GREAT LAKES FISHERY COMMISSION

Project Completion Report[1]

A description of the migratory behavior of steelhead (*Oncorhynchus mykiss*) and longnose suckers (*Castostomus catostomus*) in the Pere Marquette River, Michigan

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A description of the migratory behavior of steelhead (*Oncorhynchus mykiss*) and longnose suckers (*Catostomus catostomus*) in the Pere Marquette River, Michigan

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Introduction

Rainbow trout (*Oncorhynchus mykiss*) were first introduced to the Pere Marquette River in 1887, and were naturalized in this and other Lake Michigan tributaries shortly after initial introduction (Krueger 1985). The migratory form of rainbow trout, steelhead was among the strains established in Lake Michigan tributaries. The popularity of these fish among sport anglers developed much earlier than the more recently introduced chinook salmon (*O. tschawytscha*) and coho salmon (*O. kisutch*).

Steelhead have been most successful in those rivers that provide unobstructed passage from the lake to spawning and rearing habitats in upstream river reaches, such as the Pere Marquette River and the Little Manistee River. Spawning habitats must have an abundance of large gravel and cobble substrates, and rearing habitats must have cool water (< 25 C) available year round. The predominant life history form of steelhead expressed in Lake Michigan tributaries is one that includes two years of growth in the river after hatching, followed by a spring migration of smolts to the lake, and then three years of growth in the lake before returning to spawn in the spring of the fifth year. Other variants are expressed in some Lake Michigan tributaries, including some fish that out-migrate after one year of stream growth and others which grow three years in the stream before out-migrating. Lake growth ranges from 1 to 5 years. One other variant has been introduced in the past 20 years in the form of the Skamania strain. This fish also spawns in the spring (March - May), but unlike the original strain, this strain migrates into its spawning stream in late summer preceding spawning. The original or winter strain delay migration to its spawning stream until late fall or early spring of its spawning year (October - April).

Several activities in Lake Michigan tributaries may diminish the potential of streams to produce steelhead, including obstructions to upstream or downstream migration, changes in the thermal regime of the river, and occlusion of spawning gravels with fine sediments. Migration obstructions such as hydroelectric dams are known to prevent steelhead from reaching the most suitable habitats for spawning in some watersheds, such as the Muskegon watershed and the mainstem of the Manistee River. In addition, some obstructions have been placed in rivers specifically to obstruct migration of another anadromous species, the sea lamprey (*Petromyzon marinus*). A two-meter vertical weir was placed in the Betsie River in 1974 following the removal of a hydroelectric dam at Homestead, near Benzonia specifically to prevent invasion of sea lamprey adults into upstream habitats of the Betsie River. Steelhead and other migratory salmonids are capable of passing over this obstruction, and have been moderately successful at colonizing upstream reaches of the Betsie. Barriers such as this also block the passage of native potamodromous species that do not have the leaping ability of salmonids, including northern pike, burbot, many sucker species, and smaller species such as trout-perch. Alternative barriers that would differentially block movement of sea lamprey, but allow passage of other species are more appropriate to maintaining the integrity of the Great Lakes fish assemblages vertical barriers such as the one on the Betsie River.

One alternative barrier that has the potential to be more selective is an electric barrier, coupled with a fish ladder or passage channel that would allow passage of most fish except lampreys. Electric barriers have been successful in limiting sea lamprey migration to and from spawning habitats (Bergstedt and Seelye 1992). A consequence of using a traditional electric barrier to limit sea lamprey spawning migration was incidental mortality suffered by steelhead and other fish which were migrating to upstream spawning habitat (Dahl and McDonald 1980). Traditional electric barriers used 115-volt AC with DC fish diversion leads (Bergstedt and Seelye 1992).

Recent advances in electric barrier technology have reduced the mortality of adult steelhead and steelhead smolts that encounter an electric barrier (Rozich 1989). The improved barriers used pulsating DC incorporated with modern electronics to provide a consistent and uniform field, oriented such that a fish moving parallel to stream flow always intercepted the maximum voltage gradient. They seemed to be effective at preventing upstream migration of adult sea lampreys. However, the barriers would not pass adult steelhead migrating upstream without the aid of an alternative route free of an electrical field.

Barriers that are impassable to migrating adult steelhead will have a detrimental effect on the viability of the steelhead population and the river fishery. Barriers such as hydroelectric dams that did not provide adequate passage for migrating anadromous steelhead produced significant decreases in adult returns (Raymond 1979). Part of the losses was attributed to mortality suffered by steelhead smolts, which were killed by turbines in their downstream migration. However, decreased flows delayed upstream migration by adults and reduced the amount of spawning habitat available upstream of the dam. The delayed migration of adult anadromous steelhead not only reduced the number of steelhead embryos produced, but also delayed their development, and resulted in reduced condition of smolts and increased mortality suffered by smolts during their downstream migration. The increased residence time of adult steelhead below the barrier may have used excess energy reserves necessary for the continued migration to spawning habitat, resulting in a decrease in the number of steelhead that successfully spawn.

Little is known about the behavioral response of adult steelhead to any barrier to upstream migration and the associated energetic losses that they incur while searching for passage around the barrier. Palmisano and Burger (1988) used an electric barrier to guide chinook salmon adults into a side channel where a weir and trap were installed to capture the fish. The barrier seemed to work effectively and the salmon found their way up the alternate channel without the electric barrier. However, they did not record the delay encountered by these fish as they sought the alternate channel. Even less work has been published on the behavioral response of adult steelhead to electric or other barriers and the efficiency with which they find alternative routes of passage. Studies on other salmonid species (e.g., Fleming and Reynolds 1991) should provide insights into what behavior might be expected for steelhead.

The similarities in migration timing of longnose suckers (*Catostomus catostomus*) and steelhead make the two species a likely combination for migratory examination. Steelhead and longnose suckers share spawning migrations during the first half of the year (primarily February through May) in Michigan rivers. Steelhead migrations are well studied in their native streams and rivers tributary to the Pacific basin, and throughout their range in North America. Successful introductions of steelhead into the Great Lakes region have created opportunities to examine the interactions of non-native fish with native fish species such as the longnose sucker. The study of steelhead and longnose sucker migrations in the Pere Marquette River provides a unique opportunity to examine the movement and behavior of two fish species in a Michigan river where there are no physical barriers to migration for either species.

The operation of a proposed electric sea lamprey barrier in the Pere Marquette River may cause delays or cessation of spawning migrations in fish species that migrate up the river during the electric barrier operation. Previous operations of an electric lamprey barrier in the same location as the proposed barrier did not allow steelhead to successfully migrate around or through the barrier (Rozich 1989). An electric lamprey barrier, combined with a fish ladder has been proposed for installation in the Pere Marquette River. Yet little is known about the timing, duration and speed migration of steelhead and longnose suckers in the Pere Marquette. This information is vital in order to allow effective operation of the electric barrier and fish ladder. The barrier needs to be in operation throughout the duration of lamprey migration in the river, yet it should not operate beyond this necessary period in order to minimize its effect on other fishes. The spring migrations of steelhead and longnose suckers overlap that of sea lampreys in the Pere Marquette River. Furthermore, information on the speed and duration of the spawning migration of steelhead and longnose suckers is needed in order to determine if the electric barrier has an effect on the number and timing of non-target spawners that pass upstream after the barrier goes into operation. Finally, there is little available information on the importance of fall or winter migrating steelhead in the Pere Marquette. Yet if fall or winter migrating steelhead is an important component of the migratory run, it has the potential to minimize the impact of the electric barrier on the steelhead fishery because the barrier will not need to operate during fall months.

While the passage of sucker species was not considered as a design element of the proposed electrical barrier, they are indeed an exploited species in the Pere Marquette River. A few weeks after the winter river ice has melted, fishers can be found in abundance along the banks of the river near Branch, Michigan, downstream to the terminus of the river, pursuing migratory suckers well into the month of April. There is also an event called "Sucker Festival" that celebrates the recreational sucker fishery on the Pere Marquette River. The operation of the electrical barrier may adversely affect future populations of migratory suckers in the Pere Marquette River. Little is known of the relationship between the longnose sucker and Pere Marquette River ecosystem. Future radio telemetry studies in the Pere Marquette River will provide a better understanding of the electrical barrier's potential effect on migratory species other than steelhead, and possibly provide a clearer understanding of the longnose sucker's role in the Pere Marquette River.

This study is designed to provide quantitative descriptive data on the migration of adult steelhead and longnose suckers into the Pere Marquette River from which can be used to evaluate the potential effect on their respective spawning migrations from the operation of the proposed electrical sea lamprey barrier. The proposed electric barrier on the Pere Marquette River will be located near Custer, Michigan. Our objectives are to:

1) Describe the timing of migration initiation by adult steelhead and longnose suckers by describing the temporal distribution of steelhead capture in the reach immediately upstream of Pere Marquette Lake and by describing the date of arrival of radio-equipped fish at the Custer weir site.

2) Determine the speed of upstream movement by adult steelhead and longnose suckers from the old US 31 bridge at Ludington to Custer and from Custer to Bowman Bridge;

3) Determine the percent passage of radio-tagged fish at Custer.

Two aspects of adult movement will be evaluated: movement rates of fish over large distance (10^3 m), and the proportion of migrants that pass upstream of the barrier.

Methods

Fish Capture

Steelhead and longnose suckers were collected in the lower Pere Marquette River for use in the telemetry study of fish movement from February to May, 1997 and from November, 1997 to April, 1998. We used two methods of capture, hook-and-line fishing and fyke nets in order to obtain fish for our study. Hook-and-line fishing was used within an 8 km reach of the river immediately upstream of Pere Marquette Lake, and was used continuously throughout the study (Figure 1). Fyke nets measuring 122 by 183 cm with a 5 cm stretch mesh, were fished at various locations within 1 km upstream of Pere Marquette Lake during the spring 1997 field season. The mouth opening of the fyke nets measured 100 cm by 122 cm, and the nets were 33 meters long. By the end of the spring 1997 field season, a location 0.25 km upstream of Pere Marquette Lake was chosen, where three fyke nets placed adjacent to each other blocked almost the entire width of one channel of the river (Figure 2). The adjacent net configuration was used for the spring 1998 field season. The fyke nets were used from February to April and were placed as soon as ice conditions permitted their use in the river. Fyke nets were not used in the fall months (October – December), due to heavy amounts of leaf material in the river. The nets were checked daily for the presence of steelhead and longnose suckers. All fish captured in the nets were identified, and the length and weight were determined prior to their release.

Radio tag implant procedure

Steelhead and longnose suckers larger than one kilogram were selected for radio tag implants. Collected fish suitable for implants were anesthetized in a tank filled with tricaine (MS-222) dissolved in river water. Weight, length, sex, and time and location of capture were recorded from the fish when they were no longer able to maintain an upright posture within the anesthetic tank. The sex of the steelhead was determined by several factors: the presence of a pronounced kype (indicative of males); the ease of scale

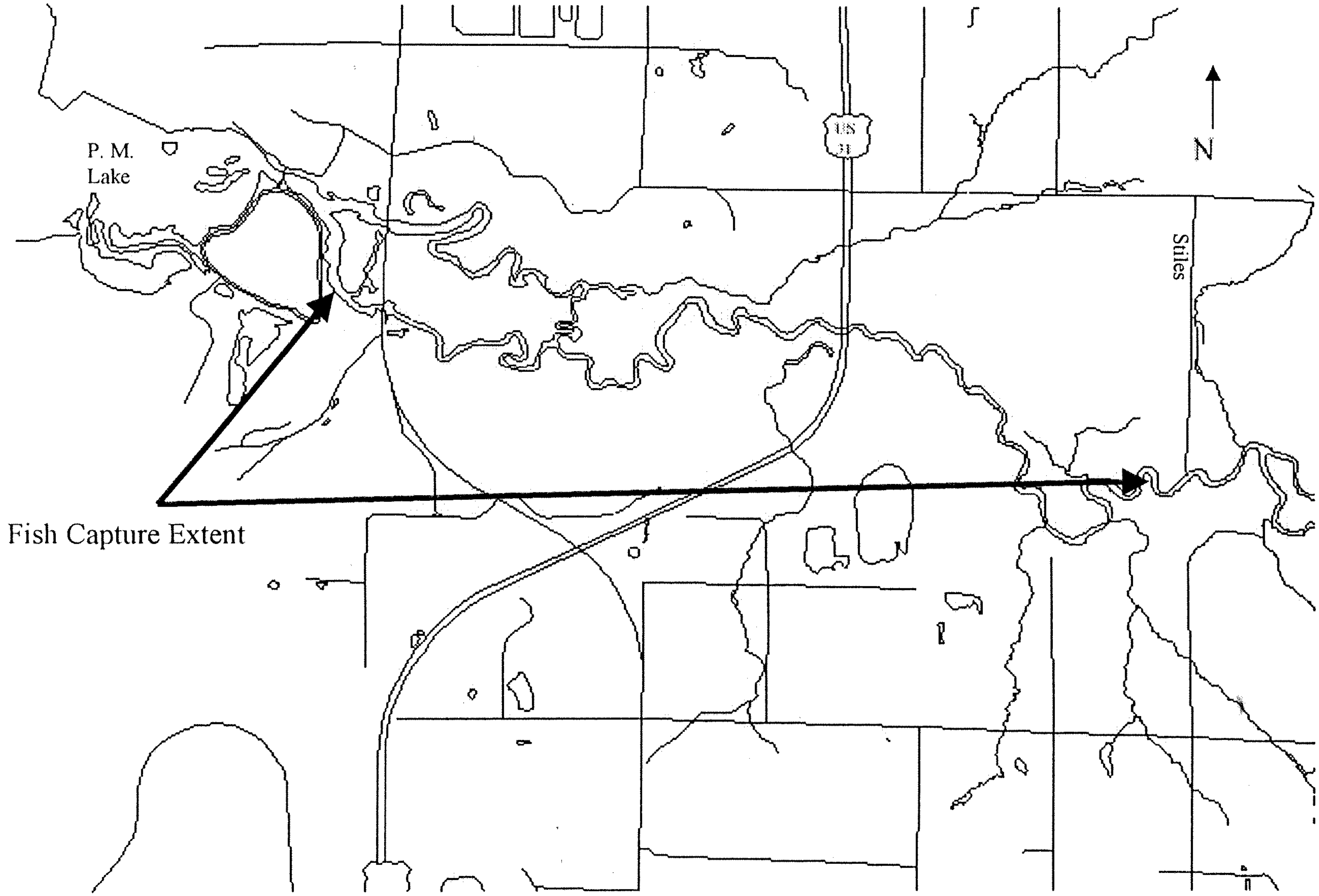

Figure 1. Hook-and-line steelhead capture area in the Pere Marquette River 1997-1998.

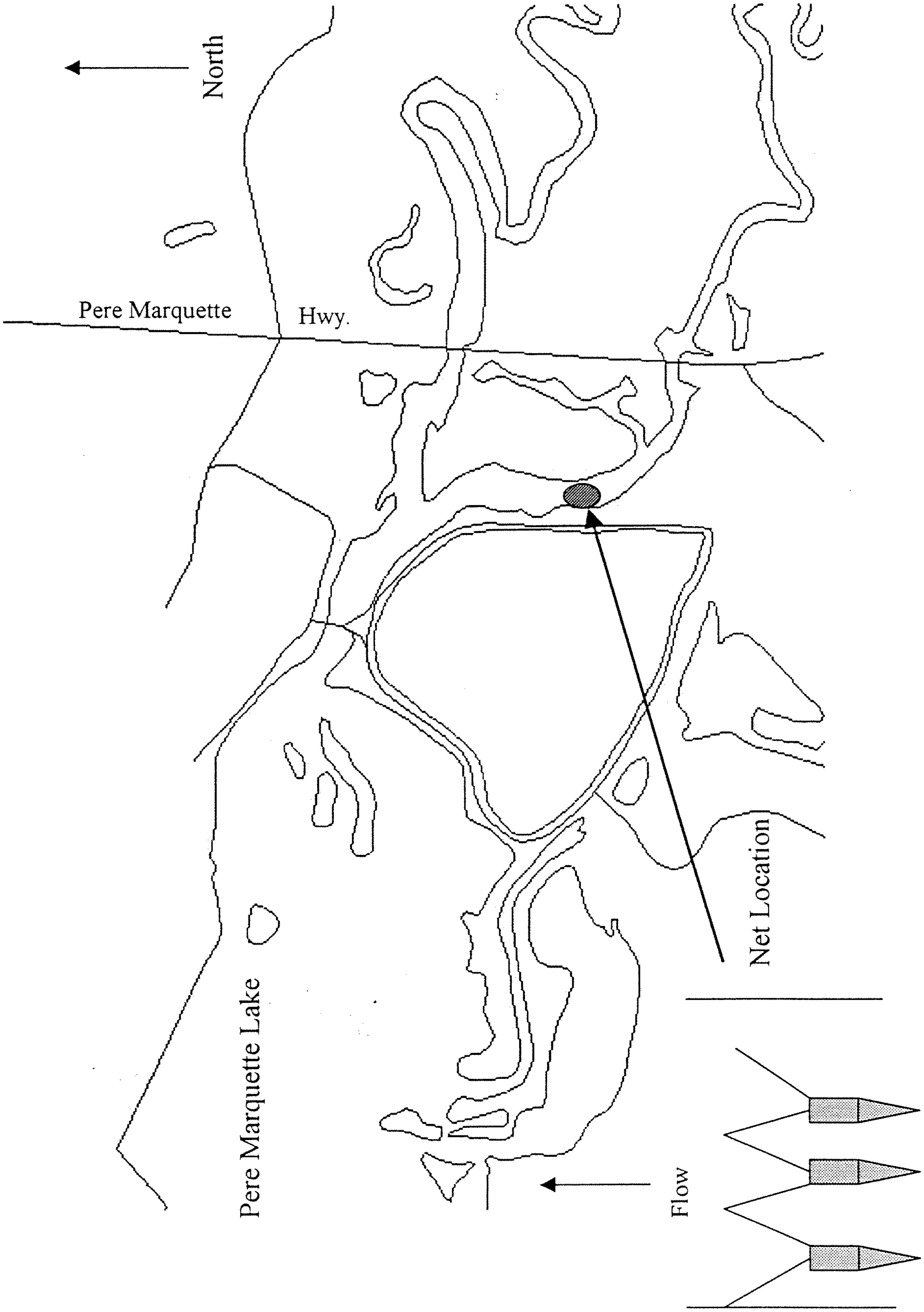

Figure 2. Fyke net set location in the Pere Marquette River 1997 and 1998.

removal (scales detach with little effort indicates female, not readily detachable indicative of male); and by visual inspection of the gonads during the surgical implant procedure. The sex of longnose suckers was determined by a visual inspection of the gonads during the surgical implant procedure, and the presence of pronounced lateral band coloration and tubercles on the anal fin (indicative of males). The fish were placed inverted in a V-trough surgical table lined with indoor-outdoor carpet, and scales were removed from a longitudinal row for 4 cm along the abdomen approximately 2 cm posterior of the pelvic fins, and from a small area adjacent to the dorsal fin. A 4 cm long incision was made in the abdomen region where the scales were removed and the fish were implanted with a LOTEK Engineering, Inc. CFRT-7A digitally encoded radio transmitter into the peritoneal cavity. The radio tags measured 16.0 mm in diameter by 83.0 mm long, and weighed 29 gm in air and 12.8 gm in water. An incision the width of a surgical blade was made posterior to the larger incision and the radio transmitter antenna was drawn through. The radio tags were rated to last for 282 days at a 5-second burst rate. The incisions were closed with 000 gut suture and a numbered floy tag was inserted in the area where the scales were removed adjacent to the dorsal fin. The gills of the fish were irrigated with river water during the surgical procedure. The radio-tagged fish was transferred to another tub with river water where the fish remained until it maintained an upright posture within the tub. The radio tagged fish was released as close to the point of capture as possible. Fish captured in the fyke nets were released approximately 200 m upstream of the nets.

Monitoring movements of radio-tagged fish

The movements of steelhead radio-tagged during the spring 1997 field season were monitored at the site of the proposed electrical barrier in Custer, Michigan (Figure 3). Radio tagged fish were monitored using an SRX-400 receiver with W-17 firmware that allowed for scanning of multiple channels and numerous frequencies developed by LOTEK. Two yagi antennae were mounted 90 m apart to detect direction of movement, the date and time of arrival of a radio-tagged fish into the reception area, and the date and time of departure when the radio-tagged fish left the reception area. The receiver was programmed to scan antennae sequentially and for each check of an antenna, the receiver

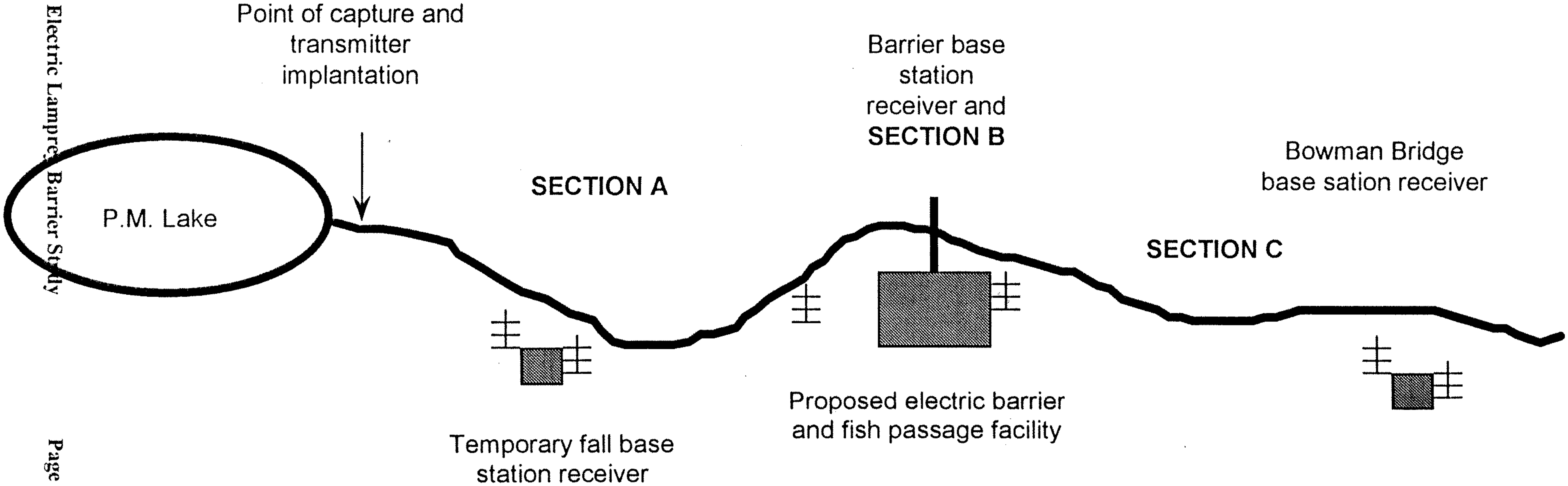

Figure 3. Spatial arrangement of 1997 and 1998 radio telemetry study sections in the Pere Marquette River, Michigan.

recorded the presence of all coded transmitters that were in the listening range of the antenna. The use of coded transmitters increased the time resolution possible for detecting movements of individual fish. All data were logged in the memory of the receiver, and then downloaded periodically to maintain a continuous record. The Michigan Department of Natural Resources provided a power supply and a structure to house the receiver.

The movements of fish radio-tagged during the 1997-98 field season were monitored by use of three fixed (base) stations, each equipped with a scanning, continuously recording receiver and a series of fixed-direction antennae. A portable base station was positioned approximately 12 km downstream of the proposed electric barrier on private property (43° 55' 9.5"N, 86° 21' 33.7" W, WGS-84), on the north side of the river, near the end of Stiles Road. The portable base station consisted of a LOTEK SRX-400 receiver with W-17 firmware and a weatherproof secured enclosure. A solar panel was used to supply power to the receiver at the remote site. Two yagi antennae were mounted 20 m apart to detect direction of movement, the date and time of arrival of a radio-tagged fish into the reception area, and the date and time of when the radio-tagged fish left the reception area. The primary purpose of using the downstream base station was to gain more information about the movement of fall radio-tagged steelhead. The portable base station was left at this location until radio-tagged fish were detected at the Custer site. The portable base station was relocated approximately 40 km upstream of Pere Marquette Lake to a site 2 km upstream of the Bowman Bridge public access site that marks the downstream end of a reach that contains much of the spawning habitat used by steelhead in the Pere Marquette River. The portable base station remained at this location for the remainder of the study. A portable hand-held SRX-400 receiver was used to verify that each radio tag was functioning prior to and after surgical implantation, and to verify the location of the radio-tagged steelhead downstream of the fall-placed base station.

Assessment of adult steelhead and longnose sucker passage

Three study sections were used as a means of assessing movements of radio-tagged fish to provide base-line data for comparison with a follow-up study after the electric lamprey weir is in operation (Figure 3). Some of the key features of the spatial arrangement were:

-Section A (from a point approximately 20 km downstream of the barrier to a point directly downstream of the barrier) is unaffected by the barrier operation. Thus, rates of fish movement and percent of fish passing through this zone act as a true control or reference site for the entire duration of this study and the follow-up study.

-Section B (within the detection zone including the barrier and extending directly downstream from the barrier) provides a control during years the barrier was not operating and provides the data needed for estimating the impact of the barrier during years of barrier operation.

-Section C (approximately 28 km upstream of the barrier) provides for a true control during years when the barrier is not operating. During years of barrier operation, data from this zone allows us to determine if fish compensate movement rates if the barrier facility delays their migration. If no compensation is observed, data from this zone will also serve as a control.

The primary variables of interest are 1) rate of passage through each section and 2) percent of fish traversing the entire sections' length. The rate of passage is an important variable because this is used to determine if the barrier/fish ladder delay the fish's migration to upstream sections. Likewise, the percent of fish traversing each section is used as a measure of the number of fish unable to traverse the barrier/fish ladder and "balking" or dropping back out of the section.

The time for passage from the release location of the radio-tagged fish to the downstream antenna at the barrier was used to calculate movement rates through Section A. To estimate fish movement rate through the barrier section (Section B), we measured the time required for a fish to move from the lower antenna to the time it arrives immediately upstream of the barrier. For the final movement rate estimate (Section C), we used the time from the last record of the fish being immediately upstream of the barrier to the time it is first detected by the upstream base station. A determination of the direction of movement was necessary to assess movement rates through each section. A minimum of two records from one base station was necessary to determine the direction of movement for a radio-tagged fish on any given day. Radio-tagged fish whose direction of movement could not accurately be determined from the record of the base station receivers, were not used in the speed of movement through section analyses. From these arrangements, we were able to determine the dates when much of the migration of steelhead and longnose suckers occurs, as well as the time required for transit between the fixed base stations and the proportion of fish that completed each segment of the migration.

Similarly, passage through a section was determined as the number of radio-tagged fish that reached the upper limit of a section as a percent of those that moved upstream of the lower (downstream) limit of the section. A power analysis was performed on the 1998 radio telemetry data using PASS 6.0 to determine what sample size ($\alpha = 0.05$, $\beta = 0.90$) would be adequate to detect a migratory delay of 7 days that could be caused by the operation of the proposed electrical sea lamprey barrier. The power analysis was performed on fish that were radio-tagged from January to April 1998. Fall radio-tagged fish could remain in the river for a longer period of time and bias power analysis by increasing the mean time to pass through the Custer reception area.

Environmental monitoring

Because weather, stream discharge and stream temperature data are likely to be important cues in the migratory process, we monitored stream discharge, and stream temperature. Stream discharge data was obtained from the U.S. Geological Survey for the gauge station at Scottville. Stream temperature was monitored by means of Onset Hobo electronic thermographs: one located at the old U.S. 31 bridge in Ludington, one at Custer, one at the Indian Bridge public access on Reek Road, one at the Upper Branch public access site, and one at the public access site located in Baldwin.

Results

Fish Capture

Much of the effort in the spring, 1997 spawning run went into developing fish capture systems that were effective in the unique habitats of the lower Pere Marquette River. During the spring, 1997 migration, 18 steelhead were captured and we implanted digitally encoded radio transmitters into 14 steelhead that were suitable for surgical implantation (Table 1). Six of the 14 steelhead were caught by hook-and-line and eight were caught in fyke nets. In the fall 1997 - spring 1998 migration, we implanted transmitters into 54 steelhead and 33 longnose suckers. Ten of the 54 steelhead were captured and implanted in fall 1997 (24 October to 16 December), and all of the fall radio-tagged fish were captured by hook-and-line. The longnose suckers were captured in fyke nets. About half of the steelhead implanted with radio tags in the spring 1997 field season and 36% in the spring 1998 field season were captured by hook-and-line.

Table 1. Catch of steelhead and longnose suckers used in radio telemetry study on Pere Marquette River, Michigan, 1997 – 1998.

Period / Species	No. fish Caught	No. fish Tagged	Mean length (mm) (range)	Mean weight (kg) (range)	No. Males	No. Females	No. radio-tagged fish caught by Hook	Fyke
Spring, 1997 Steelhead	18	14	650.6 (270 - 800)	3.7 (0.8 - 5.8)	8	6	6	12
Winter - Spring 1997 - 1998 Steelhead	84	54	679 (535 - 800)	3.2 (1.2 - 4.6)	16	38	26	28
Longnose sucker	200	33	491 (420 - 550)	1.6 (1.0 - 2.0)	18	15	0	33

The total fish catch in fyke nets for 1997 (25 net-days of effort from 11 March to 6 April), was 456 fish including bowfin (*Amia calva*), and sucker species (*Catostomus catostomus, Catostomus commersoni, Moxostoma anisurum, Moxostoma erythrurum,* *Moxostoma macrolepidotum, Moxostoma valenciennesi*) that dominated the catch (Table 2). The total fish catch in fyke nets for 1998 (49 net-days of effort from 23 February to 20 April), was 2,801 fish including many of the same species that were caught in the 1997 catch (Table 2). The fyke nets were removed from the river for a seven-day period (10 March to 17 March 1998), when the river froze over. Rockbass (*Ambloplites rupestris*) dominated the 1998 catch with 1,521 fish being caught in the nets.

Table 2. Fyke net catch data for the spring 1997 and spring 1998 field seasons.

	Number of Fish Caught	
Scientific name	**1997**	**1998**
Ambloplites rupestris	12	1521
Ameiurus melas	0	10
Ameiurus nebulosus	0	1
Amia calva	162	198
Catostomus catostomus	20	200
Catostomus commersoni	69	444
Cyprinus carpio	0	2
Dorosoma cepedianum	0	1
Esox lucius	36	111
Ictalurus punctatus	0	2
Lepomis gibbosus	0	1
Lota lota	1	0
Micropterus dolomieu	0	8
Moxostoma anisurum	89	40
Moxostoma erythrurum	16	12
Moxostoma macrolepidotum	10	80
Moxostoma valenciennesi	2	0
Oncorhynchus kisutch	4	0
Oncorhynchus mykiss	13	70
Perca flavescens	2	39
Petromyzon marinus	4	45
Pomoxis nigromaculatus	5	9
Salmo trutta	9	4
Stizostedion vitreum	2	3
Total Catch	**456**	**2801**

Timing of Migration

During the spring 1997 field season, radio-tagged steelhead were observed moving upstream through the Custer reception area from 23 March to 4 April (Figure 4). Radio-tagged fish were observed moving upstream through the Custer reception area from 6 January to 17 April 1998, for the fall 1997 to spring 1998 field season (Figure 5). However, much of the upstream movement occurred over a brief period, from 25 March to 17 April. The period was more extended than in 1997, perhaps because river temperature increased earlier in 1998 and because the river became ice-free nearly one month earlier than in 1997. In both years, temperature and discharge data suggest that fish are moving in response to a sudden increase in discharge and water temperature (Figures 4 and 5). Radio-tagged steelhead and longnose suckers were recorded at the Custer base station when water temperatures were greater than 3.5°C and stream flows were greater than 736 cfs, for 1997 and 1998.

Speed of Movement Through Base Station Reception Areas

Typically, when steelhead arrived at the Custer station (Section B), they moved through the station quickly. The mean duration of passage through the 150 m section for the spring 1997 field season was 6 minutes (n = 8, σ^2 = 26.1 minutes), for upstream-bound fish and 7 minutes (n = 4, σ^2 = 35.5 minutes), for downstream-bound fish (kelts returning to the lake after spawning). Six of the eight fish that arrived at Custer passed upstream through the monitored section quickly (less than 1 day), and arrived within a 7-day period from 23 March to 4 April. This suggests that the fish were responding to similar cues to initiate upstream migration and that they can make the passage from near Pere Marquette Lake to Custer in one day or less. The mean duration of passage for the fall 1997-spring 1998 field season was 32 minutes (n = 26, σ^2 = 5221.8 minutes), for upstream-bound fish and 11 minutes (n = 9, σ^2 = 178 minutes), for downstream-bound fish. One steelhead took 11 hours and 12 minutes to move downstream through the Custer reception area. Data from this fish was not used in the calculation of downstream movement time because it was felt that the longer duration was atypical when compared to the other 9 fish that were moving downstream. There were seven radio-tagged steelhead recorded at

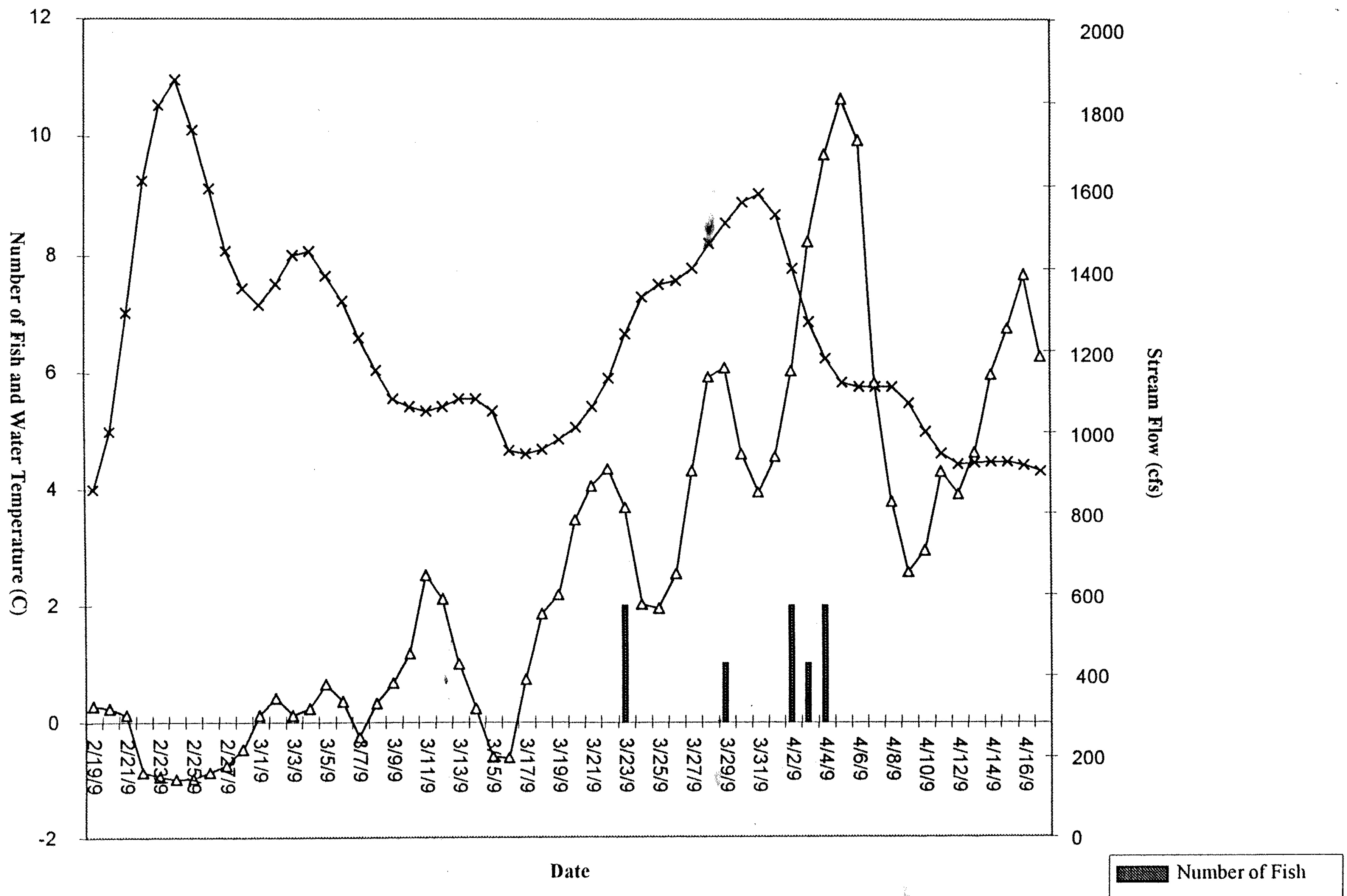

Figure 4. The number of radio-tagged steelhead recorded at Custer 1997.

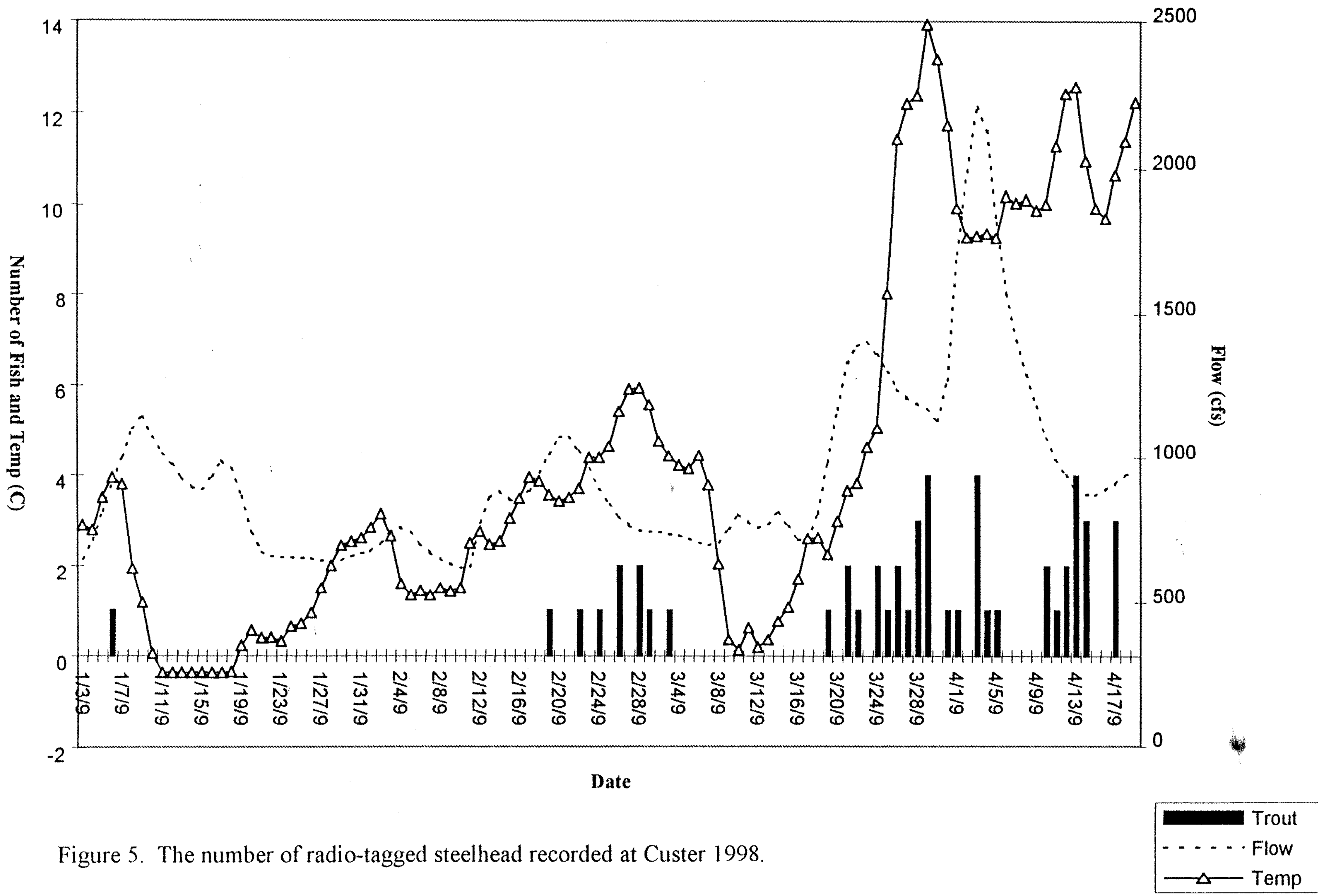

Figure 5. The number of radio-tagged steelhead recorded at Custer 1998.

Custer who's direction of travel could not be determined by use of only the Custer base station data. One of the seven fish was within receiver range for 10 days. All but one of the steelhead that reached Custer moved upstream of Custer. There was no significant difference ($t = 1.8$, $p < 0.05$, $\alpha = 0.05$, $df = 27$), in the time of upstream passage between the spring 1997 and fall 1997-spring 1998 data.

The mean number of days between release of marked fish and arrival at Custer was 7.8 days ($n = 8$, $\sigma^2 = 122.9$ days), with a range of 0.5 to 33 days for steelhead radio-tagged during the spring 1997 field season (Table 3). We did not have a second base station to monitor during the spring, 1997 migration, and have no data on passage at the Bowman station. The mean number of days between release of marked fish and arrival at Custer was 18 days ($n = 26$, $\sigma^2 = 709.5$ days), with a range of 2 to 126 days, for fall 1997 to spring 1998 radio-tagged steelhead. However, if the fish tagged in fall, 1997 are excluded, the mean number of days between release of marked fish and arrival at Custer was 11 days ($n = 24$, $\sigma^2 = 160.8$ days), with a range of 2 to 51 days. There was no significant difference in the mean time from release to arrival at Custer between the spring 1997 and spring 1998 radio-tagged steelhead ($t = 2.05$, $p < 0.05$, $\alpha = 0.05$, $df = 29$).

Table 3. Number of fish arriving at base stations and time taken to reach base station for steelhead in 1997 and 1998 and longnose suckers in 1998.

No. fish implanted	No. fish at Custer	Mean no. days from release to Custer (Section A)	No. fish at Bowman	Mean no. days from Custer to Bowman (Section C)
Spring, 1997 Steelhead				
14	8	7.8 (0.5 - 33)	not monitored	
Fall 1997 to Spring, 1998 Steelhead				
54	34	18 (2 - 126)	14	9 (1 - 28)
Longnose suckers				
33	8	16.6 (2 – 24)	0	

The mean number of days between leaving Custer and arriving at the Bowman Bridge base station was 9 days (n = 10, $\sigma^2 = 80$), with a range of 1 to 28 days. The mean time radio-tagged fish moved through the 600 m section was 22 minutes (n=7, $\sigma^2 = 291$ minutes), going upstream and 186 minutes (n=1) in a downstream direction.

Three of the 10 fish that were radio-tagged during the fall 1997 portion of the 1997-98 field season were recorded at the temporary base station located downstream of Custer. Five of the seven other steelhead were not found in the river one to three days after radio tag implantation, and two of the seven steelhead were observed, using a portable receiver, approximately 0.25 km upstream of Pere Marquette Lake one day after they had been surgically implanted with a radio tag. Two of the three fish recorded at the temporary base station were later recorded at the Custer base station. There were no fall radio-tagged steelhead recorded at the Bowman Bridge receiver site.

The mean duration of passage for longnose suckers through the Custer reception area was 20 minutes (n = 8, $\sigma^2 = 261.6$ minutes) for upstream-bound fish and 90 minutes (n = 1) for downstream-bound fish. The mean number of days between release of tagged suckers and arrival at Custer was 16.6 days (n = 8, $\sigma^2 = 84.2$ days), with a range of 2 to 24 days. There was no significant difference in the time of passing through the 150 m long Custer station between the radio-tagged suckers and steelhead ($t = 2.04$, $p < 0.05$, $df = 32$).

Percent Passage Through Base Station

In the spring, 1997 migration, at least 57% of the marked steelhead passed upstream of the Custer barrier location (Table 3). At least 63% of the marked steelhead including the steelhead that were radio-tagged in the fall, passed by the Custer station in the spring 1998 field season. The Bowman station recorded 26% passage in the spring 1998 field season.

At least 24% of the marked longnose passed by the Custer station (Table 3). Analysis of small-scale movements of steelhead and longnose suckers was not necessary in the vicinity of the Custer base station due to the short time of passage through the reception area for each species. Radio-tagged longnose suckers were not recorded at the Bowman Bridge base station. Ten of the 33 radio-tagged longnose suckers were presumed dead after they had been located repeatedly at their release location for one month or longer.

Determination of Adequate Sample Size for Steelhead

A power analysis was performed on the time of upstream passage from release through the Custer reception area for 24 steelhead that were radio-tagged from January through April. The purpose of the power analysis was to determine what sample size would be adequate to detect upstream migratory delays of 3, 6, 7, and 9 days at varying alpha and beta levels (Table 4). The time unit of minutes was used to standardize the data used in the power analysis, since many of the fish passage times through the vicinity of the Custer weir were measured in minutes. The mean travel time from time of release to passage through the Custer reception site was 16915.12 minutes (11.75 Days) with a standard deviation of 18133.75 minutes (12.59 Days). The power analysis indicated that at least 30 steelhead would have to be recorded moving upstream at the Custer base station for an alpha of 0.05 and a power of 0.9 to detect a 7 day delay in upstream movement. Because 44 steelhead were radio-tagged and released during the spring 1998 field season, and 24 were recorded moving upstream at Custer, the actual number of steelhead that would need to be implanted with a radio transmitter to detect a 7 day delay for at least 30 steelhead at Custer is 55. Power analyses were not performed on the spring 1997 data due to the small sample size (Eight steelhead recorded moving upstream through Custer).

Table 4. Necessary sample size at Custer to detect an upstream migration delay of 3, 6, 7, and 9 days at alpha levels of 0.01,0.05 and 0.1 and, power levels of 0.80, 0.90, and 0.99 for 24 steelhead passing through the Custer reception site from January to April 1998. Multiply necessary sample size by a factor of 1.83 to determine the number of fish that must be implanted in order to yield the necessary sample size.

	Necessary Sample Size to Detect Delay of:			
α=	3 Days	6 Days	7 Days	9 Days
	Power = 0.80			
0.01	180	47	36	23
0.05	111	29	22	14
0.10	81	21	16	10
	Power = 0.90			
0.01	230	61	45	29
0.05	153	40	30	19
0.10	117	30	23	14
	Power = 0.99			
0.01	383	99	73	46
0.05	279	71	53	33
0.10	230	59	43	27

Determination of Adequate Sample Size for Longnose Suckers

A power analysis was performed on the time of upstream passage from release through the Custer reception area for eight longnose suckers that were radio-tagged from January through April 1998 (Table 5). The mean travel time from time of release to passage through the Custer reception site was 24683.26 minutes (17.14 Days) with a standard deviation of 13332.17 minutes (9.26 Days). The power analysis indicated that at least 18 longnose suckers would have to be recorded moving upstream at the Custer base station for an alpha of 0.05 and a power of 0.9 to detect a 7 day delay in upstream movement. Because 33 longnose suckers were radio-tagged and 8 were recorded moving upstream at Custer, the actual number of longnose suckers that would need to be implanted with a radio transmitter to detect a 7 day delay for at least 18 longnose is 75.

Table 5. Necessary sample size at Custer to detect an upstream migration delay of 3, 6, 7, and 9 days at alpha levels of 0.01,0.05 and 0.1 and, power levels of 0.80, 0.90, and 0.99 for 8 longnose suckers passing through the Custer reception site from January to April 1998. Multiply necessary sample size by a factor of 4.123 to determine the number of fish that must be implanted in order to yield the necessary sample size.

	Necessary Sample Size to Detect Delay of:			
α=	3 Days	6 Days	7 Days	9 Days
	Power = 0.80			
0.01	103	27	20	13
0.05	69	18	14	9
0.10	55	15	11	7
	Power = 0.90			
0.01	131	34	26	16
0.05	92	24	18	11
0.10	75	20	15	9
	Power = 0.99			
0.01	211	55	41	25
0.05	161	42	31	19
0.10	139	36	27	17

Discussion

Timing of Migration

A pattern of initiation of upstream migration has been established from two successive years of observing radio-tagged fish in the Pere Marquette River. It appears that the timing of migration initiation is tied to increased water temperature and subsequent increased stream flows. The shorter duration of upstream migration in 1997 than in 1998 is probably due to the colder water temperatures during the months of January and February. Water temperatures were less than 3.5°C in January and February 1997, and water temperatures exceeded 3.5°C for periods in January and February 1998. Steelhead are known to initiate migration over a range of temperatures and have been reported to spawn in water temperatures from 5.0-12.5°C (Beschta et al. 1987). Longnose sucker migrations have been known to intensify as a result of increasing temperatures in a Wisconsin stream (Bailey 1969), and Geen et al. (1965) have suggested that rising stream temperatures may be associated with the onset of upstream migration. Even though the duration of upstream migration differed from 1997 to 1998, the peak of upstream migratory activity appears to be similar for the 1997 and 1998 field season, occurring during the last two weeks of March and the first two weeks of April.

Speed of Movement Through Base Station Reception Areas

Radio-tagged fish are moving quickly upstream through the Custer and Bowman base stations. The short passage time through the base state reception areas indicates that the base stations are located in an area that does not provide adequate spawning habitat for steelhead and longnose suckers. The variability associated with the mean number of days from release to appearance at Custer necessitated a power analysis to determine adequate sample sizes for future movement analyses in the vicinity of the electric barrier. The variability could be caused by a small sample size or bias incurred by radio-tagged fish that remain in the river for a long period following tag implant (greater than two weeks), prior to upstream migration.

Percent Passage Through Base Station

The percentage of radio-tagged steelhead passing through the Custer base station increased from 1997 to 1998. The increased passage of radio-tagged steelhead may be the result of a larger sample size (n = 54) for 1998. A larger sample size increases the chance of a radio-tagged fish surviving surgical implantation, migrating upstream and passing Custer. The increased passage may also be the result of improved monitoring methods. The spring 1997 field season served as an evaluation period to install and evaluate the Custer base station. It is possible that radio-tagged steelhead may have passed undetected through the Custer reception area during this evaluation period.

The percent passage of radio-tagged longnose was much lower than the percent passage of the tagged steelhead. Longnose suckers were not as successful at reaching the Custer station. It is possible that the spawning habitat for longnose suckers is downstream of the habitats used by steelhead, and this may account for their absence at Bowman. However, at least 30% of the longnose suckers implanted with radio tags did not survive long enough to migrate to Custer. The suckers may have suffered higher mortality or impairment from the radio transmitters, which were larger, relative to the fish size than they were for steelhead. Winter (1996) suggests that fish should not be equipped with transmitters that weigh more than 2 % in air of the fish's weight out of water. The radio tags used in our study weighed 1.8 % of mean weight, and measured 17 % of the mean length of the longnose suckers we implanted with radio tags. Even so, the suckers that did reach Custer were moving almost as quickly as the steelhead. A smaller radio tag would likely reduce incidence of mortality from the surgical implant procedure.

Evaluation of Methods

The combination of fyke nets and hook-and-line methodology were successful and necessary in producing fish for the implantation of radio tags. Steelhead avoid the net when a solitary fyke net was placed in areas likely to catch steelhead. However the multiple array of fyke nets appeared to reduce net avoidance by steelhead. It is recommended that future netting operations block as much of the river as possible using the multiple net configuration to ensure successful steelhead capture. Care must be taken t   aintain complete blockage from the surface to the bottom of the river in any location v   e the fyke net may be placed. Additional concern for steelhead mortality in fyke n   may be necessary. Scott McKinley of the University of Waterloo, Ontario, Canada, c   rved that fyke nets increase mortality among confined *Salmo salar* (personal c   munication). However, we attempted to minimize net mortality by frequently c   king nets, and only observed increased steelhead mortality in fyke nets when water t   perature exceeded 11 °C.

r   io tags were implanted in fish far downstream of the proposed barrier so that any i   mediate responses of the fish to the surgery would be likely to abate by the time they   ere ready to ascend the river. However, it is unlikely that surgical implant procedure a   versely affected the steelhead's ability to migrate upstream. As water temperatures and s   eam flow increased, radio-tagged fish appeared to be more likely to move upstream. The increased temperature and flow effect is most pronounced in steelhead that migrated upstream of Custer in as little as 0.5 days, and past the Bowman Bridge base station in as little as five days from release.

The LOTEK receivers did not always provide enough information to determine direction of movement. However, data from the portable base station located at Bowman Bridge often provided enough additional information to determine if a radio-tagged fish passed the Custer site. The future addition of a LOTEK DSP-500 will allow for continuous real-time monitoring of a multiple antennae and multiple frequencies of radio-tagged fish within the vicinity of the Custer reception area, thus reducing the number of radio-tagged fish whose direction of movement can not be determined. The DSP-500 can support a multiple underwater antennae array that will allow for small-scale movement analysis of radio-tagged fish.

Sample size recommendations for steelhead were made based on a migration delay of 7days. The choice of delay time, alpha and beta levels are best determined after a discussion between fisheries managers occurs to determine what delay time and significance levels are adequate for fisheries management objectives. Combinations of the parameters that would result in actual sample sizes greater than 100 steelhead may be unattainable. A great deal of time and effort was put forth to collect enough steelhead to find 54 that were suitable for radio tag implants in a year where the number of migrating steelhead in the Pere Marquette River was most likely reduced.

The large longnose sucker sample sizes suggested by the power analysis indicate that a sample size of eight fish was too small to account for variation in the time to migrate upstream beyond the Custer base station. Again, the use of a smaller radio tag should provide insight into the variation of the time of upstream migration of longnose suckers.

The purpose of radio-tagging fall-run steelhead was to determine timing of passage through the Custer base station and to examine their migratory behavior. It appears most of the steelhead that were radio-tagged in December of 1997 did not remain in the Pere Marquette River. Whether this represents typical behavior for staging steelhead or a response to the transmitter implantation procedure cannot be determined. However, the fact that fish tagged in February to April rarely left the river suggests that steelhead in the river in December are more prone to return to the lake. Migrating steelhead are known to use holding or staging areas that are also referred to as overwintering areas (Burger et al. 1983). Hooton and Lirette (1986) observed immigrating steelhead that occupied a heavily fished area within a western Canadian river for an extended period of time 3 to 4 months prior to spawning. Little is known of the significance of the staging areas. It is possible that they may serve as a source of energy, such as a location with an abundant food supply, or possibly a refuge from harsh winter river conditions such as icing.

Future Considerations

Clearly, the telemetry data that we have obtained over the previous two years demonstrate that steelhead and longnose suckers move quickly upstream in the Pere Marquette River when they begin their final ascent of the river for spawning. Furthermore, both species move quickly past the site where the electric barrier will be constructed. These data will allow us to evaluate both how long the barrier and fish passage structure delay movement for both species and if they decrease the proportion of fish that pass upstream of Custer.

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