1-1-2002

# Diet of Shovelnose Sturgeon Downstream from Gavins Point Dam: Final Report

Charles R. Berry Jr.
*South Dakota State University*

Berry, Charles R. Jr., "Diet of Shovelnose Sturgeon Downstream from Gavins Point Dam: Final Report" (2002). *US Army Corps of Engineers, Omaha District*. Paper 59.
http://digitalcommons.unl.edu/usarmyceomaha/59

# Diet of Shovelnose Sturgeon Downstream from Gavins Point Dam: Final Report

By

Charles R. Berry Jr.
USGS-South Dakota Cooperative Research Unit
Department of Wildlife and Fisheries Science
South Dakota State University
Brookings, South Dakota
57007-1696

To
U. S. Army Corps of Engineers
Omaha District, Omaha Nebraska
Contract No. 96X3123 O&M CC5300753AOYPPS

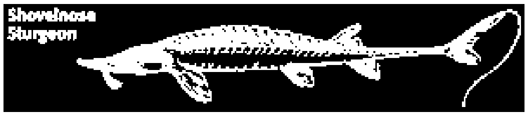
Project Staff

Dr. Charles R. Berry, Principal Investigator
Mr. Patrick J. Braaten, Project Leader 1993
Mr. Jonathan D. Erickson, Project Leader 1994
Mr. Jeffery Shearer 2001
Mr. Robert Smith, Technician 1993
Dr. Reid Goforth, NBS Project Officer

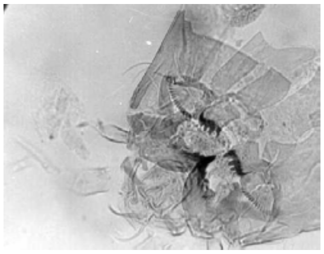
October 1996 (Revised March 2002)

# Acknowledgements

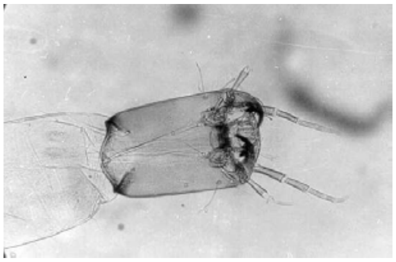
This study was funded by the U. S. Army Corps of Engineers (Contract No. 96X3123 O&M CC5300753AOYPPS) as Research Work Order Number 42. At the time of the study, the South Dakota Cooperative Fish and Wildlife Research Unit was jointly supported by South Dakota State University, the South Dakota Department of Game, Fish and Parks, Wildlife Management Institute, the U. S. Fish and Wildlife Service, and the National Biological Service (now defunct). The Unit was moved to the U. S. Geological Survey in 1996. South Dakota State University supported the study by waiving part of the normal overhead. The study was initiated by Mr. Mark Harburg of the Corps, but later supervised by Ms. Rebecca J. Latka. We thank Ms. Latka for assistance with the Corps contract details and patience during the final writing of the report, and Ms. Connie Walker (Fish and Wildlife Service) for her assistance with contracting details. The contract was interrupted by a Federal budget "continuing resolution" so samples in November 1993 and March 1994 were sponsored by South Dakota State University. The study was conducted in concert with a similar study in Montana by D. Megargle and R. White, who helped us with comments about our study. The sturgeon diet study by the South Dakota and Montana Coop Units ultimately led to a larger study of the benthic fishes of the entire Missouri River main stem. The final report for the South Dakota portion of the sturgeon diet study was submitted in October 1996. In 2001, the text, figures, tables, and database were converted to an electronic format that was compatible with the Crops of Engineers web page, references were added, and statistical analyses were recalculated and reviewed. Mr. Jeff Shearer did most of the work on the revision and statistical analyses. Ms. Shelly Kopplin assisted with formatting the electronic final version. Dr. Tim Wittig, Department of Mathematics and Statistics, SDSU reviewed the statistical procedures.



John Erickson, Robert Smith, and Doug Dieterman (L-R) hold a shovelnose sturgeon on the boat dock at Clay County Park.



Head capsule of a midge larva (*Chironomini*) showing mandibles, ventromental plates, and mentum



Head capsule of a midge larva (*Demicryptochironomus* sp.) showing mandibles, antennae, and mentum

# Table of Contents

## EXECUTIVE SUMMARY

The diet of shovelnose sturgeon (*Scaphirhynchus platorhynchus*) in the Missouri River downstream from Gavins Point Dam was characterized in 1993 (N=100 fish) and 1994 (N=103 fish) for comparison with similar data collected in 1971-72 (N=130 fish) by Modde and Schmulbach (1977, hereafter Modde). The primary difference among years in the South Dakota studies was river discharge, which was low in 1993 (9-22 kcfs; kcfs=thousand cubic feet per second), moderate in 1994 (18-31 kcfs), and high in 1971-72 (26-49 kcfs). We compared sturgeon diet weight and the weight of benthic and drifting invertebrates among years, among monthly discharges in 1993 and 1994, and among three types of river substrates. We also compared our results with those of Megargle and White (1997) who conducted a concomitant study in Montana portions of the Missouri River where discharges were relatively natural. Our <u>working hypothesis</u> was: sturgeon diet quantity and quality decreases as discharge increases because high discharges make the prey (benthic and drifting invertebrates) less available and less accessible to the predator (the sturgeon).

For the predator (sturgeon), we found no difference in diet weight <u>among years</u> of low, medium, and high flow. However, diet weight did decrease as discharges increased among months within a year, but other factors like temperature and seasonal changes in

invertebrate biomass are also changing monthly. All sturgeon used in the analysis ranged in length from 408 to 675 mm (standard length). We recaptured five sturgeon that had been tagged in the same river reach 13 years earlier by Dr. Jim Schmulbach. These individuals had grown an average of 12 mm in length; two had gained weight and three had lost weight.

For the prey (invertebrates), biomass during years of low and medium flows was always higher than that reported by Modde for high discharge years (71-72). Other evidence that discharge influenced the benthos was our finding that the benthic biomass in large pools dropped from 128 mg/m$^2$ during 1993 (our low-discharge year), to 98 mg/m$^2$ during 1994 (our medium-discharge year).

Shovelnose sturgeon dietary weight from March through November ranged from 83 to 375 mg (dry weight) in the 1970s study and from 69 to 2,166 mg during the current study. In both studies, diet weight was much higher in March than during other months. Diet weight was negatively related to flow in 1993 ($r$=-0.13) and in 1994 ($r$=-0.73). Modde also reported a negative correlation between diet weight and discharge ($r$=-0.85), but Megargle reported a positive relation between mean monthly discharge and sturgeon diet weight. A summary of the discharge-diet correlation data follows:

| Discharge (kcfs) with year and location of study | Correlation to sturgeon diet weight |
|---|---|
| **Controlled, 26-49,**<br>SD, 1972 | **Negative**<br>*r*=-0.85, P<0.05 |
| **Controlled, 18-31,**<br>SD, 1994 | **Negative**<br>*r*=-0.73, P=0.066 |
| **Controlled, 9-22,**<br>SD, 1993 | **Negative**<br>*r*=-0.13, P=0.8 |
| **Natural, 5-17,**<br>MT, 1993-1994 | **Positive**<br>*r*=0.91, P=0.004 |

The diet of shovelnose sturgeon was dominated by aquatic invertebrates (11 Orders), but sturgeon also ate four kinds of terrestrial insects, and a few fish. The diet was dominated by midges (48%), mayflies (13%), and caddisflies (17%). Dietary content in the 1970s and 1990s was similar in that midges dominated during the summer months (60% of weight) when this taxon also became abundant in the benthos and drift. When midges increased in the diet, caddisflies declined to about 5% of the total dietary weight. Mayflies appeared in the diet more in summer than in fall or spring. A difference between our results and those of Modde was that we found no trend in the amount of sand in the stomachs whereas Modde reported higher quantities in the summer than during other times of the year.

The benthic community of the 1970s was similar to that in the 1990s. Midges (Order Diptera) were dominant (i.e. 88% of weight and 98% of number in the 1990s). Mayflies and caddisflies made up 5-10% of the benthos depending on the season. Pools with sandy substrates yielded an invertebrate biomass averaging 69 mg/m$^2$, while chutes averaged 101 mg/m$^2$. However, large pools that accumulated silt and coarse organic material during low flows yielded about 128 mg/m$^2$. High variation in the data obscured monthly differences for the three primary invertebrate groups, and for the total benthic biomass. The seasonal trend was toward higher benthic biomass during summer months than during other seasons. For total benthic biomass, there was a difference among years that seemed to support the working hypothesis that low flows allowed benthic biomass to increase. Benthic biomass during years of low and medium flows was always higher than that reported by Modde.

The <u>drifting invertebrate community</u> was different from the benthic community. The drift was made up of 17 orders of aquatic and terrestrial insects, but was dominated by mayflies (13%), aquatic fly larvae (12%) and pupae (18%), beetles (16%), and caddisflies (21%). Mayflies appeared in the drift and the benthos in greatest biomass in the summer. There was no difference among years in total drift biomass, perhaps because biomass is stable over the range of flows we evaluated. However, there were differences in drift biomass among months in 1993 ($P$=0.0001, F=7.19) and 1994 ($P$=0.0001, F=19.07), but only in 1994 (moderate flows) was drift related to temperature and discharge ($P$<0.05). The general pattern was greater drift biomass in summer than in fall and spring.

In summary, the results of the three studies of interest evaluate sturgeon diet over a variety of discharges (4,000-40,000 cfs). Other important variables are 1) natural (MT) vs controlled discharge (SD), 2) rocky (MT) vs sand (SD) substrates, 3) few pools (MT) vs many pools (SD), and 4) drift-aufwuchs (MT) vs drift-benthos (SD) communities. Natural discharges into natural habitat were positively related to sturgeon diet whereas controlled discharges into disturbed habitat were negatively related to sturgeon diet.

# FIGURES

# TABLES

Table 10. Mean monthly benthos biomass (mg/m$^2$) in three habitat types during years of low (15-22 kcfs), medium (18-32 kcfs) and high (26-49 kcfs) discharges from Gavins Point Dam. p. 80

Table 11. Mean monthly biomass (mg/m$^3$) collected from three habitat types during low (15-22 kcfs), medium (18-32 kcfs), and high (26-49 kcfs) discharges from Gavins Point Dam, Yankton, South Dakota. p. 81

# INTRODUCTION

Shovelnose sturgeon (*Scaphirhynchus platorhynchus*) was studied because 1) it is a bottom-oriented (benthic) species that is part of a benthic fishes assemblage that may be declining in abundance (Hesse et al. 1993, Berry and Young 2001), and 2) the shovelnose sturgeon is a potential model for the pallid sturgeon (*S. albus*), which is endangered (Ruelle and Keenlyne 1994). Shovelnose and pallid sturgeon are native fishes of the Missouri River where the aquatic and floodplain habitat, sources of nutrients, fish community, and river discharges have changed (Hesse et al. 1989, Hesse and Sheets 1993, Becker and Gorton 1995, Schneiders 1999).

Our study was designed to investigate the relation between discharge and sturgeon diet downstream from Gavins Point Dam where river discharge is controlled (Figure 1), and was concomitant with a similar study in the Missouri River in Montana where annualdischarge patterns are relatively natural (Megargle and White 1997). Other differences are that substrates are primarily sandy and silty with a burrowing (benthic) invertebrate community in the South Dakota reach compared to a primarily rocky substrate with an attached (aufwuchs) community in the Montana reach. Our study was to repeat, as much as possible, that of Modde and Schmulbach (1977) who found that the diet of shovelnose sturgeon downstream from Gavins Point Dam was made up of drift organisms when discharge decreased, and benthic organisms when discharge increased.

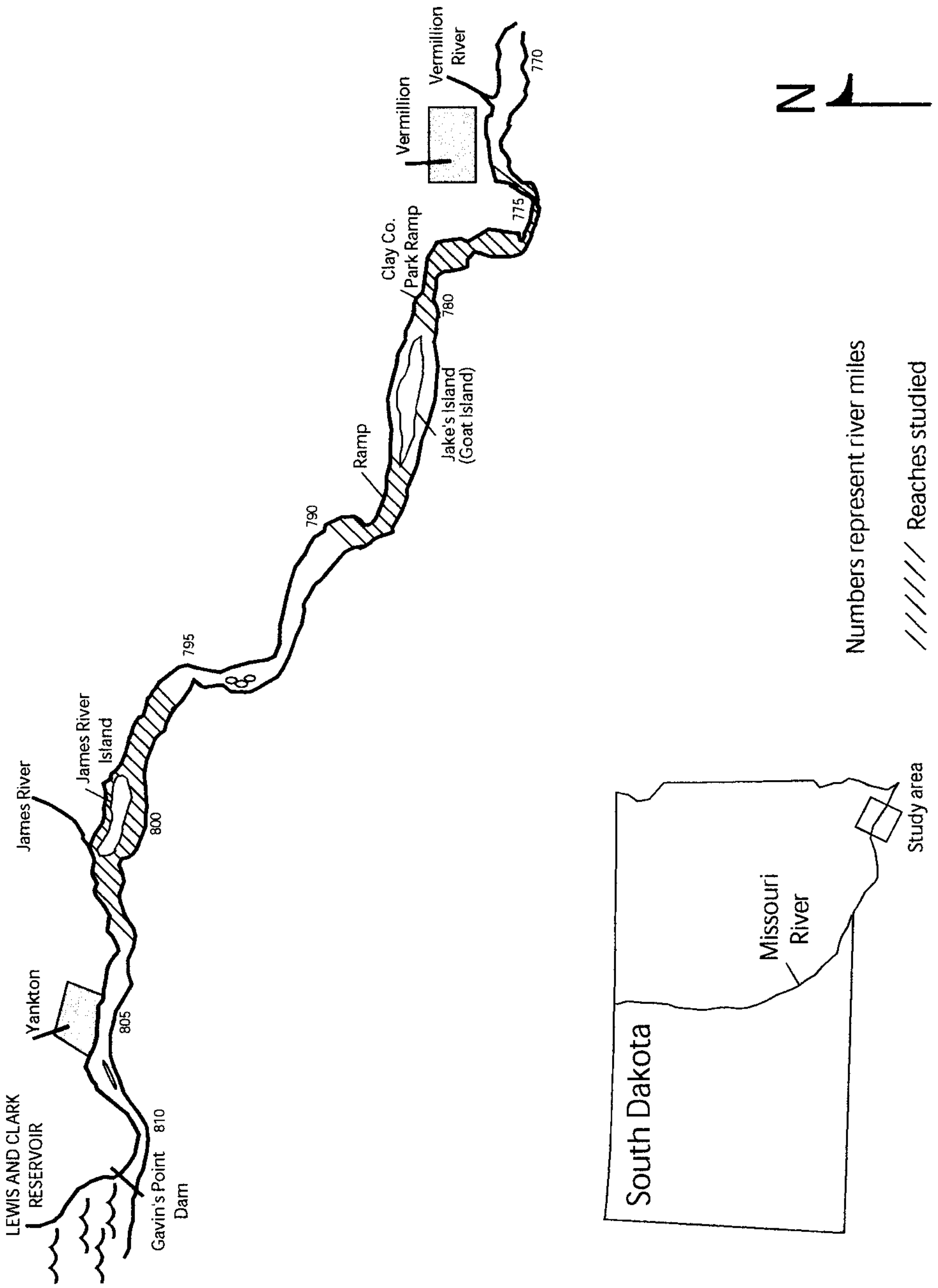


Figure 1: Map of the study area on the Missouri River from Gavins Point Dam near Yankton, SD to Vermillion, SD. Exact locations of pools was marked on Corp of Engineers aerial graphs (Aug. 10, 1989) that are archived at South Dakota State University, Department of Wildlife and Fisheries Sciences.

Increased discharge can influence fish feeding by reducing the size and shape of the search space (reviewed by O'Brien and Showalter 1993, Tyler 1993), and quality of the benthic and drifting forage (Walburg et al. 1971, Modde and Schmulbach 1977, Weisel 1979). Shovelnose sturgeon may seek slack-water areas in part because the areas concentrate benthic invertebrates (Latka et al. 1995).

The _hypothesized relationship_ between discharge and the invertebrate community is: when discharge and water levels decline in the fall, invertebrates are flushed or drift (migrate) from backwaters and side channels. Eddies and pools beside the main channel produce dense invertebrate communities because substrates are stable and organic, and drift accumulates there, thus being both abundant and accessible to sturgeon that actively feed during fall and winter. When natural or managed discharges increase in the spring, the drifting invertebrate community is less dense (diluted) than in winter, and individual invertebrates drift too fast for sturgeon to capture. Sturgeons respond by becoming more benthivorous, as might be predicted by optimum foraging theory (Tyler and Calow 1985, Gerking 1994). However, _benthic_ invertebrates (e.g., midges) have a smaller body size than those in the drift (e.g., mayflies and caddisflies), and are also scarce in the shifting sand substrate. Consequently, benthic feeding results in reduced diet biomass for sturgeon, and a change in stomach contents from large invertebrates (e.g., mayflies and caddisflies) to small midge larvae and sand. Two factors that sometimes confound the hypothesized relationship between discharge and invertebrate community metrics (diversity, biomass) are water temperature and invertebrate life cycles.

*Goals and Objectives*

Our goal was to determine the relationship between shovelnose sturgeon diet and discharge. We tested the working hypothesis that increased discharge and river level decreased the amount of food consumed by shovelnose sturgeon, possibly because of reduced availability and accessibility of invertebrate prey.

Our objectives were to compare sturgeon diets with discharge levels from March through November of two years (1993 and 1994), to compare diets among three years (1972, 1993, 1994) that differed in discharge from Gavins Point Dam, and compare the composition and quantity of organisms in the benthos and drift among discharge levels and among three macrohabitats.

Application of the data relates to managing Gavins Point Dam to maintain the services of the dam while conserving the population of shovelnose sturgeon and to increase our understanding of shovelnose sturgeon ecology in a regulated river.

## Literature Review

Fish diets depend on two major factors - **the prey**, which for shovelnose is aquatic and terrestrial invertebrates, and **the predator**. Modde and Schmulbach (1973, 1977) reported on the invertebrate community in the South Dakota portion of the river in the 1973 paper, and on sturgeon diets in the 1977 paper. They discussed how discharge might affect the prey, specifically the accessibility (drifting speed) of invertebrates, and the number and kinds of invertebrates in the drift and benthos.

### *Flow and fish behavior*

Flow (e.g. discharge, stage, water velocity) can affect sturgeon in many ways. Most studies of sturgeon response to flow have been to investigate environmental requirements for spawning migrations (Kohlhorst 1976, Hurley et al. 1987, Kieffer and Kynard 1993) or habitat selection (Hurley et al. 1987, Erickson 1992, Latka et al. 1995, Quist et al. 1999, Bramblett and White 2001). In general, shovelnose sturgeon do not migrate great distances, and usually have modest movements upstream in the spring and downstream in the fall in the Platte River (E. Peters, University of Nebraska, personal communication), Yellowstone River (Bramblett and White 2001), Kansas River (Quist et al. 1999), and Pool 13 of the Mississippi River (Hurley et al. 1987). During high flows (about 1 m/s), shovelnose sturgeon move out of the main channel to velocity refuges such as tributary mouths, inside bends, and behind wing dams along the channel border (Latka et al. 1995, Quist et al. 1999). An exception in Pool 13 occurred during drought years when flow was exceptionally low, at which time shovelnose sturgeon remained in the channel of the more riverine portion of the pool (Curtis 1990, Curtis et al. 1997).

Discharge can also influence fish feeding. The location space in which a visual predator responds to prey is semicircular, and current velocity, debris, and turbidity can reduce the size and shape of the search space (reviewed by O’Brein and Showalter 1993, Tyler 1993). Shovelnose sturgeon usually forage benthically using sensory organs on the snout, barbels, and mouth (Weisel 1979), but are also opportunistic (Walburg et al. 1971), presumably using sight to feed on drifting insects when river discharges are low (Modde and Schmulbach 1977).

Discharge may affect shovelnose sturgeon diet. Latka et al. (1995) hypothesized that shovelnose sturgeon seek slack-water areas in part because the areas concentrate benthic invertebrates. The diet of shovelnose sturgeon downstream from Gavins Point Dam was made up of terrestrial insects and drifting Tricoptera (69%) when discharge decreased, and benthic chironomids when discharge increased (Modde and Schmulbach 1977).

However, shovelnose sturgeon in a natural area of the upper Missouri River above Fort Peck Reservoir were opportunistic feeders on aquatic invertebrates (e.g., trichopterans, ephemeropterans, dipterans, plecopterans), and, while diet biomass was positively related to discharge, diet composition was not related to discharge (Megargle 1997, Megargle and White 1997).

### *Sturgeon life history*

The shovelnose sturgeon is an ancient species that inhabits rivers of central North America. Its life history and status was reviewed by Keenlyne (1997). Its range includes the large rivers of the Missouri, Mississippi, and the Ohio river basins (Bailey and Cross 1954). Shovelnose sturgeon are long-lived fish with a subterminal mouth (Weisel 1979) well suited to eat riverine benthos (Hoopes 1960, Held 1969, Walburg et al. 1971, Modde and Schmulbach 1977, Carlson et al. 1985). Studies have been done on reproduction (Henry and Ruelle 1992), contaminant burden (Ruelle and Keenlyne 1992), and taxonomic confusion with the pallid sturgeon (Bailey and Cross 1954, Keenlyne et al. 1994). Modde and Schmulbach (1977) stated that shovelnose metabolism must be high in winter because full stomachs in winter indicate active feeding, which is triggered by active digestion and metabolism.

Shovelnose sturgeon in the Mississippi River basin used main-channel border habitat and in-stream structures that Hurley et al. (1987) called preferred activity centers. Shovelnose seem to prefer discrete riverine reaches, but move between the activity centers within a reach (Helms 1974, Hurley et al. 1987). Shovelnose sturgeon are also found in sandbar pools (Schmulbach et al. 1975) and tributary confluences of the Missouri River (Latka et al. 1994). In the Kansas River, most overwintering shovelnose sturgeon avoided outside bends where velocity was >0.8 m/s, and were located over sandy substrates in channel crossovers and inside bends where velocity was 0.02-0.79 m/s (Quist et al. 1999, Quist and Guy 1999).

Shovelnose sturgeon behavior is sometimes explained by prey accessibility and abundance, but such explanations usually lack data on the prey. For example, Hesse et al. (1989) suggested that modified discharges may change the benthos and drift, thus altering feeding opportunities and behavior. Latka et al. (1995) speculated that one reason shovelnose sturgeon moved from the main channel into tributaries was because the swift discharges in the channel prevented the concentration of benthic invertebrates. Shortnose sturgeon (*Acipenser brevirostrum*) in the Connecticut River used areas where hydraulic conditions favored their preferred molluscan food (Buckley and Kynard 1985, Kieffer and Kynard, 1993).

### *Benthos and drift*

Benthic invertebrates (termed benthos) live in, under, or on the substrate (e.g. sand, rocks, woody debris). Morris et al. (1968) distinguished between aufwuchs (living on rock surfaces), benthos (burrowing in bottom sand and mud), and drift (drifting in the current). Most macroinvertebrates remain hidden during the day and increase activity at night when they may enter a second invertebrate community -- the drift (Waters 1972, Koetsier and Bryan 1995). Drift may be purposeful or accidental.

Purposeful drift is a behavioral trait that includes drifting to reach new food sources, to migrate downstream as a developmental stage cohort, or to avoid high-density communities. Accidental drift is due to dislodgement from the substrate, or scouring of benthic organic material. The expected positive relation between discharge velocity and drift is not always found (reviewed by Allen 1995, Petts and Calow 1996). Petts and Calow (1996, page 224-225) stated that there is little doubt that changes in velocity pattern result in increased drift, but rate of change may be important. Rapid increases during hydropower peaking cause catastrophic drift of insects and fish larvae (Cushman 1985, Irvine 1985), but releases simulating large floods may (Rempel et al. 1999) or may not (Cushman 1985) increase drift. Fluctuating discharge in the Missouri River did not increase the number of invertebrates leaving artificial substrates (Troelstrup and Hergenrader 1990). Increased flows after spates scour sand and sediment and add to the effects of velocity by causing more animals to drift (Marmonier and Chatelliers 1991). Certain types of regulated discharges can increase invertebrate production (Morgan et al. 1991).

Drift also increases when river velocity drops too low. Drift increases when low velocity tolerances of insects are exceeded (Petts and Calow 1996). Low-flow drift may explain the increased drift seen by Modde and Schmulbach (1973) from dewatered areas in the fall.

Settling out of drifting animals in pools may serve as a major brake on downstream transport but the few studies provide little support for this proposition (summarized by Allen 1995, p 226). Benthic macroinvertebrates shifted from deep water to shallow water of the shore zone (a flow refugium) during annual flooding of a large, gravel-bed river (Rempel et al. 1999). Any benthic invertebrate may at some time be captured in the drift, but some taxa are particularly common. Among the insects, many of the Ephemeroptera, some Diptera, and some Plecoptera and Tricoptera are common components of the drift, in roughly that order (Allen 1995).

### *Missouri River macroinvertebrates*

The benthos and drift in the Missouri River have been studied with particular reference to differences in benthic biomass in different riverine macrohabitats. In the Missouri River upstream from Fort Peck Dam, invertebrate communities (number of family groups, relative weight, biomass) differed only slightly among benthic habitats. Ephemeroptera, Diptera, Plecoptera, and Tricoptera were the dominant orders in the benthos of main channel, shoreline (shallow zone) and side-channel macrohabitats (Megargle 1997). These groups also dominated the drift without evidence of a relation between temperature or discharge. Most of the river substrate was rock and cobble, which would support an aufwuchs community but not a benthic (burrowing) community. Also, Megargle reported that there was a lack of “settling eddies and backwaters” regardless of discharge.

In North Dakota reaches of the riverine Missouri, the benthos was characterized in main channel, channel border, side channel, backwater and tributary confluence macrohabitats. A total of 138 species representing 69 families and 18 orders were identified. Samples were dominated by Diptera (46%), of which 96% were chironomid midges. Oligochaeta (41%), Gastropoda (6.2%) Trichoptera (1.6%) and Ephemeroptera (1%) were also present (Mizzi 1994, Mizzi and Berry 1994).

In the South Dakota segment of the river that was the focus of our study, the first investigations into the benthos and drift communities began after Gavins Point Dam closed (reviewed by Nord and Schmulbach 1973). We concluded that 1) there was little similarity between the taxonomic composition of the drift and the mainstream benthos, and 2) terrestrial taxa accounted for about 20% of the drift standing crop. Drift in the unchannelized river along the South Dakota-Nebraska border was 8 times greater than that in the channelized river along the Iowa-Nebraska border. Most of the benthic standing crop was in cattail marshes rather than in chutes and backups (Volesky 1969). The invertebrate biota on artificial substrate multiple-plate samplers varied only slightly among five sites (Nord and Schmulbach 1973). Caddisflies were the dominant group on the samplers (about 80% of the standing crop) followed by ephemeropterans, chironomids and simuliids (black flies). Samples placed in slow water had greater species diversity at each of the five sites, whereas fast-water samplers had larger standing crops. Mestl and Hesse (1993) summarized their own work and that of six other authors to conclude that benthic production from main channel, chute, and backwater habitats in the 93-km section of the unchannelized Missouri River along the South Dakota-Nebraska border declined 61% between 1963 and 1980. In contrast to river reaches in Montana where gravel dominated the substrate (Megargle and White 1997), the South Dakota river bottom substrate is primarily sand in flowing water areas and silt in low flow backwaters and pools.

In the middle Missouri River, there were differences in densities and taxonomic composition of the benthic invertebrate communities in abandoned channels, the main active channel, dike pools, and revetment habitats (Atchison et al. 1986). The abandoned channel habitats were characterized by finer sediment particles, higher benthos densities, and a lower number of taxa than on rock substrates in higher velocities of other macrohabitats.

*Literature synthesis*

Shovelnose sturgeon make modest migrations, moving upstream in the spring to spawn and downstream later. They use all major macrohabitats of a river throughout the year, including tributary confluences, inside bends, backwaters, and chutes. Shovelnose sturgeon are insectivores that are built to feed on the bottom, but their diet includes drifting insects, primarily trichopterans, ephemeropterans, dipterans, and plecopterans in the Missouri River. The invertebrates of the Missouri River are well known and major groups in the benthos are usually found in the sturgeon diet, but order of importance may change depending on river reach.

Modde and Schmulbach (1977) proposed that monthly changes in discharge might affect the accessibility (drifting speed) of invertebrates, and the number and kinds of invertebrates in the drift and benthos. Their key point was that discharge and temperature were inversely related to stomach biomass. When discharge was high (>850 $m^3$/sec, 30,000-40,000 cfs) in spring, summer and fall, mean stomach biomass was <2 g. During low flows in December through March (566 $m^3$/s; 20,000 cfs), stomach biomass increased to 6-8 g. Megargle and White (1997) found the opposite: as monthly discharge increased from about 6,000 cfs in April to 16,000 cfs in June/July, diet biomass increased. In Megargle’s study, stomach biomass was correlated with discharge ($P=0.004$, $R^2=0.83$) but no relation was evident with temperature. The difference between the two studies may relate to changes in the natural hydrograph (Montana) vs controlled dam releases (South Dakota). Also, maximum discharge was 16,000 cfs in Megargle’s study in Montana, and was 40,000 cfs in Modde’s study in South Dakota.

## METHODS

*Location and study sites*

Sturgeon were collected monthly from June through September and in November in 1993, and from March through September in 1994. Fish were collected in three areas below Gavins Point Dam: 1) Yankton area, river mile 803.3-796 2) Highline area, river mile 790-785 and 3) Clay County Park area, river mile 782-771.5 (Figure 1). This reach retains some of the natural character of the historic Missouri River (i.e., snags and woody debris, braided channels, sand bars, undeveloped riparian zone), and is in the National Recreational River section downstream from Gavins Point Dam (Schmulbach et al. 1981, NPS 2000). Water quality and quantity are somewhat unnatural because flows are controlled by the upstream dam. Water from Gavins Point Dam is probably clearer and cooler than was natural, and flow regulation has changed hydrologic characteristics, such as reducing the magnitude and duration of the flood pulse, and increasing the annual discharge minima (Galat and Lipkin 2000).

We collected fish from two types of pools and from chutes. Type I pools (<1 ha) were located immediately behind sandbars, and usually had sandy substrates. Our Type I pools were similar to pools sampled by Modde and Schmulbach (1977). Type II pools were also behind sandbars but were larger than Type I pools and had substrates composed of organic matter during low discharges and sand with some detritus during high discharges. Type III habitat (chutes) were secondary channels that had greater velocity than pools, and were located within sandbar complexes or near rare hard points. Chute substrate was usually sand and gravel. Missouri River sandbar habitat is quite changeable as it responds to flow variation and vegetation encroachment.

*Fish collection*

Experimental monofilament gill nets (1.9-3.8 cm, bar mesh) were used to capture shovelnose sturgeon in all habitats. Nets were set parallel to the current in depths from 1-3 m. Nets were usually set overnight but a few nets were set for 5 h during mid-day. We used other gears (electrofishing, set line angling, drifting nets) in August and September of 1994 when sturgeon catch rates were low, probably because fish were more dispersed during those months than during other times of the year (Modde and Schmulbach 1977).

Fish were killed with a blow to the head, measured (standard length, mm), weighed (g), and opened to remove the alimentary tract, which was fixed in 10% formalin. In the laboratory, biota in stomachs were separated from detritus and sand, and preserved in 70% ethanol. Fish condition (C) was calculated as $C_{SL}=(W/L^3)x10,000$.

We separated diet organisms by order and used the key of Merritt and Cummins (1984) to further identify aquatic flies (Diptera) and caddisflies (Trichoptera) to family. After we identified and counted diet items, organisms were dried at 65°C for 24 h, and then weighed to the nearest 0.1 mg. Detritus and sand in the stomach were combusted for 45 minutes at 550°C and then weighed. Data were recorded as mg dry weight.

*Invertebrate collection*

Benthic samples were collected using a ponar dredge (15 cm x 15 cm). Five dredge samples were taken at the end of each gill net set over sandy substrates, whereas only one sample was taken if the net end was over soft organic material. We collected only one dredge sample from organic substrates because of the large volume of material to sort. Dredged material was placed with water in a 19-L pail and mixed. The suspended material was filtered through a sieve (#100 U.S. Standard Testing Sieve, 149 mm aperture) to collect invertebrates. The filtering process was repeated five times, enough to remove most of the organic matter from the sand. Sieved material was placed in a plastic bag and fixed in 10% formalin.

Drift samples were collected near the surface and near the bottom at dusk. A Wisconsin-type conical net (0.2 $m^2$ opening) was deployed for 10 min at each depth from a boat anchored in a secondary channel near the Clay County Park dock. The volume of water passing through the net was the product of the opening size ($m^2$), velocity (m/s), and time (s). Velocity was determined using a Marsh-McBirney current velocity meter. The collected material was emptied into a pail with water, sieved through a #100 sieve, placed in a plastic bag, and fixed in 10% formalin.

Benthic and drift organisms were manually separated from other material under a dissecting microscope. Organisms were picked from debris and identified to order and family as was done with stomach contents. Benthic data were reported as $mg/m^2$ and drift data were reported as $mg/m^3$ dry weight. Overall, our methods were essentially the same as those used by Modde and Schmulbach (1977).

### *River discharge*

We obtained discharge data for our study and for that of Modde and Schmulbach (1977) from records of the U. S. Geological Survey. Mean monthly discharge refers to the average discharge for a 30-d period prior to fish collection for each month. We report discharge as thousand cubic feet per second (kcfs) and provide in Appendix A conversions to the metric system. We labeled the years as low, medium, and high discharge as shown in the following table.

| Year | Discharge (kcfs) | Discharge label |
|---|---|---|
| 1971-72 | 26-49 | high |
| 1994 | 18-31 | medium |
| 1993 | 9-22 | low |

*Experimental design and analyses*

One objective was to compare our data from March through November, 1993 and 1994, with data collected by Modde and Schmulbach in 1971 and 1972. Our study began in June 1993 so we could not duplicate their samples for March, April, and May, and Modde and Schmulbach did not collect fish for all 12 months of one year. Consequently, our final design to evaluate the influence of the independent variables "mean monthly discharge" and "year" was as follows:

| Flow | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov |
|---|---|---|---|---|---|---|---|---|---|
| High | 1972 | 1972 | 1972 | 1972 | 1972 | 1972 | 1972 | 1971 | 1971 |
| Med | 1994 | 1994 | 1994 | 1994 | 1994 | 1994 | 1994 | ---- | ---- |
| Low | ---- | ---- | ---- | 1993 | 1993 | 1993 | 1993 | ---- | 1993 |

We compared dependent variables (stomach content weight, mg; benthic biomass, mg/m$^2$; drift biomass, mg/m$^3$) among years using multiple t-tests, and among habitats and months within years using analysis of variance (ANOVA). Modde’s data set was compared with our 1993/94 data set using multiple t-tests because monthly means were the only values reported. A Bonferroni multiple comparisons procedure was used when differences ($P \leq 0.05$) were detected for main effects. Comparison between habitat types was precluded when interaction with year and month was encountered. Pearson correlations ($r$) were used to examine relationships of the dependent variables with discharge and water temperature.

We used Ivlev's electivity index (Ivlev 1961) to evaluate the selectivity of shovelnose sturgeon for four diet items: Chironomidae, the chironomid genus *Chernovshkiia*, benthic Ephemeroptera, and drifting Hydropsychidae. Ivlev’s index compares the relative abundance of food items with abundance in the environment. Values range from -1 (avoidance) to +1 (selection); values near zero indicate opportunistic feeding. We used Morista's similarity index (Morista 1959) to compare the proportion of diet items to their proportion in the benthos where fish were captured. Morista values range from 0 to +1 with numbers above +0.7 indicating high similarity. All statistical outputs and other data are archived at SDSU.

# RESULTS AND DISCUSSION

*Fish*

We collected 100 shovelnose sturgeon from June through November 1993. Fish length ranged from 445 to 657 mm; weights ranged from 328 to 918 g; condition ranged from 0.32 to 0.35 (Appendix B). The $\log_{10}$ of length and weight were related ($r^2$=0.80; Appendix K). Sample size was adequate (14-33 fish) for all months, except August (6 fish) when fish were difficult to capture, despite doubling effort (Appendix B).

In 1994, we collected 103 fish from March through September. Fish ranged in length from 408 to 656 mm; weight range was 208-1,222 g; condition ranged from 0.33 to 0.39 (Appendix B). The $\log_{10}$ of length and weight were related ($r^2$=0.75; Appendix L). Sample size was adequate (10-30 fish), except during late summer when fish were difficult to capture (only 2 fish in July). In August 1994, we captured seven fish in gill nets and obtained three fish from University of South Dakota students who were electrofishing in the area (Appendix B).

Modde and Schmulbach (1977) used data from 130 stomachs collected monthly from October 1971 to September 1972. Their fish ranged in length from 450 to 600 mm fork length and in weight from 298 to 805 g. Condition factors ranged from 0.31 to 0.36 (Appendix B).

We collected five fish that had been tagged in 1980 by Dr.

James Schmulbach, University of South Dakota, Vermillion. The fish were recaptured within about 15 km of his tagging site. In 13 years, four fish grew about 12 mm in standard length, and one fish was 11 mm shorter than when tagged in 1980 (Table 1). Two fish gained weight; three lost. Such slow growth was also noted by Schuckman (1982) who made population estimates of shovelnose sturgeon in the South Dakota reach of the Missouri River. During his survey, he recaptured 10 fish that had also been tagged a decade earlier by Schmulbach. The fish had grown about 0.9 mm/yr in standard length (range=0-22 mm), and about 5.6 g/yr in weight (range=3.9-166.4 g)(Schuckman (1982). Six tagged fish recaptured in the Montana study showed an average annual fork length increase of 4.7 mm/year (SD=8.5) (Megargle and White 1997), which is a faster growth rate than we found.

### *Sturgeon diet biomass*

Average dietary biomass from March through November ranged from 83 to 375 mg in Modde's study and from 69 to 2,166 mg in ours (Table 2, Figure 2). The value for stomach contents in March 1994 (2,166 mg) was 10 times that of other months and was, of course, significantly higher than the diet in other months (Table 2). Megargle and White (1997) also found higher diet weight in November (and in April and May) than in summer months.

There were significant differences among months in 1993

(*P*=0.006, F=3.8) and 1994 (*P*=0.0001, F=71.2), but not between years (t=-1.28, *P*=0.877). Diet weight was not related to temperature or discharge (see box below), especially after the high diet values for March were removed from the analysis (Figure 14).

| **Year** | **Temperature (°C)** | **Discharge (kcfs)** |
|---|---|---|
| 1993, Low | *r*=0.48 | *r*=-0.13 |
| | *P*=0.414 | *P*=0.839 |
| 1994, Medium | *r*=-0.75 | *r*=-0.73 |
| | *P*=0.054 | *P*=0.066 |

Our working hypothesis that low discharge would concentrate invertebrates allowing sturgeon to feed more effectively was not supported. Modde sampled year-round whereas we and Magargle (1997) only sampled during open water months. Consequently, Modde's range of discharges was 40 kcfs whereas our maximum range was 12 kcfs and Megargle's was 11 kcfs (see box).

| **Study/year** | **Duration** | **Discharge (kcfs)** |
|---|---|---|
| Modde | Oct. 71-Sept. 72 | 26-49 |
| Megargle | April-Oct. 1993, 1994 | 5-12, 6-17 |
| This study | March-Nov. 1993, 1994 | 9-22, 18-31 |

Modde found the highest weight of stomach contents in the winter months of December, January, and February, as did Moser and Ross (1995) for Atlantic sturgeon (*Acipenser oxyryhnchus*). We did not sample during winter because of ice, but we did collect fish just after ice melted in March 1994. We found fish with very full stomachs, so we tentatively agree with Modde that fish feed heavily in the cold-water winter months. The amount of drifting invertebrates was also very high in March, 1994 (Figure 13), and might have been caused by the scouring effects of the ice break-up (Scrimgeour et al. 1994). Shortnose sturgeon (*Acipenser_brevirostrum*) also had maximum stomach fullness in spring when river temperatures reached 10°C (Dadswell 1979).

Sturgeon ate aquatic macroinvertebrates from 11 orders, but also ate four kinds of terrestrial insects and a few fish (Appendix C). About 48% of the stomach contents were midge larvae (family Chironomidae); an additional 17.4% were other aquatic flies (Order Diptera). We agree with Modde and Schmulbach (1977) that midges are more abundant in the diet during summer months than during fall and spring, increasing from about 30% of the diet in March to about 60% in summer months in all three years (Figure 3). Midge weight also varied significantly among months in 1993($P$=0.004, F=4.2) and 1994 ($P$=0.0001, F=10.5; Table 3). In Montana, diets also consisted of aquatic and terrestrial invertebrates and a few fish larvae in 1993, which was the year with the lowest flows. Dominant orders were Ephemeroptera, Trichoptera, Plecoptera, with Diptera making up 8.6-10.5% of gut content biomass depending on year. Montana shovelnose sturgeon consumed prey in proportion to their availability, and more sprawling and crawling invertebrates were available because there was more rocky substrate (94%) than in the South Dakota river reaches.

Caddisflies in the Family Hydropsychidae made up about 15% of the diet with other caddisflies (Order Trichoptera) making up another 2% (Appendix C). We confirmed Modde and Schmulbach's (1977) finding that hydropsychid numbers decreased in the diet in the summer as the percentage of midges increased, dropping from about 40% of the diet in March to about 5% in summer months, then increasing to 40% again in the fall (Figure 4). Hydropsychid weight in the diet changed among months in 1993 (*P*=0.003, F=4.3) and 1994 (*P*=0.0001, F=16.0; Table 3).

Mayflies (Ephemeroptera) were less abundant in the diet than midges, but similar to caddisflies (13%; Appendix C), with higher percentages being utilized in late summer (Figure 5). The proportion in the diet was different among months in 1993 (*P*=0.002, F=4.5) and 1994 (*P*=0.0001, F=10.7; Table 3).

Modde suggested that more sand appeared in the stomach when sturgeon probably increased foraging effort in May and June when drift and benthic biomass was low. We did not see the same trend (Appendix N). Our findings and Modde's are summarized as follows:

| Year | Discharge | Mean sand (mg) in stomach (range) |
|---|---|---|
| 1993 | low | 250 mg (131-406) |
| 1994 | medium | 373 mg (112-729) |
| 1972 | high | 194 mg (68-472) |

Electivity values suggest that shovelnose sturgeon are opportunistic feeders (Table 4). Values for Chironomidae were mostly negative, while values for *Chernovskiia* were mostly positive. Most electivity values for mayflies (Ephemeroptera) were negative in 1993, but usually positive in 1994. Fish in our study and in that of Modde and Schmulbach (1977) seemed to select drifting caddisflies (electivity > 0.79; Table 4) in March. After March; however, most electivity values are negative and many are >-0.5. Modde and Megargle reported that sturgeon ate invertebrates in proportion to their occurrence when the taxon was abundant, which would also indicate opportunistic feeding behavior.

Chironomidae and Ephemeroptera often dominate the benthos in lotic systems (Merritt and Cummins 1996), as is the case in our study area (Modde and Schmulbach 1973). While the ventrally protrusible mouth of shovelnose sturgeon is designed for benthic foraging, the burrowing habits of many midges and some mayflies (e.g., Ephemeridae) may make them less susceptible than other benthos to sturgeon predation. However, burrowing insects would be collected by our ponar dredge, thus explaining some of the negative electivity values for midges and mayflies.

Filter-feeding caddisflies (Hydropsychidae) were very abundant in our study area, especially *Hydropsyche orris* (Modde and Schmulbach 1973, Nord and Schmulbach 1973). Hydropsychidae require stable substrate (i.e. snags) for attachment in systems dominated by sandy bottoms (Benke et al. 1984, Lillie and Hilsenhoff 1992). Sturgeon may only forage on hydropsychids when their drift densities are high, as occurrence in the benthos would be low over the sandy, unstable substrate where sturgeon were typically collected. This may partially explain the high electivity values in March, while values were negative in other months.

### *Benthic invertebrate biomass*

Eleven orders of aquatic invertebrates and a few representatives of four terrestrial orders were found in the benthic samples (Appendix C). Benthic biomass was dominated by midges, mayflies, and caddisflies. Midges made up 20-90% of the community in 1993 and 1994 (Figure 6). This finding agrees with that of Modde and Schmulbach (1973) who found that of the nine invertebrate taxa in the benthos, two midge families (Chironomidae, Ceratopogonidae) made up 88% of the weight and 98% of the number. Caddisflies usually made up 20-40% of the benthos in summer months, but in other months made up a smaller portion (Figure 7). Mayflies (Figure 8) showed a similar trend of summer maxima, and were especially abundant (about 50% of the benthic biomass) in the low-flow year of 1993. While midge biomass differed between months in 1993 (*P*=0.001, F=5.2) and 1994 (*P*=0.001, F=4.5), standard errors for caddisflies (Hydropsychidae) and mayflies (Ephemeroptera) were large and thus, differences among months were not significant (*P*>0.4, Table 5).

A taxonomic issue arose during our study. Modde and Schmulbach (1977) identified the dominant midges as belonging to the family Ceratopogonidae (biting midges or no-see-ums), but we found many midges in the family Chironomidae, mostly *Chernovskiia*, which was not described by invertebrate taxonomists until 1977. The invertebrate taxonomist who assisted Modde (Mr. Pat Hudson, see Hudson 1971) identified our dominant midges as belonging to the genus *Chernovskiia*. Therefore, midges in the chironomid genus *Chernovskiia* probably dominated the benthos (and sturgeon diet) in both studies. Midges inhabit flowing water in areas well protected from the dislodging influence of current (Teskey 1984).

There was a difference among years in the biomass of benthic invertebrates that suggests a negative relationship between discharge and benthic biomass (Figure 9). In the year when discharge was low, benthic biomass was high. Statistical analyses showed that benthic biomass was significantly higher in the medium-flow year than in the high-flow year (multiple T-test, t-3.47, *P*=0.013, df=6), and also higher in the low-flow year than in the high-flow year (Table 6). However, a discharge-benthic biomass relationship was not apparent when discharges (average for 30 d prior to sampling) within years were examined (Table 6). Pearson correlations (*r*) between discharges prior to sampling and benthic biomass at sampling were negative for the low-flow (1993) and medium-flow (1994) years. However, there was a general trend toward higher benthic biomass in summer months, which is probably because of recruitment and growth (Allen 1995). There was no correlation between river temperature (Appendix M) at the time of sampling and benthic biomass:

| Year | Temperature (C°) | Discharge (kcfs) |
|---|---|---|
| 1993 | *r*=0.05/*P*=0.943 | *r*=0.28/*P*=0.657 |
| 1994 | *r*=0.35/*P*=0.443 | *r*=0.41/*P*=0.357 |

*Invertebrate drift biomass*

We found organisms representing various orders of aquatic and terrestrial insects in the drift (Appendix E). Our data and those of Modde and Schmulbach (1973) agree that drift is dominated by more types of organisms than is the benthic community. Present in proportions >13% were aquatic flies, dipteran pupae, caddisflies, mayflies, and beetles. We sampled the benthic community resident in sand and silt/coarse organic material on the river bottom. Other sources of drifting organisms would be 1) those from rocky substrates (e.g., natural gravel bars and unnatural rip rap), 2) snags and other large woody debris, and 3) terrestrial sources. Megargle found so few invertebrates in the drift (0-4/$m^3$) that he suggested that sturgeon do not use the drift community.

The biomass of dipterans, caddisflies, and mayflies varied among months ($P<0.01$; Table 7), except for hydropsychids during the medium flow year ($P=0.4$). These three groups made up about 65% of the weight of drifting organisms in our study and about 85% of that reported by Modde and Schmulbach (1973). Modde and Schmulbach (1973) found 48 drifting taxa of which 80% were aquatic and 20% terrestrial.

The percentage of all aquatic fly larvae (Order Diptera) in the drift was inversely related to the percentage of caddisflies over the course of the study (compare Figures 10 and 11). Mayflies appeared in the drift in highest biomass in the summer (Figure 12), and they also had highest biomass in the benthos in the summer (Figure 8).

Drift weight did not differ when low (1993) and moderate (1994) discharge years were compared (Table 8, Figure 13) as

Modde hypothesized. However, Modde found drift biomass differences among months when water levels suddenly changed. We also found differences in drift biomass among months (Table 8) in 1993 (*P*=0.0001, F=7.19) and 1994 (*P*=0.0001, F=19.07).

In 1993, there was no significant correlation between drift and discharge or between drift and temperature, but in 1994, stronger relationships were apparent (see table below):

| Variable | 1993 Low Flow | 1994 Moderate Flow |
|---|---|---|
| discharge | *r*=-0.29/*P*=0.64 | *r*=-0.76/*P*=0.049 |
| temperature | *r*=0.5/*P*=0.38 | *r*=-0.79/*P*=0.037 |

The general pattern was higher drift biomass in summer than in fall and spring (Figure 13). Modde stated that increases in drift during the summer months were due to temperature increases (he reported *r*=+0.9) and more invertebrate movement. Drift biomass depends on various factors including temperature, invertebrate population density, and discharge (Ciborowski 1987).

### *Habitat influences*

The shovelnose sturgeon we collected probably moved through each kind of habitat (small pools, large pools, chutes) on a diurnal and seasonal basis. Megargle found sturgeon in all sampled macrohabitats (e.g., eddies, scour holes, main channel) and assumed that they did not feed only where they were collected (Bramblett 1996). Shovelnose in other rivers preferred discrete riverine reaches, but moved between activity centers within a reach (Helms 1974, Hurley et al. 1977, Curtis et al. 1997). Interactions among month, year, and habitat type prevented us from examining main effect differences in habitat types (Table 9). However, Morista index values were >0.6 for 51% of the comparisons between diet composition and benthos composition, thus indicating some similarity between the kinds of benthic items eaten and the kinds of items available in the benthos where the fish were collected (Appendix F). In other words, some fish appeared to be caught where they were eating.

Because the bottom substrate differed among habitats, we predicted that the biomass in the benthos might also vary among habitats. Benthic biomass was higher in large pool habitat (Type II) than chute habitat (Type III) ($P$=0.047, F=3.13; Table 10). Small pools (Type I) with sand substrates yielded an invertebrate biomass averaging about 69 mg/m$^2$ (range=9-168 mg/m$^2$) for 5 months, whereas biomass from larger Type II pools with organic bottom material averaged about 128 mg/m$^2$ (range=5-367 mg/m$^2$). Gravel and sand bottom chutes yielded an invertebrate biomass of about 101 mg/m$^2$ (range=25-193 mg/m$^2$).

When discharge was higher throughout 1994, our medium discharge year, habitat influences on benthos weight were not as apparent (Table 10). Benthic biomass was similar in Type I pools (mean=61 mg/m$^2$) and Type II pools (mean=98 mg/m$^2$). We assumed that the higher discharges scoured Type II pools of the organic material that supported high benthic biomasses in the low-discharge year. Water velocity can influence colonization patterns of benthic invertebrates (Mackey 1992). At high discharges, substrate movement discourages colonization, whereas at lower discharges, the substrate is more stable and debris accumulates, thus promoting the influx of burrowing and clinging invertebrate guilds (Cummins and Merritt 1984, Mackey 1992).

We also noted some differences in the kinds of benthic invertebrates among habitat types during our low-discharge year (Appendix G, H, and I). Mayfly biomass was greater in large pools with organic substrates (mean=120.3 mg/m$^2$) than in sandy bottoms of small pools (mean=12.2 mg/m$^2$) or chutes (mean=5.2 mg/m$^2$). The biomass of midges tended to be higher in large pools with organic substrates (mean=50.6 mg/m$^2$) than in small pools (mean=39.2 mg/m$^2$) and chutes (mean=31.1 mg/m$^2$) where substrates were sand and gravel. Habitat influences and monthly changes in discharge did not appear to influence caddisfly benthic biomass, which was low and highly variable. However, caddisfly larvae were much more common in all habitats during years of low and medium discharge than during the high-discharge year of Modde's study.

# CONCLUSION

Most of our findings agreed with those of Modde and Schmulbach (1973, 1977). Shovelnose sturgeon are opportunistic feeders and eat aquatic arthropods, particularly larvae of the insect orders Trichoptera, Diptera, and Ephemeroptera. The drifting invertebrate community is more evenly represented by more kinds of invertebrates than is the benthic community. The quantity and quality of the drifting and benthic community depend on temperature, the life cycle of the organisms (although we have no data on life cycles), and on discharge. The results of our study, Modde's study, and that of Megargle (1994 study on shovelnose sturgeon diets in Missouri River, Montana) are summarized in the following table:

|  | Date | Number Sturgeon examined | Variable | Diet items[a] | Results[b] |
|---|---|---|---|---|---|
| Berry | 1994 | 103 | discharge | DTE | yearly diff. – NS<br>monthly diff. - S |
| Megargle | 1994 | 99 | discharge | TEDP | yearly diff. – NS<br>monthly diff. - S |
| Modde | 1971 | 130 | discharge | DTE | discharge : diet<br>*r* = -0.85 |

[a] D = midges, T = caddisflies, E = mayflies, P = stoneflies, in order of importance

[b] NS = not significant, S = significant

We contributed new information when we discovered that five fish tagged 13 years earlier had grown very little. We found that the dominant dipterans were midges in the family

Chironomidae (genus *Chernovskiia*) instead of the family Certopogonidae. Another novel contribution was our finding that substrates differed according to pool size and that sandy substrates of small pools were not as heavily colonized with invertebrates as the muddy substrates of larger pools. We also found that when discharge increases, the muddy, organic material is scoured from larger pools, thus reducing the benthic standing crop. We found that sturgeon diets were somewhat similar to the benthos in habitats (small pools, large pools, chutes) where fish were captured. However, our main goal was to investigate the relation between discharge and sturgeon diet.

Our working hypothesis was: sturgeon diet quantity and quality decreases as discharge increases because high discharges make the prey (benthic and drifting invertebrates) less available and less accessible to the predator (the sturgeon). In support of this hypothesis, we found that among months in any year, diet weight was negatively related to average discharge over the 30 days before fish were sampled in our study. Correlations factors were r=-0.13 (P=0.8) for the low discharge year (1993) and -0.73 (P=0.066) for the moderate discharge year (1994). For high discharges, Modde found a higher correlation (r=-0.85) than we found during our years of lower discharge. We have two pieces of evidence that prey changed in availability (i.e., concentration) or vulnerability (e.g., drift speed, depth in the substrate) as discharge changed. First, when discharge increased in 1994, the benthic biomass in large pools dropped 1.3X. Secondly, there was a negative relation between discharge and drift in 1994 ($r$=-0.76) and a weaker relationship in 1993 ($r$=-0.29).

Some results did not support the working hypothesis. For example, diet weight was similar among years of low, medium, and high discharge. Perhaps sturgeon change their feeding behavior or location to maximize their rate of net energy gain (Helfman 1994). In theory (Marginal Value Theorem, p 82, Tyler and Calow, 1985), an animal will abandon a habitat patch when the rate of energy gain falls to a value equal to the average net rate of energy gain in the habitat as a whole. The slow growth demonstrated by the recaptured, tagged fish, and the lack of small sturgeon (Hesse et al. 1989) in recent collections, suggests that sturgeon find enough food for maintenance, but not for growth or reproduction. Another finding that did not support the working hypothesis was that drifting invertebrate biomass was similar among years. Perhaps yearly production might be somewhat consistent at flows we examined.

Data on sturgeon behavior and energetics are needed to help evaluate the effect of discharge on diet and ultimately growth. A general model from studying other fish (salmonids, dace) is that foraging attempts vary with water velocity according to a concave relationship i.e. above some velocity, foraging attempts and success decrease (Kalleberg 1958 cited in Zorn and Seelbach 1995, Godin and Rangeley 1989, Tyler 1993, O'Brien and Showalter 1993). For shovelnose sturgeon in the modified Missouri River, it might be assumed that at some discharge the fish may have a net energy loss and slow growth, as described in principle by Tyler and Calow (1985). The Missouri River from Gavins Point Dam to Sioux City, Iowa has great habitat diversity in which sturgeon should be able to find optimum water velocity conditions for feeding, but altered forage production, water temperatures, and substrate quality may hamper foraging success.

# REFERENCES

Allen, J. D. 1995. Drift. Pages 221-237 in J. D. Allen. Stream Ecology: Structure and function of running waters. Chapman and Hall USA, New York.

Atchinson, G. J., R. Bachmann, J. Nickum, J. Barnum, and M. Sanheinrich. 1986. Aquatic biota associated with channel stabilization structures and abandoned channels in the middle Missouri River. Final Technical Report E-86-6 to the U. s. Army, Corps of Engineers, EWQOS Work Unit VA, Omaha, Nebraska.

Bailey, R. M., and F. B. Cross. 1954. River sturgeon of the American genus Scaphirhynchus: Characters, distributions, and synonymy. Paper in Michigan Academy of Sciences, Arts, and Letters 39: 169-208.

Becker, D. A., and R. D. Gorton. 1995. The Missouri River: A formula for ecosystem change. Pages 275-297 in S. Johnson and A. Bouzaher, editors. Conservation of Great Plains Ecosystems. Kluwer Academic Publishers, Boston.

Benke, A. C., T. C. Van Arsdall, Jr., D. M. Gillespie, and F. K. Parrish. 1984. Invertebrate productivity in a subtropical blackwater river: the importance of habitat and life history. Ecological Monographs 54:25-63.

Berry, C. R., Jr., and B. A. Young. 2001. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone Rivers, Vol. 1 of Introduction to the benthic fishes study. [Available at: http://www.now.usace.army.mil/html/pd-e/planning.html].

Bramblett, R. G. 1996. Habits and movement of pallid and shovelnose sturgeon in the Yellowstone and Missouri Rivers, Montana and North Dakota. Ph. D. dissertation. Montana State University, Bozeman.

Bramblett, R. G., and R. G. White. 2001. Habitat use and movements of pallid and shovelnose sturgeon in the Yellowstone and Missouri Rivers in Montana and North Dakota. Transactions of the American Fisheries Society 130:1006-1025.

Buckley, J., and B. Kynard. 1985. Yearly movements of shortnose sturgeons in the Connecticut River. Transactions of the American Fisheries Society 114:813-820.

Carlson, D. M., W. Pflieger, L. Trial, and P. Haverland. 1985. Distribution, biology, and hybridization of Scaphirhynchus albus and S. platorynchus in the Missouri and Mississippi Rivers. Environmental Biology of Fishes 14:51-59.

Ciborowski, J.J.H. 1987. Dynamics of drift and microdistribution of two mayfly populations: a predictive model. Canadian Journal of Fisheries and Aquatic Sciences 44:832-845.

Cummins, K. W., and R. W. Merritt. 1984. Ecology and distribution of aquatic insects. Pages 59-65 *in* R. Merritt and K. Cummins, editors, Aquatic insects of North America. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Curtis, G. L. 1990. Habitat use by Shovelnose Sturgeon in Pool 13, Upper Mississippi River, Iowa. M.S. Thesis. Iowa State University, Ames.

Curtis, G. L., J. S. Ramsey, and D. L. Scarnecchia. 1997. Habitat use and movement of shovelnose sturgeon in Pool 13 of the upper Mississippi River during extreme low flow conditions. Environmental Biology of Fishes 50:175-182.

Cushman, R. M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North American Journal of Fisheries Management 5:330-339.

Dadswell, M. J. 1979. Biology and population characteristics of the shortnose sturgeon in the Saint John Estuary, New Brunswick, Canada. Canadian Journal of Zoology 57:2186-2210.

Erickson, J. D. 1992. Habitat selection and movement of pallid sturgeon in Lake Sharpe, South Dakota. M.S. Thesis, South Dakota State University, Brookings.

Galat, D. L., and R. Lipkin. 2000. Restoring the ecological integrity of great rivers: historical hydrographs aid in defining reference conditions for the Missouri River. Hydrobiologia 422/423:29-48.

Gerking, S. D. 1994. Feeding ecology of fish. Academic

Press, New York.

Godin, J. J., and R. W. Rangeley. 1989. Living in the fast lane: effects of cost of locomotion on foraging behavior in juvenile Atlantic salmon. Animal Behavior 37:943-954.

Held, J., 1969. Some early summer foods of the shovelnose sturgeon in the Missouri River. Transaction of the American Fisheries Society 98:514-517.

Helfman, G. S. 1994. Adaptive variability and Mode Choice in foraging fishes. Pages 3-18 *in* Deanna Souder, K. Fresh, and R. Feller, editors. Theory and application in fish feeding ecology. University of South Carolina Press, Columbia.

Helms, D. 1974. Shovelnose sturgeon, Scaphirhyncus platorynchus, (Rafinesque), in the navigational impoundments of the Upper Mississippi River. Transactions of the American Fisheries Society 98:514-517.

Henry, C. J., and R. Ruelle. 1992. A study of pallid sturgeon and shovelnose sturgeon reproduction. U.S. Fish and Wildlife Service, Fish and Wildlife Enhancement, Pierre, South Dakota.

Hesse, L. W., G. E. Mestl, J. W. Robinson. 1993. Status and Selected Fishes in the Missouri River in Nebraska with recommendations for their recovery. Pages 327-340 in L. Hesse, C. Stalmaker, N. Benson and J. Zuboy, editors. Proceedings of the symposium on restoration planning for the rivers of the Mississippi River ecosystem. National Biological Survey, Biological Report 19, Washington, DC.

Hesse, L. W., J.C. Schmulbach, J. Carr, K. Keenlyne, D. Unkenholz, J. Robinson, G. Mestl. 1989. Missouri River fishery resources in relation to past, present and future stresses. Pages 352-371. *in* D. P. Dodge (ed), Proceedings of the International Large River Symposium. Canadian Special Publication of Fisheries and Aquatic Sciences 106.

Hesse, L. W., and W. Sheets. 1993. The Missouri River Hydrosystem. Fisheries 18(5):5-14.

Hoopes, D. T. 1960. Utilization of mayflies and caddisflies by some Mississippi River fishes. Transactions of the American Fisheries Society 89:32-34.

Hudson, P. L. 1971. The Chironomidae (Diptera) of South Dakota. Proceedings of South Dakota Academy of Science. 50:155-174.

Hurley, S. T., W. A. Hubert, and J. Nickum. 1987. Habitats and Movements of Shovelnose Sturgeon in the Upper Mississippi River. Transaction of the American Fisheries Society 116:655-662.

Irvine, J. R. 1985. Effects of successive flow perturbations on stream invertebrates. Canadian Journal of Fish and Aquatic Sciences 42:1922-1927.

Ivlev, V. S. 1961. Experimental ecology of the feeding fishes. Translated by Douglas Scott. Yale University Press, New Haven, CT.

Keenlyne, K. D. 1997. Life history and status of the shovelnose sturgeon. Environmental Biology of Fishes 48:291-298.

Keenlyne, K. D., C. J. Henry, A. Tews, and P. Clancey. 1994. Morphometric Comparisons of Upper Missouri River Sturgeons. Transactions of the American Fisheries Society 123:779-785.

Kieffer, M. C., and B. Kynard. 1993. Annual movements of shortnose and Atlantic sturgeon in the Merrimack River, Massachusetts. Transactions of the American Fisheries Society 122:1088-1103.

Kohlhorst, D. W. 1976. Sturgeon spawning in the Sacramento River in 1973, as determined by distribution of larvae. California Fish and Game 62:32-40.

Koetsier, P., and C. F. Bryan. 1995. Effects of abiotic factors on macroinvertebrate drift in the lower Mississippi River, Louisiana. American Midland Naturalist 134:63074.

Latka, D. C., J. Ramsey, and J. Morris. 1995. Selection of tributary confluence habitat by shovelnose sturgeon in the channelized Missouri River. Pages 250-261 *in* A. D. Gershanovich and T. I. J. Smith, editors. International Symposium on Sturgeons, VNIRO Publishing, Moscow, Russia.

Lillie, R. A., and W. L. Hilsenhoff. 1992. A survey of the aquatic insects of the lower Wisconsin River, 1985-1986, with notes on distribution and habitat. Wisoconsin Department of Natural Resources, Technical Bulletin No. 178, Madison.

Mackey, R. J. 1992. Colonization by lotic macroinvertebrates: a review of process and patterns. Canadian Journal of Fisheries and Aquatic Sciences 49:617-628.

Megargle, D. J. 1997. Temporal variation in diet and food selection of shovelnose sturgeon in the Missouri River above Fort Peck Reservoir, Montana. M. S. thesis, Montana State University, Bozeman.

Megargle, D. J., and R. White. 1997. Temporal variation in diet and food selection of shovelnose sturgeon in the Missouri River above Fort Peck Reservoir, Montana. Final Report to the U. S. Army Corps of Engineers, Omaha District, Omaha, Nebraska.

Marmonier, D. J., and M. Chatelliers. 1991. Effects of spats on interstitial assemblages of the Rhone River; importance of spatial heterogeneity. Hydrobiologia 210:243-251.

Merritt, R. W., and K. Cummins, editors. 1984. Aquatic Insects of North America. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Merritt, R. W., and K. Cummins, editors. 1996. Aquatic Insects of North America, 3rd edition. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Mestl, G. E., and L. W. Hesse. 1993. Secondary production of aquatic insects in the unchannelized Missouri River, Nebraska. Pages 341-349 in L. Hesse, C. Stalnaker, N. Benson, and J. Zuboy, editors. Proceedings of the symposium on restoration planning for the rivers of the Mississsippi River ecosystem. National Biological Survey, Biological Report 19, Washington, D. C.(Available from the National Technical Information Service, Springfield, Virginia).

Mizzi, J. A. 1994. Zooplankton, macroinvertebrates, herptile, and ichthyofaunal biodiversity of riverine habitat on the upper Missouri River. M. S. thesis, South Dakota State University, Brookings.

Mizzi, J. A., and C. Berry. 1994. Zooplankton, macroinvertebrates, herptile, and ichthyofaunal biodiversity of riverine habitat on the upper Missouri River. Proceedings of the South Dakota Academy of Science 73:242-243.

Modde, T. C., and J. C. Schmulbach. 1973. Seasonal changes in the drift and benthic macroinvertebrates in the unchannelized Missouri River in South Dakota. Proceedings of the South Dakota Academy of Science 52:118-126.

Modde, T., and J.C. Schmulbach. 1977. Food and Feeding Behavior of the Shovelnose Sturgeon, Scaphirhynchus platorynchus, in the Unchannelized Missouri River. South Dakota. Transaction of the American Fisheries Society 106:602-608.

Morgan, R. P., R. Jacobsen, S. Weisberg, L. McDowell, and A. Wilson. 1991. Effects of flow alteration on benthic macroinvertebrate communities below the Brighton hydroelectric dam. Journal of Freshwater Geology 6:419-429.

Morista, M. 1959. Measuring of interspecific association and similarity between communities. Mem. Fac. Sci. Kyushu. Univ. Ser. E. Bio. 3:65-80.

Morris, L. A., R. Langemeier, T. Russell, and A. Whitt. 1968. Effects of mainstem impoundments and channelization upon the limnology of the Missouri River, Nebraska. Transactions of the American Fisheries Society 97:380-388.

Moser, M. L., and S. W. Ross. 1995. Habitat use and movements of shortnose and Atlantic sturgeons in the Lower Cape Fear River, North Carolina. Transactions of the American Fisheries Society 124:225-234.

Nord, A. E., and J. C. Schmulbach. 1973. A comparison of the macroinvertebrate aufwuchs in the unstabilized and stabilized Missouri River. Proceedings of the South Dakota Academy of Science 52:127-139.

NPS (National Park Service). 2000. General management plan: Missouri National Recreational River, Nebraska, South Dakota. National Park Service, O’Neill, Nebraska.

O'Brien, W. J., and J. J. Showalter. 1993. Effects of current velocity and suspended debris on the drift feeding of arctic grayling. Transactions of the American Fisheries Society 122:609-615.

Petts, G., and P. Calow. 1996. River biota: diversity and dynamics: selected extracts from the rivers handbook. Blackwell Science Ltd, Cambridge, Massachusetts.

Quist, M. C., and C. S. Guy. 1999. Spatial variation in population characteristics of shovelnose sturgeon in the Kansas River. Prairie Naturalist 31:65-74.

Quist, M. C., J. Tillma, M. Burlingame, and C. Guy. 1999. Overwinter habitat use of shovelnose sturgeon in the Kansas River. Transactions of the American fisheries Society 128:522-527.

Rempel, L. L., J. Richardson, and M. Healy. 1999. Flow refugia for benthic macroinvertebrates during flooding of a large river. Journal of the North American Benthological Society 18:34-48.

Ruelle, R., and K. D. Keenlyne. 1992. Contaminants in Missouri River sturgeon. U.S. Fish and Wildlife Service, Report No. SD-FWE-93-01, Pierre, South Dakota.

Ruelle, R., and K. Keenlyne. 1994. The suitability of shovelnose sturgeon as a pallid sturgeon surrogate. Proceedings of the South Dakota Academy of Science 73:67-82.

Schmulbach, J. C., G. Gould, and C. L. Groen. 1975. Relative abundance and distribution of fishes in the Missouri River, Gavins Point Dam to Rulo, Nebraska. Proceedings of South Dakota Academy of Sciences 54:194-222.

Schmulbach, J. C., J. J. Schuckman, and E. Nelson. 1981. Aquatic habitat inventory of the Missouri River from Gavins Point Dam to Ponca State Park, Nebraska. Completion Report (Contract DACW45-80-C-0155) to U.S. Army Corps of Engineers, Omaha, Nebraska.

Schneiders, R. K. 1999. Unruly River. University Press of Kansas, Lawrence.

Schuckman, J. J. 1982. Population estimate of shovelnose sturgeon in the unchannelized Missouri River. MS Thesis, University of South Dakota, Vermillion.

Scrimgeour, G. J., T. D. Prowse, J. Culp, and P. Chambers. 1994. Ecological effects of large river ice break up: a review and perspective. Journal of Freshwater Biology 32:261-275.

Teskey, H. J. 1984. Aquatic diptera. Pages 448-466 in R. Merritt and K. Cummins editors. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Co., Dubuque, Iowa.

Troelstrup, N. H., Jr., and G. L. Hergenrader. 1990. Effects of hydropower peaking flow fluctuations on community structure and feeding guilds of invertebrates colonizing artificial substrates in a large impounded river. Hydrobiologia 199:217-228.

Tyler, J. A. 1993. Effects of water velocity, group size, and prey availability on the stream-drift capture efficiency of blacknose dace. Canadian Journal of Fisheries and Aquatic Sciences 50:1055-1061.

Tyler, P., and P. Calow. 1985. Fish energetics: new perspectives, Johns Hopkins University Press, Baltimore, Maryland.

Volesky, D. F. 1969. A comparison of the macrobenthos from selected habitats in cattail marshes of the Missouri River. M. A. thesis, University of South Dakota, Vermillion.

Walburg, C. H., G. Kaiser, and D. Hudson. 1971. Lewis and Clark Lake tailwater biota and some relation of the tailwater and reservoir fish populations. Pages 449-467 *in* Gordon E. Hall editor. reservoir fisheries and limnology. American Fisheries Society Special Publication 8, Bethesda, Maryland.

Waters, T. F. 1972. The drift of stream insects. Annual Review of Entomology 17:253-272.

Weisel, G. F. 1979. Histology of feeding and Digestive Organs of the shovelnose sturgeon, Scaphirynchus platorynchus. Copeia 1979:518-525.

Zorn, T. G., and P. W. Seelbach. 1995. The relation between habitat availability and the short-term carrying capacity of a stream reach for smallmouth bass. North American Journal of Fisheries Management 15:773-783.

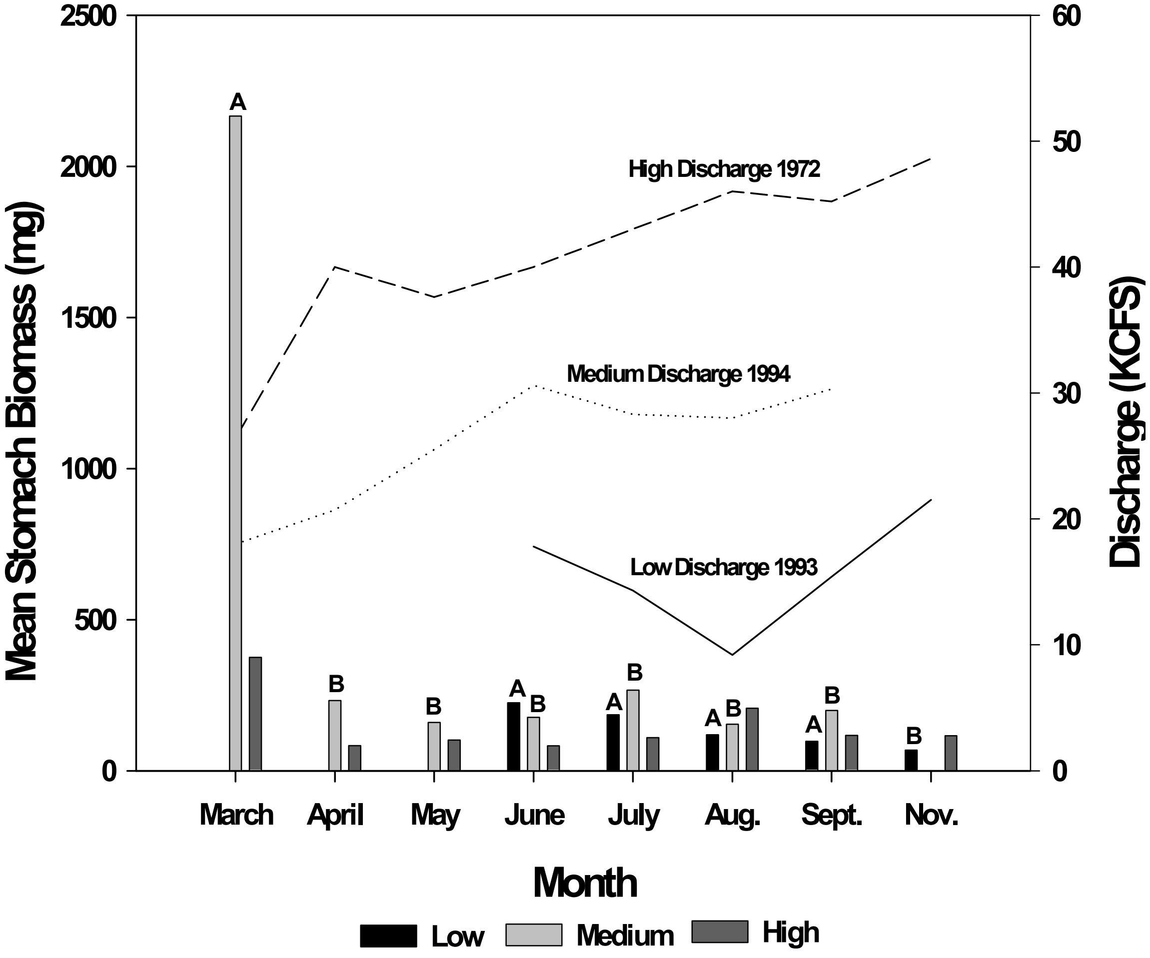


Figure 2. Mean monthly weight (mg) of shovelnose sturgeon stomach biomass during three years with different discharge levels from Gavins Point Dam. High discharge (26-49 kcfs) occurred March through September 1972, medium discharge (18-32 kcfs) from March through September 1994, and low discharge (15-22 kcfs) occurred from June through September and November 1993. Letters (A,B) indicate significant difference (*P*≤0.05) among months for the lower and medium discharge years.

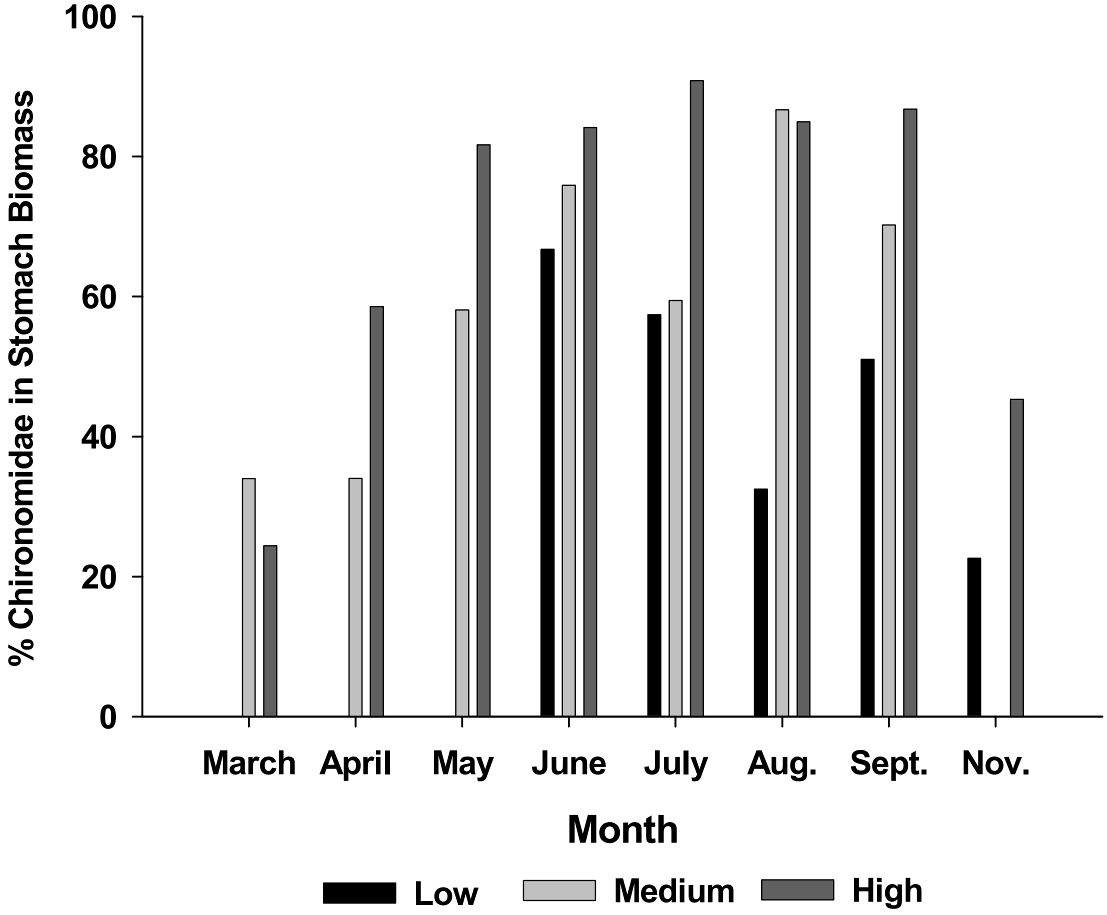


Figure 3. Percentage of Chironomidae in the stomach biomass of shovelnose sturgeon captured below Gavins Point Dam in all habitats during three discharge levels. Low (15-22 kcfs) discharge from June through September and November 1993, medium discharge (18-32 kcfs) from March through September 1994, and high discharge (26-49 kcfs) from March through September 1972.

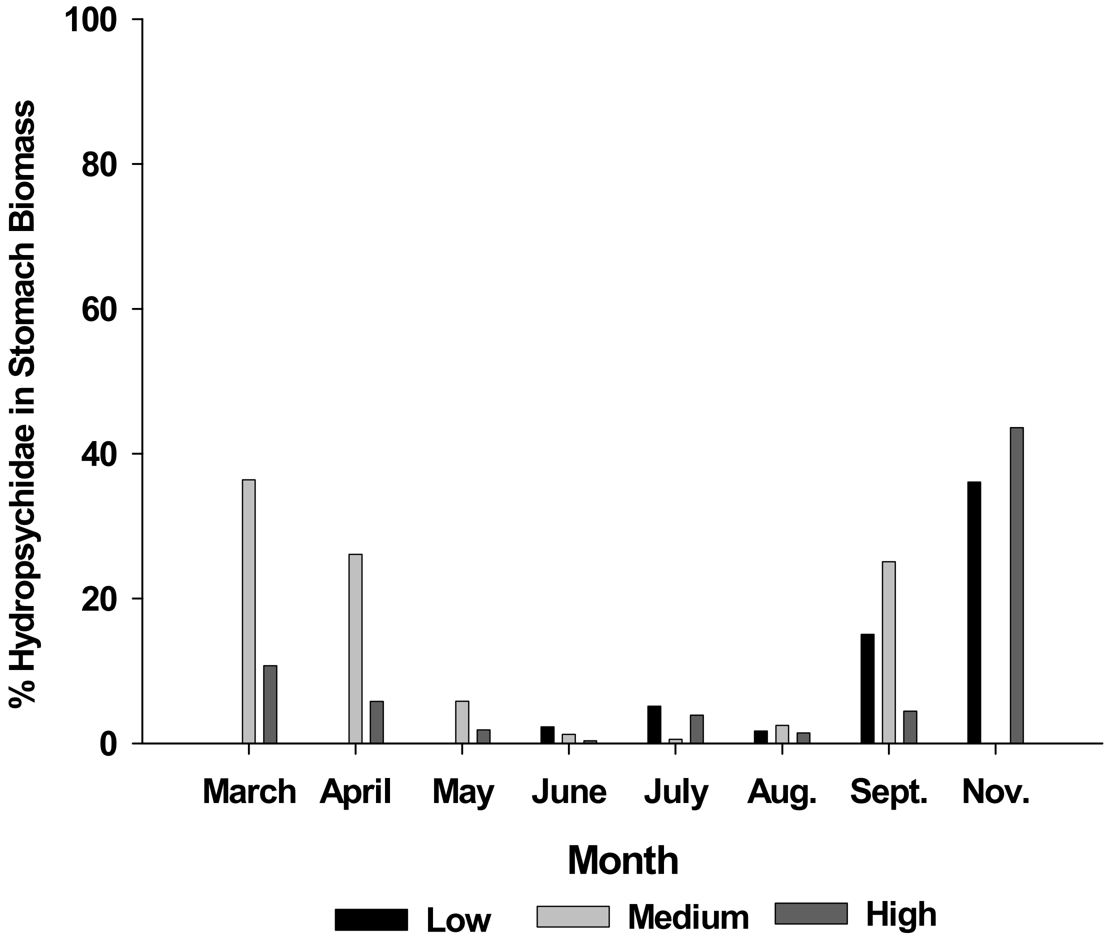


Figure 4. Percentage of Hydropsychidae in the stomach biomass of shovelnose sturgeon captured below Gavins Point Dam in all habitats during three discharge levels. Low (15-22 kcfs) discharge from June through September and November 1993, medium discharge (18-32 kcfs) from March through September 1994, and high discharge (26-49 kcfs) from March through September 1972.

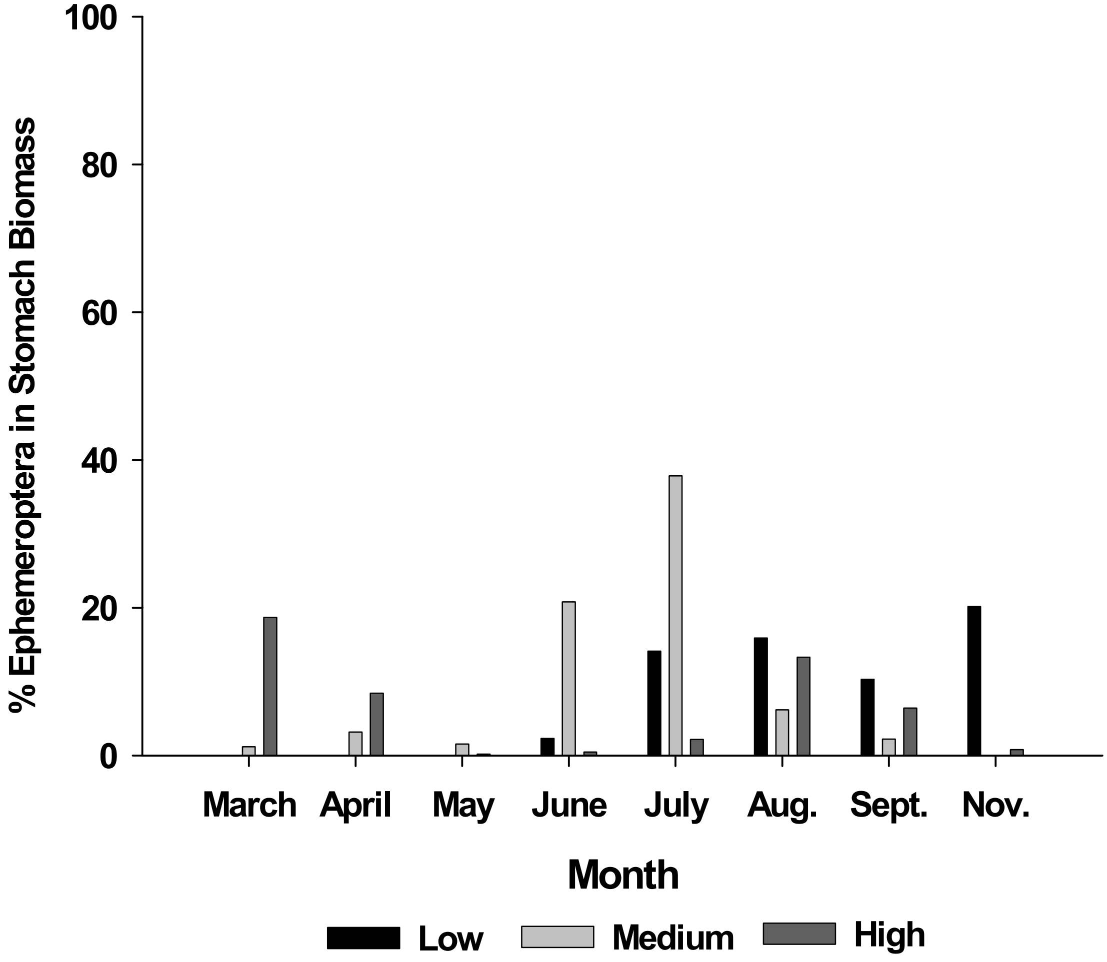


Figure 5. Percentage of Ephemeroptera in the stomach biomass of shovelnose sturgeon captured below Gavins Point Dam in all habitats during three discharge levels. Low (15-22 kcfs) discharge from June through September and November 1993, medium discharge (18-32 kcfs) from March through September 1994, and high discharge (26-49 kcfs) from March through September 1972.

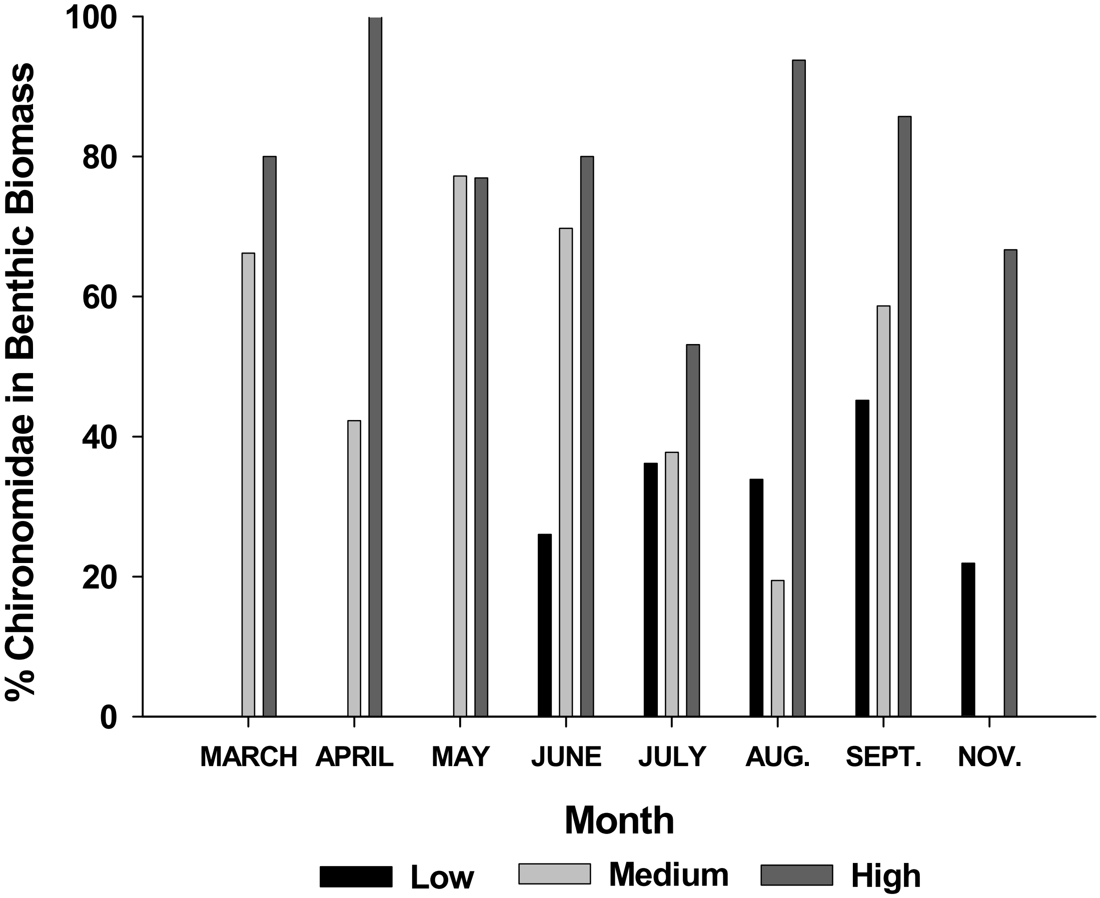


Figure 6. Percentage of Chironomidae in benthic biomass from all habitats sampled below Gavins Point Dam during three discharge levels. Low (15-22 kcfs) discharge from June through September and November 1993, medium discharge (18-32 kcfs) from March through September 1994, and high discharge (26-49 kcfs) from March through September 1972.

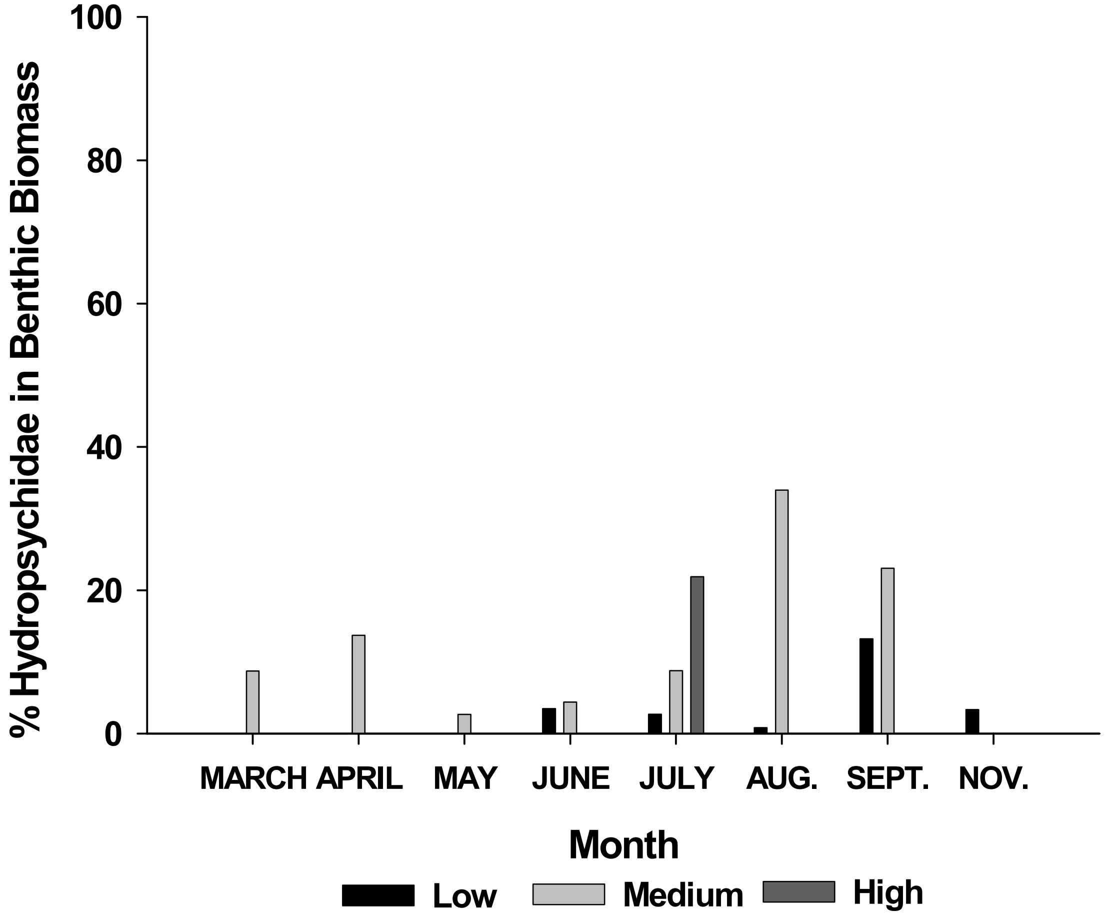


Figure 7. Percentage of Hydropsychidae in benthic biomass from all habitats sampled below Gavins Point Dam during three discharge levels. Low (15-22 kcfs) discharge from June through September and November 1993, medium discharge (18-32 kcfs) from March through September 1994, and high discharge (26-49 kcfs) from March through September 1972.

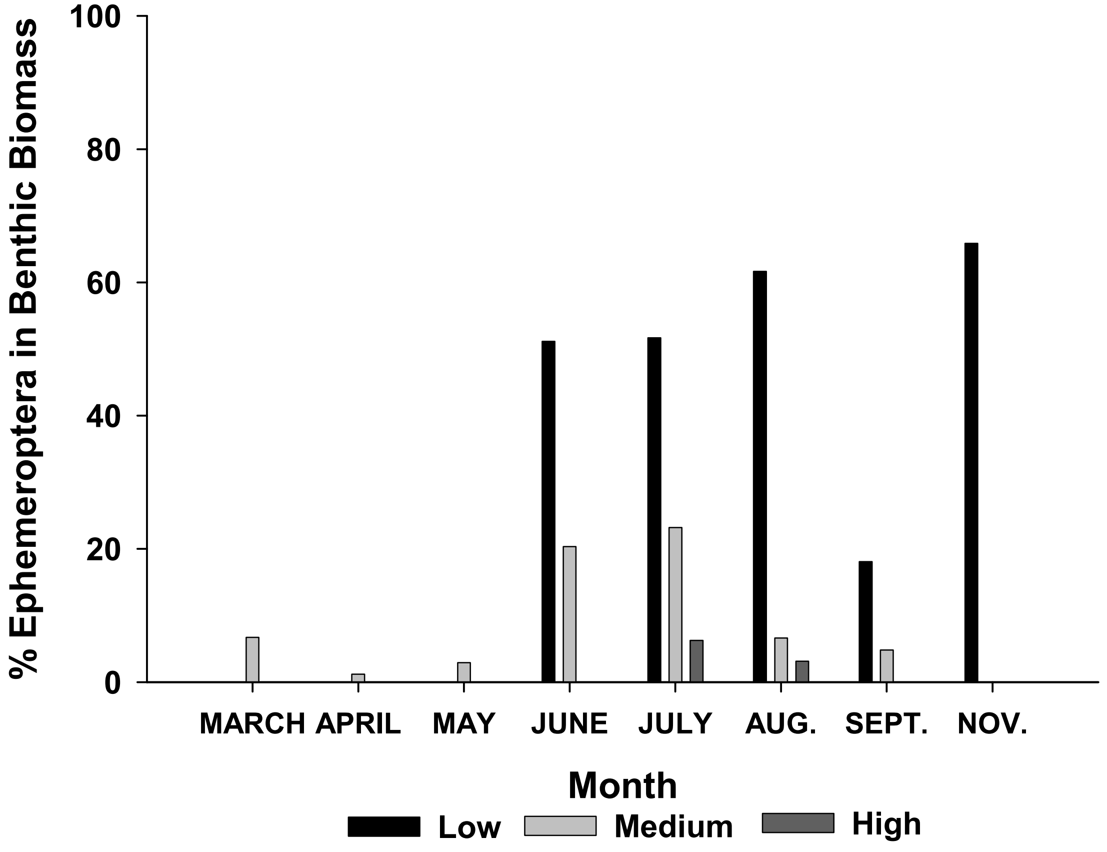


Figure 8. Percentage of Ephemeroptera in benthic biomass from all habitats sampled below Gavins Point Dam during three discharge levels. Low (15-22 kcfs) discharge from June through September and November 1993, medium discharge (18-32 kcfs) from March through September 1994, and high discharge (26-49 kcfs) from March through September 1972.

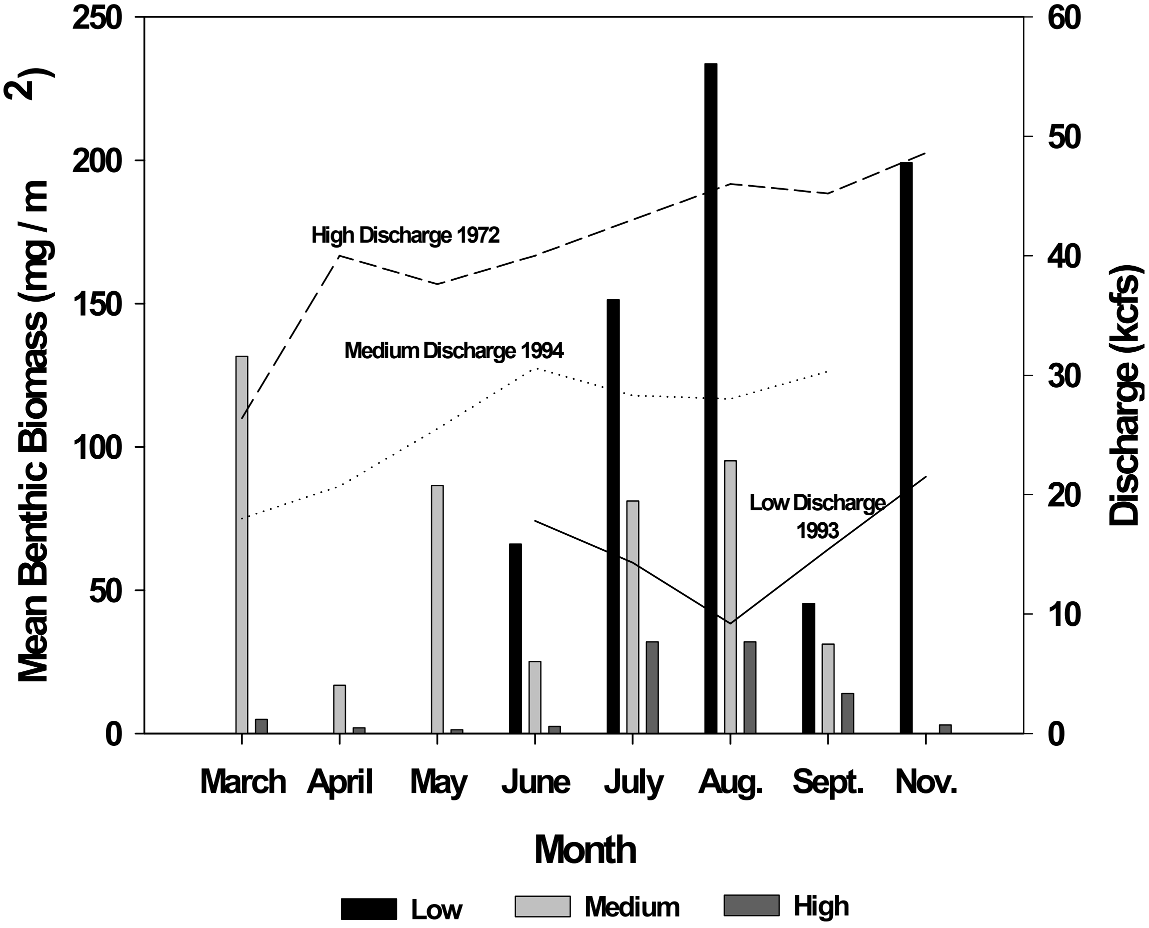


Figure 9. Mean benthic biomass (mg/m$^2$) of samples collected below Gavins Point Dam under different discharge levels. Low (15-22 kcfs) discharge from June through September and November 1993, medium discharge (18-32 kcfs) from March through September 1994, and high discharge (26-49 kcfs) from March through September 1972. No significant difference ($P \geq 0.05$) between months within discharge levels.

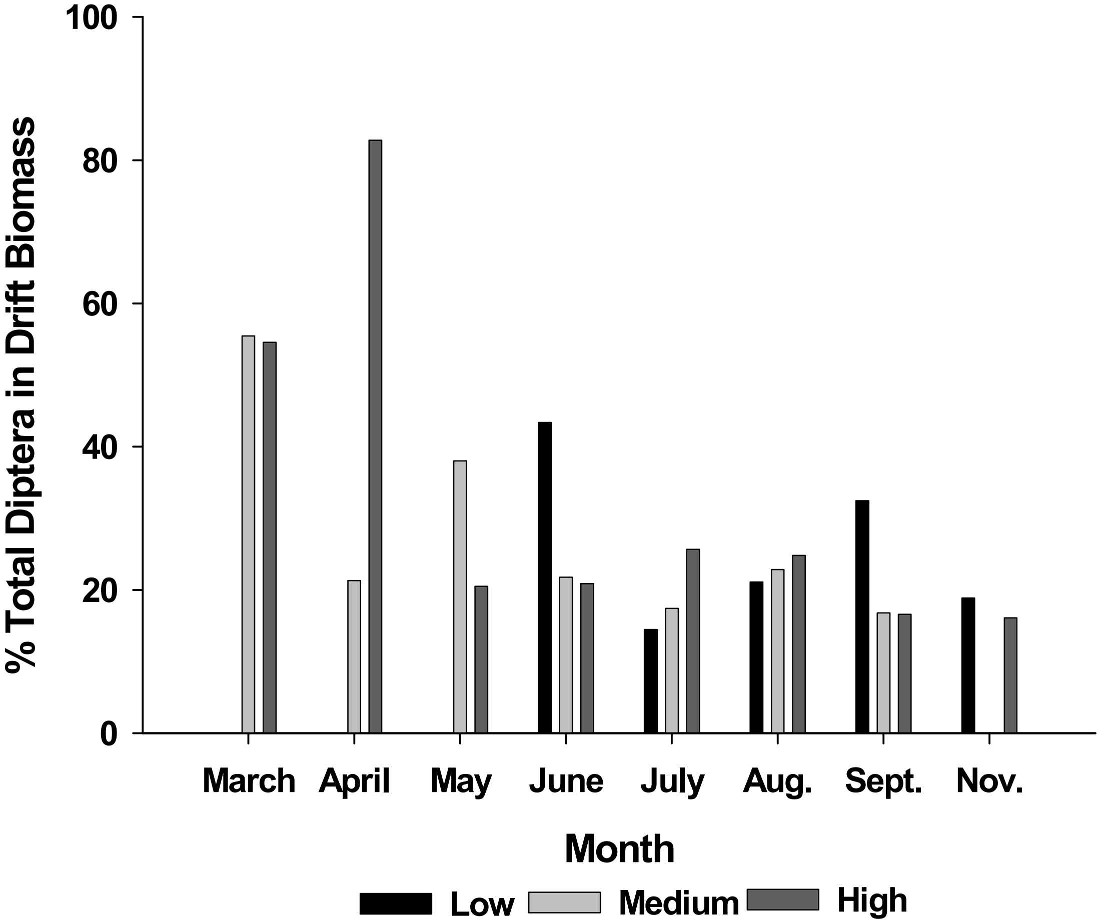


Figure 10. Percentage of Dipterans in drift biomass from all habitats sampled below Gavins Point Dam during three discharge levels. Low (15-22 kcfs) discharge from June through September and November 1993, medium discharge (18-32 kcfs) from March through September 1994, and high discharge (26-49 kcfs) from March through September 1972.

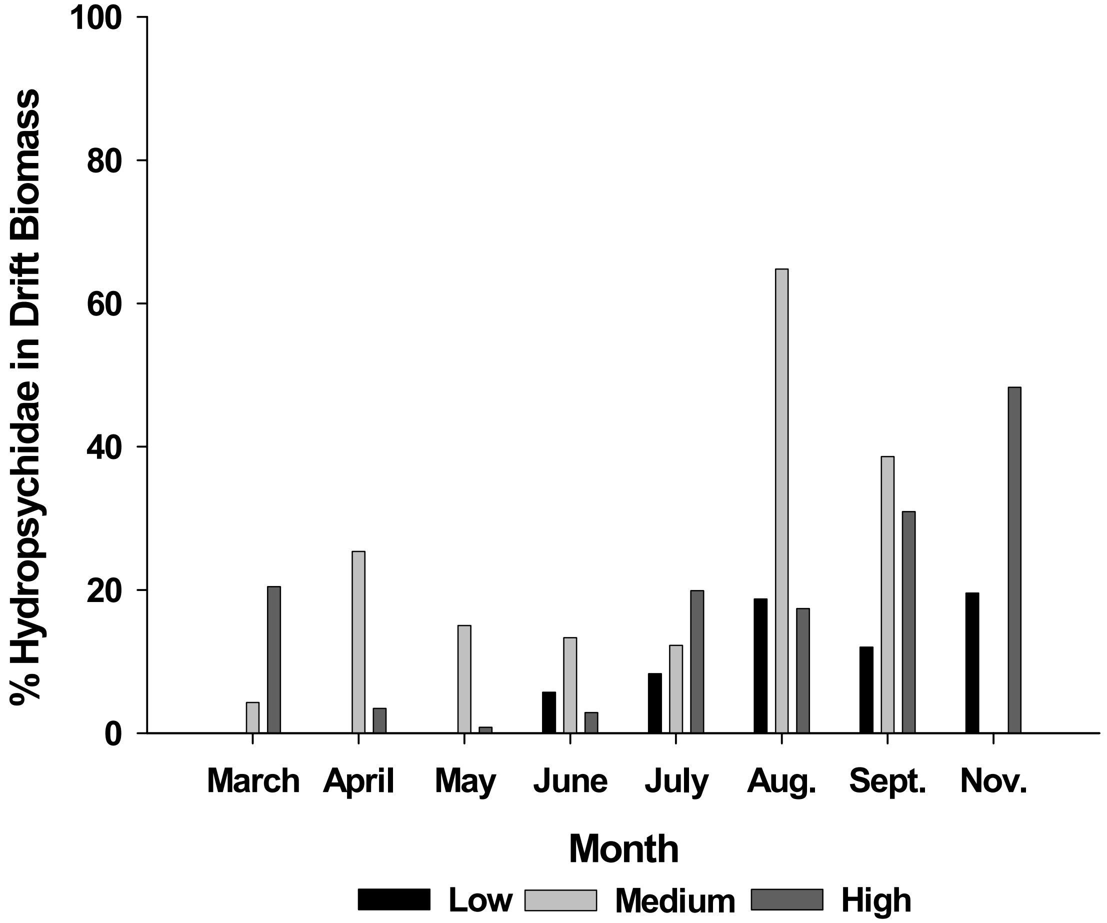


Figure 11. Percentage of Hydropsychidae in drift biomass from all habitats sampled below Gavins Point Dam during three discharge levels. Low (15-22 kcfs) discharge from June through September and November 1993, medium discharge (18-32 kcfs) from March through September 1994, and high discharge (26-49 kcfs) from March through September 1972.

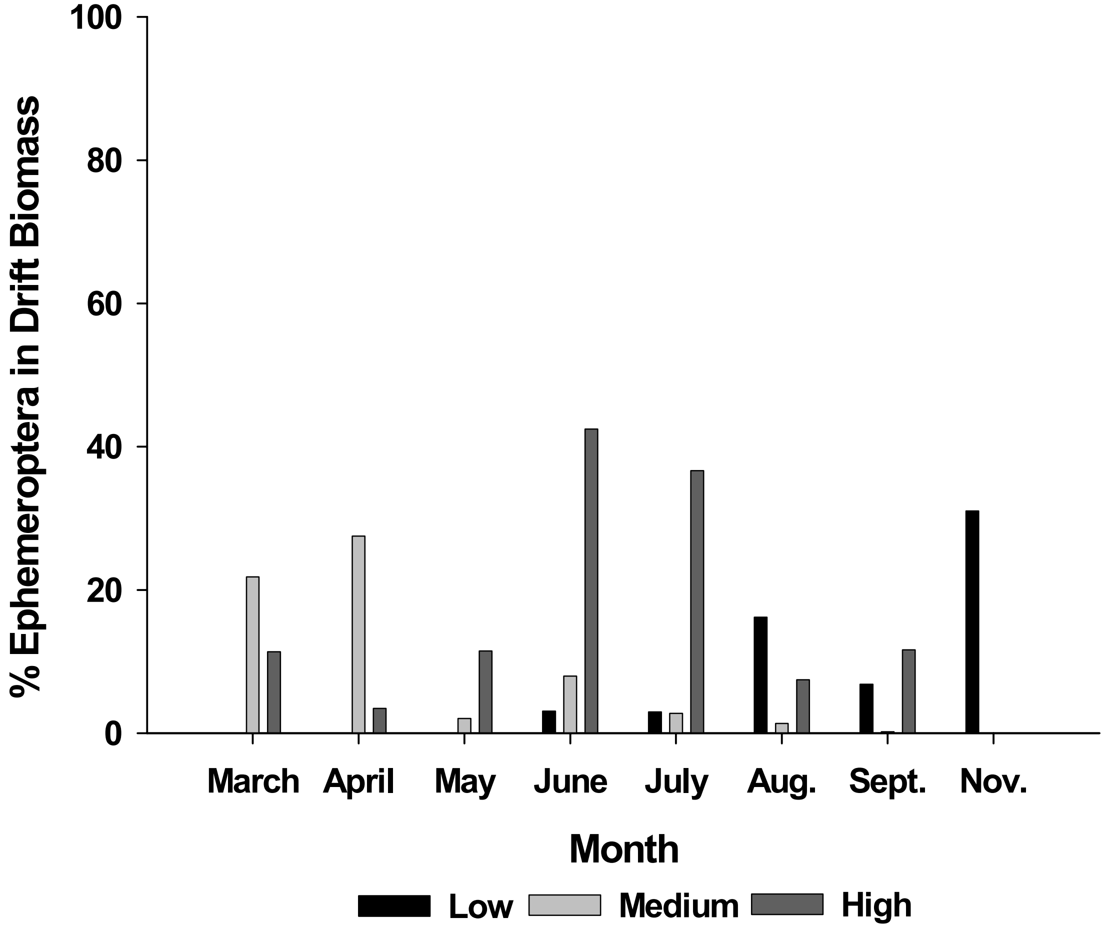


Figure 12. Percentage of Ephemeroptera in drift biomass from all habitats sampled below Gavins Point Dam during three discharge levels. Low (15-22 kcfs) discharge from June through September and November 1993, medium discharge (18-32 kcfs) from March through September 1994, and high discharge (26-49 kcfs) from March through September 1972.

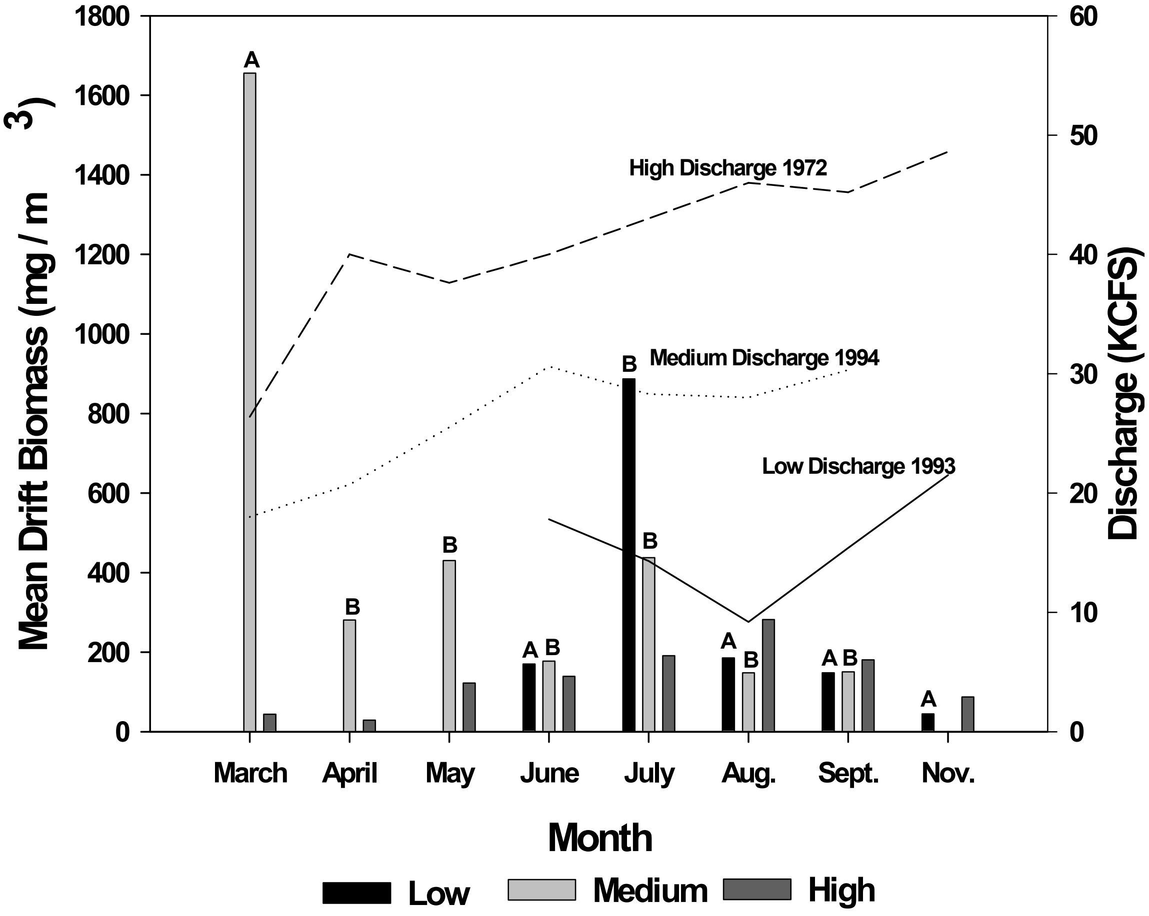


Figure 13. Mean drift biomass (mg/m$^3$) of samples collected below Gavins Point Dam under different discharge levels. Low (15-22 kcfs) discharge from June through September and November 1993, medium discharge (18-32 kcfs) from March through September 1994, and high discharge (26-49 kcfs) from March through September 1972. Letters (A,B) indicate significant difference ($P \leq 0.05$) between months within discharge levels.

Figure 14. Stomach contents (dry weight, mg) of shovelnose sturgeon captured during spring, summer, and fall months from the Missouri River below Gavins Point Dam. Dietary weight values for March were removed in high- and medium-flow years showing that there was no indication of any relation between discharge and dietary weight.

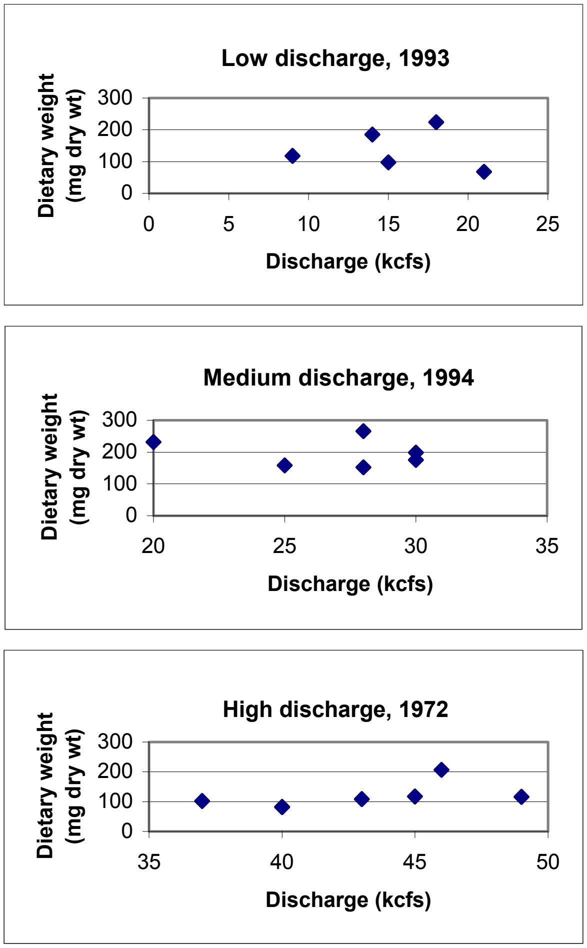


Table 1. Tag number, length, and weight of five shovelnose sturgeon tagged in 1980 and recaptured in 1993 in the Missouri River near Vermillion, South Dakota.

| | Fork length (mm) | | | Weight (g) | | |
|---|---|---|---|---|---|---|
| Tag | 1980 | 1993 | Change | 1980 | 1993 | Change |
| 5247 | 523 | 539 | +16 | 510 | 504 | -6 |
| 5478 | 569 | 558 | -11 | 615 | 487 | -128 |
| 5226 | 501 | 508 | +7 | 480 | 491 | +11 |
| 5287 | 500 | 505 | +5 | 430 | 498 | +68 |
| 5289 | 520 | 540 | +20 | 450 | 522 | +72 |

Table 2. Mean weight (mg dry wt) of stomach contents by month for shovelnose sturgeon, and discharge (kcfs) from Gavins Point Dam. Low discharge (9-22 kcfs) was from June through September and November 1993, medium discharge (18-31 kcfs) was from March through September 1994, and high discharge (26-49 kcfs) was from March through November 1972. Bonferroni multiple comparison procedure used to indicate significance ($P \leq 0.05$) between months for ANOVA results. Values followed by a common letter (superscript) are not significantly different.

| | Discharge | | | Mean stomach biomass (mg) | | |
|---|---|---|---|---|---|---|
| Month | Low | Medium | High | Low | Medium | High |
| March | -- | 18.0 | 26.4 | -- | $2166.2^{a}$ | 375.2 |
| SE | | | | | (139.4) | |
| April | -- | 20.7 | 40 | -- | $232.2^{b}$ | 83.0 |
| SE | | | | | (81.0) | |
| May | -- | 25.5 | 37.6 | -- | $159.8^{b}$ | 102.1 |
| SE | | | | | (34.3) | |
| June | 17.8 | 30.6 | 40 | $224.8^{a}$ | $176.5^{b}$ | 82.6 |
| SE | | | | (40.8) | (21.9) | |
| July | 14.3 | 28.3 | 43 | $185.6^{a}$ | $266.9^{b}$ | 109.9 |
| SE | | | | (32.6) | (40.1) | |
| August | 9.2 | 28.0 | 46 | $118.7^{a}$ | $153.7^{b}$ | 206.8 |
| SE | | | | (43.2) | (77.5) | |
| Sept. | 15.4 | 30.3 | 45.2 | $97.8^{a}$ | $199.9^{b}$ | 117 |
| SE | | | | (21.1) | (31.9) | |
| Nov. | 21.5 | -- | 48.6 | $68.5^{b}$ | -- | 116.1 |
| SE | | | | (11.5) | | |
| *P* value | | | | 0.006 | 0.0001 | |
| F value | | | | 3.81 | 71.21 | |

Multiple T-tests indicate no significant difference ($P \leq 0.05$) in stomach content weight between discharge levels.

Table 3. Mean monthly weight (mg) of Chironomidae, Hydropsychidae, and Ephemeroptera in shovelnose sturgeon stomachs during years with low (15-22 kcfs), medium (18-32 kcfs), and high (26-49 kcfs) water discharges. Bonferroni multiple comparison procedure used to indicate significance ($P \leq 0.05$) between months for ANOVA results. Values followed by a common letter (superscript) are not significantly different.

| | Chironomidae | | | Hydropsychidae | | | Ephemeroptera | | |
|---|---|---|---|---|---|---|---|---|---|
| Discharge<br>Month | Low | Medium | High | Low | Medium | High | Low | Medium | High |
| March | -- | $736.3^{a}$ | 91.5 | -- | $788^{a}$ | 40.3 | -- | $25.6^{d,e}$ | 70.2 |
| SE | | (113.0) | | | (118.8) | | | (4.4) | |
| April | -- | $79.0^{b}$ | 48.6 | -- | $60.6^{b}$ | 4.8 | -- | $7.4^{b,c,d}$ | 7 |
| SE | | (29.4) | | | (32) | | | (2.6) | |
| May | -- | $92.8^{b}$ | 83.4 | -- | $9.3^{b}$ | 1.9 | -- | $2.5^{b,c}$ | 0.2 |
| SE | | (24.8) | | | (5.4) | | | (0.9) | |
| June | $150.0^{a}$ | $133.9^{b}$ | 69.5 | $5.1^{a}$ | $2.2^{b}$ | 0.3 | $5.2^{a}$ | $36.7^{e}$ | 0.4 |
| SE | (32.3) | (22.6) | | (1.3) | (1.0) | | (1.4) | (7.3) | |
| July | $106.5^{a,b}$ | $158.6^{a,b}$ | 99.8 | $9.5^{a}$ | $1.5^{b}$ | 4.3 | $26.2^{b}$ | $101.0^{a}$ | 2.4 |
| SE | (26.8) | (98.8) | | (2.5) | (0.1) | | (6.0) | (59.1) | |
| August | $61.3^{a,b}$ | $133.2^{b}$ | 175.7 | $3.2^{a,b}$ | $3.8^{b}$ | 3 | $30^{b}$ | $9.5^{b,c,d,e}$ | 27.5 |
| SE | (30.6) | (72.8) | | (1.5) | (1.3) | | (19.3) | (5.2) | |
| Sept. | $49.9^{a,b}$ | $140.3^{b}$ | 101.5 | $14.7^{a,b}$ | $50.1^{b}$ | 5.2 | $10.1^{a,b}$ | $4.4^{c}$ | 7.5 |
| SE | (17.2) | (36.5) | | (4.7) | (10) | | (2.7) | (2.0) | |
| Nov. | $15.5^{b}$ | -- | 52.6 | $24.7^{b}$ | -- | 50.6 | $13.8^{a,b}$ | -- | 0.9 |
| SE | (5.8) | | | (6.9) | | | (3.7) | | |
| *P* value | 0.004 | 0.0001 | | 0.003 | 0.0001 | | 0.002 | 0.0001 | |
| F value | 4.17 | 10.54 | | 4.28 | 15.96 | | 4.49 | 10.68 | |

Table 4. Electivity values for shovelnose sturgeon feeding on benthic Chironomidae, *Chernovskiia*, Ephemeroptera and drifting Hydropsychidae under different discharge levels (low, 15-22 kcfs; medium, 18-32 kcfs; high, 26-49 kcfs).

| Month | Benthos | | | | | | | Drift | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Chironomidae | | | *Chernovskiia* | | Ephemeroptera | | Hydropsychidae | | |
| | Low | Medium | High | Low | Medium | Low | Medium | Low | Medium | High |
| March | | -0.265 | -0.538 | | -0.720 | | -0.662 | | 0.841 | 0.791 |
| April | | 0.088 | 0.317 | | -0.675 | | 0.669 | | 0.146 | -0.479 |
| May | | -0.195 | -0.101 | | 0.044 | | -0.363 | | -0.234 | -0.572 |
| June | -0.634 | -0.405 | -0.009 | 1* | 0.482 | -0.446 | 0.186 | -0.200 | -0.824 | -0.864 |
| July | -0.249 | -0.981 | 0.259 | 0.410 | 0.633 | -0.082 | 0.479 | -0.208 | -0.928 | -0.785 |
| August | -0.557 | -0.868 | -0.052 | 0.719 | 0.520 | -0.124 | 0.504 | -0.472 | -0.447 | -0.836 |
| Sept. | -0.288 | 0.023 | 0.006 | 0.307 | -0.538 | -0.057 | -0.454 | 0.060 | -0.078 | -0.851 |
| Nov. | -0.298 | | -0.376 | -0.618 | | 0.068 | | 0.280 | | -0.089 |

* No *Chernovskiia* collected in benthos.

Table 5. Mean monthly benthic biomass (mg/m$^{2}$) of Chironomidae, Hydropsychidae, and Ephemeroptera from three substrate types during years with low (15-22 kcfs), medium (18-32 kcfs), and high (26-49 kcfs) water discharges. Bonferroni multiple comparison procedure used to indicate significance ($P \leq 0.05$) between months for ANOVA results. Values followed by a common superscript letter were not statistically significant.

| | Chironomidae | | | Hydropsychidae | | | Ephemeroptera | | |
|---|---|---|---|---|---|---|---|---|---|
| Months | Low | Medium | High | Low | Medium | High | Low | Medium | High |
| March | | $87.1^{a}$ | 4 | | 11.5 | 0 | | $8.8^{a,b}$ | 0 |
| SE | | (18.6) | | | (3.4) | | | (3.8) | |
| April | | $7.1^{b}$ | 2 | | 2.3 | 0 | | $0.2^{b}$ | 0 |
| SE | | (1.5) | | | (1.0) | | | (0.1) | |
| May | | $66.8^{a}$ | 1 | | 2.3 | 0 | | $2.5^{b}$ | 0 |
| SE | | (26.9) | | | (2.0) | | | (1.1) | |
| June | $17.2^{a}$ | $17.5^{b}$ | 2 | 2.3 | 1.1 | 0 | 33.8 | $5.1^{a,b}$ | 0 |
| SE | (9.4) | (3.3) | | (2.1) | (0.6) | | (28.2) | (2.1) | |
| July | $54.7^{a,b}$ | $30.6^{a,b}$ | 17 | 4.1 | 7.1 | 7 | 78.2 | $18.8^{a}$ | 2 |
| SE | (16.0) | (5.5) | | (2.6) | (2.6) | | (53.8) | (7.4) | |
| August | $79.1^{b}$ | $18.5^{b}$ | 30 | 1.9 | 32.3 | 0 | 144.0 | $6.3^{a,b}$ | 1 |
| SE | (13.7) | (3.9) | | (0.5) | (23.9) | | (86.5) | (3.0) | |
| Sept. | $20.5^{a}$ | $18.3^{a,b}$ | 12 | 6.0 | 7.2 | 0 | 8.2 | $1.5^{a,b}$ | 0 |
| SE | (2.5) | (3.7) | | (2.7) | (3.5) | | (2.3) | (0.6) | |
| Nov. | $43.6^{a,b}$ | | 2 | 6.6 | | 0 | 131.1 | | 0 |
| SE | (10.4) | | | (2.8) | | | (115.4) | | |
| *P* value | 0.001 | 0.001 | | 0.407 | 0.570 | | 0.687 | 0.025 | |
| F value | 5.20 | 4.45 | | 1.01 | 0.80 | | 0.57 | 2.56 | |

Table 6. Mean benthic biomass ($mg/m^2$) from three substrate types and discharge (kcfs) from Gavins Point Dam. Low discharge (15-22 kcfs) was from June through September and November 1993, medium discharge (18-32 kcfs) was from March through September 1994, and high discharge (26-49 kcfs) was from March through November 1972. Bonferroni multiple comparison procedure used to indicate significance ($P \leq 0.05$) between months for ANOVA results.

| | Discharge | | | Mean benthic biomass | | |
|---|---|---|---|---|---|---|
| Month | Low | Medium | High | Low | Medium | High |
| March | -- | 18.0 | 26.4 | -- | 131.6 | 5 |
| SE | | | | | (29.1) | |
| April | -- | 20.7 | 40 | -- | 16.8 | 2 |
| SE | | | | | (8.2) | |
| May | -- | 25.5 | 37.6 | -- | 86.5 | 1.3 |
| SE | | | | | (32.4) | |
| June | 17.8 | 30.6 | 40 | 66.1 | 25.1 | 2.5 |
| SE | | | | (40.6) | (4.1) | |
| July | 14.3 | 28.3 | 43 | 151.3 | 81.1 | 32 |
| SE | | | | (61.4) | (22.5) | |
| August | 9.2 | 28.0 | 46 | 233.6 | 95.1 | 32 |
| SE | | | | (89.6) | (31.3) | |
| Sept. | 15.4 | 30.3 | 45.2 | 45.4 | 31.2 | 14 |
| SE | | | | (8.3) | (4.9) | |
| Nov. | 21.5 | -- | 48.6 | 199.1 | -- | 3 |
| SE | | | | (124.3) | | |
| *P* value | | | | 0.445 | 0.056 | |
| F value | | | | 0.94 | 2.15 | |

* Multiple T-test indicates significant difference in benthic biomass between medium and high discharge ($t=3.47$, $P=0.013$, $df=6$) levels and low and high discharge ($t=3.57$, $P=0.023$, $df=4$) levels.

Table 7. Mean monthly drift biomass (mg/m$^3$) of Diptera, Hydropsychidae, and Ephemeroptera during years with low (15-22 kcfs), medium (18-32 kcfs), and high (26-49 kcfs) water discharges. Bonferroni multiple comparison procedure used to indicate significance ($P \leq 0.05$) between months for ANOVA results. Values followed by a common superscript letter were not statistically significant.

| | Dipterans | | | Hydropsychids | | | Ephemeropterans | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | Low | Medium | High | Low | Medium | High | Low | Medium | High |
| March | -- | $918.1^a$ | 24 | -- | 70.7 | 9 | -- | $361.1^a$ | 5 |
| SE | | (42.8) | | | (11.0) | | | (138.5) | |
| April | -- | $59.8^b$ | 24 | -- | 71.2 | 1 | -- | $77.2^b$ | 1 |
| SE | | (20.8) | | | (33.4) | | | (38.8) | |
| May | -- | $163.5^b$ | 25 | -- | 64.6 | 1 | -- | $8.8^b$ | 14 |
| SE | | (43.7) | | | (17.7) | | | (3.8) | |
| June | $73.7^a$ | $38.5^b$ | 29 | $9.7^a$ | 23.6 | 4 | $8.8^a$ | $14.1^b$ | 59 |
| SE | (7.4) | (14.8) | | (2.7) | (8.1) | | (4.2) | (7.5) | |
| July | $128.3^b$ | $76.2^b$ | 49 | $73.5^b$ | 53.5 | 38 | $401.8^b$ | $12.1^b$ | 70 |
| SE | (27.1) | (9.3) | | (12.3) | (11.1) | | (215.7) | (2.2) | |
| August | $39.1^a$ | $33.8^b$ | 70 | $34.7^a$ | 95.9 | 49 | $28.5^a$ | $2.0^b$ | 21 |
| SE | (4.5) | (10.2) | | (8.3) | (36.6) | | (6.6) | (2.0) | |
| Sept. | $28.0^a$ | $25.2^b$ | 30 | $17.8^a$ | 58.0 | 56 | $8.6^a$ | $0.3^b$ | 21 |
| SE | (5.1) | (5.7) | | (4.2) | (19.6) | | (3.9) | (0.3) | |
| Nov. | $8.4^a$ | -- | 14 | $8.7^a$ | -- | 42 | $3.4^{a,b}$ | -- | 0 |
| SE | (3.6) | | | (1.9) | | | (2.2) | | |
| *P* value | 0.0001 | 0.0001 | | 0.0001 | 0.444 | | 0.014 | 0.0001 | |
| F value | 12.51 | 57.40 | | 11.21 | 1.02 | | 3.57 | 15.26 | |

Table 8. Mean drift biomass (mg/m$^3$) in the Missouri River (RM 870). Low discharge (15-22 kcfs) was from June through September and November 1993, medium discharge (18-32 kcfs) was from March through September 1994, and high discharge (26-49 kcfs) was from March through November 1972. Bonferroni multiple comparison procedure used to indicate significance ($P \leq 0.05$) between months for ANOVA results. Values followed by the same superscript letter were not significantly different.

| | Discharge | | | Mean drift biomass | | |
|---|---|---|---|---|---|---|
| Month | Low | Medium | High | Low | Medium | High |
| March | -- | 18.0 | 26.4 | -- | 1655.9$^a$ | 44 |
| SE | | | | | (283.4) | |
| April | -- | 20.7 | 40 | -- | 280.8$^b$ | 29 |
| SE | | | | | (103.6) | |
| May | -- | 25.5 | 37.6 | -- | 430.0$^b$ | 122 |
| SE | | | | | (93.6) | |
| June | 17.8 | 30.6 | 40 | 170.0$^a$ | 177.0$^b$ | 139 |
| SE | | | | (54.2) | (72.4) | |
| July | 14.3 | 28.3 | 43 | 886.7$^b$ | 437.3$^b$ | 191 |
| SE | | | | (274.1) | (52.2) | |
| August | 9.2 | 28.0 | 46 | 185.3$^a$ | 148.0$^b$ | 282 |
| SE | | | | (38.0.) | (40.7) | |
| Sept. | 15.4 | 30.3 | 45.2 | 148.0$^a$ | 150.2$^b$ | 181 |
| SE | | | | (37.5) | (1.6) | |
| Nov. | 21.5 | -- | 48.6 | 44.5$^a$ | -- | 87 |
| SE | | | | (9.5) | | |
| *P* value | | | | 0.0001 | 0.0001 | |
| F value | | | | 7.19 | 19.07 | |

* Multiple T-tests indicate no significant difference ($P \leq 0.05$) in drift weight between discharge levels.

Table 9. Mean monthly weight (mg) of stomach contents of shovelnose sturgeon collected from three habitat types during low (15-22 kcfs), medium (18-32 kcfs), and high (26-49 kcfs) discharges from Gavins Point Dam, Yankton, South Dakota. Habitat I is small, sandbar pools, habitat II is large pools, and habitat III is chutes. Bonferroni multiple comparison procedure used to indicate significance ($P \leq 0.05$) between months for ANOVA results.

| | Low Discharge | | | Medium Discharge | | |
|---|---|---|---|---|---|---|
| Month Habitat | I | II | III | I | II | III |
| March | | | | 2239.9$^{a}$ | 2158.0$^{a}$ | -- |
| SE | | | | (165.1) | (154.4) | -- |
| N | | | | 3 | 27 | 0 |
| April | | | | 288.1$^{b}$ | 141.4$^{b}$ | 112.5 |
| SE | | | | (123.7) | (55.2) | -- |
| N | | | | 7 | 3 | 1 |
| May | | | | 161.8$^{b}$ | 107.5$^{b}$ | 189.5 |
| SE | | | | (49.1) | (102.8) | (55.7) |
| N | | | | 8 | 2 | 3 |
| June | 251.3$^{a}$ | 129.0$^{a,b}$ | 310.0 | 182.7$^{b}$ | -- | 173.7 |
| SE | (55.1) | (18.1) | (133.9) | (20.5) | -- | (31.1) |
| N | 14 | 11 | 8 | 6 | 0 | 13 |
| July | 54.5$^{a,b}$ | 248.7$^{a}$ | 136.1 | 307.0$^{b}$ | -- | 226.8 |
| SE | (51.6) | (56.1) | (25.3) | -- | -- | -- |
| N | 2 | 12 | 10 | 1 | 0 | 1 |
| August | 38.1$^{a,b}$ | 169.2$^{a,b}$ | 214.4 | 247.8$^{b}$ | 9.8$^{b}$ | 162.0 |
| SE | (7.0) | -- | (87.3) | -- | -- | (101.0) |
| N | 3 | 1 | 2 | 1 | 1 | 6 |
| Sept. | 49.4$^{a,b}$ | 110.8$^{a,b}$ | 111.5 | 128.6$^{b}$ | 223.6$^{b}$ | -- |
| SE | (12.9) | (33.0) | (41.8) | (37.0) | (39.3) | -- |
| N | 3 | 8 | 3 | 5 | 15 | 0 |
| Nov. | 59.1$^{b}$ | 73.9$^{b}$ | 171.2 | | | |
| SE | (14.9) | (14.0) | -- | | | |
| N | 15 | 7 | 1 | | | |
| *P* value | 0.006 | 0.039 | 0.596 | 0.0001 | 0.0001 | 0.987 |
| F value | 4.46 | 2.85 | 0.71 | 46.37 | 28.80 | 0.08 |

*ANOVA indicates a significant three-way interaction ($P=0.0001$, F=27.35) between month, habitat type, and discharge level.

Table 10. Mean monthly benthic biomass (mg/$m^2$) collected from three habitat types during low (15-22 kcfs), medium (18-32 kcfs), and high (26-49 kcfs) discharges from Gavins Point Dam, Yankton, South Dakota. Habitat I is small, sandbar pools, habitat II is large pools, and habitat III is chutes. Bonferroni adjustment used to indicate significance ($P \leq 0.05$) between months for ANOVA results.

|  | Low Discharge |  |  | Medium Discharge |  |  |
|---|---|---|---|---|---|---|
| Month Habitat | I | II | III | I | II | III |
| March |  |  |  | 168.1 | 58.7 | -- |
| SE |  |  |  | (26.6) | (22.4) | -- |
| N |  |  |  | 4 | 2 | 0 |
| April |  |  |  | 9.3 | 53.9 | -- |
| SE |  |  |  | (2.2) | (50.4) | -- |
| N |  |  |  | 10 | 2 | 0 |
| May |  |  |  | 90.4 | 37.5 | 98.9 |
| SE |  |  |  | (38.2) | (29.7) | (68.2) |
| N |  |  |  | 6 | 2 | 6 |
| June | 14.5 | 5.2 | 140.2 | 25.2 | -- | 25.0 |
| SE | (5.6) | -- | (92.1) | (5.9) | -- | (6.3) |
| N | 6 | 1 | 5 | 6 | 0 | 6 |
| July | 109.0 | 130.4 | 193.4 | 87.1 | 269.8 | 35.0 |
| SE | (84.9) | (70.5) | (145.1) | (33.9) | (56.9) | (9.4) |
| N | 2 | 4 | 4 | 6 | 2 | 9 |
| August | 142.7 | 367.0 | 182.6 | 20.7 | 138.5 | 123.8 |
| SE | (22.9) | (251.2) | (71.8) | (5.9) | (71.1) | (51.7) |
| N | 6 | 6 | 5 | 6 | 3 | 11 |
| Sept. | 26.3 | 51.5 | 65.6 | 26.4 | 31.9 | 32.6 |
| SE | (7.8) | (7.2) | (46.6) | (9.9) | (3.6) | (8.0) |
| N | 4 | 6 | 2 | 2 | 2 | 6 |
| Nov. | 103.1 | 260.4 | 115.4 |  |  |  |
| SE | (51.5) | (208.4) | (14.6) |  |  |  |
| N | 4 | 9 | 2 |  |  |  |
| *P* value | 0.014 | 0.805 | 0.943 | 0.0001 | 0.112 | 0.300 |
| F value | 4.30 | 0.40 | 0.18 | 6.13 | 2.72 | 1.27 |

* ANOVA indicates no significant ($P \leq 0.05$) three-way or two-way interaction between month, habitat type, and discharge level. Main effects indicate higher benthic biomass in 1993 than 1994 ($P=0.021$, F=5.48) and habitat II than habitat III ($P=0.047$, F=3.13).

Table 11. Mean monthly drift biomass (mg/m$^{3}$) collected from three habitat types during low (15-22 kcfs), medium (18-32 kcfs), and high (26-49 kcfs) discharges from Gavins Point Dam, Yankton, South Dakota. Habitat I is small, sandbar pools, habitat II is large pools, and habitat III is chutes. Bonferroni adjustment used to indicate significance ($P \leq 0.05$) between months for ANOVA results. Values followed by a common superscript letter were not significantly different.

| | Low Discharge | | | Medium Discharge | | |
|---|---|---|---|---|---|---|
| Month Habitat | I | II | III | I | II | III$^{a}$ |
| March | | | | -- | 1655.9$^{a}$ | -- |
| SE | | | | -- | (283.4) | -- |
| N | | | | 0 | 2 | 0 |
| April | | | | -- | 280.8$^{b}$ | -- |
| SE | | | | -- | (103.6) | -- |
| N | | | | 0 | 2 | 0 |
| May | | | | 428.7$^{a}$ | -- | 432.6 |
| SE | | | | (132.3) | -- | (162.1) |
| N | | | | 4 | 0 | 2 |
| June | 204.6$^{a,b}$ | -- | 135.5$^{a}$ | -- | -- | 177.0 |
| SE | (113.2) | -- | (10.6) | -- | -- | (72.4) |
| N | 4 | 0 | 4 | 0 | 0 | 4 |
| July | 593.5$^{a}$ | 490.3$^{a}$ | 1972.8$^{b}$ | -- | -- | 437.3 |
| SE | (44.3) | (137.1) | (639.5) | -- | -- | (52.2) |
| N | 2 | 4 | 2 | 0 | 0 | 4 |
| August | 134.3$^{b}$ | 201.7$^{b}$ | 280.0$^{a}$ | 148.0$^{b}$ | -- | -- |
| SE | (37.4) | (64.7) | (83.3) | (40.7) | -- | -- |
| N | 2 | 4 | 3 | 4 | 0 | 0 |
| Sept. | 76.8$^{b}$ | 98.4$^{b}$ | 141.2$^{a}$ | 150.2$^{b}$ | -- | -- |
| SE | (32.9) | (19.7) | (40.4) | (1.6) | -- | -- |
| N | 2 | 8 | 2 | 2 | 0 | 0 |
| Nov. | -- | 44.5$^{b}$ | -- | | | |
| SE | -- | (9.5) | -- | | | |
| N | 0 | 4 | 0 | | | |
| *P* value | 0.019 | 0.001 | 0.003 | 0.003 | 0.045 | 0.076 |
| F value | 6.03 | 9.13 | 13.49 | 23.19 | 20.77 | 3.80 |

* ANOVA indicates a significant three-way interaction ($P$=0.0001, F=14.33) between month, habitat type, and discharge level.

# APPENDICES

Appendix A. Conversion between the discharge measurements $m^3$/sec, and $ft^3$/sec; 100 $m^3$=3,531.4 $ft^3$, kcfs=thousand cubic feet per second.

| cubic meters / second | cubic feet / second | (kcfs) |
|---|---|---|
| 283 | 10,000 | (10) |
| 570 | 20,000 | (20) |
| 850 | 30,000 | (30) |
| 1,132 | 40,000 | (40) |
| 1,500 | 53,000 | (53) |
| 2,000 | 70,620 | (70.6) |

Appendix B. Number of sturgeon stomachs analyzed and mean condition (k) reported monthly by Modde for 1971-72, and condition calculated from data collected in 1993 and 1994 for shovelnose sturgeon captured in the Missouri River between the mouth of the James River and Clay County State Park and discharge (kcfs) from Gavins Point Dam, Yankton, South Dakota. Standard error (SE) in parentheses.

| | Number of Shovelnose Sturgeon | | Condition | | |
|---|---|---|---|---|---|
| Month | 1993 | 1994 | Modde | 1993 | 1994 |
| March | -- | 30 | 0.341<br>(0.005) | -- | 0.394<br>(0.008) |
| April | -- | 11 | 0.343<br>(0.006) | -- | 0.346<br>(0.008) |
| May | -- | 13 | 0.314<br>(0.013) | -- | 0.350<br>(0.012) |
| June | 33 | 19 | 0.320<br>(0.013) | 0.329<br>(0.005) | 0.333<br>(0.007) |
| July | 24 | 2 | 0.350<br>(0.008) | 0.339<br>(0.005) | 0.342<br>(0.046) |
| Aug. | 6 | 10 | 0.355<br>(0.025) | 0.317<br>(0.011) | 0.381<br>(0.018) |
| Sept. | 14 | 20 | 0.355<br>(0.015) | 0.350<br>(0.007) | 0.337<br>(0.010) |
| Nov. | 23 | -- | 0.362<br>(0.009) | 0.352<br>(0.005) | -- |

Appendix C. Overall percentage (%) of shovelnose sturgeon stomach biomass and biomass associated with the benthos found in samples taken from the Missouri River for the months June, July, August, September, and November 1993. T represents a value below 0.1%.

| | Percentage of overall dry weight (%) | |
|---|---|---|
| Food items | Stomach biomass | Benthos biomass |
| Diptera | | |
| Chironomidae | 20.6 | 46.9 |
| *Chernovskiia* | 26.4 | 8.4 |
| Ceratopogonidae | 1.1 | 9.3 |
| Simuliidae | 0.1 | 1.4 |
| Pupae | 1.5 | 3.5 |
| Diptera fragments | 14.5 | -- |
| Empididae | 0.2 | T |
| Dolichopodidae | 0.3 | 0.1 |
| Tipulidae | 0.8 | T |
| Trichoptera Misc. | 1.9 | 1.5 |
| Hydropsychidae | 15.3 | 4.3 |
| Ephemeroptera | 12.9 | 19.3 |
| Coleoptera | 0.7 | 0.9 |
| Hemiptera | 0.5 | 1.9 |
| Decopoda | 0.5 | T |
| Isopoda | 1.3 | 0.2 |
| Amphipoda | T | T |
| Collembola | T | 0.4 |
| Odonata | 0.1 | 1.1 |
| Arachnida | 0.1 | 0.1 |
| Fish | 0.5 | -- |
| Hymenoptera | 0.3 | 0.1 |
| Orthoptera | 0.3 | T |
| Homoptera | 0.1 | 0.2 |
| Thysanoptera | T | 0.2 |

Appendix D. Mean percent biomass of Chironomidae by month in the ration and benthos, with standard error (SE). Samples collected during low (15-22 kcfs), medium (18-32 kcfs), and high (26-49 kcfs) discharge levels from Gavins Point Dam, Yankton, South Dakota.

| | Low Dicharge | | | Medium Discharge | | | High Discharge | | |
|---|---|---|---|---|---|---|---|---|---|
| | % Chironomidae Wt. | | Stomach | % Chironomidae Wt. | | Stomach | % Chironomidae Wt. | | Stomach |
| Month | Ration | Benthos | IOM | Ration | Benthos | IOM | Ration | Benthos | IOM |
| March | | | | 36.3 | 70.8 | 417<br>(40) | 24.0 | 80.0 | 118 |
| April | | | | 43.0 | 62.2 | 209<br>(26) | 51.9 | 100 | 75 |
| May | | | | 56.9 | 80.0 | 729<br>(352) | 81.6 | 100 | 461 |
| June | 61.0 | 31.6 | 268.9<br>(28.5) | 74.3 | 73.1 | 432<br>(132) | 98.3 | 100 | 472 |
| July | 47.3 | 67.2 | 228.8<br>(38.5) | 55.1 | 44 | 534<br>(287) | 90.2 | 53.1 | 137 |
| Aug. | 50.2 | 60.8 | 405.5<br>(129.7) | 62.6 | 59.2 | 112<br>(42) | 84.5 | 93.8 | 102 |
| Sept. | 41.5 | 52.8 | 214.0<br>(55.1) | 51.4 | 66 | 179<br>(35) | 86.8 | 85.7 | 124 |
| Nov. | 29.1 | 67.3 | 131.4<br>(28.4) | | | | 45.3 | 100 | 68 |

Appendix E. Percent dry weight (%) of invertebrate orders in the drift for the months of June, July, August, September, and November (pooled) 1993, and percent by number for the months of March, April, May, June, July, August, September (pooled) 1994. At each location, drift was collected at the surface and near the bottom. T represents a value below 0.1%.

| Food Items | Percentage | |
|---|---|---|
| | Dry weight, 1993 | Number, 1994 |
| Diptera | | |
| Chironomidae | 5.9 | 28.7 |
| *Chernovskiia* | 2.4 | 1.4 |
| Ceratopogonidae | 0 | T |
| Simuliidae | 2.7 | 2.2 |
| Pupae | 18.0 | 19.9 |
| Empididae | T | T |
| Dolichopodidae | T | T |
| Tipulidae | 0.3 | 0 |
| Chaoboridae | 0.2 | 0.1 |
| Culicidae | 0.1 | 0 |
| Stratiomyidae | 0 | 0 |
| Muscidae | 1 | T |
| Trichoptera misc. | 4.7 | 2.3 |
| Hydropsychidae | 16.0 | 18.3 |
| Ephemeroptera | 13.1 | 4.3 |
| Coleoptera | 15.5 | 4.7 |
| Hemiptera | 6.7 | 1.4 |
| Isopoda | 0.7 | T |
| Amphipoda | 0.4 | 0.2 |
| Collembola | 0.4 | T |
| Odonata | 0.5 | T |
| Arachnida | 1.2 | 0.8 |
| Hymenoptera | 3.8 | 3.4 |
| Orthoptera | T | 0 |
| Aphididae | 1.7 | 2.1 |
| Hydracarina | 1.7 | 0.5 |
| Thysanoptera | 0.1 | 0.1 |
| Homoptera | 3.8 | 0.6 |
| Lepidoptera | 0.2 | T |
| Gastropoda | 0 | T |
| Plecoptera | 0 | 0.1 |
| Decapoda | 1 | T |
| Fish larvae | 0 | 8.2 |

Appendix F. Morista index values by month from food items collected in stomachs of shovelnose sturgeon and in the benthos from different habitats and under different discharge levels from Gavins Point Dam. Low discharge level (15-22 kcfs) was from June through November 1993 and medium discharge level (18-32 kcfs) was from March through September 1994. Habitat I (I) is sand bar pools, Habitat II (II) is large pools with or without an organic bottom, and Habitat III (III) is chutes, chute points, or hard points. Samples were collected in the Missouri River from Yankton to Vermillion, South Dakota.

| | Morista index values | | | | | |
|---|---|---|---|---|---|---|
| | Low discharge | | | Medium discharge | | |
| Month | I | II | III | I | II | III |
| March | | | | 0.861 | 0.678 | -- |
| Range | | | | 0.653-0.980 | 0.436-1.000 | -- |
| N | | | | 3 | 27 | 0 |
| April | | | | 0.597 | 0.419 | -- |
| Range | | | | 0.330-0.967 | 0.364-0.446 | -- |
| N | | | | 7 | 3 | 0 |
| May | | | | 0.837 | 0.969 | 0.846 |
| Range | | | | 0.409-0.933 | 0.969-0.970 | 0.619-0.962 |
| N | | | | 8 | 2 | 3 |
| June | 0.099 | 0.338 | 0.169 | 0.513 | -- | 0.534 |
| Range | 0.026-0.380 | 0.012-0.831 | 0.023-0.714 | 0.107-0.939 | -- | 0.061-0.963 |
| N | 14 | 11 | 8 | 5 | 0 | 13 |
| July | 0.983 | 0.617 | 0.886 | 0.075 | -- | 0.179 |
| Range | 0.968-0.998 | 0.240-0.908 | 0.398-0.983 | -- | -- | -- |
| N | 2 | 12 | 10 | 1 | 0 | 1 |
| August | 0.584 | 0.291 | 0.551 | 0.243 | 0.220 | 0.256 |
| Range | 0.329-0.905 | -- | 0.378-0.725 | -- | -- | 0.149-0.426 |
| N | 3 | 1 | 2 | 1 | 1 | 6 |
| September | 0.913 | 0.609 | 0.923 | 0.981 | 0.615 | -- |
| Range | 0.881-0.942 | 0.140-0.997 | 0.894-0.944 | 0.960-1.000 | 0.199-0.985 | -- |
| N | 3 | 8 | 3 | 5 | 15 | 0 |
| November | 0.638 | 0.692 | 0.908 | | | |
| Range | 0.265-0.999 | 0.420-0.970 | -- | | | |
| N | 15 | 7 | 1 | | | |

Appendix G. Mean monthly benthic biomass ($mg/m^2$) of Ephemeroptera in samples collected from three habitat types during different levels of discharge from Gavins Point Dam. Habitat I (I) is sand bar pools, habitat II (II) is large pools with or without an organic bottom, and habitat III (III) is chute, chute points, and hard points. Low discharge level (15-22 kcfs) was June through November 1993, medium discharge level (18-32 kcfs) was March through September 1994, and high discharge level (26-49 kcfs) was October 1971 through September 1972. Standard error (SE) and number of samples (N) included for each month.

| | | Low Discharge | | | Medium Discharge | | | High Discharge | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Month | Habitat | I | II | III | I | II | III | I | II | III |
| March | | | | | 12.7 | 0.9 | -- | 0 | | |
| SE | | | | | (4.5) | (0.9) | -- | -- | | |
| N | | | | | 4 | 2 | -- | -- | | |
| April | | | | | 0.2 | 0.5 | -- | 0 | | |
| SE | | | | | (0.1) | (0.5) | -- | -- | | |
| N | | | | | 10 | 2 | -- | -- | | |
| May | | | | | 4.7 | 0 | 1.0 | 0 | | |
| SE | | | | | (2.2) | 0 | (0.5) | -- | | |
| N | | | | | 6 | 2 | 6 | -- | | |
| June | | 0.2 | 337.9 | 13.3 | 4.5 | -- | 5.7 | 0 | | |
| SE | | (0.2) | -- | (12.9) | (2.8) | -- | (3.3) | -- | | |
| N | | 6 | 1 | 5 | 6 | -- | 6 | -- | | |
| July | | 0.5 | 193.2 | 2.2 | 17.8 | 90.5 | 3.5 | 2 | | |
| SE | | (0.5) | (120.0) | (1.1) | (8.6) | (6.9) | (1.4) | -- | | |
| N | | 2 | 4 | 4 | 6 | 2 | 9 | -- | | |
| Aug. | | 50.3 | 352.6 | 6.2 | 1.6 | 20.7 | 5.0 | 1 | | |
| SE | | (27.1) | (231.2) | (2.5) | (0.7) | (10.5) | (4.2) | -- | | |
| N | | 6 | 6 | 5 | 6 | 3 | 11 | -- | | |
| Sept. | | 10.2 | 5.2 | 13.4 | 2.2 | 1.7 | 1.2 | 0 | | |
| SE | | (6.0) | (2.2) | (2.2) | (2.2) | (1.7) | (0.7) | -- | | |
| N | | 4 | 6 | 2 | 2 | 2 | 6 | -- | | |
| Nov. | | 41.6 | 200.0 | 0 | | | | 0 | | |
| SE | | (28.9) | (192.8) | 0 | | | | -- | | |
| N | | 4 | 9 | 2 | | | | -- | | |

Appendix H. Mean monthly benthic biomass (mg/m$^2$) of Chironomidae in samples collected from three habitat types during different levels of discharge from Gavins Point Dam. Habitat I (I) is sand bar pools, habitat II (II) is large pools with or without an organic bottom, and habitat III (III) is chute, chute points, and hard points. Low discharge level (15-22 kcfs) was June through November 1993, medium discharge level (18-32 kcfs) was March through September 1994, and high discharge level (26-49 kcfs) was October 1971 through September 1972. Standard error (SE) and number of samples (N) included for each month.

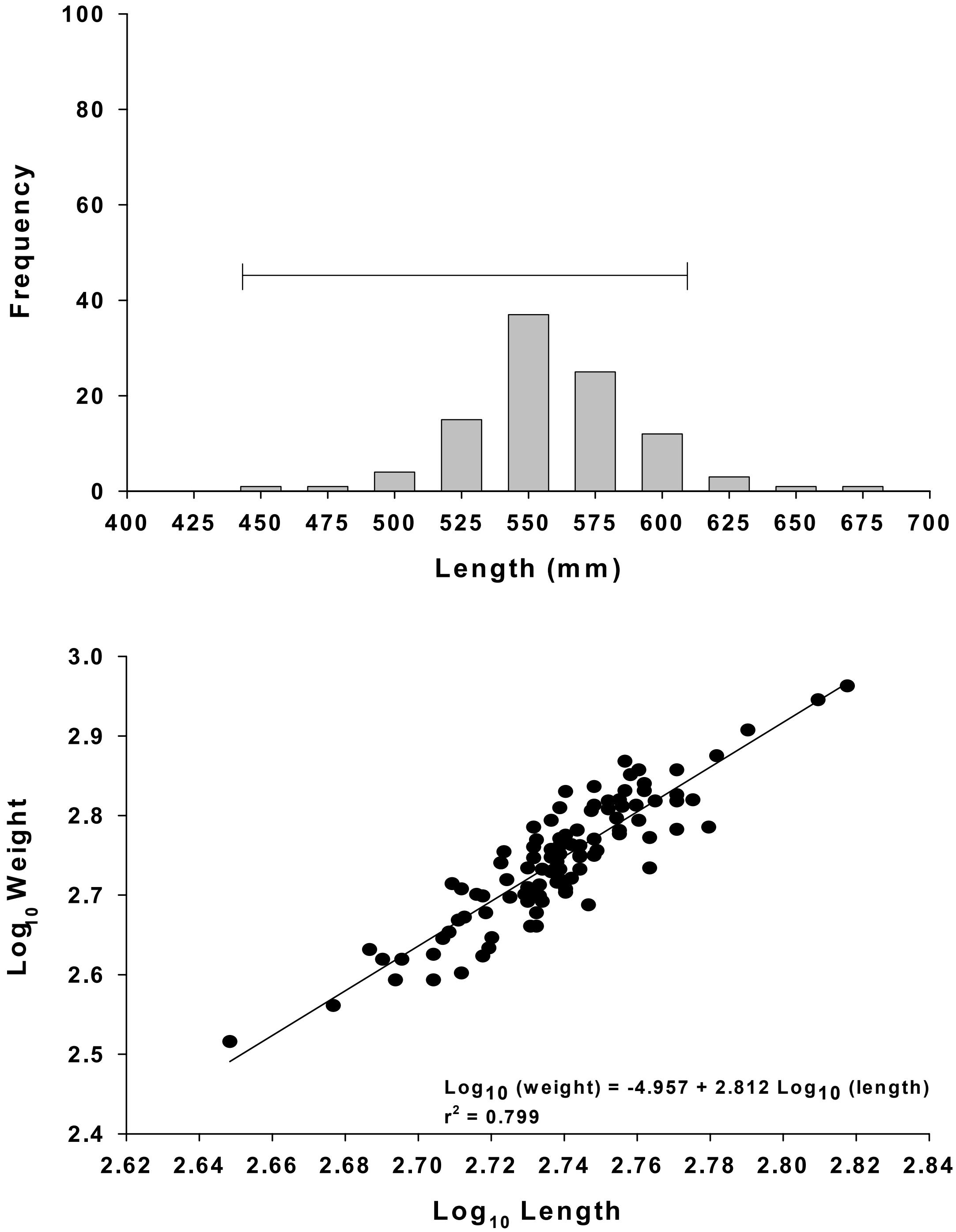
| | Low Discharge | | | Medium Discharge | | | High Discharge | | |
|---|---|---|---|---|---|---|---|---|---|
| Month Habitat | I | II | III | I | II | III | I | II | III |
| March | | | | 108.6 | 44.0 | -- | 4 | | |
| SE | | | | (19.3) | (13.0) | -- | -- | | |
| N | | | | 4 | 2 | -- | -- | | |
| April | | | | 6.7 | 9.1 | -- | 2 | | |
| SE | | | | (1.5) | (6.5) | -- | -- | | |
| N | | | | 10 | 2 | -- | -- | | |
| May | | | | 62.8 | 29.8 | 83.2 | 1 | | |
| SE | | | | (25.0) | (22.0) | (59.9) | -- | | |
| N | | | | 6 | 2 | 6 | -- | | |
| June | 2.2 | 112.9 | 16.0 | 17.5 | -- | 17.5 | 2 | | |
| SE | (0.8) | -- | (7.2) | (3.0) | -- | (6.0) | -- | | |
| N | 6 | 1 | 5 | 6 | -- | 6 | -- | | |
| July | 59.1 | 83.1 | 24.1 | 31.5 | 54.3 | 24.7 | 17 | | |
| SE | (14.3) | (35.9) | (3.7) | (11.3) | (2.6) | (6.5) | -- | | |
| N | 2 | 4 | 4 | 6 | 2 | 9 | -- | | |
| Aug. | 68.5 | 95.2 | 72.4 | 14.4 | 46.3 | 13.2 | 30 | | |
| SE | (19.4) | (22.4) | (33.2) | (4.0) | (19.7) | (1.9) | -- | | |
| N | 6 | 6 | 5 | 6 | 3 | 11 | -- | | |
| Sept. | 19.0 | 20.0 | 25.5 | 21.6 | 19.0 | 16.9 | 12 | | |
| SE | (3.0) | (4.6) | (0.5) | (6.9) | (14.7) | (4.8) | -- | | |
| N | 4 | 6 | 2 | 2 | 2 | 6 | -- | | |
| Nov. | 58.4 | 42.8 | 17.7 | | | | 9 | | |
| SE | (17.5) | (15.3) | (3.0) | | | | -- | | |
| N | 4 | 9 | 2 | | | | -- | | |

Appendix I. Mean monthly benthic biomass (mg/m$^2$) of Hydropsychidae in samples collected from three habitat types during different levels of discharge from Gavins Point Dam. Habitat I (I) is sand bar pools, habitat II (II) is large pools with or without an organic bottom, and habitat III (III) is chute, chute points, and hard points. Low discharge level (15-22 kcfs) was June through November 1993, medium discharge level (18-32 kcfs) was March through September 1994, and high discharge level (26-49 kcfs) was October 1971 through September 1972. Standard error (SE) and number of samples (N) included for each month.

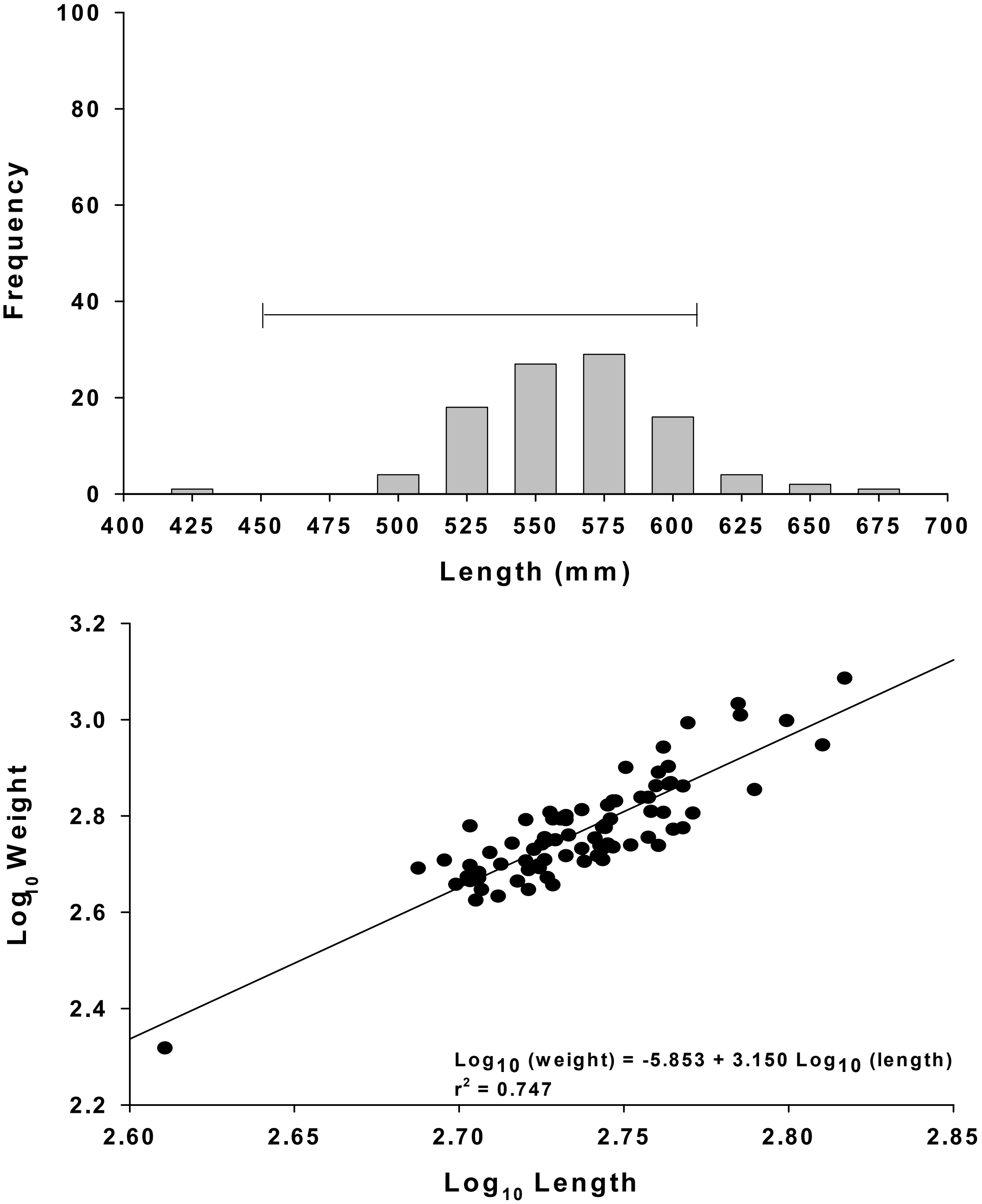
| | | Low Discharge | | | Medium Discharge | | | High Discharge | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Month | Habitat | I | II | III | I | II | III | I | II | III |
| March | | | | | 13.0 | 8.7 | -- | 0 | | |
| SE | | | | | (4.9) | (3.5) | -- | -- | | |
| N | | | | | 4 | 2 | -- | -- | | |
| April | | | | | 2.0 | 3.9 | -- | 0 | | |
| SE | | | | | (1.1) | (3.0) | -- | -- | | |
| N | | | | | 10 | 2 | -- | -- | | |
| May | | | | | 5.2 | 0 | 0.2 | 0 | | |
| SE | | | | | (4.5) | (0.0) | (0.2) | -- | | |
| N | | | | | 6 | 2 | 6 | -- | | |
| June | | 0 | 0.9 | 5.4 | 1.7 | -- | 0.4 | 0 | | |
| SE | | (0.0) | -- | (5.1) | (1.1) | -- | (0.4) | -- | | |
| N | | 6 | 1 | 5 | 6 | -- | 6 | -- | | |
| July | | 0.5 | 8.8 | 1.3 | 10.9 | 22.0 | 1.3 | 7 | | |
| SE | | (0.5) | (6.0) | (0.8) | (5.7) | (2.2) | (0.8) | -- | | |
| N | | 2 | 4 | 4 | 6 | 2 | 9 | -- | | |
| Aug. | | 3.2 | 1.5 | 0.9 | 1.7 | 7.8 | 55.7 | 0 | | |
| SE | | (1.2) | (0.4) | (0.3) | (0.9) | (3.5) | (42.9) | -- | | |
| N | | 6 | 6 | 5 | 6 | 3 | 11 | -- | | |
| Sept. | | 9.5 | 3.3 | 7.3 | 0.9 | 8.6 | 8.8 | 0 | | |
| SE | | (8.1) | (1.6) | (3.9) | (0.0) | (8.6) | (8.8) | -- | | |
| N | | 4 | 6 | 2 | 2 | 2 | 6 | -- | | |
| Nov. | | 9.7 | 6.6 | 0 | | | | 0 | | |
| SE | | (3.8) | (4.2) | (0.0) | | | | -- | | |
| N | | 4 | 9 | 2 | | | | -- | | |

Appendix J. List of fish species caught from Missouri River below Gavins Point Dam, Yankton, South Dakota during 1993 and 1994.

| Genus / species | Common name | 1993 | 1994 |
|---|---|---|---|
| *Scaphirhynchus platorhynchus* | Shovelnose sturgeon | 100 | 127 |
| *Polyodon spathula* | Paddlefish | 1 | 0 |
| *Lepisosteus osseus* | Longnose gar | 3 | 4 |
| *L. platostomus* | Shortnose gar | 9 | 7 |
| *Hiodon alosoides* | Goldeye | 47 | 192 |
| *H. tergisus* | Mooneye | 2 | 0 |
| *Dorosoma cepedianum* | Gizzard shad | 1 | 0 |
| *Cyprinus carpio* | Common carp | 17 | 10 |
| *C. cyprinus* | Quillback | 1 | 0 |
| *Carpiodes carpio* | River carpsucker | 196 | 41 |
| *Cycleptus elongatus* | Blue sucker | 11 | 18 |
| *Ictalurus punctatus* | Channel catfish | 29 | 23 |
| *Pylodictis olivaris* | Flathead catfish | 1 | 0 |
| *Esox lucius* | Northern pike | 0 | 1 |
| *Morone chrysops* | White bass | 0 | 2 |
| *Micropterus dolomieu* | Smallmouth bass | 0 | 3 |
| *Pomoxis annularis* | White crappie | 0 | 2 |
| *P. nigromaculatus* | Black crappie | 0 | 1 |
| *Stizostedion canadense* | Sauger | 18 | 17 |
| *S. vitreum* | Walleye | 0 | 19 |
| *Aplodinotus gruniens* | Freshwater drum | 15 | 32 |
|  | Totals: | 451 | 499 |



Appendix K. Length and weight data for shovelnose sturgeon captured from June through September and November 1993 from the Missouri River near Vermillion, South Dakota. A. Length frequency histogram with bar indicating length range for 130 fish analyzed by Modde and Schmulbach (1997). B. Length-weight regression.



Appendix L. Length and weight data for shovelnose sturgeon captured from March through September 1994 from the Missouri River near Vermillion, South Dakota. A. Length frequency histogram with bar indicating length range for 130 fish analyzed by Modde and Schmulbach (1997). B. Length-weight regression.

Appendix M: Water temperature ranges for sample dates in 1993 and 1994, and number of shovelnose sturgeon netted. Not all netted fish were kept for stomach analysis.

| 1993 | | | 1994_ | | |
|---|---|---|---|---|---|
| Dates Sampled | Temperature Ranges (°C) | Number shovelnose netted | Dates Sampled | Temperature Ranges (°C) | Number shovelnose netted |
| | | | 3/15,16 | 5.5 | 14 |
| | | | 4/18,19 | 11.5 | 5 |
| 5/27,6/4,9,10,11 | 18-19 | 50 | 5/11,12,13,14 | 14.5 | 13 |
| | | | 6/15,16,17 | 22.2-22.5 | 19 |
| 7/6,7,12 | 21.5-25 | 25 | 7/11,12,13,14 | 21.8-23.7 | 2 |
| 8/9,12,16,17 | 25-26 | 6 | 8/1,2,3,8,9,10 | 21.5-24.5 | 6 |
| 9/8,9,13,14 | 16-21.5 | 14 | 9/12,13,14,15 | 21.1-22.5 | 26 |
| 11/1,2 | 6-7 | 22 | 11/15 | 5.5 | 14 |

Appendix N. Sand or inorganic matter (mg) (stomach IOM) in stomachs of shovelnose sturgeon during 1971-1972 (high discharge) data from Modde and Schmulbach (1976), 1994 (moderate discharge), and 1993 (low discharge).

| | **Low Discharge** | **Medium Discharge** | **High Discharge** |
|---|---|---|---|
| Month | Stomach IOM | Stomach IOM | Stomach IOM |
| March | -- | 417<br>(40) | 118 |
| April | -- | 209<br>(26) | 75 |
| May | -- | 729<br>(352) | 461 |
| June | 268.9<br>(28.5) | 432<br>(132) | 472 |
| July | 228.8<br>(38.5) | 534<br>(287) | 137 |
| August | 405.5<br>(129.7) | 112<br>(42) | 102 |
| September | 214.0<br>(55.1) | 179<br>(35) | 124 |
| November | 131.4<br>(28.4) | -- | 68 |