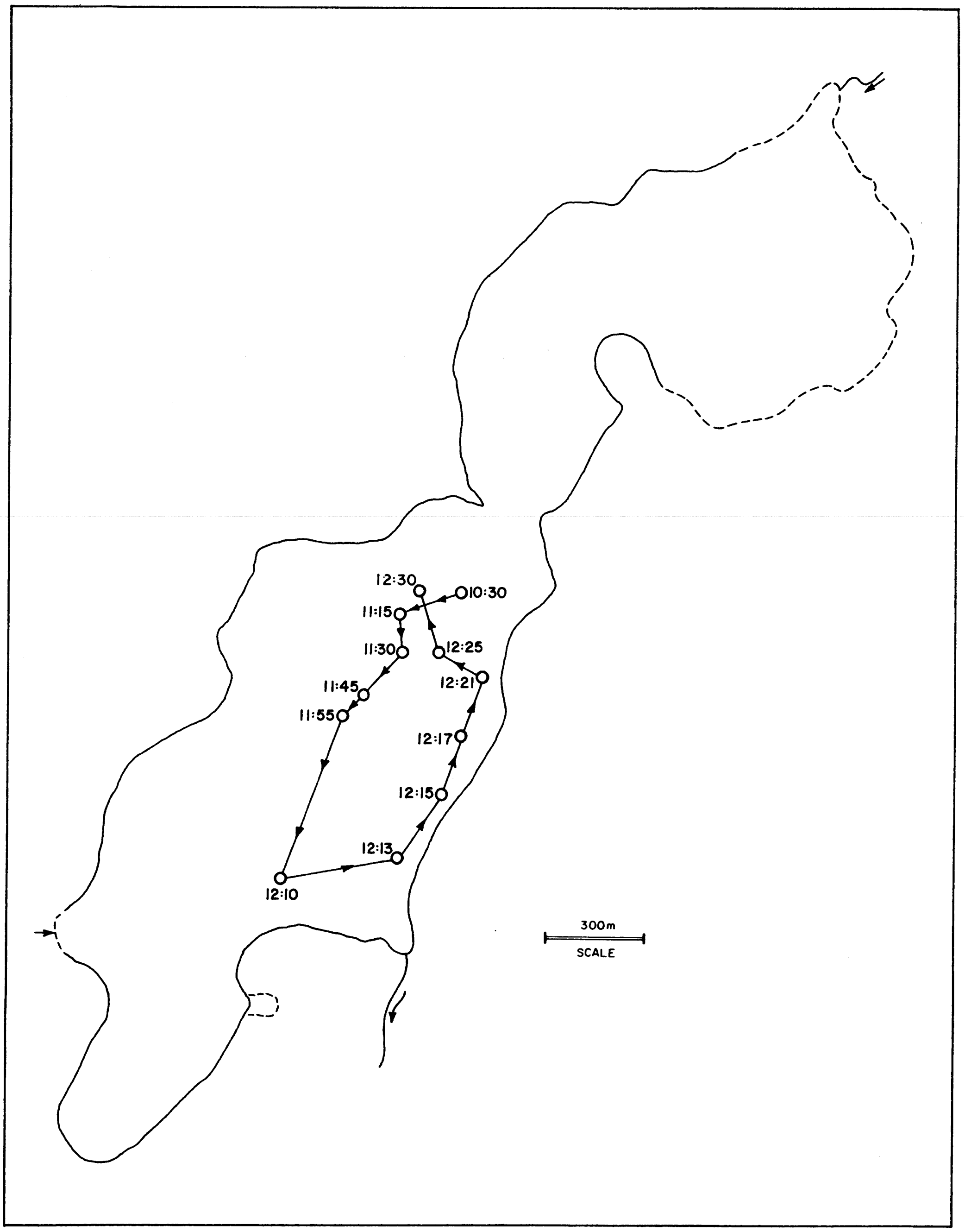

FIGURE 15. *Movements of fish No. 12 in Black Lake on 5 Nov 76 from 10:30 a.m. to 12:30 p.m.*

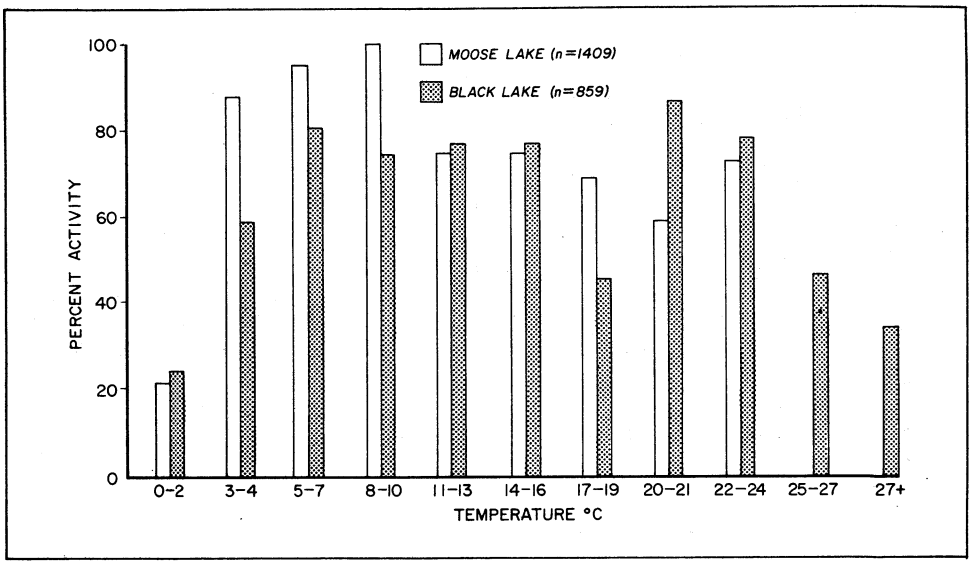

FIGURE 16. *Percent activity at various water temperatures of radio-tagged muskellunge in Moose and Black Lakes.*

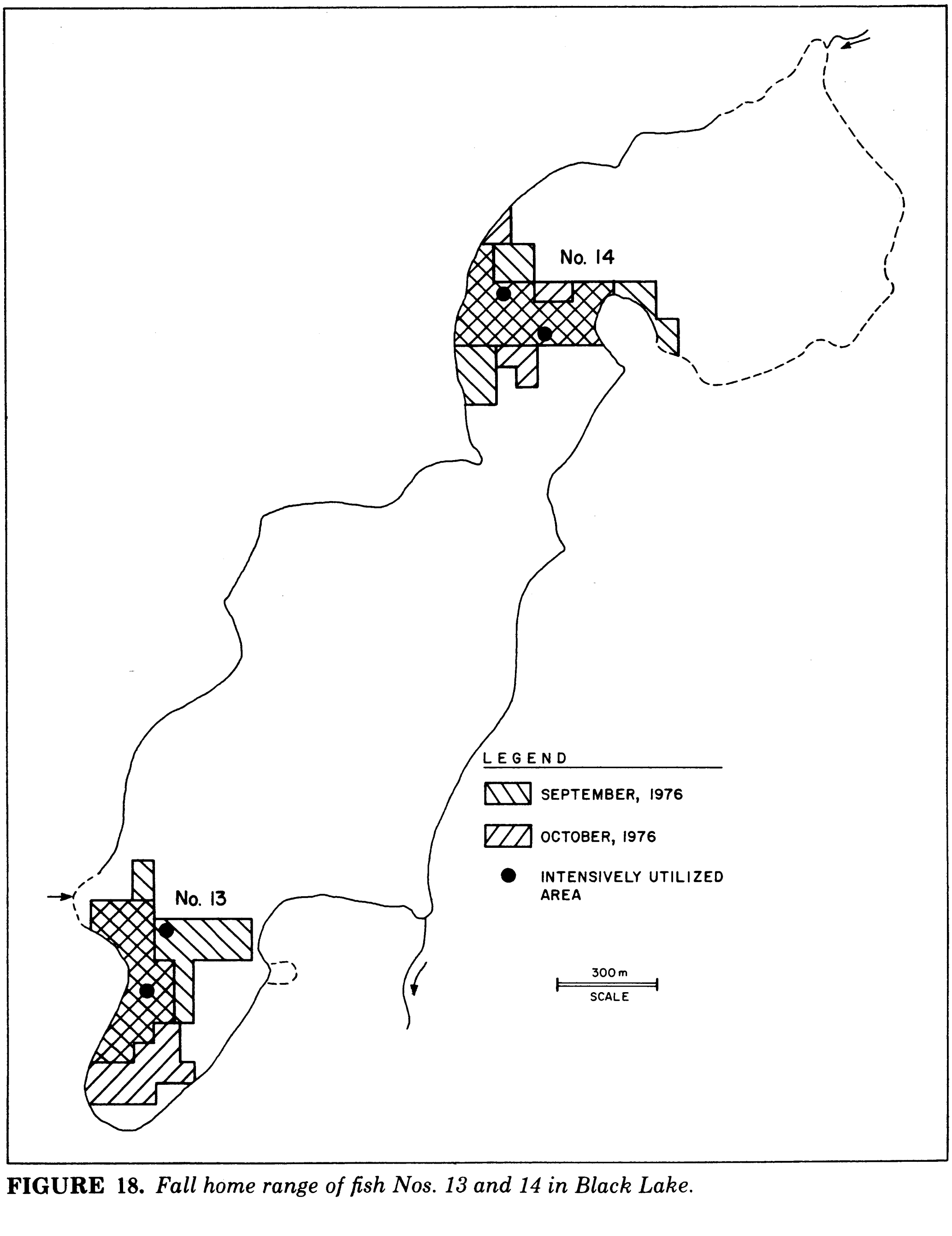

FIGURE 18. *Fall home range of fish Nos. 13 and 14 in Black Lake.*

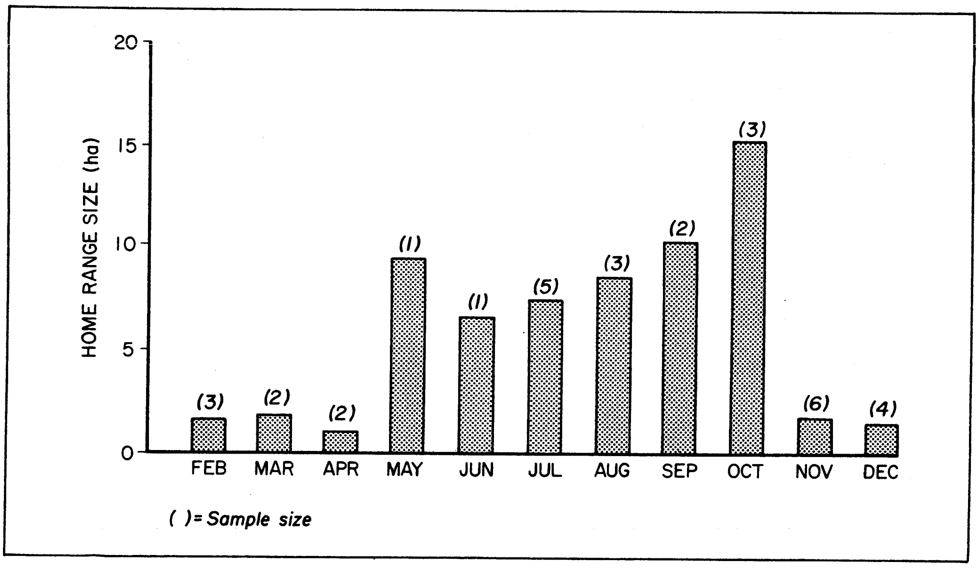

FIGURE 17. *Mean monthly home range size of 11 radio-tagged muskellunge in Moose Lake.*

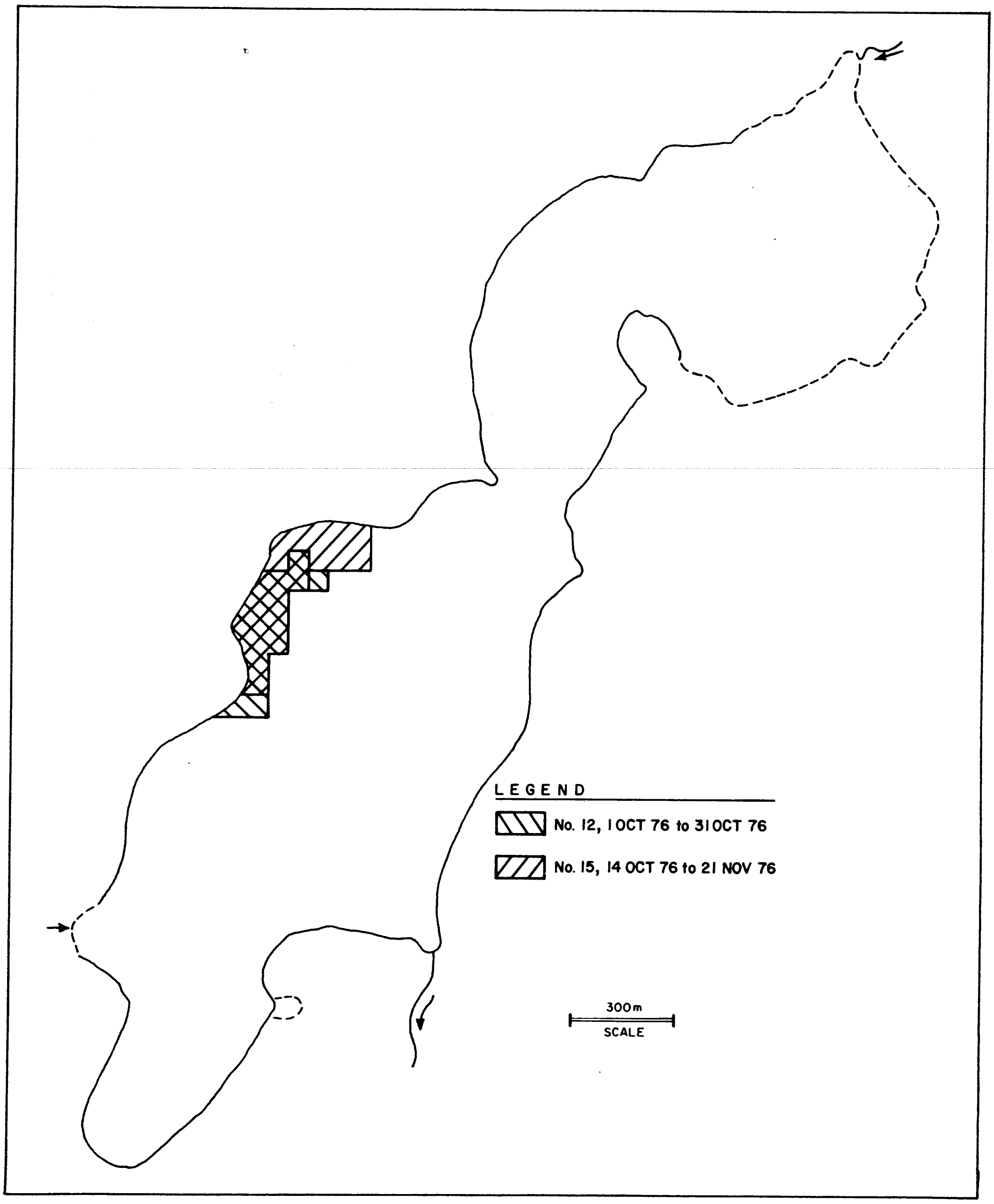

FIGURE 19. *Overlapping home ranges of fish Nos. 12 and 15 in Black Lake.*

SPAWNING ACTIVITIES

The movements of five radio-tagged muskellunge onto spawning areas were observed in mid-April 1977. As soon as the ice went out the water temperatures began to rise rapidly and the activity of the muskellunge increased greatly. The only positive sex determination possible was made on fish No. 18, a 3.2 kg male. Milt was easily squeezed from the fish during the tagging procedure on 23 October 1976. This indicated an advanced degree of gonadal development by late fall.

Three muskellunge (Nos. 13, 16 and 18) on Black Lake were tracked during the spawning season. During the winter, No. 13 remained fairly inactive about 0.4 km north of South Creek Bay. On 4 April, this fish began moving and moved about the entire south basin until 14 April when it began staying in South Creek Bay (Fig. 21). The ice broke up on 12 April. On 14 April the water temperature at 1 m in South Creek Bay was 8.3°C while water temperatures in adjacent areas of the south basin ranged from 6.5-7.5°C at the same depth. Fish No. 13 remained in South Creek Bay until 20 April when the water temperature reached 14°C. At this time the fish began moving over the entire southern portion of the lake. It is believed that spawning occurred between 14 and 20 April in South Creek Bay.

Fish No. 16 moved to the area near the mouth of Fishtrap Creek in the north bay (Fig. 21) on 14 April after being observed near the narrows between north bay and the southern basin. There the water temperature was 8.9°C at 1 m while adjacent areas had water temperatures of 6.5-7.5°C at the same depth. This fish remained near the mouth of Fishtrap Creek until 24 April when it roamed more extensively but remained in north bay. The water temperature was 13.8°C when No. 16 left the mouth of Fishtrap Creek where spawning probably had occurred.

Muskellunge No. 18 utilized the same spawning area as fish No. 16 (Fig. 21) beginning on 14 April, but left the creek mouth on 21 April when the water temperature was 13.3°C. All three muskellunge in Black Lake were active 100% of the time tracked from 9 April through 27 April. From 14-20 April this constant activity was confined to an area less than 1 ha where I believe they spawned.

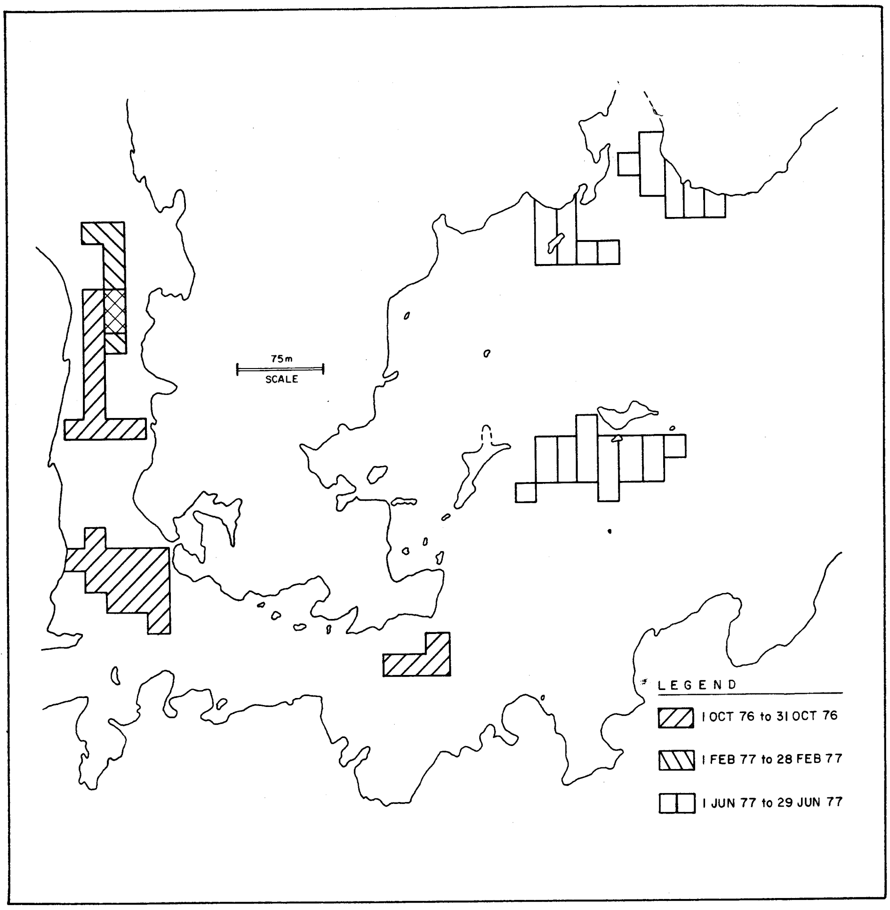

FIGURE 20. *Fall, winter and spring home ranges of fish No. 7 in Moose Lake.*

Fish Nos. 7 and 8 in Moose Lake were observed during the spawning season. No. 7 wintered in an area of Cattail Bay (Fig. 22). On 11 April, No. 7 was located in the area of Folson Island. On 13 April this fish was moving about Cattail Bay where the water temperature was 10.5°C at 1 m while adjacent areas in the lake ranged from 7.5-9.5°C at 1 m. The water temperatures warmed rapidly in the abnormally warm, sunny days of 12-15 April. By 15 April the water temperature in Cattail Bay was 13.9°C.

Spawning activity was observed between 7:00 p.m. 15 April and 3:00 a.m. 16 April near the southeast entrance to Cattail Bay (Fig. 22). Using a seal beam light from a canoe, I observed six untagged muskellunge plus No. 7. There was constant activity of No. 7 and occasional splashing from fish breaking the surface. On three different occasions I was able to attract muskellunge by splashing a stick in the water. The splashing could be a cue to attracting males to a spawning female. By 2:00 a.m. a thunderstorm was approaching and the rain began at 2:25 a.m. The spawning activity continued after 2:00 a.m. but it was less intense. Tracking was discontinued at 3:00 a.m. due to the storm.

On the night of 16 April the water temperature had dropped to 13.3°C in Cattail Bay and spawning activity occurred but seemed to be less intense. No. 7 remained in the same area as the previous night and was moving almost constantly. Again using a light, No. 7 as well as one untagged muskellunge was observed. During the days of 16-18 April No. 7 remained in the vicinity of the spawning area (moving constantly) and later moved into the open water of Folson Island.

Based on night observations using a light, no physical injury was noted on No. 7 after carrying a 300-day transmitter since 16 October 1976.

After being unable to locate No. 8 since 18 December 1976 this 4.5 kg fish was found in the bay at the mouth of Farmers Creek (Fig. 22) on 13 April 1977. The water temperature was 10.9°C in this location on 13 April and 7.5-9.5°C in adjacent waters. I believe that No. 8 spawned in this area where it remained until 20 April when the water temperatures reached 13.9°C. After 20 April this fish moved out of the bay but remained within 0.5 km of the bay until 3 May.

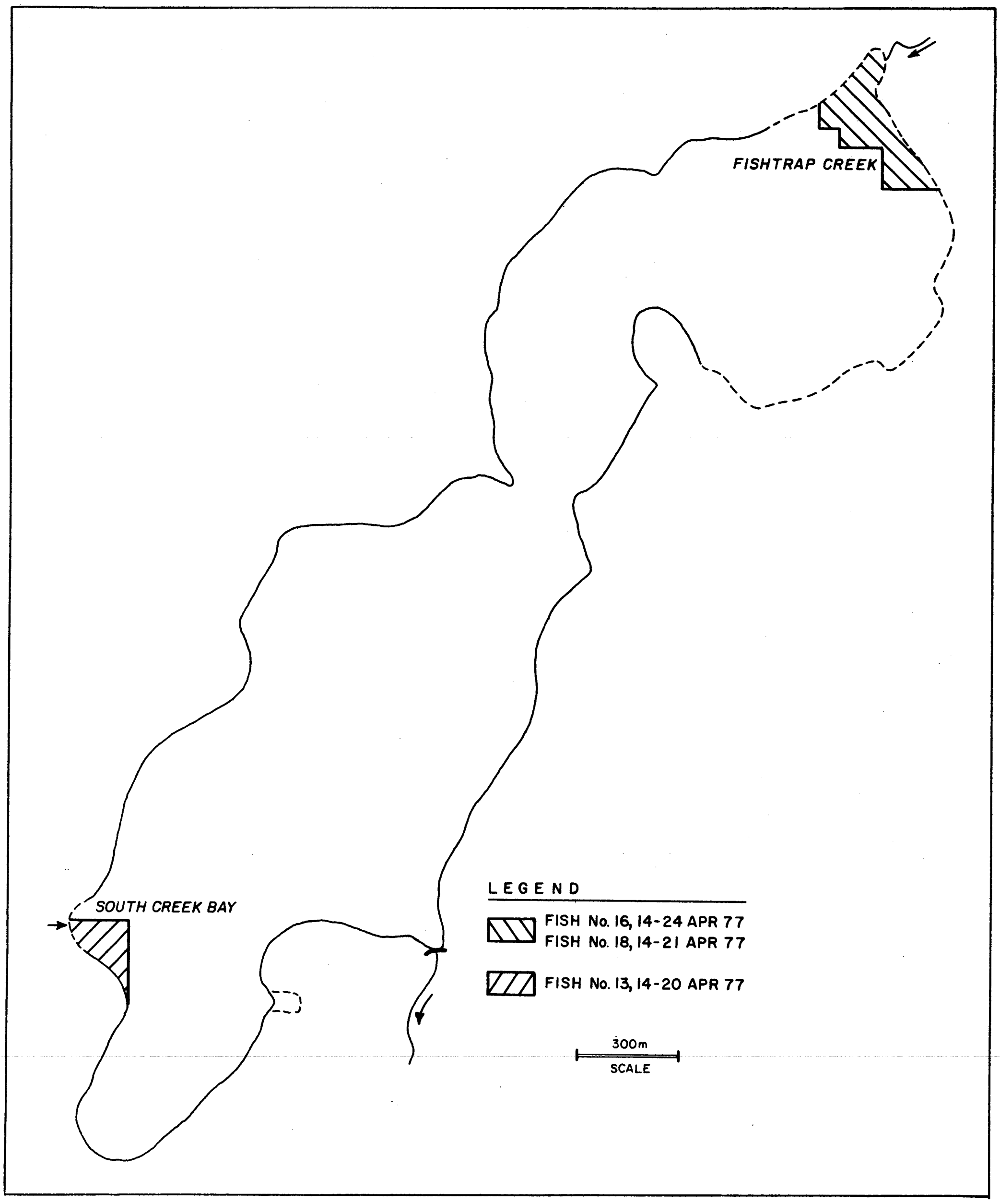

FIGURE 21. *Muskellunge spawning sites in Black Lake.*

DESCRIPTION OF SPAWNING SITES

The two spawning areas identified in Black Lake had very similar characteristics. Both were in areas with water depths of 1 m or less, with muck bottoms and much debris and dead vegetation. Both areas were in bays with influent streams which could have increased the water temperatures of these areas. In both areas the ice had thawed from the shoreline and open water was exposed to radiant energy. The lake proper remained covered with ice.

The Farmer's Creek spawning area in Moose Lake is very similar to the Black Lake spawning sites, with an influent stream, muck and debris bottom, depths generally less than 1 m and temperatures 1 to 2.5°C warmer than the main body of Moose Lake. Farmer's Creek spawning area in the fall of 1977, when the water level was drawn down, is shown in Figure 23. The Cattail Bay spawning site, in late fall, is shown in Figure 24. Note the debris, dead vegetation and scattered rocks over a muck and sand bottom. The water depth during the spawning period was less than 1 m and a more rapid warming trend was noted, even though no influent stream is present.

This does not suggest that these are the only muskellunge spawning sites in Moose and Black Lakes. They were merely the only sites observed in this study.

EFFECT OF TRANSMITTERS

I have no evidence indicating that the external radio transmitters used in this study influenced the results. There was no mortality during the tracking period.

Muskellunge No. 11 was caught on a large surface bait on 15 August 1977. The angler reported the fish as 3.8 kg in weight, 80.5 cm in length and in good condition. This represents a 0.2 kg increase in weight and a 1.5 cm increase in length after carrying a temperature sensitive external radio transmitter for 37 days.

Fish No. 2 was observed both swimming and resting in the Big Moose River on four separate occasions. There were no weeds caught on the transmitter nor was a fungus infection visible on the fish. On 6 September 1976 no movement or activity of No. 2 could be detected after several fixes. The results were the same on several consecutive days. On 3 October, No. 2 was recaptured in a hoop net but the transmitter had fallen off, apparently on 2 September. Careful examination of the transmitter attachment area showed only minor evidence of the transmitter having been there. The skin had not been eroded but there were a few missing scales around the area of attachment. It is doubtful that an angler would have ever noticed the attachment site of the transmitter. This fish had grown 7 cm in length and 0.4 kg in weight since being tagged on 26 June 1976. On 31 October 1976, after the water level of Moose Lake had been drawn down about 0.9 m, the transmitter carried by No. 2 was recovered. The attachment wire had broken and it was still emitting a strong signal.

Muskellunge No. 7 was observed during the spawning season on the nights of 15-16 April 1977. As in other fish observed, no weeds were caught on the transmitter nor was any physical damage to the body of the fish visible. This fish was observed swiming rapidly and its movements appeared similar to the untagged fish observed at the same time.

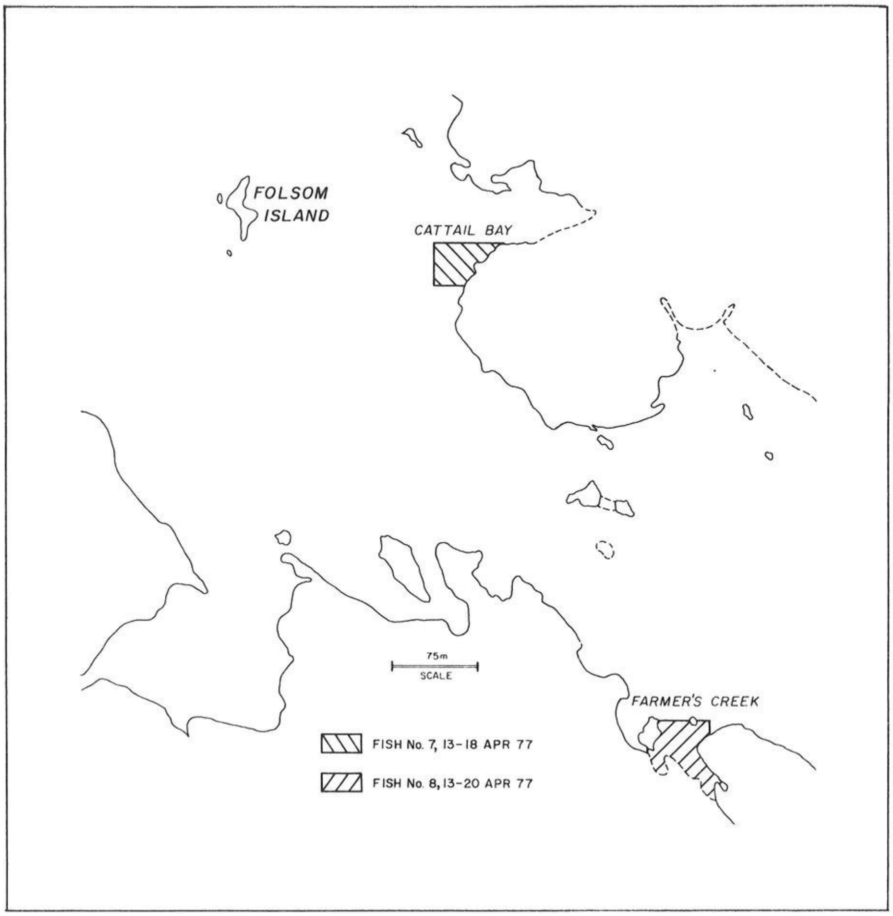

FIGURE 22. *Muskellunge spawning sites in Moose Lake.*

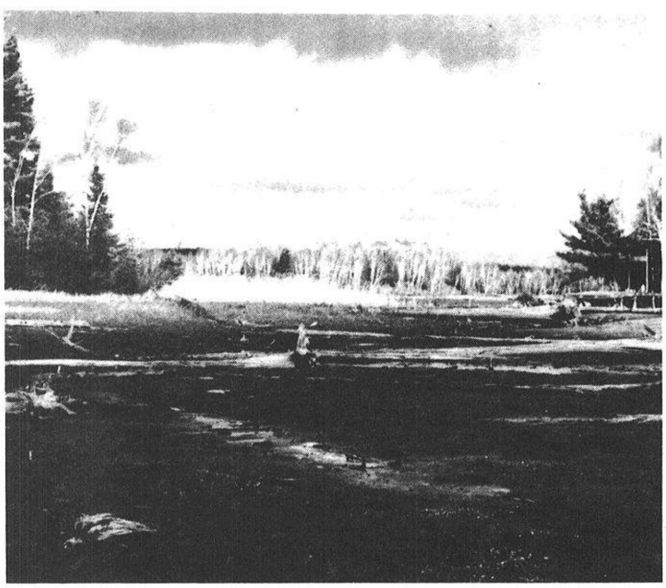

FIGURE 23. *Farmer's Creek muskellunge spawning site.*

FIGURE 24. *Cattail Bay muskellunge spawning site.*

DISCUSSION

Biotelemetry using external radio-transmitters proved to be an effective method of studying the movements and behavior of the muskellunge. Concurrent studies on muskellunge in Ontario were carried out successfully using radio transmitters surgically implanted in the body cavity (Minor and Crossman 1978) and internal ultrasonic transmitters (Crossman 1977). Radio telemetry is a much more efficient means of tracking fish in a low conductivity freshwater environment than ultrasonic telemetry (Stasko and Pincock 1977 and Winter, 1976). Key advantages are that radio signals can be received above the water surface at distances exceeding 1 km and that ice covering during winter has little effect on the radio signal. These factors increase tracking efficiency.

A major assumption in all telemetry studies is that the transmitter-tagged individuals represent the behavior of conspecifics. Young et al. (1972) and Stasko (1975a) stated that confidence in the results from telemetry observations increases when tagged fish feed normally and strike at anglers' bait. In this study I believe that the transmitters had a minimal effect on the muskellunge's behavior and that the resulting data and observations represent the behavior of other muskellunge in the respective waters. Tagged fish did feed and grow normally, strike at anglers' bait and exhibit swimming and spawning behavior similar to untagged muskellunge. The amount of handling was minimized. Fish were removed from nets, tagged without the use of anesthetic and released within a 5-minute period, which also increased confidence in the results (Stasko and Pincock 1977).

Winter (1976; 1977) and Haynes et al. (1978) successfully used similar transmitter attachment methods. However, the modification using the single wire loop attachment rather than two individual attachment wires prevented the occurrence of one wire breaking, leaving the transmitter dangling by the second wire. Using one wire loop insures that when the wire breaks the entire unit falls off the fish. The offset fusiform shape with the attachment wire coming out of the anteriormost point of the transmitter prevents weeds from catching on the transmitter. This is especially important on species such as muskellunge inhabiting weedy areas.

Seasonal variation in home range size found in this study is similar to the findings of Minor and Crossman (1978). However, what they refer to as a breakdown of home range in the spring and fall is relected by both increased home range size and long movements in this study. This is in contrast to findings by Malinin (1970) and Diana et al. (1977) who found that no home range is established by the closely related nothern pike (*Esox lucius* Linnaeus). Findings in this study indicate that muskellunge do not hold a home range exclusive of conspecifics and are in agreement with Crossman (1977).

The home range sizes of the tracked muskellunge in Moose Lake ranged from 2.3 to 27.7 ha and in Black Lake it ranged from 0.2 to 2.7 ha. The larger grid square size used in analysis of the Moose Lake home range data would tend to slightly overestimate the home range size when compared to Black Lake. However, it is apparent that other factors did influence the difference in size of the home ranges between the two lakes. Such factors could have been lake size, predominant prey species and their size and abundance. Johnson (1963) stated that availability of food is a factor likely to influence home range size of muskellunge. If forage fishes are present, muskellunge may stay near their food source. DNR lake survey results suggest that catastomids are the predominant forage in Moose Lake while centrarchids and perch make up the forage base in Black Lake. Movements of these prey species may influence the home range and movements of the muskellunge in these lakes.

Reproduction is another factor influencing the home range size and behavior of the muskellunge. Intense activity in the fall may be related to increased feeding during gonadal maturation, while in spring the fish must locate and/or migrate to a suitable spawning habitat.

Results of this study suggest that temperature is one of the significant factors influencing the general behavior of the muskellunge. Minimum activity occurred at 0-2°C during winter with greatly increased activity at 3-4°C and above. Activity did not decrease greatly until temperatures exceeded 25°C. In the Ontario muskellunge, Minor and Crossman (1978) indicated that movement is minimal below 3.5°C and maximum from 10-15°C. In comparison Casselman (1978) found the northern pike to be least active at temperatures below 6°C with maximum activity occurring from 14-19°C.

In early spring the movement of the tracked muskellunge increased before water temperatures began to rise. This suggests that factors other than temperatures influence the onset of spawning. It is most likely that a combination of environmental factors such as temperature, increasing photoperiod and increasing oxygen levels might inititate movement to spawning areas. However, Fabricius (1950) stated that rising temperature is the primary factor influencing spawning. Spawning sites identified in this study were 0.5-1.5°C warmer than adjacent areas. Spawning activities of 1 radio-tagged and 6 untagged muskellunge were observed during the night at temperatures between 10° and 14° C. Minor and Crossman (1978) reported spawning activites only during daylight hours at temperatures from 10.5-15.5°C and Williamson (1942) stated that spawning occurs from 10-14°C. However, the same type of spawning habitat was utilized by muskellunge in all three studies. These behavioral differences cannot be explained at present.

The information gained in this study could provide guidance in the potential development of artificially created muskellunge spawning areas and the rehabilitation of existing spawning areas, thus enhancing natural reproduction of the muskellunge.

SUMMARY

1. External radio transmitters were successfully used to obtain 2,268 fixes on 18 muskellunge over a 14-month period causing no mortality or noticeable ill effects on the fish.

2. Muskellunge showed two peaks in movement. One occurred in the fall followed by minimum movement during winter. The second occurred in spring with intermediate movement in summer.

3. The maximum average swimming velocity of muskellunge observed was 50.8 m/minute.

4. Temperature correlated with both movement and activity of muskellunge. Minimum activity occurred at tempratures below 2°C during winter, while activity levels rapidly increased at 3-4°C. Activity did not drop sharply until temperatures reached 25°C.

5. Muskellunge moved out of an area with low oxygen levels to areas of higher oxygen levels during late winter.

6. Mean monthly home range size of tracked muskellunge varied from 2.3 to 27.7 ha in Moose Lake to 0.2 to 2.7 ha in Black Lake.

7. Four spawning areas were identified and spawning activities were observed. Muskellunge moved onto spawning grounds when water temperatures reached 8-10°C and remained on spawning grounds for 5-10 days until temperatures reached approximately 14°C.

8. Spawning activities of 1 radio-tagged and 6 untagged muskellunge were observed at night in depths less than 1 m over muck/sand bottom with much debris and dead vegetation. Spawning areas were approximately 1.5°C warmer than adjacent waters.

APPENDIX A: Preliminary Study

An attempt was made prior to the study in Moose and Black Lakes to evaluate the effects of both the internal and external transmitters on the survival of muskellunge. Maximum survival is important in this study since individual fish will be tracked for periods of up to one year. Therefore, the best mode of tagging had to be determined.

Since muskellunge are rather rare, their close relative the northern pike was used. Seventeen northern pike were obtained ranging from 50 to 80 cm in length. The fish were placed in a well-aerated 1,500 liter tank at 18°C. Four fish were used as controls. Dummy internal transmitters were placed in four fish using the method described by Hart and Summerfelt (1975). Dummy external transmitters were placed on four fish using the method described by Winter (1977). Fish were anesthetized using tricainemethane sulfonate (M.S. 222) prior to the tagging procedure. Five fish were used in practicing the surfical procedures of transmitter attachment and implantation prior to the experimental study.

TABLE 4. *Survival of northern pike with dummy internal transmitters versus dummy external transmitters.*

	No. Northern Pike Surviving		
Days After Tagging	External	Internal	Controls
0	4	4	4
5	4	3	4
15	4	2	3
25	3	1	3
35	2	0	3
45	1	0	1
	18	10	18

Results indicate no significant difference in survival between northern pike tagged with dummy external transmitters and controls (Table 4). Fish tagged with internal transmitters had a lower survival rate. Fungal infection probably due to handling and captivity appeared to be the cause of death in fish used in this experiment. No loss in buoyancy or equilibrium was observed after recovery from the anesthetic.

LITERATURE CITED

CASSELMAN, J. M.
1978. Effects of environmental factors on growth, survival, activity, and exploitation of northern pike. *In* Kendall, R. L. ed. Selected coolwater fishes of North America. Am. Fish. Soc. Spec. Publ. 11:114-128.

COCHRAN, W. W. AND R. D. LORD, JR.
1963. A radio-tracking system for wild animals. J. Wildl. Manage. 27 (1):9-24.

CROSSMAN, E. J.
1956. Growth, mortality and movements of a sanctuary population of Maskinonge (*Esox masquinongy* Mitchill). J. Fish. Res. Bd. Canada 13 (5):599-612.
1977. Displacement and home range movements of muskellunge determined by ultrasonic tracking. Env. Biol. of Fishes 1 (2):145-158.

DEPARTMENT OF NATURAL RESOURCES
1970. Wisconsin muskellenge waters. Wis. Dep. Nat. Resour. Pub. 237-70. 25 pp.

DIANA, J. S., W. C. MACAY, AND M. EHRMAN
1977. Movements and habitat preference of northern pike (*Esox lucius*) in Lac Ste. Anne, Alberta. Trans. Am. Fish. Soc. 106 (6):560-565.

FABRICIUS, E.
1950. Heterogeneous stimulus summation in the release of spawning activities in fish. Fish. Bd. Sweden. Inst. Freshwater Res. 29:57-99.

HART, L. G. AND R. C. SUMMERFELT
1973. Homing behavior of the flathead catfish (*Pylodictus olivaris*), tagged with ultrasonic transmitters. *In* Proc. 27th Ann. Conf. Southeast. Assoc. Fish and Game Comm. pp. 520-528.
1975. Surgical procedures for implanting ultrasonic transmitters into flathead catfish (*Pylodictus olivaris*). Trans. Am. Fish. Soc. 104:50-59.

HAYNES, J. M., R. H. GRAY, AND J. C. MONTGOMERY.
1978. Seasonal movements of sturgeon (*Acipenser transmontanus*) in the mid-Columbia River. Trans. Am. Fish. Soc. 107 (2):275-280.

HOLT, C. S., G. D. S. GRANT, G. P. OBERSTAR, C. C. OAKES, AND D. W. BRADT.
1977. Movement of walleye, *Stizostedion vitrium*, in Lake Bemidji, Minnesota as determined by radio-biotelemetry. Trans. Am. Fish. Soc. 106 (2):163-169.

JOHNSON, J. S.
1960. Sonic tracking of adult salmon at Bonneville Dam, 1957. U.S. Fish and Wildl. Serv. Fish Bull. 176:471-485.

JOHNSON, L. D.
1963. The traveling musky. Wis. Conserv. Bull. 28 (4):10-11.

MALININ, L. K.
1970. Use of ultrasonic transmitters for the marking of bream and pike. Biol. Vod. Inf. Byull. 8:75-78 (Fish. Res. Bd. Can. Transl. Ser. 2146).

MINOR, J. D. AND E. J. CROSSMAN
1978. Home range and seasonal movement of muskellunge as determined by radiotelemetry. *In* Kendall, R. L. ed. Selected coolwater fishes in North America. Am. Fish. Soc. Spec. Publ. 11:146-153.

OEHMCKE, A. A., L. D. JOHNSON, J. KLINGBIEL, AND C. WISTROM
1968. The Wisconsin muskellunge. Wis. Dep. Nat. Resour. Pub. 225-68. 12pp.

RONGSTAD, O. J. AND J. R. TESTER
1969. Movements and habitat use of the white-tailed deer in Minnesota. J. Wildl. Mgt. 33 (2):366-379.

SINIFF, D. B. AND J. R. TESTER
1965. Computer analysis of animal-movement data obtained by telemetry. BioScience 15 (2):104-108.

SMITH, R. L.
1966. Ecology and field biology. Harper & Row, New York, NY. 686 pp.

STASKO, A. B.
1975a. Underwater biotelemetry, an annotated bibliography. Fish. Res. Bd. Can. Tech. Rep. No. 534. 31 pp.
1975b. Progress of migrating Atlantic salmon (*Salmo salar*) along an estuary, observed by ultrasonic tracking. J. Fish. Biol. 7:329-338.

STASKO, A. B. AND D. G. PINCOCK
1977. Review of underwater biotelemetry, with emphasis on ultrasonic techniques. J. Fish. Res. Bd. Can. 34:1261-1285.

TREFETHEN, P. S.
1956. Sonic equipment for tracking individual fish. U.S. Fish and Wildl. Serv. Spec. Sci. Rep. Fish. No. 179. 11 pp.

WILLIAMSON, L. O.
1940. Muskellunge tagging—Progress Report No. 1. Wis. Conserv. Bull. 5 (6):51-53.
1942. Spawning habits of the muskellunge, northern pike. Wisc. Conserv. Bull. 7 (5):10-11.

WINTER, J. D.
1976. Movements and behavior of largemouth bass, *Micropterus salmoides*, and steelhead, *Salmo gairdneri*, determined by radiotelemetry. PhD Thesis, Univ. Minn. 200 pp.
1977. Summer home range movements and habitat use by four largemouth bass in Mary Lake, Minnesota. Trans. Am. Fish. Soc. 106 (4):323-330.

YOUNG, A. H., P. TYTLER, F. G. HOLLIDAY, AND A. MACFARLANE
1972. A small sonic tag for measurement of locomotory behavior in fish. J. Fish. Biol. 4:57-65.

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