GREAT LAKES FISHERY COMMISSION

1997 Project Completion Report[1]

Movements of walleye and lake sturgeon in the Bad River, Wisconsin, with regard to potential sea lamprey barrier sites

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INTRODUCTION

The Bad River, Wisconsin (Figure 1), produces more larval sea lampreys *Petromyzon marinus,* than any other U.S. tributary to Lake Superior, contributing an estimated 15-25% of the parasitic sea lamprey population (John Heinrich, U.S. Fish and Wildlife Service, Marquette Biological Station, personal communication). Sea lamprey management agents estimated that the Bad River contained 1,048,000 larval sea lampreys in 1991 (Popowski and Klar 1992). Following a lampricide treatment in August 1991, the number of residual larvae was estimated to be 24,000 in 1992, indicating a 97.7% effective treatment in 1991 (Klar and Schleen 1993). The Bad River drains a watershed of approximately 2,256 km^2 (Sather and Threinen 1966) and has a mean annual discharge of about 1,000 cubic feet per second (CFS). Because of the Bad River's size, complexity, lack of access, groundwater inputs, and backwaters, the effectiveness of this treatment is lower than in many other tributaries treated for sea lampreys.

The Bad River Band of Lake Superior Chippewa, owners of most of the mainstream riparian property, would like the use of lampricides to be reduced or eliminated in the Bad River. Tribal leaders have expressed a strong interest in alternative controls for sea lamprey, have supported the release of sterile males in the Bad River, and are interested in evaluating the possibility of using a barrier to block the upstream migration of sea lampreys. Tribal support will be required if a sea lamprey barrier is constructed in the Bad River.

Prior to constructing a barrier in the Bad River, the State of Wisconsin would require an environmental assessment of the potential impacts of building a barrier. At a minimum, the assessment would require a study of anadromous fish movements. Knowledge of anadromous fish movements will be beneficial when establishing site priorities for a barrier and to indicate potential fish passage needs. This information will also allow tribal leaders to measure the effects that a sea lamprey barrier may have on the aquatic resources of the Bad River and Lake Superior.

Figure 1. Geographic location of the Bad River, Wisconsin.

BACKGROUND

Benefits of a barrier dam

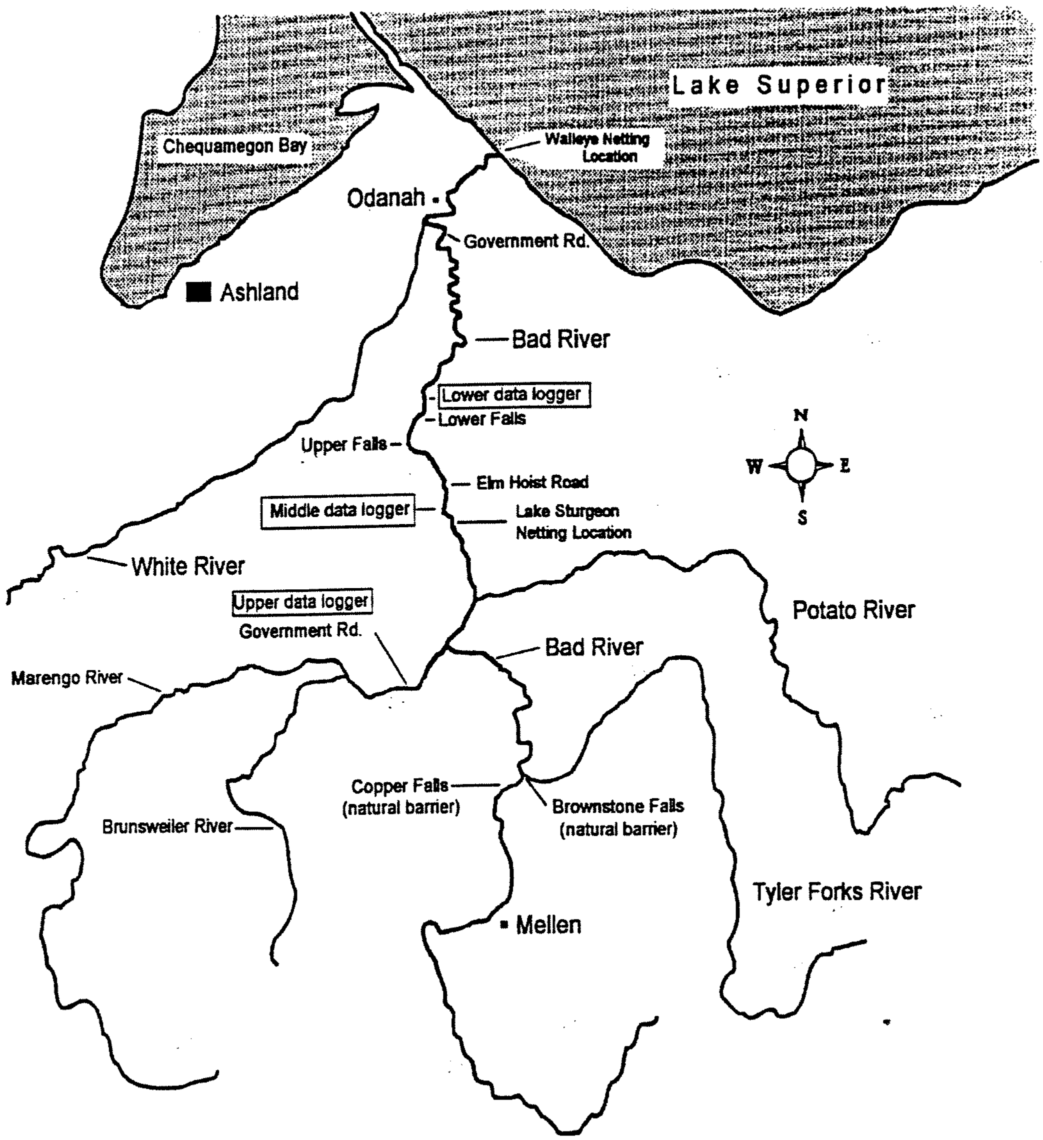
The 16 km stretch upstream of the mouth of the Bad River is characterized by a wide, swampy floodplain with low banks. Due to the topography, there is no site that would allow barrier construction (using any existing technology) and eliminate the need for lampricide treatments by blocking off all spawning habitat. Therefore, after barrier construction, lampricide treatments of the lower mainstream would still be required. Two sets of natural falls existing on the main stem of the Bad River are located 35 (lower falls) and 37 river kilometers (upper falls) upstream from the mouth (Figure 2). These falls may be a natural barrier to some anadromous fishes, but are not to sea lampreys. Lamprey management agents have determined that there are two primary locations under consideration for a sea lamprey barrier in the Bad River system: near the Elm Hoist Road bridge on the main stem and near the Government Road bridge on the Marengo River (Figure 2).

The Great Lakes Fishery Commission's (GLFC) vision statement emphasizes a goal of reducing lampricide use 50% by the year 2000. An effective barrier on the Bad River, located in the vicinity of the Elm Hoist Road bridge, is estimated to reduce TFM (3-trifluoromethyl-4-nitrophenol) use from 3,882 kg (8,550 lb) per treatment to 2,270 kg (5,000 lb), a 41% reduction. The alternative to a sea lamprey barrier on the main stem of the Bad River is a barrier on the Marengo River near the Government Road bridge. A barrier in this location would reduce lampricide use less than 10%, but would reduce staff time by 44% and stream miles treated by 26%.

Prior to 1995, the Bad River had been treated 10 times, requiring a total TFM use of 42,222 kg (93,000 lb), which has a 1996 value of $2.6 million. The inclusion of staff costs increases the cost of those 10 past treatments to about $4.0 million. A typical treatment of the entire river costs $428,000, and is generally required every 3 years, resulting in an annual treatment cost in 1996 dollars of $143,000. Sea lamprey management agents estimate that a barrier on the main stem of the Bad River near the Elm Hoist Road bridge would reduce the cost of future treatments to $61,000 annually, resulting in an annual savings of $82,000 when compared to current treatments.

A new low-head barrier is estimated to cost $1.4 million. If a 1% annual maintenance cost is added and the total amortized over 50 years, the annual barrier cost in 1996 dollars would be $45,000. These analyses disregard the history of increasing prices of TFM, the value to the fishery of reducing lamprey induced mortality of Lake Superior fishes and of reducing exposure of non-target animals to lampricide, and the potential impacts a barrier may have on fish movements and the ecological dynamics of the Bad River.

Figure 2. Netting locations, and locations of data logging stations, upper and lower falls, Elm Hoist Road bridge, and major tributaries of the Bad River, Wisconsin, 1996.



During the 1991 lampricide treatment, 202 kilometers of the Bad River system were exposed to lampricide. A barrier on the mainstream Bad River, located near the Elm Hoist Road bridge, would reduce the length of stream treated to about 1/3 of that treated in 1991 and reduce the habitat available to larvae by more than 80%, resulting in more effective and efficient treatments and fewer residual larvae. The upstream reaches, which are often most difficult to treat, would be eliminated from further treatments.

Based on the estimated abundance of parasitic lampreys in Lake Superior and the proportion originating from residual larvae in the Bad River, a barrier on the Bad River could reduce parasitic phase sea lamprey populations in Lake Superior by 20% or more. The net result would be a reduction of lamprey induced mortality on Lake Superior fishes, and progress toward the *fish community objective* (Busiahn 1990) of a 50% reduction in parasitic-phase sea lampreys in Lake Superior by the year 2000.

In addition to the aforementioned benefits, there are other significant advantages to establishing a barrier on the Bad River. A well-designed trap built into a barrier, such as that on the Brule River, Wisconsin, can capture 70% or more of the spawning adult sea lamprey run. The current trapping location by the lower Bad River falls captures 3-9% of the estimated spawning population (Shively 1994). An effective trap would reduce the number of spawners available to spawn downstream from the barrier and would enhance the effectiveness of the Sterile Male Release Technique, currently being implemented on the Bad River, by increasing the ratio of sterile to fertile males.

Another potential benefit of a barrier is improved fish assessment, such as that provided by the barrier on the Brule River, Wisconsin. A barrier dam equipped with a viewing window and videotape recorder would furnish high quality fishery assessment data upon which management decisions could be based. Currently, assessment data of Bad River anadromous fish stocks is limited.

<u>Bad River Fishery</u>

The Bad River supports spawning populations of many anadromous fishes, including lake sturgeon *Acipenser fulvescens*, and walleyes *Stizostedion vitreum*. It is one of only two tributaries on the south shore of Lake Superior with a self-sustaining stock of lake sturgeon (Slade 1996). Lake sturgeon are considered a "species at risk" by the U.S. Fish and Wildlife Service, and a threatened species in North America (Williams et al. 1989). The abundance, distribution and movements of lake sturgeon and walleyes in the Bad River are poorly understood. Both species have been captured upstream and downstream of the upper and lower falls (Slade and Rose 1994; Bad River Natural Resources Department, unpublished data), but it is unknown whether these were anadromous fish of Lake Superior origin.

Past assessments of spawning walleyes and lake sturgeon have been hindered by limited resources and high water in the spring. Some assessment work has been limited in scope, and other studies, although comprehensively planned, have resulted in limited success (Slade and Rose 1994). Regardless, resource management agencies and tribal subsistence fisherman have demonstrated that the Bad River supports self-sustaining populations of lake sturgeon and walleye (Shively and Kmiecik 1989; Schram 1994; Slade and Rose 1994; GLIFWC unpublished data; Bad River Natural Resources Department, unpublished data).

Biotelemetry has been used for a variety of applications in fisheries management and has proven to be useful when monitoring the movements of both juvenile and adult sturgeons (Hurley 1983; Thuemler 1988; Curtis 1990; Kieffer and Kynard 1993; Smith et al. 1993; Auer 1995; Moser and Ross 1995), and adult walleyes (Ager 1976; Pitlo 1984; Heidinger et al. 1989; Kingery and Bonneau 1991). In 1995, funding was obtained to utilize biotelemetry in a study to describe the movements of adult lake sturgeon, walleyes, and white suckers (*Catostomus commersoni*) before, during, and after their spawning migrations in the Bad River.

One radio tagged lake sturgeon and one radio tagged white sucker moved upstream of the Elm Hoist Road bridge during the 1995 study indicating that fish passage may be required for lake sturgeon and white suckers if a barrier was constructed near the Elm Hoist Road bridge (Slade et al. 1996). Information on anadromous walleye movements during 1995 was inconclusive with regard to the need for fish passage at a barrier dam constructed near the Elm Hoist Road bridge. No radio tagged walleyes, lake sturgeon, or white suckers were observed in the Marengo River during 1995, leaving the question of fish passage needs associated with a Marengo River barrier dam unanswered.

Funding was requested and obtained from the Great Lakes Fishery Commission in 1996 to continue the study of movements of anadromous walleyes and lake sturgeon in the Bad River. Results of that study are presented here.

OBJECTIVES

The primary objectives of the study were to determine, through the use of biotelemetry, if anadromous walleyes migrate upstream of the Elm Hoist Road bridge in the main stem of the Bad River and if anadromous walleyes and lake sturgeon migrate upstream of the Government Road bridge in the Marengo River. That information will be used by sea lamprey management agents and the Bad River tribe to identify potential fish passage needs at each location. Once identified, fish passage needs could determine whether the tribe will approve the construction of a sea lamprey barrier.

If radio tagged lake sturgeon and/or walleyes migrated upstream of the Elm Hoist Road bridge, secondary objectives were to estimate the percent of each species that migrated upstream of the potential barrier location, and to determine the stream discharge present at the time of migration.

METHODS

In March 1996, 40 radio tags (10 for lake sturgeon and 30 for walleye), purchased from Advanced Telemetry Systems (ATS), were "tuned" to their individual frequencies by placing them in the Bad River and recording the strongest radio signal of each tag with a hand held receiver (ATS Model R2100). A data logging station was set up at each of three locations above the highwater line on the banks of the Bad River: approximately 1.5 river kilometers (RKM) downstream from the lower falls (lower station), approximately 2.0 RKM upstream of the Elm Hoist Road bridge (middle station), and approximately 1.0 RKM downstream of the Government Road bridge on the Marengo River (upper station) (Figure 2). Each station consisted of a data logger (DCC II Model D5041) and receiver (Model R2100) rented from ATS and two directional Yagi antennas affixed to a 3.1 or 4.6 m antenna mast. One antenna was directed upstream and one downstream. Each station was powered by a 12V DC deep cycle marine battery. Batteries were replaced biweekly. The receiver, data logger, and deep cycle battery were placed in a cooler for protection from moisture.

Thermographs, manufactured by Onset Inc., were activated and placed near the middle and upper data logging stations on May 21. Thermographs were programmed to record water temperature to the nearest 0.1 degree Celsius every 2 hours throughout the study. Mean daily water temperature (MDT) was calculated as the average of all temperature readings recorded for each calendar day.

Multi-filament nylon and monofilament gill nets were fished in Lake Superior immediately adjacent to the mouth of the Bad River, 0.2 RKM upstream from the mouth of the Bad River, and about 1.0 RKM upstream from the Elm Hoist Road bridge (Figure 2). Gill nets were 1.8 m deep, 30.5 or 61.0 m long, and measured 10.2, 11.4, 20.3 or 25.4 cm stretch-mesh. To avoid problems with high stream flows following iceout, initial netting efforts for walleyes took place through the ice near the mouth of the river. Nets were fished under the ice near the mouth of the Bad River perpendicular to river flow almost nonstop from March 12 to April 12 when ice conditions began deteriorating rapidly.

Following ice out on April 19, nets were set May 1-3, and May 7-9 in Lake Superior adjacent to the mouth of the Bad River to collect walleyes. Nets were set about 1.0 RKM upstream from the Elm Hoist Road bridge on May 13-17, 21-24, 28-31 and on June 3-4 to collect lake sturgeon. Nets were lifted and cleaned twice daily while fishing through the ice and as necessary when fishing in open water with time between lifts dependent on stream flow and subsequent debris load.

Upon capture, walleyes were placed in a holding tank and transported 1.0 RKM upstream from the mouth of the Bad River. Each fish was then weighed to the nearest gram, measured to the nearest 1.0 mm (total and fork length), and tagged with a consecutively numbered, yellow Floy streamer tag. Procedures for lake sturgeon were the same except that measurements of girth (mm) were also taken. Prior to attachment, the frequency of each radio transmitter was programmed into the receiver and checked again for signal strength. Radio tags were externally attached near the base of the dorsal fin to walleyes (ATS model 10-28) and lake sturgeon (ATS model 10-35). Radio tags transmitted signals on 25 frequencies in the 152-154 megahertz band. Walleye and lake sturgeon radio tags were differentiated by pulse rate (e.g. walleye-50 pulses per minute (ppm)., sturgeon-75 ppm.). Radio tags had a life expectancy of 90 days.

After the first walleye was radio tagged, a collapsible Yagi antenna and a receiver (ATS model 2100) were used to locate tagged fish in the 7.5 km stretch of Bad River from the access point to the mouth. On the first day that all of the fish were not located, data loggers and receivers were installed at the previously described locations. Following installation of the data loggers and receivers, data were downloaded from each data logger using a notebook computer once or twice each week. Data recorded by each data logger were then edited for "noise" (radio signals from sources other than the radio tags). Radio signals recorded by the data logger were considered to be observations when the frequency and pulse rate matched that of one of the transmitters in use and the signal was recorded for at least two consecutive times. The data logger installed at the Government Road bridge location malfunctioned on May 21 and was sent back to ATS for repairs. The data logger was reinstalled on May 31 and functioned properly until another malfunction occurred on June 12. At that time, we determined that it was not necessary to return the data logger for repairs since the study was due to be completed in two weeks and any radio tagged fish moving past the logging station would have to first pass the other two logging stations located downstream. No malfunctions were evident at the two downstream logging stations.

In addition to data logging stations, a portable ATS 2100 receiver, equipped with a collapsible Yagi antenna, was used to locate radio tagged fish during tracking surveys conducted by snowmobile, ATV, boat, foot and air. The frequency, pulse rate, location and time of day were recorded for each radio tagged fish located during tracking surveys. Each record was considered an observation. Location was recorded to the finest resolution possible on topographical maps of the Bad River watershed published by the U.S. Geological Survey (USGS). The distance traveled between observations of each fish was measured and recorded to the nearest 0.5 km.

Records of mean daily discharge (MDD) were obtained from the USGS, Madison, Wisconsin. The USGS gauging station is located about 100 m downstream of the Elm Hoist Road bridge.

RESULTS

Assessment netting through the ice began on March 12 (julian day 72). Water temperature was 2.2 °C and MDD was 675 CFS (Figure 3). Nets were fished through the ice near the mouth of the Bad River until April 12 (Table 1). A total of 2,554 fish was captured in 514 hours of netting. White sucker was the most common species caught (2,311 fish), followed by northern pike *Esox lucius* (199 fish). Only 10 walleyes were captured through the ice. Following ice out, nets were fished in Lake Superior adjacent to the mouth of the Bad River for a total of 38 hours. White sucker was the most commonly captured species (95 fish), followed by longnose sucker *Catostomus catostomus* (34 fish). No walleyes were captured in the lake. Beginning on May 13 (julian day 134) nets were fished upstream of the Elm Hoist Road bridge to capture lake sturgeon. Water temperature was 13 °C and MDD was 1,300 CFS (Figure 3). A total of 71 fish was captured in 346.5 hours of netting. White sucker was the most commonly caught species (65 fish), and one lake sturgeon was captured (Table 2).

Fish movements and locations were monitored through July 24 (julian day 206). Water temperature ranged from a low of 1.0 °C in March and April to a high of 23.0 °C on June 13 (Figure 3). When available, water temperatures recorded with a handheld thermometer were used to fill in missing temperatures before the temperature loggers were deployed. Discharge ranged from a low of 290 CFS on June 23 (julian day 175) to a high of 12,000 CFS on April 20 (julian day 111) (Figure 3).

A total of 1 lake sturgeon and 9 walleyes was captured and radio tagged. The lake sturgeon was a 1,050 mm (total length) male that appeared to be in a postspawning condition and was moving downstream. Radio tagged male walleye (8) ranged from 445 to 519 mm total length (mean = 476), and the single female was 520 mm total length. Complete biological and marking statistics of all fish radio tagged are listed in Table 2.

MOVEMENTS AND DISTRIBUTION

Walleyes

The number of observations recorded per fish ranged from 7 to 24. Based on these observations, we grouped walleye movements into 5 primary categories.

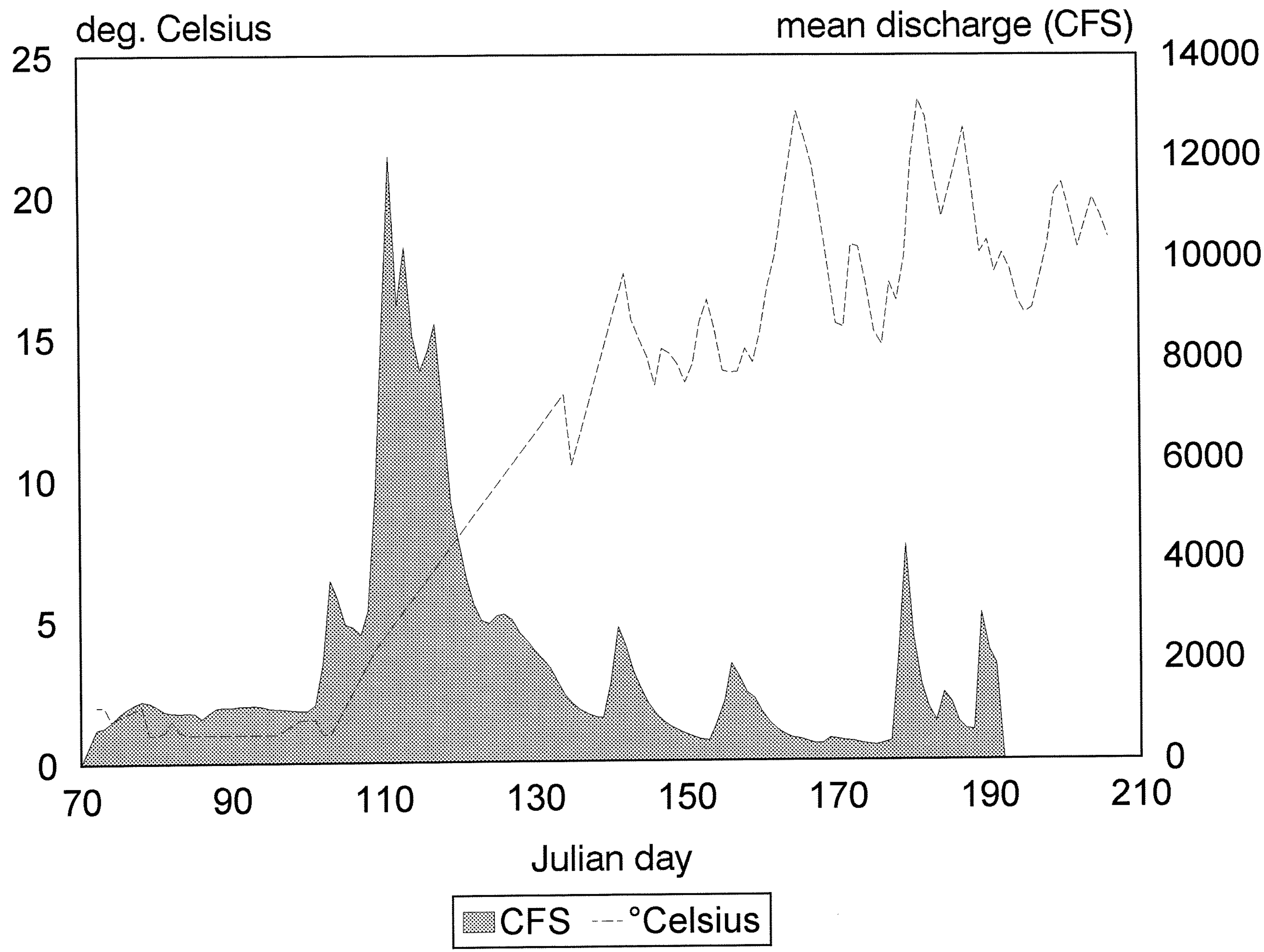


Figure 3. Temperature and Discharge profiles of the Bad River, March 10 (julian day 70) - July 24 (julian day 206), 1996.

Table 1. Summary of gill netting effort and catches for each set/lift from March - June, 1996.

Date Set	Time Set	Date Retrieved	Time Retrieved	Target Species	Hours Effort	Water Temp.(°C)	Net Length (m)	Mesh Size (cm)	Catch by Species: White Sucker	Northern Pike	Longnose Sucker	Walleye	Shorthead Redhorse	Silver Redhorse	Rockbass	Smallmouth Bass	Black Bullhead	Burbot	Black Crappie	Rainbow Trout	Lake Sturgeon
12-Mar	1400	13-Mar	700	Walleye	17	2	61	10.2	229	4						1					
13-Mar	1000	13-Mar	1630	Walleye	6.5	2	61	11.4	77	5		1	5								
13-Mar	1730	14-Mar	700	Walleye	13.5	1.5	61	11.4	98	8				5							
14-Mar	1500	15-Mar	700	Walleye	16	1.5	61	11.4	95	9		3	1	5							
18-Mar	700	18-Mar	1600	Walleye	9	2	61	11.4	19	1											
18-Mar	1700	19-Mar	730	Walleye	14.5	1.5	61	11.4	18	1											
19-Mar	800	19-Mar	1630	Walleye	8.5	1	61	11.4	18												
19-Mar	1700	20-Mar	730	Walleye	14.5	1	61	11.4	17												
20-Mar	800	20-Mar	1630	Walleye	8.5	1	61	11.4	15	1											
20-Mar	1700	21-Mar	700	Walleye	14	1.2	61	11.4	55	5		1									
21-Mar	830	21-Mar	1700	Walleye	8.5	1.1	61	11.4	178	4											
21-Mar	1830	22-Mar	700	Walleye	12.5	1.1	61	11.4	162	13				1							
22-Mar	930	22-Mar	1630	Walleye	7	1.5	61	11.4	116	12					1						
22-Mar	1700	23-Mar	800	Walleye	15	1.2	61	11.4	126	14					1						
23-Mar	930	23-Mar	1630	Walleye	7	1.1	61	11.4	38	5											
23-Mar	1700	24-Mar	700	Walleye	14	1.2	61	11.4	46	3			1								
24-Mar	800	24-Mar	1700	Walleye	9	1	61	11.4	31	2			1								
24-Mar	1730	26-Mar	1000	Walleye	40.5	1.5	61	11.4	87	16											
26-Mar	1000	26-Mar	1700	Walleye	7	1	61	11.4	49	21											
26-Mar	1830	27-Mar	700	Walleye	12.5	1	61	11.4	91	7											
27-Mar	800	27-Mar	1800	Walleye	10	1	61	11.4	40	6		1	1								
27-Mar	1830	28-Mar	700	Walleye	12.5	1	61	11.4	51	2					1						
28-Mar	800	28-Mar	1600	Walleye	8	1	61	11.4	31	6							1				
28-Mar	1730	29-Mar	700	Walleye	13.5	1	61	11.4	55	4								1			
29-Mar	800	29-Mar	1630	Walleye	8.5	1	61	11.4	40	4											
1-Apr	730	1-Apr	1700	Walleye	9.5	1	61	11.4	36	6											
1-Apr	1800	2-Apr	700	Walleye	13	1	61	11.4	64	3		1									
2-Apr	800	2-Apr	1700	Walleye	9	1	61	11.4	27	1			4								
2-Apr	1800	3-Apr	630	Walleye	12.5	1	61	11.4	26	4											
3-Apr	730	4-Apr	700	Walleye	23.5	1	61	11.4	30	3							1				
4-Apr	800	4-Apr	1700	Walleye	9	1	61	11.4	76	4		1							1		
4-Apr	1800	5-Apr	700	Walleye	13	1	61	11.4	44	1		1									
5-Apr	800	5-Apr	1630	Walleye	8.5	1	61	11.4	32	5											
5-Apr	1700	6-Apr	700	Walleye	14	1	61	11.4	53	1											
8-Apr	630	6-Apr	1700	Walleye	10.5	1	61	11.4	27	3											
8-Apr	1800	9-Apr	700	Walleye	13	2	61	11.4	25	1		1									
9-Apr	730	9-Apr	1700	Walleye	9.5	2	61	11.4	19	4											
9-Apr	1800	10-Apr	730	Walleye	13.5	1	61	11.4	24	3											
10-Apr	800	10-Apr	1700	Walleye	9	1	61	11.4	15												
10-Apr	1800	11-Apr	800	Walleye	14	1.5	61	11.4	27	4											
11-Apr	1530	12-Apr	800	Walleye	16.5	1	61	11.4	3	3									1	1	
12-Apr	900	12-Apr	1730	Walleye	8.5	2	61	11.4	1												
30-Apr	100	30-Apr	1400	Walleye	4	6	61	11.4	3												
1-May	800	1-May	1330	Walleye	5.5	10	61	11.4	19		4										
1-May	815	1-May	1345	Walleye	5.5	10	61	11.4	15		7		1								
1-May	830	1-May	1400	Walleye	5.5	10	61	11.4	19		7										
1-May	845	1-May	1445	Walleye	6	10	61	11.4	18		16										
8-May	830	8-May	1430	Walleye	6	10	61	11.4	6	1											
8-May	900	8-May	1430	Walleye	5.5	10	61	11.4	15	1				1							
8-May	1430	9-May	800	Walleye	17.5	10	61	11.4	12	1	1										
8-May	1430	9-May	900	Walleye	18.5	10	61	11.4	49				1	2							
13-May	1400	17-May	900	L.Sturgeon	91	13	45.8	11.4	4												
13-May	1400	17-May	900	L.Sturgeon	91	13	30.5	20.3													
21-May	800	23-May	1400	L.Sturgeon	54	13	61	20.3													
29-May	1400	31-May	1500	L.Sturgeon	49	13	30.5	20.3													1
3-Jun	1530	4-Jun	1700	L.Sturgeon	25.5	13	30.5	20.3													

Table 2. Biological and marking statistics of walleye and lake sturgeon captured and radio tagged in the Bad River, Wisconsin, from March to May, 1996.

Species	Radio Tag Frequency (Mhz)	Floy Tag Number	Total length (mm)	Fork length (mm)	Sex	Weight (kg)	Girth (mm)	Date of Capture	Sexual Condition	Gill net Size Stretch mesh (cm)	Release Location (RKM)
Walleye	152.103	102	445	419	M	0.35	---	3/13/96	Prespawn	11.43	1.2
Walleye	153.183	103	469	449	M	1.47	---	3/15/96	Prespawn	11.43	1.2
Walleye	152.044	104	483	457	M	1.16	---	3/15/96	Prespawn	11.43	1.2
Walleye	152.193	107	477	452	M	1.05	---	3/21/96	Prespawn	11.43	1.2
Walleye	152.222	108	520	490	F	1.81	---	3/27/96	Prespawn	11.43	1.2
Walleye	153.153	109	458	436	M	1.00	---	4/2/96	Ripe	11.43	1.2
Walleye	152.282	110	462	438	M	0.91	---	4/4/96	Prespawn	11.43	1.2
Walleye	152.313	111	519	492	M	1.47	---	4/5/96	Prespawn	11.43	1.2
Walleye	153.213	114	495	471	M	0.57	---	4/9/96	Prespawn	11.43	1.2
Lake Sturgeon	152.132	252	1050	990	M	7.71	360	5/30/96	Spent	20.3	44.2

The first pattern was exhibited by only one walleye (freq. 153.213), which migrated 29 RKM up the mainstem of the Bad River to a point about 6 RKM below the lower set of falls (Figure 4). The last observation of this walleye was on July 11 (julian date 193) at which time it remained in the Bad River. This was the furthest upstream movement within the Bad River that was observed for any of the 9 walleyes.

The second pattern of movement was also observed for only one walleye (freq. 153.183). That fish moved in and out of the Bad River from Lake Superior twice, never migrated further upstream than 11 RKM and was last observed on July 11 at RKM 6 (Figure 5).

The third pattern of movement was exhibited by three walleyes (freq. 152.193, 152.222, 152.282). Those fish were never observed further upstream than the junction of the Bad and White rivers, which is located about 7.6 RKM from the point of release (Figures 6 - 8). Two of those walleyes (freq. 152.282, 152.222) were last observed on July 17 (julian date 199) in Lake Superior. The third walleye from that group (freq. 152.193) was last observed on April 18 (julian date 109) at RKM 6.5.

The fourth pattern of movement was shown by three walleyes (freq. 152.044, 153.153, 152.313) as well. Those walleyes moved up the Bad River and into the White River (Figure 9 - 11). One of the walleyes (freq. 152.044) was last observed on July 17 in Lake Superior near the mouth of the Bad River. The other two walleyes were last observed in the White River on July 11 (freq. 153.153, RKM 17) and July 24 (julian date 206) (freq. 152.313, RKM 38.5).

The final pattern of walleye movements was only observed for one walleye (freq. 152.103). That fish moved upstream to near the junction of the White and Bad rivers (RKM 7.5) 11days after being tagged (Figure 12). During the remainder of the tracking period, the walleye moved back and forth from the mainstem of the Bad River to the White River, never moving further than 5.6 RKM upstream from the junction of the two rivers. The last observation of the walleye was on July 11 at which time it was located in the mainstem of the Bad River at RKM 12.5.

Lake Sturgeon

The radio tagged male lake sturgeon (freq. 152.132) was released at 1300 hours on May 30 (julian date 151). At 1612 hours, the sturgeon was first recorded by the Elm Hoist Road logging station, which was located 3.2 RKM downstream of the point of release. The sturgeon remained in range of the data logger until 1812 hours, after which it presumably continued downstream. On May 31 (julian date 152), the lake sturgeon was recorded at the falls logging station (RKM 33.5) at 0056, 0218, and 0248 hours. Later that morning (sometime between 0600 and 0900) the lake sturgeon was located from the air at RKM 32. The lake sturgeon then moved back upstream and on June 1 (julian date 153) the sturgeon was again recorded on the falls logging station at 0429, 0437, 0439, 0452, and 0454 hours (Figure 13). The observation recorded at 0454 on June 1 was the last observation for the fish. Aerial tracking did

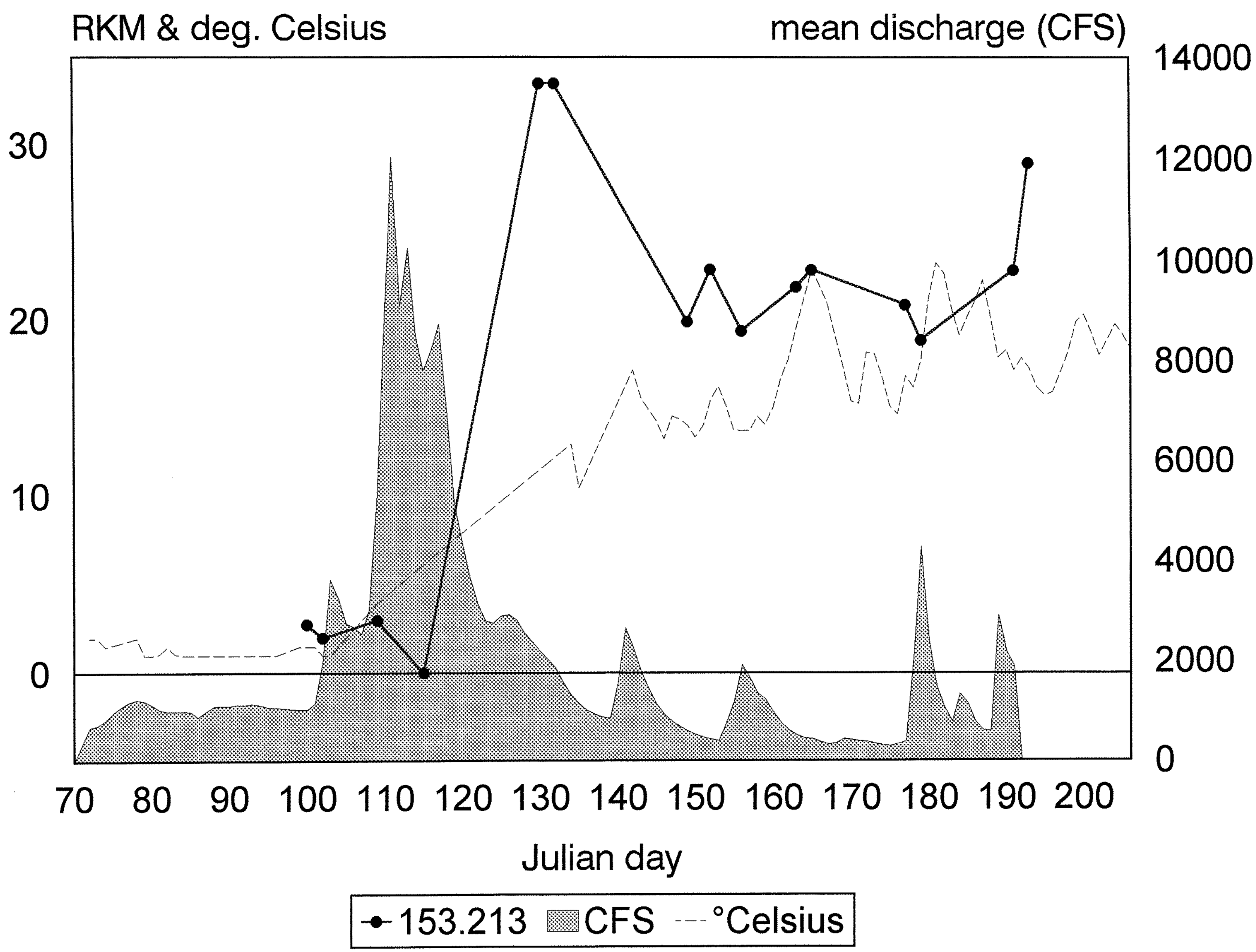


Figure 4. Movement pattern of a male walleye (freq. 153.213) tagged and released near the mouth of the Bad River on April 9, 1996 (julian day 100).

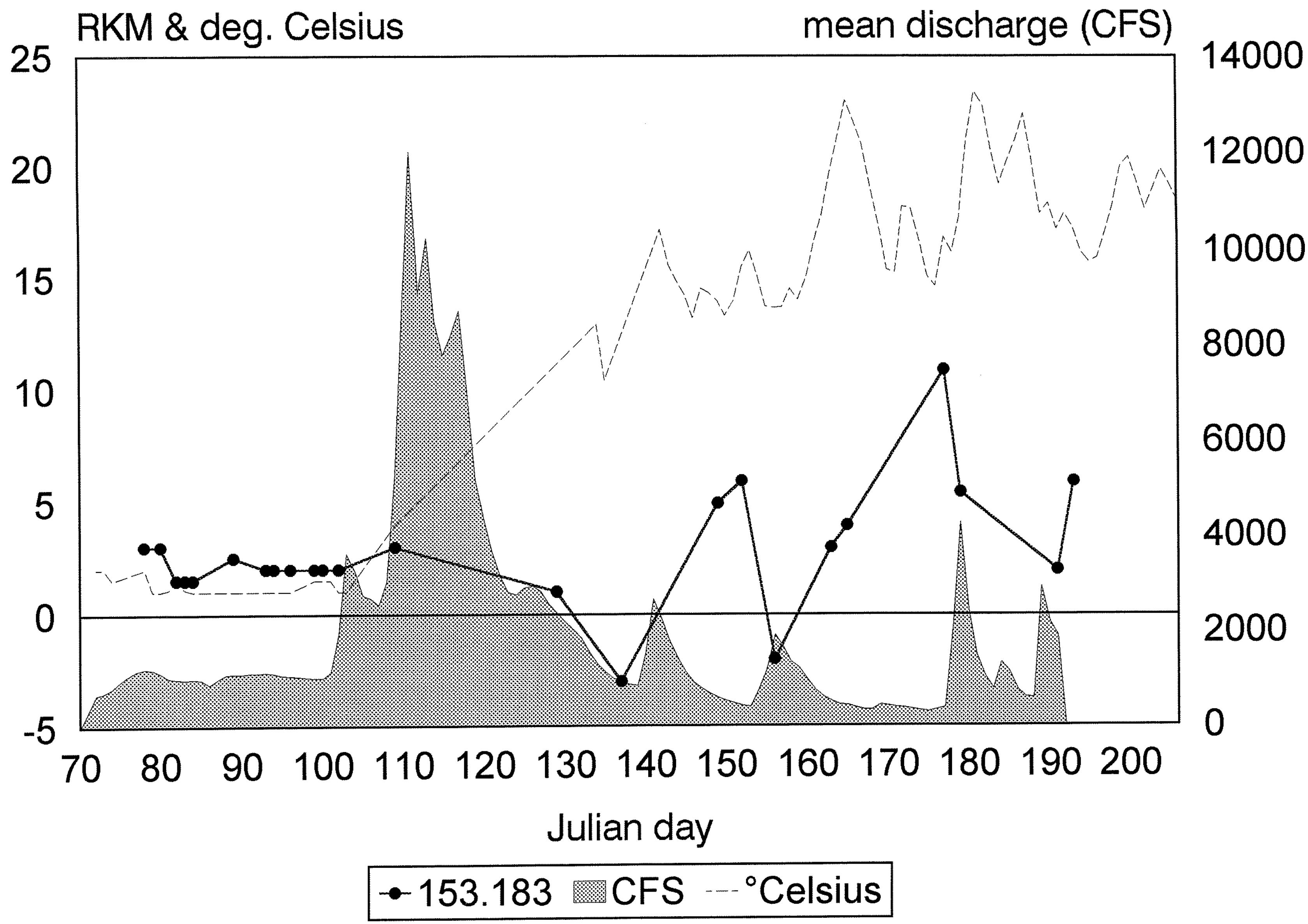


Figure 5. Movement pattern of a male walleye (freq. 153.183) tagged and released near the mouth of the Bad River on March 15, 1996 (julian day 75).

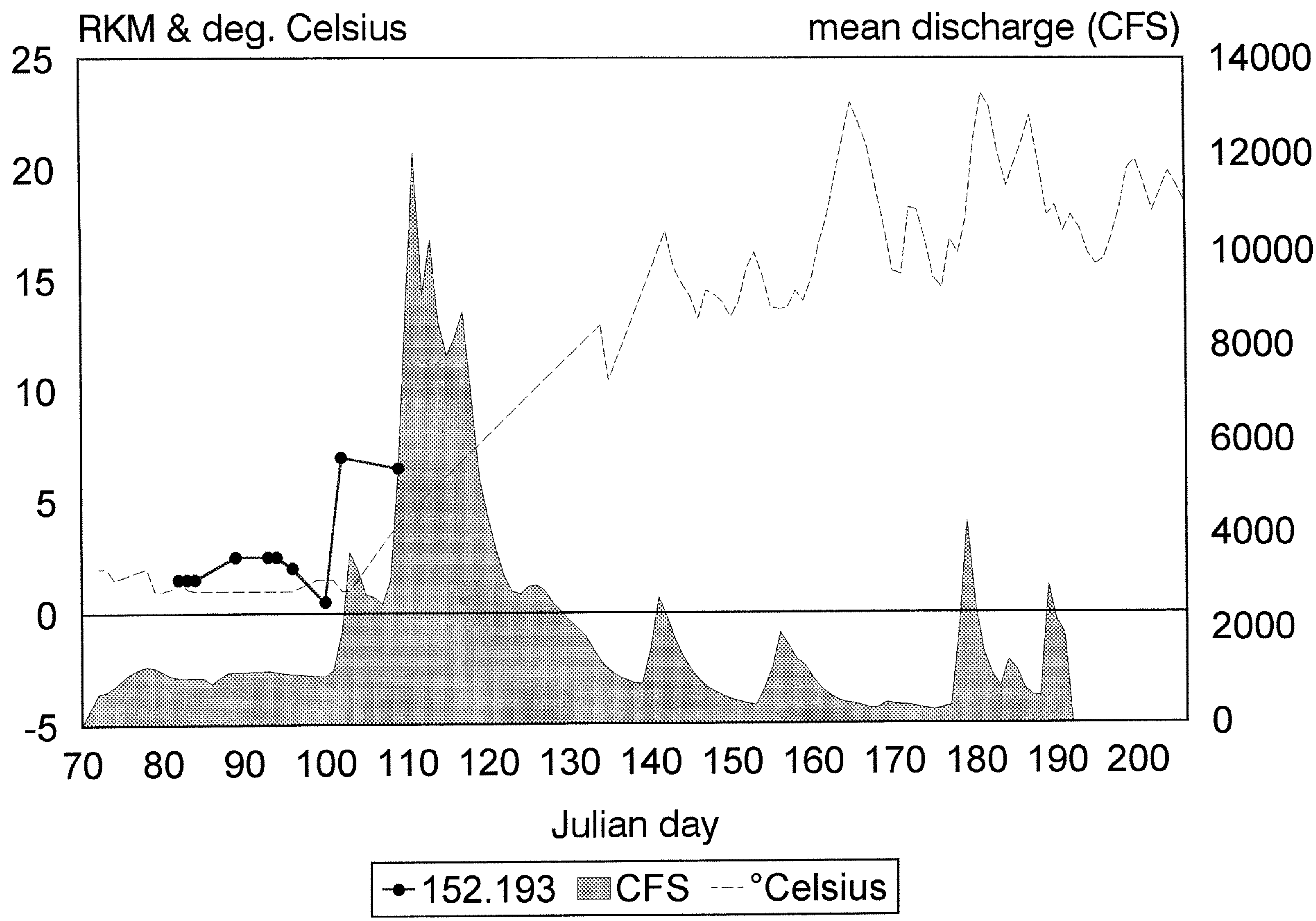


Figure 6. Movement pattern of a male walleye (freq. 152.193) tagged and released near the mouth of the Bad River on March 21, 1996 (julian day 81).

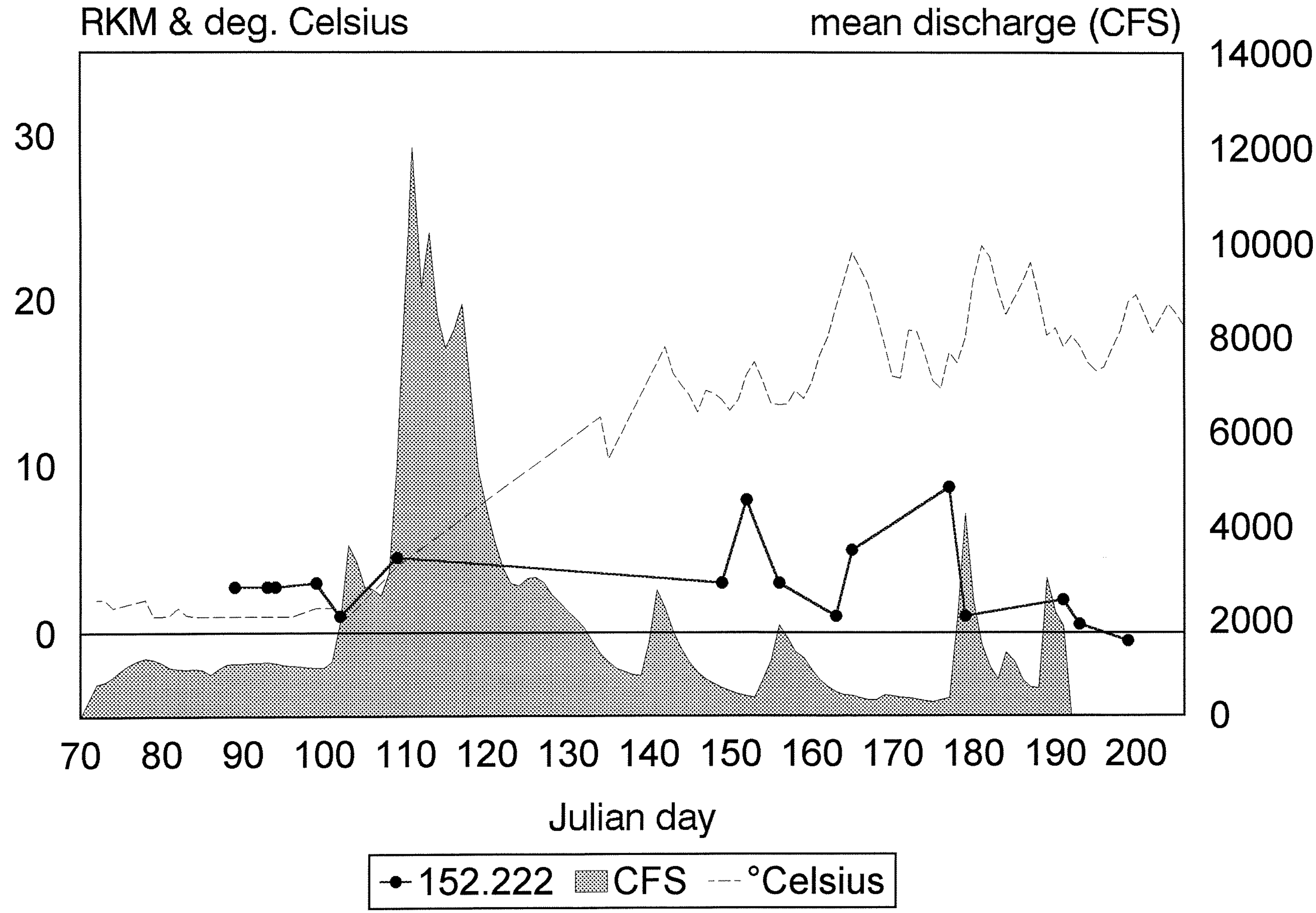


Figure 7. Movement pattern of a male walleye (freq. 152.222) tagged and released near the mouth of the Bad River on March 27, 1996 (julian day 87).

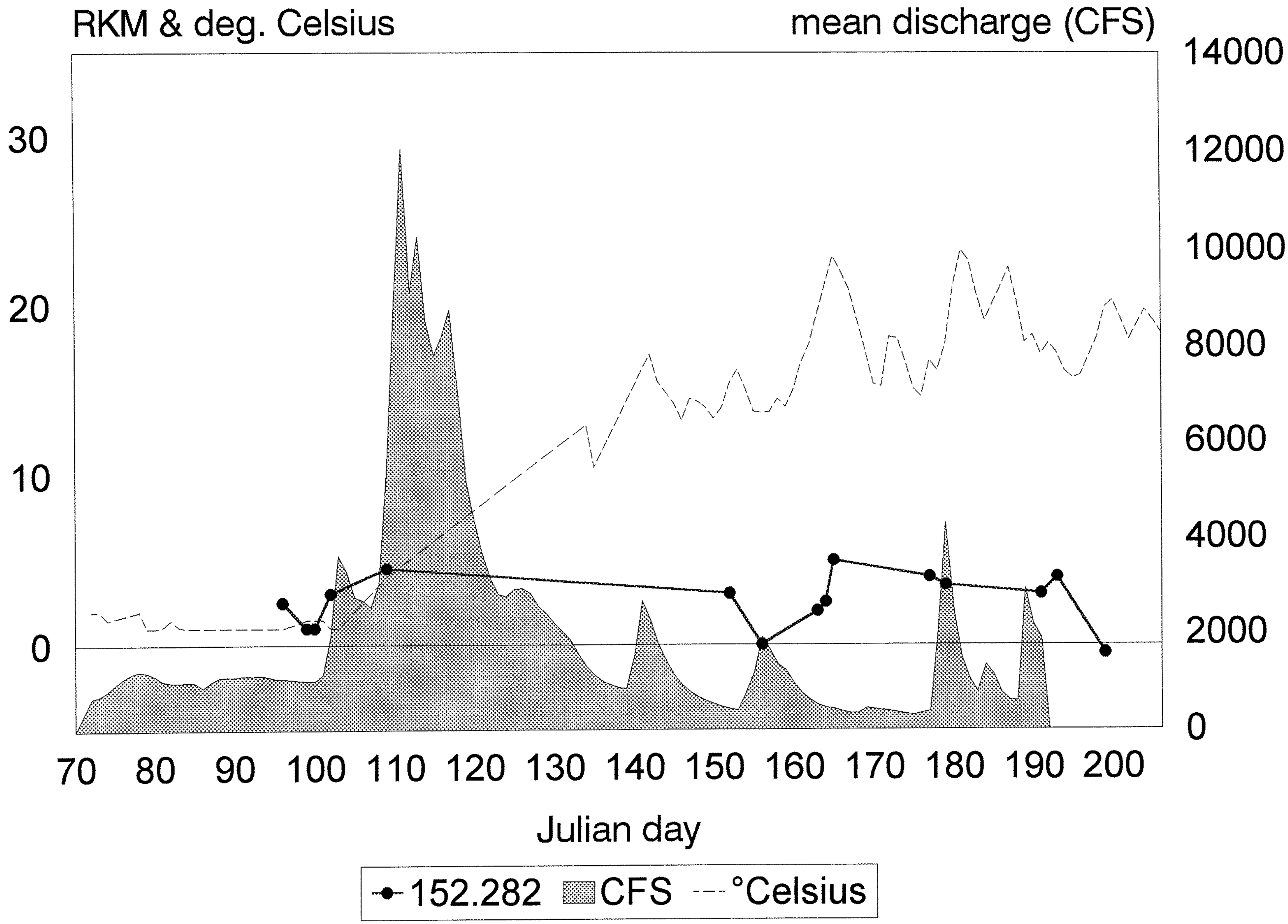


Figure 8. Movement pattern of a male walleye (freq. 152.282) tagged and released near the mouth of the Bad River on April 9, 1996 (julian day 100).

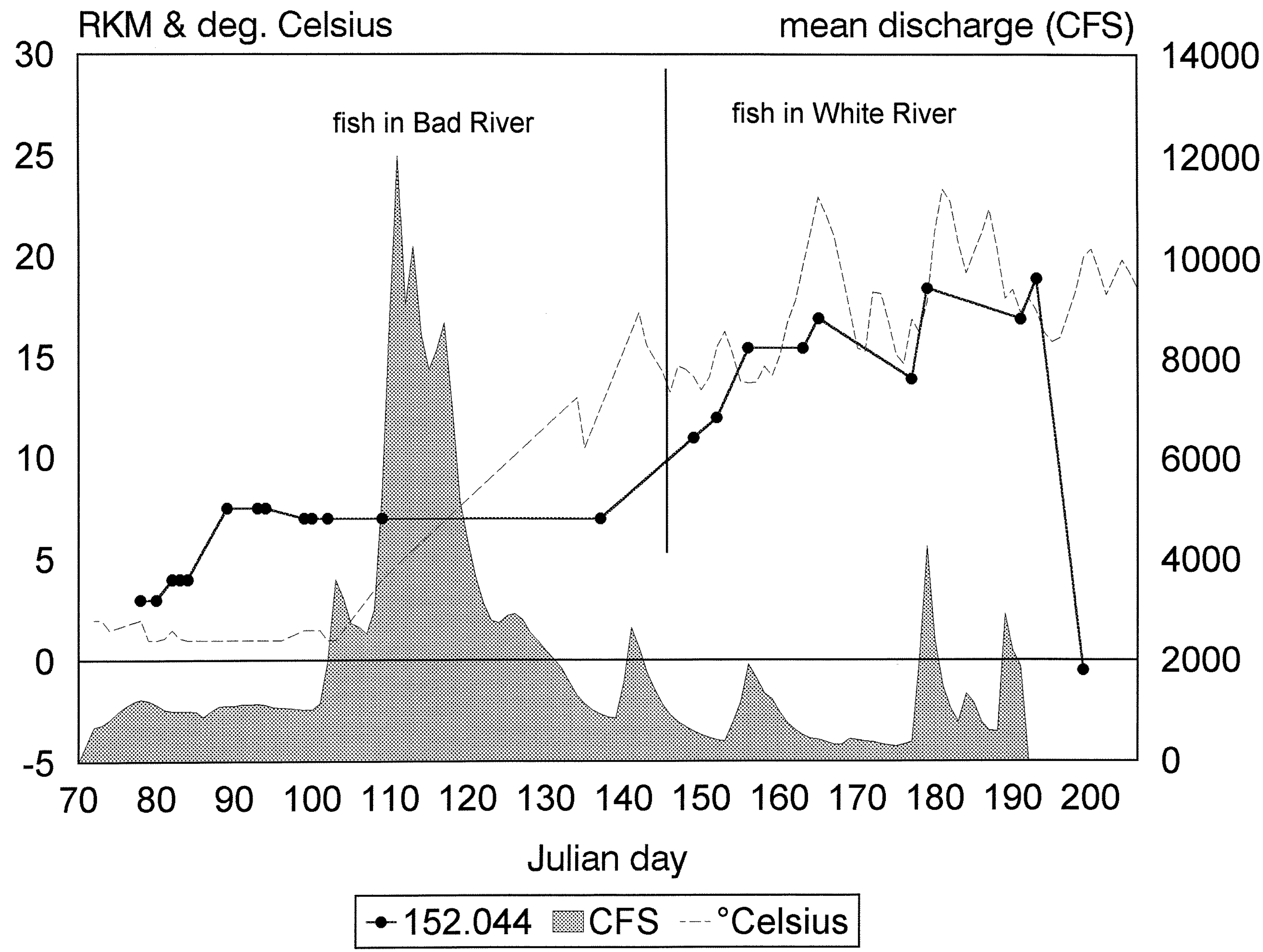


Figure 9. Movement pattern of a male walleye (freq. 152.044) tagged and released near the mouth of the Bad River on March 15, 1996 (julian day 75).

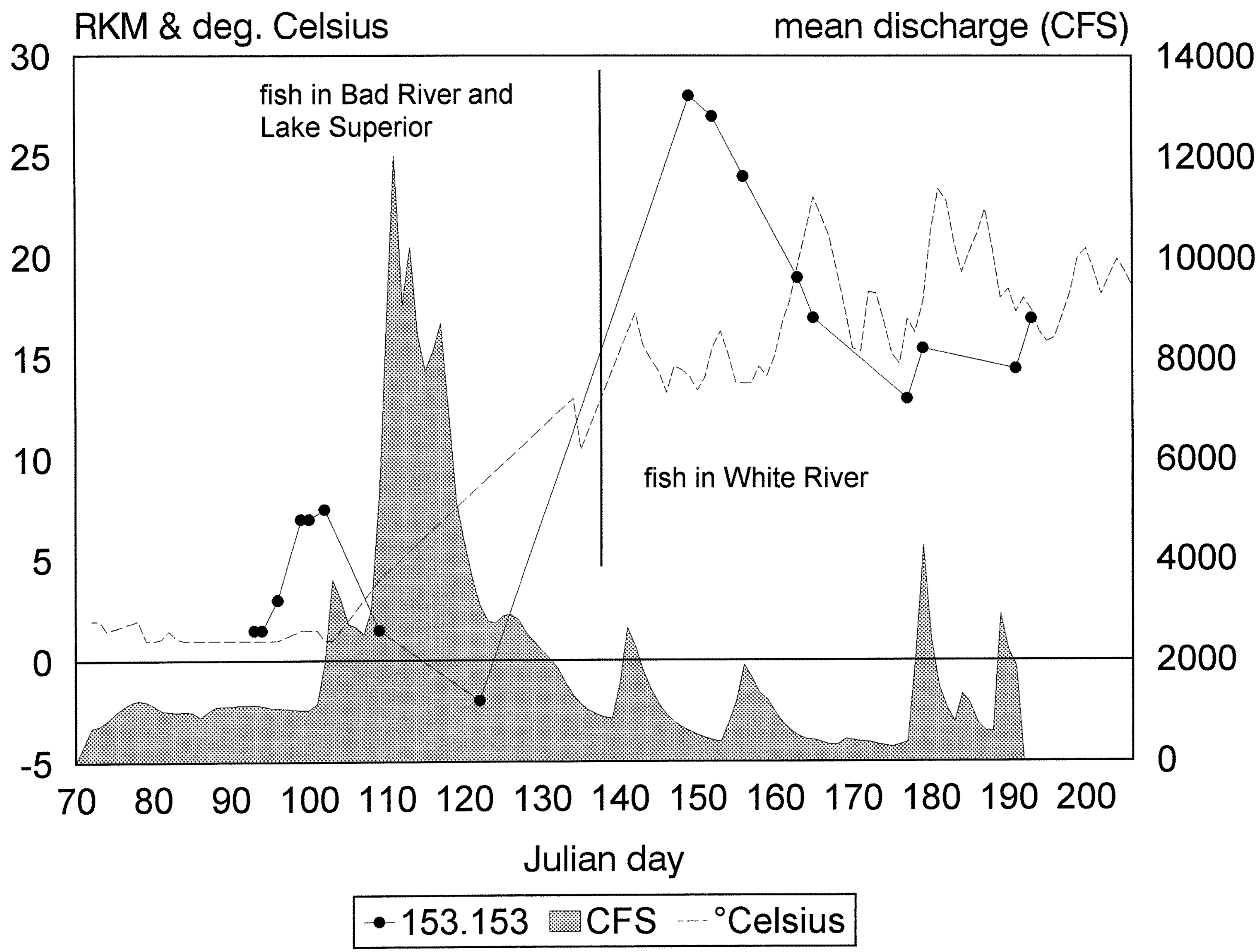


Figure 10. Movement pattern of a male walleye (freq. 153.153) tagged and released near the mouth of the Bad River on April 2, 1996 (julian day 93).

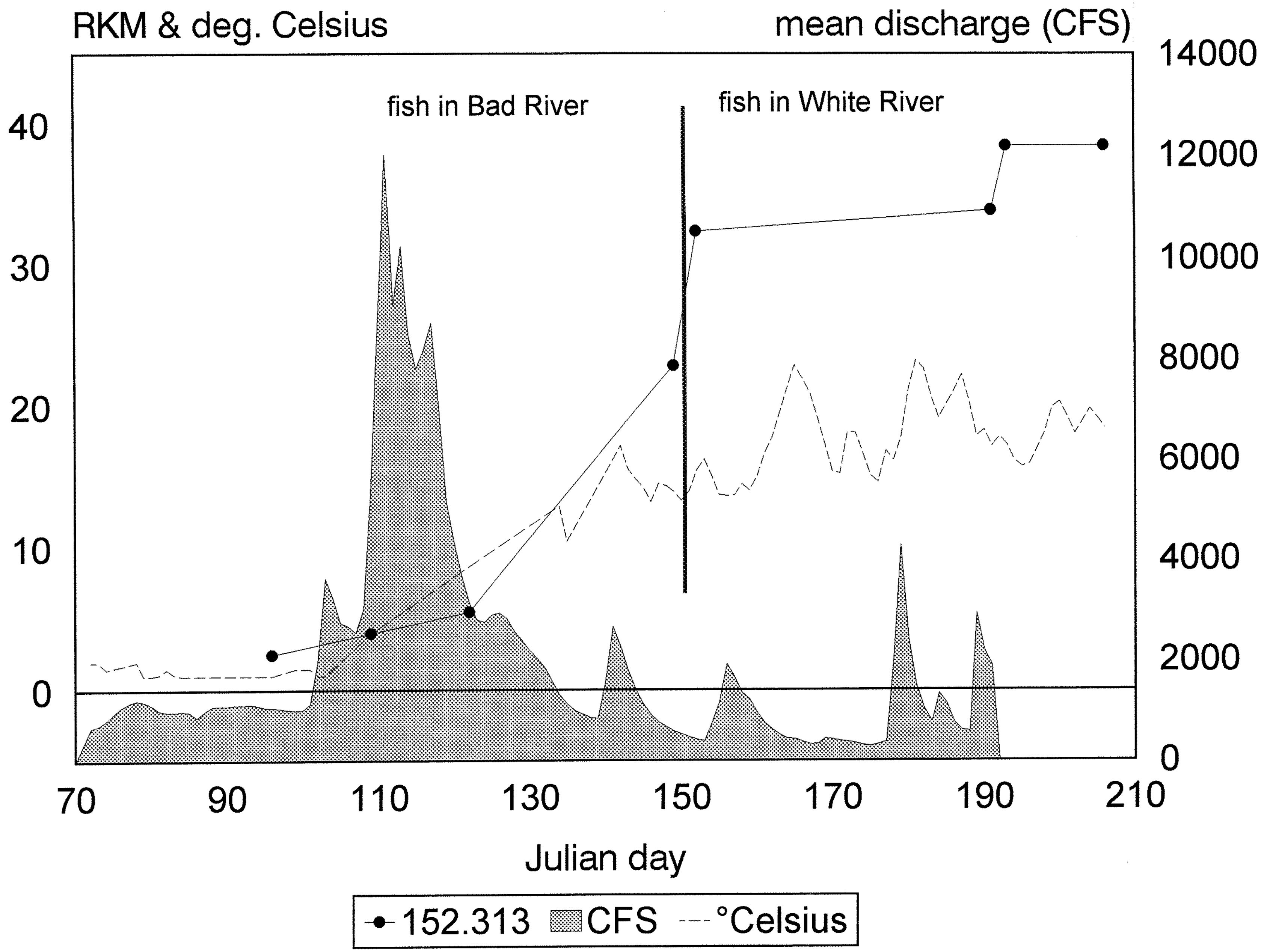


Figure 11. Movement pattern of a male walleye (freq. 152.313) tagged and released near the mouth of the Bad River on April 5, 1996 (julian day 96).

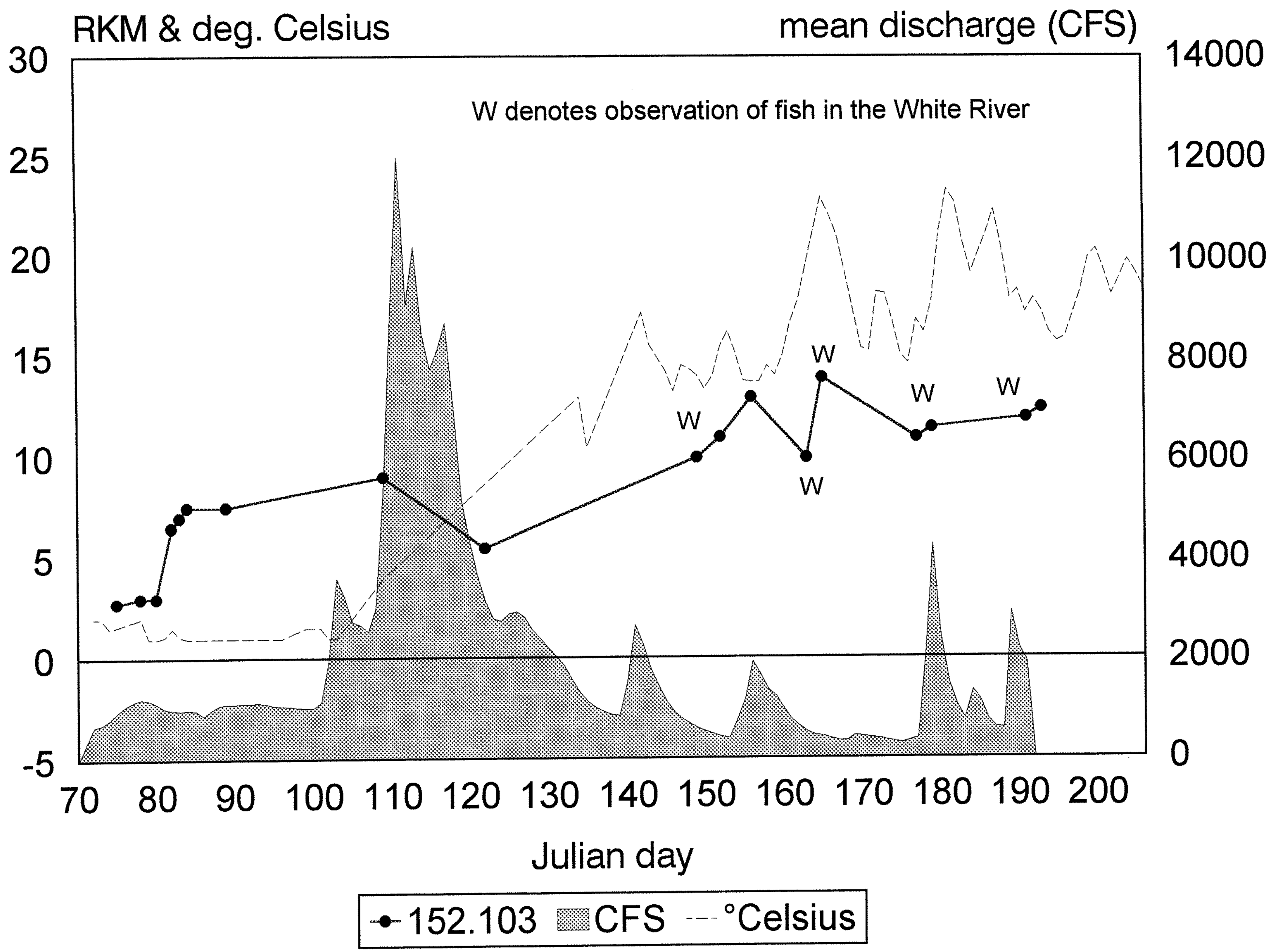


Figure 12. Movement pattern of a male walleye (freq. 152.103) tagged and released near the mouth of the Bad River on March 13, 1996 (julian day 73).

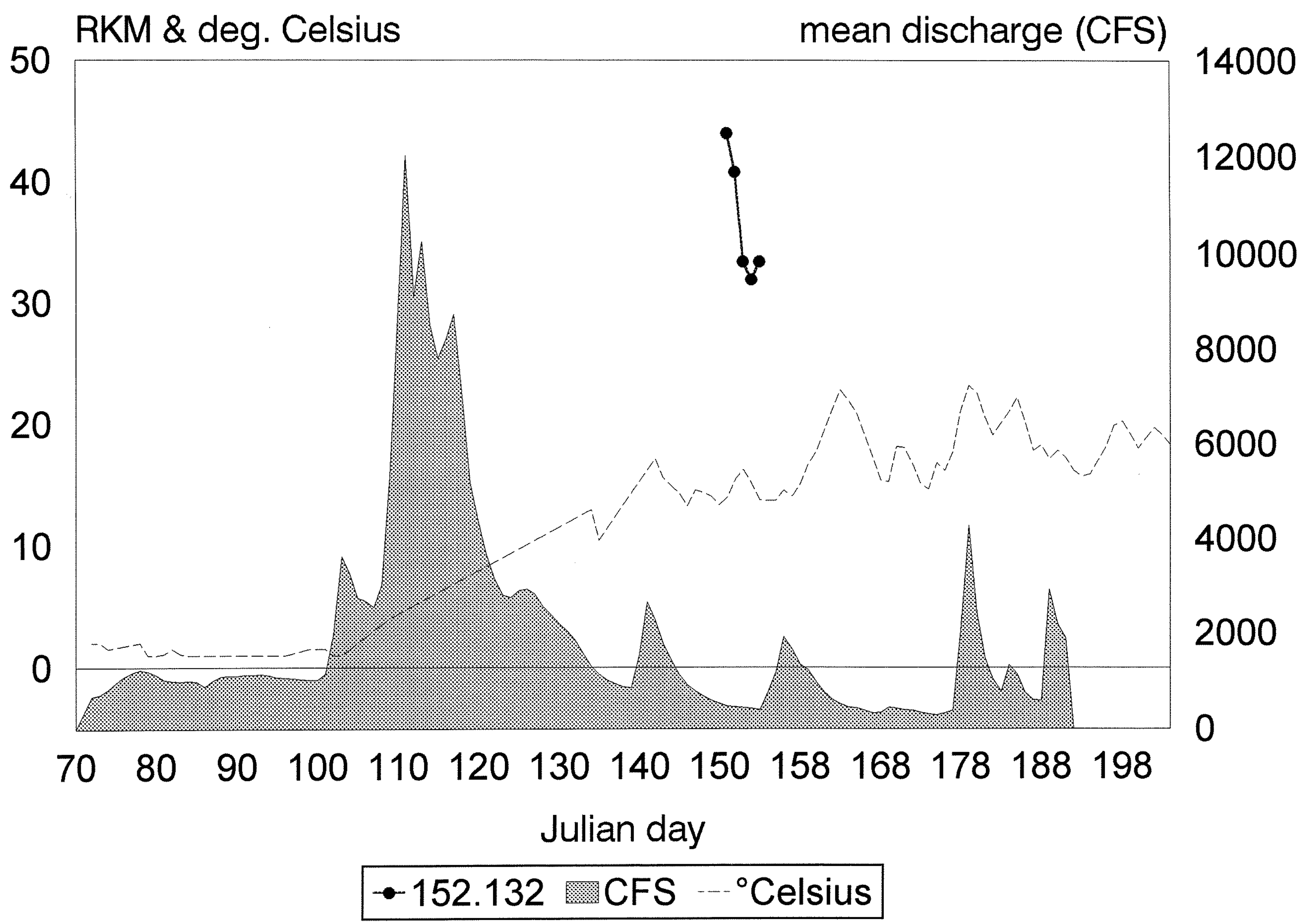


Figure 13. Movement pattern of a male lake sturgeon (freq. 152.132) tagged and released above the Elm Hoist Road bridge on May 30, 1996 (julian day 151).

not detect the lake sturgeon anywhere within the Bad River watershed or westward along the Lake Superior coastline to Chequamegon Bay, suggesting that the fish rapidly moved downstream and eastward into Lake Superior.

DISCUSSION

None of the 9 radio tagged walleyes moved as far upstream as the lower Bad River falls. Of the 9 walleyes, 3 (33%) migrated an extended distance upstream in the White River, 3 (33%) migrated upstream only to the junction of the White and Bad rivers, 1 (11%) moved back and forth between the White and Bad rivers, and 1 (11%) moved back and forth between Lake Superior and the Bad River. Only 1 (11%) of the walleyes showed any indication of an extensive migration up the mainstem of the Bad River, and that fish did not move all of the way up to the lower falls.

Walleye spawning migrations begin soon after ice out at water temperatures of 3.3-6.7 °C, and spawning in Wisconsin generally occurs between mid April and early May, peaking at water temperatures of 5.6-10 °C (Becker 1983). Walleye spawning has been known to occur over a temperature range of 5.6-11.1 °C (Scott and Crossman 1973). During 1995, netting for walleyes began shortly after ice out when water temperatures ranged from 2.5-4.6 °C, but stream discharge increased and made gill netting inefficient and difficult. To avoid that problem in 1996, efforts to capture walleye began a month prior to ice out. It has been presumed that anadromous walleyes in the Bad River congregate near or in the mouth of the river prior to upstream migration and we hoped to capitalize on this behavior. However, despite 514 hours of gill netting effort through the ice, only 9 walleyes were tagged. During the same time period, 2,311 white suckers and 199 northern pike were captured, indicating that the nets were effectively sampling fish moving into the river mouth. This suggests that walleyes do not congregate in the lower river prior to their spawning migration, that they remain in Lake Superior itself until immediately after ice out, or that few anadromous walleyes utilize the Bad River. Unstable ice conditions prevented netting attempts in Lake Superior prior to spring breakup. Nets were set in the open water of Lake Superior adjacent to the mouth of the Bad River following ice out, but shifting ice packs in the area necessitated constant monitoring and frequent relocation of the nets.

An extended period of snow melt (following a winter of record snowfall) combined with a rainy spring resulted in river flows that prevented netting for nearly a month after ice out. As in 1995, it appears that anadromous walleyes moved into and up the Bad River to spawn during this period of high discharge and rising water temperature. Tribal fishermen began spearing walleyes at the lower falls during this time period as well (personal observation).

Based on tribal harvest in the Bad River (GLIFWC, unpublished data), we know that anadromous walleyes congregate and spawn in the lower rapids, but the question of whether passage of walleyes upstream from a sea lamprey barrier located near the Elm Hoist Road bridge on the Bad River, or the Government Road bridge on the Marengo River would need to be considered remains unanswered. Further information about the distribution of anadromous walleyes in the Bad River system will be required before any questions of fish passage needs can be answered.

Although the numbers of tagged walleye in this study were small, two interesting observations were made. As indicated earlier, tribal harvest records have documented that anadromous walleyes congregate and spawn in the lower rapids of the mainstem Bad River. However, a third of the walleyes that we tagged appeared to utilize the White River for spawning in 1996. The second interesting observation was the amount of time that the walleyes spent in the system. Though not documented, it has often been assumed that anadromous walleyes moved in and out of the system relatively quickly. This was not the case in our study, where 6 of the 9 walleyes remained in the Bad River watershed at the conclusion of our tracking efforts in mid-July, nearly 4 months after being tagged at the mouth of the system.

Water temperatures of 13.0-18.0 °C, 9.0-18.0 °C, and 11.7-15.0 °C are believed to be cues to lake sturgeon spawning (Harkness 1923; Roussow 1957; Priegel and Wirth 1977). Lake sturgeon have been observed spawning at temperatures of 10.0-18.0 °C in the Bad River (Slade and Rose 1994) and 9.5-19.0 °C in the Sturgeon River, Michigan (Auer 1995). In the Wolf River, Wisconsin, when water flow is high and water temperature increases slowly, spawning begins when water temperature reaches 11.5 °C. During seasons of low water and rapid temperature rise, spawning does not begin until water temperatures reach 14.5-15.0 °C (Priegel and Wirth 1977).

During 1995, a radio tagged lake sturgeon moved upstream of both sets of rapids and past the potential Elm Hoist Road bridge barrier location (Slade et al. 1996). Therefore, in 1996, netting efforts for lake sturgeon were shifted to a location above Elm Hoist Road bridge to evaluate fish passage needs at the Marengo River barrier location. In 1995, 26 of 36 lake sturgeon were captured from May 7-9, during a period of low discharge and rapidly rising water temperature (about 13 °C) (Slade et al. 1996).

High discharge and netting efforts for walleye near the mouth of the Bad River prevented any attempts at capturing lake sturgeon prior to May 13, 1996. Water temperatures had already reached 13 °C by that time and MDD was 1,300 CFS. Though it was possible to set nets, the attempts were relatively inefficient due to the discharge level and associated debris. Nets were fished as often as possible during the next two weeks, though conditions for netting were only optimal for brief periods of time. During one of those periods, on May 30, the only lake sturgeon captured in 1996 was taken. As discussed earlier, it appeared that this fish was a spent male on its way back downstream. The subsequent rapid downstream movement of this individual supports this conclusion. This also indicates that the delays experienced in attempting to capture lake sturgeon likely resulted in missing the upstream movement of fish. Though the capture of the sturgeon above the Elm Hoist Road bridge location reinforces the 1995 conclusion that sturgeon passage at that site may be necessary, it fails to answer any questions about where sturgeon may be spawning upstream of that location. If at all possible, any future attempts at examining lake sturgeon movements upstream of Elm Hoist Road should focus on capturing fish earlier, and should continue to fish for sturgeon moving back downstream after spawning to get a better estimate of how many fish are spawning above that location.

We did not experience as many problems with the data loggers during 1996 as we did during 1995. Only one of the data loggers malfunctioned and had to be sent to ATS for repair during the field study. Also, in 1995, it was apparent that the data logging stations did not detect the movements of all fish (e.g. observations were recorded of fish moving downstream from the falls at the lower data logging station that were not recorded at the middle data logging station). Though we did experience this problem in 1996, it was not as prevalent as in 1995. As in 1995, we combined our monitoring and tracking efforts with those of Dr. John Kelso of Fisheries and Oceans Canada who conducted a study of sea lamprey movements. All of the sea lamprey tagged by Dr. Kelso in 1996 were released between the Falls logging station and the Elm Hoist Road bridge logging station. Eighty-seven percent (26 of 30) of the lamprey were detected on their initial movement past a logging station, and were later confirmed to be past the stations by other tracking methods. Based on these observations, we conclude that data loggers are a useful tool, but they should not be the sole method of monitoring movements.

RECOMMENDATIONS

We recommend that other sites for a potential sea lamprey barrier be evaluated regarding possible fish passage requirements. Evidence of lake sturgeon movements beyond the Elm Hoist Road bridge was obtained in both 1995 and 1996. To date, information about fish passage needs at the Marengo River site is inconclusive. Additional information regarding the movements of anadromous fish in the Bad River will allow tribal leaders and resource managers to evaluate all available options.

We recommend further study of the movements of native anadromous fish in the Bad River, since the site selection of a potential sea lamprey barrier or barriers in the Bad River depends not only on access, land ownership and topography, but on potential fish passage needs as well.

We recommend that any further studies of anadromous fish (particularly walleyes) movements should include monitoring the White River with a logging station(s) and manual tracking efforts, as it appears that the White River may receive a substantial portion of the anadromous walleye run. Information on walleye distribution in the system is sorely lacking, and is difficult to ascertain due to problems in capturing walleyes that are associated with the timing of their upstream spawning migration. Radio tagging efforts in the future may benefit from the use of tags with longer battery life, or programmable transmitters that would allow walleyes to be tagged at the falls while spawning, on their outbound migration when stream flows are declining, or during the winter months.

We recommend further monitoring of anadromous lake sturgeon movements during their spawning run with radio telemetry equipment. Evidence of lake sturgeon migrations above the potential Elm Hoist Road bridge barrier dam location was obtained in both 1995 and 1996. However, in neither year were we successful in determining the full extent of the upstream movements of lake sturgeon. Because the Bad River is only one of two U.S. tributaries to Lake Superior that supports a reproducing population of lake sturgeon, it is imperative that the spawning needs of this species be adequately described and protected. This information may prove very useful in restoration efforts of lake sturgeon populations elsewhere in the Great Lakes.

We recommend continued use of data loggers in future studies of fish movements, but more intensive surveillance of the entire watershed should be conducted via aircraft. Due to the size and limited access of this system, tracking by boat and foot is very labor intensive. Data loggers should only be placed in locations where they can be readily accessed. This will allow for both regular performance checks and more time for manual tracking.

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