259650025 FWS

F-150

HABITATS AND MOVEMENTS OF PALLID AND SHOVELNOSE STURGEON IN THE YELLOWSTONE AND MISSOURI RIVERS, MONTANA AND NORTH DAKOTA

by

Robert Glenn Bramblett

A thesis submitted in partial fulfillment
of the requirements for the Degree

of

Doctor of Philosophy

in

Biological Sciences

MONTANA STATE UNIVERSITY-BOZEMAN
Bozeman, Montana

February 1996

242pp.

The National Biological Service, Montana Cooperative Fishery Research Unit, Montana State University and the author greatly appreciates and acknowledges the United States Bureau of Reclamation, Montana Area Office, Billings, Montana for printing this document.

APPROVAL

of a thesis submitted by

Robert Glenn Bramblett

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency and is ready for submission to the College of Graduate Studies.

Dr. Robert G. White — Robert G. White (Signature) — 2/21/96 (Date)

Approved for the Department (Biology)

Dr. Ernest R. Vyse — E R Vyse (Signature) — Feb. 20/96 (Date)

Approved for the College of Graduate Studies

Dr. Robert L. Brown — ______ (Signature) — ______ (Date)

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a doctoral degree at Montana State University-Bozeman, I agree that the library shall make it available to borrowers under rules of the Library. I further agree that copying this thesis is allowable only for scholarly purposes, consistent with "fair use" as prescribed in U. S. Copyright Law. Requests for extensive copying or reproduction of this thesis should be referred to University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106, to whom I have granted "the exclusive right to reproduce and distribute my dissertation in and from microform along with the non-exclusive right to reproduce and distribute my abstract in any format in whole or part."

Signature R G Brust

Date 1/22/96

ACKNOWLEDGMENTS

I wish to express my gratitude to my graduate advisor, Dr. Robert G. White for his support, guidance, and friendship during this project. I also thank Drs. Clifford Bond, Lynn Irby, Calvin Kaya, Thomas MacMahon, and Patricia Munholland who served on my thesis committee. Drs. Patricia Munholland and John Borkowski provided statistical consulting. Dr. Daniel Gustafson provided the study area map and performed computer programming. Pat Clancey of the Montana Department of Fish, Wildlife and Parks (MDFWP) initiated telemetry of pallid and shovelnose sturgeon in this study area in 1989, and MDFWP biologist Ann Tews continued with the research beginning in 1992. Ann Tews and Pat Clancey captured most of the sturgeon used in this study. I thank Dr. Phillip Stewart of MDFWP Region Seven for the loan of a boat. Steve Krentz and Allan Sandvol of the U. S. Fish and Wildlife Service (USFWS) Office of Ecological Services in Bismarck, North Dakota also captured sturgeon for this study. M. Baxter, C. Endicott, D. Gustafson, E. Jeans, S. Lohr, D. Megargle, J. Piccolo, D. Venditti and J. Zelenak assisted in the field. Funding for this study was provided by Division of Cooperative Units, National Biological Service; USFWS Ecological Services offices in Helena, Montana and Bismarck, North Dakota, and USFWS Denver Regional Office.

TABLE OF CONTENTS

TABLE OF CONTENTS, Continued

TABLE OF CONTENTS, Continued

LIST OF TABLES

LIST OF TABLES, Continued

LIST OF TABLES, Continued

LIST OF TABLES, Continued

LIST OF TABLES, Continued

LIST OF TABLES, Continued

LIST OF FIGURES

LIST OF FIGURES, Continued

Figure Page

LIST OF FIGURES, Continued

LIST OF FIGURES, Continued

LIST OF FIGURES, Continued

LIST OF FIGURES, Continued

LIST OF FIGURES, Continued

Figure Page

LIST OF FIGURES, Continued

LIST OF FIGURES, Continued

LIST OF FIGURES, Continued

LIST OF FIGURES, Continued

LIST OF FIGURES, Continued

ABSTRACT

Habitat use and movements of the endangered pallid sturgeon and the closely related shovelnose sturgeon are poorly known. Using radio and sonic telemetry, I obtained observations of microhabitat and macrohabitat use and movements on 24 pallid and 27 shovelnose sturgeon in the Yellowstone and Missouri rivers in Montana and North Dakota. Pallid sturgeon preferred sand and avoided gravel/cobble substrates. Shovelnose sturgeon preferred gravel/cobble and avoided sand substrates, although individual shovelnose sturgeon were variable in substrate use. Pallid sturgeon used depths ranging from 0.6 to 14.5 m, while shovelnose sturgeon used depths ranging from 0.9 to 10.1 m. Median depths at pallid sturgeon locations were significantly greater than at shovelnose sturgeon locations, and there was significant variation in mean depths among individual pallid and shovelnose sturgeon. Pallid and shovelnose sturgeon used bottom current velocities ranging from 0 to 1.37 m/s, and 0.02 to 1.51 m/s, respectively. Mean bottom current velocities were significantly greater at shovelnose sturgeon locations than at pallid sturgeon locations, although analysis of variance indicated that difference was due to location in the Yellowstone River versus the Lower Missouri River. Pallid sturgeon were most often relocated in the lower 28 km of the Yellowstone River in spring and summer and in the Lower Missouri River in fall and winter. Shovelnose sturgeon were most often relocated in the 114 km of the Yellowstone River from the Intake diversion dam to the confluence in all seasons. Only rarely were either species relocated in the Upper Missouri River. Pallid sturgeon aggregations in late spring and early summer indicate that spawning may occur in the lower 13 km of the Yellowstone River. Home range of both species ranged to over 250 km. Both species moved during both day and night and less during fall and winter than during spring and summer. Linear regression models suggested that discharge and photoperiod may be important environmental cues for movements of both species. Pallid sturgeon used moderately diverse, dynamic macrohabitats while shovelnose sturgeon were less selective in macrohabitat use. Substantial differences in habitat use and movements between adult pallid and shovelnose sturgeon indicate that shovelnose sturgeon have limited utility as pallid sturgeon surrogates.

INTRODUCTION

Pallid sturgeon (*Scaphirhynchus albus* Forbes and Richardson) were listed as endangered in 1990 under the Endangered Species Act of 1973 (Dryer and Sandvol 1993). There is little quantitative information on movements and habitat use. This study was implemented to supplement research initiated by the Montana Department of Fish, Wildlife and Parks (MDFWP) and the U. S. Fish and Wildlife Service (USFWS) on pallid sturgeon and a closely related species, the shovelnose sturgeon (*Scaphirhynchus platorynchus* Rafinesque).

REVIEW OF PALLID AND SHOVELNOSE STURGEON BIOLOGY

Description and Taxonomy

The sturgeons (Family Acipenseridae) are large freshwater or anadromous fishes of the infraclass Chondrostei. Sturgeons have a holarctic distribution (Berra 1981). Infraclass Chondrostei have retained ancestral features including a cartilaginous skeleton, retention of the notochord as adults, heterocercal tail, spiracle, spiral valve, and five rows of boney scutes derived from ganoid scales (Moyle and Cech 1982; Birstein 1993). Both sexes of Acipenseridae are morphologically similar, except females are generally larger (Gilbraith et al. 1988). However, sexual dimorphism was reported for *Acipenser ruthenus*, as paired fins were slightly longer in the females (Breder and Rosen 1966).

Sturgeons are an ancient group, with fossils known from the Upper Cretaceous (Bailey and Cross 1954). There are about 24 living sturgeon species comprising 4 genera (*Acipenser*, *Huso*, *Psuedoscaphirhynchus*, and *Scaphirhynchus*; Rochard et al. 1990). The beluga sturgeon, an old world species, is the world's largest freshwater fish, reaching weights of 1,300 kg and lengths of up to 8 m (Berra 1981). The largest North American sturgeon is the white sturgeon (*Acipenser transmontanus*), which grows to about 4 m in length and up to 590 kg in weight. Chondrosteans are a highly endangered group as most species are endangered or threatened (Birstein 1993).

River sturgeons (Genus *Scaphirhynchus*) are characterized by a flattened shovel-shaped snout; a long, slender, and completely armored caudal peduncle; prolonged upper lobe of the caudal fin; and the absence of a spriacle (Smith 1979). This morphology and such features as small eyes, a tough leathery skin (Cross and Collins 1975), dorsoventrally flattened body, and sensitive barbels are adaptations to a life in large, swift, and turbid rivers. Three species of *Scaphirhynchus* are known: pallid sturgeon, shovelnose sturgeon, and Alabama sturgeon (*S. suttkusi*). Pallid and shovelnose sturgeon occur in the Mississippi river basin, while Alabama sturgeon, only recently described, are found in the Mobile Bay Basin (Williams and Clemmer 1991).

The pallid sturgeon was first described by Forbes and Richardson (1905) based on nine specimens collected from the Mississippi River near Grafton, Illinois in 1904. They considered pallid sturgeon to represent a new genus and named the species *Paraschaphirhynchus albus*. In a later review of *Scaphirhynchus*, Bailey and Cross (1954) considered *albus* and *platorynchus* to be congeners of the genus *Scaphirhynchus*. They resemble the old world genus *Psuedoscaphirhynchus*, and together the two genera comprise the subfamily Scaphirhychinae.

Carlson et al. (1985) described the occurrence of hybrids between *S. albus* and *S. platorynchus* in the Mississippi and Missouri Rivers in Missouri. Electrophoretic examination of pallids, shovelnose, and hybrids found them to be indistinguishable at all 37 loci examined (Phelps and Allendorf 1983). The authors attributed the genetic similarity of the two species to recent or incomplete reproductive isolation accompanied by rapid morphological differentiation.

Pallid sturgeon closely resemble shovelnose sturgeon but attain larger sizes. Pallids are generally lighter in color than shovelnose, although color is not consistently reliable for distinguishing the two species (Kallemeyn 1983). Important meristic and morphometric features used to separate pallids from shovelnose are the dorsal and anal fin ray counts, arrangement and length of the barbels, the height of the tenth lateral plate, and lesser degree of scutellation (Bailey and Cross 1954). Pallid sturgeon have 37 or more dorsal fin rays and 24 or more anal fin rays. The bases of the outer barbels are usually posterior to the bases of the inner barbels, so that the bases form a curve that is convex anteriorly. In contrast, the bases of the barbels of shovelnose sturgeon are even. In pallid sturgeon, the inner barbels are less than one sixth the head length, and shorter than the outer barbels (Pflieger 1975).

Distribution

The range of the pallid sturgeon is the mainstem of the Mississippi River from its mouth to the confluence of the Missouri River, and the Missouri River upstream to Fort Benton, Montana as well as the lower portions of a limited number of tributaries. These tributaries include the lower 56 km of the Big Sunflower River (Keenlyne 1989) and the St. Francis River, the lower 64 km of the Kansas River (Cross 1967), the lower 34 km of the Platte River (Keenlyne 1989), and the lower 322 km of the Yellowstone River

(Brown 1971). The total length of its habitat is about 5,725 kilometers of river. Bailey and Cross (1954) noted that the pallid sturgeon's habitat was mostly limited to turbid waters. Smaller rivers such as the Ohio River, or the Mississippi above the confluence with the Missouri, have none, or very few, records of pallid sturgeon occurrence. This is in contrast to the range of the shovelnose sturgeon, which in addition to these areas of sympatry also includes most large tributaries such as the Red, Arkansas, Ohio, and upper Mississippi Rivers, as well as the Rio Grande River (Bailey and Cross 1954; Lee et al. 1980).

Abundance

Despite being one of the largest North American freshwater fishes, the pallid sturgeon is a poorly known species; it was not described until 1905 (Forbes and Richardson 1905). Bailey and Cross (1954) stated that the species is "nowhere common". Although pallid sturgeon were probably never as abundant as shovelnose sturgeon (Forbes and Richardson 1905, Bailey and Cross 1954, Fisher 1962), in recent years a decline in pallid sturgeon abundance has been documented, particularly in the Missouri River from the Fort Peck dam in Montana downstream to the Gavin's Point dam near Yankton, South Dakota (Keenlyne 1989). Although poor sampling efficiencies in large rivers may contribute to its apparent rareness (Kallemeyn 1983), observations of pallid sturgeon over its entire range have declined from an average of 50 per year in the 1960's to just 6 per year in the 1980's (Keenlyne 1989). Shovelnose sturgeon have also been reduced in abundance (Bailey and Cross 1954) but apparently have not declined to the same extent as pallid sturgeon.

Causes of Decline

Most authors attribute the decline of pallid sturgeon to the massive habitat alterations that have taken place over virtually all of its range (Kallemeyn 1983; Gilbraith et. al. 1988; Keenlyne 1989; Dryer and Sandvol 1993). Starting with Fort Peck in 1938, a total of six mainstem dams have been built on the Missouri River. Approximately 51% of the total range of the pallid sturgeon has been channelized for barge navigation and 28% has been impounded. The remaining 21% of its range is below dams, and therefore has altered temperature, flow, and sediment dynamics (Keenlyne 1989).

Habitat modifications such as dams and channelization are thought to have impacted pallid and shovelnose sturgeon by blocking movements to spawning or feeding areas, destroying spawning areas, altering temperatures, turbidity, and flow regimes, and reducing food supply (Keenlyne 1989). Moreover, these alterations have led to a loss of sediment loads and flood pulses thereby disrupting the processes of meandering, erosion and accretion (Hesse 1987). This causes a loss of connection to the floodplain which reduces allocthonous carbon inputs, causing a decline in overall productivity (Hesse 1987; Junk et al. 1989). Also, reduction in habitat diversity and quantity may effectively remove habitat-related reproductive isolating mechanisms, thereby leading to hybridization between pallid and shovelnose sturgeon.

Commercial fishing is known to have severely reduced sturgeon stocks in the Missouri and Mississippi in the late 1800's (Keenlyne 1989). Although pallids were not usually distinguished from shovelnose or lake sturgeon in the catch records, it is likely that their stocks also suffered from overharvest. As long ago as 1951, declines in Mississippi and Missouri River stocks of sturgeon were noted (Barnickol and Starret 1951). The commercial catch of shovelnose sturgeon in parts of the Mississippi River declined up to 94% during the period from 1899 to 1946 (Barnickol and Starret 1951). Shovelnose and probably pallid sturgeon were considered a nuisance by some commercial fisherman and were intentionally destroyed (Carlander 1954; Moos 1978). Forbes and Richardson (1905) reported that pallid sturgeon represented only a small portion of the commercial sturgeon harvest in the Mississippi, but they were much more prevalent in the catch of the Lower Missouri River.

Pollution of the waters in the pallid and shovelnose sturgeon's range may also be a threat to their survival. High levels of pollutants in the Mississippi and Missouri River has precipitated fish consumption warnings and restricted commercial fishing in some areas (Keenlyne 1989). Because the pallid sturgeon has a long life span, and feeds on other fishes and insects (Carlson et al. 1985), it would tend to bioaccumulate pollutants. Concentrations of heavy metals and organic compounds found in pallid sturgeon from the Missouri River may be high enough to have an effect on reproduction (Ruelle and Keenlyne 1993).

Habitat

Habitat use by pallid sturgeon is poorly known. Pallid sturgeon distribution and general observations seem to indicate that they require large, turbid riverine habitat with a firm sandy or gravelly substrate (Bailey and Cross 1954). Bailey and Cross (1954) noted that pallid sturgeon were most closely associated in habitat and distribution with sicklefin chub (*Macrhybopsis meeki*), a species of large, turbid rivers (Lee et al. 1980). Notably, the sicklefin chub is another candidate species for endangered status. Cross and Collins (1975) state that the pallid sturgeon is restricted to large, muddy rivers with swift currents. Researchers in Missouri captured both pallid and shovelnose in gear-sets along sandbars on the inside of riverbends, and in deeply scoured pools behind wing dams, indicating overlap of habitat use by the two species. However, 4 of 11 pallids captured in the Missouri study were captured in gear-sets in swifter currents where shovelnose sturgeon were less numerous (Carlson et. al. 1985).

Quantitative data on habitat use by pallid sturgeon are limited. Several pallids have been observed by SCUBA diving and gillnetting in the tailwaters of Fort Peck dam on the Missouri River, particularly during the winter months. Depths in this tailpool range to 12.2 m (Clancy 1990). Prior to this study, habitat data gathered by use of radio telemetry from the fish captured below Fort Peck dam have yielded a total of five observations of habitat use on two pallid sturgeon. One of the pallid sturgeon moved about 272 km downstream, and the other moved about 72 km downstream from the Fort

Peck tailrace during the period from March to mid-June. Current velocity near the river bottom at relocation sites ranged from 0.46 to 0.96 m/s, turbidity ranged from 12 to >100 Jackson tubidity units, while depth ranged from 1.7 to 2.7 m. Both of these individual pallid sturgeon appeared to prefer turbid water, as relocations in the vicinity of the confluence with the Milk River were consistently in the plume of turbidity along the north bank where the Milk River entered the Missouri River.

Pallid sturgeon movements and habitat use were studied in Lake Sharpe, South Dakota using sonic telemetry (Erickson 1992). Lake Sharpe is a 137 km segment of the Missouri River below Oahe Dam and above Big Bend Dam; the upper segment is riverine. Pallid sturgeon were most often found at depths from 4 to 6 m, bottom current velocities from 0 to 0.73 m/s, and substrates ranging from mud to gravel and cobble. Pallid sturgeon movement was greater at night and was positively correlated with water temperatures and discharge, and larger fish moved more than smaller fish. However because Lake Sharpe is a highly altered habitat, it is possible that these data do not reflect true habitat preference.

The shovelnose sturgeon is a benthic, rheophilic species that occurs in large rivers, living primarily in the strong currents of the main channels over sand or gravel substrates (Bailey and Cross 1954). In Pool 13 of the upper Mississippi River, radio-tagged shovelnose sturgeon were found exclusively in the riverine portion of this habitat, which also has sections that are of a more lentic nature (Hurley et al. 1987). Habitat use differed between spring and summer. In the high water of spring shovelnose sturgeon used velocity refuges such as wing dams. In the summer when water levels were lower, shovelnose sturgeon were found in main channels more often. Depths at shovelnose sturgeon locations ranged from 1 to 10 m (mean, 4.4 ± 0.07 m). Bottom current velocities at shovelnose sturgeon locations ranged from 5 to 65 cm/s (mean, 33 ± 0.5 cm/s). Surface current velocities ranged from 10 to 105 cm/s (mean, 59 ± 0.9 cm/s). Most relocations were over sand substrate, but shovelnose sturgeon were also found associated with the large rock substrate that composed the wing dams.

Helms (1974) captured shovelnose sturgeon in the upper Mississippi River by drifting trammel nets. Catch per unit effort (CPUE) was highest in tailwater areas below dams (mean, 5.3 fish/drift; $N = 32$ drifts), where shovelnose sturgeon made up 80% of the catch. CPUE was lower in main channel, main channel border, and side channel habitats (means, 2.9; 2.5; 3.0; $N = 240$; 484; 33 drifts respectively). Low current velocity habitats could not be sampled by this method.

In the upper Mississippi River, shovelnose sturgeon were generally sedentary, but did exhibit movements of up to 11.7 km/d (Hurley et al. 1987). Helms (1974) also found modest movement of tagged shovelnose sturgeon; mean upstream and downstream distances from capture site were 2.6 and 0.8 km, respectively. However, individual shovelnose sturgeon were recaptured as far as 193 km from the original capture site. Schmulbach (1974) reports downstream movements of up to 534 km, while Moos (1978) documented movements of up to 250 km for shovelnose sturgeon in the Lower Missouri River.

Food Habits

As with other biological attributes, information on the diet of pallid sturgeon is limited. Carlson et al. (1985) examined nine pallid sturgeon stomachs. They found that fish (primarily cyprinids) and larval Trichoptera were the most prevalent food items by volume (38% for each) and frequency of occurrence (56% for each). The remainder of the stomach contents were comprised of other aquatic insects and invertebrates, as well as plant material and sand, which were probably taken incidentally. In the same study, the stomachs of shovelnose sturgeon (*N* = 234) contained fewer fish (2% by volume; 4% by frequency of occurrence) while pallid/shovelnose hybrids (*N* = 9) were intermediate in fish consumption (31% by volume; 22% by frequncy of occurrence). A pallid sturgeon from the Kansas River also had fish and larval aquatic insects in its stomach (Cross 1967).

Feeding behavior of pallid sturgeon has been observed in captivity. At Aksarben Aquarium in Nebraska, a single pallid sturgeon is fed goldfish and other small fish. A pallid sturgeon specimen and some presumed pallid/shovelnose hybrids held at Blind Pony hatchery in Missouri are fed small fish and crayfish. Pallid sturgeon broodstock held at the Gavin's Point National Fish Hatchery in South Dakota are fed live rainbow trout along with prepared broodstock diet.

Modde and Schmulbach (1977) studied food habits of shovelnose sturgeon in an unchannelized reach of Missouri River in South Dakota. Stomach contents consisted primarily of benthic insects. Trichoptera, Diptera and Ephemeroptera were the most important groups, although many other macroinvertebrate groups were represented. No fish were found in shovelnose sturgeon stomachs. The authors described the shovelnose sturgeon as an opportunistic macroinvertebrate feeder that does not exhibit specific preferences for any food items. Trichoptera, Diptera and Ephemeroptera were again found to be the most important food items in shovelnose sturgeon stomachs in the Mississippi and Missouri Rivers in Missouri (Carlson et al. 1985). However, in this study a few fish were found in shovelnose sturgeon stomachs. In a recent study in the Missouri River above Fort Peck reservoir in Montana, Trichoptera, Diptera and Ephemeroptera were the most prevalent invertebrate food items in shovelnose sturgeon stomachs. Larval fish were also found in the diet during late spring months (Douglas Megargle, Montana Cooperative Fishery Research Unit, Pers. Comm.). Other authors also report that benthic insects are the most important food items (Eddy and Surber 1947; Barnickol and Starret 1951, Hoopes 1960; Held 1969, Helms 1974; Elser et al. 1977, Berg 1981; Gardner and Berg 1982; Gardner and Stewart 1987).

Reproduction and Early Life History

Pallid sturgeon are long lived, slow growing and mature at advanced ages. (Gilbraith et al. 1988). Fogle (1961) reported that males were sexually mature at 3 to 4 years old and lengths of 533 to 584 mm. However, Keenlyne and Jenkins (1993) estimated that males reach sexual maturity at age 5 to 7 years, and may not spawn every year. Females were estimated to begin egg development at age 9 to 12 years, and spawn for the first time at ages 15 to 20, with intervals of several years between spawning. Factors such as forage availability and other environmental conditions may influence age of sexual maturity and the length of intervals between spawning years (Dryer and Sandvol 1993).

Keenlyne et al. (1992) reported on the fecundity of a pallid sturgeon specimen captured in the Missouri River in North Dakota. The specimen weighed 17.1 kg, was 140.4 cm in fork length, and was estimated to be 41 years old, based on pectoral fin annuli. Ovary mass was 11.4% (1.925 kg) of total body weight. Oocytes averaged 87/g, yielding a fecundity estimate of 170,000 eggs. Oocytes were in late state of maturity as indicated by a uniformly light black color and ovoid shape. Oocytes ranged from 2.5 to 3.0 mm in length and 2.0 to 2.5 mm in diameter.

Time of spawning has not been well documented, but is believed to occur sometime from March through July depending on location (Forbes and Richardson 1905; Gilbraith et al. 1988; Keenlyne and Jenkins 1993). More recent observations include adults in spawning condition in late May and early June in the vicinity of the Missouri/Yellowstone River confluence (Allan Sandvol, USFWS, pers. comm.).

Little information on pallid sturgeon reproduction exists. Sampling for young of the year fishes below Gavin's Point Dam (Kozel 1974), in Lake Oahe (Beckman and Elrod 1971) and for larval fishes in the middle Missouri (Hergenrader et al. 1982) have yielded no pallid sturgeon. There is no information on the locations or physical parameters of pallid sturgeon spawning habitat. However, their spawning habitat must be similar to that of the shovelnose sturgeon as hybridization has been documented (Carlson et al. 1985). Introgression may be occurring because reproductive isolating mechanisms have been lost due to degradation of, or the blocking of access to, preferred pallid sturgeon spawning habitat.

Details of pallid sturgeon spawning are not known but may be similar to those reported for other sturgeon species. Breder and Rosen (1966) report that as a group, sturgeon exhibit uniform spawning behavior. All sturgeon species spawn in the spring or early summer, are multiple spawners, and release their eggs at intervals. The adhesive eggs are released in deep channels or rapids and are left unattended (Gilbraith et al. 1988). The larvae of Acipenserids are pelagic, becoming buoyant or active immediately after hatching (Moyle and Cech 1982). White sturgeon in the Columbia River spawned in the swiftest water velocities available (0.8 - 2.8 m/s mean column velocity) over cobble, boulder or bedrock substrates in depths of 4 to 23 m (Parsley et al. 1993).

Shovelnose sturgeon are reported to spawn over rocky or gravely substrates in main channel habitats of the Mississippi and Missouri Rivers and their major tributaries (Moos 1978; Helms 1974). In the Tongue River, Montana, shovelnose sturgeon spawned when water temperatures reached 17°C to 21.5°C in early June to mid-July (Elser et al. 1977). In the Missouri River near Vermillion, South Dakota, shovelnose sturgeon spawned when water temperatures reached 18° to 19°C (Moos 1978). In the Missouri

River above Fort Peck reservoir in Montana, shovelnose sturgeon spawned in June and early July (Berg 1981).

Larval pallid and shovelnose sturgeon are nearly identical (Carlson 1983). However, recent work (Snyder 1994) has provided some diagnostic characters to separate pallid and shovelnose sturgeon larvae, except for recently hatched specimens less than 10 mm (total length; TL). However, identification of certain larger specimens remains difficult due to overlap of characters. Also, it is suspected that the pallid sturgeon broodstock used to produce the specimens for the study by Snyder (1994) were actually pallid x shovelnose sturgeon hybrids.

Age and Growth

The age and growth of pallid sturgeon is not well documented. The largest specimen on record was 30.8 kg (Brown 1971). Six pallid sturgeon from Lake Oahe on the Missouri River in South Dakota were aged and lengths were back calculated by using pectoral fin ray cross sections (Fogle 1963). Estimated ages ranged from 5 to 10 years. Average lengths at ages were as follows: 1 = 279 mm; 2 = 378 mm; 3 = 470 mm; 4 = 574 mm; 5 = 638 mm; 6 = 672 mm; 7 = 732 mm; 8 = 790 mm; 9 = 838 mm; 10 = 881 mm.

Kallemyn (1983) presented length-weight relationships for fish from Lake Oahe and Lake Sharpe (two mainstem Missouri River reservoirs in South Dakota) based on the data of Fogle (1961; 1963) and June (1981), respectively. These relationships showed that from ages O to 6 or 7, and a length of 600 mm, pallid sturgeon increase their length relatively more than their body weight. After 600 mm is reached, weight increases more rapidly than length. Findings of a recent study supported this growth pattern (Keenlyne and Maxwell 1993).

Carlson et al. (1985) aged pallid, shovelnose and hybrid sturgeon from the Missouri and Mississippi Rivers in Missouri. Eight pallid sturgeon had estimated ages ranging from age 4 to age 9 and had slower growth than the Lake Oahe fish aged by Fogle (1963). Lengths of pallid sturgeon were significantly greater than lengths of shovelnose sturgeon of the same age, while hybrids were generally intermediate in length.

Keenlyne et al. (1992) aged a 1404 mm fork length pallid sturgeon taken from the Missouri River in North Dakota. The specimen weighed 17.1 kg, and age was estimated at 41 years based on pectoral fin ray annuli, the oldest pallid sturgeon on record. However, the authors note that if size is a reasonable indicator of age, this specimen was not unusually old, since larger specimens have been captured.

Helms (1974) aged shovelnose sturgeon from the Mississippi River. Ages ranged from 0 to 12 years and fork lengths ranged from 188 mm to 716 mm. However, other authors (Christiansen 1975; Berg 1981) have questioned these growth rates as being higher than those reported elsewhere (Schmulbach 1974). Berg (1981) aged 122 shovelnose sturgeon from the Missouri River above Fort Peck Reservoir in Montana. Ages ranged from 8 to 33 years and averaged 21.3 years. Fork lengths ranged from 533 to 945 mm; weights ranged from 0.8 to 3.9 kg. Similar sizes are reported from the Yellowstone River in Montana (Peterman and Haddix 1975; Elser et al. 1977, Backes et al. 1994). Reports from the upper portions of the Missouri and Yellowstone River systems in Montana and North Dakota indicate that both pallid and shovelnose sturgeon attain larger sizes in the upper basin than in the lower portions of the Missouri and Mississippi basins (Helms 1974; Haddix and Estes 1976; Elser et al. 1977; Rehwinkle 1978; Berg 1981; Keenlyne 1989; Backes et al. 1994; Keenlyne et al. 1994).

REVIEW OF UNDERWATER TELEMETRY

Both radio (Haynes et al. 1978; Buckley and Kynard 1985; Wooley and Crateau 1985; Hurley et al. 1987; Curtis 1990; Hall et al. 1991; Seibel and Kynard 1992) and ultrasonic (McCleave et al. 1977; Apperson and Anders 1990; Hall et al. 1991; Kieffer and Kynard 1992; Moser and Ross 1995) transmitters have been used in sturgeon telemetry studies. Because radio signals penetrate the water/air interface, rapid relocations by moving boats (Hall et al. 1991) or aircraft (Tyus 1990) are possible. However, radio signals cannot be received from tagged fish in deep water particularly in waters of high conductivity such as the Missouri (Clancy 1990) and Yellowstone rivers. Clancy (1991) found that radio signals of tagged pallid sturgeons were not detectable in water deeper than 4.6 m.

Ultrasonic telemetry is superior to radio telemetry in salt water or deep fresh water with high conductivity because unlike radio signals, sonic signal strength is not attenuated in these habitats. Disadvantages of ultrasonic telemetry are that signals are adversely affected by aquatic vegetation, thermoclines, turbulence, boat motors and raindrops (Strasko and Pincock 1977; Winter 1983). Also, because a hydrophone must be submerged in the water to receive sonic signals, locations over large areas are time consuming and range of detection is less than with radio signals.

Surgical implantation of radio and/or sonic transmitters has been used in sturgeon telemetry studies (Wooley and Crateau 1985; Hall et al. 1991; Kieffer and Kynard 1993; Moser and Ross 1995). Internal transmitters do not cause drag or abrasion and cannot be snagged, although the procedure takes longer to perform than external attachment, and the fish must undergo a longer recovery period (Winter 1983). This method is considered best for long-term attachment (Strasko and Pincock 1977; Winter 1983). Tyus (1988) documented long-term retention of surgically implanted radio transmitters in Colorado squawfish (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*) of up to 8 years. However, loss of surgically implanted transmitters has been documented for shortnose sturgeon (Kieffer and Kynard 1993), Atlantic sturgeon (Moser and Ross 1995), channel catfish (*Ictalurus punctatus*, Summerfelt and Mosier 1984; Marty and Summerfelt 1986), and rainbow trout (*Oncorhynchus mykiss*; Chisolm and Hubert 1985).

Other sturgeon researchers have used external attachment of transmitters (McCleave et al. 1977; Haynes et al. 1978; Buckley and Kynard 1985; Wooley and Crateau 1985; Hurley et al. 1987; Apperson and Anders 1989; Hall et al. 1991; Kieffer and Kynard 1993; Seibel and Kynard 1992; Moser and Ross 1995). External transmitter loss has been reported for pallid sturgeon (Clancy 1990; 1991), Atlantic sturgeon (Kieffer and Kynard 1993; Moser and Ross 1995), and shortnose sturgeon (Kieffer and Kynard 1993; Moser and Ross 1995).

STUDY OBJECTIVES

The overall objective of this study was to describe and compare habitat use and movements of pallid and shovelnose sturgeon in the Yellowstone and Missouri rivers in Montana and North Dakota. Observations of habitat use and movements of pallid and shovelnose sturgeon were obtained through radio and sonic telemetry. Specific hypotheses tested considered differences in substrate use, depth, current velocities, channel width, locations, home range, movement patterns, movement rates, diel movement, grouping of sturgeon, and macrohabitats between pallid and shovelnose sturgeon. Differences in habitat use and movements between telemetered individuals of both species and among seasons were also examined.

STUDY AREA

The study area included about 375 km of the Missouri River from Fort Peck dam in Montana, downstream to the headwaters of Lake Sakakawea in North Dakota as well as the lower 113 km of the Yellowstone River from the Intake diversion dam at Intake, Montana to its confluence with the Missouri River in North Dakota (Figure 1). The Pallid Sturgeon Recovery Plan identifies the study area as a recovery-priority area based on recent records of pallid sturgeon occurrence and the probability that this area provides suitable habitat for pallid sturgeon recovery (Dryer and Sandvol 1993). Hereafter, the confluence of the Yellowstone River and Missouri River will be referred to as the confluence. The overall study area can be divided into three distinct reaches (Tews 1994):

1) The Yellowstone River (river km 0.0 - 113.0). The Yellowstone River is the longest undammed river in the contiguous United States, and its lower reaches represent what is probably the most pristine large prairie river in North America (White and Bramblett 1993), although 31% of its drainage basin area is behind dams (Koch et al. 1977). Discharge, temperature, sediment load and suspended sediment are all higher in the Yellowstone River than in the Missouri River. The mean annual discharge of the Yellowstone River at Sidney, Montana, located about 47 km above the confluence of the Missouri River for 78 years of record (1911 - 1931, 1934 - 1993) is 361 m^3/s (12,760

ft^3/s). The highest instantaneous peak flow on record was 4503 m^3/s (159,000 ft^3/s). The lowest instantaneous low flow on record was 13.3 m^3/s (470 ft^3/s). Water temperatures at this gage ranged from 0.0 °C to 29.0 °C (water years 1951 - 1985). Daily sediment load at this station ranged from 63 to 3,030,000 tons, while suspended sediment ranged from 8 to 26,800 mg/L (water years 1971 to 1981, 1983 - 1992; U. S. Geological Survey 1993).

The upper part of the study reach has numerous islands, bars, backwaters and chutes; a primarily cobble and gravel substrate; a sinuous to irregular (Kellerhals et al. 1976) channel pattern and an average slope in a representative reach of 0.046% (Koch 1977). At Sidney, Montana, located about 47 km above the confluence of the Missouri River, slope declines and sand replaces gravel as the predominant substrate while islands, bars and lateral channel habitats remain common.

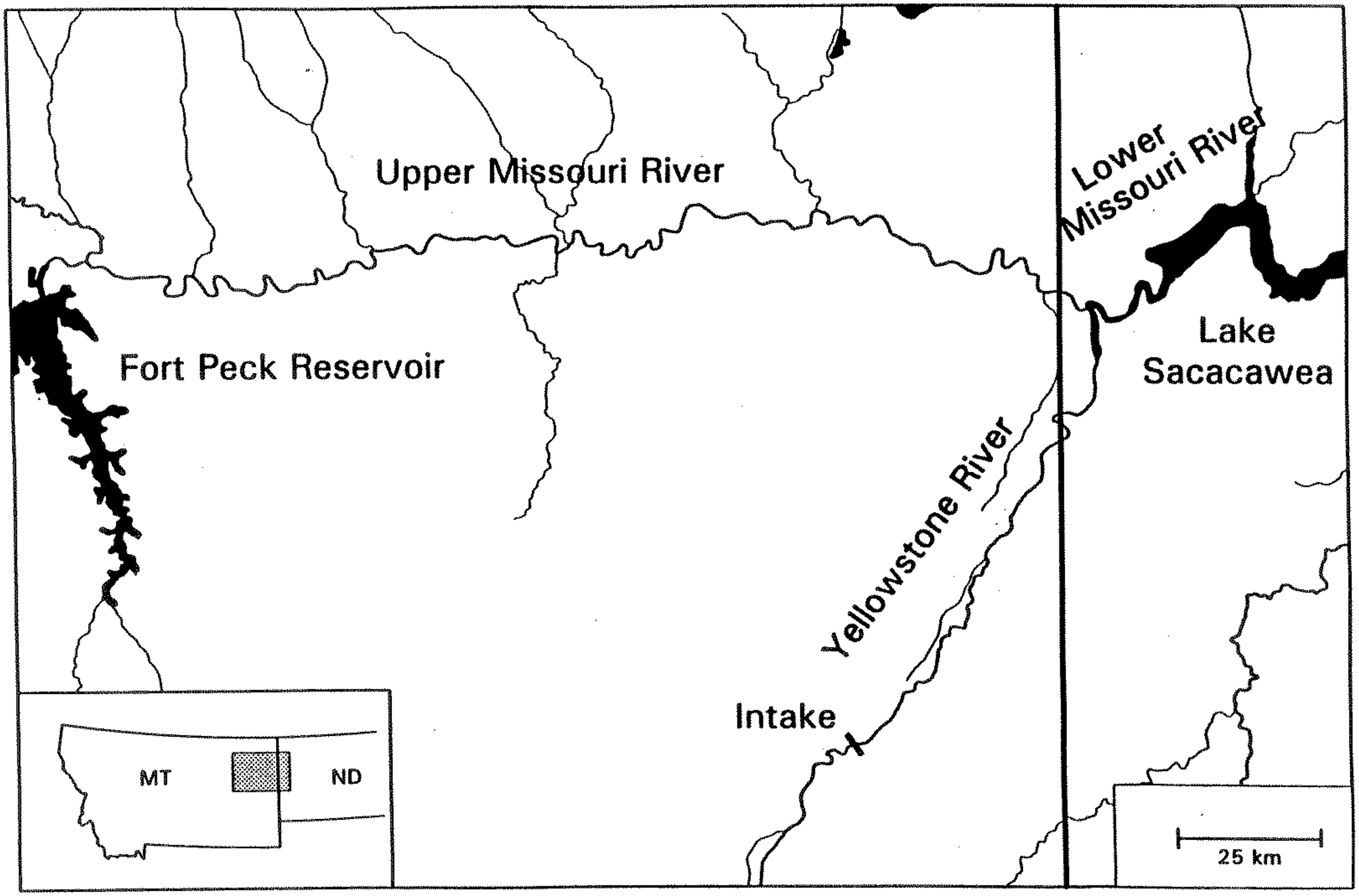

Figure 1. Map of the study area.

2) Upper Missouri River (river km 2545.4 - 2850.5). In contrast to the free-flowing Yellowstone River, the hydrograph, sediment dynamics and temperature regime of this reach of the Missouri River in the study area have been altered by the completion of Fort Peck Dam in 1937 (Gardner and Stewart 1987; Hesse 1987; Latka et al. 1993). Although the Milk and Poplar rivers, entering the Missouri River 17.2 and 140 km below Fort Peck dam, respectively, help restore some of the river's natural character, temperatures are affected for the entire 298 km length of the Missouri River below Fort Peck dam in Montana (Gardner and Stewart 1987).

This reach includes the Fort Peck dam tailrace and dredge cuts, located just below Fort Peck dam. The area is characterized by relatively cold, clear water from the hypolimnetic release, 56.5 m below the surface of the reservoir at full pool (Gardner and Stewart 1987). Because this water carries no suspended sediment, severe bank and bed degradation has occurred in this area. Substrates which were probably formerly primarily sand are now gravel and cobble, and the lack of turbidity allows abundant growth of periphyton. Located 2..6 and 10.0 km below the dam are areas known as the dredge cuts that were deepened by dredging during construction of Fort Peck dam. The dredge cuts are essentially lentic habitats whose level is controlled by the level of the river. Depths in the dredge cuts are generally greater than those found elsewhere in the study area, ranging to about 14 m, and velocities near zero are common (Tews 1994).

The river undergoes a transition from an erosional to a depositional character, although this is due to the impacts of Fort Peck dam rather than natural factors as on the Yellowstone River. Prior to the construction of Fort Peck dam, the entire reach was probably depositional. Substrate in the upper part of the reach is cobble and gravel, while the lower part of the reach is characterized by numerous shifting sand bars (Gardener and Stewart 1987). Gradient is generally lower than that in the Yellowstone River, ranging from 0.011% to 0.028% (Tews 1994).

The mean annual discharge of the Missouri River at Culbertson, Montana, located about 63 km above the confluence of the Yellowstone River for 44 years of record (1941 - 1952, 1958 - 1993; all post-Fort Peck dam) is 291 m^3/s (10,270 ft^3/s). The highest instantaneous peak flow on record was 2215 m^3/s (78,200 ft^3/s). The lowest instantaneous low flow on record was 16.3 m^3/s (575 ft^3/s). Water temperatures at this gage ranged from 0.0 °C to 24.5 °C (water years 1965 - 1979). Daily sediment load at this station ranged from 421 to 147,000 tons, while suspended sediment ranged from 30 to 2,940 mg/L (water years 1972 to 1976; USGS 1993).

3) Lower Missouri River (river km 2475.0 - 2545.4). This reach extends from the confluence of the Yellowstone and Missouri rivers located about 5 km east of the Montana - North Dakota border to the headwaters of Lake Sakakawea. The amount of riverine habitat in this reach varies with the elevation of water in Lake Sakakawea. At full pool (560 m), this reservoir inundates all but about 24 km of the Missouri River. However, because of below full pool water elevations in Lake Sakakawea during this

study, about 50 - 80 km of riverine habitat existed below the confluence of the Yellowstone River (Tews 1994). Due to the influence of the Yellowstone River, the Missouri River regains some of its natural character below the confluence of the two rivers. Sandbars and islands are common, and depths are greater than in the Yellowstone or Upper Missouri Rivers.

METHODS

Capture and Transmitter Attachment

Adult pallid and shovelnose sturgeon were captured by drifting sinking trammel or gill nets. Nets were set perpendicular to the current and drifted for 1 to 42 min, average drift time was about 7 min (Tews 1994). Nets were 1.8 m high by 15 - 37 m long and either mono- or multi-filament gill or trammel nets (Tews 1994; Krentz 1994). One pallid sturgeon was captured by hand by SCUBA divers in a semi-riverine area adjacent to the dredge cuts below Fort Peck dam. Most pallid and shovelnose sturgeon for this study were captured by MDFWP or USFWS biologists; although in 1992, five shovelnose sturgeon were obtained from anglers at the Intake diversion dam on the Yellowstone River. Following capture, sturgeon were weighed, measured, and fitted with transmitters.

A variety of sonic and radio transmitters, either surgically implanted or externally attached were used in this study. All fish received a radio transmitter, and some fish received both radio and sonic transmitters. Surgically implanted transmitters were implanted following the methods of Clancey (1992). The fish were suspended in 6.4 mm netting with their ventral surface up. River water was pumped over the gills with a small bilge pump. Two incisions were made in the ventral body wall: the primary incision about 64 mm long and located about midway along the longitudinal axis of the body; the secondary incision was about 25 mm long and located just anterior of the pelvic fins. The sonic transmitter was inserted first and positioned anterior to the primary incision. Next, the antenna of the radio transmitter was fed into a catheter which was then inserted into the primary incision and pushed posteriorly along the inner body wall until it appeared at the secondary incision. The catheter and antenna were then pulled through the secondary incision while simultaneously inserting the radio transmitter into the primary incision (Ross 1981). About 20 cm of antenna was left trailing from the secondary incision. Both incisions were closed with a series of individual inverted mattress sutures using Ethibond green braided polyester suture material attached to an OS-4 curved cutting needle. The transmitters and all surgical equipment were soaked in Novalsan disinfectant prior to implantation. Following surgery, the fish were held in a live car in quiet water for about 20 min and then released.

The external radio and sonic transmitters were attached to the dorsal fin, following methods used successfully for white sturgeon (Apperson and Anders 1989). Plastic-coated braided stainless steel wires attached to the transmitter were passed through the fleshy base of the dorsal fin. The wires were then passed through holes in a mounting plate cut from a piece of PVC tubing the same size as the transmitter, convex side towards the dorsal fin. The wires were then secured with crimps made from copper tubing. The plastic coating was stripped from the stainless steel wires at the crimps. This allowed the two dissimilar metals to contact each other, therefore the crimps and wires should degrade by electrolysis, allowing the transmitter to detach after an unknown length of time.

Telemetry

Each radio transmitter had a unique frequency between 48.00 and 49.99 Mhz, and each sonic transmitter had a unique pulsed code at 75 kHz. Radio transmitters allowed aerial surveys of the large study area, and sonic transmitters allowed the possibility of relocating fish in water too deep for radio signals to penetrate the water/air interface. An Advanced Telemetry Systems scanning radio receiver and a Sonotronics model USR-91 sonic receiver with a submersible directional hydrophone were used to locate fish.

Telemetered fish were located using a combination of boat and aircraft searches. During May through August 1992, May through November 1993 and May through September 1994, fish were located approximately bi-weekly during aerial surveys of the study area in a single-engine fixed-wing aircraft. Following aerial surveys, observations were made from a 5.3 m aluminum jet boat. During other time periods, fish were located approximately monthly, primarily by MDFWP biologists.

During aerial surveys, a whip-style antenna was attached to the wing strut of the aircraft, and when radio signals were loudest the fish's location was marked on 7.5 minute U. S. Geological Survey (USGS) topographic maps. The precision of aerial relocation was about ± 0.4 km.

Boat surveys proceeded in a downstream direction. This allowed a quiet approach by drifting over sturgeon rather than motoring up into radio range from downstream. Sturgeon relocations made from the boat were done by first detecting the radio signal with a whip-style antenna. Range of radio reception varied with depths of fish and conductivity of the water. The deeper the fish and the higher the conductivity, the shorter the range of reception. The radio signal was generally initially received with the whip antenna at a range of 400 to 600 m or more.

Once a radio signal was detected, one of two methods of determining the fish's location was used, depending on if the fish had both sonic and radio transmitters or just a radio transmitter. For those fish with radio transmitters only, locations were determined by triangulating the radio signal from shore with a directional loop antenna. Surveyor's pin flags were placed to define two intersecting lines that were then sighted from the river and the boat was maneuvered over the fish's location. Blind tests with dummy transmitters placed in the river showed this technique to be accurate to within about 3 m of the actual location, which is about the same as the boat's maneuvering error.

For those fish with both radio and sonic receivers, the directional loop antenna was used to determine the fish's position in the channel cross section while drifting downstream from above the fish. The boat was maneuvered to drift directly over the fish, and the motor was turned off. The loop antenna could generally receive the radio signal from distances less than about 400 m. The sonic signal was usually detectable at about 100 m and was quite directional. As the boat drifted over the fish, the signal became omnidirectional when within about a 10 m diameter area. When the location of the fish was determined, it was marked with a float. This location was then confirmed by triangulating the radio signal.

When a fish's location had been determined, it was monitored for 10 min to determine if it was moving or not by using the radio receiver and directional loop antenna. If the fish did not move for 10 min it was classified as non-moving. If the fish moved during the 10 min period, it was classified as moving.

Sampling Design

To avoid bias, and to provide good coverage of samples in time and space, a random sampling scheme was followed for gathering data. The study area was divided into six units, approximately centered on boat ramp facilities. The units were about 32 km in length.

Two types of sampling activities were conducted: 1) Daily sampling involved making relocations and habitat use observations on all fish in a selected unit. Two sampling periods were established; early morning to afternoon and midday to dusk, and two directions of travel (upstream or downstream) were possible. Following relocation flights, the units containing telemetered fish were listed. Then the unit, sampling period, and direction of initial travel were chosen randomly without replacement. All data collected during daily sampling were considered independent for subsequent analysis. 2) Diel sampling consisted of monitoring a single fish's movements and habitat use for a period of 10 to 12 or more hours during daylight hours or overnight. A sampling unit, direction of travel and time period were randomly selected, a fish was located, and this fish was relocated at least hourly during the diel sampling period. On some occasions, due to their proximity, observations were made on more than one fish during a diel sampling period. If a fish moved out of range at night, it was not relocated until the next morning due to the difficulty of navigating after dark.

Locations

Once a fish's location was determined, date and time of day was recorded, and habitat was characterized at the site. The latitude and longitude of the location was determined with a Magellan portable Global Positioning System (GPS) unit. The center of the river was digitized and geo-referenced using USGS 7.5 minute topographic maps. A computer program was used to place the latitude and longitude of fish locations on this line and to calculate the river km of fish locations.

Water Chemistry, Temperature and Discharge

Water chemistry variables were usually measured along the bank near the fish's location because strong current often prevented anchoring the boat in midchannel. These variables were found to be homogeneous with respect to channel cross section location. Water temperature was measured with a hand-held thermometer. Dissolved oxygen was measured with an Otterbine Sentry III meter, and conductivity was measured with a VWR automatic temperature compensated digital conductivity meter. Secchi disc transparency was measured with a Secchi disc attached to a calibrated rod.

Submersible miniature temperature recorders were used in three locations in the study area in May through November in 1993 and 1994. One temperature logger was placed in the Yellowstone River about 1 km above the confluence (this station will be referred to as the Lower Yellowstone River Station) and one temperature logger was placed in the Upper Missouri River (Upper Missouri River Station) about 2 km above the confluence. The third temperature logger was placed in the Lower Missouri River (Lower Missouri River Station) about 47 km below the confluence. Additional temperature data were obtained from a Montana Department of Fish, Wildlife, and Parks temperature chart recorder in the Yellowstone River about 112 km above the confluence (Upper Yellowstone River Station).

Discharge data were obtained from USGS streamflow gaging stations. Discharge on the Yellowstone River was obtained from a gaging station near Sidney, Montana. Discharge on the Upper Missouri River was obtained from a gaging station near Culbertson, Montana.

<u>Substrate</u>

The substrate at the fish's location was determined by feeling with probes made from 3 m-long steel conduits. Turbid water and/or depth usually prevented visual examination of substrates. Substrates were classed as fines and sand (0 - 4 mm); gravel (5 mm - 75 mm) and cobble (76 mm - 300 mm); boulder and bedrock (>300 mm). Blind tests with the probe over known substrates showed that pure cobble and cobble/gravel mixtures were not distinguishable, so these two classes were combined. Additionally, we discovered that much of the sand substrate in the study area existed as sand "dunes". Therefore, in 1993 and 1994, sand substrates with dunes at least 0.3 m high were classed as sand dunes.

The relative proportions of substrate classes available in the Yellowstone River and Lower Missouri River were estimated by taking substrate measurements at 1273 randomly selected points in 1993 and 1994. Location of substrate measurement points was determined by a random sampling scheme that involved randomly choosing X and Y coordinates with replacement on the plan view of the river channel during daily sampling activities. As the boat proceeded downstream, distance downstream (Y-coordinate) was determined by randomly choosing a time from 1-10 min travel time. A relative distance across the channel (X-coordinate) was determined by randomly choosing a number between 1-9 that indicated a position in the channel cross-section that corresponded to 0.10 of channel width at the chosen Y-coordinate (0 was left bank, 10 was right bank). The latitude and longitude of each random point was also recorded which allowed for estimates of substrate availability for specific river reaches.

Depth and Channel Width

Depth at the fish's location was measured with an Eagle Mach 2 recording depth finder. A cross section of the channel at the fish's location was produced by running a transect perpendicular to the direction of the current while recording the bottom profile with the depth finder. Channel width was estimated with a Ranging MK5 rangefinder. The fish's location along the cross section was marked on the chart paper by pressing the recorder's mark button. The depth of the river at the fish's location as well as the maximum depth of the channel in the cross section was recorded. Relative depth was then calculated by dividing the depth at the fish's location by the maximum depth of the channel in the cross-section. Because both pallid sturgeon and shovelnose sturgeon have morphological adaptations for a benthic existence, fish were assumed to be on the bottom of the river.

Current Velocity

Surface, mean column, and bottom current velocity was measured at the fish's location. Mean column velocity was calculated as the mean of current velocities measured at 0.2 and 0.6 total depth. Triplicate measures were taken at each level, and the mean of these three measures used for comparisons. Current velocities were measured with a Marsh-McBirney Model 201 portable meter with the velocity probe and a 6.8 kg lead weight mounted to a cable suspension system, or a General Oceanics Model 2030R velocity meter. Although sturgeon were assumed to be on the bottom of the river, surface and mean column velocities were also measured and are presented here for ease of comparison to other studies that lack bottom velocity data.

Channel Pattern and Islands and Bars

Locations used by pallid and shovelnose sturgeon were characterized by classifying the channel pattern of the reach within about 0.5 km upstream and downstream of the fish's location according to categories described by Kellerhals et al. (1976). Channel patterns were defined as: 1) straight - very little curvature within reach; 2) sinuous - slight curvature with a total lateral extent of meandering of less than about two channel widths; 3) irregular - occasional curves with a belt width of less than about two channel widths; and 4) irregular meanders - increased curves with a vaguely repeated pattern present.

The presence of islands and alluvial bars within two channel widths of the fish's location was also recorded. Alluvial bars are less stable than islands, are frequently located along sides of the channel, are at elevations lower than the valley floor, and are often not vegetated or have vegetation characteristic of an earlier sere than islands. In contrast, islands are relatively stable, usually vegetated features at or near the same elevation as the valley floor.

The type of alluvial bar was classified according the scheme of Kellerhals et al. (1976). Categories of bars were: 1) channel side bars; 2) channel junction bars; 3) point bars; and 4) midchannel bars. At locations with an island or alluvial bar, the successional stage was classed as: 1) bare or pioneer (grass, forbs, seedling willows or cottonwoods); 2) willow/cottonwood thicket; 3) young cottonwood forest; or 4) mature cottonwood gallery forest or later sere. A location was classified as both island and alluvial bar if both were present.

Finally, the river geomorphic condition within two channel widths of the fish's position was characterized as: 1) run - a straight reach; or 2) curve - a reach within two channel widths of the curve's maximum bend.

Island Density Use and Availability

Aerial photos and USGS 7.5 minute topographic maps were used to characterize the Lower Missouri River and the Yellowstone River in terms of island density (Kellerhals et al. 1976). Because islands cause more than one flow channel and create a diversity of depths and current velocities, island density was used as a measure of habitat complexity. Islands were defined as relatively stable, usually vegetated features at or near the same elevation as the valley floor (Kellerhals et al. 1976). Reaches were classified using the following categories: 1) none - no islands; 2) single - a single island, no overlapping of islands; 3) frequent - occasional overlapping of islands, with average spacing between islands less than 10 river widths; and 4) split channel - islands overlap other islands frequently or continuously, the number of flow channels is usually two or three.

Reaches ≥ 0.5 km from an island were classified as island density category 1. Reaches with islands (categories 2 - 4) were defined as lengths of river ≤ 0.5 km from an island. If islands in a reach overlapped or were spaced ≤ 0.5 apart, the reach was classed according to island density as listed above.

The center of the river was digitized and geo-referenced using USGS 7.5 minute topographic maps. The Universal Transverse Mercator (UTM) coordinates for the beginning and ending of each reach were recorded. A computer program was used to calculate the river km from the UTM's. The length of each reach was then calculated from the river km data.

Aerial photographs of the river taken in August, 1993 were used to verify and adjust the locations of reaches shown on the USGS maps. The Lower Missouri River from the US Highway 85 bridge near Williston, North Dakota, and the Yellowstone River from the confluence to the diversion structure on the Yellowstone River at Intake, Montana was classified. The Missouri River below the Highway 85 bridge did not fit this classification because it is a delta-like area mostly inundated by Lake Sakakawea at full pool. Also, only two fish were located in this area over the course of the study. The Missouri River above the confluence of the Yellowstone River was also rarely used and so was not included. Alluvial bars were not estimated because their number and magnitude varied with discharge which differed between when the fish were located and when the photographs were taken.

Only those locations made on the river with latitude and longitude recorded from the GPS unit were used in calculating use of island density categories. Since the accuracy of GPS locations is about 90 m, no location within 90 m of an island density category reach edge was used. Aerial locations were not used because the unknown accuracy of the location generates an unknown potential for misclassification with respect to island density category.

DATA ANALYSIS

In telemetry studies, individual animals are sampled over time. Because the sample size is a function of the frequency of sampling, sample sizes can be artificially inflated by increasing the frequency of sampling. This is a concern particularly when data are collected intensively, as occurs when monitoring diel activity, movements and habitat use (White and Garrott 1992), and bring into question independence of such data. In this study, data collected during daily sampling are considered independent. However, because diel sampling consisted of repeated observations of an individual fish over a relatively short period of time, data collected in this manner were not considered independent. Therefore, for analysis, daily sampling data were combined with one randomly selected data point per diel sampling period per fish. These data are referred to in the text as independent observations and are used for depth, velocity, substrate, macrohabitat and overall movement analyses. In contrast, all observations, including those from diel sampling, were used for analyses of diel activity patterns, for hourly movement rates, and for reporting overall ranges of depth and velocities used by pallid and shovelnose sturgeon.

In the dynamic environment of a large river, microhabitat features such as depth and velocity are expected to vary with discharge. Selection of these habitat variables by pallid and shovelnose sturgeon involved choosing among the range of depths and velocities available over the individual fish's home range. In order to demonstrate preference or choice by an individual sturgeon, the use of certain depths or velocities must be compared to the availability of those depths or velocities at the same time that the use is documented (Seibel and Kynard MS). Since the home range of pallid and shovelnose sturgeon may be in excess of 200 km of river, it is not feasible to measure use and availability of depth and velocity at the same time over such a large area. Moreover, to adequately describe the relative frequencies of depth and velocity over such a large area, even given stable flow conditions, would require an effort beyond the scope of this study. Therefore, only use and not preference for these microhabitat variables will be described.

When comparing depths, channel widths and current velocities at pallid and shovelnose sturgeon locations, first the normality of the data set was tested using the Komolgorov-Smirnov Test (Neter et al. 1993). If the Komolgorov-Smirnov test failed to reject the hypothesis that the data were normal, the t-test was used to test if means were significant different. In contrast, if the Komolgorov-Smirnov test rejected the hypothesis that the data were normal, the Mann-Whitney U test was used to test if the medians were significantly different.

Water Temperatures

Minimum, maximum and median daily temperatures for the four thermograph stations were tabulated. The sign test (Neter et al. 1993) was used to compare daily temperatures from all combinations of stations within each year to determine which stations had warmer or cooler water temperatures. The sign test computes the percentage of times that the value of the first variable is larger than the value of second variable, and compares this percentage to 50% under the null hypothesis. Because the different stations differed in coverage of temperatures through time, only temperatures measured on the same day were compared between stations.

Substrate

The hypothesis that substrate use by pallid and shovelnose sturgeon did not differ was tested with Pearson's χ^2 test. Because individual sturgeon had widely varying numbers of substrate observations, three separate random samples of substrate use consisting of one observation per individual fish were drawn without replacement for both species. Although this resulted in a smaller sample size and consequent reduction of power, by using only one observation per individual potential bias from individual fish with different substrate preferences and/or larger numbers of observations was eliminated.

The hypothesis that pallid and shovelnose sturgeon use substrate types in proportion to their availability was tested by using a χ^2 technique for availability estimates generated by random points (Marcum and Loftsgaarden 1977). This technique first tests the hypothesis that overall use is proportional to availability. If a significant result is obtained, confidence intervals are constructed for each resource category. If a confidence interval contains zero, the resource is used in proportion to its availability. If a confidence interval is positive, the resource class is preferred, and if it is negative the resource class is avoided. A necessary assumption is that the relative proportions of substrate available is constant. This assumption was checked by comparing estimates of substrate relative proportions from 1993 and 1994.

Substrate use by pallid and shovelnose sturgeon was compared to the estimated availability of substrates in that species' home range. The assumption that all individuals of each species has the same substrate preferences is necessary when grouping all observations for that species together for statistical testing. For example, an individual fish with a large number of observations coupled with a strict substrate preference may alter the results of the test. This assumption was checked by comparing the results of the χ^2 test from the grouped sample to the results of χ^2 tests using three random sub-samples with equal contribution from each fish. If the results from the grouped and χ^2 tests are different, the assumption that all individuals of the species have the same substrate preferences is not founded.

Depth and Channel Width

Two approaches were used in comparing depths, maximum depths, and relative depths used by pallid and shovelnose sturgeon. The first approach involved comparing overall depths used by pallid and shovelnose sturgeon.

The second approach used an analysis of variance (ANOVA) to simultaneously test the following a priori hypotheses: 1) mean depths, maximum depths, and relative depths used by pallid sturgeon and shovelnose sturgeon were not different; 2) mean depths, maximum depths, and relative depths used by pallid and shovelnose sturgeon in the Yellowstone River were not different from those used in the Lower Missouri River; 3) the difference in mean depths, maximum depths, and relative depths between shovelnose and pallid sturgeon is the same in the Lower Missouri River and the Yellowstone River (no interaction between species and rivers); 4) Variance of mean depths, maximum depths, and relative depths used by individual fish of each species in each river is equal to zero. The linear statistical model for depth, maximum depth, and relative depth was:

$$Y_{l(ijk)} = \mu + S_i + R_j + (SR)_{ij} + I(SR)_{k(ij)} + E_{l(ijk)} \quad (1)$$

$$i = 2$$

$$j = 2$$

$$\sum k(ij) = 62$$

$$1 \leq (ijk) \leq 18$$

where Si is the effect of the ith species, Rj is the effect of the jth river, (SR)ij is the effect of the species by river interaction, $I(SR)_{k(ij)}$ is the effect of the individual fish within the species by river combination, and $E_{l(ijk)}$ is the residual error term. The species (pallid or shovelnose sturgeon) and the rivers (Yellowstone or Lower Missouri Rivers) were treated as fixed effects. The individual fish was treated as a random effect, nested within one of the four species and river combinations. The residuals were tested for normality using the Wilks-Shapiro test and checked for outliers by producing boxplots.

The utility of including other variables in the linear model was checked by plotting residuals versus the values of the variables. If a pattern was apparent in the plot, the variable was included in the model. Variables checked in this manner were discharge, month and year, water temperature, hours before and after sunrise and sunset, diel category, substrate type, river kilometer (location), and Secchi disk reading. Because of small sample size, data for the Upper Missouri River were not included in the model.

Current velocity

As with depth, two approaches were used in comparing means of surface, mean column, and bottom current velocities used by pallid and shovelnose sturgeon. The first approach compared overall current velocities use by the two species.

The second approach used an ANOVA to simultaneously test the following a priori hypotheses: 1) means of surface, mean column, and bottom velocities used by pallid sturgeon and shovelnose sturgeon were not different; 2) means of surface, mean column, and bottom velocities used by pallid and shovelnose sturgeon in the Lower Missouri River and the Yellowstone River were not different; 3) the difference in means of surface, mean column, and bottom velocities between shovelnose and pallid sturgeon is the same in the Lower Missouri River and the Yellowstone River (no interaction between species and rivers) 4) Variance of means of surface, mean column, and bottom velocities used by individual fish of each species in each river is equal to zero. The linear statistical model for surface, mean column and bottom velocities was:

$$Y_{l(ijk)} = \mu + S_i + R_j + (SR)_{ij} + I(SR)_{k(ij)} + E_{l(ijk)} \qquad (2)$$

$$i = 2$$

$$j = 2$$

$$\sum k(ij) = 62$$

$$1 \leq (ijk) \leq 18$$

where S_i is the effect of the ith species, R_j is the effect of the jth river, $(SR)_{ij}$ is the effect of the species by river interaction, $I(SR)_{k(ij)}$ is the effect of the individual fish within the species by river combination, and $E_{l(ijk)}$ is the residual error term. The species (pallid or shovelnose sturgeon) and the rivers (Yellowstone or Lower Missouri Rivers) were treated as fixed effects. The individual fish was treated as a random effect, nested within one of the four species and river combinations. The residuals were tested for normality using the Wilks-Shapiro test and checked for outliers by producing boxplots. As with depth, the utility of including other variables in the linear model was checked by plotting residuals versus the values of the variables and looking for patterns. If patterns were apparent the variable was included in the model. Because of small sample size, data for the Upper Missouri River were not included in the model.

General Distribution, Home range, Diel Activity, and Movement

River kilometer of fish locations in the Yellowstone and Lower Missouri rivers were sorted into 2 km reaches and separated by season and species. Histograms were made from these data and general distributions and seasonal use were identified from the histograms. This allows identification of areas used with high frequency by pallid and shovelnose sturgeon regardless of capture location and the year in which observations were made.

To identify areas of high use temporally and spatially, aggregations of telemetered pallid and shovelnose sturgeon were identified. Aggregations were defined as more than 3 telemetered pallid or shovelnose sturgeon occupying the same 1 km reach of river on the same day. By identifying aggregations temporally, periods when pallid and shovelnose sturgeon tend to aggregate can be identified. By identifying aggregations during the presumed spawning season for pallid and shovelnose sturgeon, potential spawning locations can be identified. Aggregations are presented graphically and in tabular form.

Overall home range in kilometers was calculated by subtracting the fish's uppermost location from the fish's lowermost location. In cases where individual fish were found in the Upper Missouri River, in addition to the Lower Missouri River and/or the Yellowstone River, this segment was added to the range. Home range was also calculated for each species by season, i.e. summer = June 21 - September 22; fall =

September 23 - December 20; winter = December 21 - March 19; spring = March 20 - June 20. A Kruskal-Wallis ANOVA was used to test for differences among median seasonal ranges within species. Dunn's nonparametric multiple comparison test was used to test which seasonal home ranges were significantly different from each other. Mann-Whitney U tests were used to test for differences between median seasonal ranges between species.

Days at large was the length of time between the capture of the fish and the last relocation or until I determined that the fish had lost its transmitter. Relocations were usually attained by telemetry; however, in two cases, pallid sturgeon were captured and not radio-tagged but were later recaptured and radio-tagged at that time. Also, on one occasion a pallid sturgeon was recaptured after losing its radio transmitter. In these three cases, location and date from the captures was added to the telemetry data.

Diel activity patterns were assessed by tabulating the times when fish were observed and whether the fish was moving or not moving. This information was obtained from both daily and diel sampling activities. Sunset and sunrise tables for Williston, North Dakota were used to place the time of observation relative to sunrise and sunset. Four diel categories were established: 1) Day = ≥1 h after sunrise until ≤ 1 h before sunset; 2) Dusk = < 1 h before sunset until < one h after sunset; 3) Dark = ≥ 1 h after sunset until ≥ 1 h before sunrise; 4) Dawn = < 1 h before sunrise until < 1 h after sunrise.

The proportion of observations that were from moving fish was calculated for each diel category for pallid and shovelnose sturgeon. In addition, to examine individual variability of diel movements, the proportion of observations that were from moving fish was calculated for the three individual fish of each species with the most observations.

Direction and rate of fish movements were calculated by subtracting the river kilometer of a location from the previous location and dividing by the time between the locations. When the time elapsed between locations was greater than 24 h, movement rate was calculated as km/d. When the time elapsed between locations was less than 24 h, movement rate was calculated as km/h. Because additional movement may have occurred between locations, calculated movement rates represent the minimum movement for the time period between locations.

The Mann-Whitney U test was used to test hypotheses that the median movement rates were the same between species and between upstream and downstream movements within species. Kruskal-Wallis ANOVA was used to test the hypotheses that movement rates were the same for each season within species, followed by Dunn's multiple comparison test.

Clustering

An analysis of the degree of "clustering" or use of common reaches of river during the different seasons was performed to determine if pallid and shovelnose sturgeon were more closely associated in some seasons relative to others. First, individual fish were separated into "batches", i.e. groups of fish of the same species that were captured in the same general area (a reach of river from 1 km to about 30 km long) at about the same time (up to 21 d from first to the last capture). By forming batches, the effect of widely separated capture locations is controlled. Three batches of pallid sturgeon with five to seven individuals each were formed. Six batches of shovelnose sturgeon with two to seven individuals each were formed.

Locations (river km) of individual fish were then separated by season and batch. The mean river km location of each individual for each season was calculated. Locations from the Upper Missouri River were not used in this calculation because this would introduce a third dimension to the data. If fish in a batch are widely dispersed during a season, the variance of mean river location will be relatively large. Conversely, if fish in a batch are clustered during a season, the variance of mean river location will be relatively small. The hypothesis that fish in each batch had the same degree of clustering in each season was tested by testing for homogeneity of variance among batches using Bartlett's χ^2 Test.

Movement into the Yellowstone River and the Lower Missouri River

The number of observations of fish passing upstream from the Lower Missouri River into the Yellowstone River or Upper Missouri River were tabulated. Preference for entering the Yellowstone River or the Upper Missouri River was tested by Pearson's χ^2 observed versus expected analysis. Median discharges on the Yellowstone River and the

Upper Missouri River during periods when telemetered pallid and shovelnose sturgeon passed the confluence were compared with the Mann-Whitney U test.

Movement Regression Models

Linear regression models were constructed for movements of 24 individual pallid sturgeon and 22 individual shovelnose sturgeon. River kilometer was the response variable and predictor variables were discharge and photoperiod.

Discharge data from the USGS gaging station on the Yellowstone River near Sidney, Montana were used for locations on the Yellowstone River. Discharge data from the USGS gaging station on the Missouri River near Culbertson, Montana were used for locations on the Upper Missouri River. Since no large tributaries enter the Missouri or Yellowstone rivers below these gages, discharge in the Lower Missouri River is essentially equal to the discharge at Sidney plus the discharge at Culbertson. However, the Sidney and Culbertson gages are 47 km and 62 km above the confluence, respectively. Therefore, discharge in the Lower Missouri River was calculated as discharge at Sidney the previous day plus discharge at Culbertson the previous day. Photoperiod was calculated from a table with sunrise and sunset times for Williston, North Dakota (U. S. Navy 1977).

Models were constructed for river kilometers of each fish using discharge alone, photoperiod alone, and both discharge and photoperiod. Since discharge was different in the three river segments (Yellowstone River, upper and Lower Missouri River) separate parameter coefficients were calculated for each segment that an individual fish was located in. Photoperiod models had only one parameter estimate. Sign (positive or negative) of parameter coefficients indicate if locations predicted from the model are farther upstream or downstream as the magnitude of dependent variables increase. Sign and magnitude of parameter coefficients and coefficients of simple determination (r^2) were compared between individual fish, species and model. Because a complete data set of river temperatures was not available, models using water temperature as the predictor variable were not constructed.

These linear regression models were constructed as an exploratory data analysis tool to identify potential environmental cues for movements of pallid and shovelnose sturgeon. Hypothesis testing and confidence intervals based on these models are statistically invalid because the assumptions of independence with respect to responses and errors are clearly violated.

Island Density Use Versus Availability

Preference of island density categories was examined by using Pearson's χ^2 analysis (Nue et al. 1974). Two general hypotheses were tested: 1) use of island density categories occurs in proportion to availability, considering all categories simultaneously, and 2) use of island density categories occurs in proportion to availability, considering each category separately.

Use of island density categories by pallid and shovelnose sturgeon was estimated by calculating the proportion of independent observations in each island density category. Use was calculated for each species with all observations pooled, as well as separated by season (spring and summer only).

Availability was calculated according to the hypothesis being tested. For example when testing for preference for all pallid sturgeon pooled together, availability of island density categories for the entire pallid sturgeon range was used. When testing preference for an individual fish, only the reaches in that individual's home range were used for availability.

Individual variation in preference of island density categories was examined by testing preference of individual fish. Thirteen individual pallid sturgeon with $N \geq 10$ observations and 9 shovelnose sturgeon with $N \geq 8$ observations were tested. In addition, random samples of one and two observations from each individual fish were taken to examine the effects of many observations from few individuals on the pooled results. If the results of testing the random samples agree with results from the pooled samples, there is little individual variation.

RESULTS

Twenty four pallid sturgeon and 27 shovelnose sturgeon were captured and equipped with radio or radio and sonic transmitters (Tables 1 and 2). Fork length range was from 1151 to 1600 mm and from 581 to 947 mm for pallid and shovelnose sturgeon, respectively (Figure 2). Pallid sturgeon weight range was from 10.7 to 28.2 kg, while shovelnose sturgeon weight ranged from 0.8 to 4.2 kg.

Because the sex of pallid and shovelnose sturgeon cannot be determined externally, the sex of most of the telemetered fish was unknown. However, the presence of eggs was observed in seven shovelnose sturgeon that had transmitters surgically implanted (Table 2). Also, one telemetered pallid sturgeon was observed to be extruding eggs when it was snagged by a paddlefish (*Polyodon spathula*) angler (Table 1).

Table 1. Statistics of pallid sturgeon captured and radio tagged in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994.

Radio frequency	Date of capture	Capture location (river km)[a]	Radio transmitter weight (g) type[b]	Sonic transmitter weight (g) type[b]	Weight (kg)	TL	FL
48.520	9/30/92	2531.3	14.0 A		10.70	1349	1242
48.540	9/15/92	2523.2	14.0 A		24.50	1702	1600
48.562	5/21/94	108.0	12.7 A		18.8	1489[c]	1384
48.570	5/21/93	114.2	14.0 A			1245	1151[d]
48.580	4/15/93	2520.0	14.0 A	28.0 A	13.85	1470	1385
49.020	10/19/92	2531.3	14.0 A		16.10	1453	1366
49.030[e]	4/23/93	2.7	56.0 A		28.15	1650	1566
49.050	9/30/92	2531.3	56.0 A	88.0 A	22.20	1646	1524
49.070	10/19/92	2531.3	14.0 A		16.60	1529	1402
49.100	6/17/92	9.1	56.0 A	88.0 A	12.70	1435	1336
49.130	10/19/92	2531.3	14.0 A		10.80	1384	1308
49.170	10/21/92	2520.0	14.0 A		19.30	1585	1486
49.240	9/16/93	2542.5	32.5 A		10.80	1400	1292
49.350	4/30/94	21.2	35.0 A		17.24	1511[c]	1405
49.370	9/28/93	2531.3	33.7 A		15.90	1428	1325
49.630	9/29/93	2531.3	34.4 A		14.50	1519	1400
49.650	9/28/93	2531.3	34.1 A		16.80	1545	1430
49.670	4/24/93	3.2	35.0 C	28.0 C	14.53	1570	1365
49.680	4/10/92	2523.2	128.0 B	56.0 C	22.20	1021	945
49.712	9/28/93	2531.3	36.8 A		20.60	1635	1525
49.810	4/22/93	2.7	19.0 A		14.98	1470	1373
49.830	4/15/93	2520.0	19.0 A	28.0 A	20.20	1620	1514
49.850	9/14/93	2532.9	19.0 A		17.50	1540	1410
49.870	3/20/93	2847.9	19.0 A	28.0 A	17.68	1631	1524

[a] River kilometers 0 - 114.2 are on the Yellowstone River; 2520 - 2545.4 are on the Lower Missouri River; and 2545.4 - 2850.5 are on the Upper Missouri River.

[b] Type A transmitter: External attached to base of dorsal fin; Type B transmitter: Internal with protruding antenna; Type C transmitter: Internal.

[c] Total length calculated from TL = (FL + 47.59)/1.04 (Keenlyne and Maxwell 1993).

[d] Fork length calculated from FL = (TL - 47.59)/1.04 (Keenlyne and Maxwell 1993).

[e] This individual was known to be female because it was observed to be running eggs after being captured by an angler (Steve Krentz; USFWS Personal Communication).

Table 2. Statistics of shovelnose sturgeon captured and radio or sonic tagged in the Yellowstone and Missouri rivers in Montana and North Dakota, 1991-1994.

Radio frequency	Date of capture	Capture location (river km)	Radio transmitter weight (g) type[a]	Sonic transmitter weight (g) type[a]	Weight (kg)	TL	FL
3335	7/30/91	2847.9		28.0 C	0.77	640	581[b]
48.280	5/20/94	24.9	16.0 A		1.33	744	678
48.300	5/20/94	24.9	16.0 A		1.56	799	730
48.320	5/20/94	24.9	16 A		1.76	828	749
338	7/31/91	2847.9		28.0 C	0.95		
48.340	5/20/94	24.9	16.0 A		1.53	776	699
48.360	5/20/94	24.9	16.0 A		2.44	888	806
48.380	5/20/94	24.9	16.0 A		2.07	862	781
48.550	5/27/93	12.3	14.0		2.36	851	777
48.560	8/6/91	111.0	14.0	28.0	2.91	869	797[b]
48.590	6/9/93	7.0	12.7			940	833
48.600	8/6/91	111.0	34.0	28.0	3.09	919	844[b]
48.620	8/7/91	111.0	34.0	28.0	3.40	927	852[b]
48.640	8/7/91	111.0	34.0	28.0	3.09	914	840[b]
48.660	8/8/91	2532.9	34.0	28.0	3.09	917	842[b]
48.680	10/9/91	2536.1	34.0	28.0		919	823
48.740	8/8/91	2534.5	12.0	28.0	1.77	856	785[b]
48.760	9/4/91	2540.1	12.0	28.0	2.63	940	861
48.820[c]	6/2/92	114.2	40.0	28.0	3.04	894	825
48.840[c]	6/1/92	114.2	40.0	28.0	3.49	1021	945
48.860[c]	6/2/92	107.8	40.0	28.0	3.20	860	823
48.880[c]	6/3/92	114.2	40.0	28.0	3.78	910	878
48.900[c]	6/3/92	114.2	40.0	28.0	3.46	940	873
48.920[c]	6/1/92	114.2	40.0	28.0	4.20	1039	947
48.940[c]	6/8/92	114.2	40.0	28.0	2.90	868	803
49.710	9/28/92	2544.1	36.8		2.30	894	820
49.790	9/28/92	2544.1	36.8		2.70	856	787

[a] Type A transmitter: External attached to base of dorsal fin; Type B transmitter: Internal with protruding antenna; Type C transmitter: Internal.
[b] Fork length calculated from FL = (TL - 24.02)/1.06 (Moos 1978).

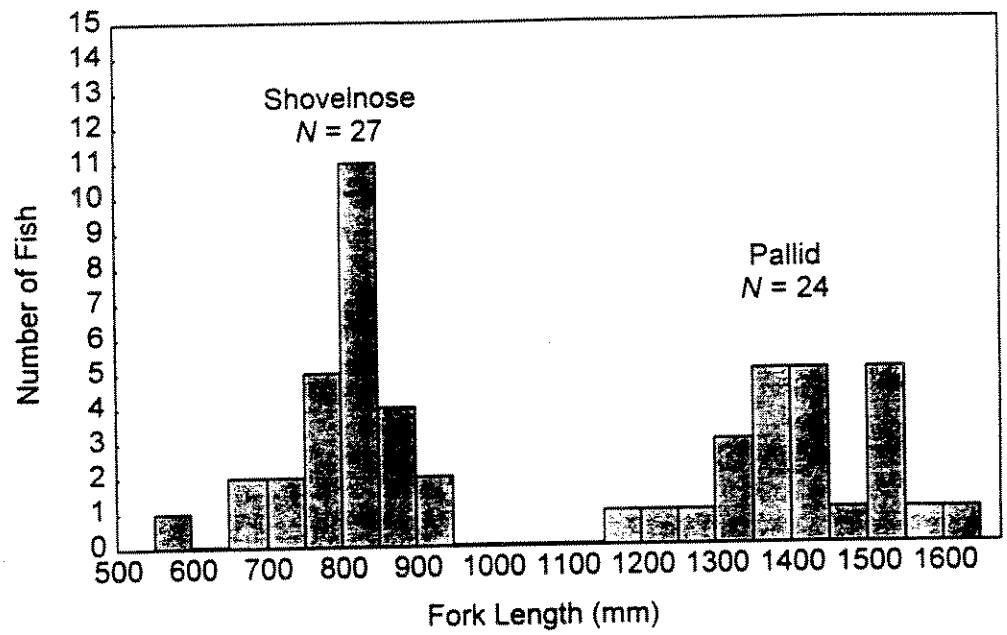

Figure 2. Fork lengths of pallid and shovelnose sturgeon telemetered in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994.

Water Chemistry and Temperature

Water chemistry was similar at locations of both species (Table 3). Water temperature at pallid sturgeon locations ranged from 3.0 to 26.0 °C compared to 3.0 to 27.0 °C at shovelnose sturgeon locations. Dissolved oxygen was similar at locations of both species; the mean at pallid sturgeon locations was 8.7 mg/L while the mean at shovelnose sturgeon locations was 9.0 mg/L. Mean conductivity was also similar; 526 umhos at pallid sturgeon locations and 536 umhos at shovelnose sturgeon locations. Secchi disk transparency was likewise similar; the mean at pallid sturgeon locations was 20 cm and the mean at shovelnose sturgeon locations was 27 cm.

Table 3. Water chemistry parameters and temperatures measured at locations of pallid and shovelnose sturgeon in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994.

	Water temperature (°C)	Dissolved oxygen (mg/L)	Conductivity (micromhos)	Secchi disk transparency (cm)
Pallid sturgeon				
Mean	15.8	8.7	526	20
Median	18.0	8.5	550	9
Minimum	3.0	7.0	67	1
Maximum	26.0	12.0	880	204
N	159	72	119	115
Shovelnose sturgeon				
Mean	18.5	9.0	536	27
Median	20.0	8.6	545	22
Minimum	3.0	7.4	287	1
Maximum	27.0	11.1	903	>100
N	144	47	81	65

Although ranks of daily water temperatures varied among thermograph stations (Figure 3), the sign test found significant differences among the four stations (Table 4, Figure 4). Temperatures in the Yellowstone River were generally higher than in the Missouri River. The Lower Yellowstone River Station had significantly higher maximum, minimum and median temperatures than the Lower Missouri River Station in both 1993 and 1994. The Lower Yellowstone River Station also had significantly higher maximum, minimum, and median temperatures than the Lower Missouri River Station in 1994. In 1994, all temperatures at the Lower Yellowstone River Station were higher than those at the Lower Missouri River Station, except for 3.18% of minimum temperatures. The Upper Missouri River Station thermograph was lost in 1994.

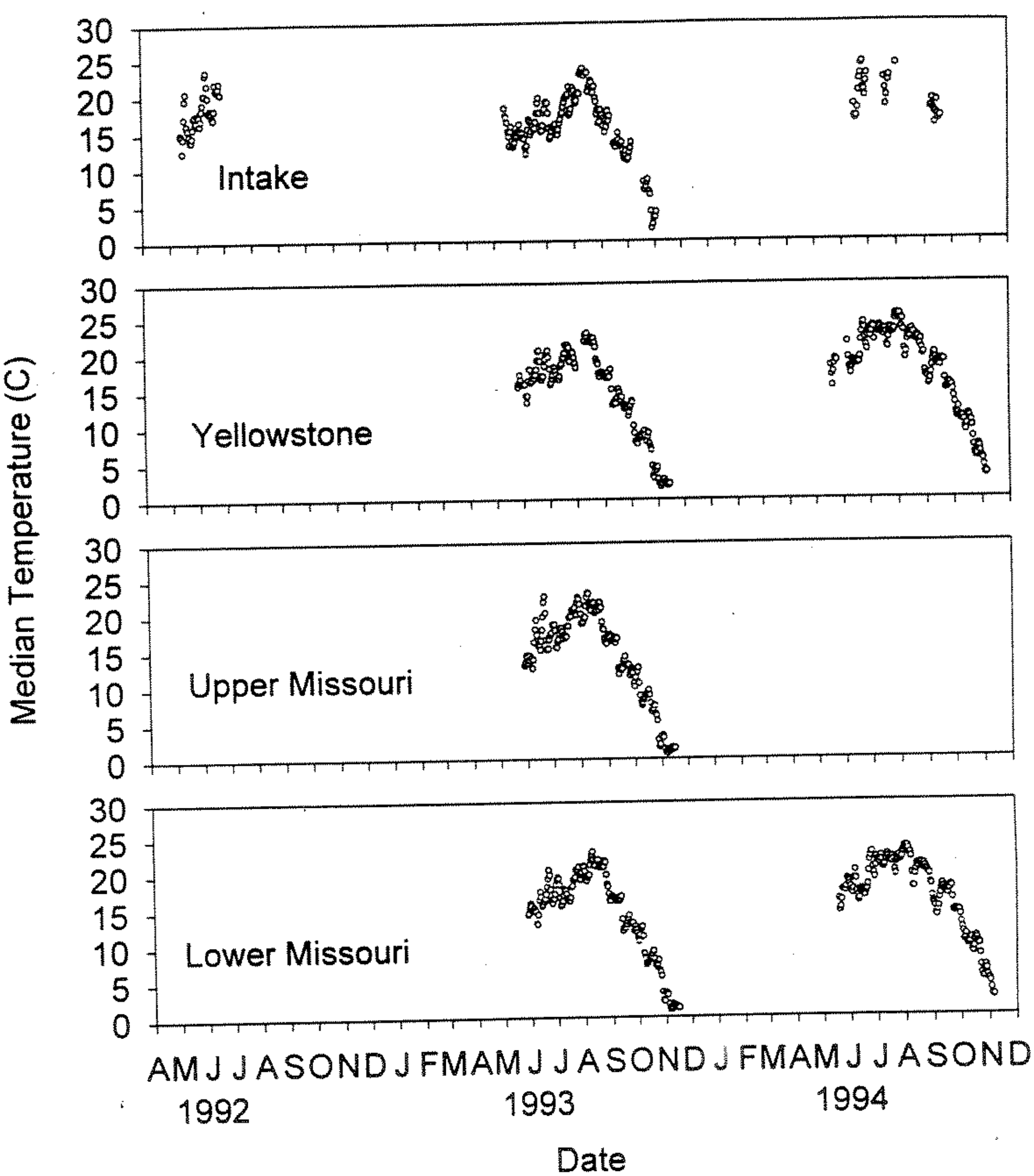

Figure 3. Median water temperatures measured at four stations in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994. The Intake thermograph was on the Yellowstone River 112 km above the confluence, the Yellowstone thermograph was 1 km above the confluence, the Upper Missouri River thermograph was 2 km above the confluence, and the Lower Missouri thermograph was 47 km below the confluence.

Table 4. Results of Sign Test for temperatures at four thermograph stations in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994. V1 and V2 are the first variable and second variables listed in the Test column, respectively. Percent V1 < V2 is the percent of non-ties in which V1 is less than V2. UY = Upper Yellowstone River Station; LY = Lower Yellowstone River Station; UM = Upper Missouri River Station; LM = Lower Missouri River Station.

Year	Test (V1 vs. V2)	Non-ties (*N*)	Percent (V1 < V2)	*P* Level
1993	LY maximum vs. UM maximum	159	38.36	0.004304
1993	LY median vs. UM median	160	33.12	0.000028
1993	LY minimum vs. UM minimum	160	35.00	0.000203
1993	LY maximum vs. LM maximum	160	31.25	0.000003
1993	LY median vs. LM median	160	33.75	0.000055
1993	LY minimum vs. LM minimum	161	40.99	0.027334
1993	UY maximum vs. LY maximum	135	49.63	1.000000
1993	UY median vs. LY median	135	62.96	0.003431
1993	UY minimum vs. LY minimum	135	77.78	0.000000
1993	UM maximum vs. LM maximum	171	28.07	0.000000
1993	UM median vs. LM median	170	57.65	0.055186
1993	UM minimum vs. LM minimum	171	68.42	0.000002
1993	UY maximum vs. LM maximum	143	36.36	0.001484
1993	UY median vs. LM median	143	58.04	0.065808
1993	UY minimum vs. LM minimum	143	96.50	0.000000
1993	UY maximum vs. UM maximum	142	38.03	0.005618
1993	UY median vs. UM median	142	42.96	0.118037
1993	UY minimum vs. UM minimum	142	78.17	0.000000
1994	LY maximum vs. LM maximum	158	0	0.000000
1994	LY median vs. LM median	157	0	0.000000
1994	LY minimum vs. LM minimum	157	3.18	0.000000
1994	UY maximum vs. LM maximum	35	11.43	0.000011
1994	UY median vs. LM median	35	51.43	1.000000
1994	UY minimum vs. LM minimum	35	88.57	0.000011
1994	UY maximum vs. LY maximum	35	45.71	0.735317
1994	UY median vs. LY median	35	82.86	0.000200
1994	UY minimum vs. LY minimum	35	100.00	0.000000

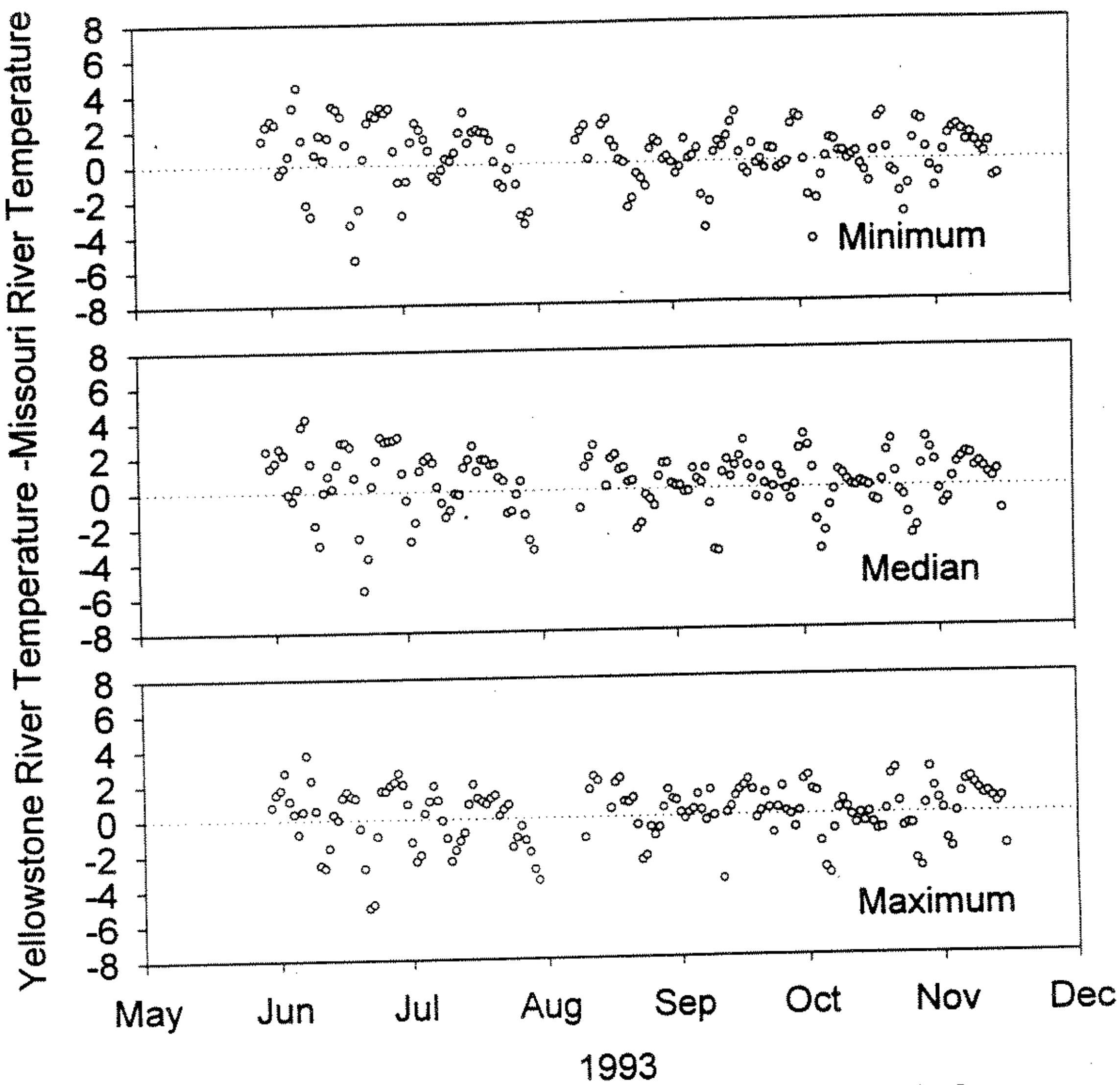

Figure 4. Minimum, median and maximum daily temperatures from the Lower Yellowstone River minus minimum, median and maximum daily temperatures from the Upper Missouri River Station, 1993. Points above zero represent temperatures that are higher at the Lower Yellowstone River Station than at the Upper Missouri River Station, and vice-versa.

Within the Yellowstone River, daily maximum, minimum and median temperatures were either significantly higher at the Lower Yellowstone River Station than at the Upper Yellowstone River Station, or not significantly different. This same pattern existed for the Missouri River; Lower Missouri River Station temperatures were either significantly higher or not significantly different than Upper Missouri River Station temperatures.

Discharge

Discharge regimes in the Yellowstone and Missouri rivers differed markedly (Table 5, Figure 5). The hydrograph of the Upper Missouri River is typical of a river regulated by a dam while the Yellowstone River's hydrograph is more typical of an

Table 5. Summary statistics for discharge data at gaging stations on the Yellowstone River near Sidney, Montana and on the Missouri River near Culbertson, Montana for water years 1992-1994.

Parameter	Yellowstone River			Missouri River		
	1992	1993	1994	1992	1993	1994
Annual mean flow (m^3/s)	284.9	366.7	264.9	204.2	193.8	228.9
Highest daily mean flow (m^3/s, date)	1,113.0 (6/20)	1,404.7 (7/29)	945.9 (5/17)	260.5 (4/20)	458.8 (7/24)	416.3 (4/23)
Lowest daily mean flow (m^3/s, date)	122.1 (8/20)	65.1 (1/4)	57.8 (8/28)	90.9 (9/26)	91.2 (10/4)	79.3 (11/23)
Annual runoff (acre-ft)	7,303	9,379	6,772	5,234	4,954	5,852

undammed river. Annual mean flow, highest daily mean flow, and annual runoff were all higher in the Yellowstone River than in the Missouri River (Table 5).

Mean annual flow, annual runoff, and highest daily mean flow in the Yellowstone River were highest in water year 1993, and lowest in water year 1994. In contrast, Missouri River mean annual flow and annual runoff were highest in water year 1994, and lowest in water year 1993.

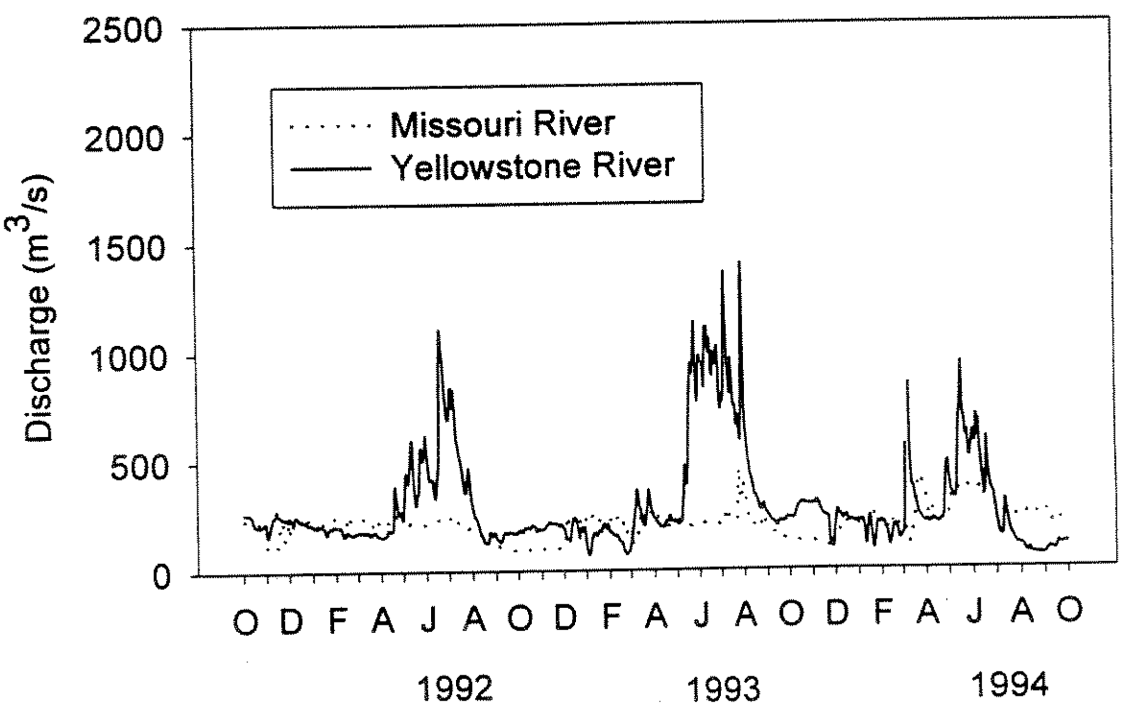

Figure 5. Discharge in the Yellowstone River at Sidney, Montana and the Missouri River at Culbertson, Montana, water years 1992-1994.

Substrate

Substrate availability showed the same pattern in both 1993 and 1994. Substrate in the Lower Missouri River was predominantly sand. In the Yellowstone River, the lower reaches of the study area were predominantly sand and the upper reaches were predominantly gravel and cobble. The transition occurred about 50 km above the confluence. Boulder and bedrock were rare throughout the study area (Figure 6). Observations of substrate use were made on 23 pallid sturgeon ($N = 181$) and 21 shovelnose sturgeon ($N = 169$). The number of observations per individual ranged from 1 to 36 for pallid sturgeon and 1 to 27 for shovelnose sturgeon (Tables 6 and 7). Pallid sturgeon were found most often (92.8%) over fines and sand (Table 6). Gravel and cobble were used less (4.4%), and use of boulder and bedrock substrates was rare (2.7%). In contrast, shovelnose sturgeon were found most often (69.2%) over gravel and cobble (Table 7). Fines and sand were used less (26.6%), and use of boulder and bedrock substrates was rare for shovelnose sturgeon (3.1%).

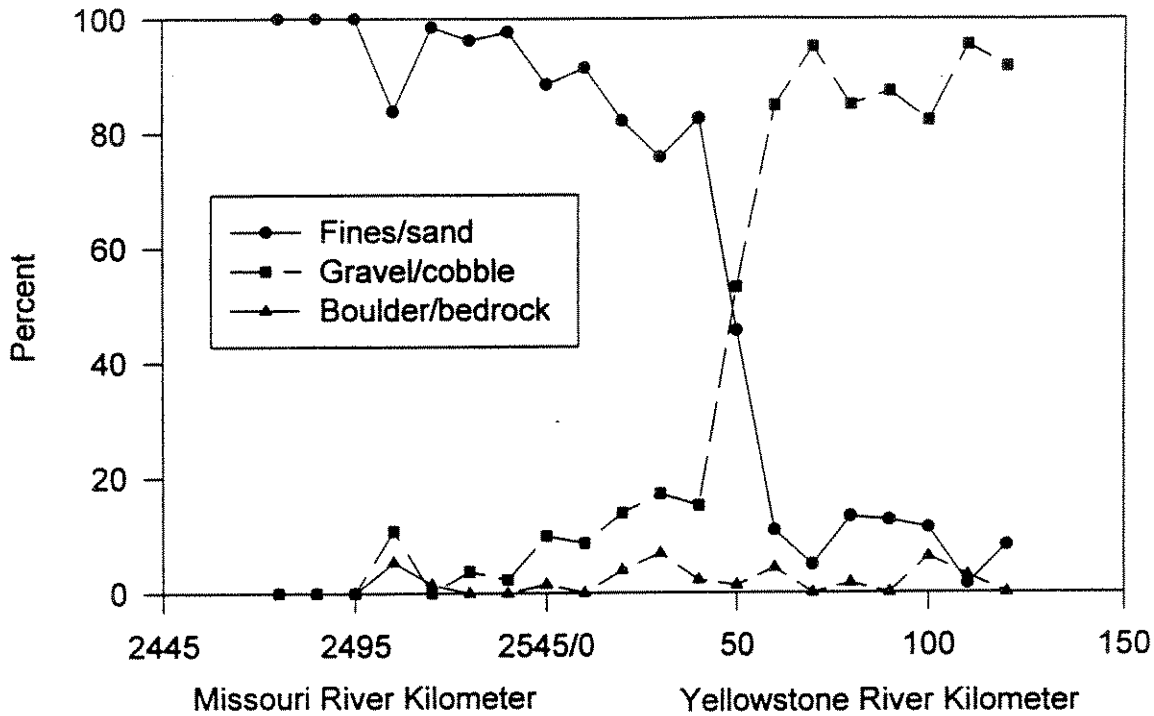

Figure 6. Estimate of distribution of substrate types in the Yellowstone and Missouri rivers in Montana and North Dakota, 1993-1994 by river kilometer from $N = 1273$ random points. River kilometer 0 is the confluence of the Yellowstone and Missouri rivers, river kilometers 0 to 150 are in the Yellowstone River, river kilometers 2445 to 2545 are in the Lower Missouri River.

The null hypothesis that substrate use by pallid and shovelnose sturgeon was the same was rejected for three random samples of substrate use (Pearson's χ^2 test: P = 0.00012; P = 0.00003; P = 0.00017; Table 8). Pallid sturgeon use of fines and sand was significantly greater than shovelnose sturgeon use, while shovelnose sturgeon use of gravel and cobble was significantly greater than pallid sturgeon use. Use of boulder and bedrock substrate was not significantly different for the two species.

Table 6. Summary of observations of substrate use by telemetered pallid sturgeon in the Yellowstone and Missouri rivers, Montana and North Dakota, 1992-1994.

Transmitter frequency	Fines and sand		Gravel and cobble		Boulder and bedrock		
	N	%	*N*	%	*N*	%	Total *N*
49.680	36	100.0	0	0.0	0	0.0	36
49.100	26	100.0	0	0.0	0	0.0	26
49.650	16	100.0	0	0.0	0	0.0	16
49.630	9	75.0	3	25.0	0	0.0	12
49.050	9	90.0	1	10.0	0	0.0	10
49.712	9	100.0	0	0.0	0	0.0	9
49.850	5	55.6	3	33.3	1	11.1	9
49.030	7	100.0	0	0.0	0	0.0	7
49.810	6	85.7	1	14.3	0	0.0	7
49.370	6	100.0	0	0.0	0	0.0	6
49.130	5	100.0	0	0.0	0	0.0	5
49.350	5	100.0	0	0.0	0	0.0	5
49.830	5	100.0	0	0.0	0	0.0	5
48.540	4	100.0	0	0.0	0	0.0	4
49.070	4	100.0	0	0.0	0	0.0	4
48.580	3	75.0	0	0.0	1	25.0	4
49.240	2	50.0	0	0.0	2	50.0	4
49.020	3	100.0	0	0.0	0	0.0	3
49.670	3	100.0	0	0.0	0	0.0	3
48.520	2	100.0	0	0.0	0	0.0	2
49.170	2	100.0	0	0.0	0	0.0	2
49.870	1	100.0	0	0.0	0	0.0	1
48.570	0	0.0	0	0.0	1	0.0	1
Totals	168	92.8	8	4.4	5	2.8	181

The hypothesis that pallid sturgeon used substrate classes in proportion to their availability was rejected (χ^2, $P < 0.05$) for the grouped sample (Table 9). Pallid sturgeon preferred fines and sand, avoided gravel and cobble, and used boulder and bedrock in proportion to their availability. Also, all three random samples for pallid sturgeon yielded the same results as the grouped sample. Because these results agree, it is reasonable to assume that all radio-tagged pallid sturgeon had similar substrate preferences.

Table 7. Summary of observations of substrate use by telemetered shovelnose sturgeon in the Yellowstone and Missouri rivers, Montana and North Dakota, 1992-1994.

Transmitter frequency	Fines and sand		Gravel and cobble		Boulder and bedrock		Total *N*
	N	%	*N*	%	*N*	%	
48.940	15	55.6	9	33.3	1	11.1	25
48.900	1	5.6	17	94.4	0	0.0	18
48.860	3	17.6	13	76.5	1	5.9	17
48.640	0	0.0	13	100.0	0	0.0	13
48.880	1	8.3	10	83.3	1	8.3	12
48.840	0	0.0	9	100.0	0	0.0	9
48.920	0	0.0	9	100.0	0	0.0	9
48.660	2	22.2	7	77.8	0	0.0	9
48.620	3	37.5	5	62.5	0	0.0	8
48.680	1	16.7	5	83.3	0	0.0	6
48.300	2	33.3	4	66.7	0	0.0	6
48.590	2	40.0	3	60.0	0	0.0	5
48.820	2	40.0	3	60.0	0	0.0	5
48.380	2	40.0	2	40.0	1	20.0	5
48.340	3	60.0	1	20.0	1	20.0	5
48.550	1	25.0	3	75.0	0	0.0	4
48.280	2	50.0	2	50.0	0	0.0	4
48.360	0	0.0	2	100.0	0	0.0	2
49.790	2	50.0	0	50.0	0	0.0	2
48.320	2	100.0	0	0.0	0	0.0	2
49.710	1	100.0	0	0.0	0	0.0	1
Totals	45	26.6	117	69.2	5	3.0	169

In 1993 and 1994 I added sand dunes as a substrate category. The χ^2 test with this additional category indicate that pallid sturgeon prefer sand dunes and avoid gravel and cobble ($P < 0.05$; Table 9; Figure 7). Sand and fines and boulder and bedrock were used in proportion to their availability.

The hypothesis that all observations of substrate use for shovelnose sturgeon were in proportion to their availability was also rejected ($P < 0.005$; Table 9). In contrast to pallid sturgeon, shovelnose sturgeon avoided sand, preferred gravel and cobble, and used boulder and bedrock in proportion to their availability. However, individual shovelnose sturgeon were more variable in their substrate use. In contrast to the grouped χ^2 test, the χ^2 tests for the three random sub-samples were not significant (Table 8). This indicates that individual shovelnose sturgeon substrate preferences are variable. Therefore, because the assumption that all telemetered shovelnose sturgeon had the same substrate preferences was not supported, the results of the overall test are not valid.

Table 8. Three random samples of one observation of substrate use per individual fish for telemetered pallid ($N = 23$) and shovelnose ($N = 21$) sturgeon in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994. An asterisk indicate substrate use that is significantly different for the two species ($P < 0.05$, Pearson's χ^2 test). Letters in parentheses indicate results of Marcum-Loftsgaarden χ^2 analysis. P = preference, A = avoidance, and NS = substrate was not significantly preferred or avoided.

	Pallid sturgeon			Shovelnose sturgeon		
Substrate class	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
Fines and sand	20*(P)	21*(P)	20*(P)	8*(NS)	8*(NS)	8*(NS)
Gravel and cobble	0*(A)	0*(A)	1*(A)	12*(NS)	13*(NS)	13*(NS)
Boulder and bedrock	3(NS)	2(NS)	2(NS)	1(NS)	0(NS)	0(NS)
Totals	23	23	23	21	21	21

Table 9. Substrate use versus availability for telemetered pallid and shovelnose sturgeon as determined by Marcum-Loftsgaarden (1980) χ^2 analysis in the Yellowstone and Missouri rivers, Montana and North Dakota, 1993-1994.

		Substrate class			
Test	Result	Sand	Sand dunes	Gravel-cobble	Boulder and bedrock
all pallids 1992-1994	reject Ho[a]	preferred	not tested	avoided	ns[b]
all pallids, 1993-1994	reject Ho	ns[b]	preferred	avoided	ns[b]
all shovelnose 1992-1994	reject Ho	avoid	not tested	preferred	ns[b]
all shovelnose, 1993-1994	reject Ho	ns[b]	ns[b]	not significant	ns[b]

[a] Reject null hypothesis that use of substrate classes occurred in proportion to their availability.
[b] Not significant ($P < 0.05$)

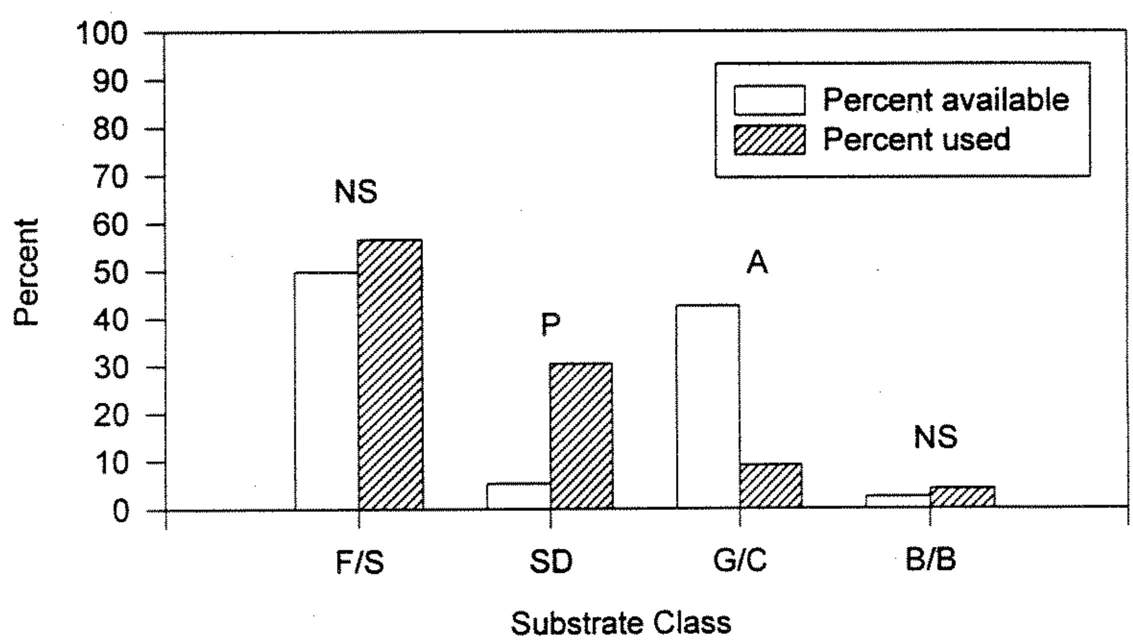

Figure 7. Substrate use and availability for telemetered pallid sturgeon in the Yellowstone and Missouri rivers, Montana and North Dakota, 1993-1994. P indicates that the substrate class was significantly preferred, A indicates that the substrate class was significantly avoided, and NS indicates that use of the substrate class was not significantly different from its availability as determined by Marcum-Loftsgaarden chi-square analysis ($P < 0.05$, see methods). Abbreviations for substrate classes are: F/S = fines and sand; SD = sand dunes; G/C = gravel and cobble; B/B = boulder and bedrock.

Depth

Independent observations of depths used were made on 24 pallid sturgeon ($N = 164$; Table 10) and 24 shovelnose sturgeon ($N = 147$; Table 11). The number of observations per individual ranged from 1 to 29 for pallid sturgeon and 1 to 23 for shovelnose sturgeon. Median depths, relative depths, and maximum depths at locations of moving

Table 10. Summary of observations of depths used by telemetered pallid sturgeon in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994.

Location	Minimum (m)	Maximum (m)	N[a] obser-vations	N fish	Mean (m)	SD (m)	N[b] obser-vations
			Depth				
Yellowstone	0.6	7.0	124	21	2.93	1.46	83
Upper Missouri	2.0	14.5	12	2	7.74	4.34	10
Lower Missouri	0.8	8.2	174	16	3.11	1.47	71
Overall	0.6	14.5	310	24	3.30	2.08	164
			Maximum depth				
Yellowstone	1.2	7.8	112	20	4.18	1.27	73
Upper Missouri	2.1	5.5	4	1	3.8	2.4	2
Lower Missouri	2.2	8.2	164	17	4.74	1.35	62
Overall	1.2	8.2	280	22	4.43	1.34	137
			Relative depth (depth/maximum depth)				
Yellowstone	0.22	1.0	112	20	0.71	0.22	73
Upper Missouri	0.50	0.93	4	1	0.72	0.30	2
Lower Missouri	0.13	1.0	161	16	0.68	0.22	59
Overall	0.13	1.0	277	22	0.70	0.22	134

[a] = All observations are used for reporting ranges.
[b] = Only "independent" observations are used for reporting means and standard deviations.

and non-moving pallid sturgeon and shovelnose sturgeon were not significantly different ($P \geq 0.05$) so observations from moving and non-moving fish were combined for further analysis.

Table 11. Summary of observations of depths used by telemetered shovelnose sturgeon in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994.

Location	Minimum (m)	Maximum (m)	N^a observations	N fish	Mean (m)	SD (m)	N^b observations
			Depth				
Yellowstone	0.9	8.8	215	19	2.2	1.00	129
Upper Missouri	4.3	10.1	7	2	7.6	3.61	2
Lower Missouri	1.2	5.8	23	6	2.4	1.35	16
Overall	0.9	10.1	245	24	2.3	1.24	147
			Maximum depth				
Yellowstone	1.4	8.8	175	19	3.0	1.19	112
Upper Missouri	--	--	0	0	--	--	--
Lower Missouri	2.3	7.0	12	2	4.7	1.79	5
Overall	1.4	8.8	187	20	3.1	1.26	117
			Relative depth (depth/maximum depth)				
Yellowstone	0.33	1.0	175	19	0.78	0.18	112
Upper Missouri	--	--	0	0	--	--	--
Lower Missouri	0.71	0.93	12	2	0.83	0.09	5
Overall	0.33	1.0	187	20	0.78	0.18	117

[a] = All observations are used for reporting ranges.

[b] = Only "independent" observations are used for reporting means and standard deviations.

Depths at pallid and shovelnose sturgeon locations were similar, but pallids used greater depths more often (Figure 8). Pallid sturgeon were found in depths ranging from 0.6 to 7.0 m (*N* = 124) in the Yellowstone River, 2.0 to 14.5 m (*N* = 12) in the Upper Missouri River, and 0.8 to 8.2 m (*N* = 174) in the Lower Missouri River. Shovelnose sturgeon were found in depths ranging from 0.9 to 8.8 m (*N* = 215) in the Yellowstone River, 4.3 to 10.1 m (*N* = 7) in the Upper Missouri River, and 1.2 to 5.8 m (*N* = 23) in the Lower Missouri River.

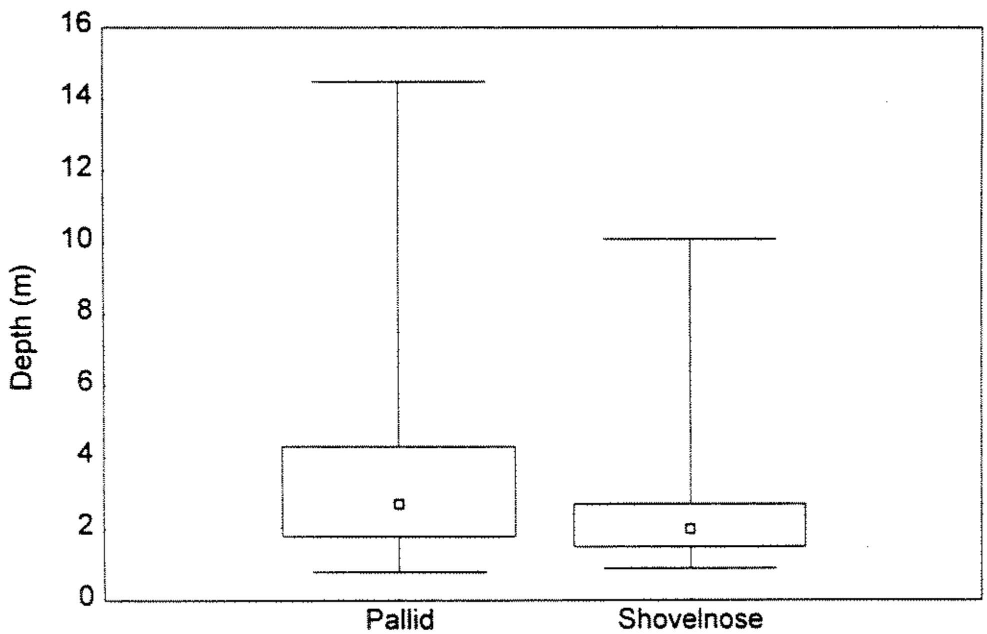

Figure 8. Depths at telemetered pallid (*N* = 164) and shovelnose sturgeon (*N* = 147) locations in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994. Small box is median, large box is 25% and 75% percentiles, and whiskers are minimum and maximum values.

The overall mean depth for pallid sturgeon was 3.30 m (*N* = 164, SD = 2.08), compared to an overall mean depth of 2.29 m (*N* =147, SD = 1.24) for shovelnose sturgeon. These means include seven observations for pallid sturgeon and two observations for shovelnose sturgeon in the Missouri River just below Fort Peck Reservoir where depths are greater than elsewhere in the study area. The greatest depth measured outside of this area was 8.8 m, in the Yellowstone River in an area scoured by a wing deflector. Excluding the observations from the Fort Peck tailrace, the overall mean depth for pallid sturgeon was 2.98 m (N =158, SD = 1.47), and the overall mean depth for shovelnose sturgeon was 2.21 m (N =145, SD = 1.04). The overall median of depths used by pallid and shovelnose sturgeon were significantly different (Mann-Whitney U test; P = 0.0000001).

Overall mean maximum depth at pallid sturgeon locations was 4.4 m and 3.1 m at shovelnose sturgeon locations (Figure 9). Overall means of maximum depths at pallid and shovelnose sturgeon locations were significantly different (t-test; $P < 0.000001$; following Levene's test for equal variance; $P = 0.241$). Mean relative depths were greater at shovelnose sturgeon locations than at pallid sturgeon locations (Figure 10). The overall mean relative depth for pallid sturgeon was 0.70 and was 0.78 for shovelnose sturgeon. These means were significantly different (Mann-Whitney U test; $P = 0.0054$). Depth and relative depth data were not normally distributed (Kolmogorov-Smirnov test; depth $P < 0.01$; relative depth $P < 0.05$), while the maximum depth data were normally distributed ($P > 0.05$).

The ANOVA based on model (1) gave the following results for depths (Table 12): 1) mean depths used by pallid sturgeon and shovelnose sturgeon were significantly different ($P = 0.0170$); 2) mean depths used by pallid and shovelnose sturgeon in the Yellowstone River were not significantly different from those in the Lower Missouri River ($P = 0.5855$); 3) the difference in mean depths between shovelnose and pallid sturgeon were not significantly different between the Lower Missouri River and the Yellowstone River (i.e. no interaction between species and rivers; $P = 0.3753$); 4) the variance among mean depths of individual fish of each species is significantly different than zero ($P = 0.0355$), after considering variation due to location in either the lower Missouri or Yellowstone river.

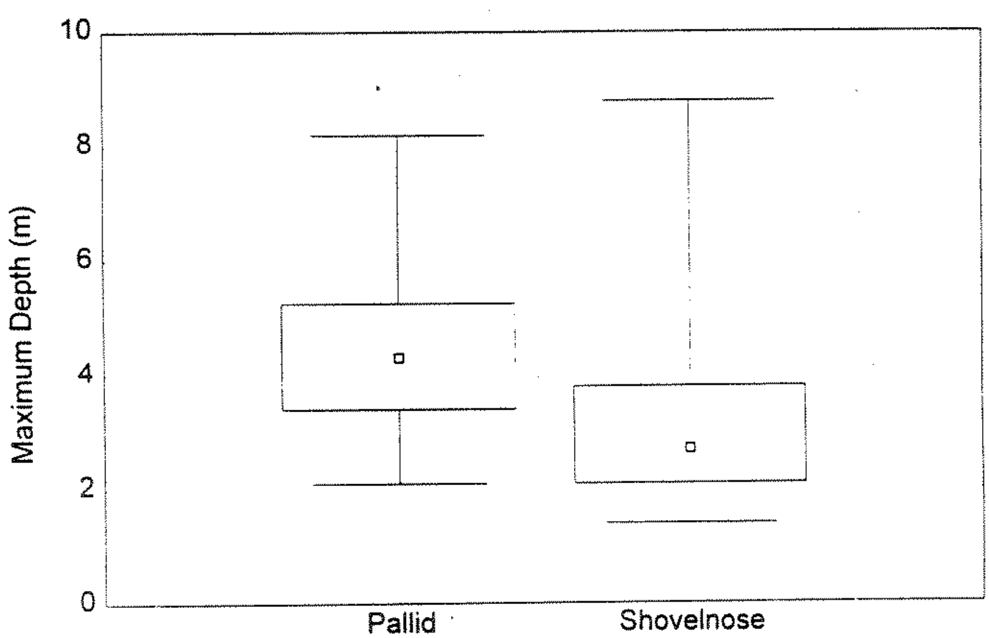

Figure 9. Maximum depths at telemetered pallid ($N = 137$) and shovelnose sturgeon ($N = 117$) locations in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994. Small box is median, large box is 25% and 75% percentiles, and whiskers are minimum and maximum values.

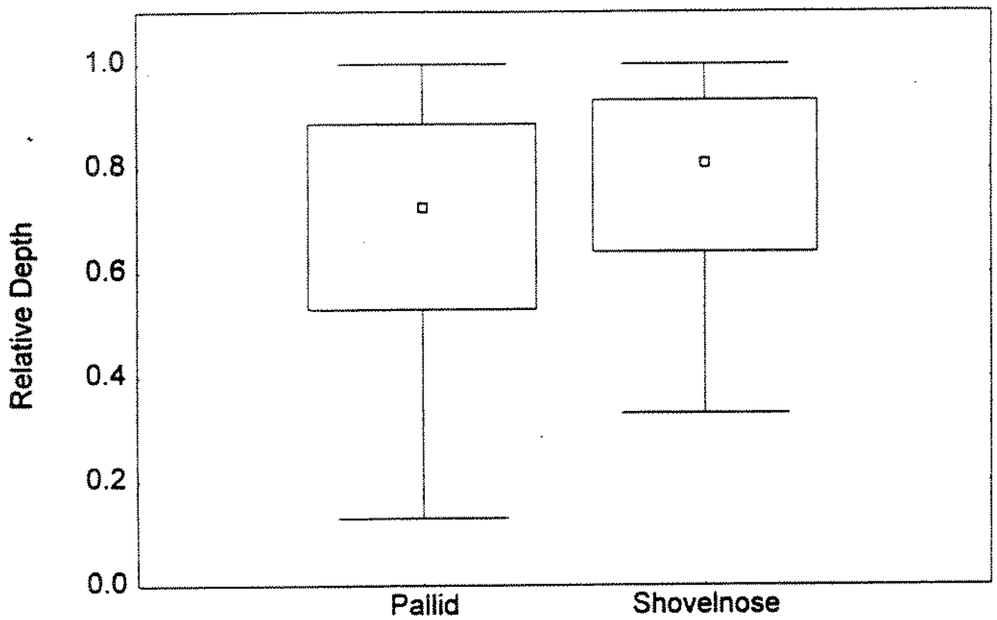

Figure 10. Relative depths at telemetered pallid (N = 134) and shovelnose sturgeon (N = 117) locations in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994. Small box is median, large box is 25% and 75% percentiles, and whiskers are minimum and maximum values.

The ANOVA based on model (1) gave the following results for depths (Table 12): 1) mean depths used by pallid sturgeon and shovelnose sturgeon were significantly different ($P = 0.0170$); 2) mean depths used by pallid and shovelnose sturgeon in the Yellowstone River were not significantly different from those in the Lower Missouri River ($P = 0.5855$); 3) the difference in mean depths between shovelnose and pallid sturgeon were not significantly different between the Lower Missouri River and the Yellowstone River (i.e. no interaction between species and rivers; $P = 0.3753$); 4) the variance among mean depths of individual fish of each species is significantly different than zero ($P = 0.0355$), after considering variation due to location in either the lower Missouri or Yellowstone river.

Table 12. Results of ANOVA Model (1) and tests of overall means of depth, maximum depths, and relative depths for telemetered pallid sturgeon and shovelnose sturgeon in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994.

Variable	Source of Variation	*P*	Degrees of Freedom
Depth	Overall	0.000001[a]	[b]
	Species	0.0170	181.55
	River	0.5855	183.22
	River x Species	0.3753	184.55
	Individual(River x Species)	0.0355	237
Maximum Depth	Overall	<0.000000[c]	250
	Species	0.0213	147.56
	River	0.0479	149.50
	River x Species	0.9423	151.24
	Individual(River x Species)	0.0036	194
Relative Depth	Overall	0.0054[a]	[b]
	Species	0.0966	179.43
	River	0.9860	181.57
	River x Species	0.7512	183.45
	Individual(River x Species)	0.1844	192

[a] Mann-Whitney U test.
[b] Degrees of freedom not defined for Mann-Whitney U test.
[c] t-test.

ANOVA results for maximum depths were as follows (Table 12): 1) mean maximum depths at pallid sturgeon and shovelnose sturgeon locations were significantly different ($P = 0.0213$); 2) mean maximum depths at pallid and shovelnose sturgeon locations in the Yellowstone River were significantly different than in the Lower Missouri River ($P = 0.0479$); 3) the difference in mean maximum depths for shovelnose and pallid sturgeon were not significantly different between the Missouri River and the

Yellowstone River (i.e. no interaction between species and rivers; $P = 0.9423$); and 4) the variance among mean maximum depths of individual fish of each species is significantly different than zero ($P = 0.0036$), after considering variation due to location in either the lower Missouri or Yellowstone river.

Results pertaining to relative depths from the ANOVA based on model (1) were as follows (Table 12): 1) mean relative depths at pallid sturgeon and shovelnose sturgeon locations were nearly significantly different ($P = 0.0966$); 2) mean relative depths at pallid and shovelnose sturgeon locations in the Yellowstone River were not significantly different from those in the Lower Missouri River ($P = 0.9860$); 3) the difference in mean depths for shovelnose and pallid sturgeon were not significantly different between the Missouri River and the Yellowstone River (i.e. no interaction between species and rivers; $P = 0.7512$); and 4) the variance among mean depths of individual fish of each species is significantly different from zero ($P = 0.1844$), after considering variation due to location in either the lower Missouri or Yellowstone river.

The Wilks-Shapiro test rejected the hypothesis that the residuals were normal ($P = 0.0001$). The boxplot indicated two outliers among the residuals. However, hypothesis testing results were robust to outliers since decisions of hypothesis tests made at the $\alpha = 0.05$ level were the same with and without the two outliers in the data set.

The slope of the relationship of predicted depth relative to hours following sunrise for pallid sturgeon was positive (slope = 0.77, Figure 11) but was not significantly

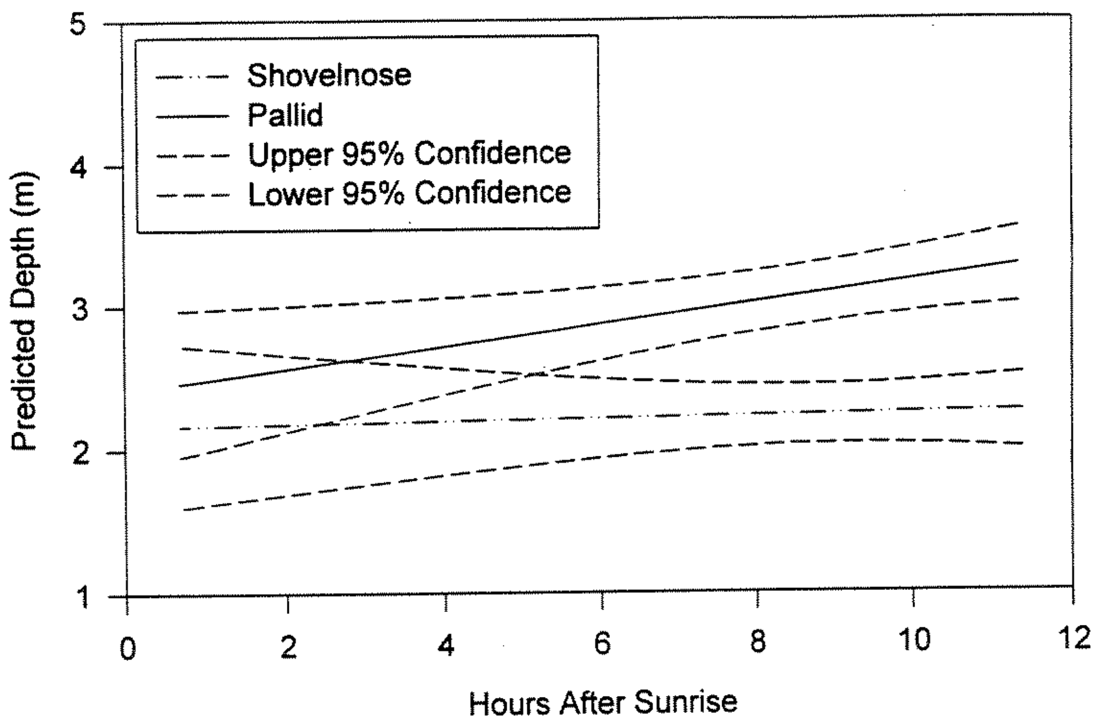

Figure 11. Predicted depths and 95% confidence intervals for telemetered pallid and shovelnose sturgeon, versus hours after sunrise.

different than 0 slope ($P = 0.1268$). The slope of the relationship of predicted depth relative to hours following sunrise for shovelnose sturgeon was only slightly positive (slope = 0.009), and also not significantly different than zero slope ($P = 0.7817$). Therefore, although not statistically significant, the data suggest that pallid sturgeon showed a greater increase in their predicted depth during the hours following sunrise than did shovelnose sturgeon.

Current velocity

Independent observations of bottom velocities used by 24 pallid sturgeon (*N* = 173; Table 13) and 24 shovelnose sturgeon (*N* = 119; Table 14) were made. The number of observations per individual ranged from 1 to 36 for pallid sturgeon and 1 to 21 for shovelnose sturgeon.

Pallid sturgeon were found using bottom velocities ranging from 0.13 to 1.32 m/s (*N* = 159) in the Yellowstone River, 0.0 to 0.70 (*N* = 12) in the Upper Missouri River, and 0 to 1.37 m/s (*N* = 244) in the Lower Missouri River (Table 13). Shovelnose sturgeon used bottom velocities ranging from 0.03 to 1.51 m/s (*N* = 172) in the Yellowstone River, 0.02 to 0.20 m/s (*N* = 2) in the Upper Missouri River, and 0.40 to 0.82 m/s (*N* = 23) in the Lower Missouri River (Table 14).

Current velocities at pallid and shovelnose sturgeon locations overlapped (Figures 12 and 13). The overall mean bottom velocity for pallid sturgeon was 0.65 m/s (*N* = 173, SD = 0.28, Table 13), and for shovelnose sturgeon was 0.78 m/s (*N* = 119, SD = 0.33, Table 14). These means include seven observations for pallid sturgeon and two observations for shovelnose sturgeon in the dredge cuts below Fort Peck Reservoir where areas of low and zero velocity are found. Excluding these observations, the overall mean bottom velocity for pallid sturgeon was 0.68 m/s (*N* =166, SD = 0.26) and for shovelnose sturgeon was 0.79 m/s (*N* =117, SD = 0.32).

Table 13. Summary of observations of current velocities used by telemetered pallid sturgeon in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994.

Location	Minimum (m/s)	Maximum (m/s)	N^a obser-vations	N fish	Mean (m/s)	SD (m/s)	N^b obser-vations
			Surface				
Yellowstone	0.27	1.82	156	21	1.06	0.33	86
Upper Missouri	0.00	0.91	12	2	0.20	0.33	10
Lower Missouri	0.49	1.58	223	12	0.99	0.34	54
Overall	0.00	1.55	391	22	0.98	0.39	150
			Mean Column				
Yellowstone	0.14	1.55	156	21	0.90	0.28	86
Upper Missouri	0.00	0.82	12	2	0.17	0.29	10
Lower Missouri	0.18	1.40	223	12	0.82	0.24	54
Overall	0.00	1.55	391	22	0.82	0.32	150
			Bottom				
Yellowstone	0.13	1.32	159	21	0.72	0.26	88
Upper Missouri	0.00	0.70	12	2	0.13	0.23	10
Lower Missouri	0.00	1.37	244	17	0.63	0.21	75
Overall	0.00	1.37	415	24	0.65	0.28	173

[a] = All observations are used for reporting ranges.
[b] = Only "independent" observations are used for reporting means and standard deviations.

Overall means of surface, mean column, and bottom velocities used by pallid and shovelnose sturgeon were significantly different (surface $P = 0.000180$; mean column $P = 0.000197$; bottom $P = 0.000613$; t-test with separate estimates of variance). Surface, column and bottom velocity data were normally distributed (Kolmogorov-Smirnov test; surface velocity $P > 0.20$; mean column velocity $P > 0.20$; bottom velocity $P > 0.05$).

Table 14. Summary of observations of current velocities used by telemetered shovelnose sturgeon in the Yellowstone and Missouri rivers in Montana and North Dakota, 1992-1994.

Location	Minimum (m/s)	Maximum (m/s)	N^a observations	*N* fish	Mean (m/s)	SD (m/s)	N^b observations
			Surface				
Yellowstone	0.04	2.16	166	18	1.20	0.46	95
Upper Missouri	--	--	0	0	--	--	0
Lower Missouri	0.78	0.99	11	1	0.88	0.11	4
Overall	0.04	2.16	177	18	1.19	0.45	99
			Mean Column				
Yellowstone	0.03	1.81	166	18	1.02	0.39	95
Upper Missouri	--	--	0	0	--	--	0
Lower Missouri	0.23	0.88	11	1	0.66	0.29	4
Overall	0.03	1.81	177	18	1.00	0.40	99
			Bottom				
Yellowstone	0.03	1.51	172	19	0.82	0.33	101
Upper Missouri	0.02	0.20	2	2	0.11	0.13	2
Lower Missouri	0.40	0.82	23	6	0.61	0.11	16
Overall	0.02	1.51	197	24	0.78	0.33	119

[a] = All observations are used for reporting ranges.
[b] = Only "independent" observations are used for reporting means and standard deviations.