Habitat associations and movements of shovelnose sturgeon in Pool 13 of the Upper Mississippi River

by

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Signatures have been redacted for privacy

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INTRODUCTION

The shovelnose sturgeon, *Scaphirynchus platorynchus*, is the smallest and most abundant of the seven species of Acipenseridae in North America. A bottom dwelling species with a preference for current, it is found in most of the large rivers in the Mississippi-Missouri-Ohio River drainage system (Bailey and Cross 1954). The shovelnose sturgeon supports a profitable commercial fishery in the Upper Mississippi River where it brings one of the highest prices per kilogram of river fish (Kline and Golden 1979). When the lake sturgeon (*Acipenser fulvescens*) was still abundant in the Upper Mississippi River, the smaller shovelnose sturgeon was looked on as a nuisance and destroyed in large numbers (Carlander 1954). As lake sturgeon populations declined due to over-exploitation, fishermen turned to shovelnose sturgeon as a source of eggs for caviar production.

Shovelnose sturgeon are now marketed as a smoked product for which the supply seldom keeps pace with demand (Helms 1974). Like many sturgeon fisheries, catches of shovelnose sturgeon have greatly declined since the peak years of the 1890s. During this period, over 180,000 kg of sturgeon a year were harvested from the Upper Mississippi River (St. Louis to Minneapolis), while present annual harvest is about 23,000 kg (Kline and Golden 1979).

Shovelnose sturgeon were most important to the commercial catch in the 1950s, making up 1.3% of the total catch (Farabee 1979). Shovelnose sturgeon have been greatly reduced in numbers and distribution due to overfishing, pollution and the impoundment of rivers (Bailey and Cross 1954). Few shovelnose sturgeon are captured by sport fishermen, only 0.03% of the total catch from the Upper Mississippi River (Farabee 1979).

Anticipated increases in barge traffic on the Upper Mississippi River has led to concerns over navigation's impact on the river's fish and fisheries. Of particular concern are species inhabiting the main channel, of which the shovelnose sturgeon is one of the most abundant (Starrett and Barnickol 1955, LGL Associates 1981, Hubert and Schmitt 1982). The shovelnose sturgeon is also one of the most abundant species found on wing dams in this area (Pitlo 1981) and modifications to these structures may impact sturgeon populations. Since little is known of this valuable fish's habitat requirements in the Upper Mississippi River, it was selected for further study.

Study Objectives

1. Determine the spring and summer habitat associations of shovelnose sturgeon.
2. Describe the physical features of the habitats in

which shovelnose sturgeon are found.

3. Determine the spring and summer movements of shovelnose sturgeon.

Taxonomy and Distribution

The shovelnose sturgeon is a member of the river sturgeons, *Scaphirynchus*. Only one other member of this genus is known, the pallid sturgeon, *S. albus*, a much larger and rarer species found primarily in the Missouri River (Kallemeyn 1983). These sturgeons are known to hybridize throughout their range indicating similar spawning requirements and habits (Carlson and Pflieger 1981). The shovelnose sturgeon, also known as the sand sturgeon, hackleback or switchtail, reaches a maximum length of 1 m and a maximum weight of 5 kg. Systematics, distribution and morphology have been described by Bailey and Cross (1954) and Weisel (1978, 1979).

Foods and Feeding

The shovelnose sturgeon is an opportunistic suctorial feeder on benthic invertebrates, primarily larval aquatic insects (Trichoptera, Ephemeroptera, Diptera) (Held 1969, Modde and Schmulbach 1977). Modde and Schmulbach (1977) found that shovelnose sturgeon annual feeding behavior was divided into three seasonal intervals on the Missouri River:

1) fall feeding on drift organisms; 2) winter feeding on a wide variety of aquatic and terrestrial invertebrates and 3) late spring and summer foraging on benthic invertebrates. Shifts in feeding activity were influenced by the timing and rates of river discharge.

In the Mississippi River, Trichoptera larvae were found to be the major food item of the shovelnose sturgeon (Hoopes 1960, Ranthum 1969). Cursory examination of stomach contents by Helms (1974) indicated a preponderance of caddisflies, mayflies and chironomids with fish eggs also being eaten on occasion. Shovelnose sturgeon were reported to congregate in areas of the Ohio River where small clams and snails were abundant (Trautman 1957).

Habitat

Shovelnose sturgeon are most abundant in channel habitats of the Mississippi, Missouri and Ohio rivers and their larger tributaries. In the impounded sections of these waters, sturgeon are restricted to the more lotic upstream areas (Fogle 1963, Held 1969, Walburg et al. 1971, Helms 1974).

In the Missouri River, shovelnose sturgeon are more abundant in unchannelized sections, especially near sandbars (Schmulbach et al. 1975). Shovelnose sturgeon were most abundant in intermediate currents in pools behind sand bars or in open water areas adjacent to the main channel (Moos 1978). Gill net catches were highest in sand bar pools between 1.8 m and 4.6 m in depth (Moos 1978). In the Minnesota River, gill net catches were highest in deeper, more swiftly flowing areas (Durkee et al. 1979). Elzer et al. (1977), working in the Tongue River, Montana, reported sturgeon were most abundant at 0.4 to 0.9 m depths in spring and early summer. Shovelnose sturgeon were found most frequently over sand and gravel bottoms (Barnickol and Starrett 1951), although they may be found over silt if it is swept by a substantial current (Bailey and Cross 1954).

Movements

Shovelnose sturgeon are capable of moving long distances but are generally sedentary much of the year. Tagged sturgeon in the Missouri River have exhibited movements of up to 540 km downstream; distance traveled increased with time at large (3.1 km after 1 year, up to 107.3 km after 5 years) (Moos 1978). Elzer et al. (1977) found that most tagged sturgeon remained within 1.6 km of their tagging location. Movements of sturgeon in the Chippewa River, Wisconsin, were characterized as multi-directional, random and limited (Christenson 1975).

Gill net catches and recapture data indicated shovelnose were most active during the spring and fall with little movement occurring during the summer (Moos 1978). Greater spring movements were thought to be associated with spawning. Spring concentrations of shovelnose sturgeon in the tailwaters of dams have been reported from many rivers (Eddy and Underhill 1974, Walburg et al. 1971, Helms 1974). Upstream movements were greater than downstream movements in May and June while upstream and downstream movements were nearly equal during July in the Tongue River, Montana (Elzer et al. 1977).

Shovelnose sturgeon tagged in the Upper Mississippi River showed little movement within a home pool (Helms 1974). Mean movement was 2.7 km upstream and 1.0 km downstream (n=279 recaptures). Movement in the Upper Mississippi River is restricted by the locks and dams except during high water when the gates are opened and the river is essentially free-flowing. Greatest distance traveled was 190 km by four fish tagged in Pool 13 and recaptured in Pool 9, 265 to 724 days after tagging (Helms 1974).

Reproduction

Like other sturgeons, the shovelnose sturgeon is not an annual spawner: 65-70% of the mature males spawn in a given year with females spawning every 2 or 3 years (Moos 1978). Males are mature at age V, fork length (FL) about 550 mm, while females mature beginning at age VII (FL about 625 mm) in the Upper Mississippi River (Helms 1974). Females averaged 9,200 eggs (range 6,700-15,600) in the Missouri River (Zweiacker 1967) while larger females in the Mississippi River averaged 27,600 eggs (range 14,100-51,200) (Helms 1974). Shovelnose sturgeon spawn between April and June (Forbes and Richardson 1920, Coker 1930, Helms 1974, Moos 1978) at water temperatures from 15.5 to 20.5 C (Christenson 1975, Moos 1978). Spawning is thought to occur over gravel areas in streams (Christensen 1975, Elzer et al. 1977) and in main channel areas (Coker 1930, Moos 1978) or on wing dams (Helms 1974) in larger rivers.

Early Life History

Little is known of shovelnose sturgeon early life history. Carlson (1981) described *Scaphirynchus* larvae and compared them to *Acipenser* larvae. Larval sturgeon were caught in channel areas near the bottom in the Missouri River (Harrow and Schlesinger 1980). Young of the year sturgeon were captured near wing dams on the Upper Mississippi River (Helms 1974). In other sturgeons, hatching takes from 5-8 days (Harkness and Dymond 1961, Smith et al. 1980, Buckley and Kynard 1981) and larvae are demersal (Stevens and Miller 1970, Taubert 1980a).

Sturgeon Telemetry Studies

With the recent development of bio-telemetry as a tool for fisheries research, several studies have utilized this technique on sturgeon. A few shovelnose sturgeon were experimentally tagged with ultrasonic transmitters in the Missouri River (James C. Schmulbach, University of South Dakota, Vermillion, personal communication). Small numbers of lake sturgeon have also been tagged with radio transmitters in the Wolf and Fox River System, Wisconsin (James Kempinger, Wisconsin Dept. of Natural Resources, Oshkosh, Wisconsin, personal communication)

The endangered shortnose sturgeon, *Acipenser brevirostrum*, has been the object of telemetry studies to determine daily and longterm movement patterns in several rivers on the East coast of the United States (McCleave et al. 1977, Heidt and Gilbert 1978, Taubert 1980b, Buckley 1982).

Other sturgeon species studied using telemetry include the Atlantic sturgeon, *Acipenser sturio*, (Dovel 1977) and the white sturgeon, *Acipenser transmontanus*. Diel and seasonal movements of white sturgeon were studied in the mid-Columbia River (Haynes et al. 1978, Haynes and Gray 1981). Movements of the sevryuga, *Acipenser stellatus*, below a dam in the Soviet Union have been examined using ultrasonic telemetry (Poddubnyy et al. 1974).

STUDY AREA

The Upper Mississippi River is one of America's largest and most scenic rivers. Formed over 10,000 years ago by the retreat of glaciers, the river has been defined by the Upper Mississippi River Conservation Committee as extending 1490 km from Hastings, Minnesota to Caruthersville, Missouri (Rasmussen 1979). In its natural state, the river was a series of deep pools separated by shallow rapids. The braided channel was filled with large snags and rocks washed in during the spring high water period.

Since 1816, the river has been manipulated to become "a highway of commerce, a highway which only incidentally happened to be made of water" (Carlander 1954). Early navigation improvements consisted of clearing large snags and rocks from the river channel. Permanent navigation improvements started in the late 1850s. In 1878, Congress authorized a 1.4 m low-water channel for the Upper Mississippi River. The U. S. Army Corps of Engineers (COE) achieved this by building hundreds of wing dams along the river. Wing dams were constructed out of 15-25 cm limestone rock and willow brush piled perpendicular to the river's flow. These low dams directed water into one main channel and maintained a sufficient depth for navigation through scouring action. Most of the 3100 wing dams now found on the river were constructed for the 1.8 m channel project of

1907 (Upper Mississippi River Basin Commission 1982).

The most dramatic change to the river occurred in the 1930s when a 2.7 m channel was authorized. The COE responded by building 29 locks and dams between Minneapolis, Minnesota and Alton, Illinois. This changed the free flowing river into a series of lake-like pools separated by riverine sections with many submerged wing dams (Rasmussen 1979).

The study pool, Pool 13, is one of 26 navigational impoundments created by this project (Figure 1). Formed by Lock and Dam 13 at Clinton, Iowa (River Mile 522.5), the pool extends 57 km to Lock and Dam 12 at Bellevue, Iowa (River Mile 556.7). The pool is essentially riverine in nature above Sabula, Iowa (River Mile 535). Width of the pool ranges between 0.5 to 6.4 km, with an area of 11,739 hectares. Low flow in Pool 13 occurs in the fall and winter with highest flows occurring in the spring. Average annual flow at Lock and Dam 13 is 1,342 m^3/second. Flow rates are dependent on natural forces and the COE (U.S. Army Corps of Engineers 1980).

A large variety of aquatic habitats exist in the Upper Mississippi River including several types of channel habitats (Figure 2). These include: 1) main channel--the area through which commercial craft pass (minimum depth 2.7 m and minimum width 122 m); 2) main channel border--the area

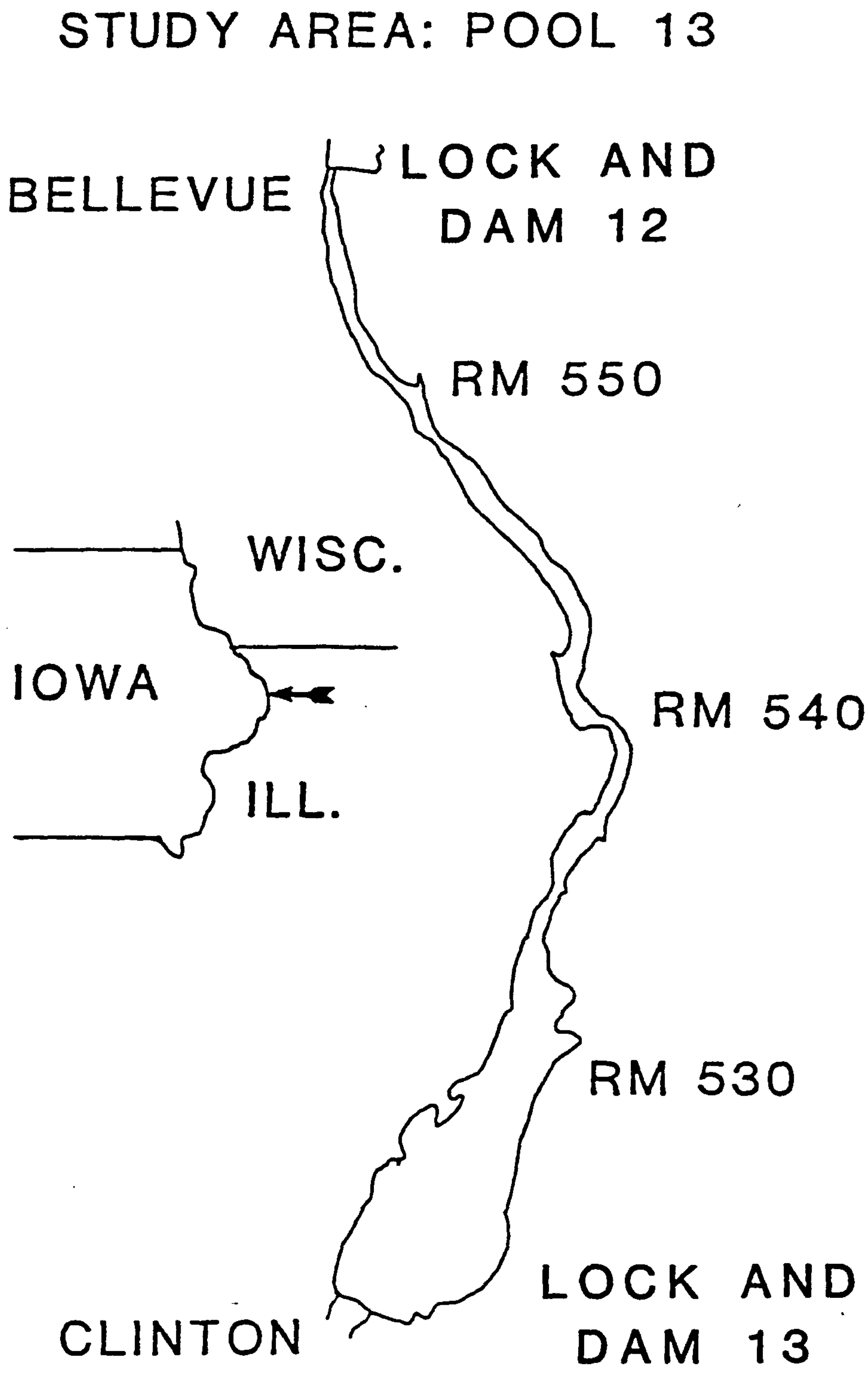

FIGURE 1. Location and profile of the study area, Pool 13, Upper Mississippi River

between the main channel and a river bank or island shore (this includes all areas in which wing dams occur); 3) side channels--diversions from the main channel in which a current occurs during the entire year; and 4) tailwaters--the turbulent area downstream from the locks and dams (lower boundary 0.8 km) (Rasmussen 1979).

In this study, I have divided main channel border into two subclasses: main channel border without wing dams (referred to as main channel border) and main channel border with wing dams (referred to as wing dam habitat). Wing dam habitat consisted of the area 50 m upstream from a wing dam, the area between wing dams, and the area 400 m downstream from a wing dam. Side channels have been similarly divided into side channel and closing dam habitats. Closing dams are wing dam-like structures stretching across side channels.

Under flat pool conditions, the available habitat is about 0.3% tailwaters, 10.1% main channel, 5.3% main channel border without wingdams, 4.8% wingdam, 4.7% side channel, 0.2% closing dam, 9.8% slough, 0.3% pond and 64.5% lake (John Pitlo, Iowa Conservation Commission, Bellevue, Iowa, personal communication). Current velocities range from zero in backwater areas to greater than 1.3 m/second in the main channel during the spring. Substrate in the upper portion of Pool 13 is predominantly sand in channel habitats with mud and silt in backwaters. Rock and gravel areas are found near wing dams and closing dams, along riprapped areas and in a few naturally occurring areas. Vegetation is nonexistent or sparse in channel areas but can be quite abundant in backwater areas.

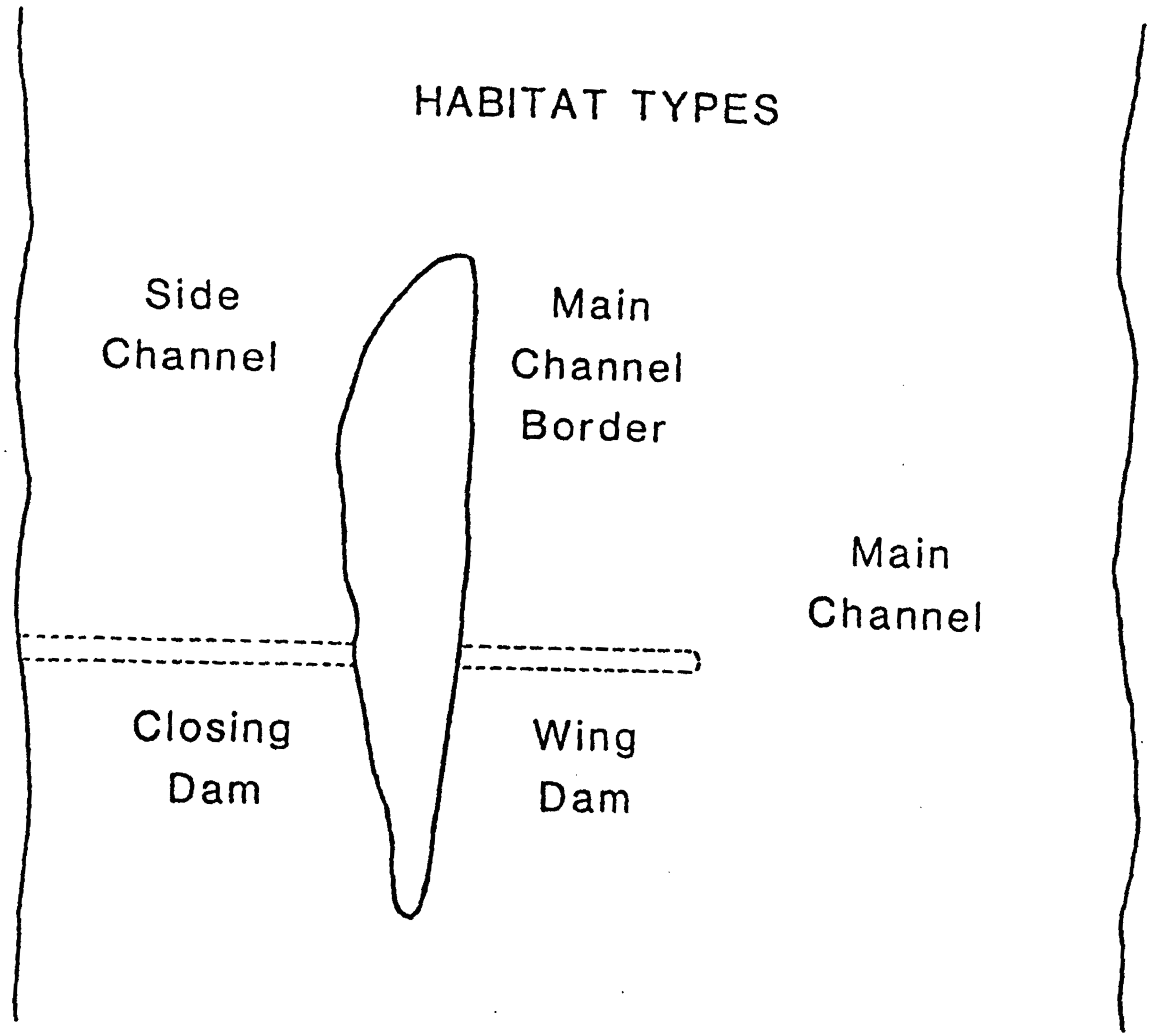

FIGURE 2. Channel habitats found in Pool 13 of the Upper Mississippi River

METHODS

Telemetry Equipment

Commercially available telemetry equipment was purchased from Dav-Tron Inc. of Minneapolis, Minnesota. Primary antenna system was a three element, 2.5 m^2 Yagi mounted on a 3 m aluminum conduit mast. Antenna elements were aligned perpendicular to the water surface. The receiver (Model DM-10) had a manual channel selector.

Transmitters (n=20) broadcast at 10 Khz intervals between the radio frequencies of 49.10 and 49.29 Mhz. Transmitters had an estimated lifespan of four months and an estimated range of 300-500 m at a depth of 2 m and a conductivity of 200 mhos. Prior to attachment, the transmitters were wrapped with three loops of stainless steel wire (1.3 mm diameter) and dipped in a plastic coating (Plastic tool grip compound, Brookstone's Tool Co., Peterborough, New Hampshire).

Finished transmitters were cylindrical in shape, weighed 35 g in air and 11 g in water, and measured 70 mm in length and 22 mm in diameter. A 25 cm whip antenna extended from each. Transmitters were externally attached using methods developed for shortnose sturgeon (Buckley 1982).

Tracking and Location

Radio-tagged sturgeon were tracked using a boat during daylight hours. Locations were attempted once a day, weather permitting. Searches were conducted on alternate sides of the main channel when moving upstream or downstream. Gross location of radio-tagged fish was achieved using the Yagi antenna. When sufficently close to radio-tagged fish, a 1000-ohm antenna load was connected which allowed the fish to be located within a 5-15 m circle. Location was achieved by the rise and loss of signal as the boat passed over the fish.

Fish locations were plotted directly on 1:4800 scale maps if close to known objects such as wing dams. Otherwise fish locations were plotted using triangulation on three or more landmarks using a hand-held compass. Depth and bottom contour were measured using a Vexilar-555 depth recorder. Current velocities at 25 cm above the bottom and 30 cm below the surface were measured using a cable mounted Teledyne-Gurley 622-E current meter. Substrates were sampled at a later time using a Peterson dredge. Other parameters recorded were date, transmitter frequency and habitat type.

Triangulations were plotted on COE hydrographic survey maps of Pool 13 (scale 1:4800) using a three-armed protractor. Distance from wing dams and closing dams was measured to the nearest 10 m as was distance from shore.

Distance traveled between locations was measured as the straight-line water distance between locations to the nearest 25 m. Rate of movement was calculated by dividing this distance by the time since the last location in days.

Trammel Netting

Relative abundance of shovelnose sturgeon in various habitats was asssessed using a bottom-drifting trammel net, 30.3 m x 1.8 m with a 9.5 mm diameter polyfoam float line and a 6.4 mm diameter leadcore bottom line. The net was composed of an inner panel of 3.8 cm multifilament nylon mesh enclosed within outer panels of 25.4 cm mesh. At each end was attached a 1.2 m wooden brail weighted with a 25 cm section of steel pipe at the lower end. The brails helped to spread the net vertically and to sink it rapidly to the bottom.

Brails were attached to 1.5 m x 25 cm wooden hydrofoil structures called mules, with 14 m of 9.5 mm nylon rope (additional line was added for spring drifts in the main channel). Mules were designed to catch the current so as to spread the net and pull it downstream. The net was set by placing a mule in the water and rapidly reversing the boat perpendicular to the current while spreading the net. The other mule was then set out and the net was allowed to drift until it snagged or approached a known obstacle.

Catch per unit effort (CPE) was calculated as the number of fish per drift (FPD) and number of fish per kilometer drifted (FPKD). Distance drifted was calculated using measured distances between landmarks, wing dams or buoys. Drifts ranged in length from 10 to 400 m and from 0.5 to 25 minutes in duration.

At each drift site, date, time, location, habitat type and length of drift were recorded and current velocities at the bottom and surface were measured. Substrates, bottom contours and water depths were measured at a later date.

Fish captured other than shovelnose sturgeon were identified to species, measured for total length and then released. All sturgeon captured were weighed to the nearest 5 g and fork lengths were measured to the nearest mm. Sturgeon over 350 mm FL were tagged with a serially numbered #3 monel strap tag affixed over the right pectoral fin about 1 cm from the body wall. Sturgeon under 350 mm were tagged with a #1 monel strap tag affixed in a similar manner. Tagged sturgeon were released near the capture site.

Tagged sturgeon were recaptured by trammel netting during the study, by Iowa Conservation Commission personnel and by commercial and sport fishermen. Return of tags by fishermen was facilitated by placing descriptive posters in bait shops and by frequent personal contacts with commercial fishermen. Tag descriptions were also given to conservation officers in surrounding counties. Distance moved by recaptured sturgeon was measured as the straight-line water distance (to the nearest 25 m) between capture locations (midpoints of drift sites). Sturgeon moving less than 100 m were considered to have exhibited no movement. Upstream and downstream movements were determined by the relative positions of the two capture locations.

Experimental sampling was conducted at three sites to determine shovelnose sturgeon relative abundance in three channel habitats: 1) main channel, 2) main channel border without wing dams and 3) main channel border with wing dams. These sites were 1) the tailwaters of Lock and Dam 12 (River Mile 556); 2) at a location known as the Sand Prairie (River Mile 550); and 3) downstream from the mouth of the Maquoketa River (River Mile 548). Sampling at the Maquoketa river site was suspended in mid-June due to low current velocities in wing dam habitats and abundant snags in main channel and main channel border habitats.

At least two drifts in each habitat type were made at each site during each sampling period. Sampling was conducted at two-week intervals between April and August, 1982. Sturgeon concentrations in other habitats were assessed using drifting trammel nets. Drift site selection was based on locations of radio-tagged fish or by trial drifts in new areas.

Data Analysis

Data were processed and analyzed using the Statistical Analysis System (SAS) (Helwig and Council 1979) operating on Iowa State University's AS/6 computer. A probability value of 0.05 was used as the level for rejection of the null hypothesis in all statistical tests. Differences among months, habitats and radio-tagged fish were determined using Kruskal-Wallis non-parametric procedures (Gibbons 1976). Chi-square goodness of fit tests were used to determine differences between spring and summer seasons in habitat utilization by radio-tagged sturgeon. The first week after tagging has been eliminated from analysis of radio-telemetry movement data to reduce possible effects of transmitter attachment. Non-parametric tests were used in most cases because of the the non-normal distributions of many of the parameters tested. Analysis of experimental drifts was done using the SAS General Linear Models procedure for a three-way analysis of variance (ANOVA). Data for the three-way ANOVA were transformed using a log (CPE+1) transformation (David Cox, Statistics Department, Iowa State University, Ames, personal communication).

RESULTS

River Conditions

Iceout occurred in mid-March and fieldwork commenced on March 24, 1982. Water levels were unusually high until mid-June in 1982. Peak water levels occurred in late April and early May with lowest levels in August. River stage in meters and water temperature in degrees Celsius during the study period are presented in Figure 3. Monthly means and ranges for river stage, discharge and water temperatures for March through August, 1982 are given in Table 1. To facilitate analysis of habitat data, the study period was divided into spring and summer periods. The spring period was from March 24 to June 20 while the summer period was from June 21 to August 21. Additional observations were made in September and October.

Telemetry

A total of 806 observations were made on 22 radio-tagged sturgeon, 587-689 mm Fl (mean=637 mm) and 755-1740 g (mean=1196 g). The first sturgeon was tagged on April 19, 1982, the 20th sturgeon on June 15. Two fish were later captured by fishermen and the tags were reattached to other sturgeon in July. Radio-tagged sturgeon were tracked an average of 79 days, range 13 to 130 days. Individual fish

FIGURE 3. River stage and water temperatures during the study period

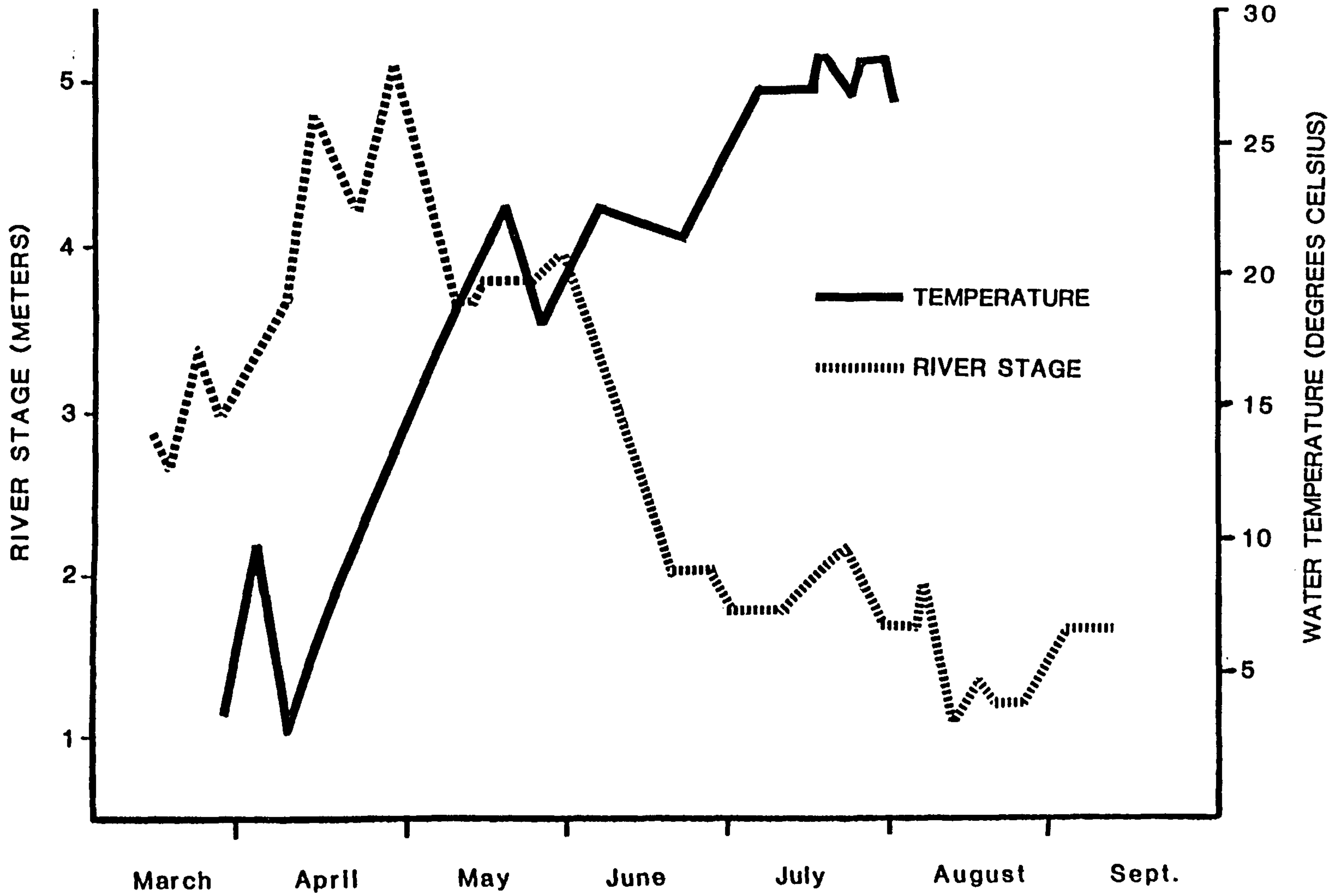
RIVER STAGE (METERS)
1
2
3
4
5
WATER TEMPERATURE (DEGREES CELSIUS)
5
10
15
20
25
30
TEMPERATURE
RIVER STAGE
March
April
May
June
July
August
Sept.

TABLE 1. Means and ranges of river stage, flow and water temperatures during the study period, March-August, 1982

Month	Stage (m)	Flow (m^3/s)	Temperature (C)
March	3.02 (2.59-3.31)	2,300 (1,390-2,650)	4.4 (3.6-7.5)
April	4.31 (3.29-5.09)	3,860 (2,650-4,740)	8.2 (2.2-14.0)
May	3.93 (3.66-4.82)	3,350 (2,960-4,390)	19.4 (15.0-22.5)
June	2.62 (1.88-3.80)	1,880 (1,190-3,170)	22.3 (21.0-24.5)
July	1.89 (1.59-2.14)	1,220 (920-1,470)	27.0 (24.0-28.0)
August	1.40 (1.13-1.89)	820 (80-1,270)	27.2 (27.0-27.5)

were located on 2 to 70 occasions, mean 37. Summary statistics for the radio-tagged fish are given in Table 2.

Some transmitters were very weak and therefore rarely located. Two fish were located less than five times and were excluded from further analysis. One, channel (ch.) 49.290, was released on May 12 and not located until May 25, 1982. This sturgeon had traveled 2.6 km downstream and across the main channnel to an area of main channel border adjacent to a riprapped area. Tag range was less than 25 m in 6 m water depth. Contact with this fish was lost 3 days

TABLE 2. Summary statistics of twenty-two radio-tagged sturgeon in Pool 13 of the Upper Mississippi River

Frequency	Tag Number	Fork Length	Weight	Tagging Date	Last Location	Days Tracked	# Obs
49.250	3975	660	1375	April 19	June 21	63	31
.200	3951	675	1285	April 20	Aug. 11	113	54
.120	3914	587	790	April 23	Sept. 4	105	48
.220	7533	608	1025	April 30	June 30	61	46
.160	3824	649	1285	May 1	July 3	63	49
.180	3979	627	1020	May 4	Sept. 5	124	71
.100	3620	649	1270	May 7	Aug. 1	86	28
.210	3747	629	1255	May 7	Aug. 21	106	56
.280	3928	661	1265	May 11	July 23	73	58
.270	7492	639	970	May 12	May 25	13	13
.290	3929	589	755	May 12	May 27	15	4
.240	8679	641	1095	May 13	Sept. 20	130	74
.190	8716	606	980	May 18	Sept. 5	110	62
.150	8671	614	1125	May 20	Aug. 21	93	68
.110	8825	682	1740	May 22	Aug. 11	81	25
.130	8891	632	1290	May 30	July 17	48	15
.140	8077	623	1100	May 31	Aug. 8	70	7
.260	8146	632	1170	June 9	Sept. 19	102	44
.230	7619	675	1625	June 13	June 27	14	6
.170	8409	623	1165	June 15	Sept. 19	96	2
.160	7656	689	1510	July 10	Sept. 4	56	32
.230	7924	629	1225	July 19	Sept. 5	48	13
Mean		637	1196			79	37
Standard Error		1.3	10.8			1.6	1.1
Range		587-689	755-1740			13-130	2-74

later. Another fish (ch. 49.170) was tagged on June 15, 1982 and was not located until September 19, 1982, a period of 96 days. This fish was located in the main channel about 15 m from the end of the wingdam on which it was captured, a lateral movement of 300 m. The transmitter was located only because of the close proximity of two other radio-tagged sturgeon on nearby frequencies since range was only 10 m. One instance of probable transmitter failure was observed after 13 days of tracking. This tag (ch. 49.270) intermittently pulsed for a few seconds on the day before contact was lost.

Trammel Netting Results

A total of 3501 fish of 23 different species were captured in 753 trammel net drifts (Table 3). Mean CPD was 4.65 fish (SE=0.26) with a median catch of two fish per drift. Up to 68 fish were caught in one drift with 575 (76.4%) of the drifts resulting in the capture of at least one fish. Total catch per drift exhibited a skewed distribution as shown in Figure 4.

Trammel netting in conjunction with radio-telemetry proved to be a successful technique for locating and capturing shovelnose sturgeon. A total of 2449 sturgeon were captured, mean 3.25 sturgeon per drift (SPD) (SE=0.21). Catches ranged up to 58 SPD, median catch of one SPD.

TABLE 3. Common and scientific names of 3501 fish captured in 753 trammel net drifts, March 24-October 19, 1982

Family Species	#	% Catch
Sturgeons-Acipenseridae		
Shovelnose sturgeon, *Scaphirynchus platorynchus*	2449	70.0
Lake sturgeon, *Acipenser fulvescens*	1	0.0
Paddlefishes-Polydontidae		
Paddlefish, *Polydon spathula*	1	0.0
Gars-Lepisosteidae		
Longnose gar, *Lepisosteus osseus*	57	1.6
Shortnose gar, *Lepisosteus platostomus*	2	0.0
Herrings-Clupeidae		
Gizzard shad, *Dorosoma cepedianum*	1	0.0
Mooneyes-Hiodontidae		
Goldeye, *Hiodon alosoides*	2	0.0
Mooneye, *Hiodon tergisus*	114	3.3
Pikes-Esocidae		
Northern pike, *Esox lucius*	1	0.0
Carps and Minnows-Cyprinidae		
Common carp, *Cyprinus carpio*	33	0.9
Suckers-Catostomidae		
Blue sucker, *Cycleptus elongatus*	7	0.2
Quillback, *Carpiodes cyprinus*	81	2.3
Smallmouth buffalo, *Ictiobus bubalus*	76	2.2
Silver redhorse, *Moxostoma anisurum*	4	0.1
Golden redhorse, *Moxostoma erythrurum*	6	0.2
Shorthead redhorse, *Moxostoma macrolepidotum*	117	3.3
Bullhead Catfishes-Ictaluridae		
Channel catfish, *Ictalurus punctatus*	56	1.6
Flathead catfish, *Pylodictus olivaris*	29	0.8
Temperate Basses-Percichthyidae		
White bass, *Morone chrysops*	8	0.2
Perches-Percidae		
Sauger, *Stizostedion canadense*	25	0.7
Walleye, *Stizostedion vitreum vitreum*	45	1.3
Drums-Sciaenidae		
Freshwater drum, *Aplodinotus grunniens*	375	10.7
	3501	100.0

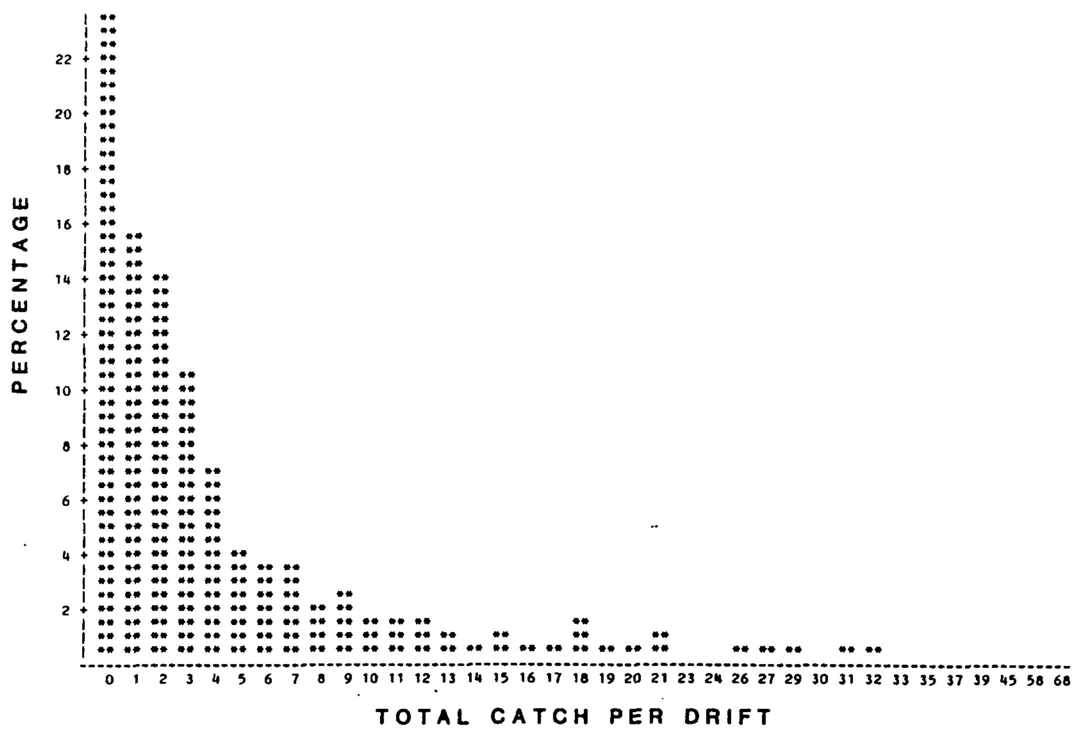

FIGURE 4. Frequency distribution of total catch per drift

Sixty-one percent of the drifts (n=462) were successful in catching sturgeon with 55% of the successful drifts (n=254) consisting entirely of shovelnose sturgeon. Sturgeon made up 70% of the total catch with lowest percentages of sturgeon in the nets occurring in April and the highest in May. The number of sturgeon per drift also exhibited a skewed distribution as illustrated in Figure 5.

Sturgeon caught in the trammel nets averaged 479 mm FL and 439 g, range 180 to 722 mm FL and 40 to 1740 g. Length-frequency distribution of sturgeon caught in the nets is given in Figure 6. Number of sturgeon caught per drift was

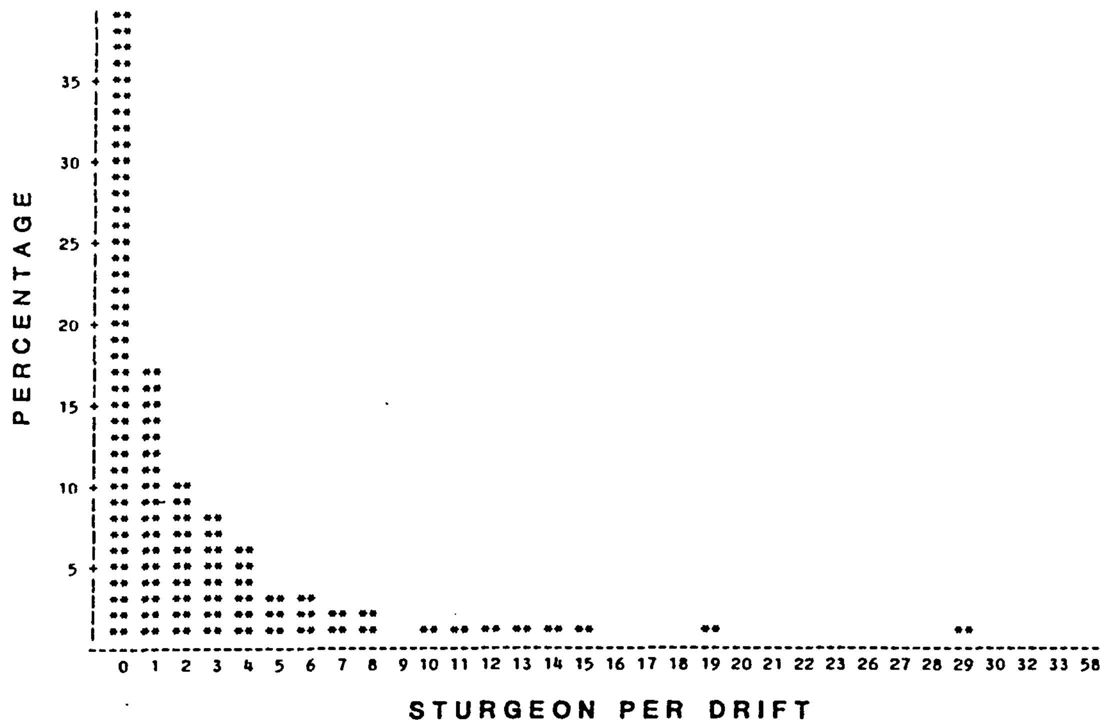

FIGURE 5. Frequency distribution of sturgeon caught per drift

positively correlated with Julian date (r=0.262, p<0.0001) and temperature in degrees Celsius (r=0.219, p<0.0001) and negatively correlated with surface current at sampling site (r=-0.14527, p<0.0292), river stage in meters above flat pool (r=-0.192, p<0.0001) and river flow in m^3/second (r=-0.190, p<0.0001). Percentage of sturgeon in the drifts was positively correlated with bottom currents at drift sites (r=0.160, p<0.025) and temperature in degrees Celsius (r=0.200, p<0.0001).

Up to seven species of fish were captured in one drift of the trammel net; median catch was one species (mean=1.35,

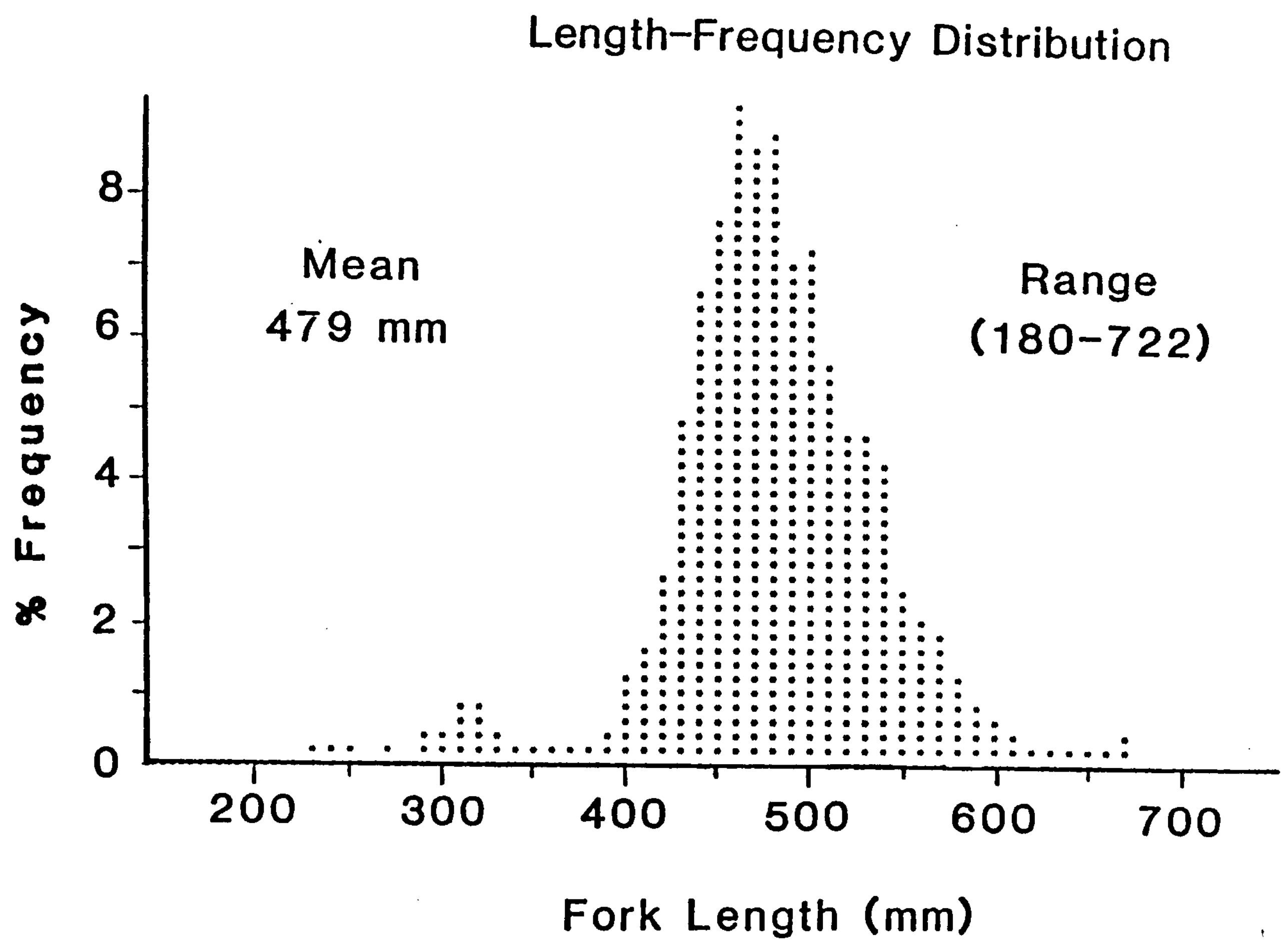

FIGURE 6. Fork length-frequency distribution of shovelnose sturgeon (n=2397) captured in drifted trammel nets, 1982

SE=0.04). The second most abundant species captured in trammel nets was freshwater drum, 10% of the total catch (Table 3). Drum were most common during the summer months. Shorthead redhorse was third in abundance (3.3%), followed by mooneye (3.3%). Mooneye were captured almost exclusively in the spring. Other common species included quillback (2.3%) and smallmouth buffalo (2.2%).

Sport fish species made up a small percentage of the catch. These included channel catfish (1.6%), walleye (1.3%), flathead catfish (0.8%), sauger (0.7%) and white bass (0.2%). Channel catfish and walleye occurred most frequently in the spring. Almost half (n=21) the walleye captured were running ripe males captured in one drift along a main channel border area (River Mile 550) on April 21, 1982. A few large catches of longnose gar also increased their relative abundance. One drift below a wing dam in April resulted in the capture of 17 gar while a drift onto a closing dam in October resulted in the capture of 18 gar.

Some species were captured only in small numbers (1 or 2 specimens): shortnose gar, northern pike, gizzard shad and paddlefish. Several species listed as rare or uncommon in Pool 13 (Rasmussen 1979) were captured: golden redhorse (n=6), silver redhorse (n=4), goldeye (n=2) and blue sucker (n=6). One endangered species (Iowa and Illinois), a lake sturgeon (FL=456 mm, weight=1260 g), was captured in a drift below a wing dam along with four shovelnose sturgeon on May 18, 1982. This fish was photographed, tagged with a monel tag (tag #8999) and released. Total CPD of all species was positively correlated with Julian date ($r=.027$, $p<0.0001$) and negatively correlated with surface currents at drift site ($r=-0.157$, $p<0.0164$), river stage (meters above flat pool) ($r=-0.225$, $p<0.0001$), and river discharge in cubic meters/second ($r=-0.220$, $p<0.0001$).

Tagging Results

A total of 2385 sturgeon were tagged in Pool 13 during 1982 and 148 (6.2%) were recaptured, including 9 radio-tagged fish. Summaries of number of sturgeon caught, tagged and recaptured are given by gear type (Table 4) and by month (Table 5). Drifted trammel nets produced the greatest number of recaptured sturgeon. Commercial fishermen returned 10 monel tags and one radio-tag. One commercial fisherman returned 9 tags while another turned in one tag and reported discarding a radio-tag in the trash. Commercial returns were low since most of the effort for sturgeon was expended in May and June and almost half the tagging in the pool occurred after this date.

TABLE 4. Number of sturgeon caught, tagged and recaptured by gear type

Gear Type	Caught	Tagged	Recaptures Monel	Recaptures Radio	Recaptures Tag Loss
Drifted Trammel	2449	2261	106	7	10
Frame Nets	97	90	5	0	0
Set Trammel	34	27	6	0	0
Fishermen	-	-	12	2	0
Otter Trawl	9	7	0	0	0
Total	2589	2385	129	9	10

TABLE 5. Summary figures of number of sturgeon caught, tagged and recaptured by month

	April	May	June	July	Aug	Sept	Oct	Total
Caught	163	740	542	595	369	93	87	2589
Tagged	154	698	497	557	332	68	80	2385
Radio-Tagged	4	13	3	2	0	0	0	22
Recaptures								
Study								
Monel	4	14	26	26	30	12	5	117
Radio	0	0	1	3	2	0	1	7
Tag loss	0	0	0	7	2	1	0	10
Fishermen								
Commercial	0	0	11	0	0	0	0	11
Sport	0	0	0	2	1	0	0	3

Movements

The distribution of shovelnose sturgeon movements (m/day) exhibited a skewed distribution (Figure 7) with little or no movement much of the time and a low frequency of long movements. Forty-eight percent of the observations were of sturgeon moving less than 50 m/day. Radio-tagged sturgeon moved an average of 339 m/day (SE=33), median=50 m/day, with movements of up to 11.7 km/day observed.

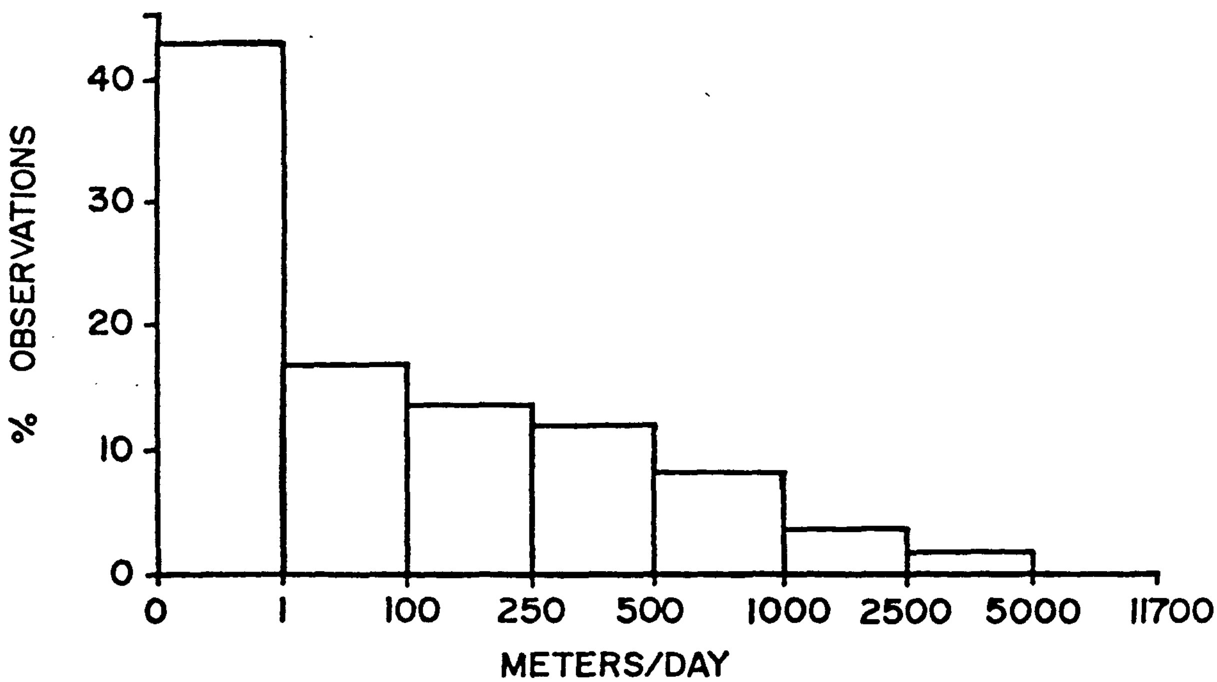

FIGURE 7. Movement rate frequency distribution (n=653) of radio-tagged shovelnose sturgeon

Recaptured strap tagged sturgeon traveled an average of 1717 m (SE=261.4) with a range of <50 m to 12.85 km (median=425 m). No movement was exhibited by 28.4% of recaptured sturgeon. Time between captures ranged from 6 hours to 111 days (mean=40 days, SE=2.8). Movement per day averaged 89 m/day (SE=20.1) with a high of 1440 m/day.

Movement Rate Differences

Calculations of movement rates are complicated by varying times between locations. For this reason, I have subdivided the telemetry data into movements with one day between locations, with 2-3 days between locations and with more than 3 days between locations. Significant differences in movement rates (m/day) between sampling months were noted for radio-tagged sturgeon with one day between observations (Kruskal-Wallis Chi-square approximation (x^2)=24.05, $p<0.0002$), for 2-3 days between observations (x^2=11.75, $p<0.0193$) and for 3 or more days between observations (x^2=16.25, $p<0.0062$). Mean distance moved per day by radio-tagged sturgeon in the months of April through September are given in Table 6 for three classifications of time between locations.

Radio-tagged sturgeon were most active during May, the spawning season, moving 600 m/day (SE=115). The second most active month was July, mean movement 277 m/day (SE=54). Lowest movement rates occurred in August (mean=73 m/day, SE=40) and June (mean=209 m/day, SE=76). Mean movement rates of radio-tagged sturgeon with one day between locations are depicted in Figure 8. An example of a mobile sturgeon (ch. 49.160) during May is depicted in Figure 9.

TABLE 6. Mean, (SE) and sample sizes of monthly movement rates (in meters) of radio-tagged sturgeon, April-September, 1982

		Time Between Locations		
Month	Overall	1 day	2-3 Days	>3 Days
April	255 (255) 4	0 (0) 3	1020 (-) 1	- - -
May	705 (107) 131	600 (115) 101	1092 (265) 29	120 (-) 1
June	231 (54) 235	209 (76) 158	259 (60) 62	348 (81) 15
July	314 (51) 173	277 (54) 117	360 (133) 42	448 (176) 14
August	204 (39) 96	173 (40) 70	327 (153) 14	242 (113) 12
September	24 (12) 14	0 (0) 5	- - -	36 (17) 9
Total	339 (33) 653	299 (40) 454	450 (72) 148	302 (60) 51

Mean movements of sturgeon strap tagged and recaptured in the same month exhibited a distribution similar to that of radio-tagged sturgeon (Figure 10). Significant differences also existed in distance traveled by recaptured

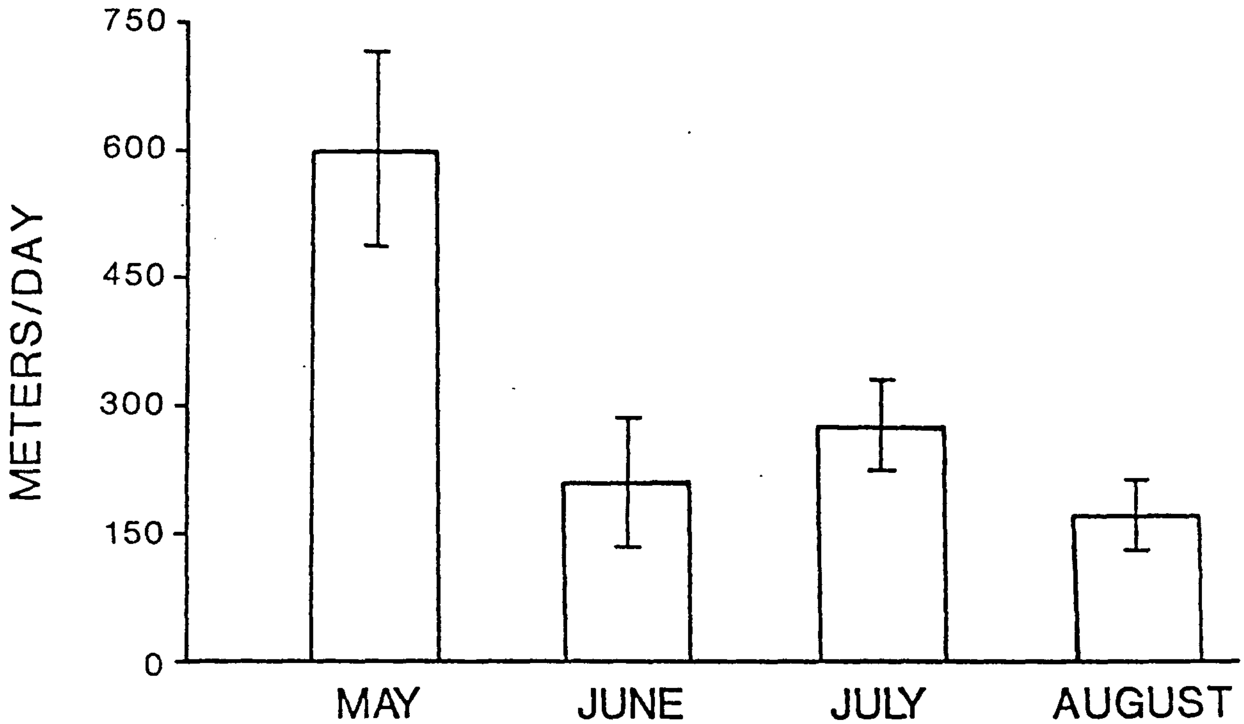

FIGURE 8. Mean monthly movement rates (±SE) of twenty radio-tagged sturgeon

fish between months of tagging (x^2=11.41, p<0.0439). Highest rates of movement for these fish occurred in May with low rates of movement in April, June and August.

Direction Traveled

No significant differences in direction moved (i.e., upstream or downstream) were noted among study months for radio-tagged sturgeon (x^2=2.14, d.f.=5, p<0.8297). Mean distance traveled by radio-tagged sturgeon was greater when moving downstream (mean=815 m, SE=123, max.=11.7 km) than when moving upstream (mean=540 m, SE=53, max.=10.8 km).

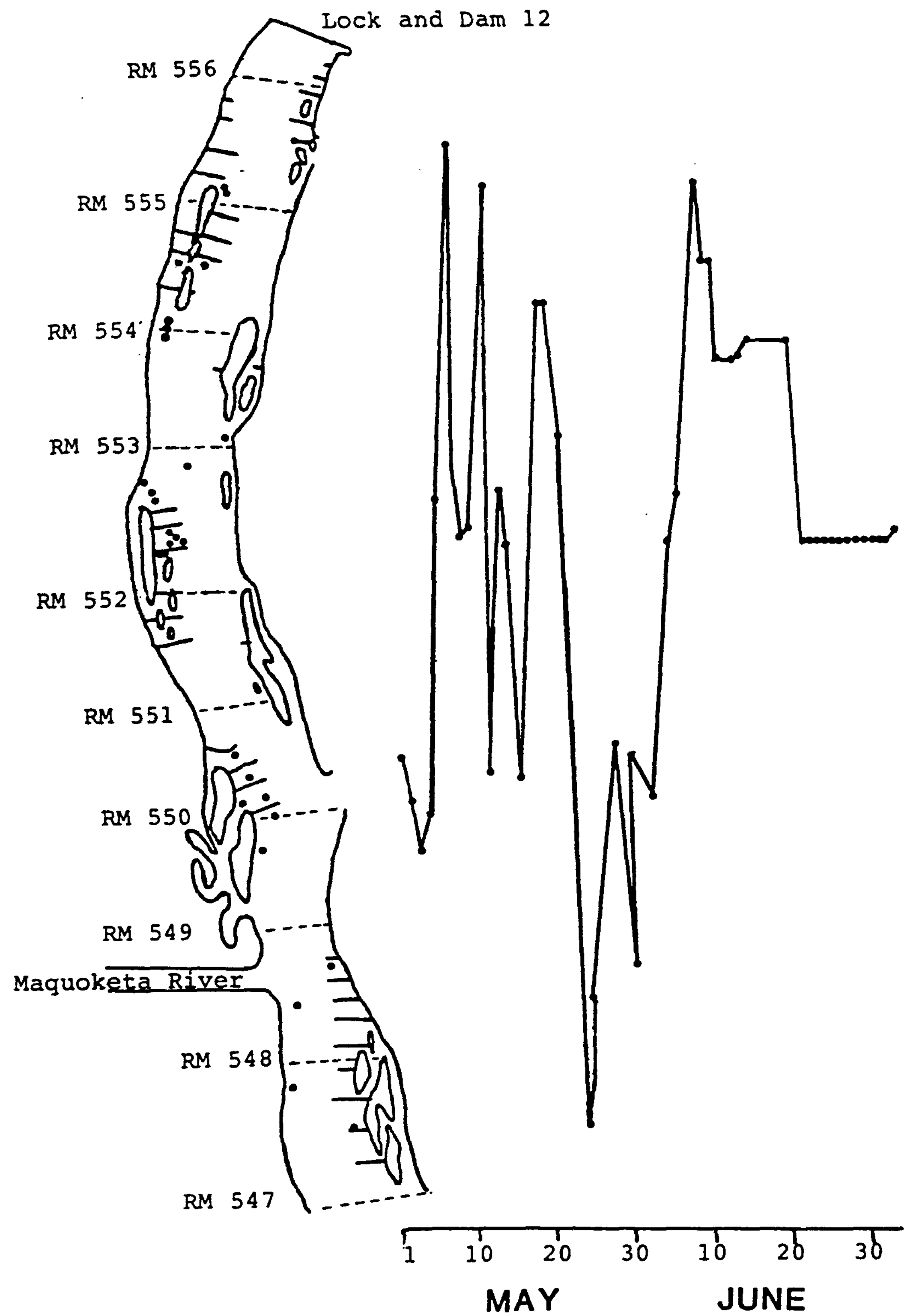

FIGURE 9. An example of a mobile shovelnose sturgeon (ch. 49.160)

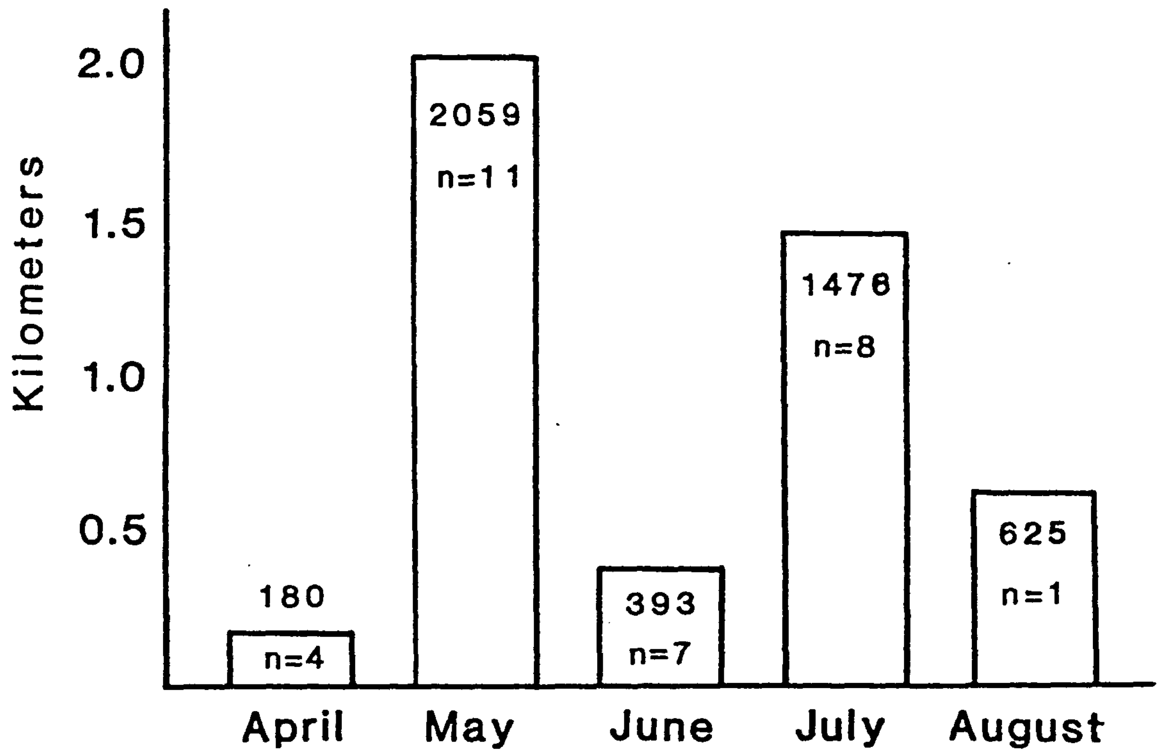

FIGURE 10. Mean movement of sturgeon strap tagged and recaptured during the same month

Sturgeon moved more often upstream (30.6%) than downstream (21.1%). Downstream movements were greater in magnitude in all months except July. Highest percentages of upstream movements (35.9%) occurred in May. Mean rate of movement by direction of travel for radio-tagged sturgeon in April-September, 1982 is given in Table 7.

Recaptured strap tagged sturgeon traveled upstream 29.3% of the time (mean distance=2386 m, SE=552) and downstream 42.2% of the time (mean distance=2404 m, SE=430). Upstream distance traveled and percentage movements were greatest in magnitude for sturgeon tagged in May.

TABLE 7. Mean rate of movement in meters/day, (SE) and sample size by direction of travel for 20 radio-tagged sturgeon, April-September, 1982

Month	# Obs.	Upstream Distance	Upstream %	Downstream Distance	Downstream %	No Movement
April	4	-	-	1020	25.0	75.0
May	131	821 (139)	35.9	1533 (299)	26.7	37.4
June	235	403 (53)	28.5	727 (312)	15.7	55.7
July	173	569 (119)	32.9	518 (105)	23.7	43.3
August	96	410 (108)	25.0	417 (85)	24.0	51.0
September	14	46 (26)	35.7	86	7.1	57.1
Total	653	540 (53)	30.6	815 (123)	21.1	48.2

Downstream distance traveled and percentages were greatest for fish tagged in June. Downtream movements were greater than upstream movements in magnitude in all months except May. Mean distance traveled by direction of travel and month for recaptured sturgeon are given in Table 8.

Distance between farthest upstream and downstream locations gives an indication of the range of individual fish. Radio-tagged sturgeon ranged over 1.9 to 21.7 km of

TABLE 8. Mean distance traveled (SE) between captures by month of tagging for 116 recaptured sturgeon, April-September, 1982

Month	# Obs.	Upstream Distance	Upstream %	Downstream Distance	Downstream %	No Movement
April	16	552 (105)	25.0	1689 (959)	50.0	25.0
May	40	3480 (802)	42.5	1874 (653)	30.0	27.5
June	26	714 (219)	30.8	3227 (968)	50.0	19.2
July	26	283 (49)	33.1	2363 (898)	24.2	42.7
August	6	-	-	3040 (2488)	50.0	50.0
September	2	-	-	-	-	100.0
Total	116	2386 (552)	29.3	2404 (430)	42.2	28.4

river with a mean range of 10.8 km (SE=0.34). Sturgeon with less than five observations or those at large for less than 30 days have been excluded. Radio-tagged sturgeon were located from River Mile 556.5, immediately downstream from Lock and Dam 12 to River Mile 541.7 while sturgeon were captured in drifted trammel nets from immediately downstream from Lock and Dam 12 to River Mile 541.

Radio-tagged sturgeon showed no interpool movement during the study period. Nor were any recaptures reported from outside the pool during 1982. In 1983, one monel tagged fish was recaptured (distance traveled >43 km) below Lock and Dam 11 in Dubuque, Iowa (Walter Duccine, commercial fisherman, Dubuque, Iowa, personal communication) and four tagged sturgeon were recaptured (distance traveled 182-190 km) below Lock and Dam 17 (Al Van Vooren, Iowa Conservation Commission, Fairport, personal communication).

Homing has been defined as the return of an animal to a previously occupied area (Gerking 1959). Eight sturgeon exhibited homing behavior to capture locations or previously used areas after long excursions away from these areas. Two sturgeon stayed within a restricted stretch of the river and exhibited short-range homing. An example of homing in shovelnose sturgeon is depicted in Figure 11.

Habitat Associations

Areas outside of the main channel offered the most important habitat for shovelnose sturgeon during this study. Areas near wing dams and closing dams were especially important. Radio-tagged sturgeon exhibited significant differences in habitat associations between the spring and summer seasons (Chi-square=231.63, $p<0.0001$, d.f.=9). Spring and summer habitat use by radio-tagged sturgeon is presented in Figure 12.

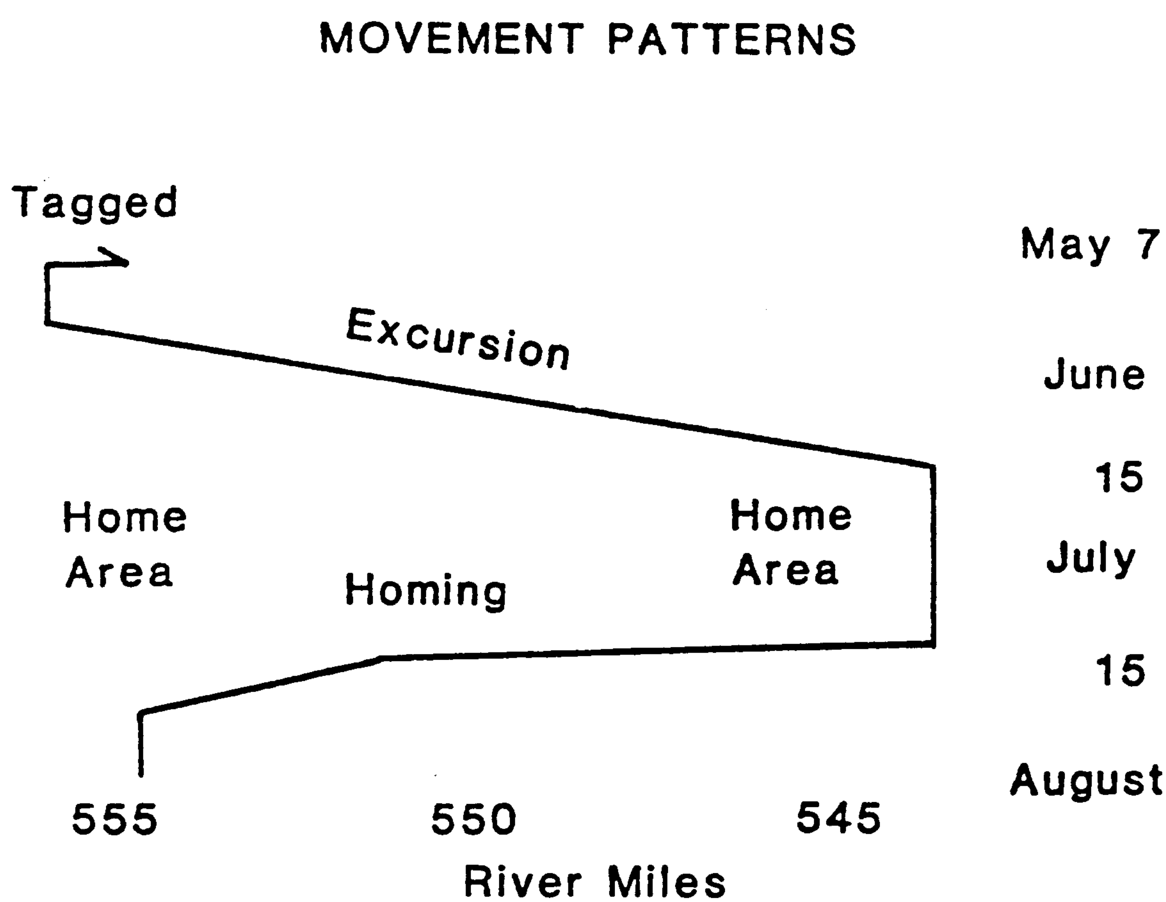

FIGURE 11. An example of homing behavior in shovelnose sturgeon

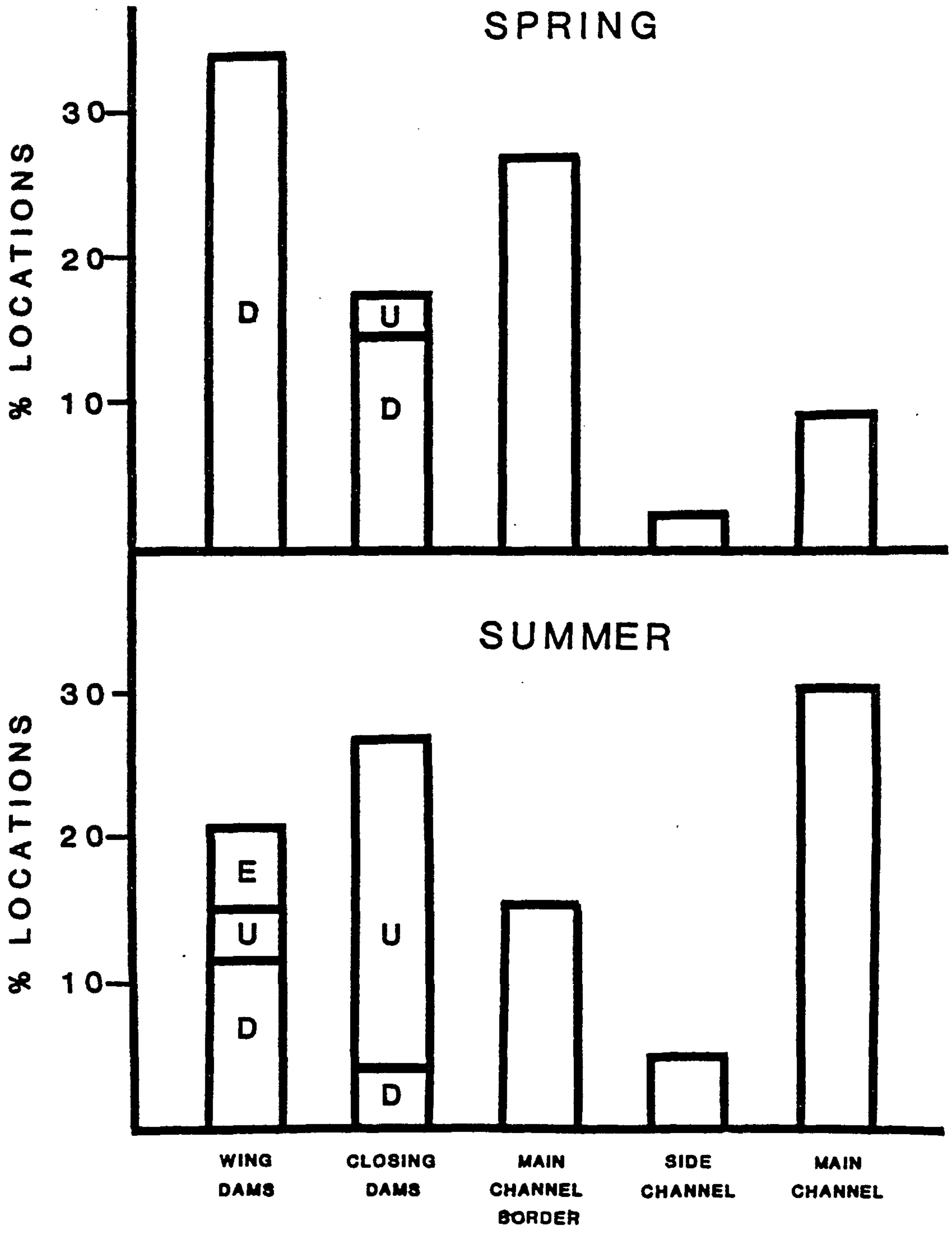

FIGURE 12. Shovelnose sturgeon habitat usage in the spring (n=399) and summer (n=400) of 1983 (D=downstream, U=upstream, E=ends)

Experimental Drifts

Habitat shifting by shovelnose sturgeon was shown by experimental drifts in main channel, main channel border and wing dam habitats. Significant differences in sturgeon numbers per kilometer drifted were detected between habitats ($F=3.69$, $d.f.=2$, $p<0.0280$) and two-week periods ($F=4.68$, $d.f.=8$, $p<0.0001$); however interaction between periods and habitats ($F=5.02$, $d.f.=16$, $p<0.0001$) was also detected. Catch of sturgeon per kilometer drifted by habitat type and period are depicted in Figure 13. These differences are best illustrated by dividing the experimental period into spring and summer periods. Mean catches and current velocities in each habitat are given in Table 9.

Spring Habitat Associations

Spring, 1982 was characterized by high river stages and fast currents. During this period, sturgeon were captured and located most frequently in sheltered areas away from the main channel. Radio-tagged sturgeon were located most frequently below wing dams (34.3%), below closing dams (15.5%) and in main channel border habitats (27.1%). Only 9.3% of the locations were made in main channel habitats. The number and percentage of spring locations in each habitat type, along with measured habitat variables in each, are presented in Table 10. Spring locations of radio-tagged sturgeon are presented in Figures 14 and 15.

TABLE 9. Mean number of sturgeon per drift (SPD), sturgeon per kilometer drifted (SPKD), and current velocities (cm/s) for experimental drifts in three channel habitats

Season / Habitat	# Drifts	SPD	SPKD	Current Velocity: Bottom	Current Velocity: Surface
Spring					
Wing Dam	45	2.6	28	33	61
M. C. Border	37	4.8	25	37	65
Main Channel	27	0.5	7	37	79
Total	109	2.8	26	36	66
Summer					
Main Channel	20	3.7	38	29	58
Wing Dam	33	0.4	7	17	27
M. C. Border	31	0.0	0	23	27
Total	84	1.7	17	25	47

Shovelnose sturgeon were captured in greatest numbers in trammel net drifts below closing dams (mean number of sturgeon per kilometer drifted (SPKD)=38, SE=5.1), but sturgeon were also frequently captured in main channel border habitats (mean SPKD=26, SE=7.3) and below wing dams (mean SPKD=23.5, SE=3.27). Low catches occurred in main channel habitats (mean SPKD=5, SE=2.01). Mean catches of sturgeon per drift and sturgeon per kilometer drifted are summarized in Table 11 along with mean current velocities in these habitats.

Sturgeon made up the greatest percentages of the catch in drifts below closing dams (77.2%) and below wing dams

FIGURE 13. Mean number of sturgeon per kilometer drifted for experimental drifts in three channel habitats

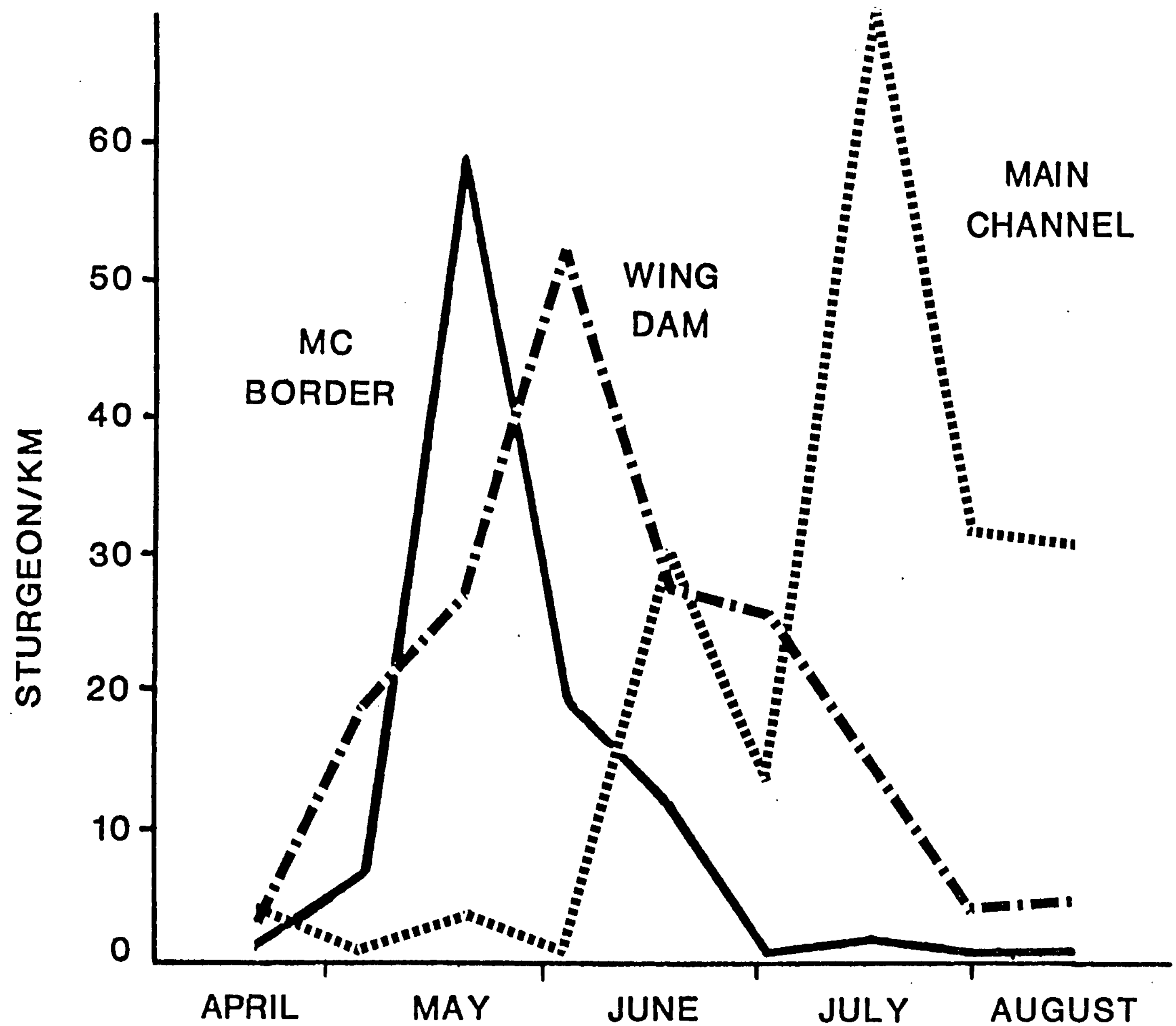
STURGEON/KM
0
10
20
30
40
50
60
APRIL
MAY
JUNE
JULY
AUGUST
MC
BORDER
WING
DAM
MAIN
CHANNEL

TABLE 10. Locations of radio-tagged sturgeon in channel habitats of Pool 13 and mean (SE) habitat variables, April 19-June 20, 1982

Habitat	#	%	Depth (m)	Bottom (cm/s)	Surface (cm/s)
Below Wing Dams	137	34.3	4.5 (0.17)	37 (1.0)	65 (2.0)
Main Channel Border	108	27.1	5.4 (0.19)	41 (1.6)	76 (2.2)
Below Closing Dams	62	15.5	4.0 (0.12)	33 (2.2)	63 (2.0)
Main Channel	37	9.3	7.3 (0.39)	38 (3.7)	92 (4.8)
Above Wing Dams	30	7.5	4.3 (0.31)	37 (2.3)	64 (7.8)
Above Closing Dams	14	3.5	4.3 (0.0)	20 (0.0)	50 (0.0)
Side Channel	10	2.5	4.3 (0.32)	39 (4.9)	52 (5.4)
Wing Dam End	1	0.3	5.1	37	71
Overall	399	100.0	5.1 (0.11)	37 (0.7)	71 (1.3)

(76.3%). Lowest percentages of sturgeon in drifts occurred in side channel (2.4%), main channel (47.1%) and main channel border habitats (54.6%) (Table 12).

Experimental drifts in main channel, main channel border and wing dam habitats resulted in the greatest catches below wing dams (mean SPKD=28, SE=5.8) and in main

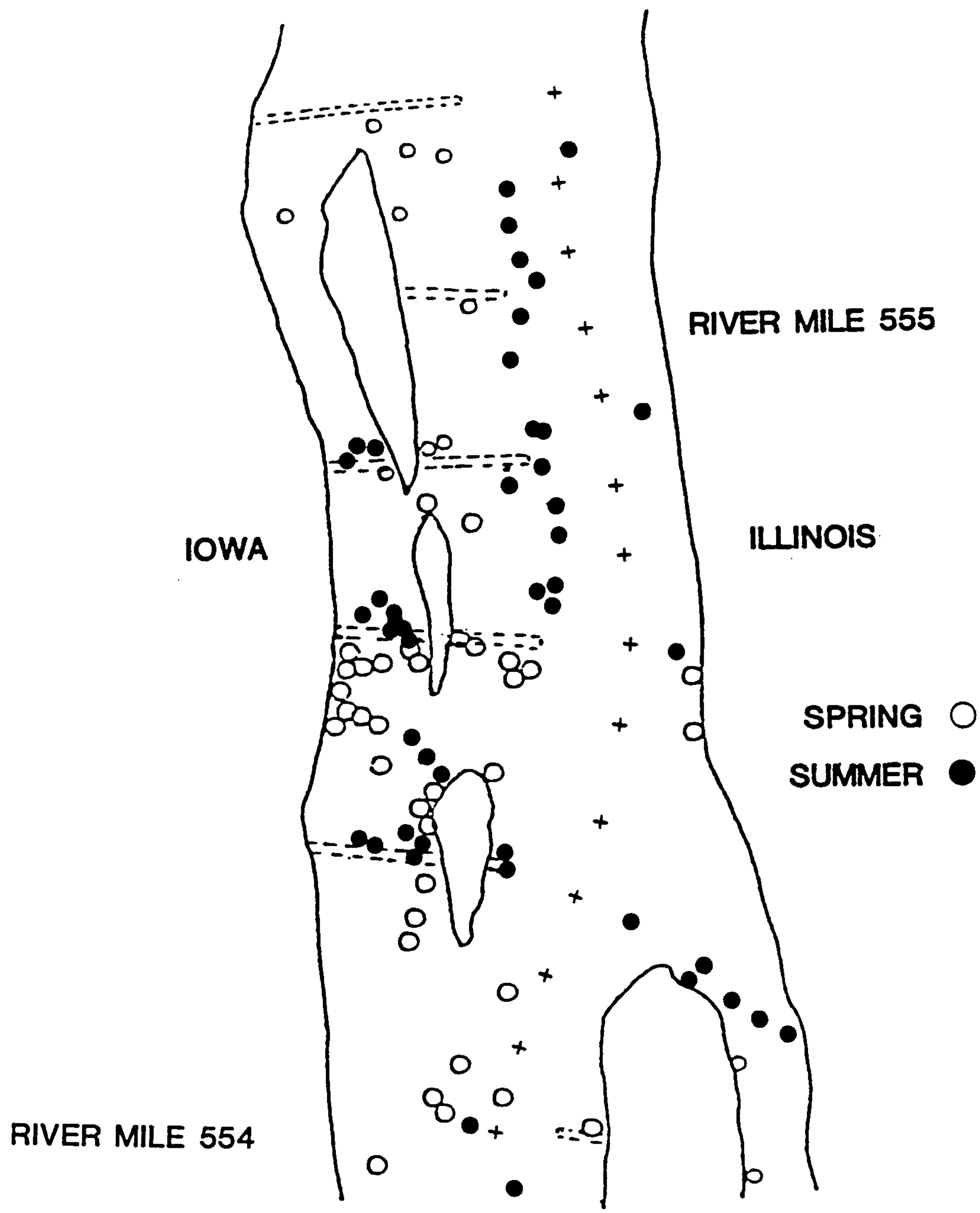

FIGURE 14. Spring and summer locations of radio-tagged shovelnose sturgeon near River Mile 555

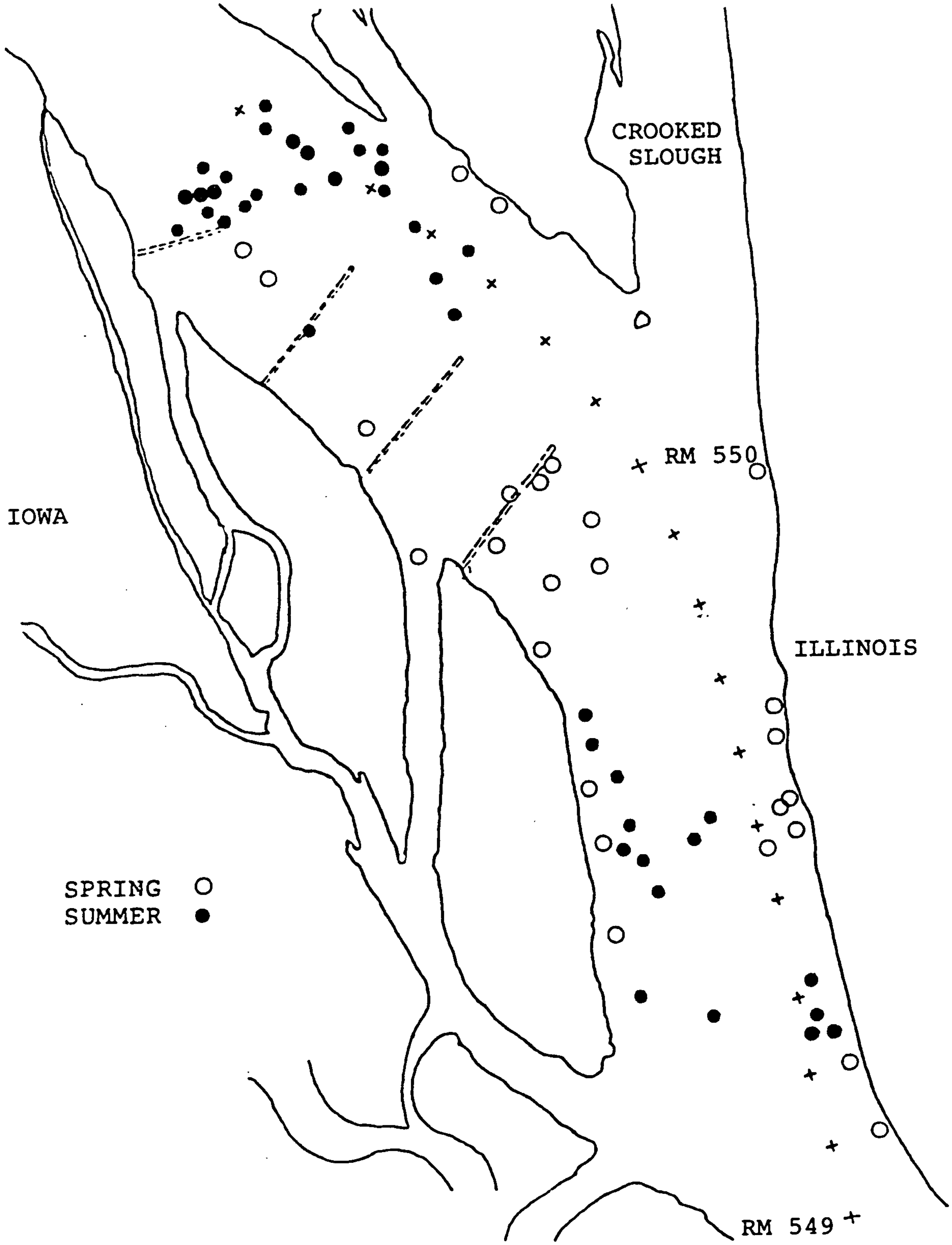

FIGURE 15. Spring and summer locations of radio-tagged shovelnose sturgeon near River Mile 550

TABLE 11. Mean catches of shovelnose sturgeon per drift and per kilometer drifted in channel habitats of Pool 13, March 24-June 20, 1982

Habitat	# Drifts	SPD	SPKD	Current Velocity Bottom	Current Velocity Surface
Below Closing Dams	149	2.9 (0.32)	38 (5.1)	44 (2.0)	66 (2.0)
Main Channel Border	77	3.4 (0.95)	26 (7.3)	35 (2.1)	69 (4.9)
Below Wing Dams	199	2.2 (0.22)	24 (3.3)	38 (1.4)	62 (2.3)
Main Channel	53	0.5 (0.15)	5 (2.0)	37 (2.5)	90 (5.2)
Side Channel	6	0.2 (0.2)	4 (4.2)	40 (5.8)	60 (5.8)
Other	7				
Spring Overall	491	2.4 (0.21)	26 (2.4)	39 (1.0)	69 (1.8)

channel border areas (mean SPKD=25, SE=9.6). Few sturgeon were captured in main channel habitats (mean SPKD=6, SE=3.4) (Table 9).

Summer Habitat Associations

During the summer, radio-tagged sturgeon were located most frequently in main channel habitats (30.4%) and on the upstream side of closing dams (23.0%). Areas near or between wing dams were also heavily utilized. Areas below

TABLE 12. Medians, ranges and and percentages of sturgeon in drifted trammel net catches in channel habitats, March 24-June 20, 1982

Habitat	Percent Sturgeon	Sturgeon per Drift		Sturgeon per km Drifted	
		Median	Range	Median	Range
Below Closing Dams	77.2	1	0-27	20	0-270
Main Channel Border	54.6	1	0-58	20	0-290
Below Wing Dams	76.3	1	0-19	8	0-240
Main Channel	47.1	0	0-2	0	0-40
Side Channel	2.4	0	0-1	0	0-17
Spring	69.9	1	0-58	8	0-290

wing dams accounted for 11.5% of the observations with areas above wing dams (3.7%) and beyond the ends of wing dams (5.7%) also being used. Many observations in main channel areas were also near wing dam ends. Numbers and percentages of locations along with measured habitat variables are presented in Table 13. Summer locations of radio-tagged sturgeon are presented in Figures 14 and 15.

Shovelnose sturgeon were captured most frequently in drifts onto closing dams, along the ends of wing dams and in drifts along a riprapped bank on the outside of a bend. Drifting a

TABLE 13. Locations of radio-tagged shovelnose sturgeon in channel habitats of Pool 13 and mean (SE) habitat variables, June 21-September 19, 1982

Habitat	Locations #	Locations %	Depth (m)	Bottom (cm/s)	Surface (cm/s)
Main Channel	122	30.4	5.1 (0.13)	34 (1.2)	63 (1.9)
Above Closing Dams	92	23.0	2.6 (0.12)	26 (0.8)	44 (1.3)
Main Channel Border	62	15.5	4.0 (0.21)	25 (1.7)	43 (2.4)
Below Wing Dams	46	11.5	3.2 (0.21)	30 (0.7)	44 (1.7)
Wing Dam Ends	23	5.7	4.9 (0.14)	34 (0.8)	53 (3.0)
Side Channel	20	5.0	3.0 (0.22)	23 (2.2)	29 (3.1)
Below Closing Dams	16	4.0	2.4 (0.19)	29 (3.5)	45 (4.7)
Above Wing Dams	15	3.7	4.2 (0.38)	30 (1.0)	51 (4.5)
Total	400	100.0	3.8 (0.08)	29 (0.5)	50 (0.9)

net short distances (10-25 m) onto closing dams resulted in the largest numbers of sturgeon caught per kilometer drifted (mean SPKD=296, SE=74). Large catches (mean SPKD=144, SE=66) also resulted from drifts at the edge of the main channel along wing dam ends. A riprapped area on the outside of a river bend with a substrate of rubble and packed sand (mean current velocity at bottom=30 cm/second, surface=64 cm/second) also produced large catches of sturgeon (mean SPKD=114, SE=18) during the summer months. Mean catches and current velocities in channel habitats are presented in Table 14.

Percentages of sturgeon in the catch were greatest in drifts along the ends of wing dams (88.6%) and in drifts onto closing dams (73.8%). Lowest percentages of sturgeon in the catch occurred in drifts in the main channel border (40%), below wing dams (53.5%) and above wing dams (51.5%) (Table 15).

Greater concentrations of sturgeon in or near the main channel during the summer was also shown by experimental drifts in three habitat types. Summer drifts were more successful in main channel habitats (mean SPKD=38, SE=10.7) than in wing dam or main channel border habitats (mean SPKD=0.3, SE=0.26). Current velocities in wing dam and main channel border habitats were much lower than those found in the main channel (Table 9).

Significant differences among habitats were detected in fork lengths (x^2=135.49, d.f.=7, p<0.0001) and weights (x^2=149.09, d.f.=7, p<0.0001) of sturgeon captured in trammel net drifts during the summer. The smallest sturgeon were captured in drifts in the main channel (mean FL=453 mm,

TABLE 14. Mean catches per drift and per kilometer drifted of shovelnose sturgeon in channel habitats of Pool 13, June 21-October 19, 1982

Habitat	# Drifts	SPD	SPKD	Current Velocity (cm/second) Bottom	Surface
Above Closing Dams	32	9.4 (1.3)	296 (74)	27 (1.4)	41 (1.4)
Wing Dam Ends	12	15.8 (3.2)	144 (66)	28 (2.3)	59 (4.4)
Riprapped Bend	12	11.8 (2.2)	114 (18)	30 (3.6)	64 (10.7)
Below Closing Dams	19	3.5 (0.8)	69 (18)	23 (2.7)	33 (2.1)
Main Channel Border	54	5.0 (1.2)	55 (16)	26 (1.9)	50 (3.5)
Above Wing Dams	17	2.1 (0.7)	52 (37)	25 (5.0)	45 (5.0)
Main Channel	55	3.4 (0.6)	30 (7)	32 (1.6)	60 (2.0)
Below Wing Dams	56	1.4 (0.3)	16 (4)	21 (2.2)	34 (3.8)
Side Channel	2	0.0	0		
Total	262	4.7 (0.4)	74 (11)	27 (0.8)	47 (1.5)

mean weight=387 g) and along the ends of wing dams (mean FL=455 mm, mean weight=358 g). Larger sturgeon were captured in drifts onto closing dams (mean FL=509 mm, mean

TABLE 15. Medians, ranges and percentages of sturgeon in drifted trammel net catches in channel habitats, June 21 to October 19, 1982

Habitat	Percent Sturgeon	Sturgeon per Drift		Sturgeon per km Drifted	
		Median	Range	Median	Range
Wing Dams Ends	88.6	13	1-30	84	20-600
Above Closing Dams	73.8	8	0-28	160	40-1400
Below Closing Dams	73.8	3	0-14	80	0-200
Riprapped Bend	71.0	10	4-33	100	36-260
Main Channel	69.0	2	0-21	20	0-300
Below Wing Dams	53.5	1	0-15	40	0-140
Above Wing Dams	51.5	1	0-12	40	0-300
Main Channel Border	40.0	0	0-29	0	0-580
Summer	60.1	2	0-33	20	0-1400

weight=521 g), along a riprapped bank on an outside bend (mean FL=509 mm, mean weight=534 G) and in main channel border habitats (mean FL=507 mm, mean weight=507 g).

Physical Variables

Water Depth

Shovelnose sturgeon were located in water depths from 1 to 10 m; mean depth at location sites was 4.4 m (SE=0.07). One-half of the observations occurred between 4 and 6 m (Figure 16). Significant differences in water depths at location sites (x^2=117.18, d.f.=5, p<0.0001) were noted between months from April through September. Locations at depths greater than 6 m occurred most often during the spring, while shallower depths were frequented more during the summer. Depth at location site showed a positive correlation with river stage (r=0.48, p<0.0001).

Current Velocity

Surface current velocities at location sites ranged from 10 to 130 cm/second, mean 59 cm/second (SE=0.9). Sturgeon were most commonly located at surface current velocities between 40 and 70 cm/second (Figure 17). Significant differences in surface current velocity between months were noted (x^2=170.45, d.f.=5, p<0.0001), with highest velocities during the spring and lowest during the summer. Surface velocities at location sites were positively correlated (r=0.63, p<0.0001) with river flow in m^3/second.

Bottom current velocities ranged from 5 to 65 cm/second

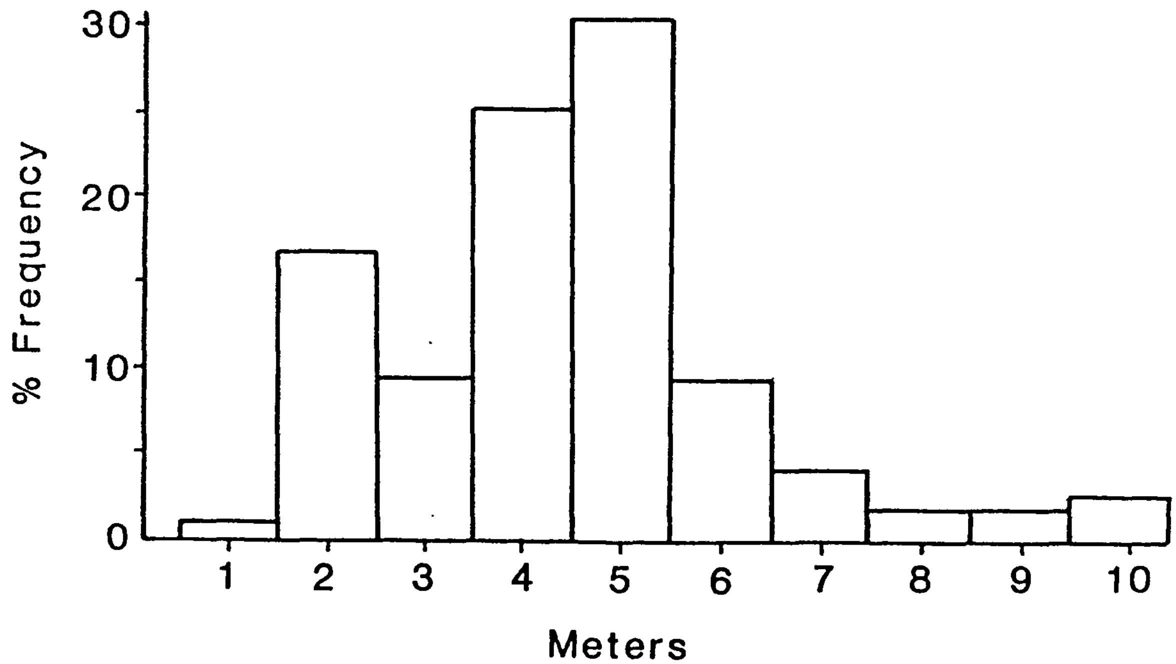

FIGURE 16. Water depths measured (n=557) at location sites of radio-tagged sturgeon

at sturgeon locations, mean 33 cm/second (SE=4.7). Sturgeon were most commonly located at 20 to 40 cm/second with a mode at 30 cm/second (Figure 18). Significant differences in bottom currents were noted between months (x^2=121.36, d.f. =5, p<0.0001), and velocity was positively correlated with river flow (r=0.52, p<0.0001).

Substrates

Sturgeon were located most often over sand substrates, but were regularly found near rock and gravel substrates such as wing dams and closing dams or riprapped areas. In

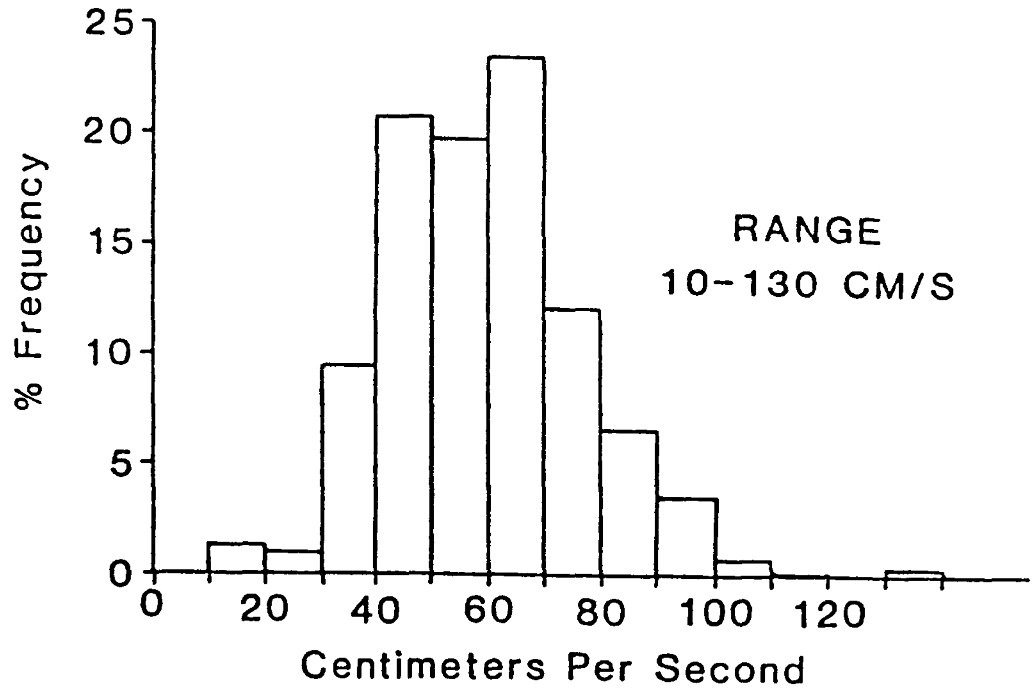

FIGURE 17. Surface current velocities measured (n=454) at location sites of radio-tagged sturgeon

the spring, sturgeon were captured in large numbers in areas with gravel substrates. Very few sturgeon were located in areas with a silt substrate.

Associations with Wing and Closing dams

Sturgeon were associated with wing and closing dams throughout the study (median distance=120 m). Close association (within 50 m) occurred in 34.3% of the locations while only 15.9% were greater than 400 m away. Frequency distribution of distances from wing dams or closing dams for radio-tagged sturgeon locations are depicted in Figure 19. No significant variation in measured distances from wing and

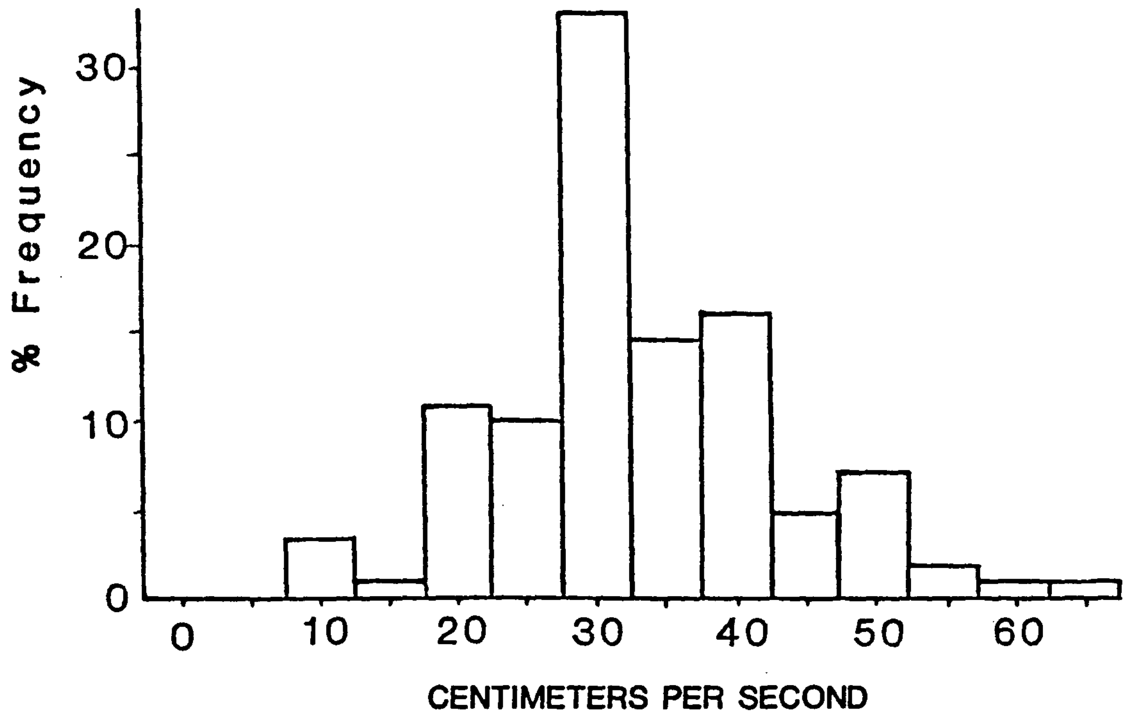

FIGURE 18. Bottom current velocities measured (n=454) at location sites of radio-tagged sturgeon

closing dams occurred in the months from April through September (x^2=3.53, d.f.=5, p<0.06182).

Although sturgeon did not shift their distances from wing and closing dams between seasons, they did shift position. During the spring sturgeon were located or captured most often below wing and closing dams while during the summer they were frequently found on the upstream faces of wing dams and closing dams or at the ends of wing dams.

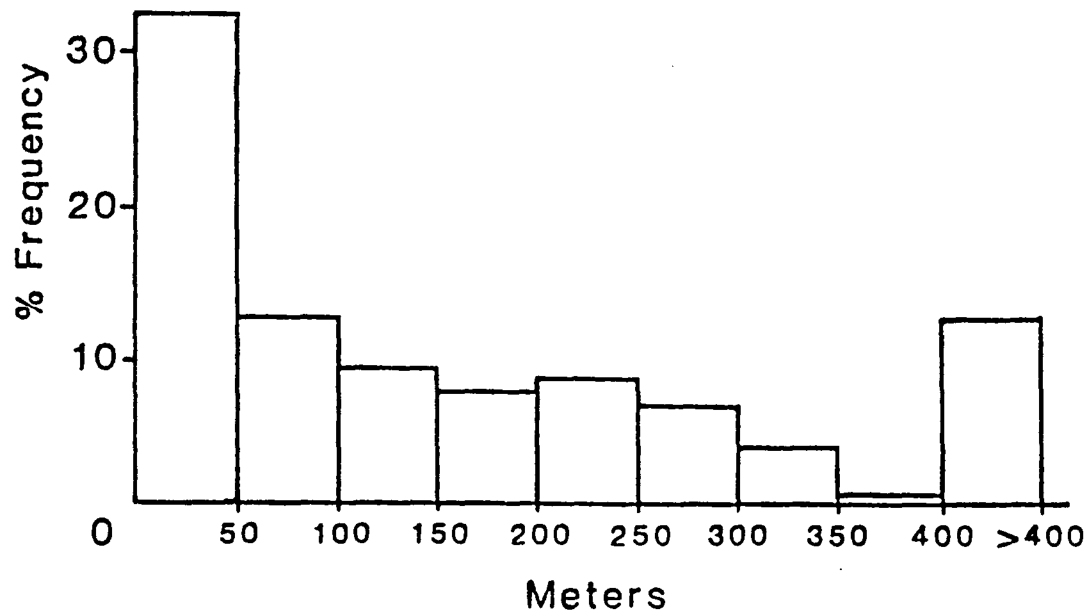

FIGURE 19. Distance from wing and closing dams at location sites (n=779) of radio-tagged sturgeon

Shoreline Association

Significant differences in distances of radio-tagged sturgeon from the river bank or an island shore were observed over the months of the study (x^2=55.06, d.f.=5, p<0.0001). During the highest river flows (April), sturgeon were closer to shore (mean distance=41 m, SE=9.9) while during the low flows (August) they were farther from shore (mean=111 m, SE=8.4). Means, standard errors, medians and ranges of distances from shore of radio-tagged sturgeon locations are given in Table 16. Distance from shore was negatively correlated with river stage (r=-0.21, p<0.001);

as river stage decreased sturgeon moved farther away from shore.

TABLE 16. Means, standard errors, medians and ranges of distance from shore (m) for twenty radio-tagged sturgeon, April-September, 1982

Month	Obs	Mean	Standard Error	Median	Range
April	22	41	9.9	25	5-190
May	204	81	5.4	50	5-300
June	247	97	4.8	70	15-375
July	186	103	5.6	80	15-340
August	96	111	8.4	100	15-280
September	14	176	18.7	115	15-240
Total	779	96	2.8	75	5-375

Riprapped banks were often utilized by shovelnose sturgeon. Radio-tagged sturgeon were located within 50 m of a riprapped area on 6.1% of the locations made. A riprapped area on the outside of a river bend (River Mile 553.4) consistently produced high catches (mean=11.8, SE=2.2) of sturgeon during the summer months.

DISCUSSION

Movement Patterns

Shovelnose sturgeon were relatively sedentary most of the time. Radio-tagged sturgeon moved less than 50 m/day in 48% of the observations. Movement varied by months with greatest movement associated with the spring spawning season. Sturgeon exhibited homing behavior and two types of movement patterns were observed: 1) long range movements between home areas and 2) short range movements within a home area.

Home areas (Winter 1977, Hubert and Lackey 1980) are restricted areas of a fish's home range in which most of the activity occurs. Sturgeon home areas were of two distinct types: 1) restricted home areas and 2) extended home areas. Restricted home areas were less than 50 m in diameter and were most often associated with wing and closing dams. Radio-tagged sturgeon spent up to 33 days in these small areas. Extended home areas were associated with main channel and main channel border areas and were less than 1 km in length.

The association of restricted home areas with river training structures may reflect the greater density of food organisms on or near these structures. These structures have been shown to have very high densities of benthic invertebrates (Hall 1980). The more open main channel and main channel border areas may have a scattered and patchy distribution of food organisms requiring greater movements between feeding sites.

Long-range movements usually involved movements to new home areas or to a previously used home area (homing). These long range movements were usually characterized by a period of constant directed movement over a period of several days. Movement between a series of preferred home areas may be a consistent pattern for the shovelnose sturgeon; such a pattern was postulated by Moos (1978) to explain grouped recaptures in the Missouri River.

Homing behavior was exhibited by many radio-tagged sturgeon and may reflect the patchy distribution of sturgeon habitat within the river. An area of closing dams in a side channel near River Mile 555 was particularly favorable for homing behavior. Many of the radio-tagged sturgeon were originally captured here and most of them returned to this area during the summer months after dispersing throughout the river during the spring. Homing was not observed by Moos (1978) in displacement experiments on tagged sturgeon.

Movement rates of sturgeon were highly variable between months. During the early spring, little movement was exhibited by tagged shovelnose sturgeon which may reflect lowered metabolism because of cooler water temperatures.

Low rates of movement (based on gill net catches and tag recaptures) by shovelnose sturgeon in the early spring were observed by Moos (1978).

Greatest activity during the study period occurred during May. This was the spawning period for sturgeon in 1982 and increased movement was probably associated with spawning. In contrast to the movement patterns in the rest of the spring and summer, movements of several sturgeon in May consisted of apparent wandering behavior up and down the river. This wandering behavior may have been associated with sturgeon seeking suitable spawning sites or other individuals in breeding condition. Greatest activity by shovelnose sturgeon during the spawning season was also observed in the Missouri River by Moos (1978).

Low rates of movement were observed in June and August with increased activity observed in July as some sturgeon homed back to previously used home areas or moved within an extended home area. Low rates of summer movement have been previously observed in shovelnose sturgeon in the Missouri River (Moos 1978) and in the Yellowstone River (Elzer et al. 1977).

Movement between navigation pools on the Upper Mississippi River has previously been documented for catfish (Hubley 1963), walleye (Hubley and Jergens 1959, Bahr 1977) and paddlefish (Gengerke 1978, Southall 1981). Upstream interpool movement by shovelnose sturgeon during a high water year has been reported (Helms 1974). Downstream interpool movement by four tagged fish in this study indicates that sturgeon can also move downstream between pools during high water periods. The opening of the gates on the dams is probably necessary to allow sturgeon passage.

Habitat Associations

Current velocity appears to be the major physical factor affecting shovelnose sturgeon distribution. The preferred range of current velocity seems to be 20 to 40 cm/second near the bottom, 40 and 70 cm/second at the surface. They associate with this preferred range by movement away from shore and towards the channel as river stage decreases or by seasonal shifts in habitat usage within main channel border areas.

Shovelnose sturgeon are able to utilize areas with higher current velocities than many other river species. At high current velocities (>40 cm/second at the bottom or >80 cm/second at the surface), few fish of any species are found. As current decreases below this range, shovelnose sturgeon are one of the first species to occur in channel habitats. During the high waters of spring, sturgeon dominated the catch in channel habitats. As flows continued to decrease, other species less tolerant of current moved into channel habitats. Sturgeon continued to make up the largest percentage of the catch in areas with fast currents.

This greater tolerance of current allows the sturgeon to utilize the swift currents of the main channel, an inhospitable habitat for most species of fish (Hubert and Schmitt 1982). Although the abundance of shovelnose sturgeon in main channel habitats has been shown before in many studies (Barnickol and Starrett 1951, Schmulbach et al. 1975, Hubert and Schmitt 1982, Helms 1974), in this study, sturgeon were most abundant in areas outside the main channel proper.

High current velocities in main channel areas appear to be the major factor limiting sturgeon abundance in the main channel. During high water, current velocities in this habitat are above 40 cm/second at the bottom, 80 cm/second at the surface and few sturgeon are found out in the main channel. At low river stages, current velocities are suitable and sturgeon are concentrated in or near the main channel. This concentration of sturgeon in the main channel during low water may be detrimental due to greater impact possibilities with propellers of commercial and recreational vessels. Shovelnose sturgeon with parts of their posterior sections missing made up 2.1% of the catch and many sturgeon exhibited injuries to their rostrum or other body parts. Increased channelization of the river may also harm sturgeon populations by raising current velocities above preferred levels.

Hard substrates offered by wing dams, closing dams, riprapped areas and submerged trees seem to be important to shovelnose sturgeon. High-profile, hard substrates offer suitable conditions for attachment of benthic invertebrates on which sturgeon feed as well as offering suitable current velocities in many cases. Use of these structures is determined by current velocities and patterns.

Emergent dams with low current velocities were not frequented by shovelnose sturgeon. During spring high water, river training structures act as barriers to flow and reduce current velocities. Spring current velocities downstream from these structures are often within the preferred range of the shovelnose sturgeon. At this time, the scour holes and immediate downstream sides of these structures are heavily utilized.

At low river stages, submerged wing dams and closing dams offer suitable conditions on their distal ends and on their upstream sides. Current velocities in these areas are increased due to the venturi effect as river flow is constricted through a narrower area. Sturgeon were quite abundant on the immediate upstream faces of some of these dams and large catches could be made by drifting short distances onto these dams using a trammel net.

The submerged wing dams and closing dams of the Upper Mississippi River appear to be similar to the sandbar habitats of the unchannelized Missouri River, where pools behind sandbars are heavily utilized by shovelnose sturgeon (Schmulbach et al. 1975, Moos 1978). Shovelnose sturgeon association with wing and closing dams of the Upper Mississippi was also documented by Pitlo (1981), who found shovelnose sturgeon to be the sixth most abundant species of the 38 species captured. Current velocities and channel morphology (i.e. dropoffs and scour holes downstream from these structures) of wing dam and sandbar habitats are similar. By offering physically similar habitat conditions, wing dams and closing dams may be fulfilling the role of sandbars as sturgeon habitat in the pre-navigation Upper Mississippi River.

Other man-made structures offer habitat for shovelnose sturgeon. Riprapped areas were frequently used, especially an area on the outside bend of the river. Natural banks were seldom used except during extreme high water periods. Greater abundance of shovelnose sturgeon along riprap banks than along natural banks has also been noted in the Missouri River (Burress et al. 1982) and in the Lower Mississippi River (Pennington et al. 1983).

Submerged trees and logs were also used by shovelnose sturgeon, especially during the spring. During the spring, largest catches were associated with the presence of a large log in the net with the sturgeon. The largest catch of fish in one drift (34 sturgeon and 34 other fish, predominantly freshwater drum) during the study was made in September when a large tree was caught in the net.

Habitat selection by shovelnose sturgeon varies with size. Small sturgeon (<400 mm FL) were captured most frequently in main channel areas, along wing dam ends and in the tailwaters. Larger sturgeon (>550 mm FL) were captured most frequently near closing dams and along a riprapped bank. This spatial separation may reflect different habitat requirements or feeding habits.

Large sturgeon were captured frequently near rocky areas while small sturgeon were generally captured in areas with fast currents. Large sturgeon may feed more on attached benthic invertebrates with small sturgeon feeding more on drift organisms. Spatial separation by size may also be the result of differences in preferred current velocities. By presenting a smaller cross-section to the flow, small sturgeon have a greater ability to tolerate current. The long caudal filament found most often on small sturgeon is filled with sensory cells and may assist them in maintaining position in swift currents (Weisel 1978). Large numbers of small sturgeon in tailwater habitat may reflect an upstream movement tendency in early life stages.

The shovelnose sturgeon's apparent preference for suitable current velocities and nearby high-profile, hard substrates seems to govern their habitat selection. Sturgeon shifted their habitat according to season and river stage and associated changes in current velocities and patterns. During spring high water, sturgeon sought shelter from the strong currents present in channel areas and were most abundant below wing and closing dams or in main channel border areas close to shore. At peak flood stages, sturgeon were closely associated with the shoreline and were often found in side channels or deep holes. Bottom stuctures, such as submerged trees and logs, were also used as shelter.

As flows decreased in the summertime, sturgeon moved away from the shoreline and towards the channel. currents than near the shore. Although still common near wing and closing dams, sturgeon were most abundant on the upstream faces of these structures or near the ends of wing dams. Main channel areas, especially near wing dams and riprap areas, were important to shovelnose sturgeon at this time. Seasonal shifting of habitats by shovelnose sturgeon was also observed by Moos (1978) in the Missouri River. Sturgeon were concentrated in sandbar pools in the spring and fall, but dispersed into channel areas in the summer.

Habitat association by shovelnose sturgeon may be related to food habits. Held (1969) postulated that sturgeon are found in strong currents because silt is swept away exposing the benthic organsims on which shovelnose sturgeon feed. Habitat for the shovelnose sturgeon closely parallels that of their major food organism in the Upper Mississippi River, Trichoptera larvae. Trichoptera larvae are little utilized by other fish species, but constitute a major food of shovelnose sturgeon (Ranthum 1969, Hoopes 1960). These larvae require: 1) a silt-free solid substrate on which to construct their nets and dwellings and 2) a constant current of water to carry food into their nets (Fremling 1960).

In summary, two factors, suitable current velocities (20-40 cm/second at the bottom) and nearby high-profile, hard substrates, appear to govern the distribution of shovelnose sturgeon. These factors are probably related to the shovelnose sturgeon's feeding ecology and its preference for benthic invertebrates as a food source.

CONCLUSIONS

1. Shovelnose sturgeon are generally sedentary, although capable of moving up to 11.7 km/day.
2. Shovelnose sturgeon are most active during the spring spawning season with lower rates of movement in the summer and early spring. Sturgeon harvest by passive gears, such as set trammel nets, could be reduced by restricting the use of such gear in tailwaters and other channel habitats during the period of active spring movement (i.e. May and early June).
3. Sturgeon movements are of two major types: 1) long range movements between home areas and 2) short range movements within a home area.
4. Homing behavior (return to a previously occupied area) is exhibited by shovelnose sturgeon.
5. Current velocities and proximity to high-profile, hard substrates appears to govern habitat selection in shovelnose sturgeon. This indicates that aquatic habitats could be manipulated to increase or decrease their suitability for shovelnose sturgeon.
6. Sturgeon are found most often at bottom current velocities between 20 and 40 cm/second and surface current velocities between 40 and 70

cm/second. Shovelnose sturgeon habitat can be eliminated by decreasing current velocities (i.e. by impoundment of rivers or by building emergent wing and closing dams) or by increasing current velocities over preferred levels (i.e. by increased channelization of the river for a deeper navigation channel).

7. Wing and closing dams offer important habitat to shovelnose sturgeon in the spring and summer. Sturgeon position themselves near these structures according to current velocities. Emergent wing and closing dams offer little if any habitat for shovelnose sturgeon. Wing and closing dams should be submergent at all times to benefit shovelnose sturgeon and should be notched if they reduce current velocities below preferred levels.
8. During the spring, sturgeon are found most often below wing and closing dams and in areas of main channel border within 50 m of shore.
9. During the summer, sturgeon are found most often in or near the main channel and on the upstream faces of wing and closing dams. By concentrating in the main navigation channel, sturgeon are susceptible to propeller impacts from commercial

and recreational watercraft. Sturgeon with obvious damage were commonly encountered and may reflect a signifigant source of mortality.

10. Habitat shifting is dependent on river stage and season and the associated changes in current velocities.

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