HOMING, SWIMMING BEHAVIOR, RANGE, ACTIVITY PATTERNS AND REACTION TO INCREASING WATER LEVELS OF WALLEYES (*STIZOSTEDION VITREUM VITREUM*) AS DETERMINED BY RADIO-TELEMETRY IN NAVIGATIONAL POOLS 7 AND 8 OF THE UPPER MISSISSIPPI RIVER DURING SPRING, 1976.

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David Mark Bahr

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Candidate: David M. Bahr

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May 17, 1977

Thesis Committee Chairperson — Date: 17 May 1977

Thesis Committee Member — Date: 17 May '77

Thesis Committee Member — Date: 17 May '77

Thesis Committee Member — Date: 17 May 1977

This thesis is approved for the College of Arts, Letters, and Sciences

Dean, College of Arts, Letters and Sciences — Date: 5/17/77

ABSTRACT

Twelve walleyes (Stizostedion vitreum vitreum) were tagged with radio transmitters between 26 September 1975 and 26 April 1976 in Pool 8 of the Upper Mississippi River. Nine of those were tagged between 13 March and 26 April 1976 in the tailwater area of Lock and Dam 7. The objectives of the study were to determine the walleye's homing ability, behavior patterns, range, diel activity patterns and reaction to increasing water levels.

Three walleyes were displaced a minimum of 10 km from the capture site and all exhibited homing behavior as defined by Crowe (1962).

The walleyes in the tailwater area were located in 15 separate areas that were classified as either eddies or backwaters. The fishes were located in eddies 39% of the tracking hours and in backwater areas 52.7% of the tracking hours. Only 8.3% of the hours were spent travelling in the main channel.

Two types of swimming patterns became recognizable. Random swimming was defined as movement having either no specific direction of travel, a slow rate of travel (10-300 m/hr) or the fish traversing small distances (127 m/movement). Directional swimming was characterized by rapid movement between study areas (300-1200 m/hr), usually in relatively straight lines and the fish travelled farther (547 m/movement).

The walleyes rested (no movement) twice as much time as was spent swimming. They rested more at night than during the day; however, when they were active, they were more active during the night. The fishes showed four distinct modes in activity at 0230, 0630, 1130 and 1830 hours with the highest peak at 0230 hours. There were diel habitat preferences where location in backwater areas would peak between 2100 and 0300 hours and eddy location would peak between 0900 and 1500 hours.

During the study period the walleyes ranged upstream to Lock and Dam 6 and downstream to Lock and Dam 8, a minimum distance of 56.3 km.

Rising water levels associated with spring runoff had no apparent effect on the walleye's behavior.

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INTRODUCTION

Objectives

The spring spawning run of walleyes (Stizostedion vitreum) in the Upper Mississippi River has traditionally been approached with great anticipation by anglers because large numbers of fishes can be easily taken (Albright and Wright, 1973). Immediately after the spawning run, catches of walleyes become increasingly difficult to take because they seemed to have moved out of those areas where they were abundant (Howard, F., 1976, personal communication). The objective of this study was to investigate the following types of behavior of walleyes during March and April, a period in which the walleyes were spawning:

1) Homing of displaced fish (radio-equipped fishes released at sites downstream from the capture site);
2) Behavioral patterns associated with swimming;
3) Range of movement;
4) Diel activity periods;
5) Fish's reaction to increased water levels.

History of Tracking

Efforts to learn about the movements of fishes began in 1873 when atlantic salmon (Salmo salar) were tagged in the Penobscot River, Maine. At that time tagging was the only method used to mark fishes. Since then, many different types of marks have been used on a wide variety of species throughout the world. Everhart, Eipper, and Youngs (1975) described four general methods to mark fishes:

1) Mutilating the fish by removing a fin or part of the maxillary bone;

2) Insertion, attachment, or injection of a foreign object or substance;
3) Innoculation of parasites or bacterial flora;
4) Injection of color marks or radioactive tags into the fish.

These marking methods usually provide data only on the minimum distance that the fishes move. No information is provided concerning diel activity patterns, paths of movement, or environmental conditions affecting such movements.

The first attempts to follow the movements of fishes began in the 1950's when Hasler (1958) attached bobbers to green sunfish (Lepomis cyanellus) and followed their progress after displacement from the capture site. These types of experiments had limited usefulness due to the unnatural restriction to the fish and exhaustion from towing the float. In addition, observations were limited to daylight hours when visibility was good (Malinin and Svirskii, 1973).

The development of bio-telemetry was a major advancement in the study of wild animal behavior. The AVM catalogue (1976) described the uses of telemetry as a simple direction-finding device to determine migratory behavior, breeding and nesting behavior, circadian patterns, home range, territoriality, and feeding habits.

Although bio-telemetry has been widely used in medicine, physiology of work and sport, and in enterology, it has only recently been applied to wild animals (Malinin and Svirskii, 1973). In 1954 LeMunyan became the first to apply telemetry to wild animals by attaching a transmitter to a diseased woodchuck near Chambersburg, Pennsylvania (Fisher, 1976). Increases in knowledge and experimentation with telemetry have enabled investigators to monitor the behavior of a wide variety of terrestrial,

aerial, and aquatic animals, including many species of fishes.

The early attempts at tracking fishes met with little success. The use of telemetry in water was hampered by significant absorption of the electromagnetic radiation by the water (Malinin and Svirskii, 1973). Johnson (1971) described the first aquatic telemetry attempt which involved attaching a 132 kilohertz transmitter to a coho salmon (Oncorhyncus kisutch) near Seattle, Washington. The transmitter had an eight hour battery life and a range of 150-300 m. More sophisticated equipment allowed Kanwisher to obtain EKG's from diving porpoises in 1956 (Johnson, 1971).

In 1969, the Cedar Creek Bio-electronics Lab of the University of Minnesota became the first to use radio telemetry to monitor freshwater fishes. Their study was designed to test their equipment on carp (Cyprinus carpiodes) and northern pike (Esox lucius) in a small stream near Bethel, Minnesota (Winter, et al., 1973).

The two most common types of telemetry systems in use today are those which transmit electromagnetic waves and ultrasonic signals. Winter, et al., (1973) described the advantages of electromagnetic wave systems:

1) Inexpensive to build;
2) Tracking can be accomplished from a boat, from shore, or from the air;
3) Long transmitter battery life;
4) The transmitters range is not interfered by fast water;
5) The same equipment can be used to track other animals.

Fossum (1975) listed the advantages of ultrasonic systems:

1) Signal intensity not affected by depth;
2) No external antenna required on the transmitter.

The major disadvantages of the electromagnetic wave system include:

1) Hinderance of the signal with increasing depth;
2) Attenuation of the signal with increasing salinity;
3) Signals can be hindered by powerlines, unshielded ignition systems, and large metal objects;
4) Snagging of the transmitter's external antenna.

The disadvantages of the ultrasonic system include:

1) Short battery life;
2) Interference of the signal by turbulent water;
3) Tracking can be done from the water only;
4) Interference of the signal by boat traffic;
5) Expensive equipment.

The limitations of both types of systems include the size of the transmitter and the cost (Morris, 1976). Malinin and Svirskii (1973) described five requirements of a transmitter. These include:

1) Low mass (not more than 1% of the total body weight of the fish);
2) Streamlined and cylindrical;
3) Insensitive to the pressures at the depths the fish operates;
4) Easily distinguishable frequencies;
5) Range greater than 200-300 m.

Most telemetry studies have been applied to fish movements. Johnson (1960) tracked several species of adult salmon and determined that the fish followed the shoreline closely, seldom straying greater than 15 m from it. Koo and Wilson (1972) placed ultrasonic transmitters on striped bass (Roccus saxitilus) and determined that they exhibit a "rest-and-go" movement rather than a continued movement. Dodson, et al., (1972) tracked American shad (Alosa sapidissima) and found that the fish remained at the leading edge of the salt water for physiological adaptation to fresh water. Warden and Lorio (1975) tracked 16 largemouth bass (Micropterus salmoides) and determined that they established a home range of about 100 m. Hart and Summerfelt (1973) tracked flathead catfish (Pylodictus olivaris) and found that they

established a home range and also exhibited some degree of homing. Kelso (1976a) attached transmitters to brown bullheads (Ictalurus nebulosus) and determined that thermal plumes altered their movements by causing them to swim slower, mill more, and turn more. Malinin and Svirskii (1973) found that sturgeon in rivers move along abridgements in the river bed at depths of 7-12 m.

The first to address the question of the mechanism of movement was Hasler, et al. (1969). They attached transmitters to 26 white bass (Morone crysops) and displaced them from the shore of Lake Mendota, Wisconsin, to the open water. They determined that white bass possess a mechanism for orienting to directional cues. McCleave and Horrall (1970) attached transmitters to cutthroat trout (Salmo clarki) and found that vision was unnecessary to find their original stream. McCleave and LaBar (1972) tagged cutthroat trout with transmitters and found that they possess a compass mechanism for navigation. Griffin (1952) defined this type of navigation as Type II homing: The ability to maintain a constant compass direction in unfamiliar territory. Malinin (1972) tagged burbot (Lota lota) in the Sogozh River in U.S.S.R. and determined that they move in the direction of cleaner and more mineralized water.

Telemetry has also been used as a fisheries management tool. Russel and Graham (Auckley, 1974) used ultrasonic transmitters on paddlefish (Polydon spathula) to find their spawning areas.

Several investigators have commented on the effect of the tags on the fishes. Peterson (1975) tracked largemouth bass, smallmouth bass (Micropterus dolomieui) and spotted bass (Micropterus punctulatus) and

their own pond returned rapidly to the capture site but that the fish displaced to another pond wandered aimlessly. They concluded that green sunfish were well oriented to landmarks within their own pond.

Hart and Summerfelt (1973) used ultrasonic transmitters to test homing behavior in flathead catfish and determined that 67% homed.

Walleyes have also been noted for a homing instinct. Stoudt (1939) and Stoudt and Eddy (1939) jaw-tagged walleyes in Lake Winnibigoshish, Minnesota in 1937 and 1938 and found that 90% of the recaptures in 1938 were caught in the same place they were tagged in 1937. They also concluded the walleyes spread throughout the lake after spawning. Eschmeyer (1950) recovered 5% of the 194 jaw-tagged walleyes in Lake Gogebic, Michigan in the same area in which they were tagged in 1947. He also noted that the walleyes spread throughout the lake after spawning. Rawson (1957) determined the spawning runs of the Montreal and Potato Rivers in Saskatchewan were discreet populations which intermixed freely during the rest of the year. Crowe (1962) determined that homing was characteristic of all walleye stocks that he investigated from 1947-1961 in the Muskegon River, Michigan. He recaptured many of the fish at the tagging site in subsequent years but few were found at other spawning sites. Olson and Scidmore (1962) found homing was a characteristic of the walleyes that they investigated in Many Point Lake, Minnesota between 1955-1960. Crowe, et al. (1963) determined the walleye population in Green Bay was local and split into discreet spawning units. All recaptures of fish during the spawning run were caught where they were originally tagged; thus, they concluded that the larger populations of walleyes return to their home spawning areas to spawn.

Crowe (1962) defined the walleye as a wanderer without complex

spawning habits, and because of this, it is important that they return to spawn at a particular site rather than any suitable area for better assurance of encountering environmental conditions conducive to spawning success. This may establish discreet sub-populations identified with particular spawning areas. Funk (1957) theorized that homing to a spawning area year after year may have a genetic basis. Dispersal after spawning may be caused by competition as the young fish grow and are crowded out thus forcing them to move to less crowded areas. Past investigations into the homing behavior of walleyes have defined homing as the tendency for spawning walleyes to return to the same spawning sites each year in preference to other available areas (Olson and Scidmore, 1962; Crowe, 1962).

The Walleye

The walleye is distributed from the Great Slave Lake in the northwest to Labrador in the northeast to northern Alabama in the south to Nebraska in the west (Niemuth et al., 1972).

Females grow faster and become larger than the males. Males mature in 2-3 yrs when they are 30-35 cm in total length. Females mature in 4-5 yrs when they reach 38-43 cm in total length. They have an average life span of 7 years in Wisconsin (Niemuth et al., 1972).

Spawning occurs in late April and early May in water temperatures ranging from 6-17° C (Table 1). Males arrive on the spawning site first and remain there after spawning (Niemuth et al., 1972; Eschmeyer, 1950). Fertilization is external with the spawn scattered over loose gravel or sand. Priegel (1970) noticed that Lake Winnebago, Wisconsin walleyes spawned over flooded vegetation. No parental care is given the young

Table 1. Comparison of water temperatures at which walleyes spawn in various sections of North America.

	Site	Temperatures during spawn run	Spawning Temperatures	Ranges
1.	Mississippi R.	9-12° C		
2.	Mississippi R. Pool 7.	---	8.5° C	---
3.	Wisconsin lakes and rivers.	3.5-9° C	9-10° C	6-17° C
4.	Michigan lakes and streams.	4-8.5° C	8-9° C	---
5.	Hemming Lake, Manitoba.	---	6° C	

1. Present study, 1976.
2. Gebken and Wright, 1972.
3. Niemuth, Churchill, and Wirth, 1972.
4. Eschmeyer, 1950.
5. Derbach, 1947.

but the lingering of males after spawning may serve to reduce the numbers of egg-eating fishes present.

Long range movements of over 80 km (50 miles) after spawning have been reported for walleyes (Anon., 1958; Anon., 1959; Carbine and Applegate, 1946; Crowe, 1962; Daley, 1960; Eschmeyer, 1942; Eschmeyer and Crowe, 1955; Hubley and Jergens, 1959; Manges, 1950; Priegel, 1968; Rawson, 1957; Smith et al., 1952). Holt (1975) attached radio transmitters to walleyes and determined they follow contours in the lake bottom during their movements. Walleyes appear more active at dusk and dawn (Hubley and Jergens, 1959; Rawson, 1957; Whitney, 1958; Ellis and Giles, 1965; Carlander and Cleary, 1949; Kelso, 1976b).

METHODS AND MATERIALS

Capture

Twelve walleyes were tagged with radio transmitters between 26 September 1975 and 26 April 1976 in navigation pool 8 of the Upper Mississippi River (river miles 694-702.3). The first two fish tagged were caught in a backwater area near Running Slough (No. 1, Figure 1) and the remainder were captured in the tailwater area of Lock and Dam 7 (Figure 1, Inset 1). Three fish were displaced from the capture site and the remainder were released at the capture site.

Preliminary Study

The three walleyes tagged in 1975 were used to determine the limits and reliability of the equipment and to acquaint the author with tagging and tracking procedures.

Processing After Capture

Total length was measured and the sex was determined by stripping the gonad of each fish at the time of capture. Scale samples were also taken from each walleye below the lateral line and posterior to the depressed left pectoral fin as described by Lagler (1952). Ages of the fishes were determined by standard scale methods described in Ricker (1971).

Electronic Tracking Equipment

The tracking system used in this study was designed by the Cedar

Table 2. Legend to Map of Navigation Pools 7 and 8 of the Upper Mississippi River.

Map Number	Identification
1.	Capture site of radio-tagged walleyes Nos. 12 and 13 on 26 September 1975, also the recapture site of walleye No. 12 on 1 April 1976.
2.	Coney Island release site of walleye Nos. 9 (14 March 1976) and 11 (15 March 1976) after displacement from the tailwater area of Lock and Dam 7.
3.	Release site of walleye No. 8 (17 March 1976) after displacement from the tailwater area of Lock and Dam 7.
4.	Entrance to West Channel where walleye No. 8 was located on 2 May 1976.
5.	Location of walleye No. 4 between 17 March and 7 April 1976 after radio-tagging in the tailwater area of Lock and Dam 7.
6.	Location of walleye No. 7 64 hr after being radio-tagged in the tailwater area of Lock and Dam 7. This is also where a dart-tagged walleye was captured on 8 May 1976 after being tagged on 22 April 1976 in the tailwater area of Lock and Dam 7.
7.	Recapture site of radio-tagged walleye No. 9 (13 May 1976).
8.	Recapture site of radio-tagged walleye No. 4 (6 July 1976).
9.	Recapture site of radio-tagged walleye No. 13 (28 April 1976).
10.	Recapture site of dart-tagged walleye (30 April 1976).
11.	Recapture site of dart-tagged walleye (30 June 1976) in Bullet Chute.
12.	Capture site of radio-tagged walleye No. 1 (19 November 1975).

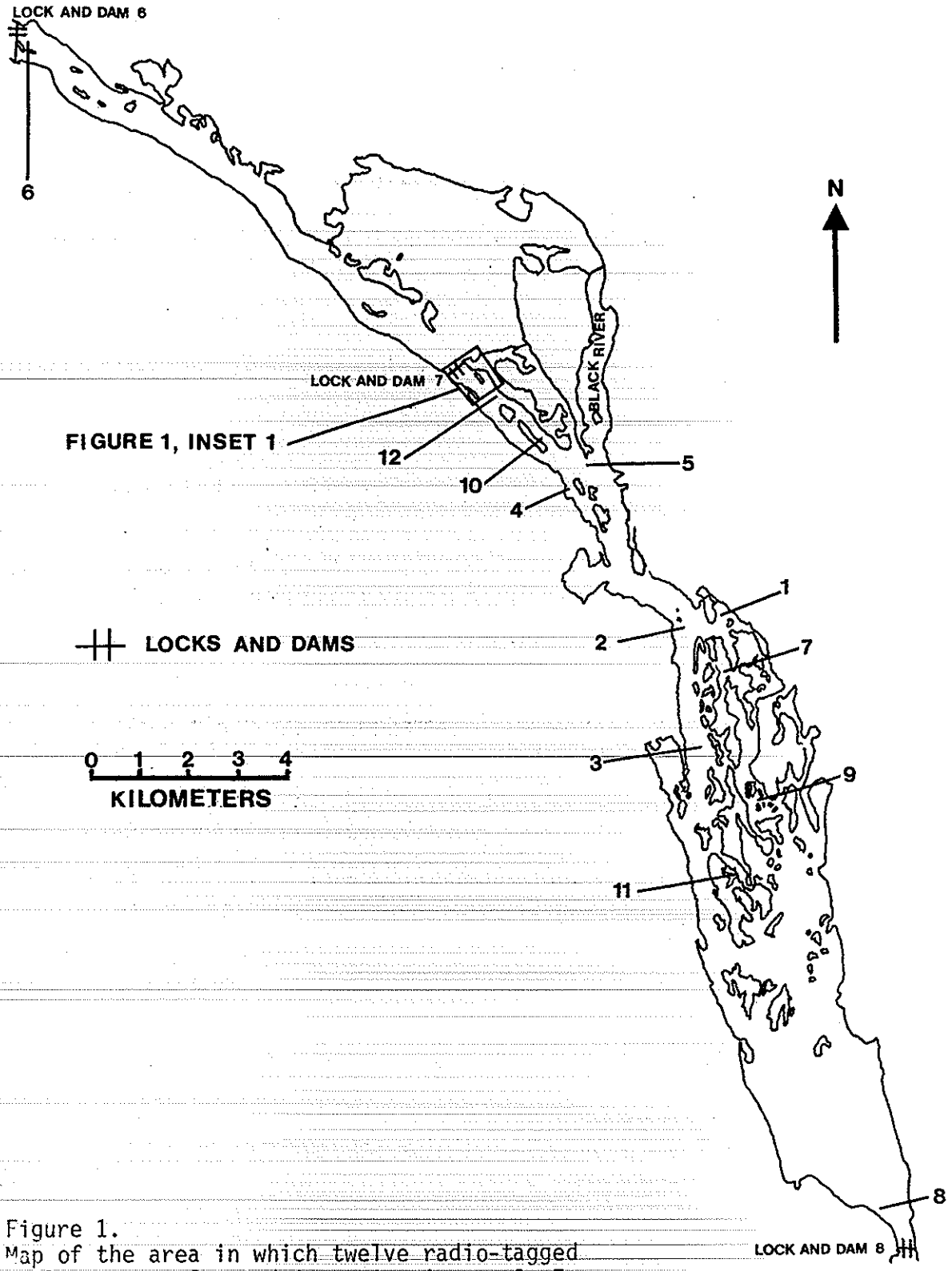
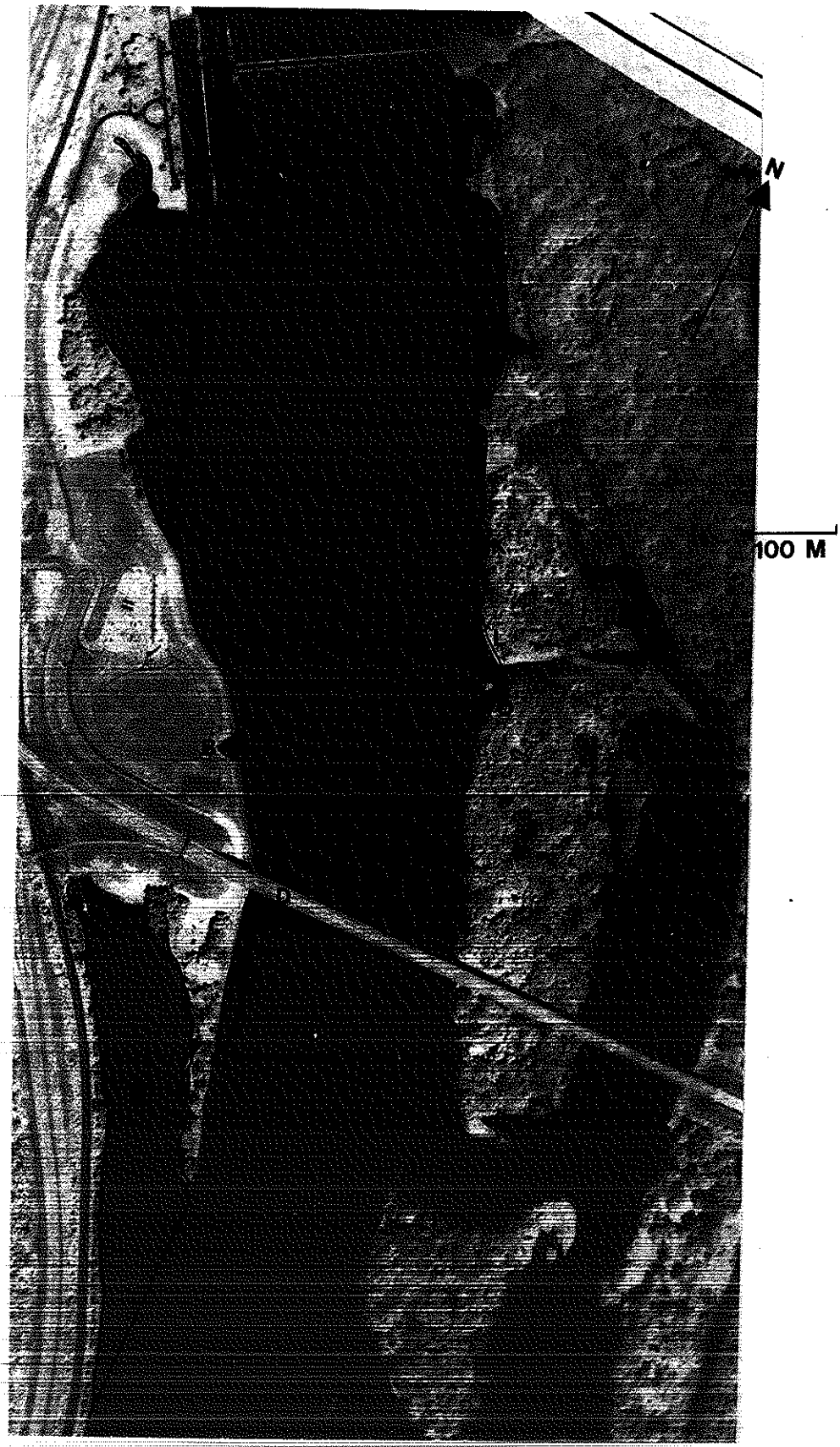


Figure 1.
Map of the area in which twelve radio-tagged walleyes were located in navigation pools 7 and 8 of the Upper Mississippi River between 26 September 1975 and 6 July 1976.

Figure 1, inset 1. Aerial photograph indicating various habitats used by nine radio-tagged walleyes in the tailwater area of Lock and Dam 7 in the Upper Mississippi River during March and April 1976.


N
100 M

Creek Bio-electronics lab of the University of Minnesota (Kuechle, et al., 1971; Ball, 1972; Winter, et al., 1973). The transmitter frequencies were between 52.5 and 53.5 mHz. Different frequencies were used to differentiate between individual fishes (Table 3).

This system consisted of three basic components: a transmitter which sent the signal (Appendix I), an antenna that received the signal (Appendix II), and a receiver which amplified and made the signal audible (Appendix II) (Plate 1).

Two unidirectional yagi and two bidirectional loop antennas were used in this study. The yagi antennas had four elements with a six meter beam that was placed for maximum forward gain and had a maximum range of 1600 m depending on the depth of the transmitter and the conductivity of the water. The mast fitted loosely into a stand that was bolted to the floor of the boat to allow easy rotation by the operator (Plate 2). The loop antenna consisted of a diamond shaped six ft length of 0.25 in aluminum tubing separated by a 4-40 pf trimmer capacitor and attached to a modified tennis racquet (Plate 1). The loop antenna was hand-held, had a maximum range of 100 m, and was used for precise tracking and to locate the fish from the air.

Tagging Procedures

A total of 12 walleyes were tagged with radio transmitters between 26 September 1975 and 26 April 1976. In addition, 15 walleyes captured in the tailwaters of Lock and Dam 7 were tagged with dart tags.

The dart tags were applied by inserting an applicator from the left side of the fish near the posterior portion of the dorsal fin and pushing anteriorly and to the right side of the fish. The tag was then anchored

Table 3. Overall description of the walleyes tagged with radio transmitters in Pool 8 of the Upper Mississippi River between 26 September 1975 and 29 April 1976.

Fish No.	Length (mm)	Weight (gm)	Sex	Age (yr)	Method of Capture	Frequency of Tag (mHz)	Capture Date	Capture Site	Release Site	Date of Last Track	Elapsed Days	Number of Days Tracked	Dates Tracked	Hours Tracked (hr)	Recovery Method	Recovery Date	Recovery Location
1	507	--	-	4.5	Angling	52.9	19 Nov 75	East Channel	East Channel	3 Dec 75	15	8	19,20,21,22,23, 26, 28 Nov, 3 Dec 1975	16	Angling	1 Jan 76	H
2	535	--	F	5.0	Angling	53.06	13 Mar 76	C	C	14 Apr 76	32	9	13,18,20,22 Mar, 8,11,12,13,14 Apr 1976	18.71	--	--	--
4	545	2090	F	5.0	Angling	52.82	17 Mar 76	C	C	14 Apr 76	28	15	17,18,22,25,26, 27,28,29,31 Mar, 2,3,6,7,13,14 Apr 76	138.5	Commercial gill net	6 Jul 76	Headwater Lock and Dam 8
5	453	1010	F	4.0	Angling	53.13	26 Apr 76	G	A	2 May 76	7	7	26,27,28,29,30 Apr, 1,2 May 1976	146.1	--	--	--
5a	563	--	F	5.0	Angling	53.13	14 Mar 76	C	C	8 Apr 76	26	2	15 Mar, 8 Apr 1976	1.06	Angling	12 Apr 76	F
6	430	1850	F	5.0	Angling	53.23	3 Apr 76	A	A	14 Apr 76	12	11	3,4,5,7,8,9,10, 11,12,13,14 Apr 1976	152.34	--	--	--
7[1]	551	1905	F	5.0	Angling	53.09	7 Apr 76	G	H	29 Apr 76	23	4	7,8,11,29 Apr 1976	4.75	--	--	--
8[2]	542	--	F	5.0	Angling	53.18	17 Mar 76	C	River Mile 692.5	4 May 76	49	5	17 Mar, 2,3,4 May 1976	57.92	--	--	--
9[2]	538	--	F	5.0	Angling	53.34	14 Mar 76	C	River Mile 695.2	15 Apr 76	33	3	14 Mar, 11,15 Apr 1976	10.52	Commercial gill net	13 May 76	Running Slough
11[2]	517	--	F	5.0	Angling	53.43	15 Mar 76	C	River Mile 695.2	14 Apr 76	31	11	17,18,19 Mar, 8,9,10,11,12,13, 14 Apr 1976	75.97	--	--	--
12[3]	460	--	-	4.5	Gill Net	53.3	26 Sep 75	Running Slough	Running Slough	--	--	--	---	0	Commercial gill net	1 Apr 76	Running Slough
13[3]	659	--	-	4.5	Gill Net	52.7	26 Sep 76	Running Slough	Running Slough	--	--	--	---	0	Commercial Gill Net	28 Apr 76	Goose Island

1. Tracked by air at Lock and Dam 6 on 11 and 29 Apr 1976.
2. Transplant.
3. Tag did not operate.

Plate 1. The loop antenna and receiver used in locating ten radio-tagged walleyes in Navigation Pools 7 and 8 of the Upper Mississippi River between 19 November 1975 and 4 May 1976.

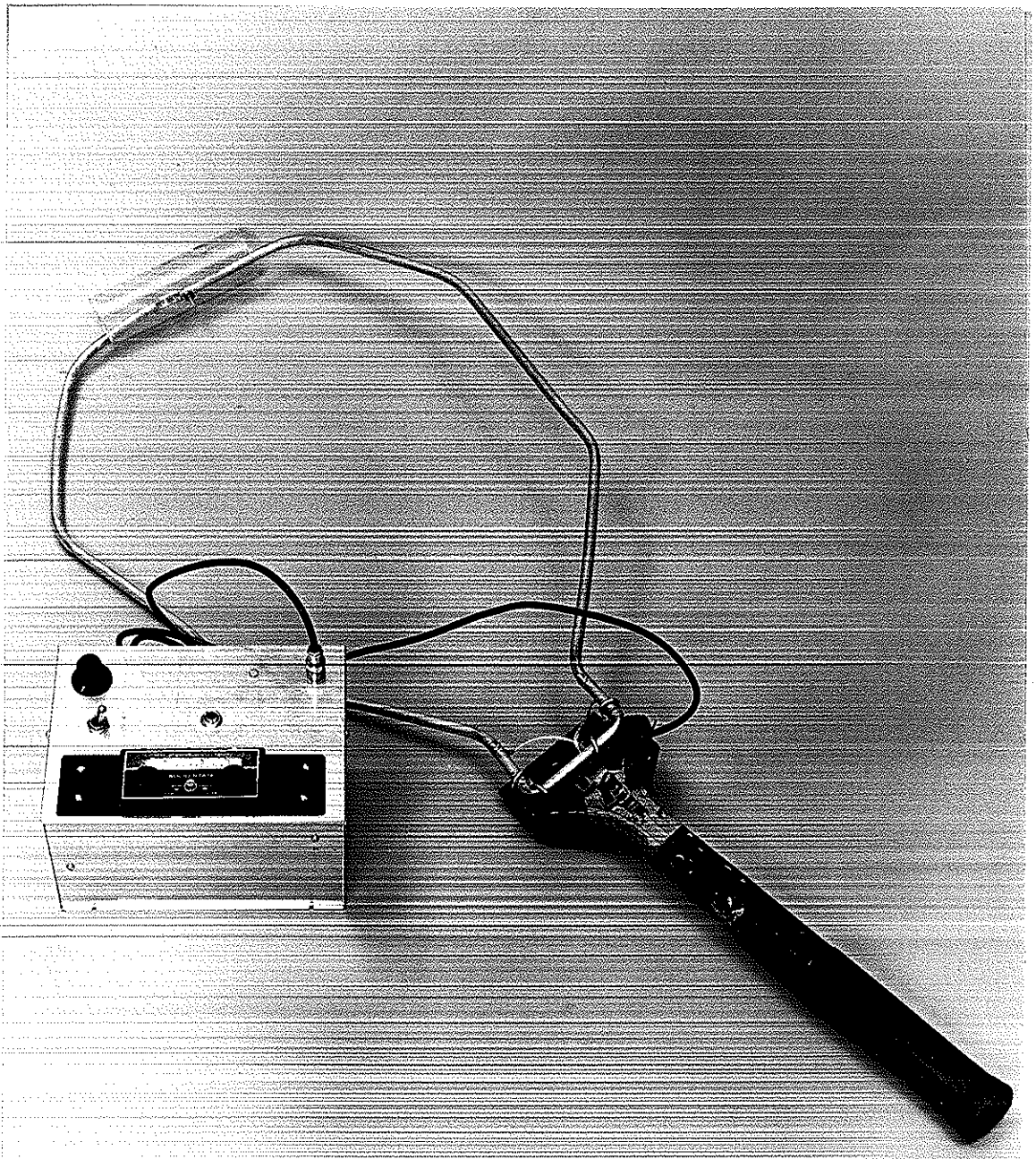
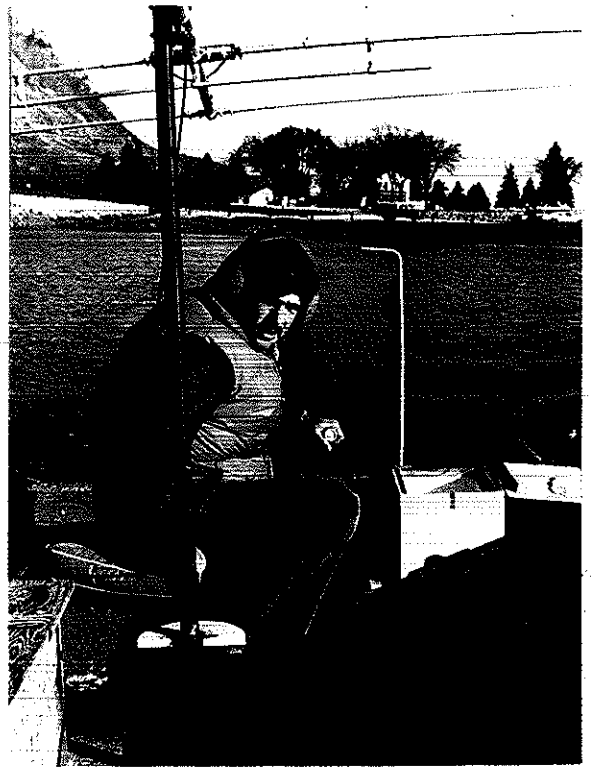
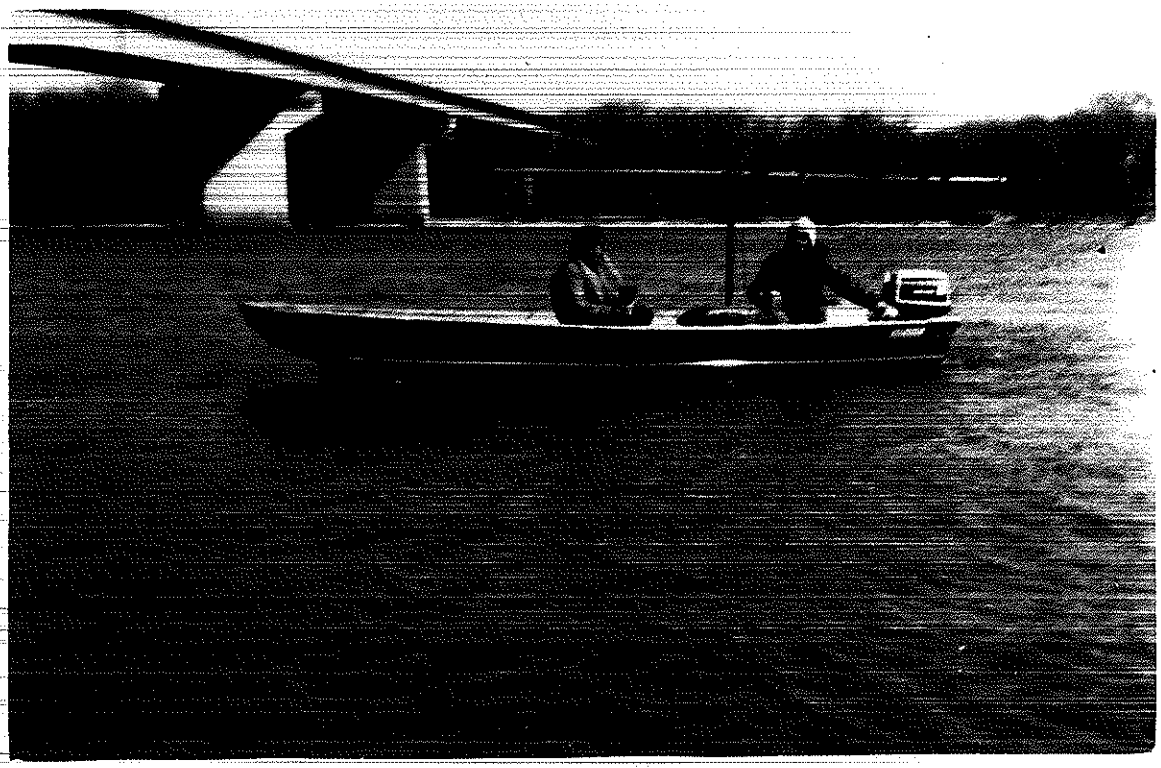


Plate 2. The yagi antenna used in locating ten radio-tagged walleyes in Navigation Pools 7 and 8 of the Upper Mississippi River between 19 November 1975 and 4 May 1976.





in the spiny rays of the dorsal fin. All walleyes tagged with dart tags were captured by angling from a recreational fishing barge located 50-60 m downstream from Lock and Dam 7 on the east side of the main channel in area G (Figure 1, inset 1).

The transmitter was anchored to the fish by placing it on the dorsal side, slightly anterior to the dorsal fin with the whip antenna trailing posteriorly and the saddle hanging on either side of the fish. Attachment of the transmitters to the first nine walleyes was accomplished by threading a 15 cm length of Beldon 22 ga teflon coated wire through an 85 mm curved upholstery needle, and pushing the needle through the fish. The ends of the wire were placed in the holes in the saddle and both ends were covered with a metal sleeve and crimped tightly. Care was taken to ensure the saddle fit snuggly (Plate 3). The procedure for the last three walleyes was basically the same except a 14 ga. I.V. catheter was used instead of a needle. This method precluded the need of threading a needle and prevented any additional tearing of musculature from a double stranded wire passing through. Two such wires were used to anchor the transmitter on the last three fish to prevent the abrasive action of a single wire (Holt, C., 1976, personal communication) (Plate 4).

Tracking Procedure and Data Collection

The fishes were tracked periodically between 20 November 1975 and 4 May 1976 (Table 3). Initial locations were determined with the yagi antenna and a loop antenna was used to delineate the position (accuracy $\pm$ 2 m in 2 m of water) (Plate 5). The fish's position was determined at 30 min intervals by motoring the boat slowly toward the greatest

Plate 3. The placement of a radio-transmitter on a walleye.

Top : The attachment wire is sewn through the dorsal musculature.
Bottom : The ends of the attachment are secured to the plastic saddle.

Plate 4. Appearance of a walleye after attachment of a radio-transmitter.

Top : A walleye prior to release.
Bottom : A walleye immediately after release.

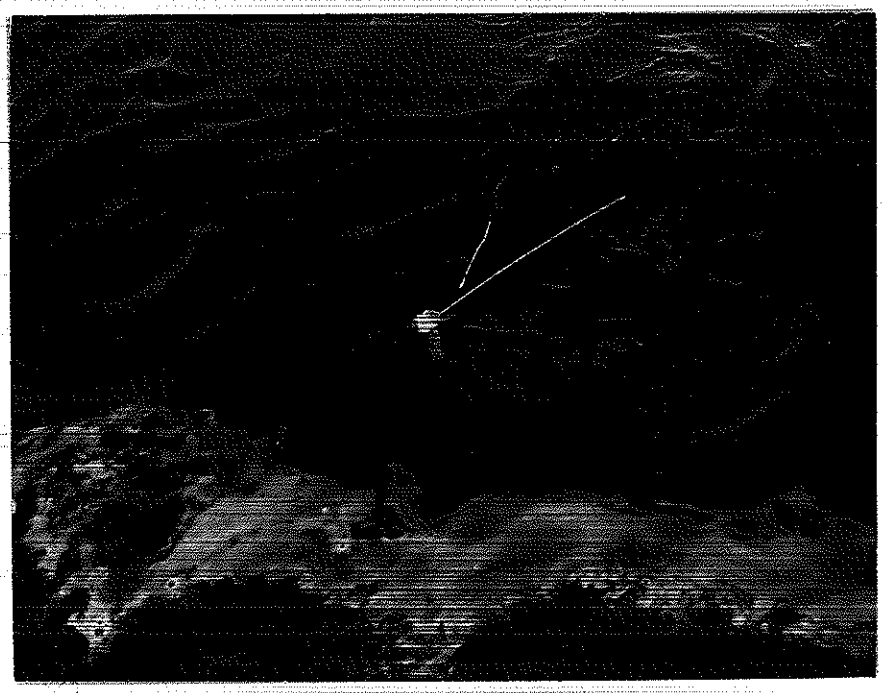
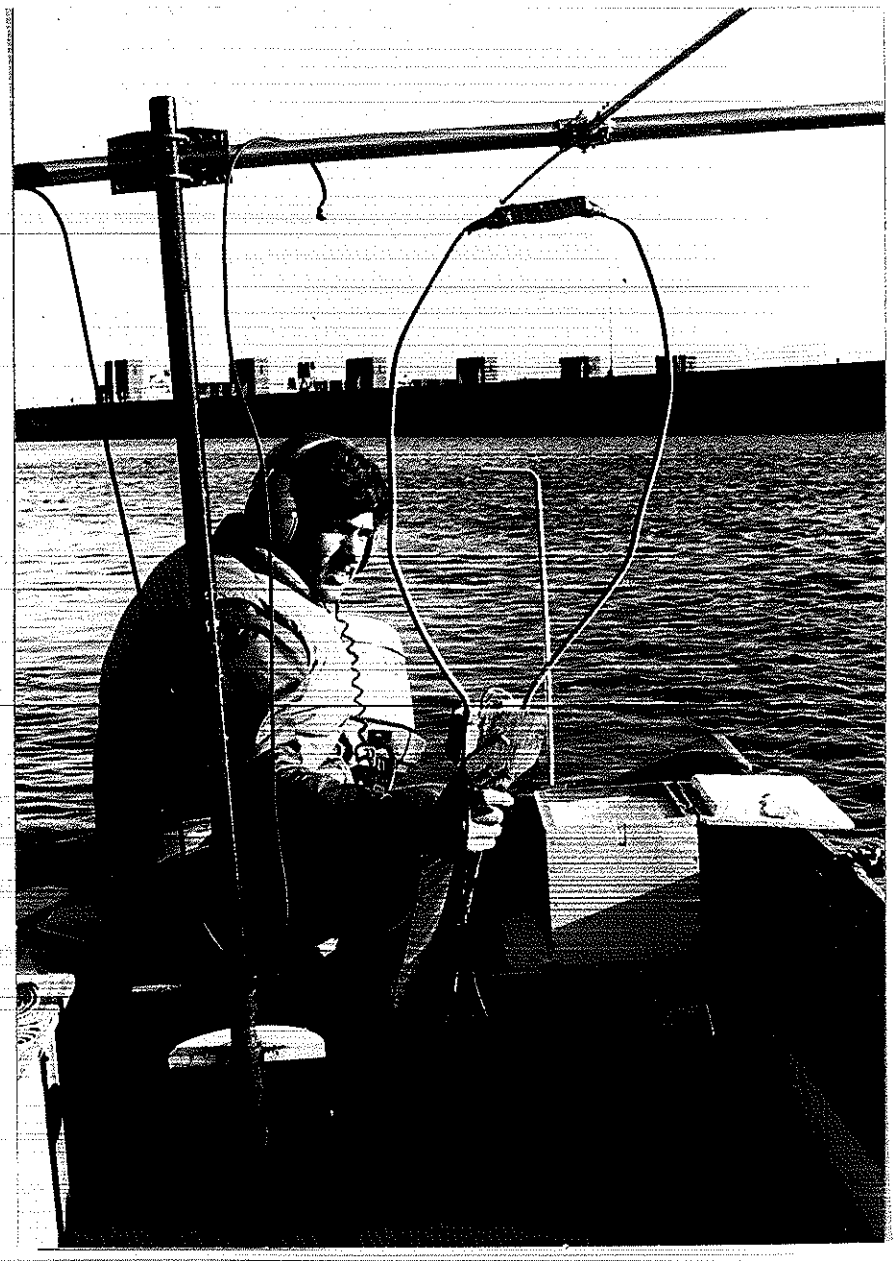


Plate 5. Operation of the loop antenna in the field to track radio-tagged walleyes.



signal intensity until a loud pulsing was heard in every direction with the gain turned low. Location, time, depth, and water temperature were recorded for each track. The percentage of cloud cover, wind direction, and current direction were recorded, and an opinion concerning current velocity, wave height, and the current weather conditions was expressed. Light penetration readings using a 200 mm diameter secchi disc and dissolved oxygen readings using an oxygen meter were determined early in the study but were abandoned midway through. The composition of the sediments was estimated by taking bottom grabs with a ponar bottom sampler and analyzing them in the field by hand. The barometric pressure and river elevations during the study were obtained later.

There were several exceptions when the above readings were not determined; when tracking was done from shore on 26 and 28 November 1975 when the ice was too thin to walk on; when tracking was done from an airplane on 18 March, 11, 13, and 24 April 1976; and when the fish was in motion during which the operator would follow the fish, staying on the outer limits of the range of the yagi antenna, being careful not to chase the fish.

RESULTS

The walleyes used in this study were between four and five yrs old and ranged between 430 mm and 564 mm in total length. All the fish were female and were ripe at the time of capture (Table 3).

Nine female walleyes were tracked for 581.25 hr between 13 March 1976 and 4 May 1976 in Navigation Pools 7 and 8 of the Upper Mississippi River. Between 14 March 1976 and 2 May 1976 eight walleyes were tracked for 393.08 hr between Lock and Dam 7 and 1850 m downstream. This is referred to as the tailwater area and was considered the area in which the fishes spawned.

Study Areas

The fishes tracked in the tailwater area established 15 separate areas in which they were tracked for periods of greater than 1.0 hr (Figure 1, inset 1). These areas can be separated into two broad categories, eddies and backwaters, based on current velocity and depth (Table 4). The eddies, areas C, D, F, G, H, J, H, J, K, L, N, and O (Figure 1, inset 1), contained variable current velocities and depths. Water flow around and over wingdams formed eddies in areas H, J, L and N. The constriction of the main channel caused by Lock and Dam 7 and the constriction of the main channel caused by the interstate, I-90, bridge formed eddies in areas F, G, and C. Area D was formed by the passage of water around the western-most bridge support of the I-90 bridge, (Figure 1, inset 1). Area K was an eddy formed by a fallen tree and area O was an eddy formed by a submerged sandbar. The backwater areas, A, B, E, I, and M (Figure 1,

Table 4. Description of areas used by nine radio-tagged walleyes in the tailwater area of Lock and Dam 7 of the Upper Mississippi River during spring, 1976.

Area	Classification	Surface Area (km)	Maximum Depth (m)	Current Description	Bottom Content (%)				
					Muck	Fine Sand	Medium Sand	Coarse Sand	Rock
A	Backwater	30.4	9.0	0	75	25			
B	Backwater	0.5	4.2	0					100
C	Eddy	3.8	6.6	Variable-medium			100		
D	Eddy	0.05	9.0	Variable-strong			100		
E	Backwater	38.1	9.3	0	20	30	40	10	
F	Eddy	2.4	9.0	Variable-strong			100		
G	Eddy	4.1	7.5	Variable-strong			100		
H	Eddy	5.1	5.7	Variable-medium			100		
I	Backwater	0.6	3.0	0		20	70	5	
J	Eddy	3.0	7.5	Variable-medium			100		
K	Eddy	0.03	4.0	Variable-slow			100		
L	Eddy	2.9	9.0	Variable-slow			100		
M	Backwater	8.6	9.0	0	100				
N	Eddy	2.4	5.1	Variable-medium			100		
O	Eddy	3.1	4.8	Variable-slow			100		

inset 1), had no measurable currents. Area G was the most used eddy by the tagged fish, and area A was the most used backwater (Table 5).

Nearly 39% of the tailwater tracking hours were spent in an eddy habitat and 52.7% were spent in a backwater habitat (Table 4). The calculated fish hours per habitat (Fish hours (fhr) = Number of fish using an area X number of hours spent in that habitat) was lower for eddies than for backwater areas indicating the fishes had a preference for backwater areas.

Table 5. Utilization of areas near Lock and Dam 7 of the Upper Mississippi River by nine radio-tagged walleyes during spring, 1976.

Areas	Number of fish using Area	Hours in Area (hr)	Percentage of total tracking hours (%)	Fish hours (fhr)
Eddy Areas				
C	7	12.41	3.2	86.87
D	2	0.82	0.2	1.64
F	4	21.96	5.6	87.84
G	6	34.62	8.8	207.72
H	4	9.28	2.4	37.12
J	1	33.95	8.6	33.95
K	1	3.9	1.0	3.9
L	4	6.47	1.6	25.88
N	4	25.7	6.5	102.8
O	1	3.17	0.8	3.17
Backwater Areas				
A	5	111.22	28.3	556.1
B	1	2.25	0.6	2.25
E	2	64.75	16.5	129.5
I	2	5.45	1.4	10.9
M	2	23.31	5.9	46.62
Total eddy use	9	152.28	38.7	590.89
Total backwater use	6	206.98	52.7	745.37

Movement

Nearly twice the amount of time was spent resting (no movement) as was spent swimming (Table 6). These patterns were nearly identical for the non-tailwater tracking period and the tailwater tracking hours. The swimming rate in the tailwater area was faster than the non-tailwater area which may have been caused by increased activity associated with "searching" for other spawning walleyes. Most of the swimming was accomplished in a "rest-and-go" manner rather than periods of long resting followed by long periods of swimming. This type of movement was similar to Koo and Wilson (1972) results while tracking striped bass in the Cheasepeake Bay.

Table 6. Summary of tracking data of nine radio-tagged walleyes in Pool 8 of the Upper Mississippi River during spring, 1976.

Tracking Period	Total hours tracked (hr)	Resting		Swimming		Total Distance Travelled (m)	Average rate (m/hr)
		hr	%	hr	%		
Tailwater	393.08	374.14	64.4	207.11	35.6	47,285	228.3
Non-Tailwater	188.17	107.97	57.4	80.2	42.6	18,392	170.3

Two types of swimming patterns became recognizable. Random swimming was defined as movement having either no specific direction of travel, a slow rate of travel (10-300 m/hr) or the fish traversing small distances (average 127 m/movement) (Figure 2). Directional swimming was characterized by rapid movement (300-1200 m/hr) between study areas, usually in relatively straight lines, and the fish usually travelled farther (average 547 m/movement) (Figure 3). Some overlap was noted between the rates of random and directional swimming due to fast "random"

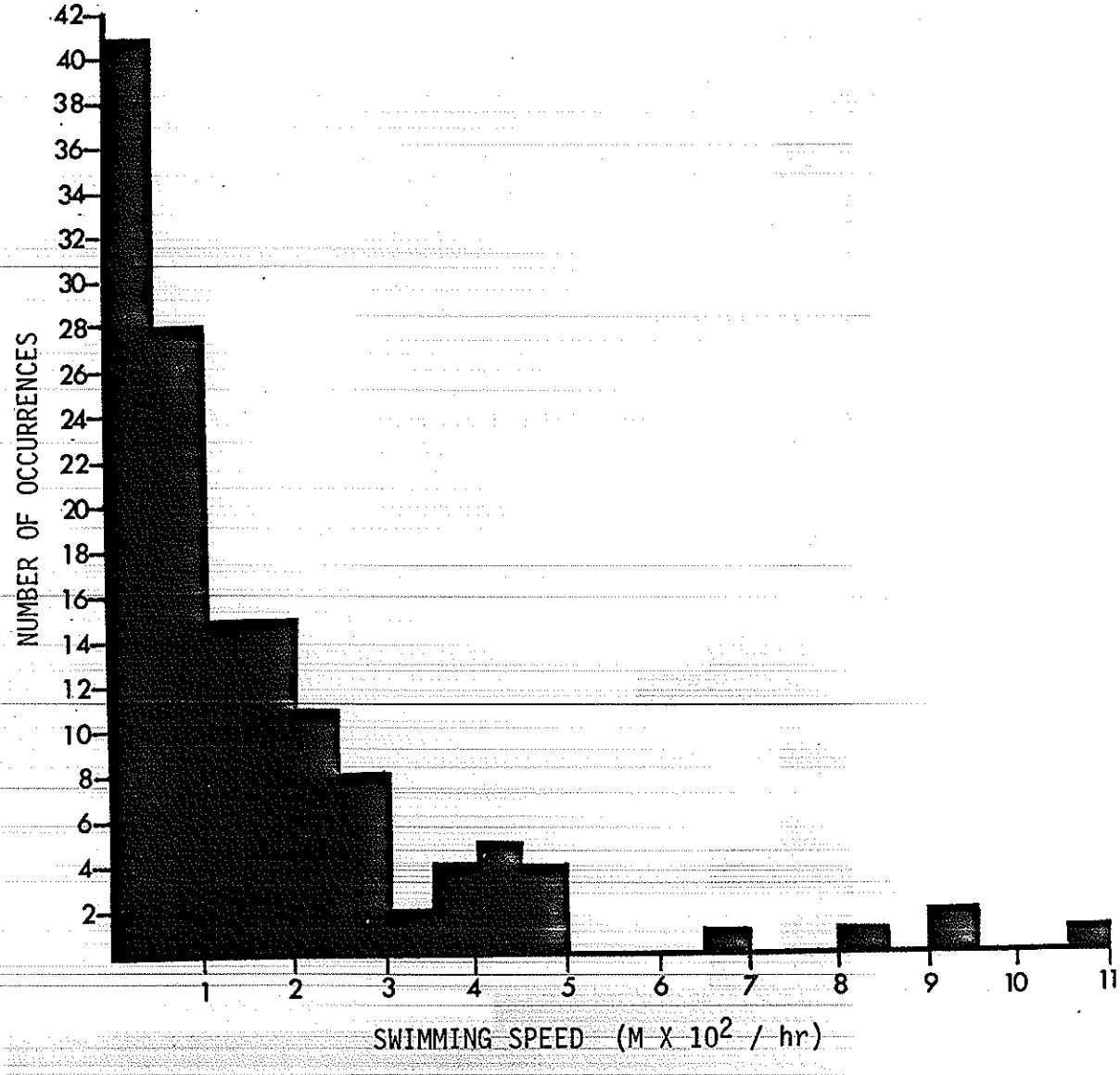


Figure 2. Swimming velocities of nine radio-tagged walleyes during periods of random swimming in Pool 8 of the Upper Mississippi River during March and April 1976.

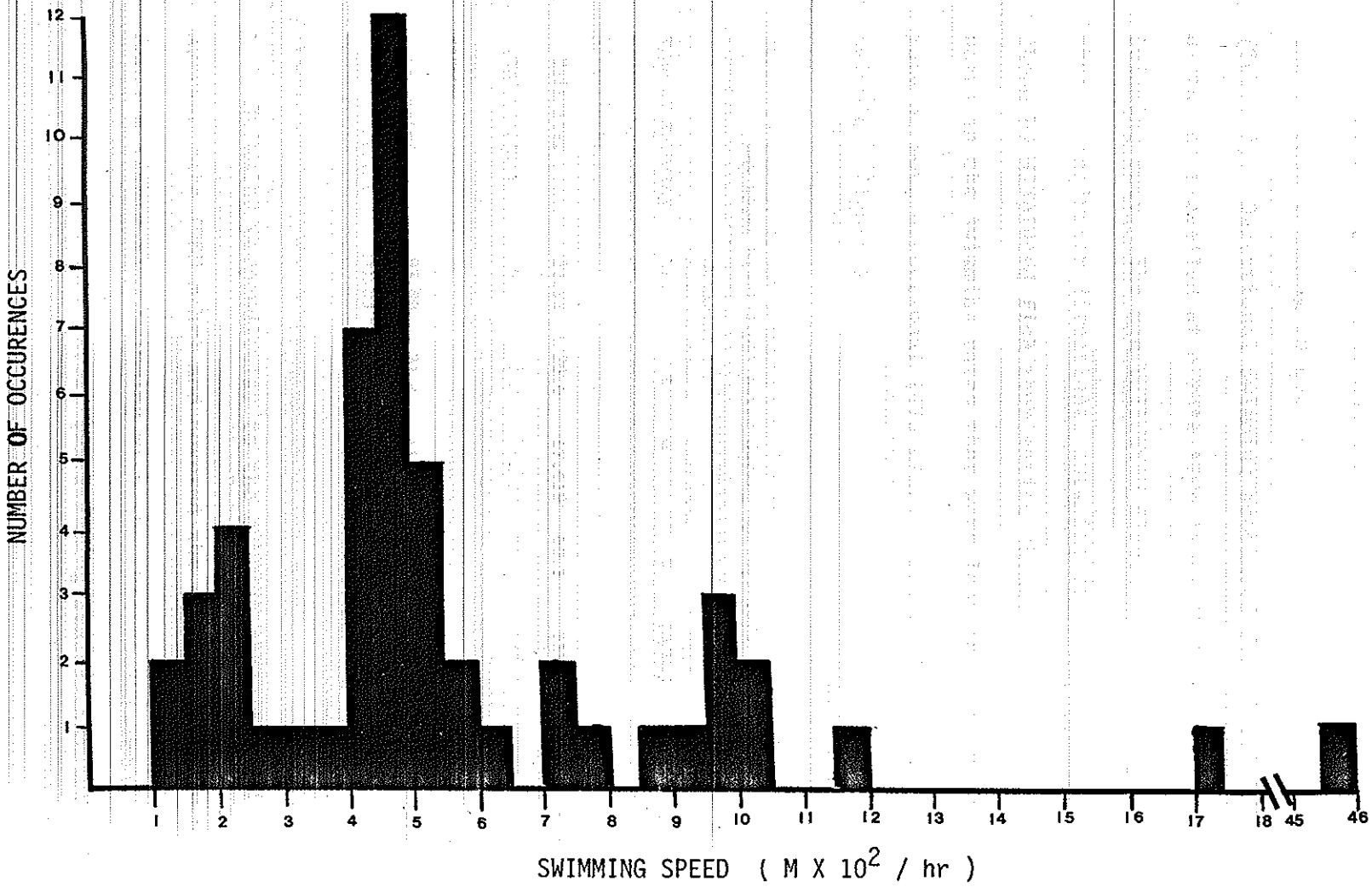


Figure 3. Swimming speeds of nine radio-tagged walleyes during directional swimming periods in Pool 8 of the Upper Mississippi River during March and April 1976.

movements in backwater areas and slow "directional" movements in the main channel (Figures 2 and 3).

Three times as many hours were spent in random swimming than in directional swimming in both the tailwater and non-tailwater areas (Table 7). Directional swimming accounted for almost 2/3 of the total distances travelled at a rate five times faster than the random swimming rate. The non-tailwater directional swimming rate was greater than the tailwater directional swimming rate and was due to activity shown by displaced fish reorienting themselves. There were distinct peaks in the swimming rates that were less than the average swimming rate of both directional (475 m/hr) (Figure 3) and random (50 m/hr) swimming (Figure 2).

Table 7. Summary of the swimming behavior of nine radio-tagged walleyes in Pool 8 of the Upper Mississippi River during spring, 1976.

	Swimming time		Distance		Average Rate	Average time to complete a movement
Type of Swimming	hrs	%	m	%	(m/hr)	(hr)
Directional						
Tailwater	33.82	26.6	17,419	60.3	515.1	0.86
Non tailwater	18.67	23.3	12,130	65.8	649.7	1.18
Random						
Tailwater	93.09	73.4	11,474	39.7	123.3	1.0
Non tailwater	61.53	76.7	6,302	34.2	102.4	1.3

Swimming perpendicular to the current accounted for the fastest average rate (969 m/hr) and covered the greatest average distance of 680.1 m (Table 8). Swimming with the current and against the current had nearly identical rates, but swimming against the current was

sustained for shorter periods and covered shorter distances. The lowest rate of swimming and the shortest average distances travelled were observed with fishes that were travelling oblique to the current.

Table 8. Summary of swimming in relation to current direction by nine radio-tagged walleyes in Pool 8 of the Upper Mississippi River during spring, 1976.

Movement relation to current	Hours Swimming (hr)	Distance Travelled (m)	Swimming Rate (m/hr)	Number of Occurrences	Average time to complete a movement (hr)	Average Distance per Movement (m)
Perpendicular to the current	10.7	5,441	969.0	8	1.34	680.1
With the current	22.89	10,020	539.0	18	1.27	556.7
Against the current	15.62	7,983	547.8	19	0.82	420.2
Oblique to the current	2.63	1,168	399.1	3	0.88	389.3

Fishes in backwater areas swam three times farther than when they were in eddy areas (Table 9). This was probably due to the larger areas in the backwaters in which the fishes could swim without any exposure to current. The fishes within the eddies swam at approximately the same rate (102 m/hr) that they swam in the backwaters (132.3 m/hr) (Table 9).

Table 9. Summary of backwater and eddy hours of nine radio-tagged walleyes in the tailwater area of Lock and Dam 7 in the Upper Mississippi River during spring, 1976.

Habitat	Total (hr)	Rest (hr)	Swimming (hr)	Distance Travelled (m)	Swimming Rate (m/hr)
Backwater	206.98	141.81	65.17	8,625	132.3
Eddy	152.28	124.36	27.92	2,849	102.0

Diel Movements

The walleyes exhibited a preference for a certain type of habitat

at various times throughout a 24 hr day (Figure 4). Between 2100 and 0300 hours, the walleyes were usually located in a backwater habitat. Between 0300 and 0600 hours there was an increase in movement out of some areas and into other areas until location within the eddies would peak between 0900 and 1500 hours, after which there was an increase in movement out of some areas and into other areas until 1800 hours. Equal efforts were spent in searching for the fishes in the eddy and backwater areas.

Of the total tailwater tracking hours, 232.06 hr were considered hours of daylight and 121.24 hr hours of darkness based on astronomical time (Hunter and Sleeper, 1974). The total tailwater movement during the day was comparable to the total tailwater movement during the night where 36.5% of the day hours and 27.4% of the night hours were spent swimming (Table 10). The average night movement was slightly faster and covered more distance than the average day movement.

The percentage of the total directional distance travelled during the day and night were nearly identical as were the percentages of the total random distance travelled during the day and night (Table 10). The night directional and random swimming rates were faster, took less time to complete and covered a greater average distance than did the day swimming. The greater percentage of the night hours were spent at rest than during the day.

Day movements within the eddies and backwaters had similar rates, average time to complete each movement, and average distance travelled per movement (Table 11). There was insufficient data on night movements in the eddies for accurate comparisons, but similar percentages of time were spent swimming during the day and night in backwater areas.

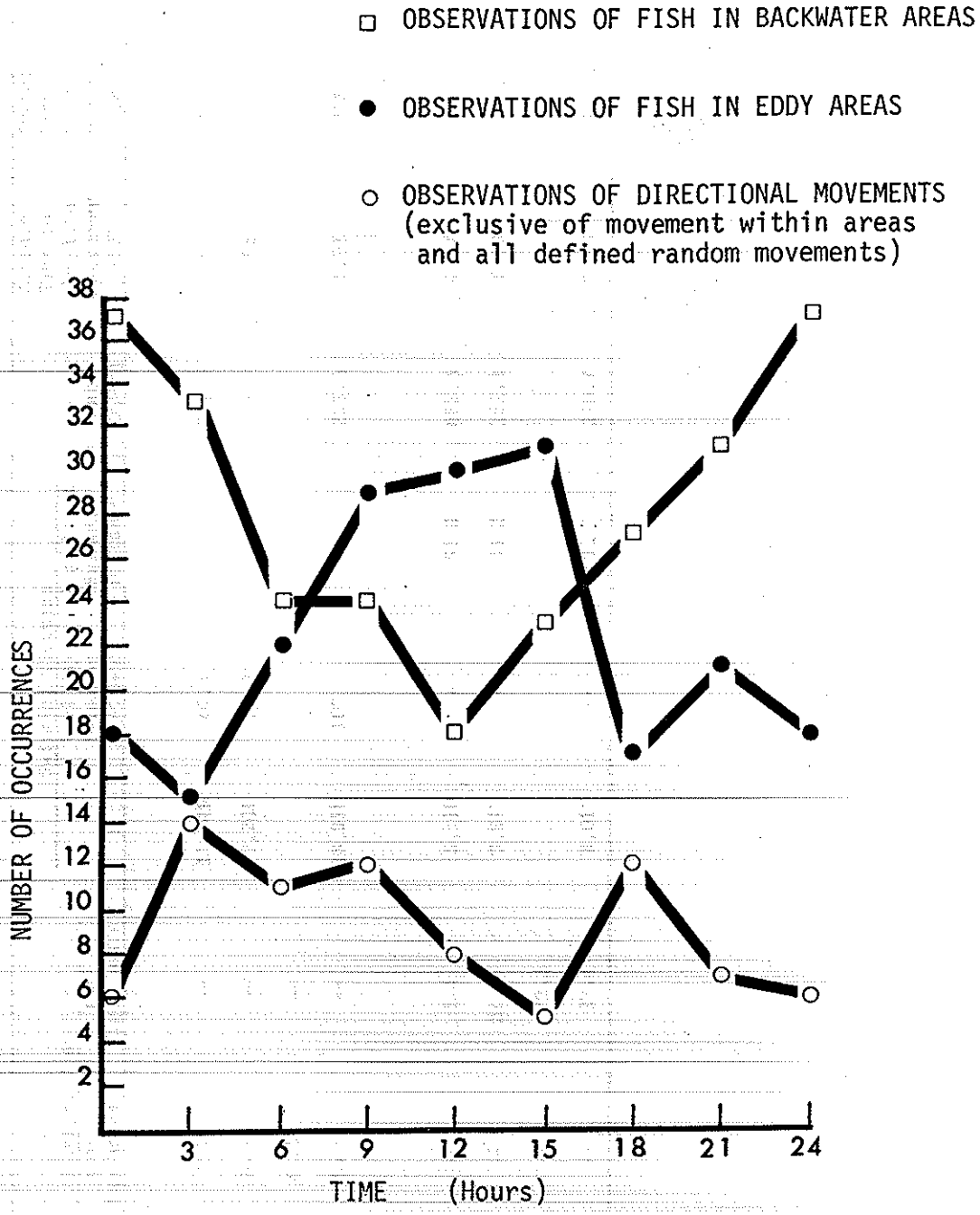


Figure 4. Total hourly observations of fish location in various habitats by nine radio-tagged walleyes in Pool 8 of the Upper Mississippi River during March and April 1976.

Table 10. Summary of the day and night movements of nine radio-tagged walleyes in the tailwater area of Lock and Dam 7 in the Upper Mississippi River during spring, 1976.

Movement period	Swimming Time			Swimming Distance			Rate (m/hr)	Average Time to Complete A Movement (hr)	Average Distance Swum per Movement (m)
	Hr	% of Day hours	% of Night hours	m	% of Day Swimming Distance	% of Night Swimming Distance			
Day									
Directional	22.51	9.7	--	11,749	62.0	--	521.9	0.87	425.0
Random	62.15	26.8	--	7,201	38.0	--	115.9	0.96	108.2
No movement	147.3	63.5	--						
Total	84.76	36.5	--	18,950	100	--	223.6	0.93	213.8
Night									
Directional	7.81	--	6.4	5,120	--	56.8	655.6	0.77	494.8
Random	25.5	--	21.0	3,897	--	43.2	152.8	0.89	198.2
No movement	87.93	--	72.5						
Total	33.31	--	27.4	9,017	--	100	270.7	0.85	244.0

Table 11. Summary of the day and night movements within eddies and backwaters of nine radio-tagged walleyes in the tailwater area of Lock and Dam 7 in the Upper Mississippi River during spring, 1976.

Area	Swimming Time			Swimming Distance					
	Hr	% of Day Eddy/Backwater Hours	% of Night Eddy/Backwater Hours	m	% of Day Swimming Distance	% of Night Swimming Distance	Rate (m/hr)	Average time to complete a movement (hr)	Average Distance Swum per Movement (m)
Eddies									
Day	24.92	26.0	--	2,786	14.7	--	111.8	1.0	111.8
Night	2.5	--	6.5	212	--	2.4	84.8	0.83	70.7
Backwaters									
Day	37.33	32.9	--	4,415	23.3	--	118.3	0.91	105
Night	23.0	--	30.6	3,685	--	40.9	160.2	1.15	184.3

The walleyes rested more at night than during the day (72.5% of the total night hours) but similar percentages of time were spent at rest during the day and night in the eddy areas (Table 12).

Table 12. Summary of the day and night periods of no movement within eddies and backwaters of nine radio-tagged walleyes in the tailwater area of Lock and Dam 7 in the Upper Mississippi River during spring, 1976.

Period of no movement	Hours	Percentage of Day Hours (%)	Percentage of Night Hours (%)
Day			
Backwaters	76.23	32.8	--
Eddies	71.07	30.6	--
Total	147.3	63.5	--
Night			
Backwaters	52.08	--	43.0
Eddies	35.85	--	29.6
Total	87.93	--	72.5

There appear to be four distinct modes in activity at approximately 0230, 0700, 1200, and 1800 with the highest activity peak (1.62 b.l./sec^{-1}) at 0230 (Figure 5). Carlander and Cleary (1949), in their studies of the activity patterns of fishes in Clear Lake, Iowa, determined the peak activity periods for walleyes were at dusk and dawn. Similarly, Kelso (1976b) using radio-tagged walleyes in the West Blue Lake, Manitoba, determined the peak activity periods at dusk and dawn. The four activity peaks in the present study may be due to an increase in activity associated with spawning.

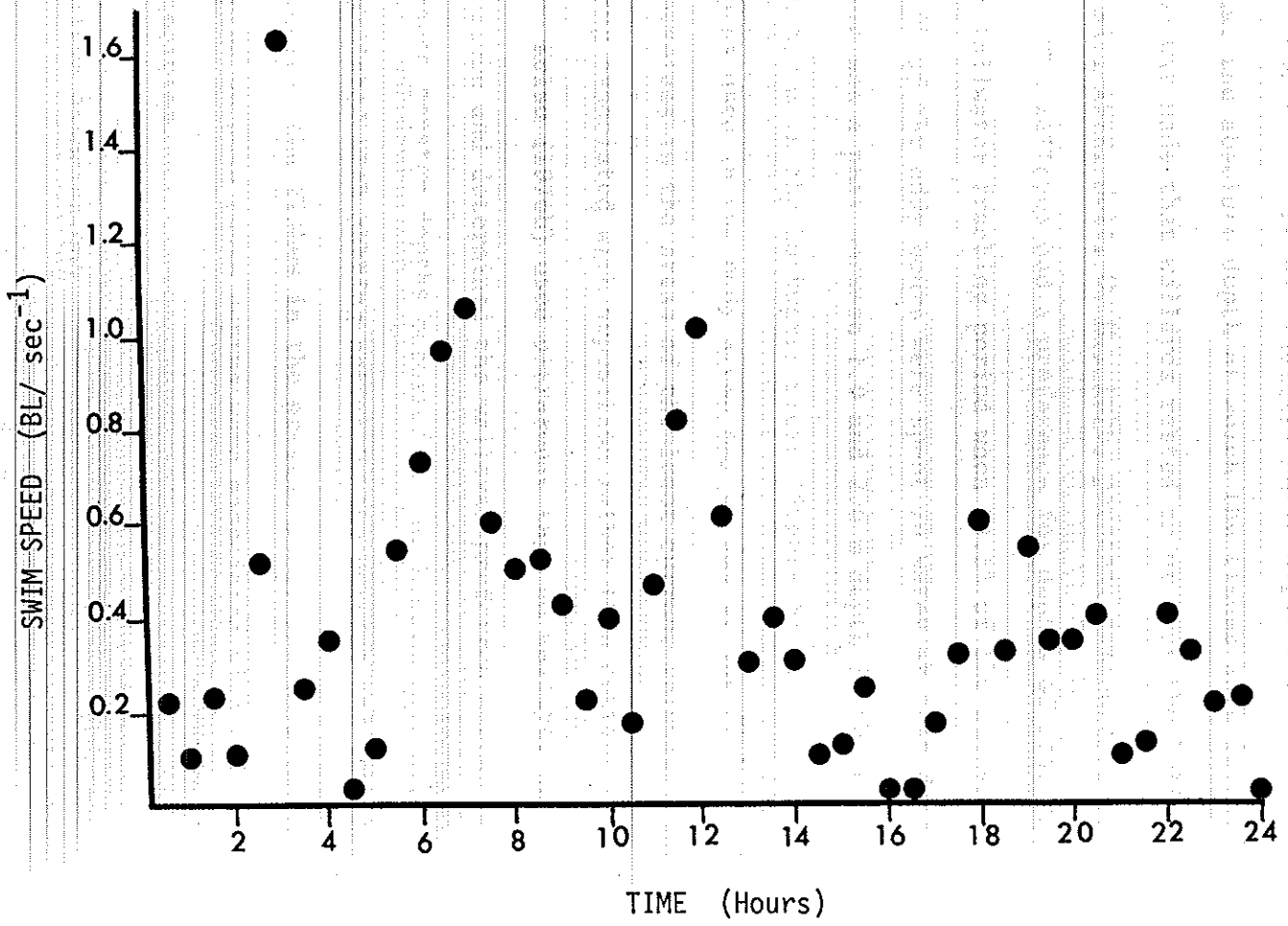


Figure 5. Average hourly swimming speeds of nine radio-tagged walleyes in Pool 8 of the Upper Mississippi River during March and April 1976.

DISCUSSION

Depth Preferences

Depth data points indicate water depth and do not necessarily equal the absolute depth at which the fishes were located. An assumption was made that walleyes rested on or near the bottom (Niemuth et al., 1972; Holt, C. H., 1976, personal communication).

The walleyes had a preference for depths of less than 5 m during the tailwater tracking period when 94.6% of the backwater hours and 66.9% of the eddy hours were spent in water at that depth (Table 13). There was a peak between 1.0 and 2.0 m depth in the eddy areas and 2.0-3.0 m in the backwater areas (Figure 6) although the shallower depths used in the eddy areas may be due to the fishes orienting themselves in the areas of the least current velocity; these areas being associated with deposition rather than cutting by the current.

Kelso (1976b) used ultrasonic tags on walleyes in West Blue Lake, Manitoba and determined the walleyes preferred depths between 5 and 10 m. Because greater depths occurred in the Mississippi River and were associated with cutting action by the current and thus high current velocity, the fishes in the present study probably chose the shallowest depths because those depths were associated with reduced current velocities.

Walleye Associations

There were a few isolated instances of two or more tagged walleyes either located together or travelling together, but these instances accounted for only 3.3% of the total hours tracked. After the fishes

Table 13. Summary of the hours spent at specific depths for eight radio-tagged walleyes in the tailwater area of Lock and Dam 7 in the Upper Mississippi River during spring, 1976.

	Eddies						Backwaters					
Depth	Hr	Percentage of Total Hours (%)	Day (Hrs)	Percentage of Day Hours (%)	Night (Hrs)	Percentage of Night Hours (%)	Hr	Percentage of Total Hours (%)	Day (Hrs)	Percentage of Day Hours (%)	Night (Hrs)	Percentage of Night Hours (%)
0.0-0.9	2.43	2.5	0.0	0.0	2.43	9.1	1.98	1.4	0.5	0.6	1.48	3.4
1.0-1.9	35.13	36.6	22.3	35.2	9.83	36.9	19.1	13.8	14.91	17.6	2.69	6.2
2.0-2.9	8.16	8.5	7.41	11.7	0.25	0.9	56.48	40.8	35.54	42.0	19.22	44.3
3.0-3.9	8.4	8.8	7.4	11.7	1.0	3.8	23.46	16.9	11.31	13.4	8.73	20.1
4.0-4.9	10.09	10.5	4.09	6.5	4.75	17.9	30.1	21.7	20.35	24.1	6.75	15.6
5.0-5.9	12.76	13.3	7.25	11.4	5.35	20.1	0.83	0.6	0.58	0.7	0.25	0.6
6.0-6.9	7.48	7.8	4.48	7.1	3.0	11.3	2.25	1.6	0.25	0.3	2.0	4.6
7.0-7.9	10.25	10.7	9.25	14.6	0.0	0.0	1.33	1.0	0.58	0.7	0.75	1.7
8.0-8.9	0.25	0.3	0.25	0.4	0.0	0.0	0.25	0.2	0.0	0.0	0.25	0.6
9.9-9.9	0.98	1.0	0.98	1.5	0.0	0.0	2.8	2.0	0.55	0.7	1.25	2.9
Total hours	95.93		63.41		26.61		138.58		84.57		43.37	

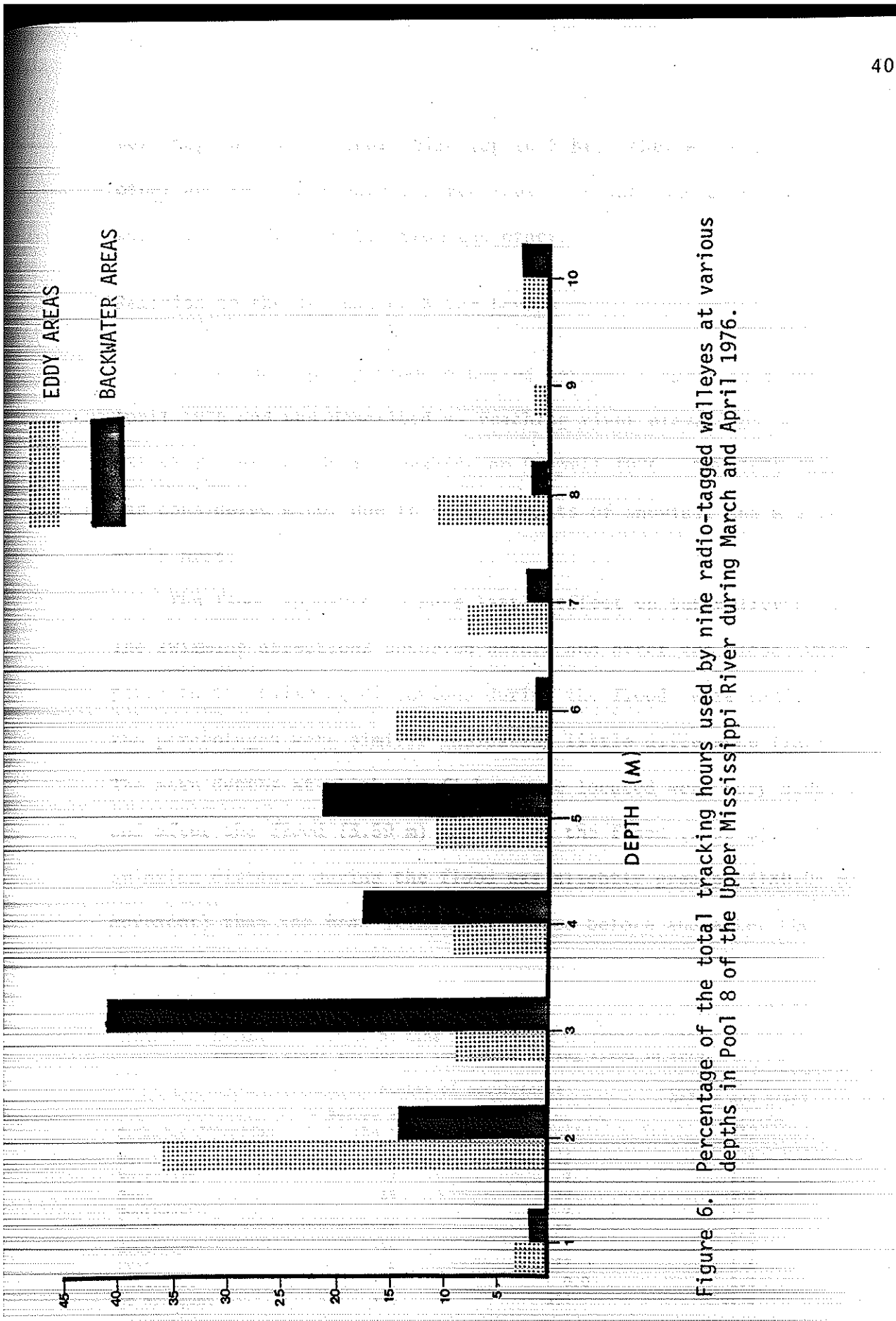


Figure 6. Percentage of the total tracking hours used by nine radio-tagged walleyes at various depths in Pool 8 of the Upper Mississippi River during March and April 1976.

were together for a short time (up to 3 hr), they would leave each other and swim in separate directions. It was concluded each fish would move independently from the others.

Reaction to the Increasing Water Levels

The annual spring flood occurred between 1 April 1976 and 14 April 1976 and was described as reaching river elevations between 637.42 ft and 640.50 ft, peaking on 5 April 1976. The 1976 flood was considered minor due to small amounts of snowfall and a slow early melt.

The flood appeared to have little effect on the walleyes' behavior. The swimming directions observed before and after the flood, when compared to the swimming directions during the flood, were random, and the percentages were similar indicating little difference (Table 14). The mean depths at which the fishes were located were very close before and after the flood (3.59 m) and during the flood (3.92 m). The mean swimming distance during the flood was slightly greater (180.04 m/movement) than the mean swimming distance before and after the flood (145.18 m/movement).

Table 14. Swimming direction of nine radio-tagged walleyes in Pool 8 of the Upper Mississippi River before, after and during the annual spring flood in 1976.

	Number of occurrences		Percentage of occurrences	
Swimming direction	Before and after the flood	During the flood	Before and after the flood (%)	During the flood (%)
North	32	49	7.3	10.8
Northeast	7	7	1.6	1.5
East	14	20	3.2	4.4
Southeast	6	7	1.4	1.5
South	41	37	9.3	8.2
Southwest	10	8	2.3	1.8
West	8	17	1.8	3.8
Northwest	6	0.0	1.4	0.0
No movement	305	304	69.5	67.3

Although the increased water levels associated with the flood appeared to have little or no effect on the behavior of the walleyes, the 1976 flood was of such minor proportions that conclusions may not be valid.

Homing

For the purposes of this study, homing was defined as the annual return of spawning walleyes to a particular site, rather than seeking any suitable spawning area (Crowe, 1962). Homing of walleyes for spawning purposes has been demonstrated in many studies (Stoudt, 1939; Stoudt and Eddy, 1939; Herman, 1947; Eschmeyer, and Crowe, 1955; Rawson, 1957; Crowe, 1962; Olson and Scidmore, 1962; Crowe et al., 1963).

Of the 12 walleyes tagged with radio transmitters and released in navigation pool 8 of the Upper Mississippi River, three were displaced from the capture site. All three of these fish displayed homing as defined by Crowe (1962). Two of these fishes (No. 9 and No. 11) were transplanted 11.27 km (7 mi) downstream and the other fish (No. 8) was transplanted 13.68 km (8.5 mi) downstream. The first fish to return (No. 11) was caught and tagged on 15 March 1976 in area C and was released near Coney Island (No. 2, Figure 1), 11.27 km downstream. Periodic checks were made daily on this fish until contact was lost on 19 March 1976. On 8 April 1976 this fish appeared near Lock and Dam 7 in area G after an elapsed time of 19 days (Figure 1, inset 1). The second fish to return (No. 9) was captured on 14 March 1976 in area C and was immediately tagged and transferred to Coney Island and released. This was the last time the fish was located until 11 April 1976 when it appeared at the original capture site after an elapsed time of 27 days. The third fish to return upstream (No. 8) was

captured on 17 March 1976 in area C and transplanted to river mile 692.5 (No. 3, Figure 1), 13.68 km downstream. That fish was last tracked in that area on 24 March 1976 until it was relocated on 2 May 1976 at river mile 699.2 (No. 4, Figure 1) in the upstream entrance to West Channel on the downstream side of a closing dam, 1.2 km (0.8 mi) downstream from the capture site.

Fishes 2, 4, 5, 5a, and 6 were all captured and released in the tailwater area. With the exception of one fish (No. 4), all the fishes remained in the tailwater area until after spawning. Fish 4, after being tagged and released on 17 March 1976, in area C, began an immediate downstream movement finally stopping at the confluence of the Black River and the Mississippi River (No. 5, Figure 1), 5.95 km (3.7 mi) downstream from the release site. That fish was tracked in that area until 7 April 1976, during which it seemed to make three attempts to move upstream through three different channels, in each case choosing a channel which would not lead it to the capture area. At 1700 hours on 13 April 1976, this fish appeared in area A after an elapsed time of 6 days.

Six walleyes (Nos. 2, 4, 5, 6, 9, and 11), including two transplants (Nos. 9 and 11), were present in the tailwater area of Lock 7 for up to 35 days until spawning was completed (furthest extent of the spawning season determined at 14 April 1976) and then dispersed immediately.

Daley (1960) concluded that the higher populations of walleyes below the locks and dams in the spring were populations moving into and out of the area rather than a population of fishes spawning in

that area. Although the data in the present study seems to support the idea of a population of walleyes selecting the tailwater area of Lock and Dam 7 as their home spawning grounds, all evidence is circumstantial since spawning was not documented.

One fish (No. 7) was captured on 7 April 1976 at 0900 hr in area G. This fish was tracked continuously until 2100 hours on 8 April 1976, when contact was lost. While tracking by airplane on 11 April 1976, this fish was detected in the tailwaters of Lock and Dam 6, 20.12 km (12.5 mi) upstream after an elapsed time of 64 hr (No. 6, Figure 1). This fish was further detected by airplane in the same area on 29 April 1976. This fish could have been in an upstream migration when it was captured and, after an initial rest period to recover from the shock of handling and tagging, resumed its upstream migration. A similar event occurred with a dart-tagged walleye captured in area G on 22 April 1976 and recaptured in the tailwaters of Lock and Dam 6 on 8 May 1976. The tailwater area of Lock and Dam 6 contains a known walleye spawning ground (Gebken and Wright, 1972) but spawning was not documented in these two fishes.

Range

Walleyes are known to range widely after spawning (Stoudt, 1939; Stoudt and Eddy, 1939; Carbine and Applegate, 1946; Herman, 1947; Eschmeyer, 1950; Manges, 1950; Smith et al., 1952; Eschmeyer and Crowe, 1955; Rawson, 1957; Anonymous, 1958 and 1959; Hubley and Jergens, 1959; Daley, 1960; Priegel, 1968; Niemuth et al., 1972). The radio-tagged walleyes used in the present study had all left the tailwater study

area by 2 May 1976. One fish (No. 9) was caught in a commercial gill net set in Running Slough (No. 7, Figure 1) on 13 May 1976 after travelling a minimum distance of 13.2 km (8.2 mi) downstream from the tailwater area where it was last tracked on 19 April 1976. Another radio-tagged fish (No. 4) was caught in a commercial gill net on 6 July 1976 in the headwaters of Lock and Dam 8 (No. 8, Figure 1) after travelling a minimum distance of 34.92 km (21.7 mi) downstream from the last area in which it was tracked near Lock and Dam 7 on April 1976. One fish (No. 12) was recaptured on 1 April 1976 in a commercial gill net in the same area in which it was originally captured on 26 September 1976 (No. 1, Figure 1). Another fish (No. 13), tagged on 26 September 1975, was recaptured in a commercial gill net 6.4 km (4 mi) downstream (No. 9, Figure 1) of the release site on 28 April 1976. In addition, there were three dart tag returns including one fish, captured in area G on 30 April 1976, that was recaptured by an angler 3.7 km (2.3 mi) downstream near a railroad bridge in the East Channel (No. 10, Figure 1). Another fish caught and tagged on 30 April 1976 in area G was recaptured by an angler on 30 June 1976 in Bullet Chute (No. 11, Figure 1), 27.68 km (17.2 mi) downstream. The other dart-tagged walleye was caught and tagged on 22 April 1976 in area G and was recaptured in the tailwaters of Lock and Dam 6 (No. 6, Figure 1), 20.12 km (12.5 mi) upstream, on 8 May 1976.

All the walleyes except two were caught in the Lock and Dam 7 study area. In the course of 107 days, these fishes ranged upstream to Lock and Dam 6 and downstream to Lock and Dam 8 (Nos. 6 and 8, Figure 1), a minimum distance of 56.3 km (35 river miles). This range is lower than the ranges of walleyes reported in other studies,

probably due to the small sample size used in the present study (Table 15).

The Effect of the Locks and Dams on Walleye Migration

There has been some question concerning the navigational locks and dams serving as barriers to walleye migration. Hubley and Jergens (1959) jaw-tagged 874 walleyes in the tailwaters of Lock and Dam 7 in April 1958. They also found a wide dispersal after spawning, recovering three fish in the tailwaters of Lock and Dam 8, 38.6 km downstream. In all, 7.2% of the recaptures moved out of the pool passing through at least one lock and dam. In another walleye tagging study (Anonymous, 1958), conducted in April 1957 in the tailwaters of navigation pool 10 of the Upper Mississippi River, 38% of the returns moved through at least one dam and one fish travelled through four dams. Daley (1960) found 11% of the recoveries of jaw-tagged walleyes in the tailwaters of Lock and Dam 4, passed out of the pool after they had spawned. Daley (1960) and Hubley and Jergens (1959) both concluded the dams do not serve as barriers to walleye migration. Two of the tagged fishes used in the present study were located in the tailwaters of Lock and Dam 6 after passing through Lock 7. There were two instances when a fish was tracked into the main locks of Lock and Dam 7 until a tow locked through upstream, after which neither fish could be located. The fishes probably locked through with the tow although no attempt was made to search in Pool 7.

It was concluded the locks and dams do not serve as barriers to walleye migration although no distinction was made whether they swim

Table 15. Ranges of walleyes reported by other investigators during periods of up to 107 days.

	Site tagged at	Time Free (days)	Minimum Distance Travelled (km)	Minimum average distance travelled per day (km/day)
1.	Pool 8, Mississippi R.	107	56.3	0.53
2.	Pool 8, Mississippi R.	48	43.5	0.91
3.	Pool 5, Mississippi R.	100	123.9	1.24
4.	Pool 3, Mississippi R.	23	78.9	3.4
5.	L. Champlain, N. Y.	30	160.9	5.36
6.	Muskegon R., Mich.	39	185.1	4.75
7.	Montreal R., Saskatchewan	77	104.6	1.36
8.	Little Cut Foot Souix, Minn.	20	20.9	1.05
9.	Fox R., Wisc.	10	88.5	8.85
10.	Red L., Minn.	68	96.6	1.42

1. Present study, 1976.
2. Hubley and Jergens, 1959.
3. Daley, 1960.
4. Hawkinson, unpub.
5. Kingsbury, 1948.
6. Eschmeyer, 1952.
7. Rawson, 1957.
8. Stoudt, 1939.
9. Herman, 1947.
10. Smith et al., 1952.

through the locks or the dams.

The Effect of the Tag on the Walleye's Behavior

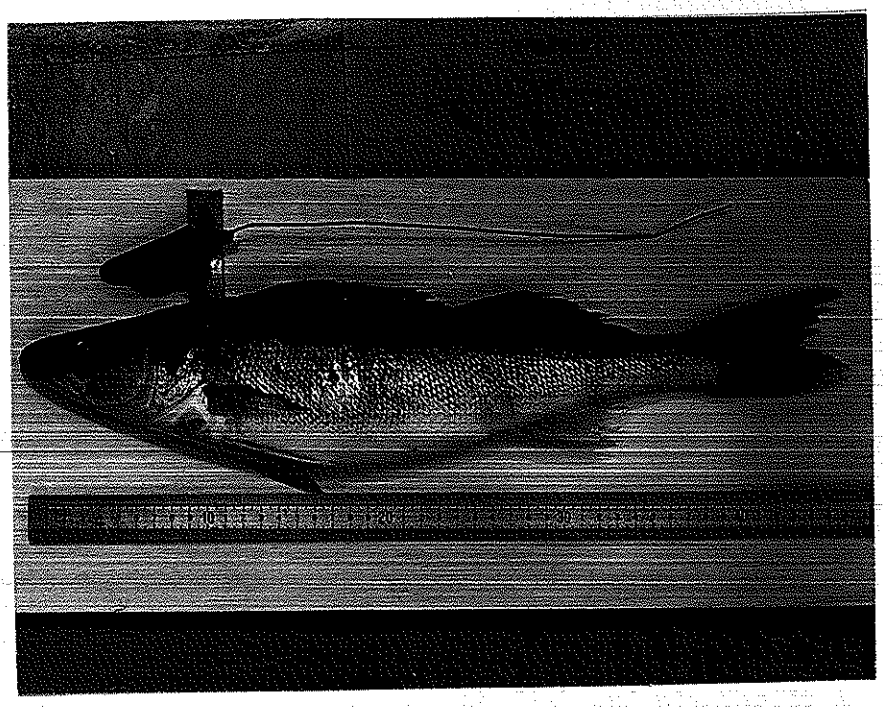
McCleave and Stred (1975) determined that the use of an external tag reduced the swimming speed of atlantic salmon smolts by 20%. The walleyes used in the present study usually remained inactive for periods of up to 24 hr after tagging, which was considered a recovery period from the trauma of handling and tagging, after which they would begin to behave in what was considered a normal fashion. Kelso (1976b) determined the transmitters he attached to walleyes in West Blue Lake, Manitoba caused short-term, up to 65 min, alterations in behavior. One fish (No. 4) reached a speed of 2722.7 m/hr indicating the transmitter did not alter its swimming ability drastically. The tag seemed to have little effect on feeding because fishes 1, 5a, and 9 were caught by anglers indicating an attempt at feeding. The fishes caught in commercial gill nets, fishes 4 (twice), 9, 12, and 13, did not appear emaciated.

An external placement of the tag had an abrasive action at the point of attachment. One fish (No. 13) recaptured on 28 April 1976 in a commercial gill net after being caught and tagged on 26 September 1975, had a 1.6 cm hole worn into the flesh where the transmitter was attached (Plate 6). This problem was alleviated by the use of two wires to attach the transmitter to the body. This method was not considered a major problem for the short period the tracking study covered.

There was a problem concerning where the fishes were released. Fishes 2, 4, 5a, 8, 9, and 11 were released in areas where there was a

Plate 6. The effect of the tag on a walleye that had been free between 26 September 1975 and 28 April 1976 when it was captured in a commercial gill net.

Top : The overall appearance of the fish and the tag.
Bottom : Close-up showing the hole caused by the wire used to attach the transmitter to the fish.



relatively strong downstream current and they would begin swimming slowly downstream until they reached either an eddy or backwater area. Unless these fish were continuously tracked following release, they could not be located for long periods of time. Fishes 5, 6, and 7 were released in backwater areas where there was no current. These fishes usually remained motionless for a period after which they would resume their normal patterns. Possibly, by placing a fish in the main current immediately after stressing it by attaching the tag, it would passively drift until it found an area that contained little or no current and remain in that area until it adjusted to the tag. This problem was alleviated by tagging the fish and placing it in an area with little or no current.

CONCLUSIONS

1. Twelve walleyes (Stizostedion vitreum) were tagged with radio transmitters between 26 September 1975 and 26 April 1976 in Pool 8 of the Upper Mississippi River. Nine of those were tagged between 13 March and 26 April 1976 in the tailwater area of Lock and Dam 7.

2. The objectives of the study were to determine the walleye's homing ability, behavior patterns, range, diel activity patterns, and reaction to increasing water levels.

3. The walleyes in the tailwater area were located in 15 separate areas in which they were tracked for periods of greater than 1.0 hr. These areas were separated into eddy and backwater areas.

4. The walleyes were located in eddies 39% of the tracking hours and in the backwaters 52.7% of the hours. Only 8.3% of the hours were spent travelling in the main channel.

5. The fishes spent twice as much time resting (no movement) as was spent swimming.

6. Two types of swimming patterns were recognizable. Random swimming was defined as movement having either no specific direction of travel, a slow rate of travel (10-300 m/hr) or the fish traversing small distances (127 m/movement). Directional swimming was characterized by rapid movement between study areas (300-1200 m/hr), usually in relatively straight lines, and the fish travelled farther (547 m/movement). Three times as many hours were spent in random swimming than in directional swimming, however, directional swimming accounted for 2/3 of the total distance travelled.

7. The average random swimming rate was 123.3 m/hr and the average directional swimming rate was 515.1 m/hr.

8. Fishes in the backwater areas travelled three times farther than when they were in the eddy areas but the rates were similar.

9. The walleyes showed diel habitat preferences. Between 2100 and 0300 hours they were usually located in backwater areas and between 0900 and 1500 hours they were located in eddy areas.

10. The walleyes rested more at night than during the day, however, when they were active they were more active at night than during the day.

11. The fishes showed four distinct modes in activity at 0230, 0630, 1130 and 1830 with the highest peak at 0230.

12. The walleyes had a preference for water depths of less than 5 m. Almost 95% of the backwater hours and 66.9% of the eddy hours were spent at those depths.

13. There was no schooling or congregating behavior.

14. Rising water levels associated with the spring runoff had no apparent effect on the walleyes' behavior.

15. Three fish were displaced from the capture site and all exhibited homing behavior as defined by Crowe (1962).

16. During the study period the walleyes ranged upstream to Lock and Dam 6 and downstream to Lock and Dam 8, a minimum distance of 56.3 km.

17. The navigation dams did not serve as barriers to walleye migrations.

18. The tag did not drastically effect the fish's behavior.

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APPENDIX

Appendix I - Electronic tracking equipment.

Appendix II - Summary of the random swimming time (hr) in each area by nine radio-tagged walleyes in Navigation Pool 8 of the Upper Mississippi River during spring, 1976.

Appendix III - Summary of the time (hr) spent in directional swimming by nine radio-tagged walleyes in Pool 8 of the Upper Mississippi River during Spring, 1976.

Appendix IV - Summary of the periods of no movement (hr) in each area by nine radio-tagged walleyes in Pool 8 of the Upper Mississippi River during spring, 1976.

Appendix V - Summary of the random swimming distance (m) in each area by nine radio-tagged walleyes in Navigation Pool 8 of the Upper Mississippi River during spring, 1976.

Appendix VI - Summary of the directional distance (m) travelled by nine radio-tagged walleyes in Navigation Pool 8 of the Upper Mississippi River during spring, 1976.

Appendix VII - Summary of the daytime movement behavior of seven radio-tagged walleyes in the tailwater area of Lock and Dam 7 in the Upper Mississippi River during spring, 1976.

Appendix VIII - Summary of the nighttime movement behavior of seven radio-tagged walleyes in the tailwater area of Lock and Dam 7 in the Upper Mississippi River during spring, 1976.

Appendix I. Electronic Tracking Equipment.

Transmitter Specifications

1) Built by: Cedar Creek Bioelectronics Lab
2660 Fawn Lake Drive N. E.
Bethel, Minnesota 55005

2) Construction Details: Ball, I. J. 1972. Field instructions for University of Minnesota Telemetry Equipment. Univ. Minn. 10 p. mimeo.

3) Power Source: 1.4 v mercury cell.

4) Potting material: Scotcheast Resin #5 (XR5235)
Source: Prehler Electrical Insulation Company
2300 North Kilbourn Avenue
Chicago, Illinois 60639

5) Weight of Potted Transmitter: 28 g

6) Weight in Water: 22.2 g

7) Length: 46 mm

8) Diameter: 18 mm

9) Battery Life: 70-80 day ave.

Receiver Specifications

1) Built by: Dr. Thomas Weeks
Biology Department
University of Wisconsin - La Crosse
La Crosse, Wisconisn 54601

2) Construction Details: Kuechle, V. B., R. A. Reichle, and R. J. Schuster. 1971. Construction details for an animal tracking receiver. Univ. Minn. 16 p. mimeo.

Preamplifier and Converter: Vangaurd Model 407
Source: Vangaurd Electronics Labs
196-23 Jamaica Avenue
Hollis, New York 11423

Automobile Radio: Channel Master Model 6280
Channel Master Model 6286

Appendix I (continued):

Beat Frequency Oscillator: Crystal
Source: Crystex
1000 Crystal Drive
Fort Meyers, Florida 33901

Receiver size (mm): Model 6280 135X 154 X 212 mm
Model 6286 190X 115 X 205 mm

Antenna components

Loop: 6 ft of 0.25 in aluminum tubing, 4-40 pf trimmer capacitor.
Range: 100 m

Yagi: Hy-gain Model 64B (230)
Source: Hy-gain Electronics Corporation
Northeast Highway 6
Lincoln, Nebraska 68501
Range: 1600 m

Coaxial Cable: RG58

Appendix II. Summary of the random swimming time (hr) in each area by nine radio-tagged walleyes in Navigation Pool 8 of the Upper Mississippi River during spring, 1976.

	Area															
Fish No.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Other	Total
2							0.28						1.92	0.5			2.7
4	2.4		2.0					0.25								37.62	42.27
5	22.15				14.93											2.66	39.74
5a																	0
6	11.81	0.5	1.55				5.95	1.5	2.09	3.77		0.67		1.75			29.59
7								1.0									1.0
8																9.17	9.17
9	4.67																4.67
11	0.88					5.0		0.2					3.82	1.5	2.0	12.08	25.48
Total	41.91	0.5	3.55	0	14.93	5.0	6.23	2.95	2.09	3.77	0	0.67	5.74	3.75	2.0	61.53	154.62

Appendix III. Summary of the time (hr) spent in directional swimming by nine radio-tagged walleyes in Pool 8 of the Upper Mississippi River during spring, 1976.

Fish No.	Tailwater Area (hr)	Other Areas (hr)	Total (hr)
2	2.13		2.13
4	6.51	14.83	21.34
5	2.52	2.09	4.61
5a			0.0
6	15.08		15.08
7			0.0
8			0.0
9	1.18		1.18
11	6.4	1.75	8.15
Total	33.82	18.67	52.49

Appendix IV. Summary of the periods of no movement (hr) in each area of nine radio-tagged walleyes in Pool 8 of the Upper Mississippi River during spring, 1976.

Fish No.	Area																Total
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Other	
2			0.25		0.75	6.58						1.17	0.22	1.5			10.47
4	2.5		0.42				1.88	0.5	0.4			2.05				64.55	72.3
5	48.14				49.07		0.25									4.42	101.88
5a			0.5			0.25								0.25			1.0
6	12.58	1.75	6.94			3.05	22.29	0.5	3.96	30.18	3.9			12.87			98.02
7							0.25	5.33								0.5	6.08
8			0.25													0.5	0.75
9	2.58		0.25	0.57												36.75	40.15
11	3.51		0.25	0.25		7.08	3.72					2.58	17.35	7.33	1.17	1.75	44.99
Total	69.31	1.75	8.86	0.82	49.82	16.96	28.39	6.33	4.36	30.18	3.9	5.8	17.57	21.95	1.17	108.47	375.64

Appendix V. Summary of the random swimming distance (m) in each area by nine radio-tagged walleyes in Navigation Pool 8 of the Upper Mississippi River during spring, 1976.

Fish No.	Area																
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Other	Total
2							104						78	39			221
4	557		101					121								4166	4945
5	2842				3609											32	6483
5a																	0
6	583	41	245				265	217	104	155		9		197			1816
7								41									41
8																506	506
9	431																431
11	130					914		208					250	145	88	1558	3293
Total	4543	41	346	0	3609	914	369	587	104	155	0	9	328	381	88	6262	47285

Appendix VI. Summary of the directional distance (m) travelled by nine radio-tagged walleyes in Navigation Pool 8 of the Upper Mississippi River during spring, 1976.

Fish No.	Tailwater Area (m)	Other Areas (m)	Total (m)
2	844		844
4	4,188	10,834	15,022
5	3,425	894	4,319
5a			0
6	5,288		5,288
7			0
8			0
9	939		939
11	2,735	402	3,137
Total	17,419	12,130	29,549

Appendix VII. Summary of the daytime movement behavior of seven radio-tagged walleyes in the tailwater area of Lock and Dam 7 in the Upper Mississippi River during spring, 1976.

	Eddy				Backwater				Directional Swimming		Total	
Fish No.	Swimming Time (hr)	Distance (m)	No Movement (hr)	Total Time (hr)	Swimming Time (hr)	Distance (m)	No Movement (hr)	Total Time (hr)	Time (hr)	Distance (m)	Time (hr)	Distance (m)
2	0.28	104	1.17	1.45	1,92	78	0.22	2.14	2.13	844	5.72	1,026
4	2.25	222	0.67	2.92	1.0	203	2.5	3.5	3.73	2,590	10.15	3,015
5	0.0	0.0	0.0	0.0	20.25	3,128	61.53	81.78	4.16	2,599	85.94	5,727
6	13.69	1,126	50.29	63.98	5.67	325	2.33	8.0	5.91	2,412	77.89	3,863
7	1.0	41	5.33	6.33	0.0	0.0	0.0	0.0	0.0	0.0	6.33	41
9	0.0	0.0	0.57	0.57	4.67	431	2.58	7.25	1.18	939	9.0	1,370
11	7.7	1,293	13.04	20.74	3.82	250	7.07	10.89	5.4	2,365	37.03	3,908
Total	24.92	2,786	71.07	95.99	37.33	4,415	76.23	113.56	22.51	11,749	232.06	18,950

Appendix VIII. Summary of the nighttime movement behavior of seven radio-tagged walleyes in the tailwater area of Lock and Dam 7 in the Upper Mississippi River during spring, 1976.

Fish No.	Eddy				Backwater				Directional Swimming		Total	
	Swimming Time (hr)	Distance (m)	No Movement (hr)	Total Time (hr)	Swimming Time (hr)	Distance (m)	No Movement (hr)	Total Time (hr)	Time (hr)	Distance (m)	Time (hr)	Distance (m)
2	0.5	39	8.0	8.5	0.0	0	0.0	0.0	0.0	0	8.5	39
4	0.0	0	0.67	0.67	4.15	651	0.4	4.55	2.78	1,598	8.0	2,249
5	0.0	0	0.0	0.0	10.21	2,595	28.91	39.12	0.45	1,720	39.57	4,315
6	1.0	111	18.18	19.18	7.76	309	12.26	20.02	4.58	1,802	43.78	2,222
7	0.0	0	0.0	0.0	0.0	0	0.0	0.0	0.0	0	0.0	0
9	0.0	0	0.0	0.0	0.0	0	0.0	0.0	0.0	0	0.0	0
11	1.0	62	9.0	10.0	0.88	130	10.51	11.39	0.0	0	21.39	192
Total	2.5	212	35.85	38.35	23.0	3,685	52.08	75.08	7.81	5,120	121.24	9,017

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In reference to the following title(s):

Homing, Swimming Behavior, Range, Activity Patterns and Reaction to Increasing Water Levels of Walleyes ... as Determined by Radio-Telemetry HN Navigational Pools 7 and 8 of the Upper Mississippi River During Spring, 1976 / David Mark Bahr, 1977.

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