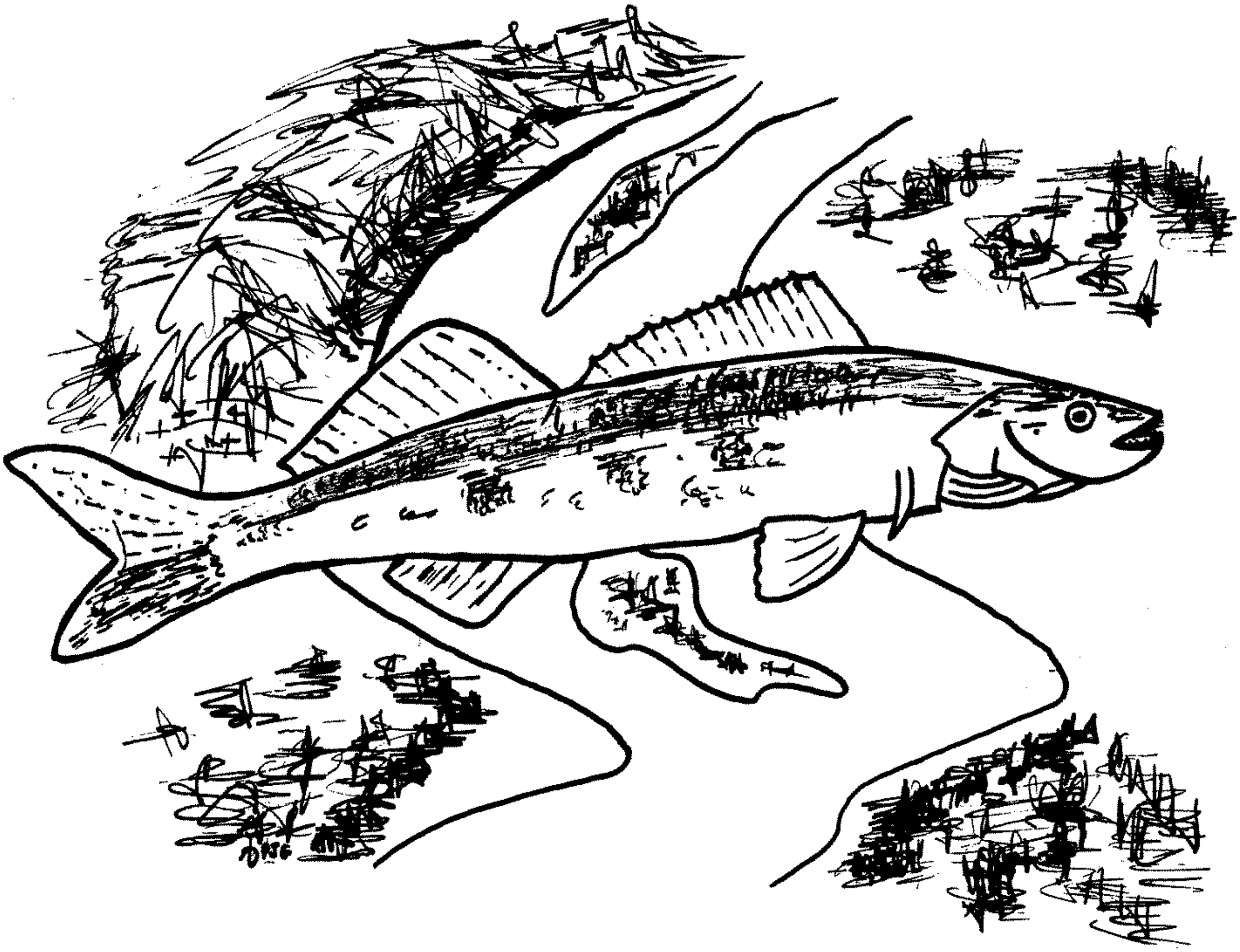
Aquatic Environmental Analysis in The Lower Yellowstone River



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ABSTRACT

This study was initiated on the lower Yellowstone River to quantify effects of stream flow alterations on selected sport fish. Efforts were concentrated on sauger (*Stizostedion canadense*) and walleye (*Stizostedion vitreum vitreum*) and effects of instream irrigation diversions on their movements, particularly during the spawning season, were assessed. Walleye migrated upstream from Garrison Reservoir to the lower most diversion (Intake), spawned, and most returned to the reservoir during spring. Sauger also concentrated below the lower diversion and the next diversion 267 km upstream (Forsyth). Sauger movement as determined by tag returns, was extensive over the Intake diversion during spring. Few sauger and no walleye migrated over the Forsyth diversion which created a 0.5 m vertical drop in the river in contrast to a turbulent slope created by boulders forming the Intake diversion.

We compared average lengths of sauger collected in 3 sections of the lower Yellowstone River and found that sauger in the upstream section were significantly longer than fish in the lower section. This was largely a result of a larger proportion of older fish in the upper section. Sauger were least abundant in the upper section and progressively more abundant in downstream sections. Growth rates and condition factors for sauger were similar in all three sections of the river. Movement and growth data indicate that a general upstream movement of mature sauger occurred after spawning.

Initial combined spawning criteria for sauger and walleye was determined by egg abundance on the spawning grounds downstream from Intake diversion. Expected range of depths for eggs at the 90 percent confidence level was from 0.46 to 1.04 m (1.5 to 3.4 feet). The upper limit was biased because we could not sample in water deeper than 0.9 m (3 feet). Expected range of velocities for eggs at a 90 percent confidence level was from 72 to 96 cm/s (2.4 to 3.1 fps). Spawning substrate was 89 percent loose cobble and pebble. Using these criteria and excluding maximum depth, the mid-range of flows which maximized suitable spawning area was similar to the historical median flow during the spawning season, 240 m^3/s (8,500 cfs) and 260 m3/s (9,170 cfs), respectively.

A method was developed for collecting Water Surface Profile (WSP) data in a large, deep, turbid river. A two man crew surveyed transects across the river with a constant recording depth sounder mounted in a boat, a range finder, and standard surveying equipment. This method was relatively fast considering the distances and depths involved. Accuracy of hydraulic predictions from the WSP program increased with increased number

of known water surface elevations at various discharges. Straight, island and braided stream sections were surveyed. The WSP program did not accurately predict hydraulic conditions for a braided section of river. Limitations and possible improvements in data collection and analysis are discussed.

OVERVIEW

This study was a continuation of earlier studies conducted on the lower Yellowstone River which addressed distribution, abundance, and some life history aspects of various fish species (Peterman and Haddix 1975, Haddix and Estes 1976). These studies were part of a large scale effort by the Bureau of Reclamation to determine the availability of water resources of the Yellowstone River and tributaries for the development of coal resources in southeastern Montana.

The objectives of this study were: (1) to assess effects of irrigation diversion structures at Forsyth and Intake on upstream migration of spawning fish, (2) to gather life history information on game fish in the river, and (3) to develop a rapid and accurate method for collecting stream profile cross sections in a deep, turbid river. A report predicting impacts of water withdrawals and the associated diversion structures on the aquatic communities of the lower Yellowstone will be forthcoming when results from several studies can be incorporated.

Walleye and sauger were selected for study during this phase of the project because they are important game fish and have a wide range. Movement of fish has been correlated to spawning, feeding, over-wintering and other biological activities. For this reason, any diversion dam which impedes movement may restrict biological activities necessary for the continued survival or abundance of a species. It, therefore, is necessary to know: (1) how the dam affects movement, (2) important biological activities of the species both above and below the diversion, and (3) if movement is restricted, how this is affecting the population in question. Life history information is generally lacking for these two species in a free flowing river system. Collection of background information on walleye and sauger in the Yellowstone was initiated by Peterman and Haddix (1975) and continued by Haddix and Estes (1976).

DESCRIPTION OF STUDY AREA

The Yellowstone River is one of this country's few remaining free-flowing rivers. The Yellowstone was described in terms of stream gradients, flow regimes, major tributaries, fish distribution, etc. (Peterman and Haddix 1975, Haddix and Estes 1976). Newell (1976) and Schwehr (1976) described distribution and composition of the major aquatic insect populations.

In review, the Yellowstone River drainage contains approximately 182,336 square kilometers, 92,981 of which lie in Montana (Figure 1). It originates in the mountains of northwestern Wyoming and flows in a general northeasterly direction to its confluence with the Missouri River in North Dakota, 1,091 kilometers downstream. Approximately 885 kilometers of the Yellowstone River are in Montana. Average gradient is 2.44 m/km, 1.53 m/km, and 0.53 m/km for the upper, middle, and lower reaches, respectively. Mean annual discharge based on a minimum of 45 years of data was 107, 200, 328, and 373 m^3/s (3,787, 7,046, 11,590 and 13,170 cfs) at Livingston, Billings, Miles City, and Sidney, respectively (U.S. Geological Survey 1976). Turbidity is seasonally high in the lower river. Based on 14 samples taken by the U.S. Geological Survey from March through September 1975, turbidity averaged 83, 110, and 239 JTUs at Huntley, Miles City, and Sidney, respectively (U.S. Geological Survey 1975). Turbidity increases in the Yellowstone River downstream from the Powder River. Turbidity in the lower Powder River was an average of 714 JTUs for 7 samples taken from March through September in 1975.

The Yellowstone River supports a trout fishery in the upper reach and a warmwater fishery in the lower reach. Diversity of species increases progressively downstream. Eleven fish species (5 families) have been recorded in the upper Yellowstone River in Montana, 20 species (8 families) were collected in the middle river, and 46 species (12 families) were collected in the lower river. A species list was compiled by Peterman and Haddix (1975).

Newell (1976) determined that a rich aquatic invertebrate population is present in the Yellowstone River with both number of species and standing crop decreasing from the upper to the lower river. Mayflies (Ephemeroptera), caddisflies (Trichoptera), and true flies (Diptera) dominated the bottom fauna. The stonefly fauna (Plecoptera) was diverse but not abundant and decreased in number of species downstream.

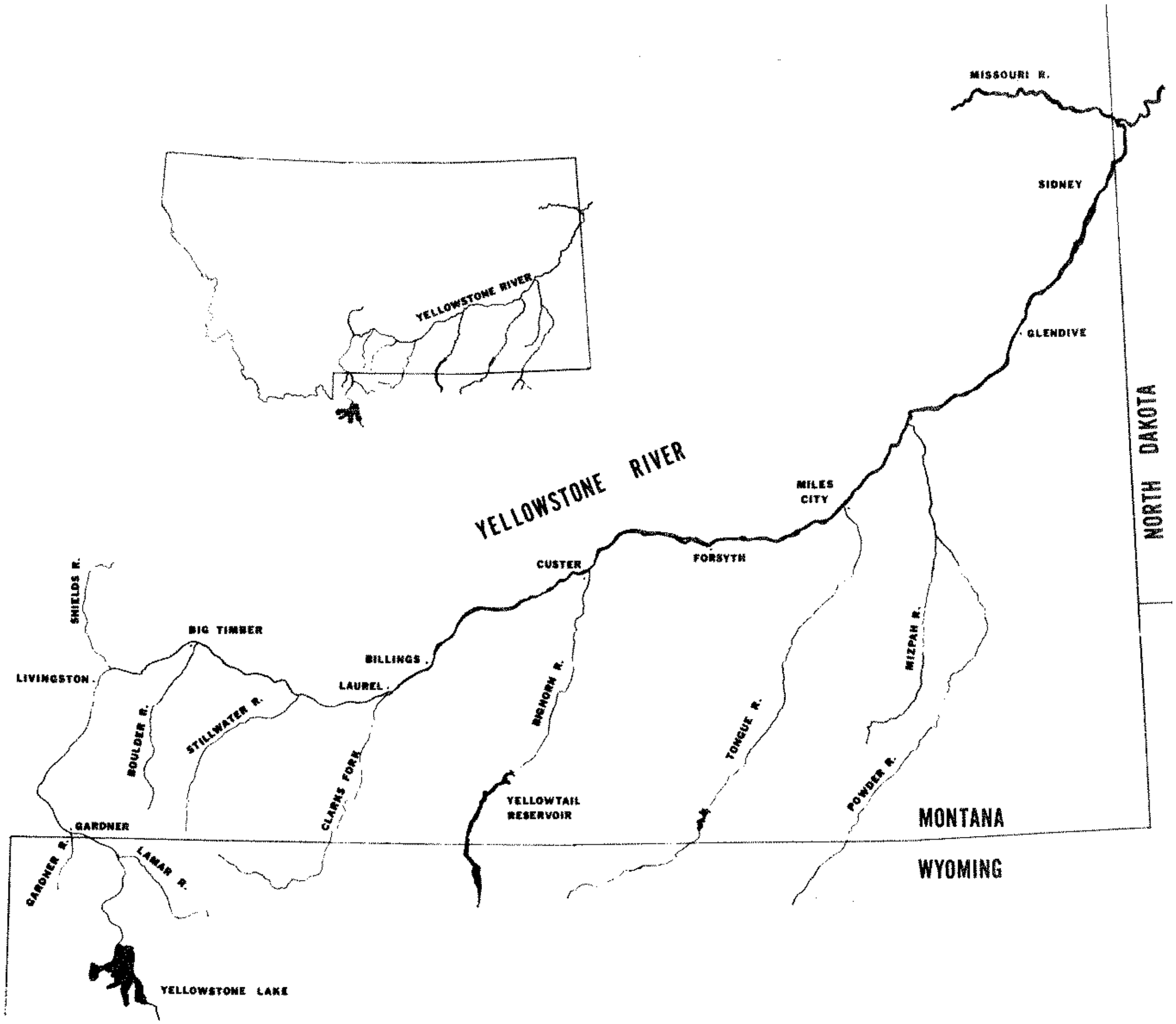


Figure 1. Map of the Yellowstone River drainage.

This study encompassed the lower half of the Yellowstone River from the mouth of the Big Horn River (river kilometer 476) downstream to the North Dakota border (approximately river kilometer 18). Major tributaries along the lower river are the Big Horn River (river kilometer 476), Tongue River (river kilometer 298), and Powder River (river kilometer 240). Two major diversions were present in the study area. Forsyth (Cartersville or Rosebud) diversion is located at river kilometer 382 and Intake diversion is located at river kilometer 114.

Forsyth diversion is a concrete structure extending 230 meters across the entire width of the Yellowstone River (Figure 2) and diverts water for irrigation along the north side of the river. During intermediate to low flows the structure created approximately a 0.5 meter vertical drop. During high spring flows and when ice jams form below the diversion the difference between water elevations immediately upstream and downstream from the diversion is less pronounced.

Intake diversion extends 219 meters across the main channel of the Yellowstone River (Figure 3) and provides water for irrigation along the north side of the Yellowstone River. This diversion provides water for users from river km 114 downstream to near the confluence with the Missouri River. A side channel, which begins to flow at a total discharge of 23,000 cfs, bypasses Intake diversion to the south. The head and tail are approximately 3 km upstream and 3 km downstream from the diversion. The diversion is a wooden structure which has been covered by large boulders to raise the head. New boulders are placed on the diversion every few years to replace boulders which are pushed downstream by ice and high water. The diversion does not form a sharp vertical drop. The downstream drop is approximately 1.2 m in 30 m and is characterized by very turbulent water. The structure can divert a maximum of 33.9 m^3/s (1,200 cfs).

Major habitat components of the lower Yellowstone River are main channel pools, runs and riffles, side channels or chutes, and backwaters. Pools are generally 1.5 to 3.0 m deep, although some are at least 5.5 m deep during low summer flows. Backwaters, an integral part of the river ecosystem, are much more common in island or braided sections of the Yellowstone River. In addition, the amount of gradually sloping gravel bars is larger in these sections.

The lower Yellowstone River contains many islands and braided areas with the exception of the reaches from Miles City (river kilometer 306) to Cedar Creek (river kilometer 172) and Sidney river kilometer 40) to the mouth. The Miles City to Cedar Creek section runs through several bedrock outcrops. Near the mouth, the Yellowstone widens and has a shifting sand and silt bottom.

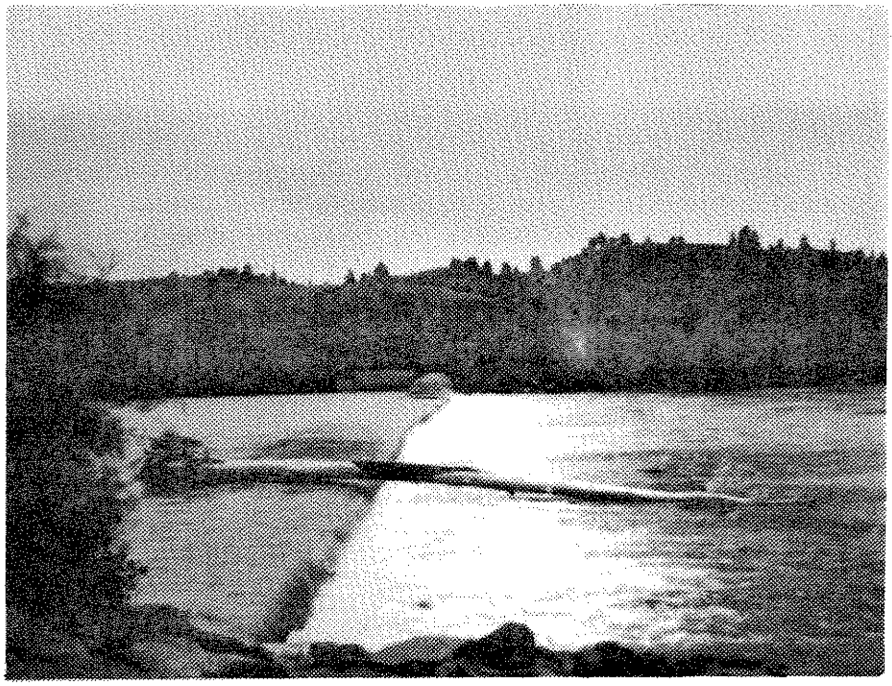


Figure 2. Forsyth or Cartersville diversion is a concrete structure which creates approximately a 0.5 meter drop in the Yellowstone River during normal summer flows.

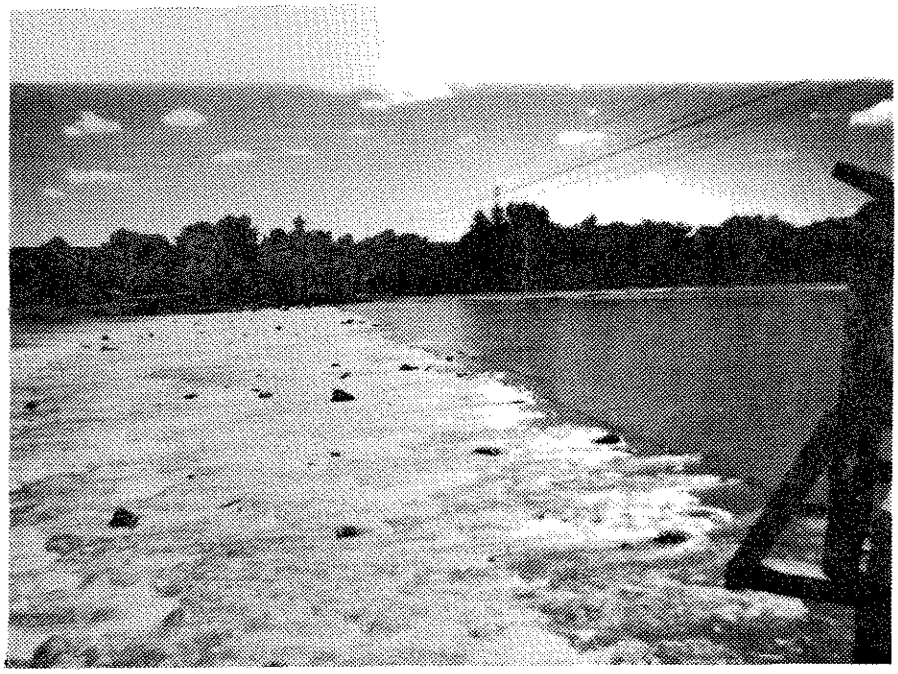


Figure 3. Intake diversion is a submerged, wooden-framed structure covered with large boulders.

EFFECTS OF DIVERSION ON UPSTREAM FISH MIGRATION

Introduction

The objective of this phase of study was to determine the effects of diversion structures at Forsyth and Intake on upstream migration of spawning fish. Diversions may directly affect sauger and walleye survival because of their wide ranging movements which have been documented in several studies (Eschmeyer 1950, Forney 1963, Wolfert 1963, Schoumacher 1965, Nelson 1968). Low head diversion structures, which span the entire width of the river, have been constructed to divert water into canals for irrigation use. Intake diversion, constructed in 1907, and Forsyth diversion, constructed in 1904, are two such structures located at river kilometers 114 and 381, respectively. In previous studies on the Yellowstone River, concentrations of walleye and sauger were found below diversion dams particularly during the spring spawning season (Figure 4) (Peterman and Haddix 1975, Haddix and Estes 1976). Both walleye and sauger are considered as prize sport fish in the lower Yellowstone River.

Methods

Fish were collected by boom electrofishing in a 5.2 by 1.5 m flat bottomed aluminum boat powered by a 85 hp motor equipped with a jet foot (Figure 5). The two positive electrodes were copper tubes shaped like spheres. Four negative electrodes constructed of 1.2 m (4 ft.) lengths of aluminum or steel conduit were suspended along each side of the boat (Peterman 1978). Amount and type of electrical output from a 4,500 watt generator was regulated by a Variable Voltage Pulsating Unit (Coeffelt VVP-10). We usually used pulsating direct current, at 10 amps, 150-250 volts, 50 percent pulse width and a frequency of 80-100 pulses per second.

To determine their relative abundance and monitor their movements, walleye and sauger were collected at four sections along the Yellowstone River both up and downstream from Intake diversion in the spring of 1977 (Figure 6). Total length and weight of individual fish were measured to the nearest 2.5 mm and 5 g, respectively; sex for mature fish in ripe or nearly ripe condition was determined. Walleye and sauger were tagged with consecutively numbered blue floy anchor tags at the posterior base of the anterior dorsal fin. We released fish near the middle of each section, and sampled north and south sides of each section

Figure 4. Adult walleye on their spawning migration below Intake diversion occasionally exceeded 3.2 kilograms (7 lbs.).

Figure 5. Electrofishing collections were made from this 5.2 meter long aluminum boat.

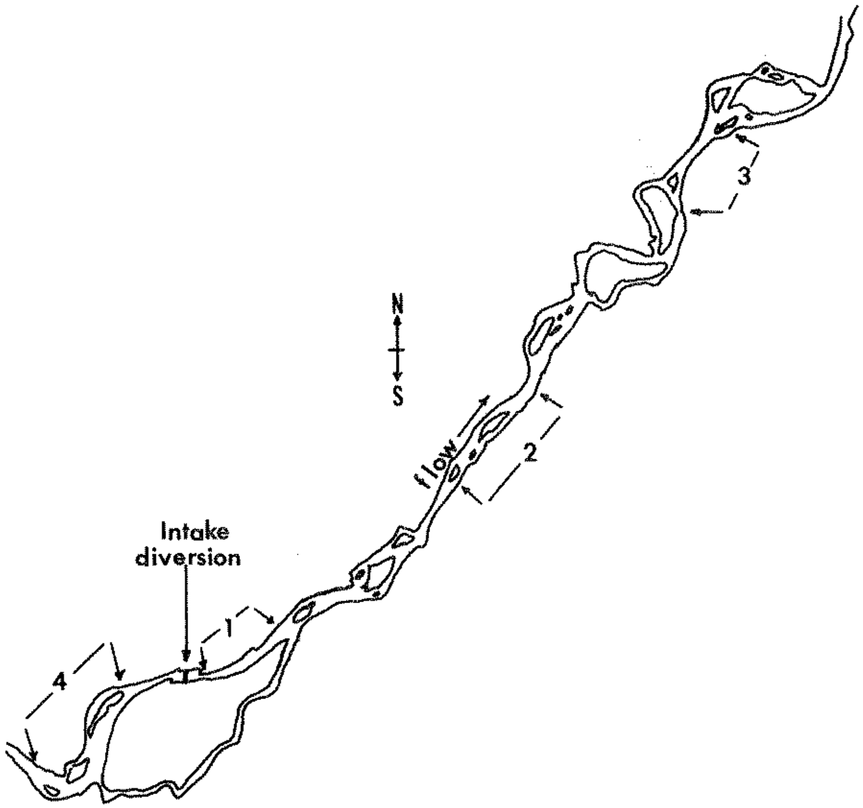


Figure 6. Electrofishing sections 1, 2 and 3 downstream from Intake diversion and section 4 upstream from the diversion, sampled during 1977.

independently. Sections 1, 2 and 3 were 0.4, 7.7 and 15.4 km downstream from the Intake diversion and were 2.6, 1.9 and 2.2 kilometers long, respectively. The upstream end of section 4 was 4.5 km upstream from Intake diversion and was 3.4 km long. Only section 1 was sampled in 1976. Fish were collected during daylight hours in 1976 prior to and including April 21. During the remainder of 1976 spring sampling, fish were collected at night because larger sample sizes were obtained (Haddix and Estes 1976). Fish were collected only during daylight hours in 1977 because maneuverability to sections 2, 3 and 4 was difficult and dangerous at night. For comparison of fish abundance between 1976 and 1977, we used only data collected during daylight hours.

Walleye and sauger were collected and tagged at three locations on the Yellowstone River during the spring from 1974 through 1977. These areas were (1) downstream from the Forsyth diversion (river kilometer 381), (2) near Miles City (river kilometer 298), and (3) downstream from Intake diversion (river kilometer 114). Biologists also tagged sauger upstream from the Forsyth diversion in 1974. Fish were also collected from August through October in 1977 at 13 locations from river kilometer 553 downstream to river kilometer 13. North Dakota Game and Fish personnel cooperated by collecting walleye and sauger near river kilometer 13 in April 1977.

Fish tag return data were broken down into three groups: (1) fish recaptured during the same year they were tagged, (2) fish recaptured during the year following tagging and during the same season they were tagged, and (3) fish recaptured during the following year but during a season other than the one they were tagged. All but one fish fit into one of these three groups. Most returns were from anglers, although some returns were from Fish and Game personnel. Returns by Fish and Game personnel were not included if the fish was caught within 5 km of the tagging site during the same season and year that it was tagged in. All angler returns were used. A difference of at least 5 km between the release and recapture location of the fish was necessary before it was considered movement.

Results

Walleye and sauger migrated to an area below Intake diversion during the spring of 1977 for the purpose of spawning. Spring densities of both species were highest in section 1 (Figure 7).

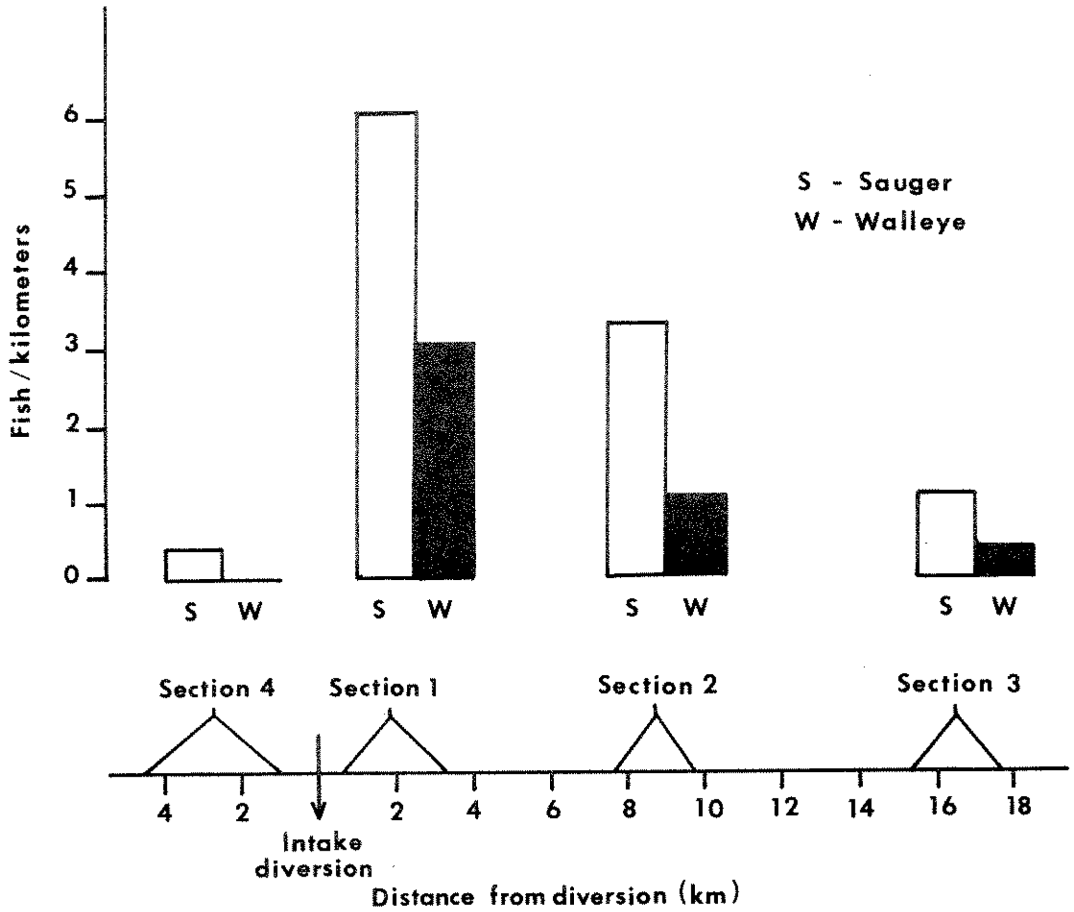


Figure 7. Average sauger and walleye abundance in four electrofishing sections near the Intake diversion in the Yellowstone River, sampled during spring 1977.

Abundance of both species decreased the farther a section was downstream from the dam; section 2 and 3, the two sections farthest downstream, had the second and third largest densities of sauger and walleye, respectively. Densities of sauger were 6.1, 3.6, 1.1 and 0.4 fish per kilometer in sections 1, 2, 3 and 4, respectively (Figure 7). Densities of walleye were 3.1, 1.1, 0.4 and 0.0 fish per kilometer for sections 1, 2, 3 and 4, respectively.

During 1977 the chronology of peak walleye abundance in the 3 sections below the dam appeared to depict the migration of fish upstream (Figure 8). The peak abundance in section 3 occurred at least 9 days prior to the peak in section 2 while the number of walleye peaked 8 days earlier in section 2 than section 1. Sections 3 and 2 and sections 2 and 1 were approximately equal distances apart; 7.7 and 7.3 km, respectively. The peak in section 1 occurred on May 23.

Sauger abundance in 1977 appeared to follow a similar trend in the 3 downstream sections, however, only 3 days separated the peak in section 2 and 1 (Figure 9). Section 2 may have peaked later as this section was not sampled on the same day that section 1 reached peak abundance (April 18).

During 1977 sauger abundance peaked 35 days before walleye reached maximum abundance in section 1 (Figures 10 and 11). Sauger were abundant throughout April in 1976 while walleye abundance peaked on April 12 in 1976. Walleye reached maximum abundance 11 days earlier in 1976 than 1977 (Figure 11). In general both walleye and sauger were more numerous in 1976 than 1977 in section 1. During April of 1977 the mean discharge was 220 m^3/s (7,753 cfs) compared to a mean discharge of 328 m^3/s (11,568 cfs) during April of 1976, at the U.S. Geological Survey gage at Sidney (U. S. Geological Survey provisional data).

Percent composition of sauger to walleye in section 1 was similar in both 1976 and 1977 with sauger comprising 75 and 70 percent of the combined catch, respectively. This was the only section we shocked during both years. Trends in abundance through the spring were similar both years. Relatively few walleye and sauger were present during early April and larger numbers during mid and late April. Most of the fish we collected were ripe or nearly ripe, similar to 1976 collections (Haddix and Estes, 1976).

Figure 8. Number of walleye collected per 5 kilometers of stream reach in sections 1, 2 and 3 downstream from Intake diversion in the Yellowstone River during spring 1977.

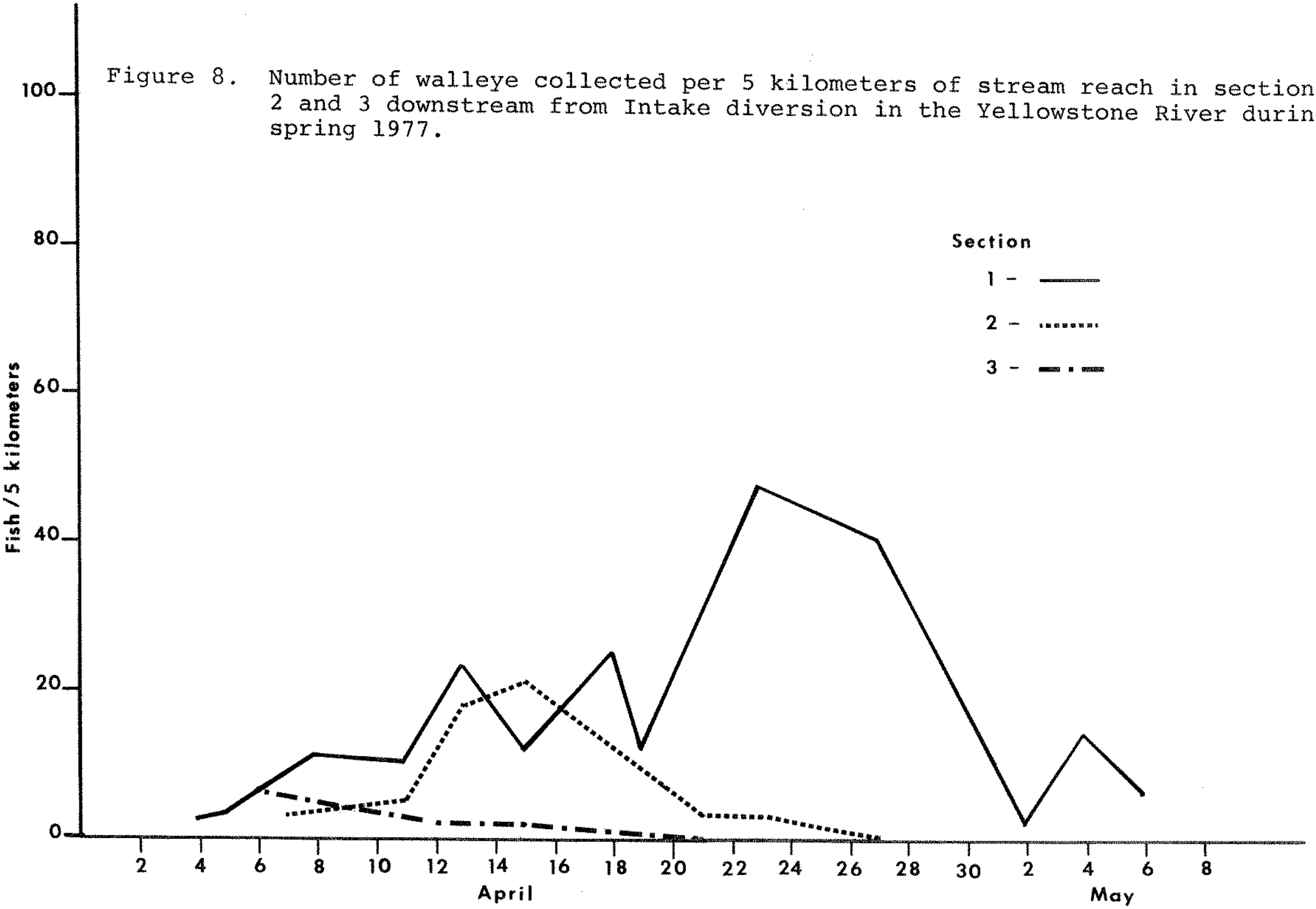
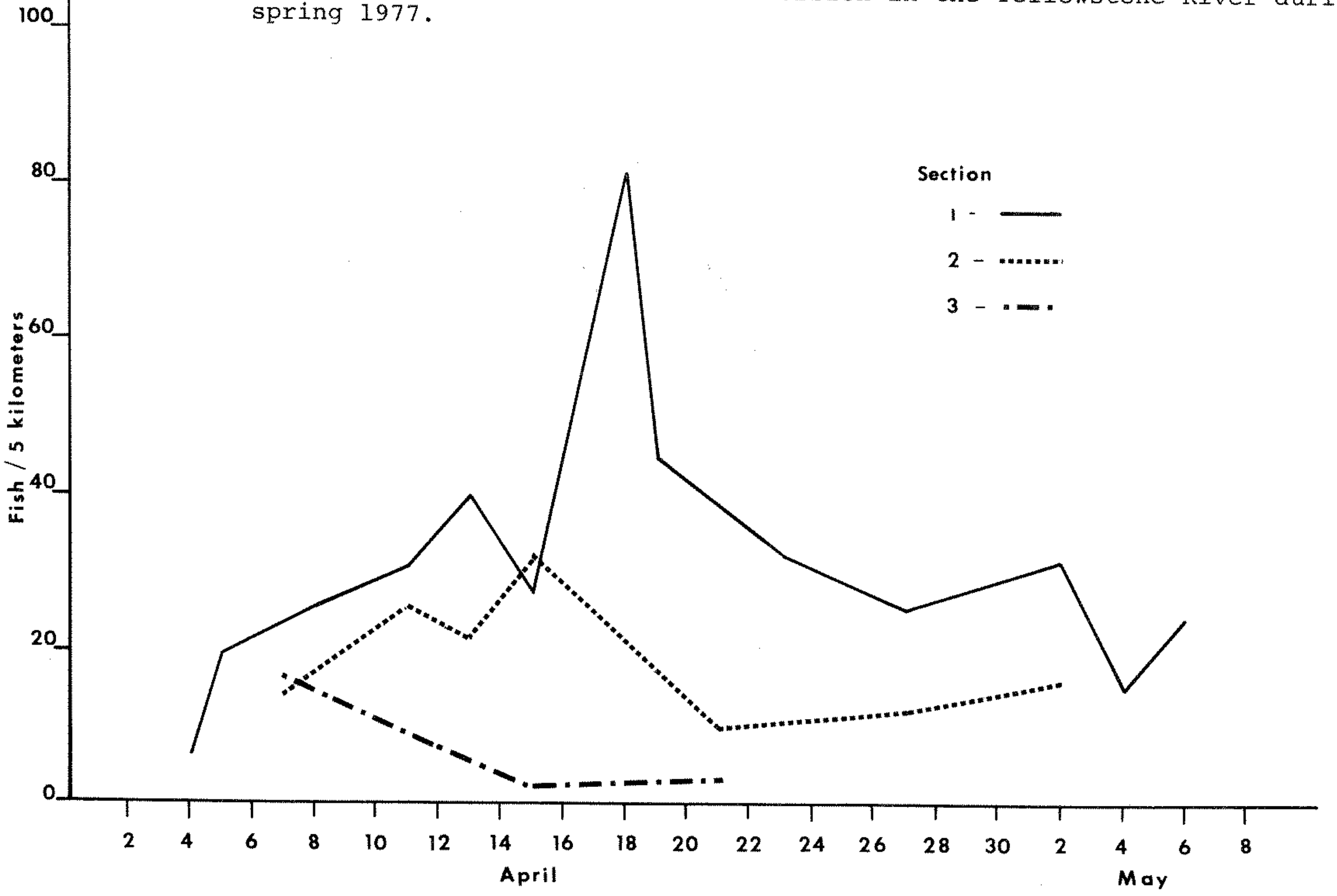


Figure 9. Number of sauger collected per 5 kilometers of stream reach in sections 1, 2 and 3 downstream from Intake diversion in the Yellowstone River during spring 1977.



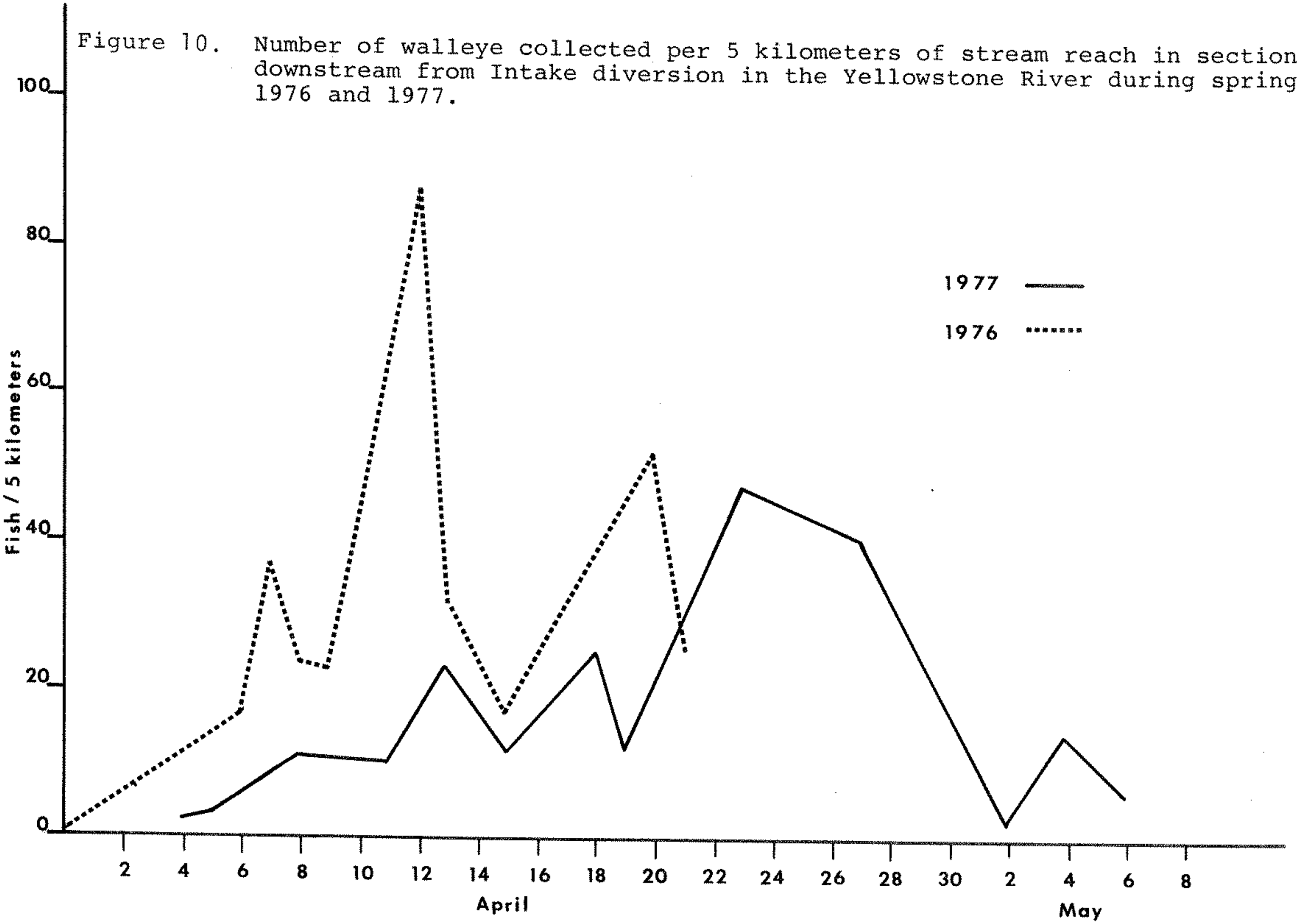


Figure 10. Number of walleye collected per 5 kilometers of stream reach in section 1 downstream from Intake diversion in the Yellowstone River during spring 1976 and 1977.

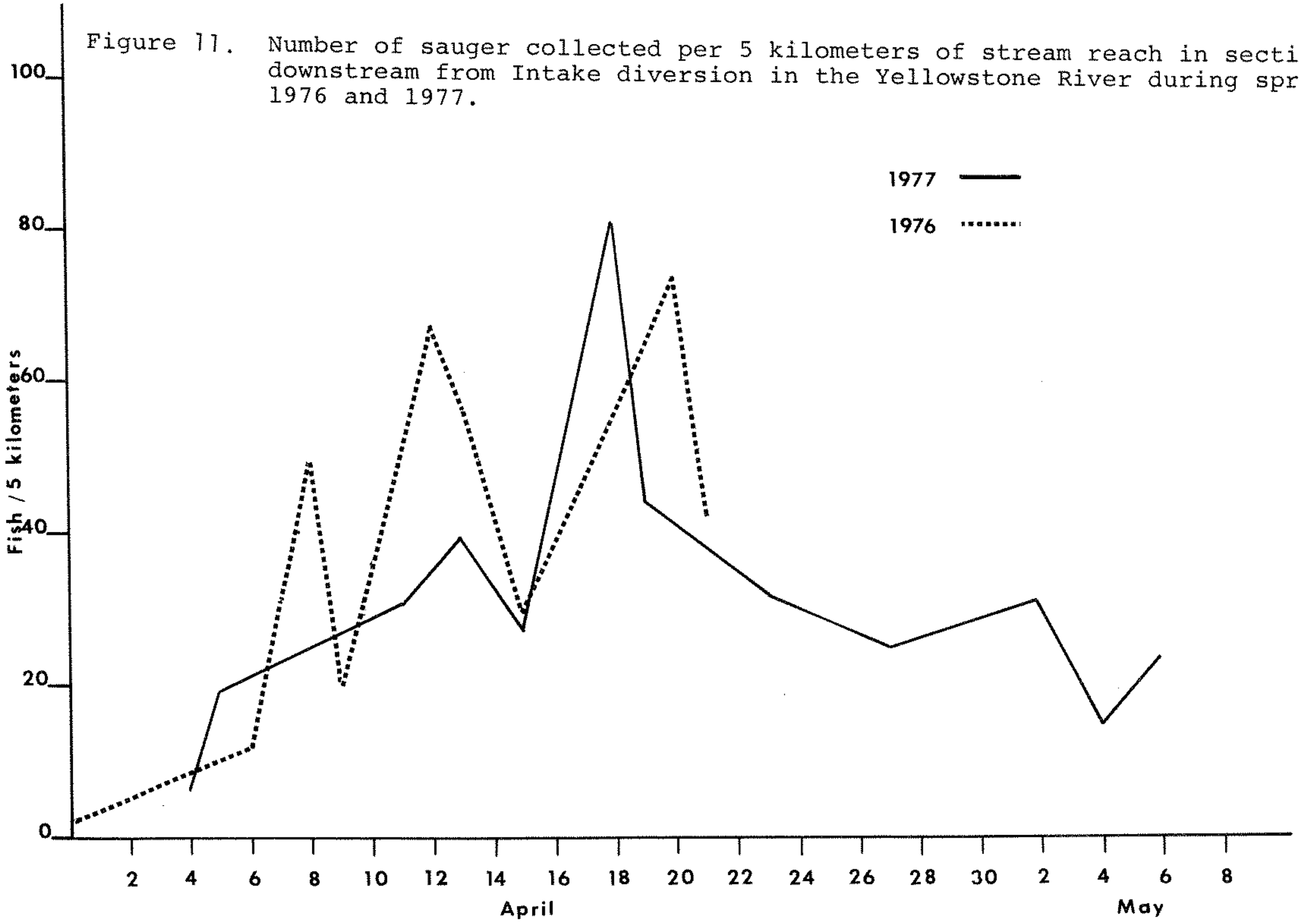


Figure 11. Number of sauger collected per 5 kilometers of stream reach in section 1 downstream from Intake diversion in the Yellowstone River during spring 1976 and 1977.

We found some movement between sections below the Intake diversion. We only recaptured 8 of 232 walleye and 10 of 548 sauger tagged below the Intake diversion during the spring of 1977. All 8 walleye and all but 2 sauger were recaptured in the same section where they were originally tagged. One of the 2 sauger which exhibited movement left section 2 and was recaptured 8 km upstream in section one 29 days later. The other sauger moved downstream 14 km from section 1 and was recaptured 3 days later in section 3. The low number of recaptures probably reflects a large population size or a large turnover of fish in the spawning area or both.

Fish and Game personnel tagged a total of 2,573 sauger and 697 walleye between September 1973 and October 1977 in the lower Yellowstone River. This includes 800 sauger and 17 walleye tagged in summer-autumn collections during 1977. Fifty-one walleye were recaptured through October 1977 including 35 returns from anglers and 16 recaptures by Fish and Game personnel. Sauger returns totaled 195; 149 by anglers and 46 by Fish and Game personnel. Walleye returns divided by tagging location were 49 from the Yellowstone River and 2 from the Tongue River. Sauger returns by tagging location were: 128 from the Yellowstone River, 56 from the Tongue River and 11 from the Powder River. A minimum harvest estimate, based on fisherman tag returns, was 5 percent for both walleye and sauger.

Movements of walleye and sauger out of the Intake area during and following spring was extensive. Using fisherman tag returns, 25 of 34 (74%) walleye tagged downstream from Intake from 1975 to 1977 and recaptured the same year were caught downstream in the Missouri River and Garrison Reservoir (Figure 12). Average distance moved downstream from the tagging site was 190 km with a range of 71 to 360 km. The majority of fish were captured in the upper one-third of the reservoir.

Although walleye concentrated below Intake diversion, fish movement did occur upstream over the structure (Figure 12). Movement over the diversion occurred in 1976 and 1977, and may have occurred in 1975. Six of 36 (17%) walleye tagged at Intake and recaptured the same year (including 2 recaptured by Fish and Game personnel) moved upstream an average of 171 km (Figure 12). None were recaptured upstream from Miles City (river kilometer 298). Six of 7 walleye recaptured during the following year, but during the same season were either captured at or downstream from the tagging location (Figure A-1).

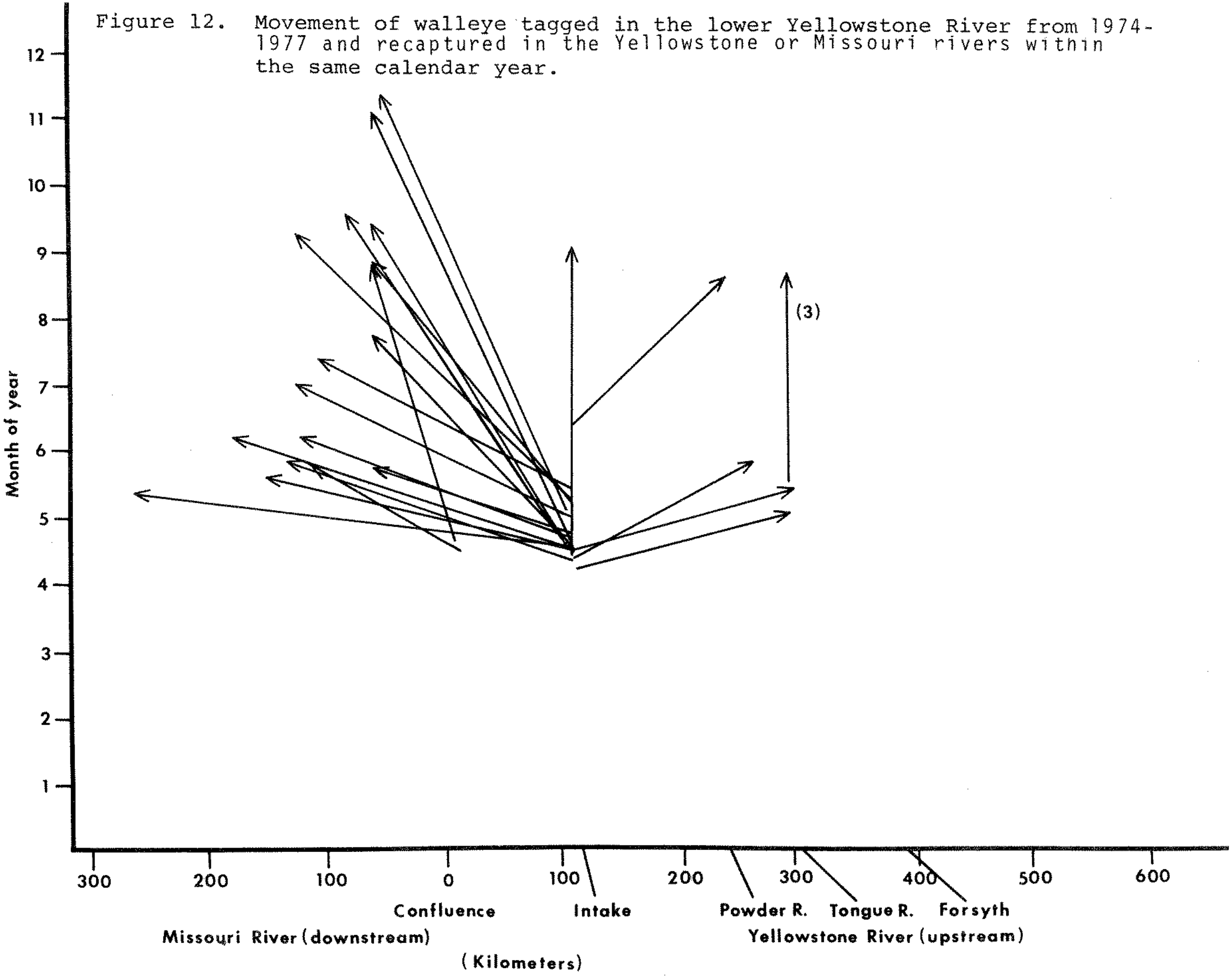


Figure 12. Movement of walleye tagged in the lower Yellowstone River from 1974-1977 and recaptured in the Yellowstone or Missouri rivers within the same calendar year.

The same trend was evident for walleye captured during the following year but in a different season (Figure A-2).

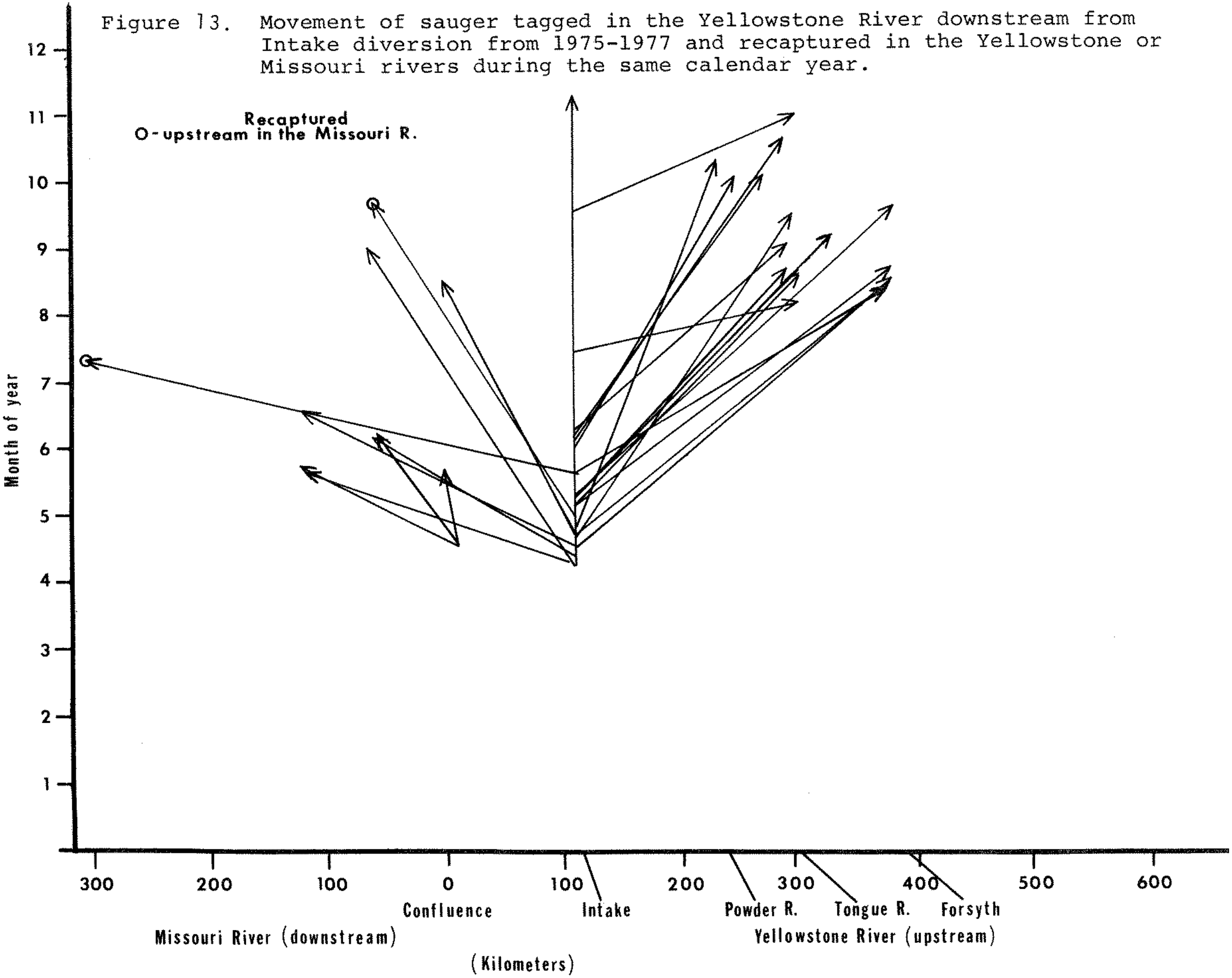
Sauger tagged downstream from Intake diversion also exhibited extensive movement but the majority moved upstream. Of 30 sauger recaptured during the year they were tagged, 17 (57%) moved upstream, 10 (33%) moved downstream, and 3 (10%) were recaptured near the tagging location during a different season (Figure 13). Sauger recaptured downstream from Intake moved an average of 172 km with a range of 13 to 417 km. Two sauger were recaptured 58 and 304 km upstream in the Missouri River from the confluence of the Missouri and Yellowstone rivers. Average distance moved by sauger upstream over Intake diversion was 203 km with a range of 129 to 269 km. No fish tagged below Intake diversion were recaptured upstream from Forsyth diversion, 269 km upstream.

Sauger recaptured during the year following tagging exhibited similar movement patterns to fish recaptured during the same year (Figure A-3). Only 2 sauger were recaptured during the same season they were tagged, and both were within 14 km of the tagging location. Seven were recaptured during seasons other than the one they were tagged; three were caught near Intake, 3 moved upstream to Miles City and Forsyth diversion, and 1 was recaptured in the Missouri River.

Walleye were seldom collected upstream from Intake diversion at any time and were scarce below Intake except during the spring. In electrofishing collections made downstream from Intake diversion, walleye constituted 20, 35, and 30 percent of the combined walleye and sauger catch during the spring of 1975, 1976, and 1977, respectively. During July 1977, walleye composed only 2 percent of the combined catch. Near Miles City, walleye comprised 3 percent of the combined walleye and sauger catch during the spring of 1975 (Haddix and Estes 1976). Near Forsyth diversion walleye comprised 4 and 3 percent of the combined catch during the spring of 1974 and 1975, respectively (Haddix and Estes 1976).

Sauger, although abundant in the lower Yellowstone River, seldom moved over Forsyth diversion as determined by tag returns. Seventeen (74%) of the sauger tagged below Forsyth diversion and recaptured during the same year were captured within 5 km of the area they were tagged (Figure A-4). Three (13%) were recaptured upstream from the diversion an average of 101 kilometers and 3 (13%) were recaptured downstream an 79 kilometers. No sauger tagged below the Forsyth diversion and recaptured the following year was recaptured upstream from the Forsyth diversion (Figure A-5).

Figure 13. Movement of sauger tagged in the Yellowstone River downstream from Intake diversion from 1975-1977 and recaptured in the Yellowstone or Missouri rivers during the same calendar year.



Although some sauger can negotiate the diversion, most appear to be restricted in their range of upstream movement by the Forsyth diversion. Of 195 tag returns, only 9 sauger were recaptured upstream from the Forsyth diversion from 1973 through 1977 (Figure A-6). Four were tagged at Forsyth, 2 near Miles City and 3 were tagged in the lower Tongue River. Average distance moved upstream from the diversion was 58 km and ranged from 5 to 126 km.

Sauger concentrated in other areas in the lower Yellowstone River drainage during the spring. Relatively large numbers of sauger were collected in the lower Tongue and Powder rivers, and in the Yellowstone River near Miles City (Haddix and Estes, 1976, Elser et al. 1977, Rehwinkel and Gorges 1977). All fish tagged in the Powder River and recaptured in the Yellowstone River moved upstream (Figures A-7 and A-8). It appears that some fish captured on supposed spawning grounds may be recaptured in several of these areas during the same or following springs. Two sauger, tagged in the lower Powder River were recaptured in the Tongue River during the the same spring and early summer. One of the sauger was recaptured only 19 days after it was tagged after moving 92 kilometers upstream. In addition, two sauger tagged in the lower Powder River in spring were recaptured below Forsyth diversion the following spring.

Those sauger, tagged in the lower Tongue River and recaptured in the Yellowstone River during the same year, generally remained near the mouth (73%) or migrated upstream (23%) (Figure A-9). Nine (82%) of the sauger captured in the Yellowstone River the following spring were caught just below or upstream from Forsyth diversion (Figure A-10). Those sauger caught the following year but during seasons other than spring exhibited similar upstream movement patterns with 7 (64%) being caught near Forsyth diversion (Figure A-11).

Sauger tagged in the Yellowstone River near Miles City and recaptured during the same year were divided in their movement patterns with fish being recaptured at the following locations: 5 (29%) in the Yellowstone River within 5 km of Miles City, 5 (29%) upstream from the mouth of Tongue River, 3 (18%) downstream from the mouth of Tongue River, and 4 (24%) in the lower Tongue River (Figure A-12). Those sauger tagged in the Yellowstone near Miles City and recaptured the following year were also divided with 8 (42%) showing no movement and 9 (49%) recaptured upstream near or above Forsyth diversion (Figures A-13 and A-14).

Discussion

Large concentrations of sauger and walleye in spawning condition were evident below Intake diversion during the spring of 1977. Returns of sauger tagged downstream from Intake diversion indicated that a large number of sauger moved over the diversion during or following the spring spawning season. Walleye could negotiate the Intake diversion, however, most of them concentrated downstream from the structure during the spawning season. Walleye were rarely collected upstream from Intake and generally moved downstream to Garrison Reservoir after spawning. Intake diversion could be more important as a motivational barrier than a physical barrier to upstream spawning migrants who, after reaching the diversion, probably searched for the nearest suitable spawning areas downstream from the diversion.

Adequate spawning habitat for these fish exists downstream from the diversion in the form of extensive cobble and gravel bars. Physical habitat is quite different between the areas just upstream and downstream from Intake. Section 1, downstream from the diversion, was a wide run with a predominantly cobble-pebble substrate which had higher than average velocities for the lower Yellowstone. Section 4, upstream from the diversion, was typified by slower than average velocities and comparatively smaller substrate (see Physical Habitat Above and Below Intake Diversion). Densities of both walleye and sauger during the spawning season decreased the farther a shocking section was downstream from Intake diversion. The highest concentrations of eggs were found in the section immediately downstream from the diversion (see Life History and Habitat Criteria for Major Sport Fish).

Forsyth diversion appears to be more of a physical barrier than Intake because of the 0.5 m vertical drop (at summer flows). A good sauger fishery exists immediately downstream from Forsyth diversion and many tagged sauger were returned from this area. However, few tagged sauger and no walleye were recaptured upstream from Forsyth diversion.

The upstream spawning migration of walleye probably does not begin until spring because of harsh conditions in the lower Yellowstone River during the winter. Ice generally breaks up and moves out during March. This break-up often begins in upstream areas, in part, because the river flows in a north-east direction. Ice jams which frequently occur in the lower Yellowstone River may interrupt these migrations. Priegel (1970) noted that male walleye did not enter the spawning marsh until after ice broke-up on the Fox River.

Intake and other lower river spawning grounds are areas where walleye and probably sauger return each spring. Several studies have found evidence of homing behavior in walleye (Forney 1963, Crowe 1962, Olson and Scidmore 1962). Forney further suggested that three distinct walleye populations existed within Lake Oneida and that differences in their distribution were evident. The distribution of walleye tag returns from Garrison Reservoir may indicate the existence of a subpopulation in the reservoir. A large majority of walleye tagged in the lower Yellowstone River were recaptured in the upper end of Garrison Reservoir. The upper area of the reservoir is characterized by more turbid, flowing water than the lower reservoir. This was not the habitat type most preferred by walleye in other Missouri River reservoirs. Walleye preferred intermediate depths and turbidities in four Missouri River reservoirs as determined by percent catch (Nelson and Walburg 1977). A turbid river habitat was not preferred by walleye as indicated by their scarcity in the Missouri River prior to impoundment. The existence of a walleye fishery in the upper end of Garrison Reservoir may be dependent on the success of walleye spawning below Intake diversion.

Sauger movements were more complex than walleye. A small portion of the Intake spawning population returned to Garrison Reservoir. Nelson (1968) reported that sauger migrated upstream from Lewis and Clark Lake on the Missouri River in fall and winter, concentrated in the tail-water below Fort Randall Dam, and returned to the reservoir after spawning in the spring. In contrast to these movements, the majority of sauger from the Intake population were recaptured an average distance of 203 km upstream from Intake. The apparent void of fish in the sample section upstream from Intake diversion in spring indicates that sauger did not concentrate in any numbers upstream from the diversion and further indicates that after spawning those fish which moved upstream over the diversion continued upstream a relatively long distance. The majority of sauger which were captured in the Powder and Tongue rivers during spring and recaptured in the Yellowstone River had moved upstream from or were located near the mouth of the tributary in which they were tagged.

Further analysis of movement patterns of the sauger population will require additional data on summer distribution of sauger tagged at Intake and other known spawning grounds. Several movement patterns may exist for the lower Yellowstone River sauger population(s). A portion of the sauger population resides downstream from Intake in the Yellowstone River and/or Garrison Reservoir. During the spring they may move upstream to spawn below Intake and return downstream or continue upstream to rear. In addition, some sauger from the upper and middle areas of the lower Yellowstone may migrate downstream to spawn below Intake and return upstream to rear in late spring. These sauger are probably a separate segment of the Yellowstone population as no sauger tagged at Intake in the spring were recaptured at purported upstream spawning grounds (Peterman and Haddix 1975, Rehwinkel and Gorges 1977, Elser et al. 1977) in following springs. Also, no sauger tagged at these upstream spawning grounds (Powder River, Tongue River, and Yellowstone River at Forsyth) were ever recaptured below Intake diversion.

The upstream movement of sauger in the Yellowstone River would act to maintain population stability in upstream areas, offsetting the downstream drift of fry following emergence. Walleye and sauger fry are poor swimmers and are carried downstream in river currents (Houde 1969, Nelson 1968). A large majority of the young fish may end up many miles downstream from where they were spawned. If a barrier in the stream, such as a diversion dam, prevents upstream migration, a reduction or elimination of the population upstream from the diversion would occur. Intake diversion does not appear to be greatly affecting sauger movement while Forsyth diversion does. Perhaps this structure has adversely affected the sauger population upstream as indicated by lower densities of sauger in the upstream areas (see Life History and Habitat Requirements of Major Sport Fish).

Besides affecting those fish which presently migrate in the Yellowstone River, other migrating species may have been present prior to construction of the diversion. Species which require passage to an upstream area for survival such as to spawn or for rearing during a certain life stage may have been eliminated, reduced in abundance, or restricted in range following construction of the diversion. This appears to be the case for shovelnose sturgeon (*Scaphirhynchus platorynchus*) which are presently not found above Forsyth diversion, but were reportedly collected along shallow gravel shoals upstream from the diversion prior to its construction. A diversion may be a barrier to some bottom dwelling fish, such as catfish, ling, shovelnose and pallid sturgeon all or most of the year, while a more pelagic species may pass over the diversion during high water or when ice jams below the diversion raise the water level.

LIFE HISTORY AND HABITAT REQUIREMENTS OF MAJOR SPORT FISH

Introduction

The objective of this section was to gather data on life history and habitat requirements of selected fish species. The two fish species chosen for this study were walleye and sauger. Relative abundance and growth of sauger were determined for fish collected in the lower Yellowstone River during the late summer and autumn of 1977. This type of data collected over a number of years, provides a basis for analysis of sauger abundance, growth and condition during natural flow regimes. Flow regimes which have been altered for a number of years because of increased water withdrawal may alter survival, growth, and condition of fish if the withdrawal affects their preferred habitat or food source. Sauger were selected for this phase of study because they were abundant throughout the lower Yellowstone River. Age and growth data was also used to try and define subpopulations of sauger within the river system.

Water fluctuations and changes in water temperature on the spawning grounds have been shown to have detrimental effects to fish eggs and embryo survival and may have a measured effect on the variability of year class strength (Walburg 1972, Nelson 1968, Johnson 1961, Koenst and Smith 1976). Walleye and sauger reproduction in the lower Yellowstone River is of particular importance not only to the river fishery but also to the Garrison Reservoir fishery. Nelson and Walburg (1977) found that variation in mean flows of Lake Oahe tributaries accounted for 70 percent of the variation in year-class strength of walleye. Large concentrations of both walleye and sauger below Intake diversion during the spawning season provided an opportunity to measure spawning habitat for both species in a river environment. Spawning time and physical conditions under which spawning occurs were determined for walleye and sauger below Intake during 1977.

Methods

Abundance and Age-growth

Forty electrofishing runs were made along 553 kilometers of the lower Yellowstone River to determine late summer-fall abundance and distribution of sauger and walleye. Sampling occurred between August 2 and October 6, 1977 and encompassed the section of river between Huntley, Montana and the North Dakota border. Fish were handled and data collected as described in Effects of Diversion on Upstream Fish Migration. Collection sites were approximately 8 km in length and consisted of one run along each shore. Sampling sections were lumped into 3 major areas for data analysis: (1) lower, downstream from Intake diversion; (2) middle, Powder River to Intake diverison; and (3) upper, Huntley diversion to Powder River.

Age-growth data was analyzed for sauger collected during both spring (below Intake) and summer-fall; data for the latter was divided into the 3 river areas. Scales were removed from all fish sampled. Scales were collected from an area below the first dorsal fin and above the lateral line. Cellulose acetate impressions of all scales were examined at 66X magnification.

To obtain back calculated lengths at annulus a curvilinear equation (method 4 in Tesh 1971) was used to describe the total length: anterior scale radius relationship:

$$\text{Log } L = K + n(\log S)$$

where L = total length (mm), S = total scale radius (mm)

K = intercept on the ordinate (log units),

n = slope.

This equation expressed the relationship as well as or better than a linear equation (Method 2 in Tesh 1971) (Appendix B).

Length-weight relationships were determined using the following equation (formula 9.3 in Ricker 1975):

$$\text{Log } W = \log a + b\ (\log L)$$

: where W = weight (g) and L = total length (mm)

Condition factors were determined for sauger 150 mm and longer by 10 mm length intervals using the following formula (Carlander 1969):

$$K = \frac{W\ (10^5)}{L^3}$$

: where W = weight (g) and L = total length (mm)

Condition factors were weighted and lumped into 50 mm length intervals to reduce length related bias.

Spawning Criteria

Walleye and sauger eggs were collected at night on a large gravel bar 0.8 km downstream from Intake diversion. This was done to determine their preferred depth, mean velocity and substrate for spawning in the lower Yellowstone River. We sampled at 0.15 m water depth intervals from 0.3 to 0.9 m along four transect lines beginning on the gradually sloping north shore (Figure 14) using a net described by Priegel (1969) (Figure 15 and 16). The net was a 51 cm square basket 12.7 cm deep, and angled at the base. It was covered by fine wire mesh (1.5 mm) and attached to a fiberglass pole. We measured water velocities at each site prior to egg sampling. One person held the net down while another person kicked and swept his feet along the bottom moving toward the net from a distance of approximately 4.6 m upstream.

The number of transects sampled each night varied because of insufficient time to complete all four transects. Twenty-five drift net sets were made from 20 seconds (approximate time required for a kick sample) to 5 minutes on the transect lines during the first two nights of sampling to determine if eggs were drifting into the kick samples. Only one egg was collected in drift samples, indicating that little drift was occurring in the net.

Additional samples were taken on eight transect lines from 4 to 25 km downstream fron Intake diversion. Four large gravel bars were sampled at depths of 0.3, 0.6 and 0.9 m (1, 2 and 3 feet) on April 24 and 26.

Egg diameters were measured to determine species. The literature suggests that walleye and sauger eggs can be distinguished by size (Scott and Crossman 1973, Priegel 1969, Priegel 1970). Diameters of 157 eggs on the Intake bar averaged (range) 2.0 (1.9-2.3), 2.3 (2.0-2.4) and 2.0 (2.0-2.4) mm on April 18, 21 and 24, respectively. Differences in size of walleye and sauger could not be determined, however, as known walleye and sauger eggs (obtained from the body cavity) both averaged 2 mm. Eggs from other species were probably not included in the analysis, as no other species spawn in early and midspring in this area of the lower Yellowstone River that have comparable egg diameters. Only four eggs with diameters outside the range of 1.8-2.4 were collected (2.7-3.0 mm).

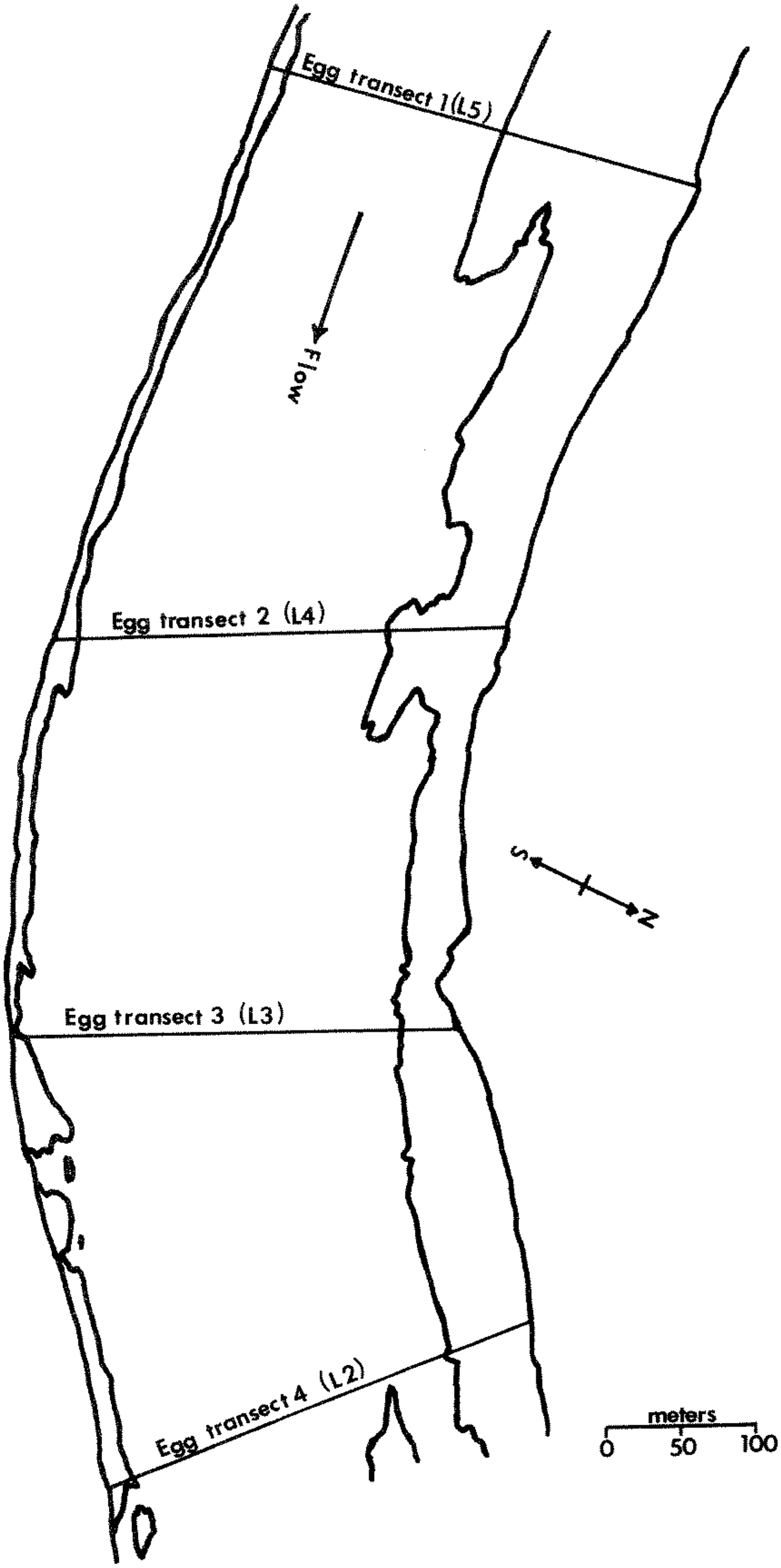


Figure 14. Map of egg transect sites located 0.8 km downstream from Intake diversion. The corresponding water surface profile cross-sections are in parenthesis.

Figure 15. Using this net, we collected eggs on the Intake gravel bar at night to develop walleye and sauger spawning criteria.

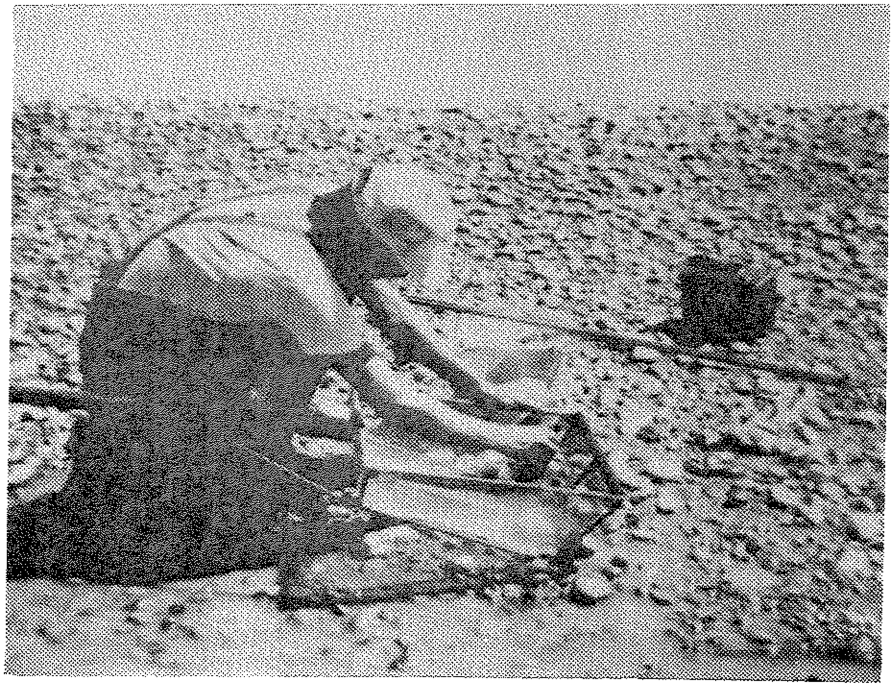


Figure 16. We counted eggs and placed them, along with the debris, into plastic containers and measured egg diameters the following day.

Results

Abundance and Age-growth

We collected 931 sauger and walleye during late summer and early autumn electrofishing runs on the Yellowstone River. Sauger comprised over 98 percent of the total catch. Walleye consisted of 5, 1, and 2 percent of the catch in the lower, middle, and upper areas, respectively. Relative abundance of sauger decreased by 55 percent from the lower to upper area. The mean number of sauger collected per 8 km section of river was 33.6, 23.2, and 15.1 in the lower, middle and upper areas, respectively (Table 1).

Mean total length of sauger in the sample increased in upstream river areas; 316, 339, and 366 mm in the lower, middle, and upper areas, respectively (Table 1). There were significant differences in mean length of sauger between the upper and middle areas ($P < 0.005$) and middle and lower areas ($P < 0.0005$).

Annulus formation probably occurred during May in 1977, with some fish forming annuli in April and June. Mean length and weight at annulus, growth (in increments of length) (Table 2), and length-weight relationships (Appendix B) were similar for sauger collected in all three river areas during summer-autumn. Grand mean total lengths at annuli did not differ between river areas by more than 15 mm for sauger through age 5 (Table 2). Sauger in the middle area were longer at similar ages than those in the upper and lower areas; the largest differences occurred at age 1, approximately 14 mm, and decreased as age increased. Grand mean increments of length were very similar between all three areas with a maximum difference of only 9 mm between areas for age groups 2 through 5 (Table 2). The largest increment of length for the combined areas was 157 mm at age 1 and increments decreased progressively through age 7 (Table 3).

Differences in back calculated weights at annuli between river areas followed the same trends observed in back calculated lengths (Table 2). Age 1 fish in the middle areas weighed more than age 1 fish in either the upper or lower areas, but the difference decreased with age and by age 5 weight of sauger in both upper and lower areas exceeded weight of sauger in the middle area. Although the length-weight relationship increased from the lower to the upper area, differences were slight (Appendix B) so a single curve was used to represent all areas (Figure 17).

Table 1. Average number of sauger per collection, their average length and the percent of age four and older sauger in collections made in three sections of the lower Yellowstone River during late summer and early autumn, 1977.

Section	Number of collections	Number of sauger per collection	Average length (mm)	Percent of age four and older sauger
Lower	7	33.6	316	13
Middle	13	23.2	339	23
Upper	18.5	15.1	366	32

Table 2 . Average calculated total length, increment of length and calculated weight for sauger collected in three areas of the lower Yellowstone River during the late summer and early autumn of 1977.

		Lower area					
		Length (mm) at annulus formation					
Year class	Number of fish (%)	1	2	3	4	5	6
1971	5 (2)	179	274	350	419	470	511
1972	18 (6)	168	253	322	377	417	
1973	16 (5)	178	267	322	365		
1974	95 (32)	151	232	293			
1975	99 (34)	150	243				
1976	62 (21)	160					
Grand mean calculated length	295	155	241	302	378	428	511
Grand mean increment of length		155	87	62	52	42	41
Grand mean calculated weight		29	109	214	417	613	1034

		Middle area						
		Length (mm) at annulus formation						
Year class	Number of fish (%)	1	2	3	4	5	6	7
1970	1 (0)	225	275	315	391	439	490	520
1971	8 (3)	202	283	361	409	443	471	
1972	18 (6)	185	263	321	367	407		
1973	40 (14)	181	260	313	352			
1974	107 (37)	163	245	304				
1975	62 (22)	161	256					
1976	50 (17)	167						
Grand mean calculated length	286	168	252	310	364	419	473	520
Grand mean increment of length		168	83	58	43	38	30	30
Grand mean calculated weight		39	131	243	391	597	857	1139

		Upper area						
		Length (mm) at annulus formation						
Year class	Number of fish (%)	1	2	3	4	5	6	7
1970	4 (1)	173	270	329	402	454	499	537
1971	7 (2)	151	234	294	367	406	443	
1972	25 (9)	163	259	328	385	426		
1973	57 (20)	156	240	302	348			
1974	114 (40)	153	238	302				
1975	38 (13)	140	248					
1976	39 (14)	155						
Grand mean calculated length	284	153	243	305	362	425	463	537
Grand mean increment length		153	90	64	52	42	40	38
Grand mean calculated weight		28	114	232	391	639	838	1302

Table 3. Average calculated total length, increment of length and calculated weight for sauger collected in the lower Yellowstone River during late summer and early autumn and those collected during the spring downstream from Intake in 1977.

		Combined areas						
		Length (mm) at annulus formation						
Year class	Number of fish (%)	1	2	3	4	5	6	7
1970	5 (1)	182	270	325	399	450	497	534
1971	20 (2)	174	260	333	395	436	470	
1972	61 (7)	169	257	323	376	418		
1973	113 (13)	165	249	307	352			
1974	316 (37)	154	237	299				
1975	199 (23)	150	245					
1976	151 (17)	160						
	865							
Grand mean calculated length		157	244	305	365	424	476	534
Grand mean increment of length		157	87	62	50	42	37	36
Grand mean calculated weight		30	114	227	392	619	878	1250

Table 3. Continued.

Year class	Number of fish (%)	Intake (spring) Length (mm) at annulus formation							
		1	2	3	4	5	6	7	8
1969	1 (0)	192	267	310	358	412	451	489	526
1970	2 (0)	164	264	317	398	450	484	507	
1971	16 (3)	197	286	370	428	466	493		
1972	35 (6)	168	262	332	367	435			
1973	104 (19)	167	255	310	344				
1974	334 (61)	165	251	298					
1975	58 (11)	162	247						
1976	2 (0) 552	162							
Grand mean calculated length		166	253	305	359	444	490	501	526
Grand mean increments of length		166	87	51	38	58	29	37	37
Grand mean calculated weight		30	113.3	208	350	673	935	1004	1172

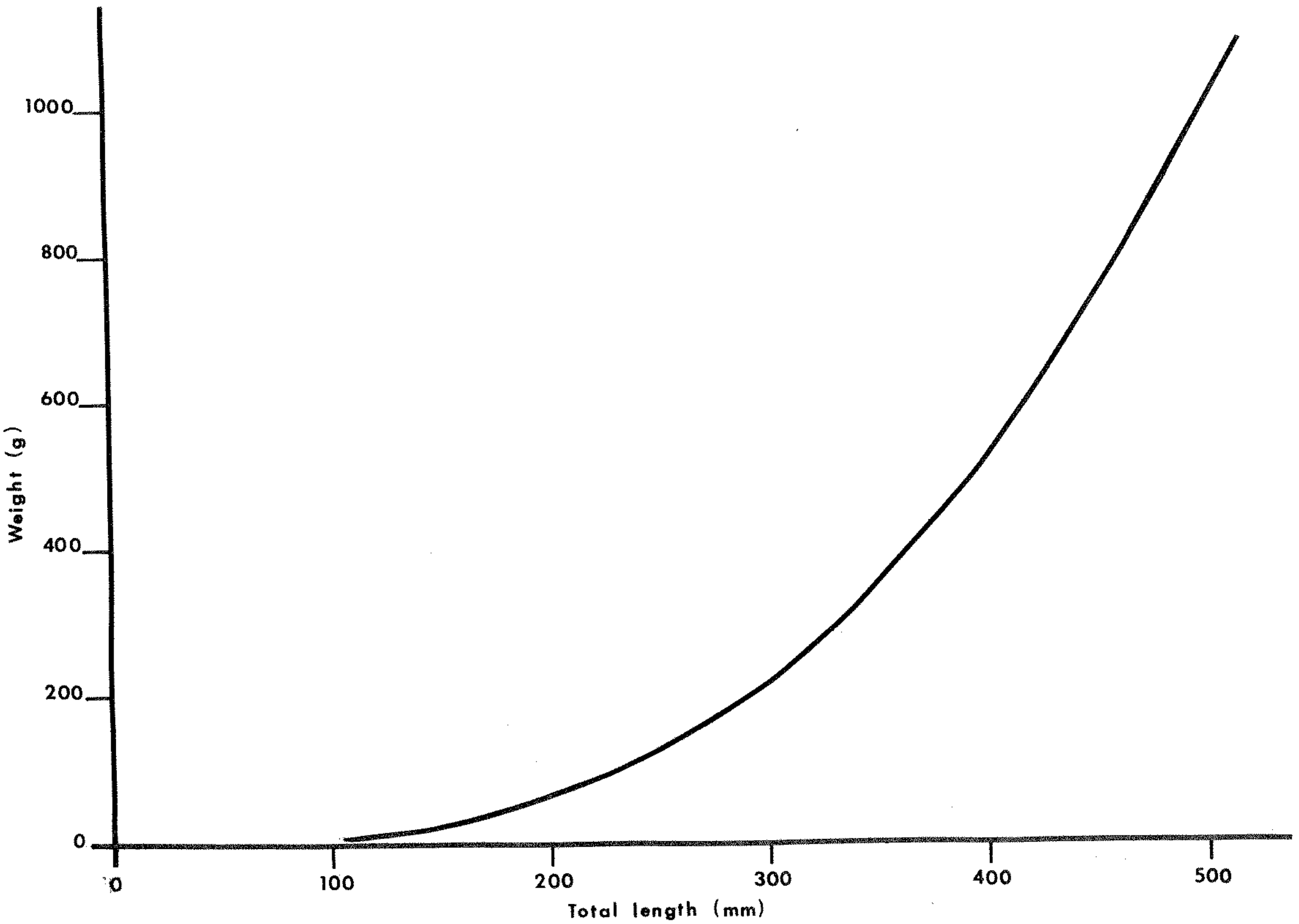


Figure 17. Total length versus weight relationship for sauger collected in the lower Yellowstone River during 1977.

Sampling during late summer-fall revealed a larger percent of older sauger in the upstream sections. The percent of age 4 and older sauger in the catch increased 2.5 fold (13 to 32 percent) from the lower area to the upper area (Table 1). Likewise, 1 and 2 year old fish comprised a larger share of the population in the downstream areas; 55, 39, and 27 percent of the sample in the lower, middle and upper areas, respectively (Table 2).

Sauger collected in the spring in the lower area were similar in total length at annulus to the combined summer-autumn catch (Table 3). Grand mean calculated weights were also similar and closely followed trends in back calculated length. Length-weight relationships were similar for both groups (Appendix B).

Three year old fish were the largest age class (37%) of sauger collected in all three areas of the lower Yellowstone during the summer-fall (Table 3). Three year old fish were also the largest year class below Intake in the spring (61%). This probably resulted from a strong age 3 year class and because age 3 sauger were more susceptible to our sampling gear than younger, smaller sauger.

Grand mean condition factors were not significantly different between river areas. Condition factors, calculated for 50 mm length intervals, indicated a relatively isometric growth pattern for sauger collected during summer and autumn. Sauger in the lower river had the smallest condition factors, and fish in the upper area had slightly better condition factors than fish in the middle area (Table 4). Sauger collected in the lower area during the spring had the smallest condition factors but they were not significantly different from the condition of the combined summer-autumn fish (Table 5). The spring spawning population also exhibited relatively isometric growth.

Spawning Criteria

Spawning of walleye and sauger was documented downstream from the Intake diversion in the spring of 1976 (Haddix and Estes 1976) and 1977. We collected 233 eggs on 5 sampling efforts during the spring of 1977 (Figure 18). Peak sauger

Table 4. Mean condition factors by 50 mm length intervals of sauger collected in three sections of the lower Yellowstone River during late summer and early autumn,1977.

Length interval (mm)	Lower		Middle		Upper	
	n[1]	$\bar{k}$[2]	n	$\bar{k}$	n	$\bar{k}$
150-199	2	0.722	1	0.734	0	
200-249	59	0.794	14	0.831	17	0.911
250-299	62	0.766	64	0.813	42	0.774
300-349	110	0.762	100	0.821	86	0.802
350-399	36	0.772	67	0.786	83	0.854
400-449	10	0.795	16	0.827	29	0.812
450-499	10	0.769	15	0.829	16	0.880
Grand mean condition factor	296	0.775	283	0.813	280	0.826

[1] n = number of fish

[2] $\bar{k}$ = mean condition factor

Table 5. Mean condition factors (k), by 50 m length intervals, of sauger collected in the lower section during the spring and in the combined lower, middle, and upper sections of the Yellowstone River during late summer and early autumn, 1977.

Length interval (mm)	Lower (spring)		Combined (summer-fall)	
	n	$\bar{k}$	n	$\bar{k}$
150-199	3	0.573	4	0.726
200-249	17	0.703	90	0.822
250-299	202	0.726	168	0.786
300-349	171	0.723	296	0.794
350-399	54	0.737	186	0.813
400-449	19	0.814	55	0.813
450-499	6	0.804	41	0.834
500-549	6	0.858	16	0.851
Grand mean condition factor	479	0.731	859	0.804

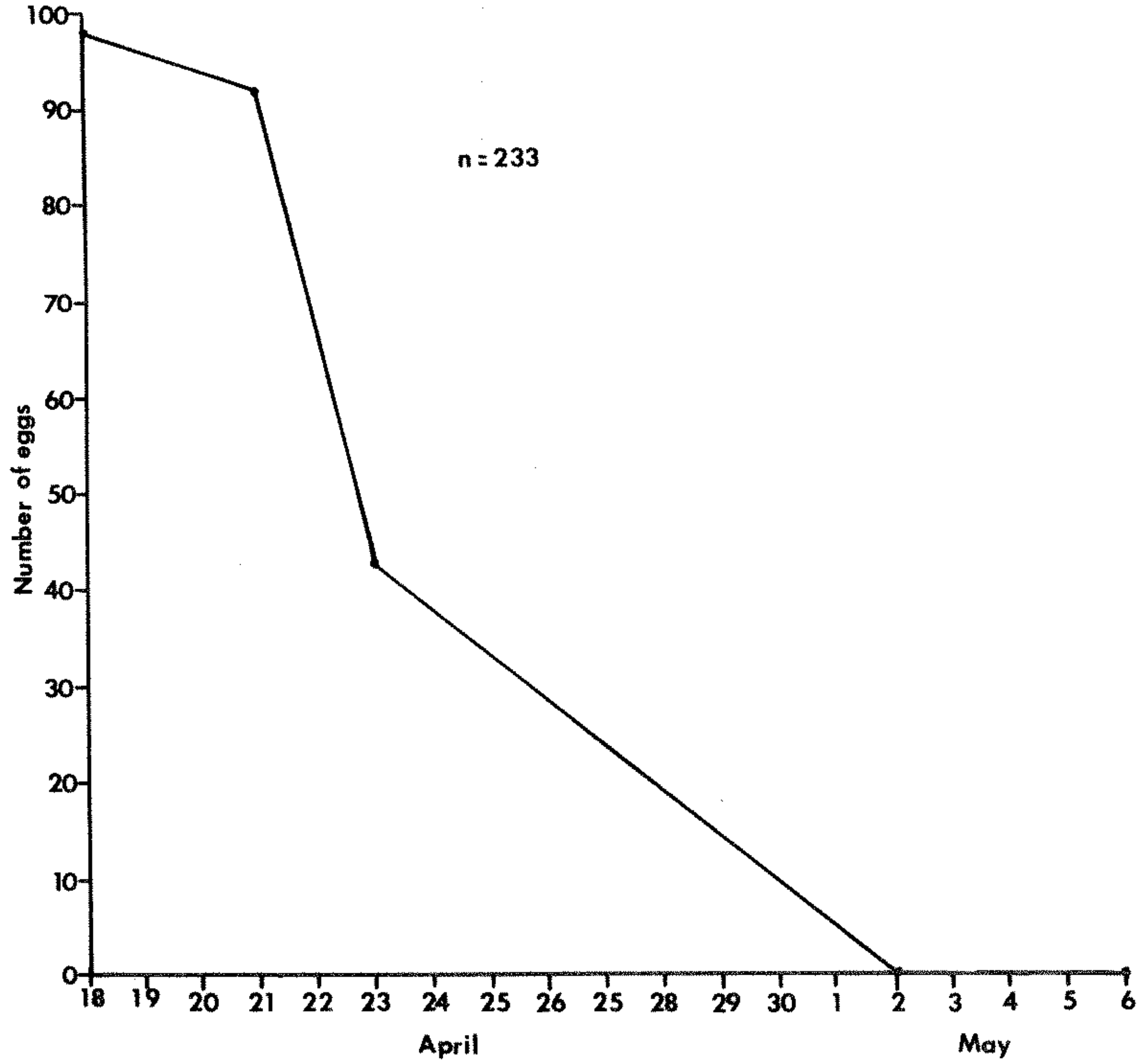


Figure 18. Total number of eggs collected on the Intake gravel bar during spring 1977.

abundance occurred several days prior to the initiation of egg sampling in 1977 and walleye abundance reached a maximum during the egg sampling period (Figures 10 and 11). Largest number of eggs (98) was collected on the first sampling date, and egg numbers decreased continually to zero by May 2.

We determined initial combined walleye and sauger spawning criteria for depth, mean velocity (measured at 0.6 the depth) and substrate on the Intake gravel bar. Eggs would be expected to occur in a range of depths from 0.46 to 1.04 m (1.5 to 3.4 feet) at a 90 percent probability level. Most eggs (71%) were collected in 0.76 m (2.5 feet) of water or deeper (Figure 19). This sharp break in the curve suggests a preferred spawning depth of over 0.6 meters.

Nearly all of the eggs were collected along transects 2 and 3 (99%) in water 0.75 m (2.5 feet) or deeper (Appendix C). Only on transect 4, the downstream most transect, did we collect a large proportion of eggs (67%) in water .60 m (2.0 feet) or shallower. Mean water velocities on transect 4 at 0.45 and 0.60 m (1.5 and 2.0 feet) usually exceeded mean water velocities at 0.75 m (2.5 feet) for both transects 2 and 3. This implies that a combination of depth and velocity are important for spawning to occur.

At the 90 percent probability level, eggs can be expected to occur in a range of velocities from 71.8 to 95.9 cm/s (2.4 to 3.1 fps) (Figure 20). The range of velocities sampled was 36.0 to 110.6 cm/s (1.19 to 3.63 fps). Eggs were not found at sites with a mean water velocity of 65.5 cm/s (2.2 fps) or slower on the Intake gravel bar.

A majority of eggs (89%) was collected over mixed pebble-cobble or pebble substrate, with the remaining 11 percent over primarily cobble substrate. No eggs were collected in substrate covered by or containing sand and silt. Nearly all eggs (97%) were found over loose substrate as opposed to compacted or semi-compacted substrate (that which could not be dislodged by kicking). Sample sites included 53 percent loose cobble-pebble, 31 percent compacted cobble-pebble, and 10 percent substrate dominated by sand.

The water surface profile program was used to predict hydraulic parameters at the four Intake egg sections (see Development of a Method for Obtaining Cross Sectional Data for the Water Surface Profile Program and its Application to Analyze Habitat on the Lower Yellowstone River). These hydraulic parameters were used to predict the amount of top width (almost

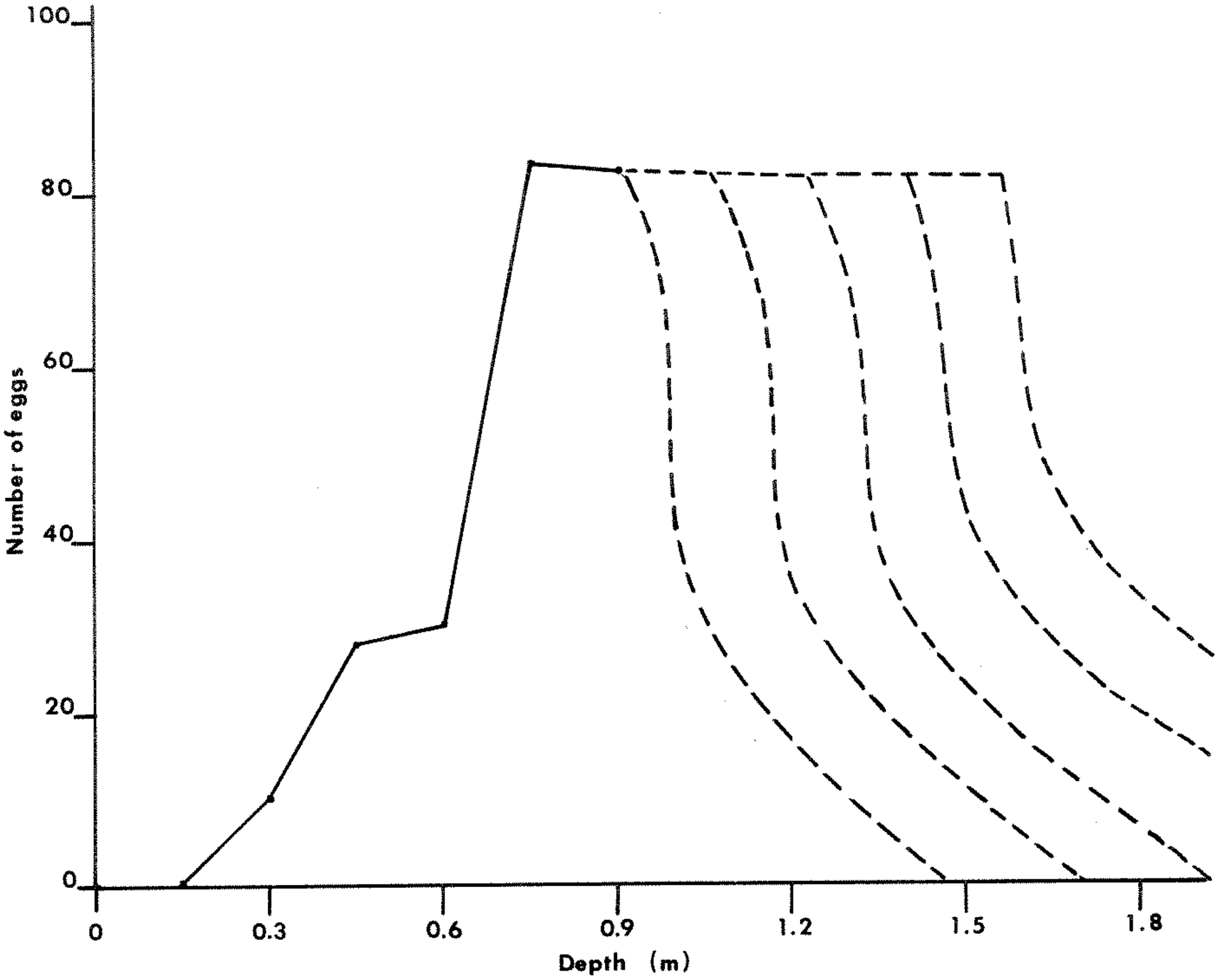


Figure 19. Total number of eggs collected at each depth interval along transect lines on the Intake gravel bar during spring 1977. Solid line represents measured egg abundance and the dashed lines are hypothetical representations of egg abundance at water depths over 0.9 m using the complement of the measured curve.

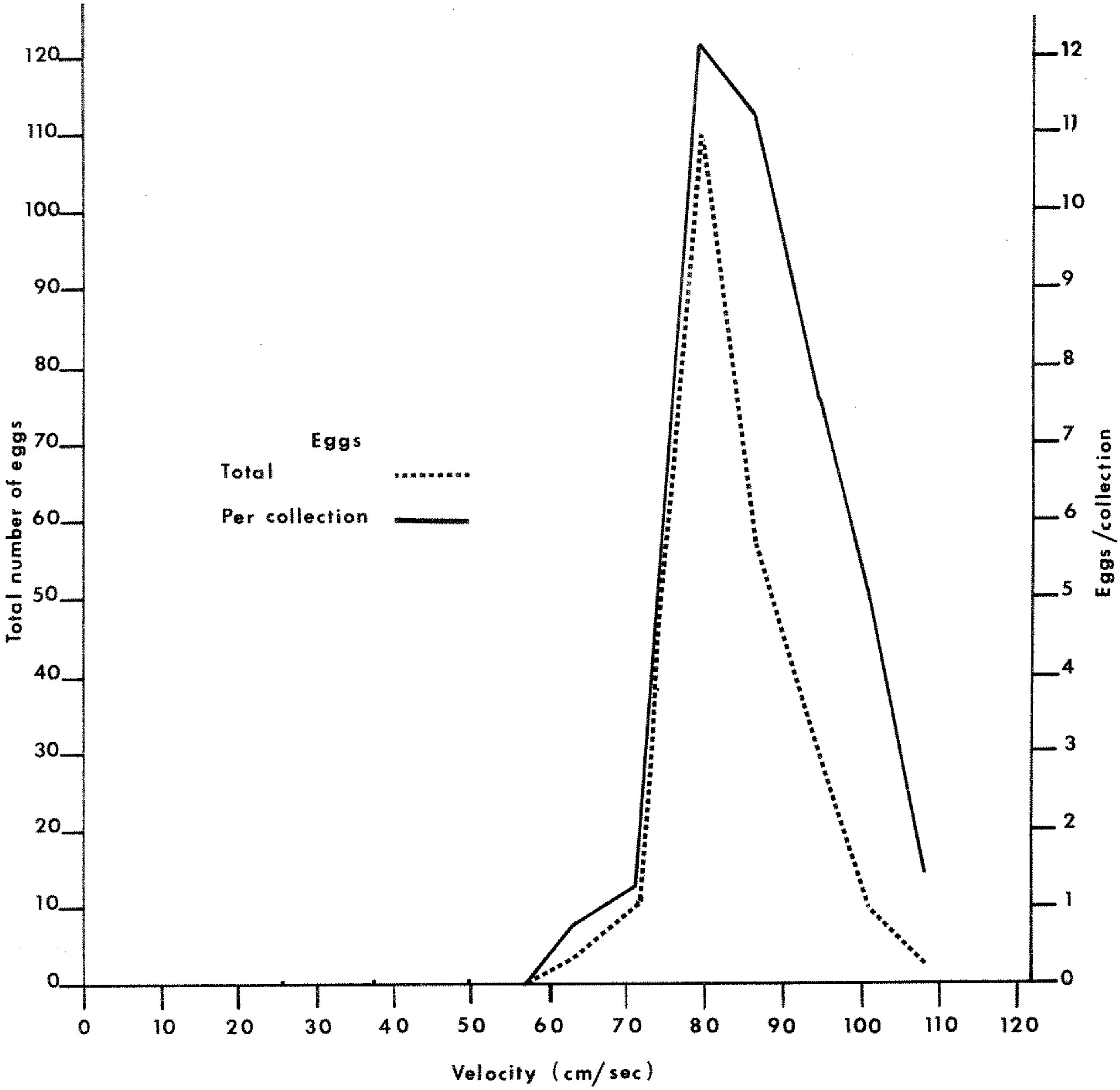


Figure 20. Total number of eggs collected at each 7.5 cm/sec water velocity interval and the number of eggs per collection at each 7.5 cm/sec interval on the Intake gravel bar during spring 1977.

identical to wetted perimeter) present at various flows which met spawning criteria at each cross-section (Figure 21). These criteria included: a mean water velocity between 70 and 96 cm/s, a depth not less than 0.46 m, and a cobble or pebble substrate. Any length of top width not meeting all the criteria was excluded.

Combined top width measurements meeting spawning criteria for all four transects declined sharply at a discharge of less than 140^3/s (5,000 cfs) (Figure 22). Optimum flows appeared to be between 170 and 310 m^3/s (6,000 and 11,000 cfs). A reduction in flow below 140 m^3/s would result in dewatering of eggs, increased silt deposition, and/or a reduction of the number of fish which actually spawn.

To determine if eggs could be collected at other sites along the river, eight additional transects downstream from the Intake bar were sampled. Only one egg was collected (Appendix D). It was found in 0.9 m (3.0 feet) of water on the large gravel bar downstream from the Intake bar.

Discussion

Abundance and Age-growth

Results from summer-autumn electrofishing collections showed differences in abundance, age composition and average length of sauger between the lower, middle and upper sections of the lower Yellowstone. Sauger in the upper section were less abundant, but had a larger average length and age than those in the lower section, while sauger in the middle section were intermediate in all three respects. However, there was little or no difference in absolute growth of sauger between the three sections. Tag returns indicated that sauger tended to move up the Yellowstone during spring and/or early summer from spawning grounds below Intake diversion and suspected spawning grounds in the lower Powder and Tongue Rivers (see Effects of Diversion on Upstream Fish Migration). These data suggest the existence of a general upstream migration of mature sauger after spawning. Berg (1977) found that average length of sauger increased in upstream sections of the 296 km reach of the Missouri River between Fort Peck Reservoir and Morony Dam. He found that sauger averaged 316 mm (531 fish) in the upper area and 289 mm (209 fish) in the lower area of this free flowing reach of the Missouri River.

Average length and weight at annulus, average increments of length and coefficients of condition were similar for sauger in all three areas and also similar to the spring spawning population downstream from Intake. Growth of Yellowstone River sauger compared favorably to reported growth data on sauger in other waters in the Missouri River drainage (Table 6).

Table 6. Grand mean total length of sauger from several different waters.

Locality (source)	Number of fish	Grand mean total length at annuli (mm) 1	2	3	4	5	6	7
Yellowstone River [1/] (present study)	859	157	244	305	365	424	476	534
Garrison Reservoir, N.D. (Carufel 1963)	318	125	221	310	386	461	587	
Upper Mississippi River Backwaters (Chistenson & Smith 1965)	42	124	229	302	345			
Lewis and Clark Lake S.D. (Nelson 1969)	1,112	188	324	404	466	514	560	
Marias River, MT., 1961 (in Peters 1964)	58	112	203	282	335	384	465	
Fort Peck, Mt., 1948 (in Peters 1964)	503	130	224	297	363	429	493	
Fort Peck, Mt., 1949 (in Peters 1964)	504	122	244	325	389	447	490	

[1/] Includes combined summer-fall fish collections.

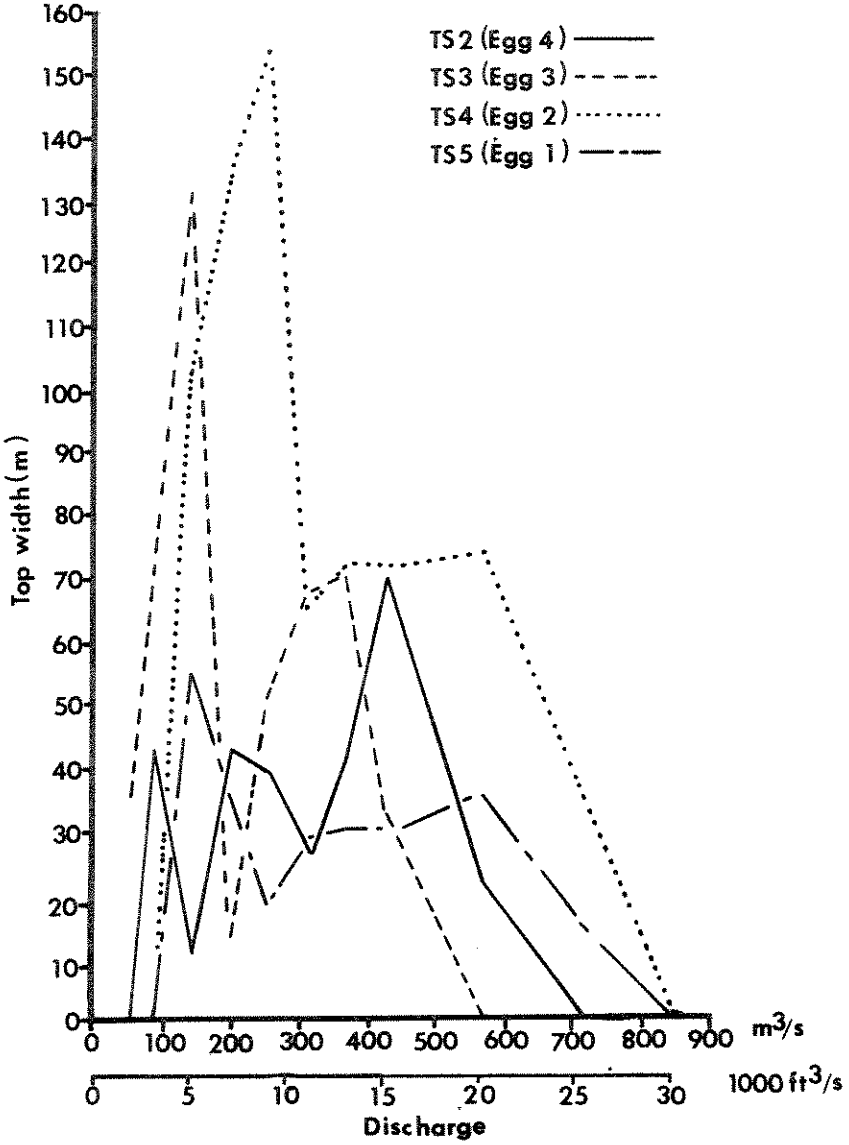


Figure 21. Amount of top width (which was nearly identical to wetted perimeter) of lower Intake transects (TS) 2, 3, 4 and 5 meeting initial, combined walleye and sauger spawning criteria of a mean velocity between 70 and 96 cm/sec, a depth of not less than 0.46 m, and a cobble or pebble substrate versus discharge.

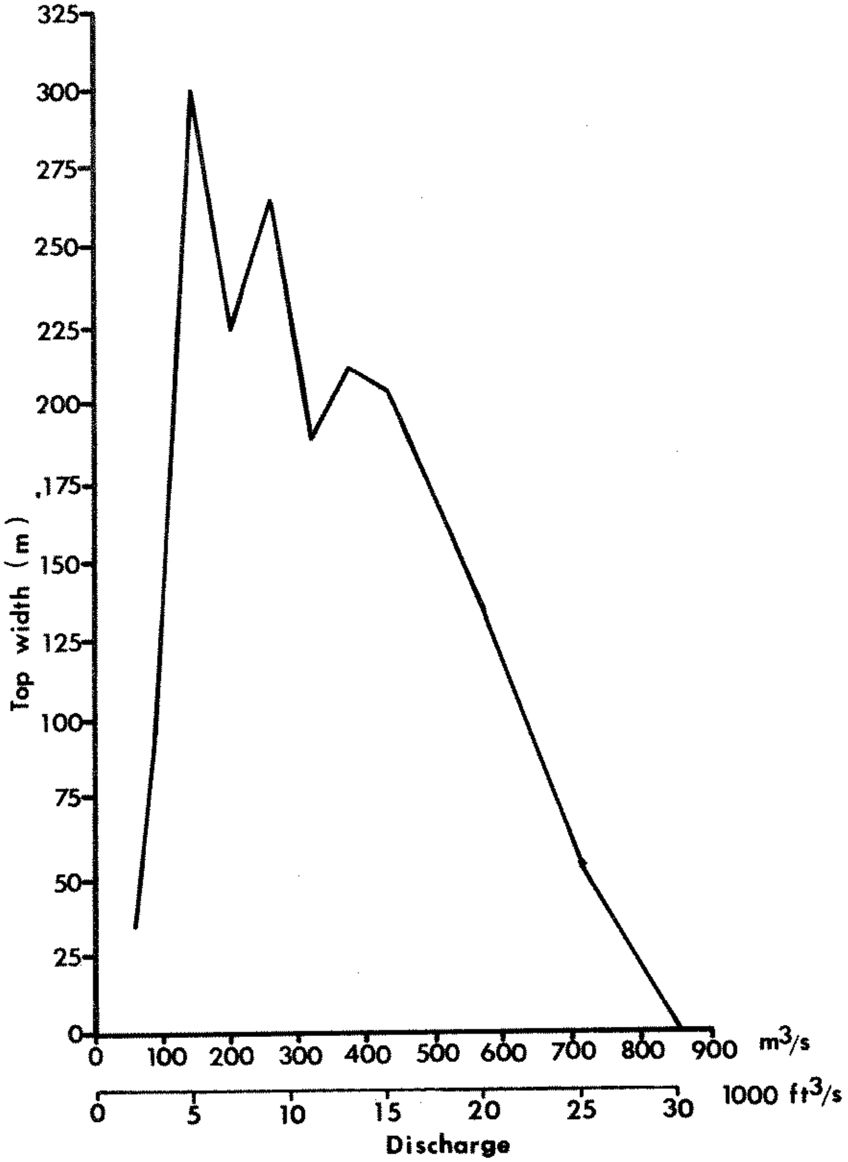


Figure 22. Combined amount of top width (which was nearly identical to wetted perimeter) of lower Intake transects 2, 3, 4 and 5 meeting initial, combined walleye and sauger spawning criteria of mean velocity between 70 and 96 cm/sec, depth of not less than 0.46 m and a cobble or pebble substrate versus discharge.

Yellowstone sauger were comparable in length to sauger in Missouri River Reservoirs through age 3 but were somewhat smaller at ages 4 and older.

Subpopulations of sauger could exist in the lower Yellowstone River as a result of the large distances between spawning areas. Growth rates of sauger were similar between river areas and between seasons in the lower area. Differences in growth rates of subpopulations would be masked because of the mixing of sauger from different spawning areas during the summer and autumn.

Further studies should include: (1) continued monitoring of summer autumn distribution and movement of sauger and other sport fish in the lower Yellowstone, (2) assessment of factors which might influence sauger distribution, growth and survival (including prey abundance, turbidity, temperature, rearing preference, etc.), and (3) continue to collect data for age-growth analysis.

Spawning Criteria

In the lower Yellowstone River walleye and sauger spawn during a period of relatively stable flows between ice-out in March and high spring flows beginning in May. Below Intake the majority of walleye and sauger spawned in water deeper than 0.6 m (2 feet) which currently would insure the survival of most of the eggs during years of normal flow fluctuations. Several authors reported that water fluctuations on spawning grounds were significant in determining year-class strength of sauger and walleye (Walburg 1972, Nelson and Walburg 1977, Priegel 1970).

Depth criteria for walleye and sauger spawning was indicative only of minimum spawning depth since we could not adequately sample water deeper than 0.9 m (3 feet). The upper range of preferred spawning depth can be hypothesized using the complement curve of measured preferred depth and extending several hypothetical curves for preferred maximum depths (Figure 19). Velocity criteria limited maximum spawning depth at 2 m.

No eggs were collected at sites with a water velocity of 66 cm/s (2.2 fps) or smaller. Egg abundance peaked and fell within the range of measured velocities which suggests that we measured the range of velocities at which the majority of fish spawned (Figure 20). The relatively fast velocities for spawning criteria (72 to 96 cm/s) would prevent silt from covering the dispersed ova. In addition, these velocities were generally associated with a relatively loose cobble-pebble substrate.

On the Intake gravel bar walleye and sauger selected pebble-cobble substrate to spawn on and also appeared to prefer loose as opposed to semi-compacted or compacted substrate. Substrate on spawning grounds was determined to be a significant factor in walleye egg survival by Johnson (1961). He observed the best survival on gravel-rubble substrate and further determined that egg survival increased by more than 10 times on a sand bottom when gravel and rubble had been added. Survival of eggs was poorest on muck bottoms.

When spawning criteria for depth, water velocity, and substrate were combined, the mid range of optimum spawning flows (determined from WSP data) was 240 m^3/s (8,500 cfs) (Figure 22). This was very similar to the historical (1939-1974) median flow for the Yellowstone River during April, 260 m^3/s (9,170 cfs) (from flow duration hydrograph compiled by U.S. Geological Survey). There was a very sharp decline in suitable spawning width at discharges smaller than 140 m^3/s (5,000 cfs) and larger than 368 m^3/s (13,000 cfs).

Sampling should continue at spawning sites on the Yellowstone River to increase the sample size and increase the range of habitats sampled. Samples should also be taken downstream from Forsyth diversion where a large number of sauger congregated, with relatively few walleye. Samples should be continued at Intake and an attempt should be made to determine the degree of overlap between walleye and sauger spawning. Presence of hybrids in the population suggests that overlap may occur to some degree every year.

Further studies should include estimates of year-class strength to determine what factors are important to survival and when they operate. Several authors determined that factors influencing year-class strength primarily affect early life stages including: (1) spawning and egg survival; (2) survival during the first summer, and (3) survival over the first winter (Johnson 1961, Priegel 1970, Nelson and Walburg 1977).

DEVELOPMENT OF A METHOD FOR OBTAINING CROSS SECTION DATA FOR THE WATER SURFACE PROFILE PROGRAM AND ITS APPLICATION TO ANALYZE HABITAT ON THE LOWER YELLOWSTONE RIVER

Introduction

Basic to determination of aquatic habitat criteria for a particular species of fish in a lotic environment is the knowledge of various physical and hydraulic characteristics of the river through its range of flows. Habitat data can be collected which relate biological activities of the fish (spawning, incubating, rearing, migrating, etc.) to physical characteristics existing in the river. Known habitat requirements of the species can then be correlated to these physical parameters and impacts predicted for altered stream flows (Bovee and Cochnauer 1977, Prewitt and Carlson 1977). One objective of this portion of the study was to develop a method to collect physical and hydraulic information on a deep, turbid, fast flowing river such as the lower Yellowstone.

Important physical criteria in a lotic environment include: depth, velocity, substrate size, channel width, and conveyance area. Since these physical parameters vary with discharge, they should be determined for the range of observed flows. The most accurate method of determining these parameters over a wide range of flows is by actual measurement, however; (1) this is extremely costly and time consuming and (2) several years may pass before flows desirable for measurement may occur. For these reasons methods have been developed for predicting various hydraulic parameters as a function of discharge (Stalnaker and Arnette 1976). The method utilized for this study was the Water Surface Profile (WSP) program developed by the U. S. Bureau of Reclamation (Dooley 1976). The program used data collected at only one discharge to predict changes in water surface elevation, velocity, wetted perimeter, and conveyance area of a stream profile cross section at other specified discharges. Dooley (1976) listed field data and descriptions needed for the WSP program. These include:

1. A map showing stream sections being studied and cross section locations.

2. Cross section survey data.

3. Distances between cross sections, including inside and outside distances at stream meanders.

4. Measured flow in cubic feet per second.

5. Corresponding water surface elevations at all cross sections at the measured flow.

6. Photographs of the stream reach being studied and photographs at each cross section.

7. Descriptions of the streambed material at each cross section (sand, gravel, cobble, boulder, muck, debris).

8. Description of bank and overbank material and vegetation (trees, brush, grass, logs).

9. Identification of points where streambed material, vegetation, and streambank change within the cross sections.

10. A list of flows to be used for predicting various physical parameters within the study section.

Problems encountered when obtaining cross-sectional data for a large turbid river too deep to wade were: (1) elevations of the streambed were difficult to obtain by standard surveying techniques, (2) breaks in streambed contour could not be observed, (3) streambed substrate partical size could not be observed, and (4) stream controls were often difficult to find. Other drawbacks in collecting data on a large versus small river were increased time, manpower, and expense. In addition, accuracy was more difficult to obtain on a large than small river. Obtaining discharges in a large river can also be a problem, however, U. S. Geological Survey gage stations were located near study sections on the Yellowstone. A method was developed to solve some of these data collection problems.

The second major objective was to determine the effects of Intake diversion, a low head dam, on the physical aquatic habitat. This was accomplished by using the WSP program on sections of river above and below the diversion structure. Intake is an important area of the lower Yellowstone River as seasonally large concentrations of walleye, sauger, paddlefish and other fish species occur there. Quantitatively assessing the previously mentioned hydraulic parameters upstream and downstream from Intake diversion would provide insight into the effects of diversion structures on physical channel features and provide additional information on life history requirements of certain fish species.

Methods

Two methods of collecting large river cross-sectional survey data for use in the WSP program were tested. Initial procedures for surveying the channel and streambank above water level and to a depth of 0.9 m (3 ft.) (wadable depth) were common to both methods (Figure 23) and closely followed that described by Spence (1975). Equal water surface elevations were located on both shores to insure that the transect was perpendicular to the general direction of flow. Permanent bench marks were placed above the high water mark on the transect line on both banks of the river. Flow measurements were obtained from the nearest U. S. Geological Survey gage station to determine discharge.

Differences in the two methods were in the technique of collecting cross-sectional data in water depths greater than 0.9 m. In the first method, an observer remained on shore while two people in a john boat measured water depths using a sounding rod. The driver moved the boat across the channel in a leap frog pattern by drifting downstream from the transect line and moving back upstream to a new point on the line. Location and distance along the transect line were determined by use of a level set upon shore and a stadia rod mounted in the boat (Cochnauer 1976). Communication between shore and boat was aided by walkie-talkies. Because depth and turbidity prevented observation of the channel bottom except in shallow water, substrate was determined by the feel of the channel with the rod. Although 3 people were required in this method, Cochnauer (1976) sounded the Snake River, Idaho with only one person in the boat by using more elaborate sounding equipment.

A second method was developed and tested which needed only 2 people. The on-shore observer used a range finder (Lietz, model SD-5F) instead of a level to determine distances and keep the boat on the transect line (Figure 24). Range finder accuracy was ± 1, ± 3, ± 5 percent at distances from 0-300, 300-500, and + 500 feet, respectively. A portable, constant recording fathometer (Raytheon, model DE-719B) powered by a 12-volt diesel battery, was mounted in the boat with the transducer suspended in a water filled container (Figure 25). Feedback was reduced by placing only enough water in the container to cover the transducer. The depth sounder print-out was calibrated in increments of 0.3 m (1 ft.) and could be interpolated to 0.03 m (0.1 ft.). Depth sounder print-outs could not be read for depths 0.6 m or shallower (Figure 26). The large diesel battery was used to insure adequate current supply for a full day's use. A voltmeter, installed in line, would permit use of a smaller car battery or extend the use of the diesel battery by informing the operator of reductions in voltage. Depth sounder accuracy decreased when current was below 11.5 v.

To provide targets for the boat driver when crossing the channel and minimize contact of the boat motor with rocks in

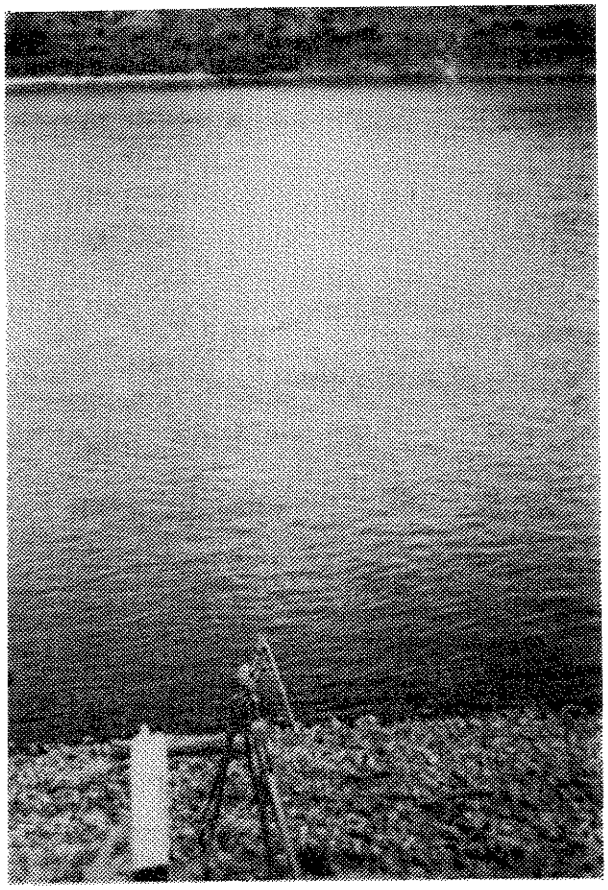


Figure 23. Distances across the channel were measured with a level (foreground) and a stadia rod (far bank). Standard survey techniques were used to obtain elevations between bench marks (steel posts) and a wadable depth (white floats).

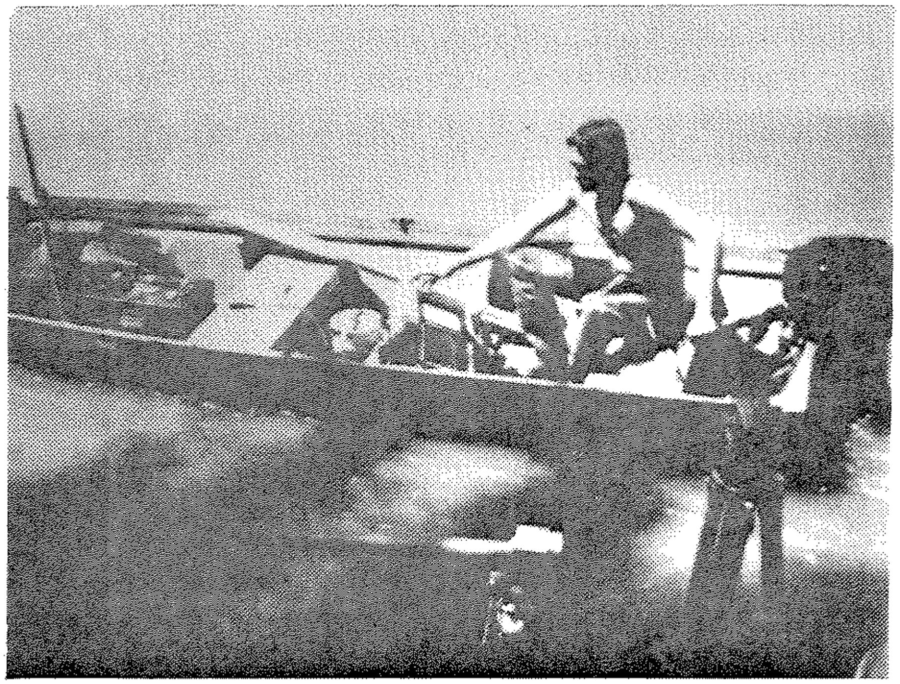


Figure 24. The range finder (center foreground) was used to measure the distance to the boat as it crossed the channel when taking depth profiles.

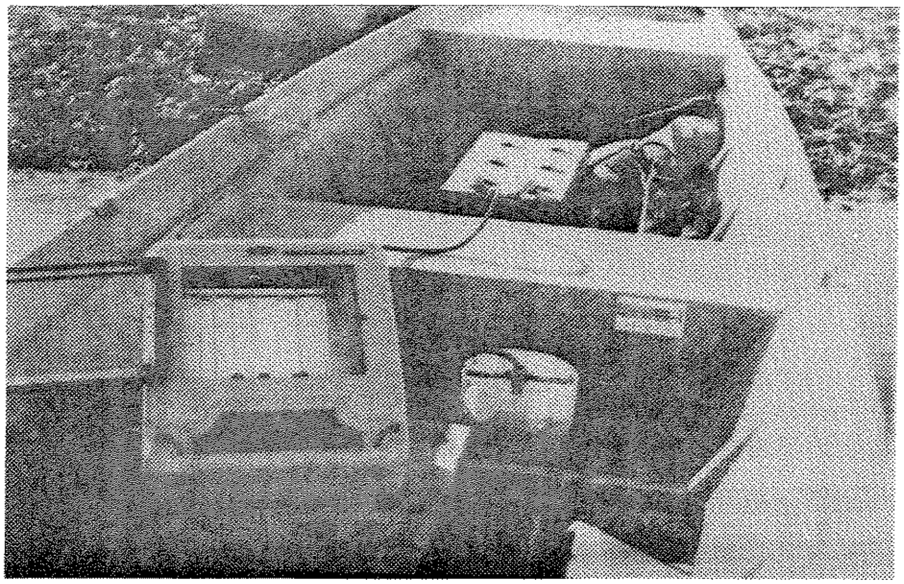


Figure 25. This portable, constant-recording fathometer had variable depth scale and a fix marker. The transducer was submerged inside the cylinder and could transmit through the hull. A large 12-volt diesel truck battery was used for the power source.

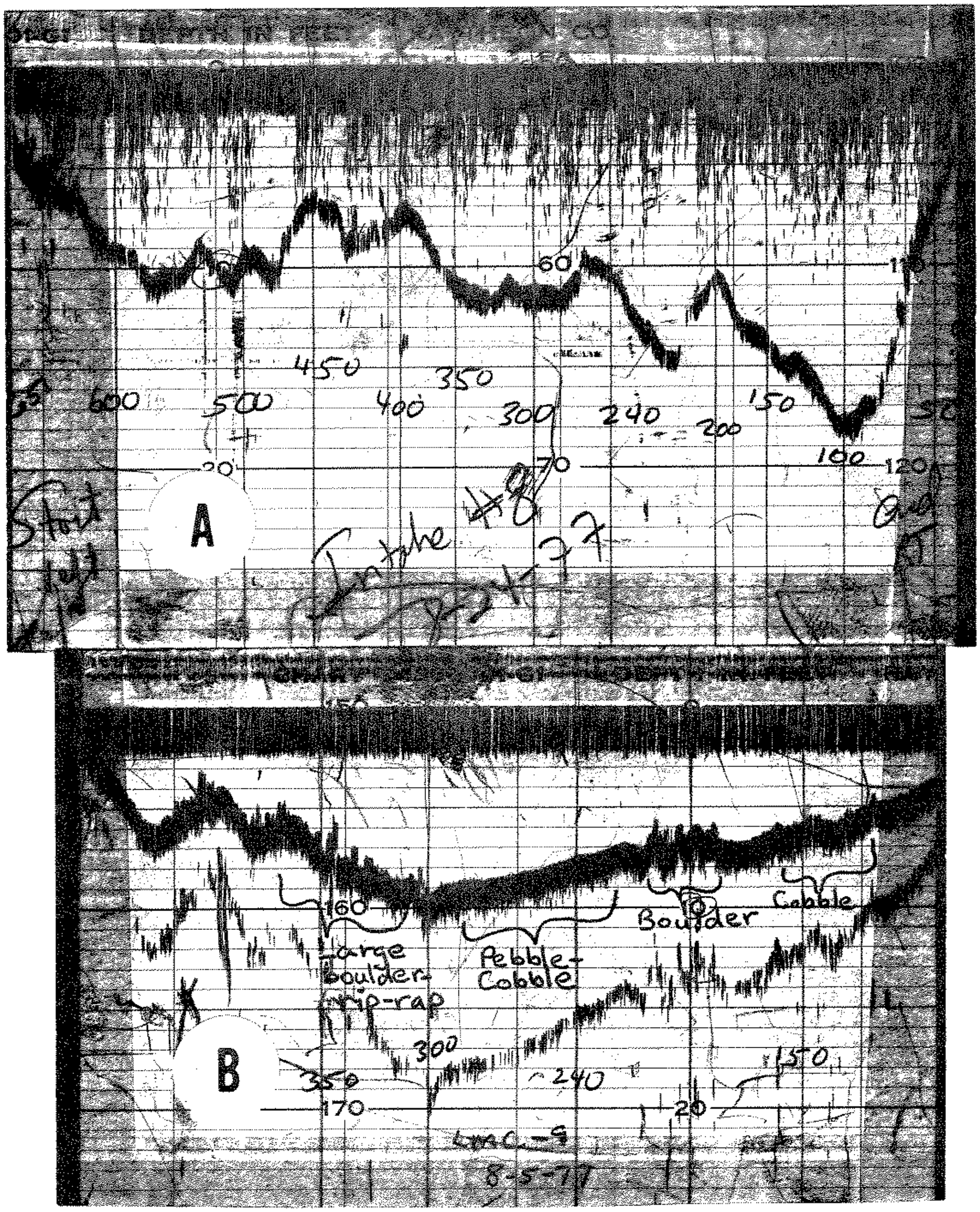


Figure 26. Original printouts of bottom profiles taken with a constant recording fathometer. Each horizontal line represents 1 foot in depth and vertical lines were automatically marked at predetermined distances from waters' edge by the boat driver. Profile A is lower Intake transect 8 and B is lower Miles City transect 9.

the shallow water along shore, two large floats were placed off each tank in 0.9 m of water (Figure 23). Use of floats reduced the distance to be read with the range finder and thus increased accuracy.

To measure profiles, the driver maneuvered the boat upstream to the float on the far side of the channel. The observer, watching through the range finder, would signal the driver with a walkie-talkie and keep him on the transect line as he moved across the channel to the near shore. The observer called out predetermined distances as the driver passed them. The driver used an automatic marker on the depth sounder to mark the location of these distances on the depth profile. Profile distances between the predetermined measurements could then be interpolated from the print-out. Maneuverability of the boat along the transect line was good during low and intermediate flows. Substrate was determined by appearance of the stream bottom on the fathometer print-out (Figure 26).

After initial trial runs, the second method was superior to the first for the following reasons: (1) less time was needed to run a profile, (2) one less person was required, (3) the depth sounder print-out provided more information than sounding, and (4) it was more cost efficient. While both methods provided similar profiles when uniform bottoms were surveyed, the depth sounder provided more accurate data for irregular and/or deep bottom profiles (Figure 26). It was possible to miss dips, rises and/or the thalweg in an irregular profile unless numerous soundings were made (Figure 26). In some sections water depths were over 5.2 m deep, making sounding difficult, particularly with the accompanying high current velocities. Changes in bottom substrate, as well as the relative roughness across a transect, were vividly depicted in the depth sounder print-outs (Figure 26). Numerous soundings in a river this deep and turbid would be needed to obtain comparable data. Predominate substrate was obtained from the print-outs by classifying degree of irregularity; bedrock and boulder were the most irregular and pebble-sand substrates were the most uniform (Figure 26).

Equipment common to both methods included a 4.3 m john boat and a 7.5 hp outboard motor, a 7.3 m collapsible stadia rod (Figure 27), a level or transit, a 100 m tape, bench markers (steel fence posts) and 2 walkie-talkies. In addition, we needed 3 people and a sounding rod for the first method, whereas 2 people, a range finder, a portable constant recording fathometer with transducer, and 2 floats were needed for the second method.

Initial costs were higher for the second method because of the additional equipment, however, by the end of the first field

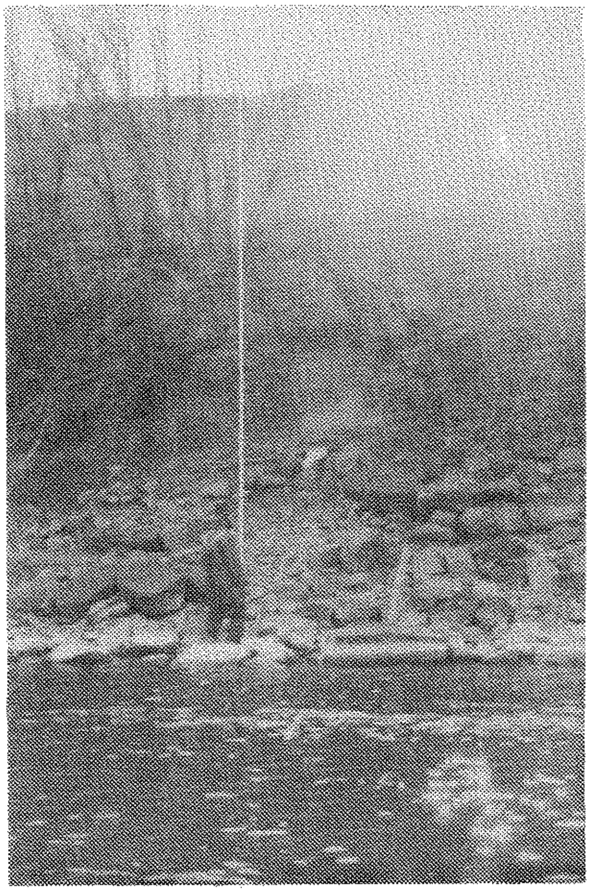


Figure 27. A 7.3 meter collapsible stadia rod was used because of the high banks in many sections of the Yellowstone River.

season, the second method was comparable in cost due to less time and manpower required to run a transect.

The WSP data was analyzed in a computer by Bureau of Reclamation personnel at Billings, Montana.

Results and Discussion

Physical Habitat Above and Below Intake Diversion

The Intake diversion backs water upstream creating a pool-like environment while downstream a long run is formed through a wide channel with predominantly gravel substrate. Water surface profiles were measured at two study sections, one upstream and one downstream from Intake diversion, in an attempt to quantify these obvious differences in physical channel features created by Intake diversion.

Eight transects were surveyed downstream from Intake diversion, six upstream and one across the diversion. Location of each transect in relation to the diversion is shown in Figure 28. A typical upstream and downstream cross section is shown in Figure 29.

Some physical parameters of each transect, during a discharge of 368.1 m^3/s (13,000 cfs), are listed in Table 7. Because upper transect 2 (U2) and lower transect 8 (L8) were nearest the dam and displayed some of the most pronounced effects of the diversion, these cross sections were analyzed separately and compared to transects upstream and downstream from the diversion, respectively. Also, lower transects 2, 4, and 6 (L246) were compared with upper transects 3, 4, and 5 (U345) to determine some general differences in the physical aquatic environment above and below the diversion dam. These six transects were chosen because: (1) they were far enough up or downstream to avoid the extremes in river environment created directly above or below the dam and (2) they were similar distances above or below the diversion (Figure 28). Thalweg depths, mean depths, top widths, and mean velocities were compared at a discharge of 368.1 m^3/s (13,000 cfs), the mean annual flow of the Yellowstone River at Sidney (U. S. Geological Survey 1975). Bankfull flow was estimated to be 1472.5 m^3/s (52,000 cfs) using the 1.5 year frequency flood flow (Leopold, et al. 1964).

At discharges larger than 566.3 m^3/s (20,000 cfs), the accuracy of predicted water surface elevations was reduced because water began flowing in two side channels that were not surveyed (Figure 28). However, even at high flows we considered the loss in accuracy small, because the combined flow down both channels did not exceed 10 percent of the total flow. Side channel number 1

Table 7. Some physical characteristics of 15 transects of the Yellowstone River at Intake during a discharge of 368.1 m^3/s (13,000 cfs).

Transect	Distance from dam (m)	Top width (m)	Wetted perimeter (m)	Mean depth (m)	Conveyance area (m^2)	Mean velocity (m/s)
L1	2584	493	493	0.70	312	1.32
L2	1612	314	315	0.94	374	1.51
L3	1354	302	302	1.06	313	1.23
L4	1046	305	307	1.23	378	1.04
L5	737	239	239	1.36	327	1.25
L6	400	388	388	0.93	375	1.02
L7	83	226	229	2.24	512	0.74
L8	56	226	230	3.51	799	0.49
U1	0 (dam)	219	222	1.37	302	1.22
U2	64	232	234	2.34	590	0.68
U3	475	227	230	2.54	589	0.66
U4	1020	226	228	2.13	474	0.79
U5	1689	322	324	1.32	409	0.92
U6	2321	199	200	1.86	378	1.01
U7	3137	271	272	1.64	431	0.89

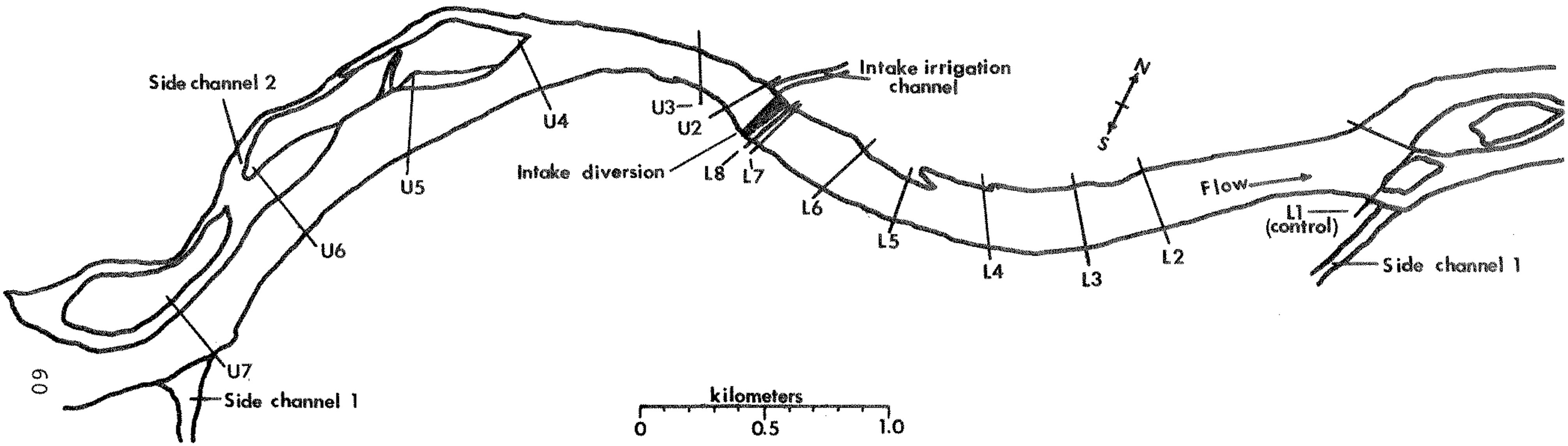


Figure 28. Location of water surface profile transects upstream and downstream from Intake diversion, Yellowstone River.

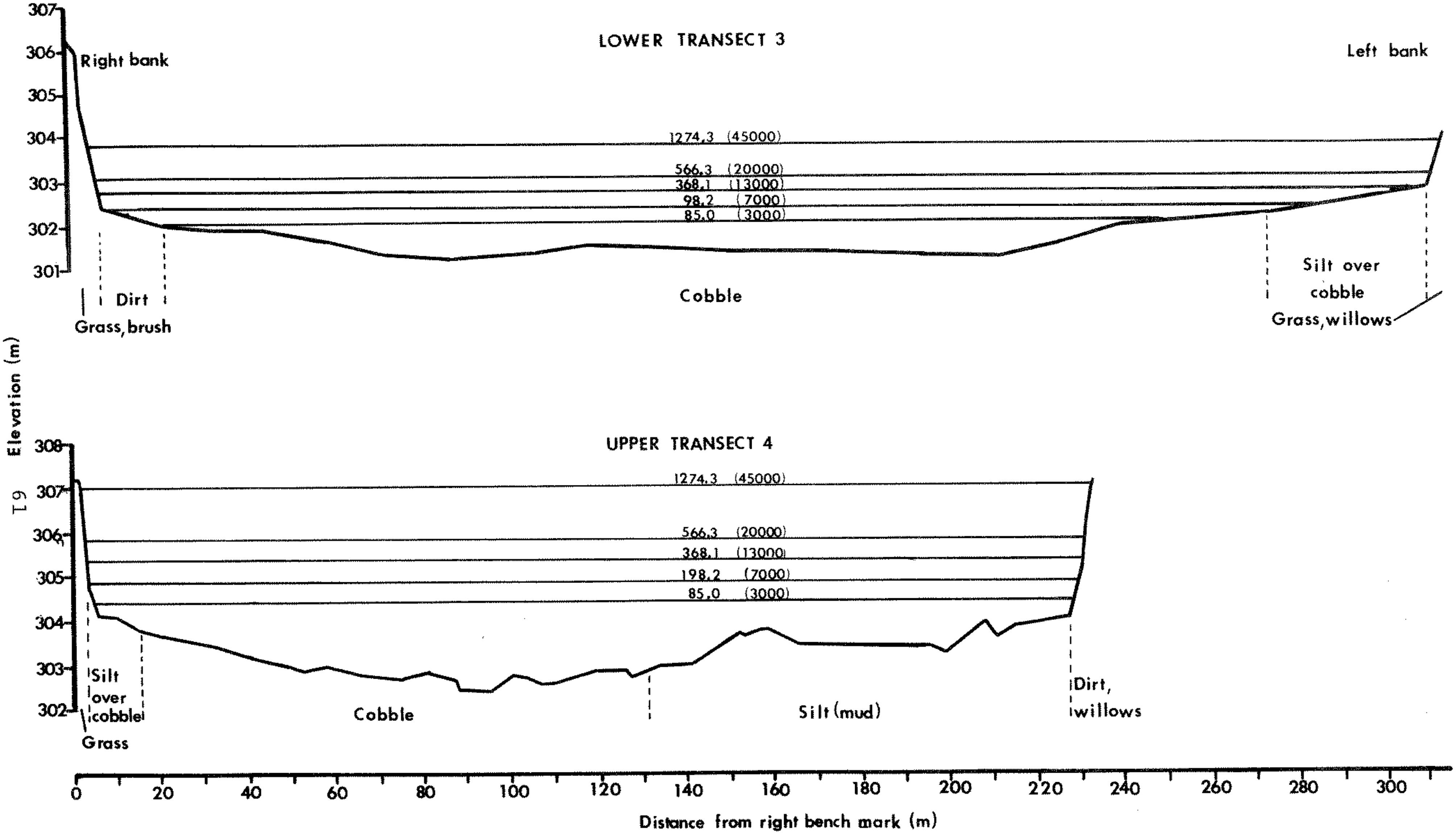


Figure 29. Typical stream cross sections and predicted water surface elevations, downstream and upstream from Intake diversion, at varous discharges in m^3/s (ft^3/s).

(Figure 28) flowed around both the upper and lower sections and did not directly influence accuracy. Side channel number 2 (Figure 28) directly affected accuracy of upper transects 4 through 6, but we considered the decrease in predictive accuracy at high flows to be minimal. During high spring flows, the discharge measured at Sidney was probably slightly greater than in the Intake study section because of withdrawal at the Intake diversion and flow circumventing the study area through side channel number 1.

Thalweg and predicted water surface elevations are shown in Figure 30. Above the diversion a deep pool was created with a maximum thalweg depth of 6.4 m during a discharge of 368.1 m^3/s (13,000 cfs) at a distance of 475 m above the diversion (U3).

Except for the scour pool directly below the dam, the downstream transects had consistently smaller mean depths than transects located similar distances upstream from the diversion (Figure 31). Grand mean depths were 2.0 and 1.0 m for U345 and L246, respectively.

Top widths upstream from the diversion were generally slightly wider than that of the diversion (219m) while most of those downstream were much wider (Table 7). Mean top widths of U345 and L246 were 258 m and 336 m, respectively (Figure 32). The diversion constricted the channel immediately up and downstream even during high discharges of 1,274 m^3/s (45,000 cfs).

At flows larger than 56.6 m^3/s (2,000 cfs), mean wetted perimeter was as much as 29 percent larger for L246 than U345 (Figure 35). Discharges of 368.1 m^3/s (13,000 cfs) and 566.3 m^3/s (20,000 cfs) were needed to wet 95 percent of the maximum perimeter (bank full flow) of L246 and U345, respectively. Because of the pool-like nature above the diversion, a low flow of 56.6 m^3/s (2,000 cfs) wetted a greater percent of the maximum perimeter for U345, 64 percent, than for L246, 50 percent.

Mean conveyance area for U345 was larger than for L246 at all discharges, again depicting the pool-like nature of the Yellowstone River above the Intake diversion (Figure 36). At small discharges this difference was more pronounced; mean conveyance area of L246 was 51 and 76 percent of U345 during discharges of 850 and 1,132.7 m^3/s (3,000 and 40,000 cfs), respectively.

The mean velocity of all the transects upstream from the diversion appeared to be influenced by the effect of the diversion backing water upstream. Downstream from the diversion mean velocities were larger than upstream, except those for transects across the scour pool. Mean velocities ranged from 0.66 to 1.01 m/s and 0.49 to 1.51 m/s upstream and downstream, respectively. With increased discharge the grand mean velocity for the downstream

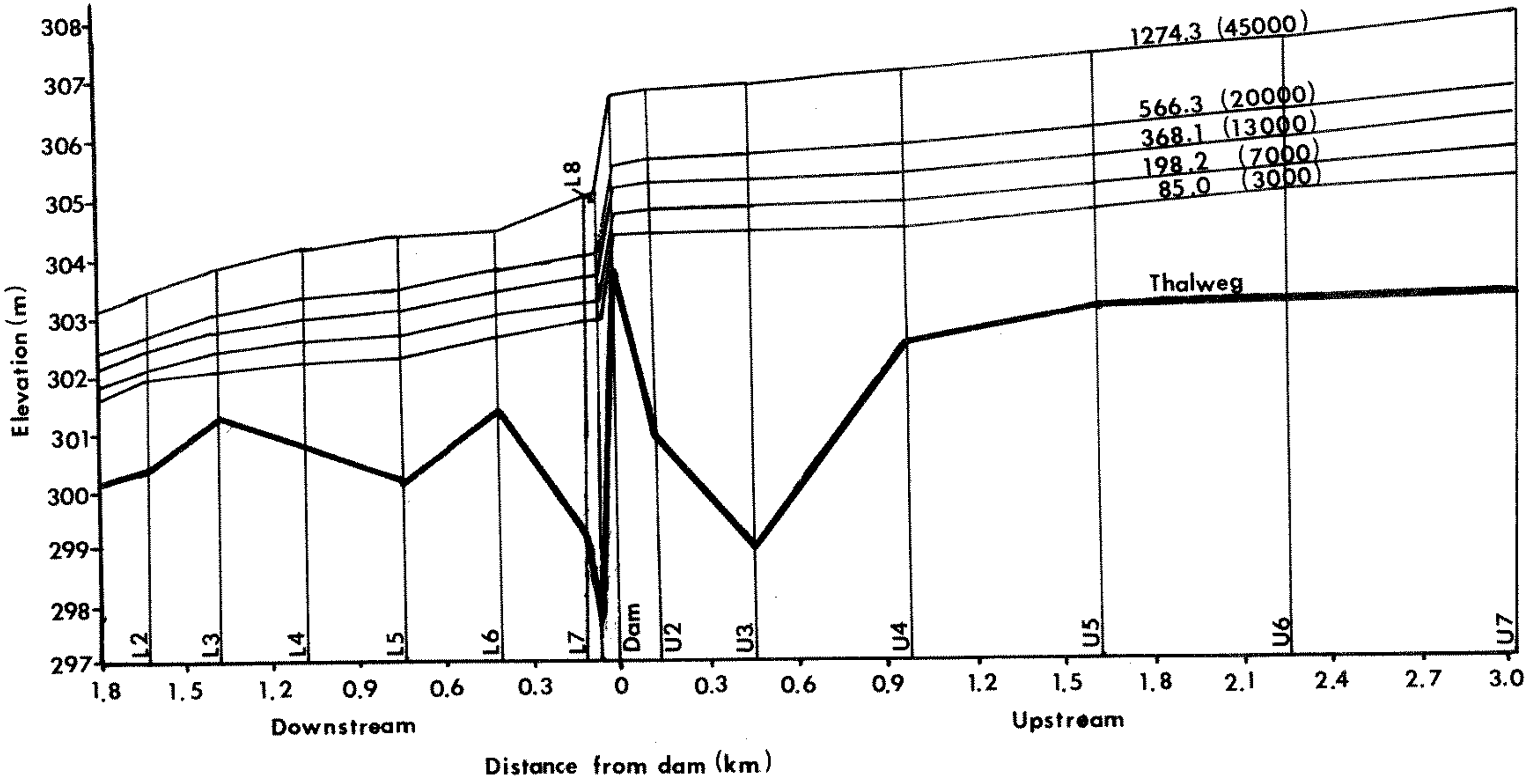


Figure 30. Thalweg and predicted water surface elevations at various discharges in m^3/s (ft^3/s) for transects upstream (U) and downstream (L) from Intake diversion dam, Yellowstone River.

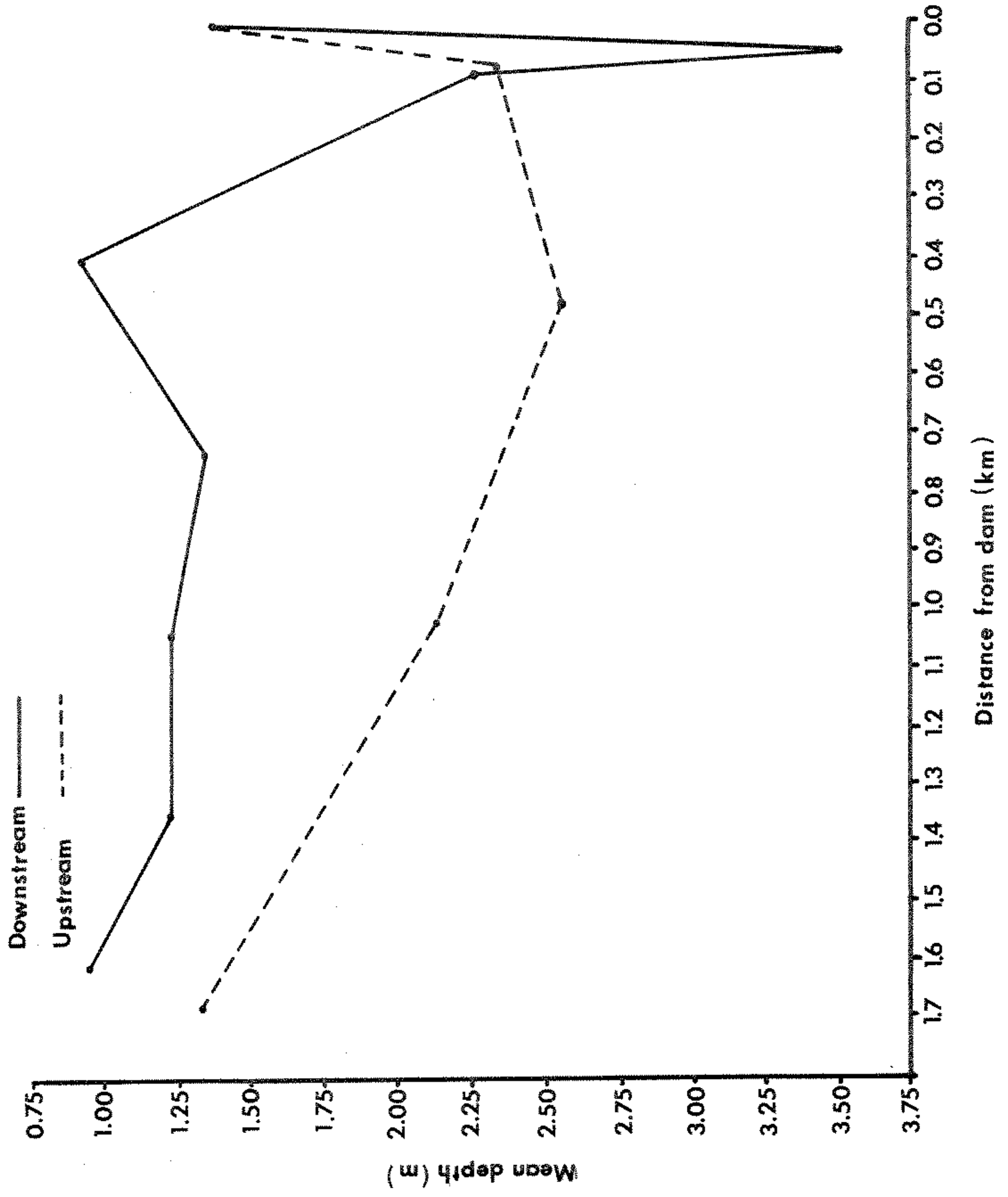


Figure 31. Mean depth of transects upstream and downstream from Intake diversion on the Yellowstone River for the mean annual discharge of 368.1 m^3/s (13,000 cfs).

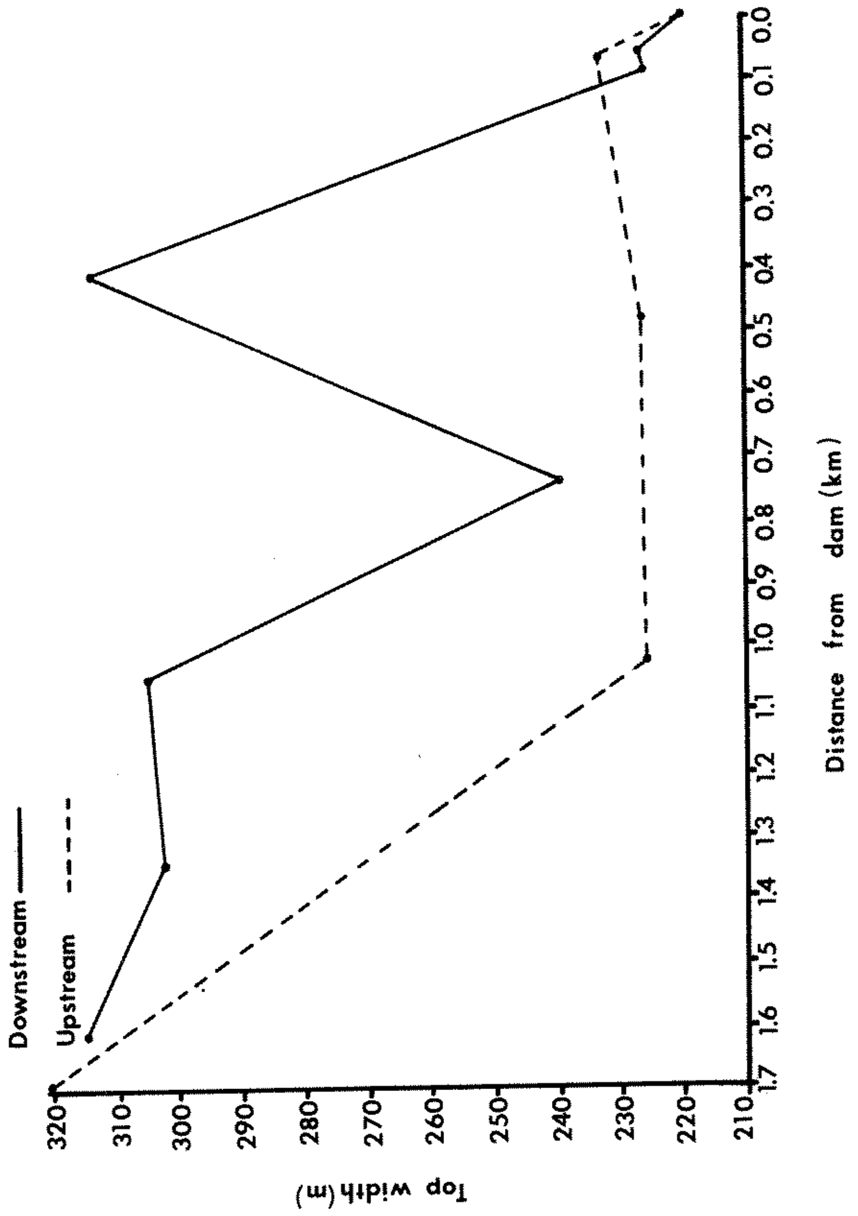


Figure 32. Top width of transects on the Yellowstone River upstream and downstream from Intake diversion for the mean annual discharge of 368.1 m^3/s (13,000 cfs).

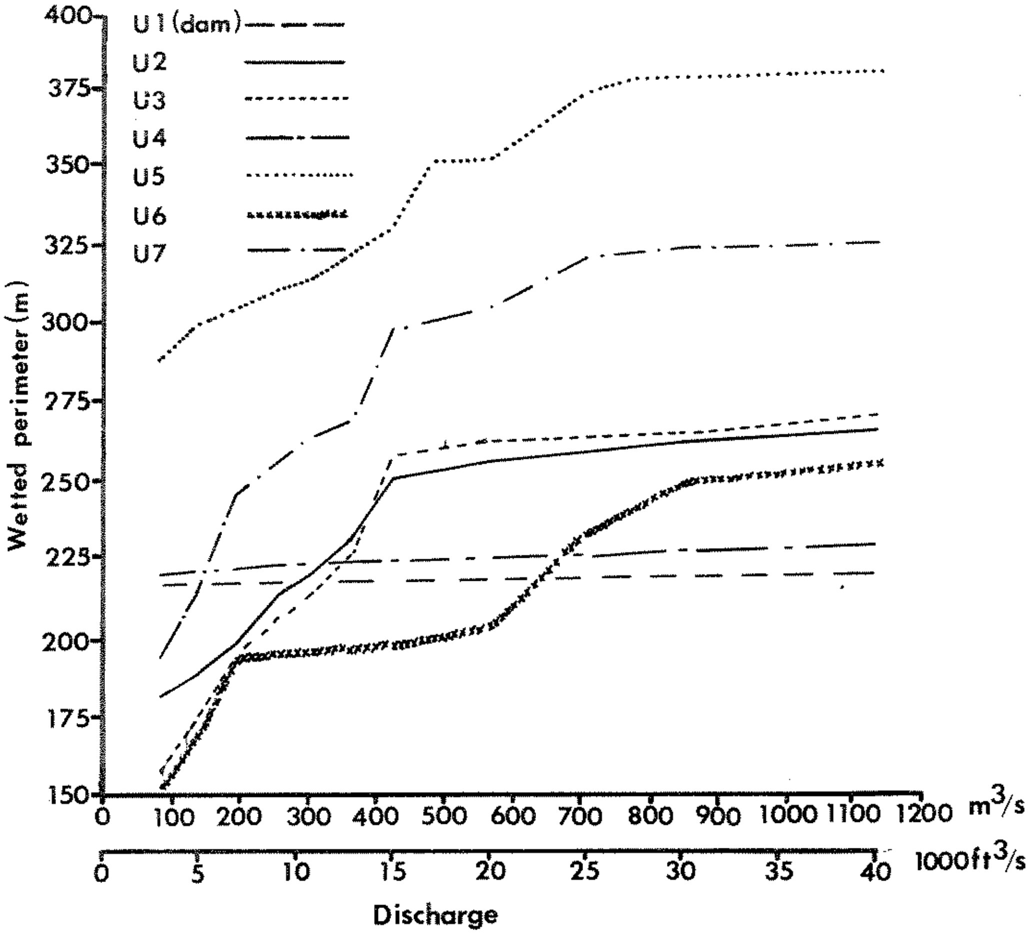


Figure 33. Wetted perimeter versus discharge for seven transects (U1 through U7) on the Yellowstone River above Intake diversion.

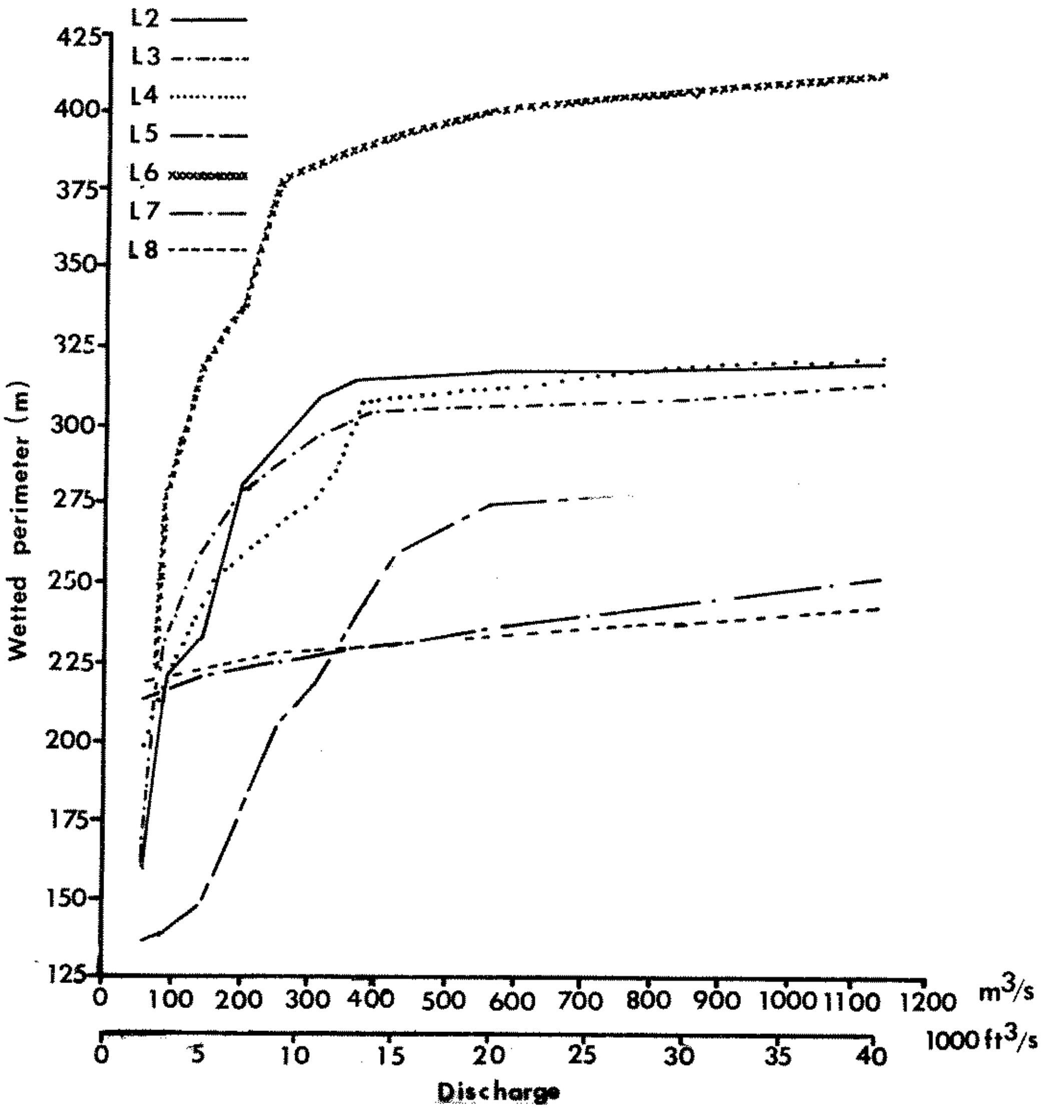


Figure 34. Wetted perimeter versus discharge for seven transects (L2 through L8) on the Yellowstone River downstream from Intake diversion.

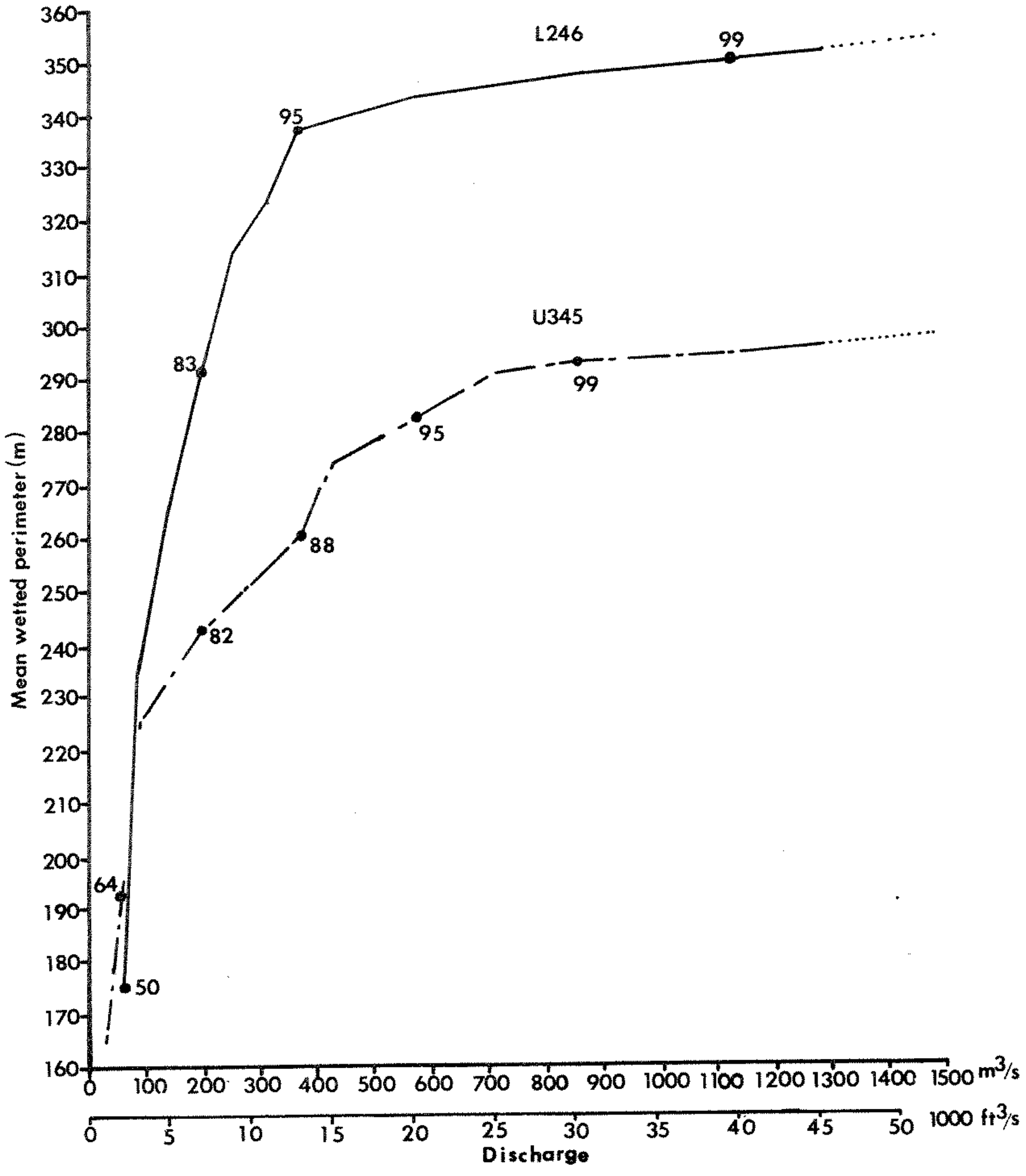


Figure 35. Mean wetted perimeter versus discharge of three transects upstream (U345) and downstream (L246) from Intake diversion on the Yellowstone River. Percentages of projected maximum wetted perimeter during bankfull flow are given.

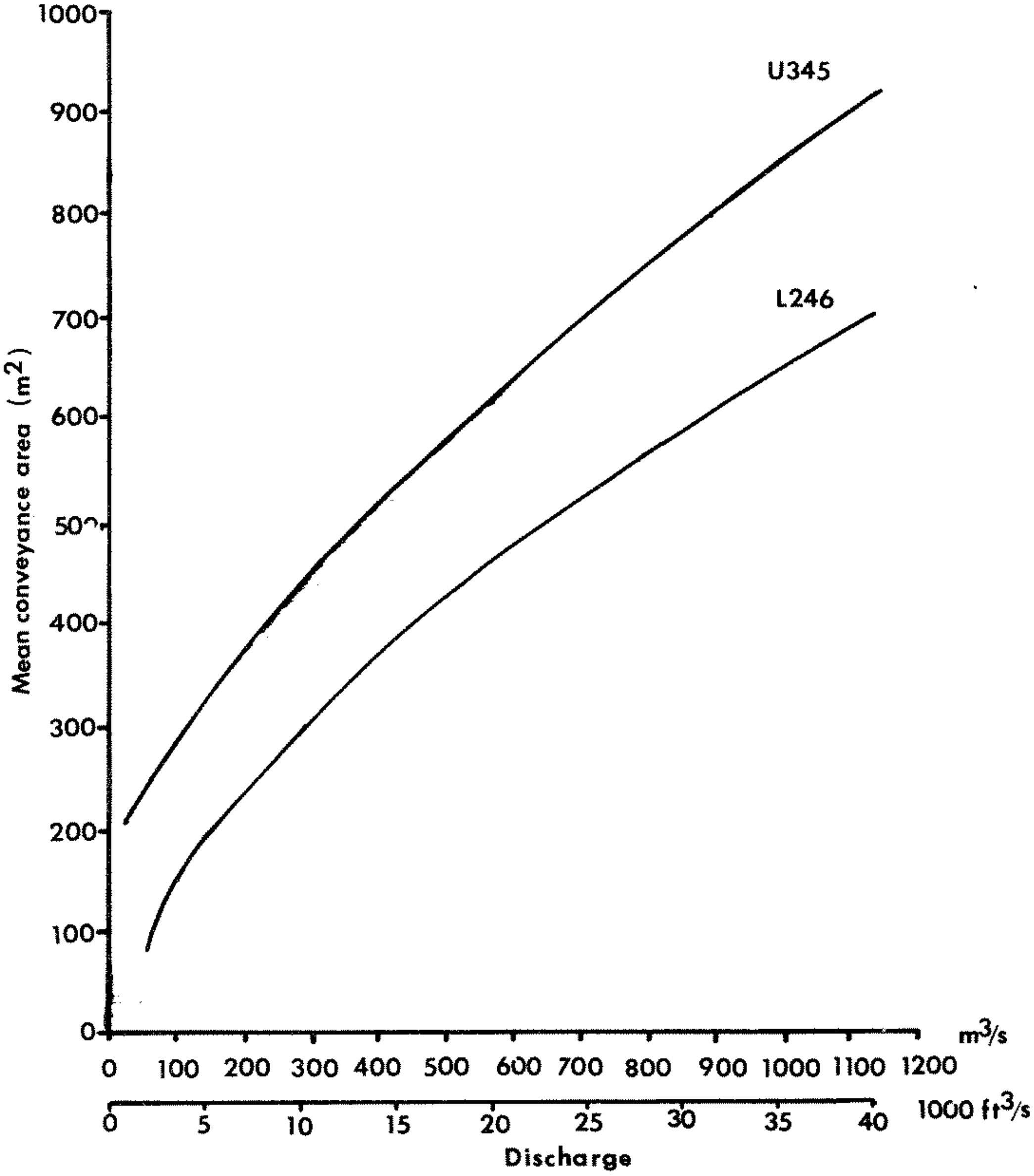


Figure 36. Mean conveyance area of upper transects 3, 4, and 5 (U345) above Intake diversion and lower transects 2, 4, and 6 (L246) below Intake diversion, Yellowstone River.

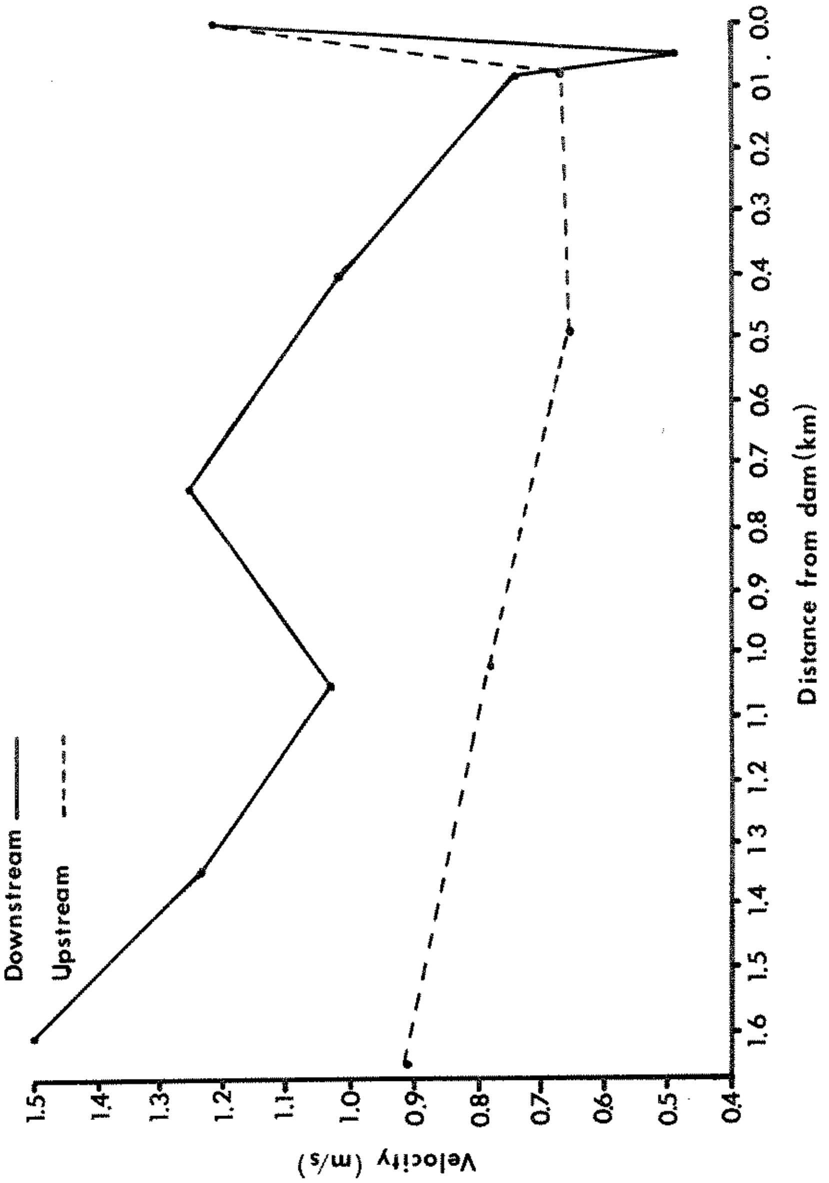


Figure 37. Mean velocity of transects upstream and downstream from Intake diversion, Yellowstone River, at the mean annual discharge of 368.1 m^3/s (13,000 cfs).

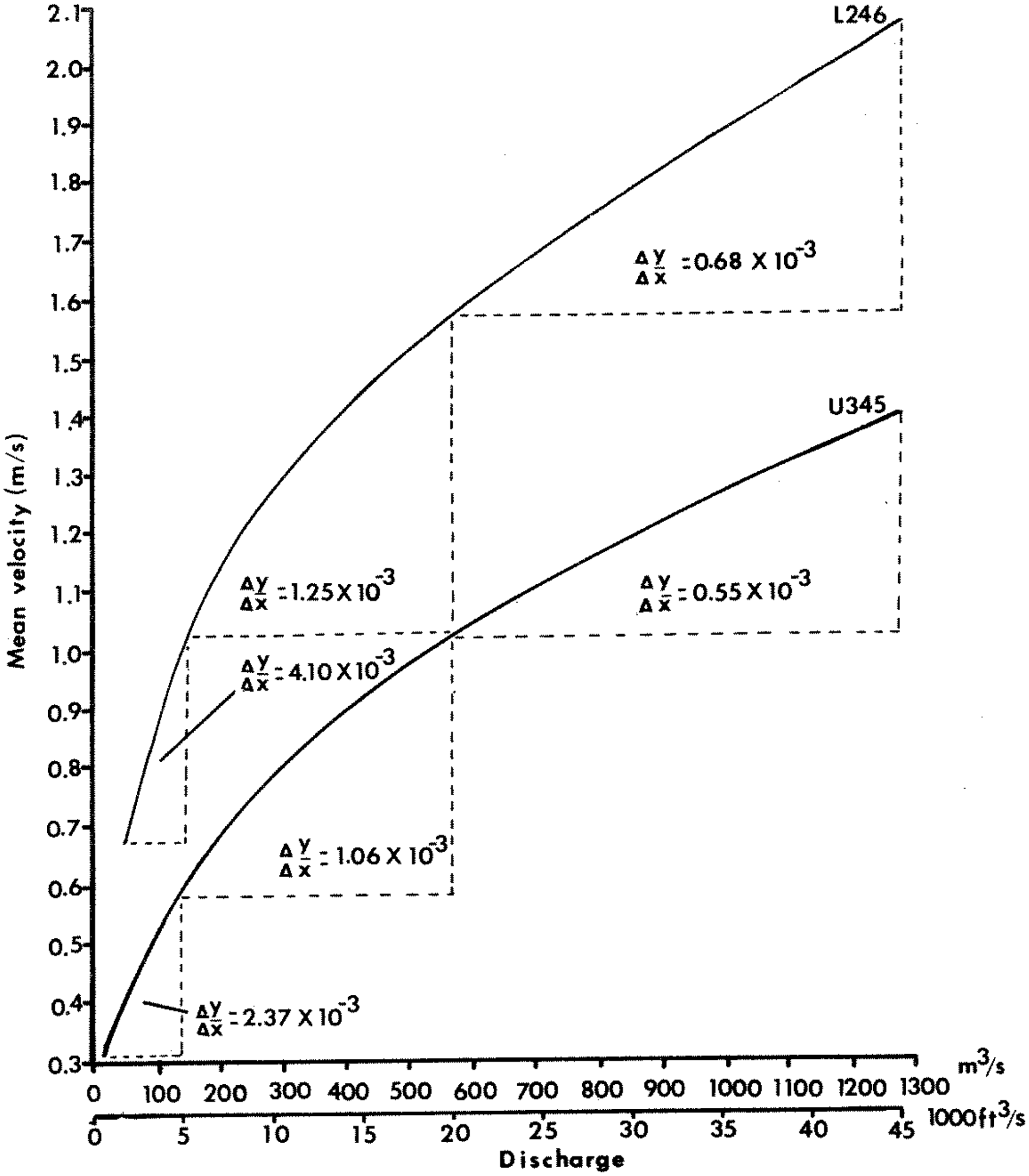


Figure 38. Grand mean velocity versus discharge of three cross sections upstream (U345) and downstream (L246) from Intake diversion, Yellowstone River.

transects (L246) increased faster than for the upstream transects (U345). The grand mean velocity increased faster at small discharges than large. Water surface gradients, 64 to 1,689 m upstream from the diversion and 56 to 1,612 m downstream from the diversion, were 0.23 m/km and 0.80 m/km, respectively (368.1 m^3/s).

Below the diversion the substrate in the scour pool was composed of riprap and boulders while downstream cobbles and pebbles were dominant (87 percent). Above the diversion the dominant substrate increased in size with distance upstream from the diversion. Pebbles and silt were the dominant particle size near the dam (67 and 33 percent, respectively), while cobbles were dominant upstream (89 percent).

Limitations of the WSP on the Lower Yellowstone

Single Channel

We surveyed 11 transects on a straight section of the Yellowstone River, downstream from State Highway 22 bridge near Miles City, to determine the accuracy of predicted water surface elevations for a relatively simple channel configuration (Transects 8 through 18, Figure 39). The transects encompassed 2.62 km of river. Water surface elevations were measured at the 8 upstream transects during various flows to check the predictive accuracy of the WSP program.

The predicted water surface elevations were closer to the observed elevations at low flows (those nearer the discharge during surveying) than at high flows. At a discharge of 137.3 m^3/s (4,850 cfs) the predicted water surface elevations averaged 0.13 m (range: 0.09 - 0.18 m) higher than the observed elevations while predicted elevations averaged 0.46 m (range: 0.33 - 0.64 m) higher than observed elevations at a discharge of 583.3 m^3/s (20,600 cfs). Average maximum depths for these transects was 1.9 m (range: 1.4 - 2.5 m) and 3.0 m (range: 2.6 - 3.6 m) at discharges of 137.3 m^3/s (4,850 cfs) and 583.3 m^3/s (20,600 cfs), respectively. Milhouse and Bovee (1978) found that the WSP program was generally accurate at a range of flows from 0.4 to 2.5 times that at the time of surveying. The range of flows at which the WSP program can accurately predict hydraulic parameters can also be increased by obtaining numerous water surface elevations.

Accuracy for this series of transects may have been affected by the fact that water surface elevations were not all surveyed at the same discharge. This happened because the transects could not all be surveyed on the same day and discharge fluctuated during this period, 123.3 to 162.3 m^3/s (4,350 to 5,730 cfs). We should have surveyed all the transects first and later obtained water surface elevations for each transect on the same day. In order to run the WSP program, the downstream most control, transect 8, was eliminated from the study reach which also may have influenced accuracy.

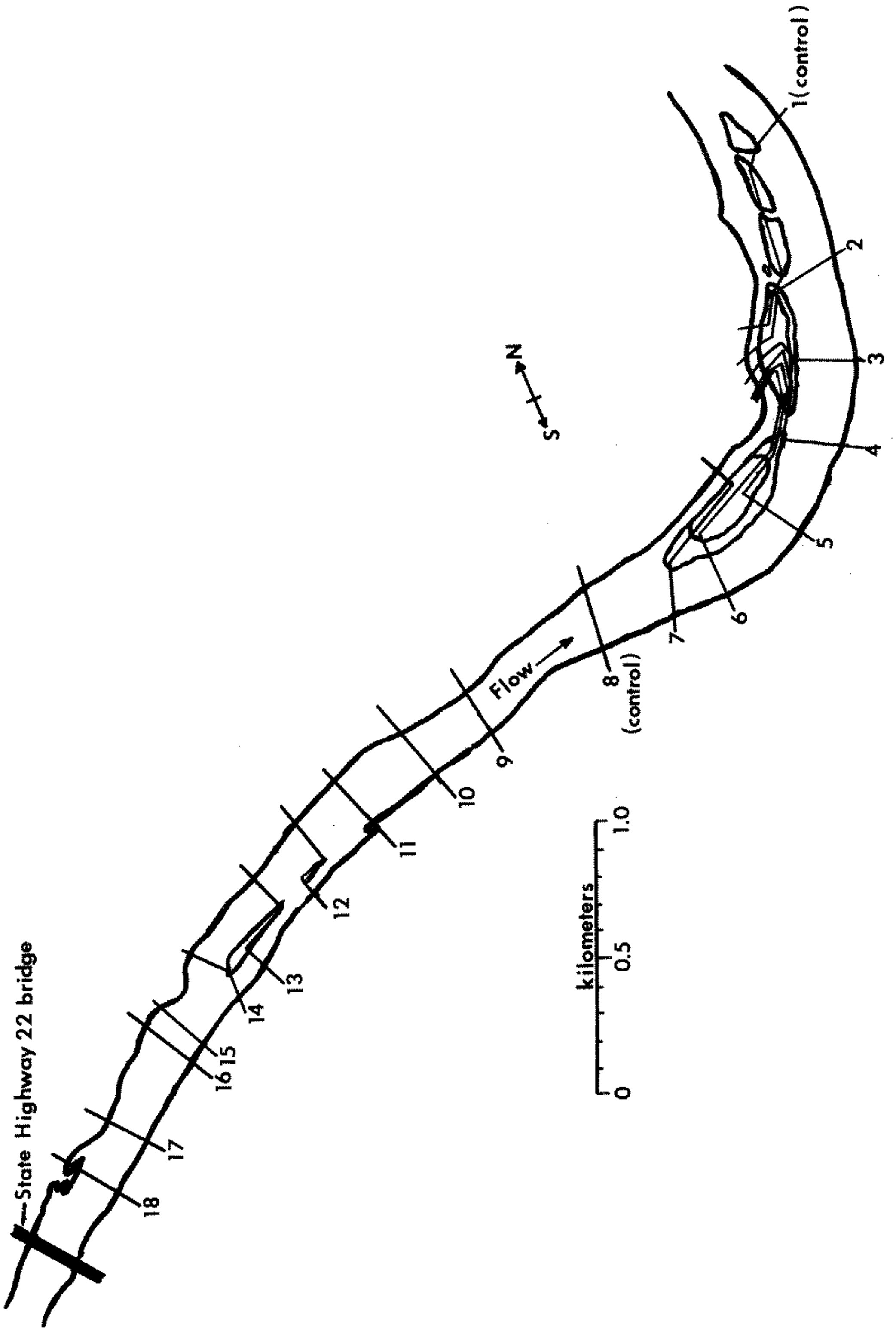


Figure 39. Location of water surface profiles at the Miles City section, Yellowstone River.

To reassess this study section the data were reanalyzed through the WSP program, but only transects 11 through 18 were included in the study reach. A series of water elevations were obtained at flows of 583.3 (20,600 cfs), 441.7 (15,600 cfs) 214.9 (7,590 cfs), 166.2 (5,870 cfs) and 137.3 m^3/s (4,850 cfs) for all 8 transects. The WSP program used these data at the downstream most transect (11) to increase the accuracy of the computed slope. The observed water surface elevations at the upstream transects (12 through 18) were compared to these new predicted elevations and were an average of 0.11 m higher than the observed values at all the discharges. Differences in predicted and observed water surface elevation did not increase with increased discharge which occurred when only one set of water surface elevations were known. Maximum difference in observed and predicted water surface elevation at a discharge of 583.3 m^3/s was 0.18 m, identical to the maximum error at a discharge of 137.3 m^3/s. The error, in predicted increase of water surface elevation with increase in discharge (from 137.3 to 583.3 m^3/s), ranged from 2 to 10 percent. Elser (1976) found the WSP accurately predicted water surface elevations (within 0.03 m) on the Tongue River for flows smaller than at the time of surveying.

The Yellowstone River should be surveyed in the late summer/fall or possibly late March/April because: (1) low water allows stream controls to be found, (2) discharges are usually not fluctuating greatly during this time, (3) less of the channel is under water which makes surveying easier, and (4) water velocities are not excessive. Accuracy of predicted hydraulic parameters for a wide range of flows can be increased by obtaining several water surface elevations over the range of flows. Because accuracy of the WSP predictions decreased for discharges with greater deviation from that at the time of survey, a minimum of two water surface elevation series should be obtained, one during the time of surveying and one during high flow. A third measurement between these extremes would also be useful, as accuracy increased by obtaining water surface elevations at several flows.

The WSP program uses the computed slope and observed water surface elevations(s) at the downstream most cross section to predict water surface elevations at transects upstream . Predicted and observed water surface elevations are then compared at the upstream transects. Because accuracy of the computed slope (and thus, other predicted hydraulic parameters) increases with increased number of known water surface elevations, it is desirable to know the degree of accuracy gained in relation to the number of known water surface elevations. Further study should reveal this relationship. This can be accomplshed by running the program several times using a combination of known water surface elevations at various flows. Suggested combinations include: (1) low flow only, (2) low flow and high flow, (3) low flow, high flow, and one intermediate flow, and (4) low flow, high flow, and a minimum of two intermediate flows.

Multiple Channel

We surveyed 7 transects along a simple braided section of the Yellowstone River near Miles City, 3.27 km downstream from State Highway 22 bridge (Transect 1 through 7, Figure 39). The study section covered a reach of 2.26 km. The upstream end of this section was divided into two channels. Downstream, the major portion of the flow in the left side channel (channel 2, Figure 40) returned to the main channel (channel 1) through a small chute between two islands (channel 3). Channel 4 contained the remaining flow. Transects on the side channels were often spaced small distances apart at stream controls but were located large distances apart on the main channel. This occurred because transects were initially chosen on the main channel with matching water surface elevations subsequently found on the side channels. The largest change in water surface elevation occurred at these short control areas on the side channels, while changes in water surface elevation along the main channel were not so obvious. For this reason, cross sections could have been more properly spaced if transects were initially chosen on the side channel(s) and expanded to the main channel. Controls on the side channel closely matched controls on the main channel. Surveying occurred during a time when flow down the side channels was small (5.3 m^3/s).

The WSP program did not accurately or consistently predict hydraulic conditions existing in this braided section of river. Problems encountered were: (1) too much water was allocated to the side channels, (2) the program predicted some unrealistically large side channel velocities (a function of No. 1) and (3) different flows were predicted at successive transects on the same channel for the same discharge.

Some of the predicted discharges down the side channels were excessive when compared to measured flows (Table 8). At a total river discharge of 126.6 m^3/s (4,470 cfs) a flow of 21.3 m^3/s (752 cfs) was predicted for side channel 3 (transect 5) while 0.6 m^3/s (21 cfs) was the actual discharge; these flows represented 16.8 and 3.7 percent of the total river discharge, respectively. Transect 6 also predicted larger than actual discharges.

The flow predicted at each transect varied greatly even though they were estimated for the same channel (Table 8). The predicted flow for side channel 3 during a total river discharge of 249.9 m^3/s (9,000 cfs) varied from 19.2 to 118.9 m^3/s (678 to 4,200 cfs); 8 to 47 percent of the total river discharge. Predicted flows down channel 4 ranged from 0.9 to 63.5 m^3/s (32 to 2,240 cfs); 0.3 to 25 percent of the total discharge.

Table 8. Observed and predicted discharges (m^3/s) for a braided section of the Yellowstone River near Miles City. Percentages of total river dicharge are in parenthesis.

	Total River Discharge	CHANNEL NUMBER				Total Side Channel Discharge
		1	2	3	4	
Observed	126.6	121.3 (95.8)	5.3 (4.2)	4.7 (3.7)	0.6 (0.5)	5.3 (4.2)
Predicted	126.6					
	Transect 7	124.1 (98.0)	2.5 (2.0)	-		2.5 (2.0)
	Transect 6	108.5 (85.7)	-	14.3 (11.3)	3.8 (3.0)	18.1 (14.3)
	Transect 5	105.1 (83.0)	-	21.3 (16.8)	0.1 (0.0)	21 4 (16.9)
	Transect 4	123.6 (97.6)	-	2.7 (2.1)	0.3 (0.2)	3.0 (2.4)
	Transect 3	126.0 (99.5)	-	-	0.6 (0.5)	-
	Transect 2	83.3 (65.8)	-	-	0.0 (0.0)	-
	Transect 1	126.3 (99.8)	-	-	0.3 (0.2)	-
Predicted	254.9					
	Transect 7	240.8 (94.5)	14.0 (5.5)	-		14.0 (5.5)
	Transect 6	130.4 (51.1)	-	60.9 (123.9)	63.5 (24.9)	123.5 (48.5)
	Transect 5	133.9 (52.5)	-	118.9 (46.7)	2.1 (0.8)	121.0 (47.5)
	Transect 4	221.3 (86.8)	-	19.2 (7.5)	14.3 (5.6)	33.5 (13.1)
	Transect 3	223.9 (87.9)	-	-	30.6 (12.1)	-
	Transect 2	251.5 (98.7)	-	-	3.4 (1.3)	-
	Transect 1	254.0 (99.7)	-	-	0.9 (0.3)	-

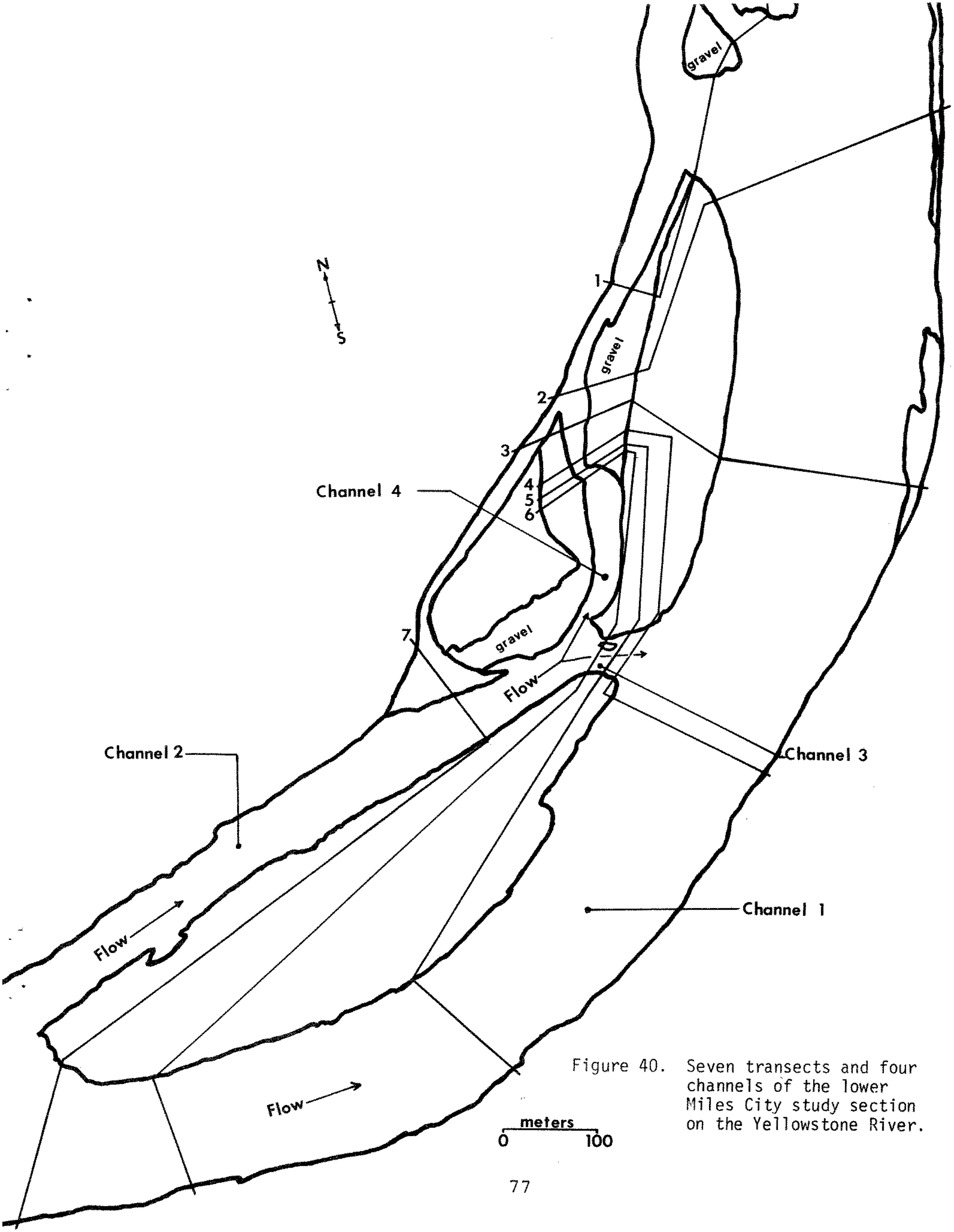


Figure 40. Seven transects and four channels of the lower Miles City study section on the Yellowstone River.

Predicted velocities at side channel cross sectional segments were often excessive, again, indicative that the program was allocating too much water to the side channels. When 4.7 m^3/s (167 cfs) of water was flowing in channel 3, the maximum and mean velocity observed was 1.23 and 0.74 m/s, respectively. The corresponding mean velocity predicted in channel 3 at nearby transects ranged from 1.13 to 4.94 m/s. In channel 4, during a discharge of 0.6 m^3/s (20 cfs) predicted mean velocities ranged from 0.00 to 6.62 m/s. At total discharges of 254.9 and 1274.3 m^3/s (9,000 and 45,000 cfs), maximum predicted cross sectional velocities in channel 4 (at transect 3) were 2.40 and 10.27 m/s (5.4 and 23.0 mi/hr.), respectively (Table 9).

The side channel discharges predicted by the WSP program were more realistic for transects 1, 2 and 7, which had only 2 channels in the cross sections (Table 8). At a total river discharge of 254.9 m^3/s (9,000 cfs) transect 3, which had 2 channels in the cross section, predicted a considerably larger side channel discharge (when compared to the other 3 transects) and erroneously high mean velocities (Table 9).

Apparently, the WSP program could not determine from which upstream channel each side channel derived its water. Channels 3 and 4 derived all their water from channel 2; however, the program did not account for this as too much water was allocated channels 3 and 4 (transects 3 through 6, Table 8). The WSP program appears to simply proportion discharge to each channel of a cross section without regard to what has happened to the water upstream. Perhaps this explains the more accurate predictions for cross sections across 2 versus 3 channels (transects 1, 2, 7). Transect 3, which bisected only 2 channels, did not fall into this pattern, as too large a flow was allocated to channel 4 (Table 8). This error may have been the result of the data portraying an erroneously wide side channel. During surveying, flow in channel 4 was confined to the thalweg. The transect line, derived by finding identical water surface elevations on each side of the channel, was not the shortest point between the two banks but extended up the channel at an angle. When predicting larger flows the program probably misinterpreted the channel as being wider than it actually was, thus, allocating too large a flow to this side channel. Transects 3, 4, 5, and 6 on channel 4 may have been influenced by this type of error as these transect lines extended up the channel at an angle. Transects 1 and 2 for channel 4 and transects across channels 2 and 3 were generally perpendicular to both banks.

The WSP program was not designed to handle multiple channels, so its application on this type of channel should be used with caution. The program should be used only for a single or at most

Table 9. Observed and mean predicted velocities (m^3/s) in side channels of the Yellowstone River, lower Miles City study section.

		CHANNEL	
Total River Discharge = 126.6 m^3/s	2	3	4
Range of observed velocities	0.32 - 0.56	0.48 - 1.24	-
Range of predicted velocities			
Transect 7	0.25	-	-
Transect 6		1.51	2.02
Transect 5	-	0.97	0.09
Transect 4	-	0.34	0.12-0.25
Transect 3	-	-	0.91
Transect 2	-	-	0.00
Transect 1	-	-	0.20
Total River Discharge = 254.9 m^3/s			
Range of predicted velocities			
Transect 7	0.46	-	-
Transect 6	-	2.15	0.82 - 2.55
Transect 5	-	1.65	0.13 - 0.30
Transect 4	-	0.68	0.50 - 0.53
Transect 3	-	-	0.62 - 2.40
Transect 2	-	-	0.29 - 0.44
Transect 1	-	-	0.63
Total River Discharge = 1274.3 m^3/s			
Range of predicted velocities			
Transect 7	0.50 - 0.69	-	-
Transect 6	-	1.17	1.29 - 2.25
Transect 5	-	1.68	0.20 - 1.38
Transect 4	-	0.87	0.99 - 2.00
Transect 3	-	-	2.16 - 10.27
Transect 2	-	-	1.10 - 1.79
Transect 1	-	-	1.23

a simple divided channel because predictions of hydraulic parameters appeared more accurate when not more than two channels were bisected by the transects. If water surface profiles are necessary for a split channel, each channel should be treated as a separate stream with WSP data gathered accordingly. It is then necessary to know the discharge in each channel of the braided stream during the time when water surface elevations are measured. To obtain accurate predictions in side channels, transects should be measured when side channel discharge is large enough to wet most of the channel.

To avoid time consuming calculations, we recommend that mean depth, an important habitat criterion, be included in the WSP print-out for each segment of a cross section at the various discharges. The capability of dividing the cross section into more than nine segments should also be incorporated into the program to increase accuracy of locating specified physical criteria (such as velocity) within the channel of a large river.

In summary, WSP program predictions can be accurate and reliable if a few common errors are avoided. First, water surface elevations for all transects should be obtained during the same discharge. Surveying should occur during periods of stable flow (late summer or fall) in the lower Yellowstone. If transects cannot all be surveyed on the same day, a set of water surface elevations should be obtained after profiles have been surveyed. Second, accuracy of WSP predictions over a wide range of flows can be increased by obtaining water surface elevations over the range of flows. Differences between observed water surface elevations and predicted water elevations at 4.25 times the flow ranged from 12 to 47 percent in the single channel section. When several more water surface elevations taken over a range of flows were included in the analysis, the differences between observed and predicted was from 2 to 10%. Three measurements, one at a high, low, and intermediate flow, are desirable. Predicting hydraulic parameters for discharges outside the range 0.4 to 2.5 times the discharge at the time of surveying may result in a significant loss of accuracy unless these extra water surface elevations are taken. And third, the WSP program should be used only for a single channel. If WSP information is desired for a split or braided channel, each channel should be treated as a separate stream and WSP data gathered accordingly.

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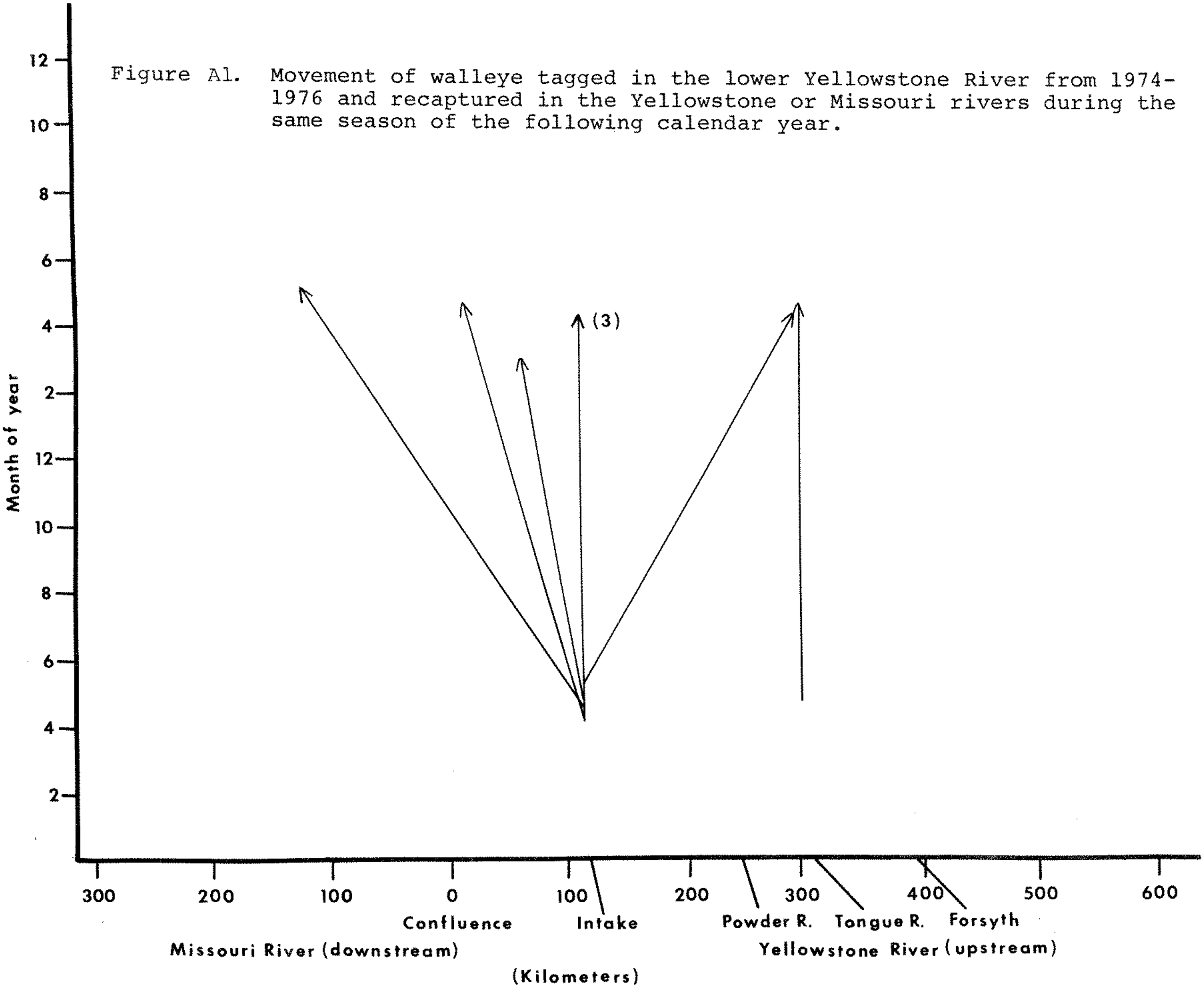
APPENDIX

Figure A1. Movement of walleye tagged in the lower Yellowstone River from 1974-1976 and recaptured in the Yellowstone or Missouri rivers during the same season of the following calendar year.



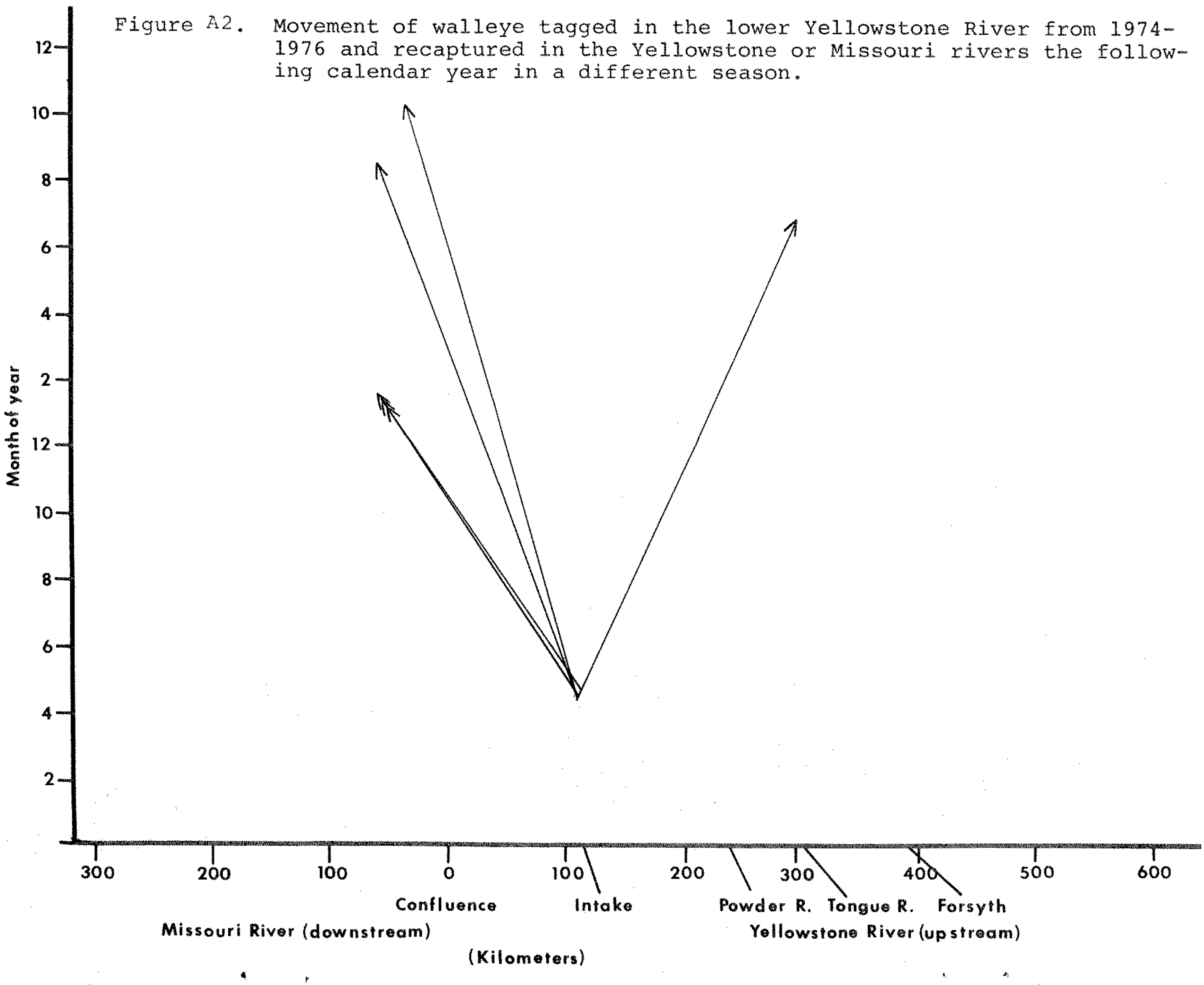


Figure A2. Movement of walleye tagged in the lower Yellowstone River from 1974-1976 and recaptured in the Yellowstone or Missouri rivers the following calendar year in a different season.

Figure A3. Movement of sauger tagged in the Yellowstone River downstream from Intake diversion from 1975-1976 and recaptured in the Yellowstone or Missouri rivers the following calendar year during the same season (——) and different seasons (----).

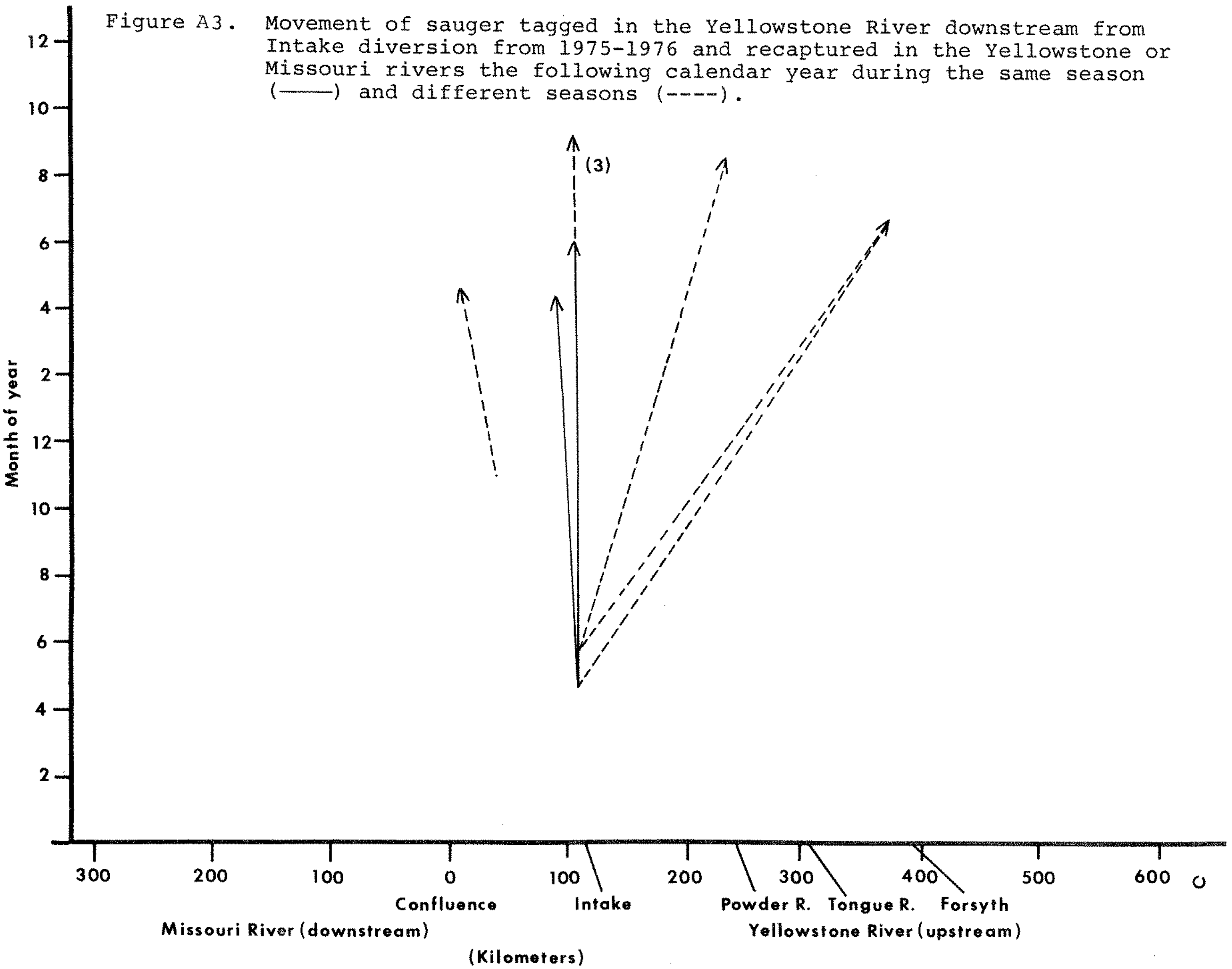


Figure A4. Movement of sauger tagged in the Yellowstone River downstream from Forsyth diversion from 1974-1977 and recaptured in the Yellowstone River during the same calendar year.

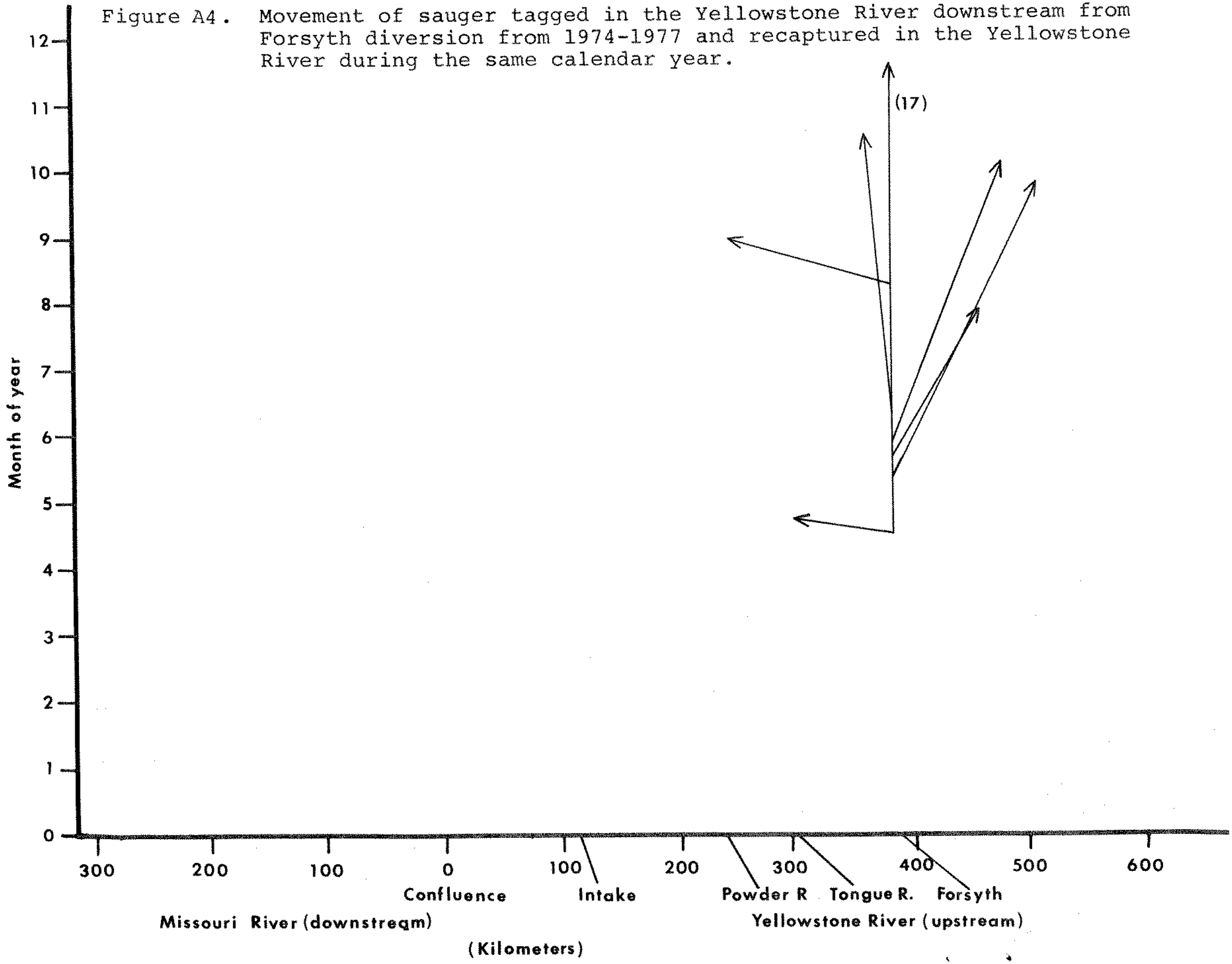
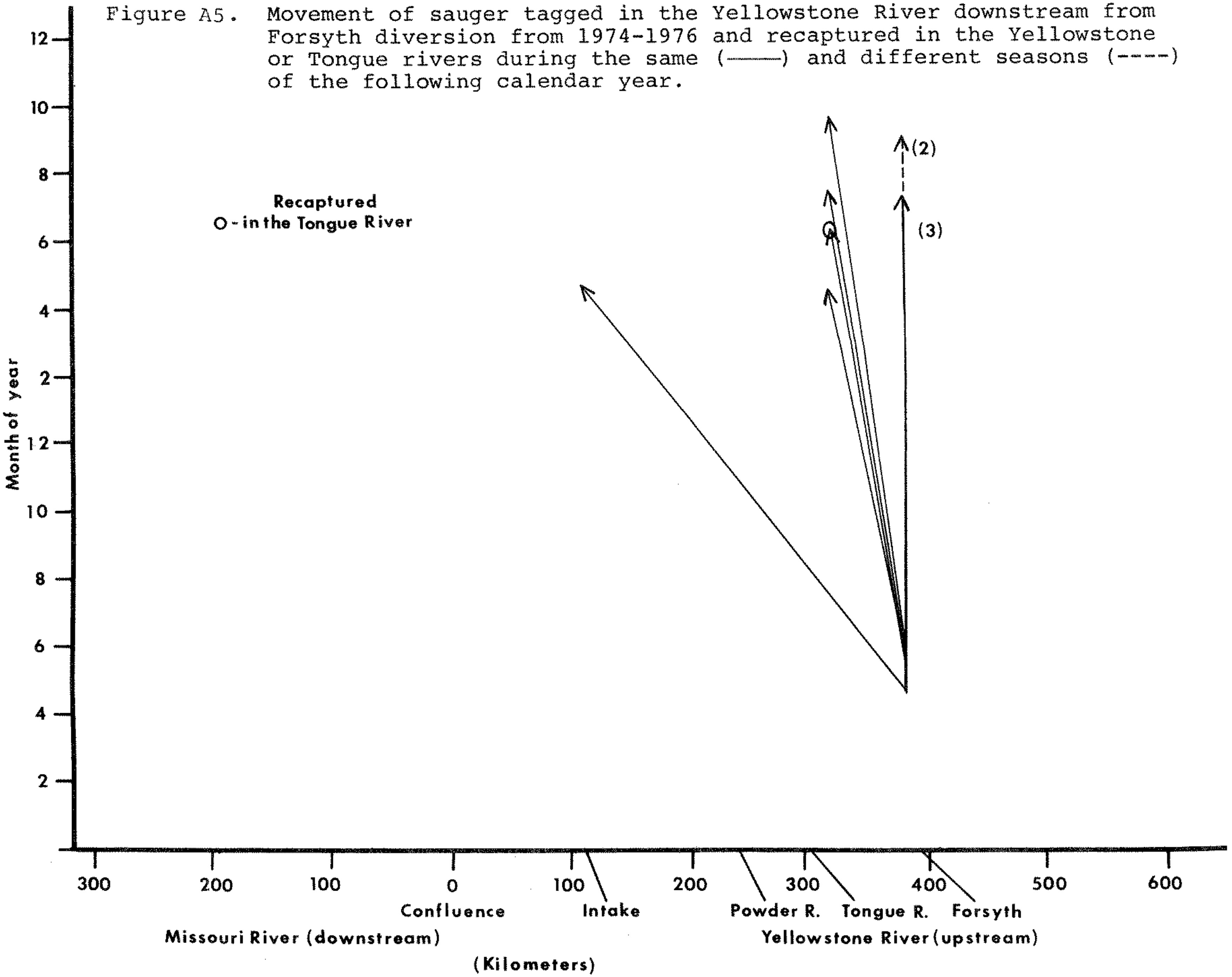


Figure A5. Movement of sauger tagged in the Yellowstone River downstream from Forsyth diversion from 1974-1976 and recaptured in the Yellowstone or Tongue rivers during the same (———) and different seasons (----) of the following calendar year.



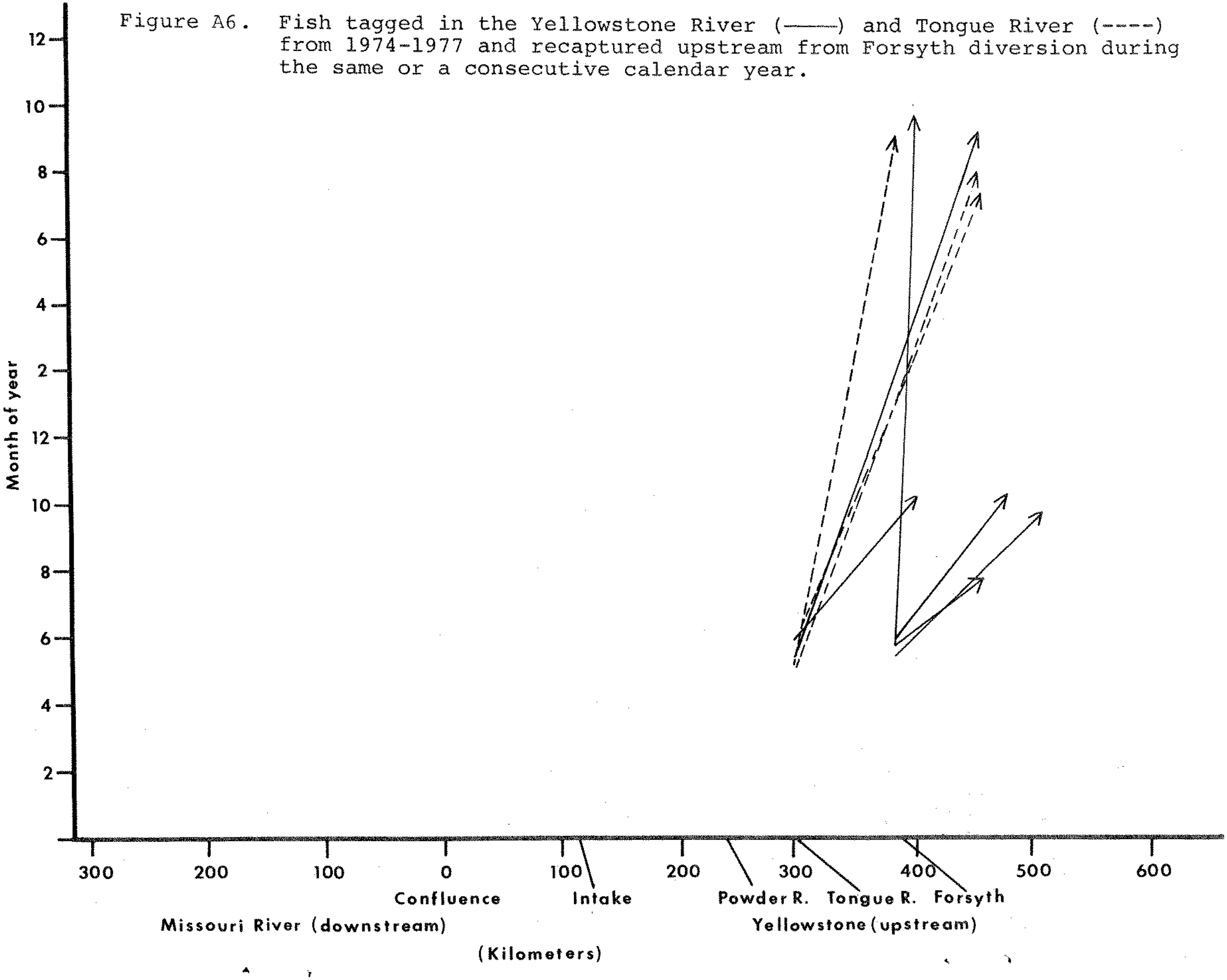


Figure A6. Fish tagged in the Yellowstone River (———) and Tongue River (----) from 1974-1977 and recaptured upstream from Forsyth diversion during the same or a consecutive calendar year.

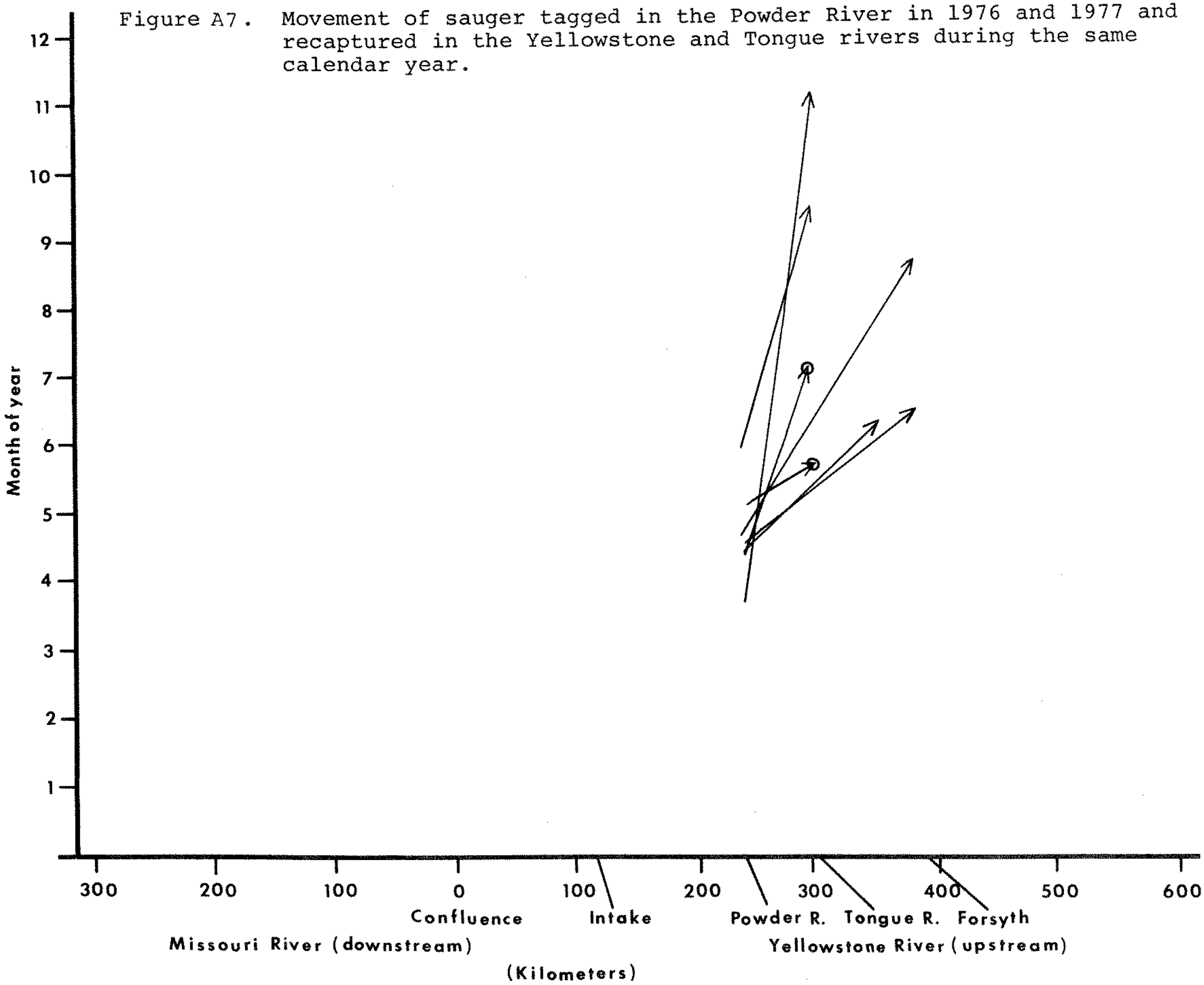


Figure A7. Movement of sauger tagged in the Powder River in 1976 and 1977 and recaptured in the Yellowstone and Tongue rivers during the same calendar year.

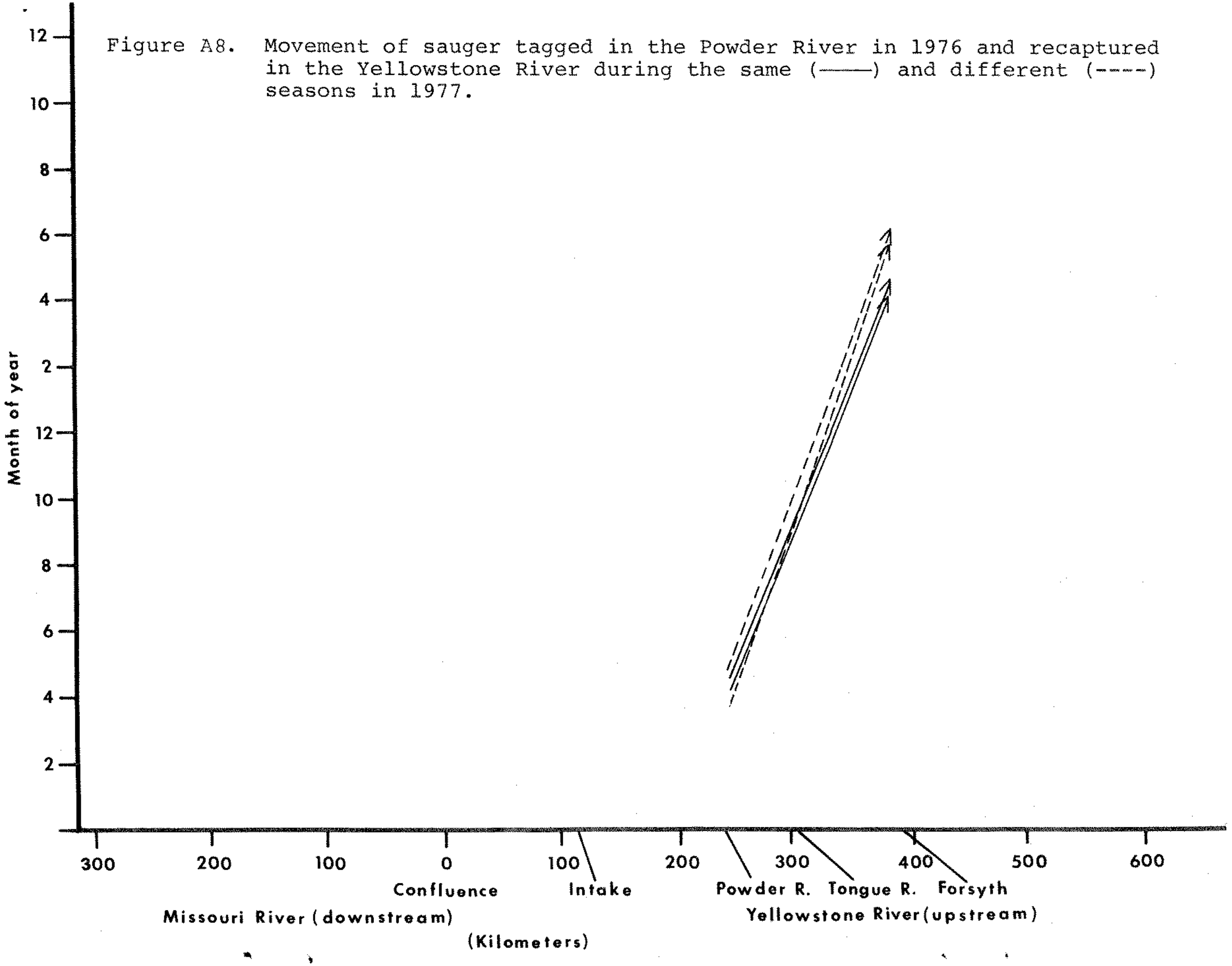


Figure A8. Movement of sauger tagged in the Powder River in 1976 and recaptured in the Yellowstone River during the same (———) and different (----) seasons in 1977.

Figure A9. Movement of sauger tagged in the lower Tongue River from 1975-1977 and recaptured in the Yellowstone River during the same calendar year.

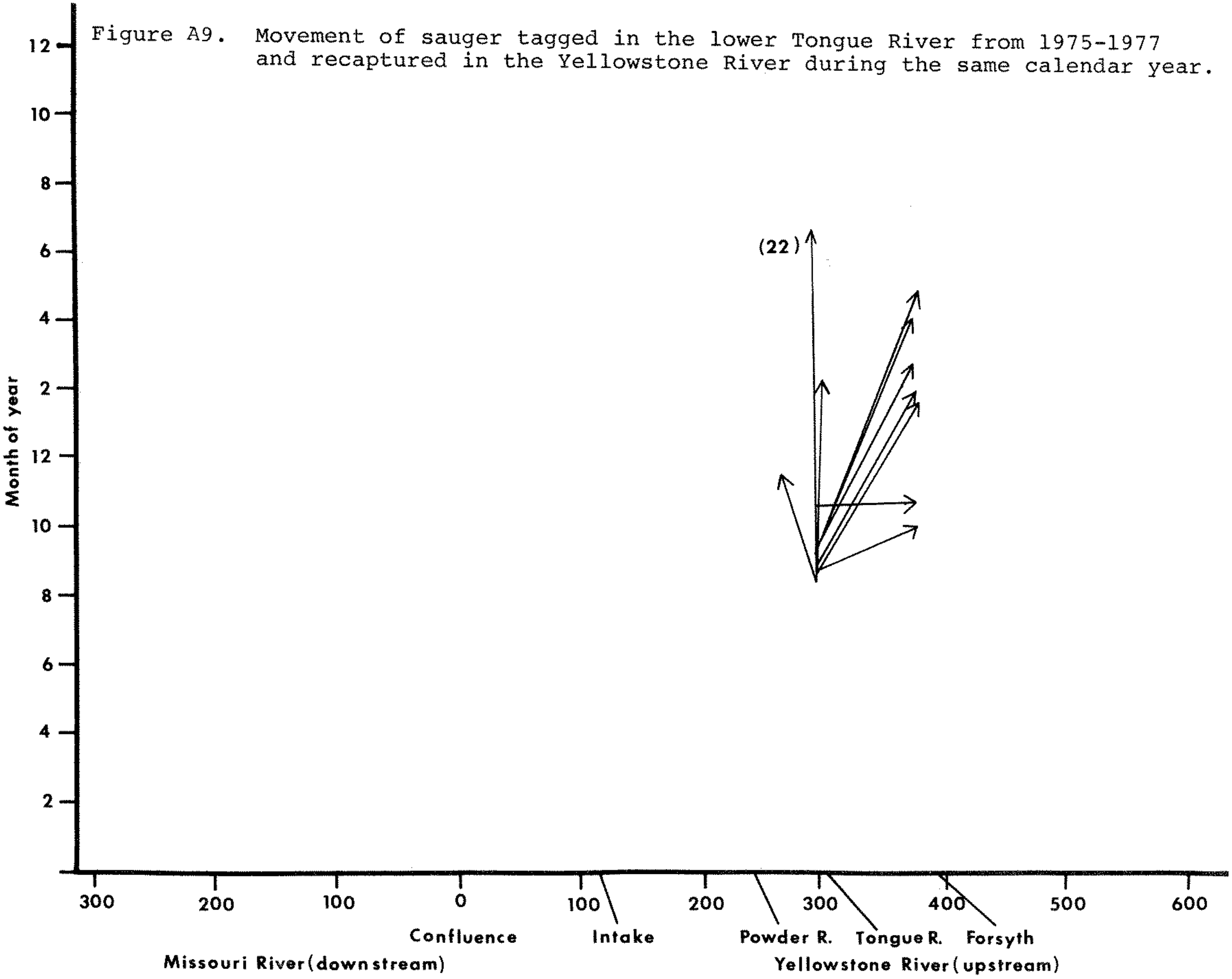


Figure A10. Movement of sauger tagged in the lower Tongue River in 1975 and 1976 and recaptured in the Yellowstone River during the same season of the following calendar year.

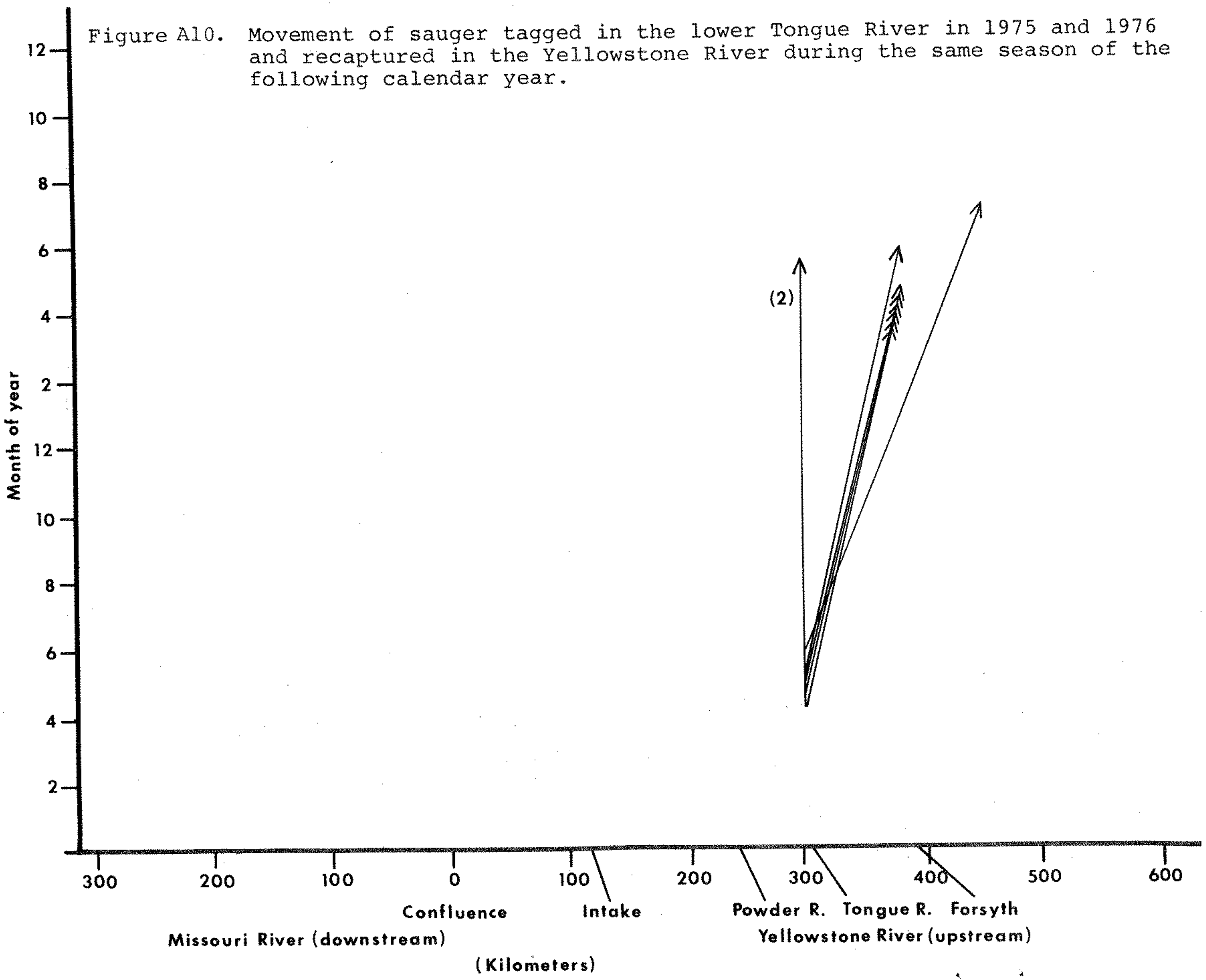


Figure A11. Movement of sauger tagged in the lower Tongue River in 1975 and 1976 and recaptured in the Yellowstone River during different seasons of the following calendar year.

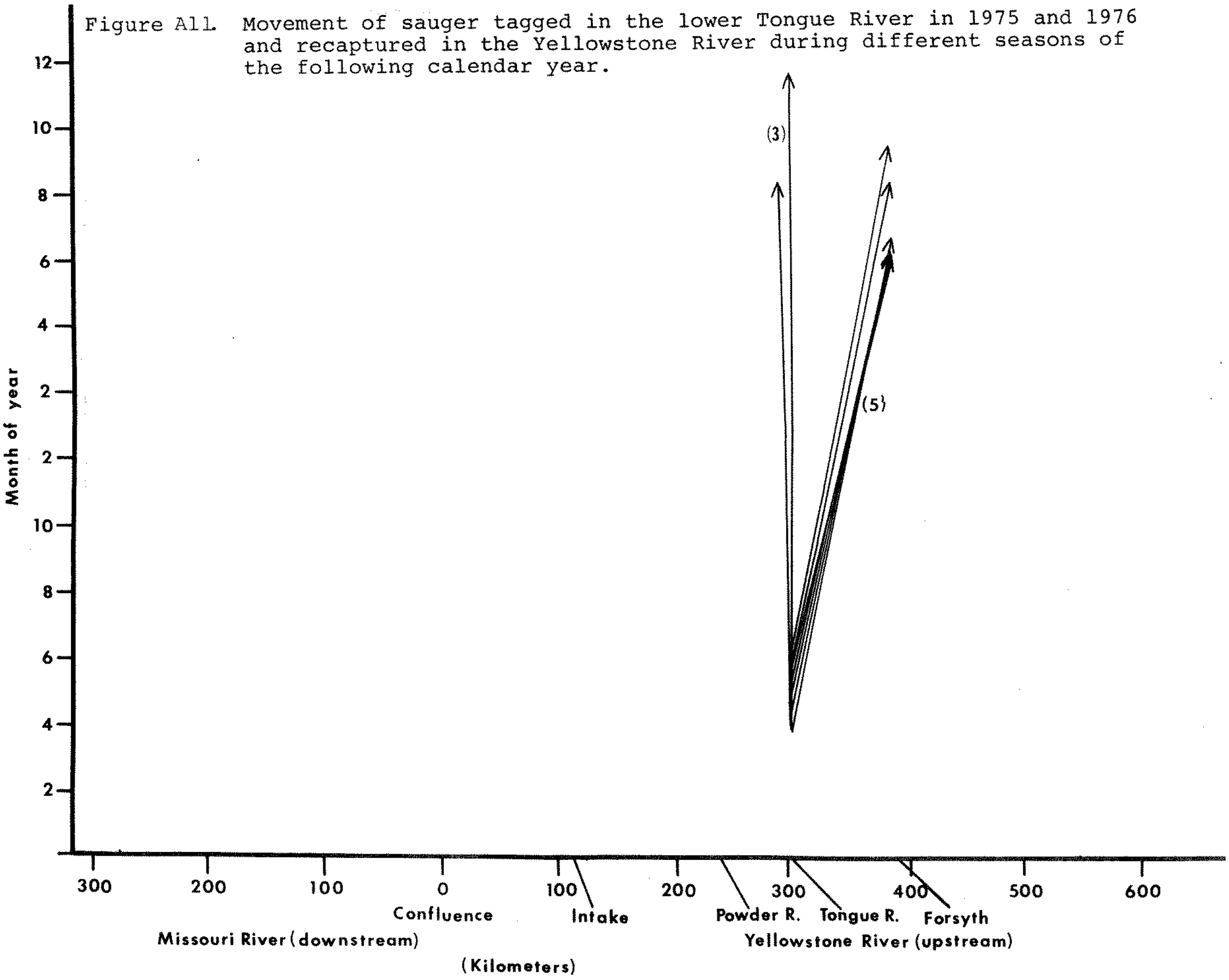


Figure A12. Movement of sauger tagged in the Yellowstone River near Miles City from 1974 to 1977 and recaptured in the Yellowstone or Tongue rivers during the same calendar year.

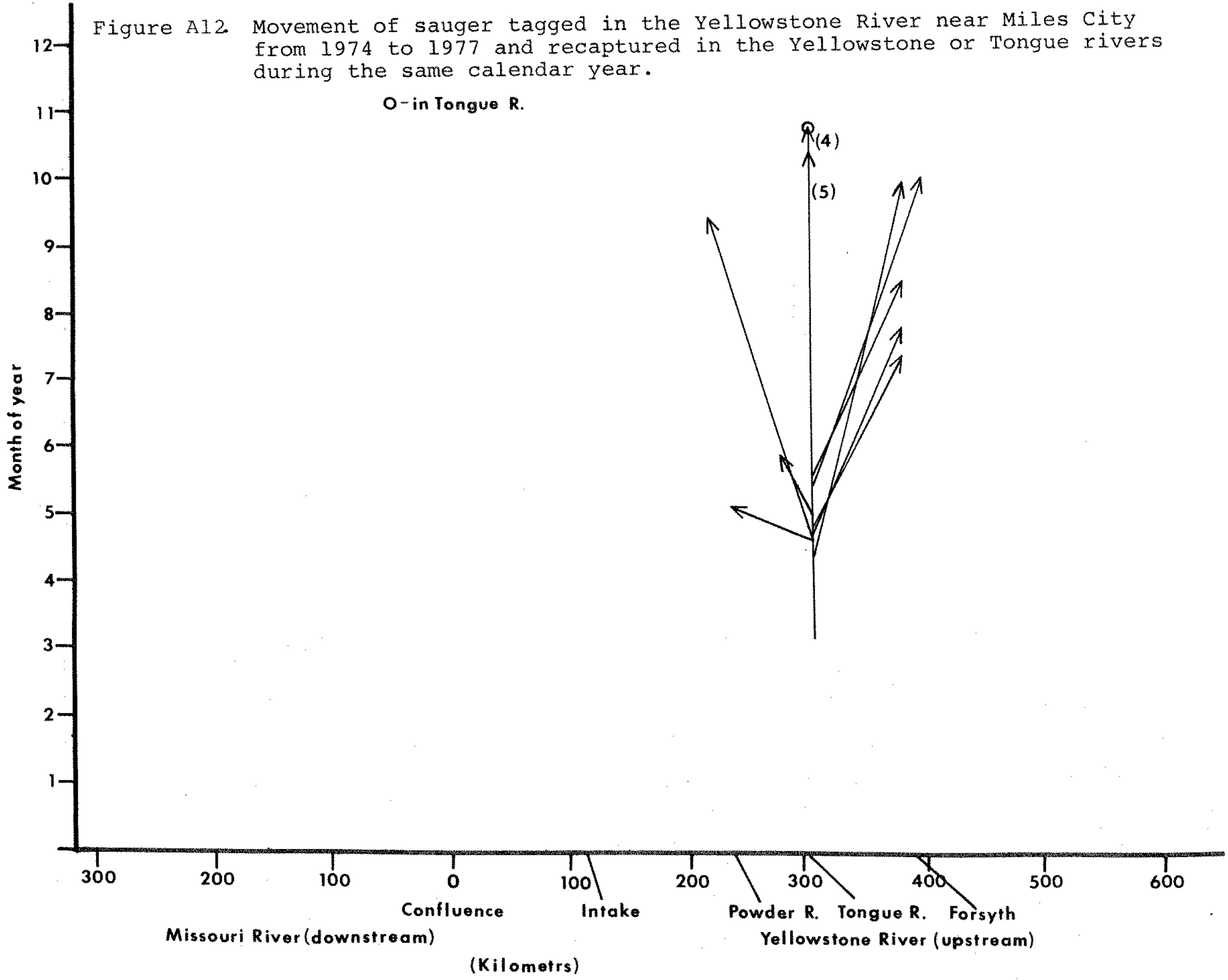


Figure A13. Movement of sauger tagged in the Yellowstone River near Miles City from 1974-1976 and recaptured in the Yellowstone River during the same season of the following calendar year.

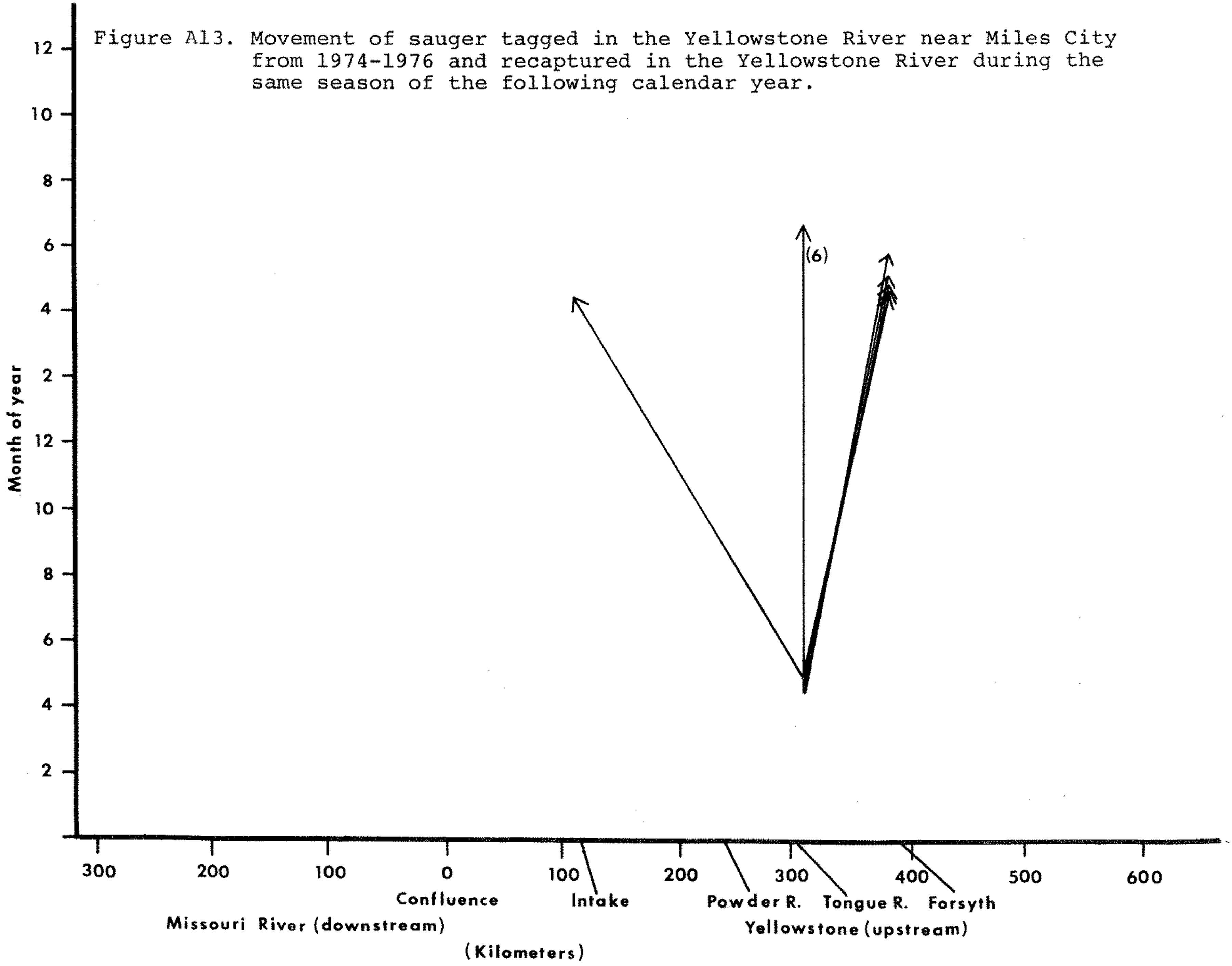
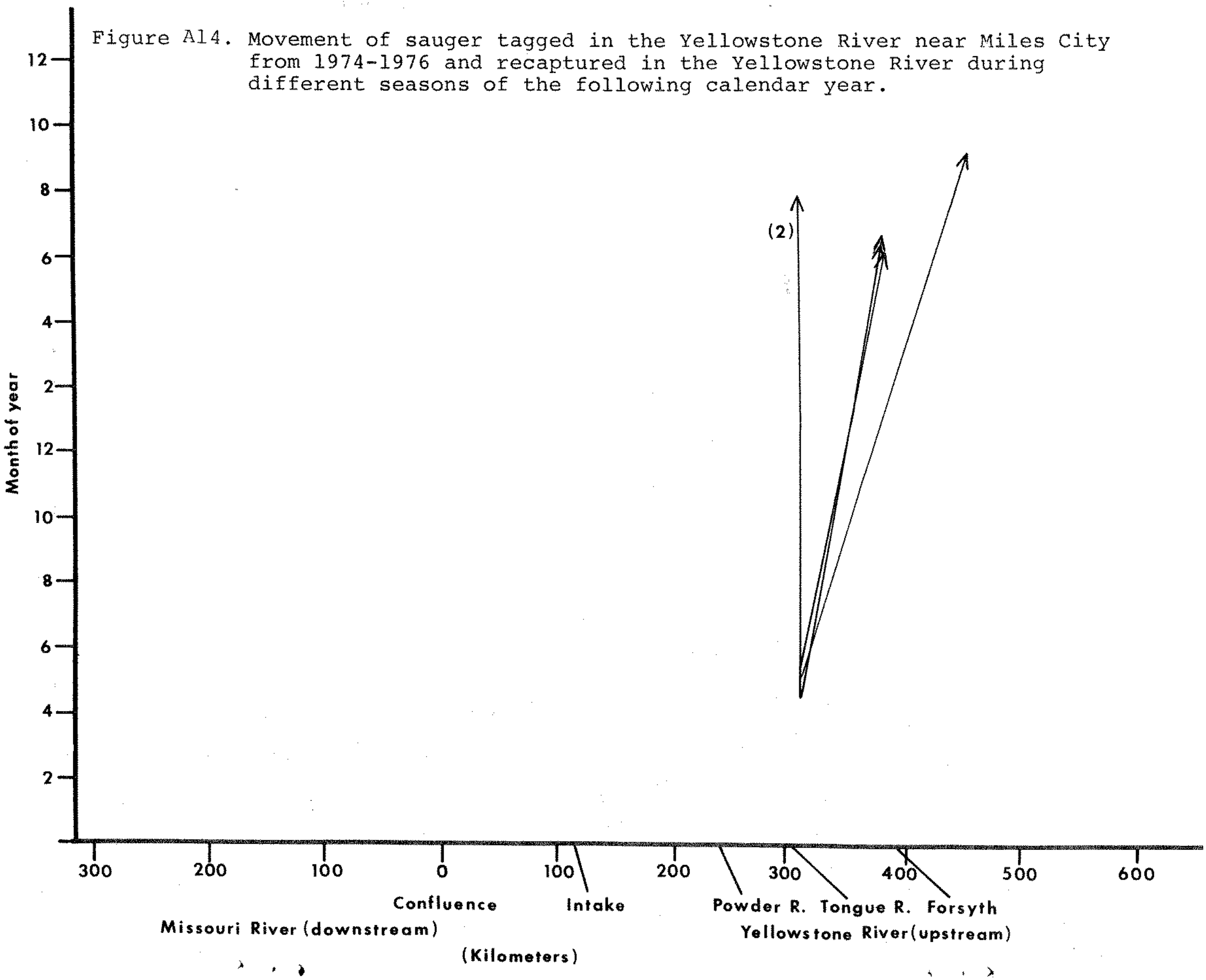


Figure A14. Movement of sauger tagged in the Yellowstone River near Miles City from 1974-1976 and recaptured in the Yellowstone River during different seasons of the following calendar year.



Appendix B Total length versus anterior scale radius and weight versus total length regressions for sauger collected in three areas of the Yellowstone River in the spring (S) and late summer to early autumn (A).

Total length versus anterior scale radius

	Linear		Curvelinear		
Area	Regression	r	Regression	r	n
Lower (S)	L=43.6 +0.690 S	.83	$l=5.69 \times S^{0.82}$	.83	479
Lower (A)	L=16.1 +0.776 S	.88	$L=4.07 \times S^{0.89}$	.89	296
Middle (A)	L=73.5 +0.629 S	.79	$L=7.22 \times S^{0.77}$	.81	283
Upper (A)	L=40.3 + 0.667 S	.82	$L=4.48 \times S^{0.87}$	.84	280
Combined (A)	L=40.5 + 0.701 S	.84	$L=4.79 \times S^{0.86}$	.86	859

Weight versus total length

Area	Regression	r	n
Lower (S)	log W=-5.634 + 3.199 log L	.97	479
Lower (A)	log W=-5.154 + 3.016 log L	.98	296
Middle (A)	log W=-5.112 + 3.008 log L	.98	283
Upper (A)	log W=-5.249 + 3.064 log L	.97	280
Combined (A)	log W=-5.247 + 3.059 log L	.98	859

L = Total length (mm)
S = Anterior median scale radius (mm) x 66
W = Weight (g)

Appendix C. Number of combined sauger and walleye eggs, depth, velocity, substrate and date sampled at 4 transect locations on a gravel bar downstream from Intake diversion in the lower Yellowstone River, sampled on April 18, 21, and 24 and May 2 and 6, 1977.

Transect (Date)	Depth (Meters)	Velocity (cm/sec)	Number of eggs	Substrate
1 (4/18)	0.30	35.97	0	Sand-cobble
	0.46	46.94	0	Sand-cobble
	0.61	53.64	0	Compacted cobble
	0.76	55.78	0	Compacted cobble
	0.91	61.87	0	Gravel, cobble
2 (4/18)	0.30	42.67	0	Sand -pebble
	0.46	46.94	0	Sand-pebble
	0.61	53.64	0	Compacted pebble
	0.76	68.88	0	Pebble
	0.91	79.55	21	Pebble-cobble
3 (4/18)	0.30	46.94	0	Pebble-cobble
	0.46	36.45	0	Compacted cobble
	0.61	68.88	0	Compacted Cobble
	0.76	79.86	21	Pebble-cobble
	0.91	81.99	10	Pebble-cobble
4 (4/18)	0.30	73.46	0	Cobble-pebble
	0.30	66.75	3	Cobble-pebble
	0.46	84.43	15	Cobble
	0.61	90.83	8	Pebble-cobble
	0.76	94.18	17	Pebble-cobble
	0.91	106.38	3	Pebble-cobble
1 (4/21)	0.30	35.97	0	Sand-cobble
	0.46	49.07	0	Sand-cobble
	0.61	50.29	0	Compacted cobble
	0.76	57.00	0	Compacted cobble
	0.91	61.26	0	Pebble-cobble
2 (4/21)	0.30	38.10	0	Sand-pebble
	0.46	48.16	0	Sand-pebble
	0.61	53.64	0	Compacted pebble
	0.76	78.94	25	Pebble
	0.91	87.48	20	Pebble-cobble
3 (4/21)	0.30	44.81	0	Pebble-cobble
	0.46	53.64	0	Compacted cobble
	0.61	66.75	0	Compacted cobble
	0.76	75.59	3	Pebble-cobble
	0.91	84.43	14	Pebble-cobble

Appendix C. Continued

Transect (Date)	Depth (Meters)	Velocity (cm/sec)	Number of eggs	Substrate
4 (4/21)	0.30	77.72	0	Cobble-pebble
	0.30	71.02	3	Cobble-pebble
	0.46	81.08	10	Cobble
	0.61	92.05	7	Pebble-cobble
	0.76	98.45	5	Pebble-cobble
	0.91	99.67	5	Pebble-cobble
2 (4/24)	0.30	41.45	0	Sand-cobble
	0.46	43.59	0	Sand-cobble
	0.61	65.53	1	Semi-compact cobble
	0.76	77.72	3	Cobble-pebble
	0.91	83.21	6	Cobble-pebble
3 (4/24)	0.30	41.45	0	Compacted cobble-pebble
	0.46	59.13	0	Compacted cobble-pebble
	0.61	72.24	0	Compacted cobble-pebble
	0.76	77.72	3	Cobble-pebble
	0.91	88.70	3	Cobble-pebble
4 (4/24)	0.30	67.97	0	Pebble-cobble
	0.30	67.97	4	Semi-compacted pebble-cobble
	0.46	73.46	3	Semi-compacted pebble-cobble
	0.61	81.08	14	Pebble-cobble
	0.76	90.83	6	Pebble-cobble
	0.91	95.40	0	Compacted cobble-pebble
4 (5/2)	0.30	75.59	0	-
	0.30	65.53	0	-
	0.46	84.43	0	-
	0.61	98.45	0	-
	0.76	99.67	0	-
	0.91	106.38	0	-
3 (5/6)	0.30	48.16	0	Pebble
	0.46	57.91	0	Compacted cobble-pebble
	0.61	66.75	0	Compacted cobble
	0.76	75.59	0	Compacted cobble
	0.91	88.70	0	Compacted cobble
4 (5/6)	0.30	77.72	0	Pebble-silt
	0.30	73.46	0	Compacted pebble
	0.46	66.75	0	Semi-compacted cobble-pebble
	0.61	98.45	0	Cobble-pebble
	0.76	103.91	0	Semi-compacted cobble-pebble
	0.91	110.64	0	Cobble-pebble

Appendix D Number of combined sauger and walleye eggs, depth, velocity and substrate at 8 transects in the lower Yellowstone sampled on April 24 and 29, 1977.

Transect (River kilometer)	Depth (Meters)	Velocity (cm/sec)	Number of eggs	Substrate
5 (109.9)	0.30	22.74	0	Compacted cobble
	0.61	22.74	0	Compacted cobble
	0.91	-	0	Compacted cobble
6 (109.6)	0.30	31.70	0	Semi-compacted cobble
	0.61	40.54	0	Compacted cobble
	0.91	46.94	1	Cobble
7 (105.7)	0.30	35.05	0	Cobble-pebble
	0.61	42.67	0	Cobble-pebble
	0.91	49.07	0	Cobble
8 (104.9)	0.30	31.70	0	Cobble-pebble
	0.61	48.16	0	Cobble-pebble
	0.91	55.78	0	Cobble
9 (100.2)	0.30	81.99	0	Pebble-cobble
	0.61	117.04	0	Pebble-cobble
	0.91	119.48	0	Cobble
10 (99.4)	0.30	35.05	0	Semi-compacted pebble
	0.61	51.51	0	Pebble
	0.91	66.75	0	Pebble
11 (89.8)	0.30	46.02	0	Compacted pebble-cobble
	0.61	56.69	0	Compacted pebble-cobble
	0.91	71.02	0	Compacted pebble-cobble
12 (89.5)	0.30	81.99	0	Pebble-cobble
	0.61	114.91	0	Pebble-cobble
	0.91	-	0	Pebble-cobble