Population Structure and Habitat Use of BENTHIC FISHES along the Missouri and Lower Yellowstone Rivers

Volume 1

Introduction to the Benthic Fishes Study

Project Volume

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Population Structure and Habitat Use of Benthic Fishes Along the Missouri and Lower Yellowstone Rivers

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2001

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PREFACE

Population Structure and Habitat Use of Benthic Fishes along the Missouri and Lower Yellowstone Rivers

This research is reported in the 12 volumes listed below. Reports are available through the U. S. Army Corps of Engineers, the primary contracting agency for the overall project. Contact: Becky Latka, U. S. Army Corps of Engineers, CENWO-PM-AE, 106 South 15th Street, Omaha, NE 68102, (rebecca.j.latka@usace.army.mil, 402/221-4602) for paper copies or access online in PDF format at: http://www.nwo.usace.army.mil/html/pd-e/planning.html. Anticipated date of publication is in (parentheses) for volumes not yet available. Please use the citation format suggested here without the email address when referencing Final Report volumes.

Project Resources. Funding and logistic support were provided by the following agencies and organizations:

Federal - U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and U.S. Geological Survey

State - Kansas Department of Wildlife and Parks, Iowa Department of Natural Resources, Missouri Department of Conservation, Montana Department of Fish, Wildlife and Parks, Nebraska Game and Parks Commission, North Dakota Game and Fish Department, and South Dakota Department of Game, Fish, and Parks.

University - Kansas State University, Iowa State University, Montana State University, South Dakota State University, University of Idaho, and University of Missouri

Non-government - The Wildlife Management Institute

Final Report: Project Volumes

Berry, C. R. and B. A. Young. 2001. Introduction to the benthic fishes study. Volume 1. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone rivers. U. S. Geological Survey, Cooperative Research Units, South Dakota State University, Box 2140b, Brookings, South Dakota 57007. charles_berry@sdstate.edu

Galat, D. L., M. L. Wildhaber, and D. J. Dieterman. 2001. Spatial patterns of physical habitat. Volume 2. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone rivers. U.S. Geological Survey, Cooperative Research Units, University of Missouri, 302 ABNR Bldg., Columbia, Missouri 65251-7240. galatd@missouri.edu

Berry, C. R., D. L. Galat, and M. L. Wildhaber. 2001. Fish distribution and abundance. Volume 3. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone rivers. U.S. Geological Survey, Cooperative Research Units, South Dakota State University, Box 2140b, Brookings, South Dakota 57007. charles_berry@sdstate.edu (available October 2001)

Pierce, C. L., C. S. Guy, P. J. Braaten, and M. A. Pegg. 2001. Fish growth, mortality, recruitment, condition, and size structure. Volume 4. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone rivers. U.S. Geological Survey, Cooperative Research Units, Iowa State University, Science Hall II, Ames, Iowa 50011. cpierce@iastate.edu (available October 2001)

Galat, D. L., L. C. Bergstedt, C. R. Berry, P. J. Braaten, D. J. Dieterman, C. S. Guy, M. A. Pegg, C. L. Pierce, M. P. Ruggles, L. C. Sappington, D. Scarnecchia, T. L. Welker, R. G. White, M. L. Wildhaber, and B. A. Young. 2002. Synthesis of the benthic fishes study. Volume 5. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone Rivers. U.S. Geological Survey, Cooperative Research Units, University of Missouri, 302 ABNR Bldg., Columbia, Missouri 65251-7240. galatd@missouri.edu (available February 2002)

Sappington, L. C., M. L. Wildhaber, and D. L. Galat. 2002. Part 1: Physical habitat and fishes databases. Part 2: Standard Operating Procedures, 1996-1998. Volume 6. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone rivers. U.S. Geological Survey, Columbia Environmental Research Center, 4200 New Haven Road, Columbia, Missouri 65201. linda_sappington@usgs.gov (available January 2002)

Final Report: Dissertation Volumes. Citations to these volumes should not include text in brackets [ ].

Bergstedt, L. C. 2001. Development of an index of biotic integrity for measuring biological condition on the Missouri River. Doctoral Dissertation, Montana State University. [Volume 7. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone rivers.] (available September 2001)

Braaten, P. J. 2000. Growth and mortality of fishes in the Missouri River, with emphasis on freshwater drum. Doctoral Dissertation, Kansas State University, Manhattan, Kansas. [Volume 8. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone rivers.]

Dieterman, D. J. 2000. Spatial patterns in phenotypes and habitat use of sicklefin chub, *Macrhybopsis meeki*, in the Missouri and lower Yellowstone rivers. Doctoral Dissertation, University of Missouri, Columbia, Missouri. [Volume 9. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone rivers.]

Pegg. M. A. 2000. Hydrological variation along the Missouri River and its effect on the fish community. Doctoral Dissertation, Iowa State University, Ames, Iowa. [Volume 10. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone rivers.]

Young, B. A. 2001 Intraspecific variation among emerald shiners (*Notropis atherinoides*) of the Missouri River. Doctoral Dissertation, South Dakota State University, Brookings, South Dakota. [Volume 11. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone rivers.]

Welker, T. L. 2000. Ecology and structure of fish communities in the Missouri and lower Yellowstone rivers. Doctoral Dissertation, University of Idaho. [Volume 12. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone rivers.]

Outreach Product

Berry, C. R., and D. L. Galat. 2001. Synopsis of the population structure and habitat use of benthic fishes along the Missouri and Lower Yellowstone rivers. Agriculture Experiment Station Bulletin 7xx, Available from: Bulletin Room, LMH112, South Dakota State University, Brookings, South Dakota 57007. (available November 2001)

EXECUTIVE SUMMARY

This report describes the benthic fishes study, which was a research project conducted on the Missouri River from Montana to Missouri between 1995 and 2000. The goal was to evaluate changes in the fish community on a large spatial scale that would assist the U.S. Army Corps of Engineers and other Federal and State agencies in managing the Missouri River system. The purposes of this volume are to: 1) provide the background and scope of the study, 2) characterize the Missouri River main-stem habitat and fishes, 3) describe the history and conduct of the benthic fishes study, and 4) recommend procedures of future multi-investigator studies with large spatial scale.

Literature about the Missouri River has been grouped into four periods. To 1880, explorers kept notes on their impressions of the river. Between 1880 and 1920, anthropologists wrote about settlement and the vanishing Indian presence. Between 1944 and 1960 authors promoted the building of dams and channelization structures. The final period, characterized by a plethora of scientific studies, began in 1970 and continues today. Of these studies, we review 1) historical fisheries surveys, 2) information on ecology of 26 benthic fishes chosen for study, and 3) concurrent studies related to fisheries.

In 1995, a consortium of Cooperative Research Units (ID, MT, SD, KA, IA, MO) and the Columbia Environmental Research Center (both now in the U.S. Geological Survey), and the Montana Department of Fish, Wildlife, and Parks began a fish study in the warm-water portion of the Missouri River System. Information in this Volume documents the administration of this $2.7 million study and details of the study design.

We divided the river into three large zones that included several study segments each. The least-impacted zone was the upper Missouri and Lower Yellowstone rivers. The inter-reservoir zone included river segments downstream from dams in Montana, North Dakota, and South Dakota. The channelized zone was downstream from Sioux City, Iowa to the Mississippi River. Fish were sampled in six macrohabitats – secondary channels with flow, secondary channels closed at the upper end, main-stem outside bends, main-stem inside bends, main-stem crossovers, tributary mouths. Five gears were used – gill net, bag seine, bottom trawl, drifting trammel net, and electrofishing. The basic experimental design was as follows: dependent variables were measures related to physical habitat (e.g. depth, velocity), to fish distribution and abundance (e.g. relative abundance, catch/effort), and to fish populations (e.g. growth, condition). Independent variables were year of study, zone, segment, and macrohabitat. We accomplished 100% of our planned fieldwork making numerous habitat measurements while we collected 134,163 fishes representing all 26 benthic species (including four endangered pallid sturgeon), 17 non-indigenous species, and 63 other species. For studies of this scale, administration, communication, standardizing procedures, and data management are emergent properties that require considerable attention.

Other Volumes of the final report give results and discuss spatial patterns of physical habitat (Volume II), fish distribution and abundance (Volume III), fish growth, condition and recruitment (Volume IV), a synthesis of results (Volume V), and standard procedures and databases (Volume VI). A unique aspect of the study was the six Ph. D. Dissertations that were written by students working on the study for each Coop Unit. Each Dissertation is directly related to findings presented in Volumes I-VI. Dissertation topics are 1) index of biotic integrity for the Missouri River, 2) ecology and structure of fish communities in the Yellowstone River area, with emphasis on the catostomid (sucker) family, 3) variation in emerald shiners from the main-stem of the river and from reservoirs, 4) effects of hydrological variation on fish, 5) growth and mortality of fishes with emphasis on the freshwater drum, and 6) abiotic factors related to sicklefin chub distribution, phenotype and habitat use.

Keywords: Missouri River, Yellowstone River, fish, fish habitat, benthic fishes, study design, project history, USGS mission, administration, communication, sampling, river, data management, graduate education, scientific presentations, river zonation, exotic fishes, games fishes, forage fishes, river substrate, regulated river, dams, Montana, North Dakota, South Dakota, Iowa, Missouri, Nebraska, Kansas, turbidity, discharge, Corps of Engineers

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INTRODUCTION

Purpose

This report describes the benthic fishes study, which was a unique research project conducted on the Missouri River from Montana to Missouri between 1995 and 2000. The research **goal** was to evaluate changes in the Missouri River fish community on a large spatial scale that would assist the U.S. Army Corps of Engineers in managing the Missouri River system. We focused on the population structure and habitat use of 26 species of benthic fishes along the entire main-stem Missouri River, exclusive of reservoirs. Our basin-wide analysis was organized within a spatial habitat hierarchy (i.e. river zones, segments, and macrohabitats) to predict how potential changes in system operation can benefit conservation and recovery of fishes and their habitats while maintaining the diversity of present-day public uses of the Missouri River. We repeated sampling for 3 years to somewhat estimate annual variability.

We present data on:

1) patterns of physical habitat variables in river zones, segments, and macrohabitats,
2) distribution of 26 benthic fish species (Table 1) and their habitat associations,
3) population characteristics of 11 benthic species, and
4) distribution of 80 other species that were also caught during the study.

The purposes of this volume are to:

1) provide the background and scope of the study,
2) characterize the Missouri River system, its fishes and habitat,
3) describe the history and conduct of the benthic fishes study, and
4) recommend procedures of future multi-investigator studies with large spatial scale.

Scope

A pilot study was done in 1995 after which fieldwork was carried out for 3 years on 15 riverine segments (18 segments in 1996) from the warm-water section of the Missouri River in Montana to the confluence with the Mississippi River in Missouri. Sampling was done from July through September each year. The lower Yellowstone River was also included in the study.

This research was conducted by Cooperative Research Units in Montana, Idaho, South Dakota, Iowa, Kansas, Missouri, by the Columbia Environmental Research Center, Columbia, Missouri, and by the Montana Department of Fish, Wildlife and Parks, Fort Peck, Montana. The Units and the Center are in the Biological Resources Division of the U.S. Geological Survey. A Ph.D. student at each Coop Unit led the fieldwork while collecting other data for a Dissertation. Researchers with the Montana Department of Fish, Wildlife and Parks (Montana FWP) worked on the Missouri River downstream from Fort Peck Dam to the confluence of the Yellowstone River, and on the Yellowstone River. Researchers at the Columbia Environmental Research Center (Columbia ERC) had direct involvement in the research through development of study objectives and design, sampling methods, analytical techniques, data management, quality assurance and control, and public information and education.

Objectives

Objectives of the benthic fishes study were:

1) Describe and evaluate recruitment, growth, size structure, body condition, and relative abundance of selected benthic fishes.
2) Characterize physiochemical features (e.g., velocity, turbidity) in dominant habitats where fishes were collected.
3) Describe use of dominant habitats by benthic fishes.

The final report for the study includes analyses to meet the above objectives, plus six Ph. D. Dissertations on topics related to the benthic fishes study.

Subjects of the Dissertations are:

- An index of biotic integrity for measuring biological conditions
- Ecology and structure of fish communities in the Yellowstone river area, with emphasis on the family Catostomidae (suckers)
- Intra-specific variation among populations of emerald shiners from the main-stem river and from reservoirs
- Effects of hydrological variation on the abundance and growth of fishes
- Basin-wide growth and recruitment of fishes, and factors influencing freshwater drum
- Abiotic factors related to sicklefin chub distribution, phenotypes, and population structure

Corps of Engineers Interests

The benthic fishes study was initially supported by the Planning Division of the Omaha District of the Corps of Engineers (Corps) to get biological information

Table 1. List of species designated as benthic fishes and special designation or functional category. Species marked with an asterisk were used for fish age and growth analysis.

Common name	*Scientific name*	Designation
Bigmouth buffalo	*Ictiobus cyprinellus*	Commercial
Blue catfish	*Ictalurus furcatus*	Recreational
Blue sucker*	*Cycleptus elongatus*	Species at risk
Brassy minnow*	*Hybognathus hankinsoni*	Prey
Burbot	*Lota lota*	Recreational
Channel catfish*	*Ictalurus punctatus*	Recreational
Common carp	*Cyprinus carpio*	Commercial
Emerald shiner*	*Notropis atherinoides*	Prey
Fathead minnow	*Pimephales promelas*	Prey
Flathead catfish*	*Pylodictus olivaris*	Recreational
Flathead chub*	*Platygobio gracilis*	Prey
Freshwater drum	*Aplodinotus grunniens*	Recreational
Hybognathus spp.*	*Hybognathus spp.*	Prey
Pallid sturgeon	*Scaphirhynchus albus*	Species at risk
Plains minnow*	*Hybognathus placitus*	Prey
River carpsucker*	*Carpiodes carpio*	Commercial
Sand shiner*	*Notropis stramineus*	Prey
Sauger*	*Stizostedion canadense*	Recreational
Shorthead redhorse	*Moxostoma macrolepidotum*	Prey
Shovelnose sturgeon*	*Scaphirhynchus platorynchus*	Catch restrictions
Sicklefin chub*	*Macrhybopsis meeki*	Species at risk
Smallmouth buffalo*	*Ictiobus bubalus*	Commercial
Stonecat	*Noturus flavus*	Prey
Sturgeon chub	*Macrhybopsis gelida*	Species at risk
Walleye	*Stizostedion vitreum*	Recreational
W. silvery minnow*	*Hybognathus argyritis*	Species at risk
White sucker	*Catostomus commersoni*	Prey

needed for compliance with the Endangered Species Act. The Corps is responsible for numerous activities on the Missouri River, including regulation of the flow regime (Sveum 1988), dredging, bank stabilization, and issuing permits under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act. Under the Endangered Species Act, the Corps must ensure that their actions do not jeopardize the continued existence of any federally listed endangered species or the habitats on which they depend. The Corps is currently in consultation with the U.S. Fish and Wildlife Service on three actions that relate to fishes: 1) ongoing operations of the dams, 2) maintenance of the bank stabilization and navigation project, and 3) review of the Missouri River Master Water Control Manual (Master Manual) for operating the system.

The benthic fishes assemblage includes the endangered pallid sturgeon and several fishes that have been candidates for listing (e.g., sturgeon chub, sicklefin chub). Information on the status of the rare fishes and their habitat may provide insight needed by the Corps to continue operation and maintenance of the system while implementing reasonable and prudent measures to conserve rare fishes.

The benthic fishes study could also benefit Corps programs for habitat restoration and improvement. The Section 1135 program is for modifying existing Corps projects to create environmental restoration or improvements. The Section 204 (dredging locations) and 206 (any location) programs are for restoring aquatic habitat. Restoration programs should be planned with an understanding of fish habitat needs. Furthermore, the restoration programs can be evaluated when baseline data on the fish community are available. The benthic fishes study meets both needs.

Other Programs
In addition to the Corps operation and maintenance programs for the Missouri River, there are other Federal and non-Federal programs that may benefit from the results of the benthic fishes study.

Federal Programs
The National Park Service and Bureau of Land Management manage three reaches of the Missouri River for scenic values. The 256-km reach upstream from Fort Peck Reservoir, Montana, is a Wild and Scenic River, and was included in our study. Two reaches in South Dakota are National Recreational Rivers; both were included in our study.

The Environmental Protection Agency (EPA) responsibilities include working with states and Indian tribes to ensure that federal environmental standards are met. Additionally, the EPA determines whether major federal management decisions, such as changes in the Master Manual, protect and restore the river. The EPA is a resource for data, technical assistance, or funds to help with community-based environmental protection of the Missouri River ecosystem.

The Bureau of Reclamation operates main-stem dams upstream from Fort Peck Reservoir (e.g., Canyon Ferry Dam), small dams on Missouri River tributaries, small dams and water diversions on the main-stem Yellowstone River (e.g. at Glendive, Montana), and small dams on tributaries to the Yellowstone River. Data from the benthic fishes study may help the Bureau assess hydrological modifications and fish passage facilities at certain dams, and compare fish community health between the relatively natural Yellowstone and the Upper Missouri river.

The Fish and Wildlife Service provides management assistance and technical information for fish and wildlife conservation, and administers the Endangered Species Act (ESA). After the pallid sturgeon was listed as endangered, meaning that it was in danger of extinction throughout all or a significant portion of its range, the Service began undertaking protective measures authorized by the ESA to conserve the species and its habitat. Such measures include protecting the species from adverse effects of Federal activities, carrying out recovery plans, purchasing important habitat, and aiding states and Indian tribes with conservation measures. Section 7 of the Act calls for consultation between the Corps and the Service about the potential effects of system operation on the pallid sturgeon and other rare and endangered species. Additionally, the Service operates the Big Muddy, DeSoto, Karl Mundt, and Charles M. Russell national wildlife refuges on the Missouri River, and the Gavins Point and Valley City national fish hatcheries where pallid sturgeon are reared for stocking.

Non-federal Programs
About 28 tribes claim water rights to the Missouri River. Many reservations now use or have plans to use Missouri river water for drinking water and irrigation. As tribal water rights issues are resolved, Federal management of listed species may need reconsideration, and may be subject to ESA Section 7 compliance. The Tribes in the basin are involved with natural resource management and several are managing federally listed species (e.g., piping plovers).

States along the Missouri River have many interests in how the river is managed. The Missouri River Basin Association (MRBA) is a coalition of basin states and tribes that was created by state Governors in 1981. The Association provides a discussion forum for issues such as endangered species recovery and drought flow management. The Missouri River Natural Resources Committee is an MRBA committee of state representatives (voting members) and Federal representatives (non-voting members) that promotes and facilitates the preservation, conservation, and enhancement of Missouri River natural resources. States manage public use of the river, including boating access and recreational and commercial fishing. Data from the benthic fishes study may relate to stocking hatchery-raised fish (e.g. walleyes) and to recreational harvest.

MISSOURI RIVER

In 2004, the United States will celebrate the Lewis and Clark bicentennial. People around the world will be visiting the basin, rereading The Journals, and trying to imagine the land, wildlife, and Native Americans that the explorers encountered in the wilderness. Lewis and Clark mentioned 31 fish species in their journals and data notebooks, but most references were brief notes about fish captured by netting or angling (Moring 1996). They characterized the Missouri River as a warm-water river that flooded twice in most spring periods, and carried large amounts of sediment and organic matter derived from the floodplain. Just 30 years after their return, work to improve the river for travel began, and we have been changing the river and studying its biota ever since (reviews by Keenlyne 1988, Schneiders 1999).

Public demands to use the river for navigation, for irrigating the arid Great Plains, for controlling devastating floods, and for generating electricity began in earnest in the early 1900s. Seven Rivers and Harbors Acts from 1912 to 1945 authorized the Federal Government to harness the river below Sioux City for navigation and flood control. The project, called the Bank Stabilization and Navigation Project, was completed in 1981 when 1176 km of river between Sioux City, Iowa, and St. Louis, Missouri, were declared channelized and stabilized. Upriver from Sioux City, the largest reservoir system in the United States was built under the Pick-Sloan Plan. Primary management responsibility is with the U.S. Army Corps of Engineers. The Corps operates the main-stem reservoir system by holding or releasing water according to a water-control plan that is detailed in the Master Manual. Released water is carried in the main-stem channel that has been modified by the Bank Stabilization and Navigation Project.

The natural hydrograph and channel geometry of the main-stem Missouri River have been altered by the dams in the upper basin and channelization in the lower basin. Impoundments have also been built in tributary watersheds that affect the main-stem water flows. Some 75 dams have been built on 53 tributaries. Throughout the basin, plant communities and land use of the flood plain have changed (Hesse 1996). Along the main-stem for example, bottomland hardwoods, grasslands, and wetlands have been replaced by agricultural cropland. Organic material (leaves) from these plant communities has been reduced (about 65%, Hesse et al. 1989), so less organic material can enter the river in floodwaters or from tributaries. Many acres of historical meander belt habitat have been lost. In the Missouri River basin, more than 1.6 million ha have been converted to agriculture or inundated by reservoir water (Hesse and Schmulbach 1991). Channelization and impoundment have eliminated many acres of habitat for native fish (CE 1981). There has been agricultural, urban, and industrial encroachment on 95% of the floodplain. These and other changes have been widely reported (Funk and Robinson 1974; Whitley and Campbell 1974; Johnson et al. 1976; Bragg and Tatschl 1977; Hesse 1987, 1996; Pflieger and Grace 1987; Hesse et al. 1988, 1989, 1993; Johnson 1992; Schmulbach et al. 1981, 1992; Galat et al. 1996; Smith 1996; Scott et al. 1997).

The impacts of impoundment, flow regulation, channelization, levees, and basin development on system ecology have been classified as first-, second-, and third-order changes (Becker and Gorton 1995). First-order changes include 1) covering 396,000 ha (990,000 acres) of bottom land and 1216 km (760 miles) of channel with impoundments in the upper river, and 2) reducing floods and river surface area of about 66,400 ha (160,000 acres) in the lower river. Second order changes are indirect changes from dam and channel operation (e.g., altered hydroperiod, channel bed change). Third-order changes result from biological and chemical events that are acting on or exerting feedback effects upon the first- and second-order events. For example, cottonwood regeneration has declined, waterfowl migration corridors moved westward, water quality changed, carbon fixation has increased in the reservoirs but decreased in riverine reaches, and native riverine fishes have been declining in abundance. Curtailed functions include floodplain inundation, natural hydrograph and water temperature, sediment and organic matter input and transport, and instream cover for fish. These alterations have contributed to an estimated loss of 216 million kg of fish production annually (Hesse and Sheets 1993).

Mitigating impacts of the channelization and impoundment has been an ongoing Corps program (Becker and Gorton 1995). The Fish and Wildlife Mitigation Plan provides for restoration work on 12,140 ha (30,000 acres) of bottomlands. Measures have been taken to improve habitat for sensitive shore birds. Erodible stream banks were protected in an aesthetic manner while improving bank habitat. Dike notching has improved fish habitat and chute restoration has improved fish and wildlife habitat. However, by 1990, 7 species of plants, 6 insects, 2 mussels, 16 fishes, 4 reptiles, 14 birds and 3 mammals were listed as endangered, threatened, or rare by state or federal agencies within the Missouri River basin (Whitmore and Keenlyne 1990). Endangered species on the main-stem included the piping plover, least tern, and pallid sturgeon. Some other fish populations were declining and commercial fish harvest was reduced 80% (IFMRC 1994).

Missouri River Habitat

The Missouri River is the longest river in the conterminous United States. It extends 3,768 km (2,339 mi) from the confluence of the Gallatin, Madison, and Jefferson rivers in southwest Montana to the Mississippi River, 24 km upstream from St. Louis, Missouri (Figure 1). Its drainage basin encompasses about one-sixth of the conterminous United States (1,371,000 km^2).

The Yellowstone River is a major tributary that joins the Missouri near Cartwright, North Dakota. The Yellowstone is important to the benthic fishes study because the lower 480 km (300 miles) is classified as a warm-water fishery, is in a relatively natural condition, and has minimum instream flows secured for fish conservation. The Yellowstone serves the study as a “control” or least-altered segment.

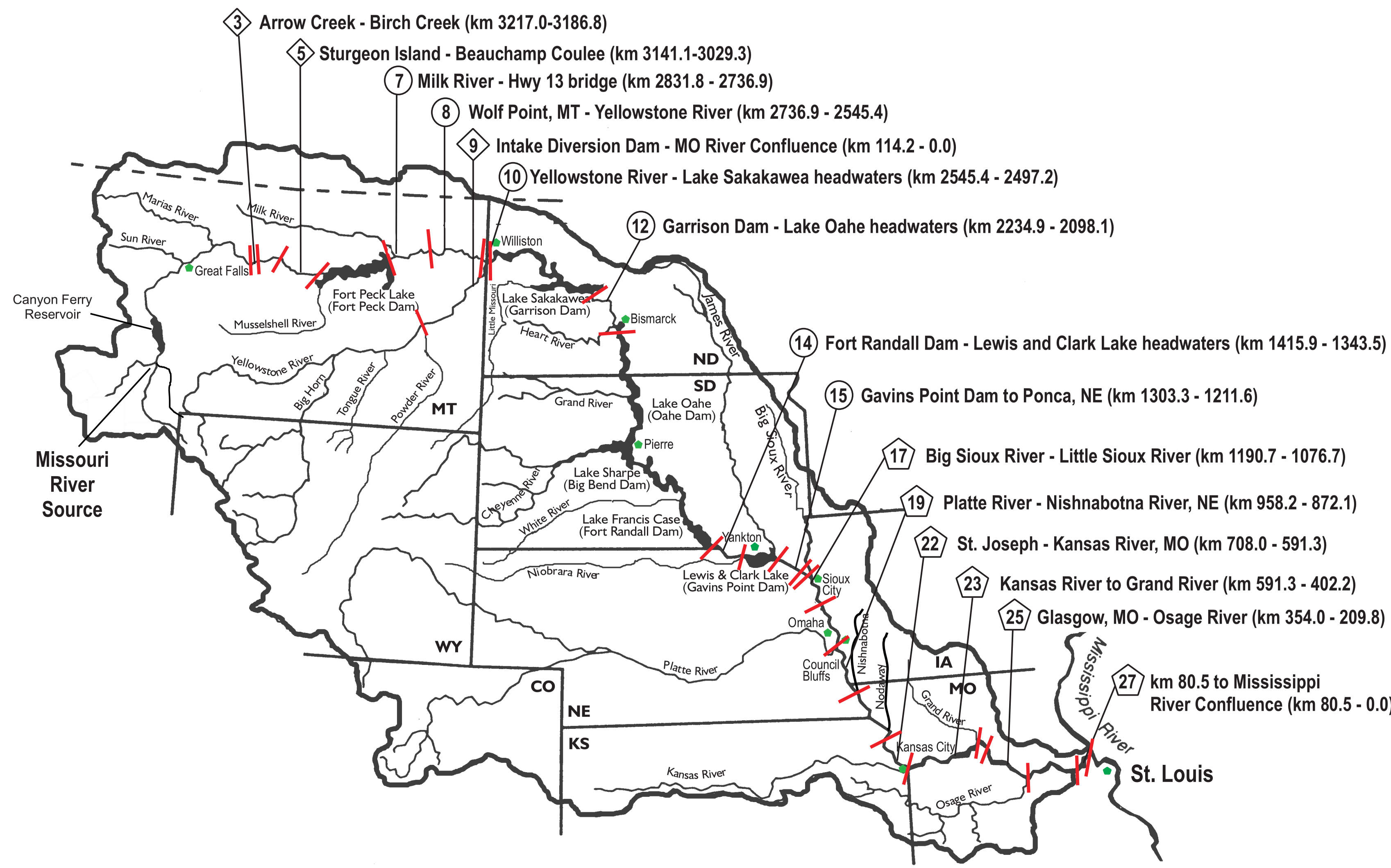


Figure 1. Map of Missouri River basin showing general locations of 15 segments sampled for physical variables from mid-June to October, 1996-1998. Segment numbers within diamonds are in the least-altered zone, numbers in circles are segments in the inter-reservoir zone, and numbers in pentagons are segments in the channelized zone. (map produced by J. Heuser, USGS, CERC).

The Missouri River basin is largely (71%) in the semi-arid Great Plains physiographic province but parts of the basin are in three other provinces: 11% in the Rocky Mountains (western basin), 17% in the Central Lowlands (eastern and lower basin), and about 2% in the Interior Highlands (south, lower basin). Average annual precipitation is about 45 cm in the Great Plains, about 80 cm in the Rocky Mountains, and over 90 cm in the Interior Highlands. Tributary water quality and quantity differ among provinces, so tributaries influence conditions in the main-stem of the Missouri River, as will be shown by our data.

Fish Habitat Classification

The hierarchical organization of a river system and its habitat subsystems begins with the watershed or basin and steps down to zones, segments, and fish macrohabitats. We partitioned the river into three zones, 27 segments, and 6 macrohabitats. River zones (least-altered, inter-reservoir, channelized) discussed below are broad river basin subdivisions.

River Zones

Today, the river can be divided into three zones of about equal length based on the type of modification. The upper 1,241 km (770 mi) has a complex of seven small main-stem dams and reservoirs that have little effect on flow, so this section represents a relatively "least-altered" zone. In this zone is the free-flowing, relatively unaltered Yellowstone River. Small dams on tributaries and diversions on the main-stem of the Yellowstone affect only about 5% of the flow. Mean annual discharge of the Yellowstone River is 373 m^3/s of which 70% is from snow pack. Hence, there is high spring runoff and then much lower flows through the fall and winter.

The 1,316-km-long (817 mi) middle or "inter-reservoir" section of the Missouri River was impounded between 1937 and 1963 by six main-stem dams. The reservoirs provide recreation, water (1,600 intakes) and hydropower (2,436 megawatts). The reservoirs are also used to control flooding and regulate flows for navigation in the 1,212-km (752 mi) lower or "channelized" zone. After dams were built, typical river changes downstream were 1) water elevation lowered by about 3 m, 2) discharge rating curve increased, 3) bed degradation increased, and 4) cross-sectional channel wider (Shen 1989). These changes are typical of those found downstream from any newly constructed dam because of sediment imbalance (Holly and Ettema 1993). The channel has degraded because sediment is being trapped in upstream reservoirs, so bottom substrates downstream from dams are scoured (Latka et al. 1993).

The channelized river zone is from North Sioux City, South Dakota, (km 1,178) to the mouth. Here, the river supports commercial barge traffic (1.5 million tons annually), and about 140 docks and terminals operate. Water is released from dams to maintain a 3-m deep navigation channel. There are about 30,400 residential and 5,345 other buildings in the flood zone, as well as numerous farms. Channel-floodplain morphology in this zone was altered by channelization, bank stabilization and levee construction to facilitate navigation and floodplain development (Schmulbach et al. 1992, Galat et al. 1996). Berner (1951) cites a 1946 Corps report describing the river before bank stabilization:

> "…the river meandered through the valley and it has not been uncommon for the wild river to erode and carry away a whole farm in the course of a day, or by avulsion, to shift several farms from one side of the river to the other. Between the rock bluffs the river in its natural state built itself high banks, easily erodible, which contained the normal high water but were overtopped by floods. These banks were from 1,500 feet to a mile apart, covered with willows, cottonwoods, and hardwoods. In general, the river followed a meandering course of bends and reaches impeded by soft and shifting bars, shoals, snags, and debris which frequently caused the formation of two or more shallow channels."

A typical historic cross section of the river in this zone shows the great habitat diversity that is described in the passage above (Figure 2).

By 1972, about 40% of the natural wetted channel area was lost, the remaining channel deepen and flow intensified (Hallberg et al. 1979). By the 1990s, the floodplain area covered by seasonal inundation had been reduced by levees to a narrow corridor that was 10% of its precontrol width (Schmulbach et al. 1992). Channelization and bank stabilization eliminated about 40,500 ha (97,200 acres) of aquatic habitat and 151,500 ha (363,600) of wetland and terrestrial habitat from the natural river and its active erosion zone (FWS 1980).

River Segments and Habitats

Each zone was sub-divided into segments. A river segment is a portion of the river where river morphology is similar and contiguous, thus allowing free fish movement. River morphology is defined as "the river landscape, or the range of landforms in the river valley

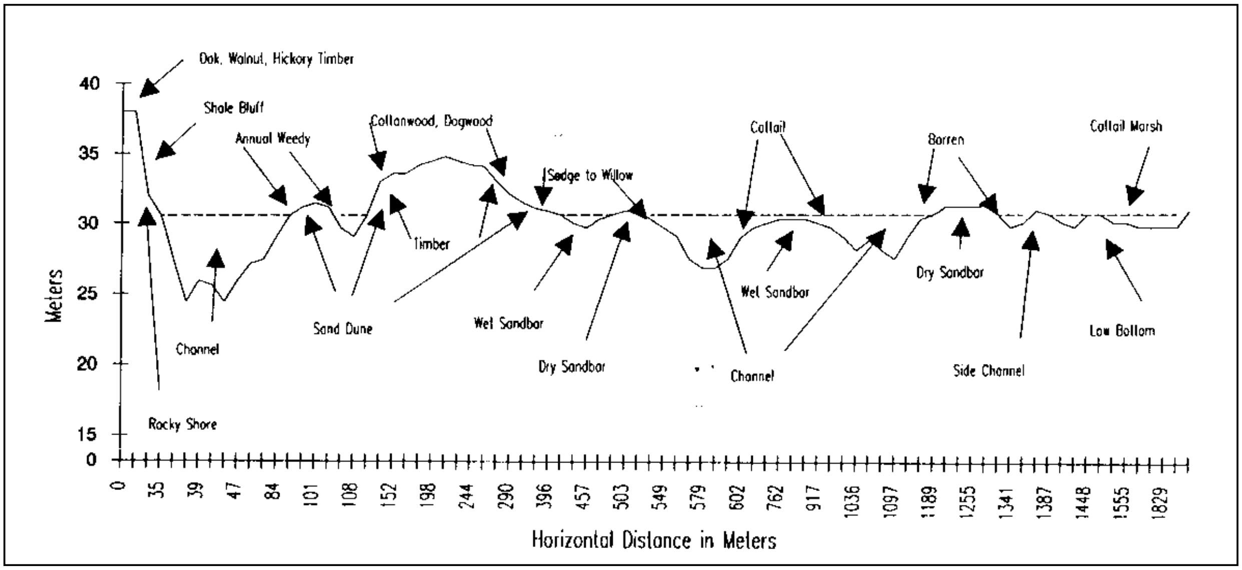


Figure 2. Typical historic cross section of the unregulated lower Missouri River (about rk 940) showing diversity of physical habitat (from Hesse and Sheets 1993).

that are shaped by the river" (Kellerhals and Church 1989). The changes in Missouri River morphology depend on location. Twenty-seven river segments were identified, 18 were sampled in 1996 and 15 thereafter (Figure 3). Segment length ranged from 30 to 191 km (18-114 miles) and averaged 108 km (64 miles). Throughout Volumes I-VI of the final report, we underlined segment numbers in the least-impacted zone, wrote bold segment numbers in the inter-reservoir zone, and italicized segment numbers in the channelized zone as such: 3, 5, 9, **7**, **8**, **10**, **12**, **14**, **15**, *17, 19, 22, 23, 25, 27*.

Segments contain numerous river bends and other macrohabitats that influence fish distribution and abundance. Macrohabitats are distinctive, repeatable natural and man-made physical features. Within each bend, we sampled three continuous macrohabitats: inside bend, outside bend, and channel cross-over. We also sampled discrete macrohabitats: tributary mouths, and connected (flow-through) and non-connected (backwater) secondary channels. Sampling representative macrohabitats within each segment accounted for the diversity of physical conditions present at the segment scale. Overall, we sampled fish and physical habitat in 1,191 macrohabitats over the three study years. Other macrohabitats that occurred infrequently in a segment, were termed "wild" macrohabitats, and included dam tail waters, bays, and shallow tributary mouths.

Macrohabitats themselves were subdivided into mesohabitats, which we recorded. For example, a tributary mouth could be either large or small; inside bends could have a sand bar, pool, steep shoreline, and channel border. Macro- and mesohabitats were selected randomly each year. We sampled this variety of habitats, which represented the physical conditions in each segment, because habitat conditions are important in defining fish community structure (Bain and Boltz 1989).

A general hypothesis about the causes of change in the Missouri River fish community is: altered channel morphology and flow regime has changed the habitat to which the native fish community adapted, thus causing shifts in population and community attributes. Aquatic macrohabitats are shaped by the river, so there was high habitat diversity in the historic natural channel. However, channel degradation below dams and channelization in the lower section reduced the number and size of some macrohabitats and isolated others from the main channel. In general, habitats associated with islands, sand bars, and backwaters have declined, whereas deep and swift channel macrohabitats have increased (FWS 1980). Remnant unchannelized segments **14** and **15** on the South Dakota-Nebraska border are still somewhat similar to historic conditions but have altered hydrographs controlled by upstream dams (Schmulbach et al. 1975, 1981; Kallemeyn and Novotny 1977, Hesse 1987). These segments are National Recreational River reaches because of their relatively undeveloped, scenic

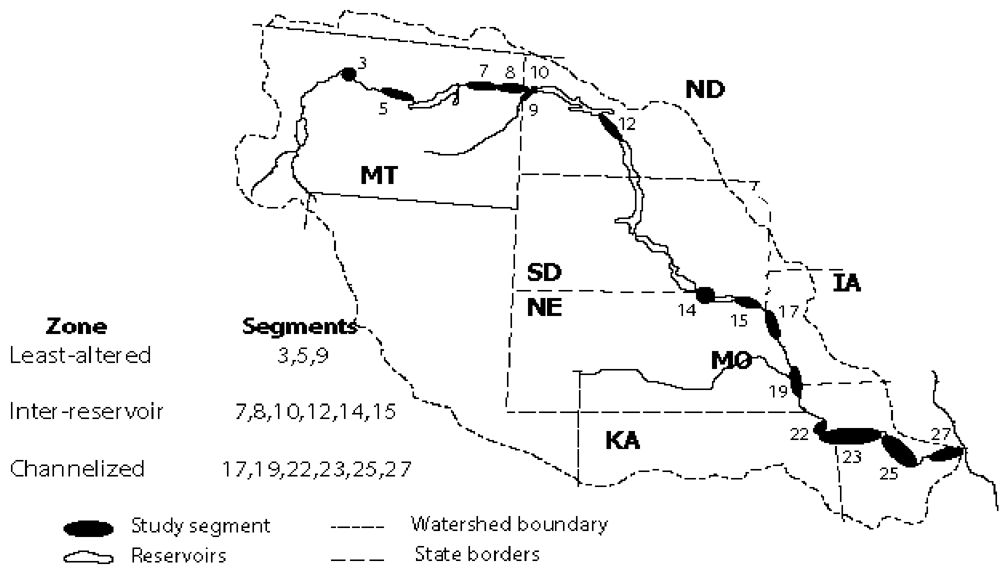


Figure 3. Map showing 15 segments in 3 zones that were the focus of the benthic fishes study.

beauty. Segment **15** downstream from Gavins Point Dam is unique because it is blocked upstream by Gavins Point Dam, but is not blocked downstream by a reservoir, nor is it channelized.

Physical Habitat Characteristics

Macrohabitats are characterized by velocity, depth, and substrate, which are features that are important to fish. Just as the number and area of natural macrohabitats has changed in each segment, physical conditions have also changed. For example, historical river velocities were usually 0.3-0.8 m/s, but downstream from dams, velocities between 0.8 m/s and 1.3 m/s occur more frequently than they do under the historic condition (Latka et al. 1993). Substrates within about 24 km (15 miles) downstream from dams changed from fine (about 0.4 mm) to course (about 10 mm) over 30 years (Shen 1989).

In the benthic fishes study, we measured depth, velocity, substrate size, turbidity, conductivity and temperature at each fish sampling location. These physical habitat variables have several applications, which is why they are traditional stream habitat measurements (McMahon et al. 1996, Bain and Stevenson 1999). They show trends in conditions among segments and among macrohabitats that explain differences in fish community or population attributes. Physical measurements can be used to predict fish habitat suitability. Physical measurements will also allow future scientists to conduct fisheries studies under similar conditions. Physical habitat data can also be used in concert with biological data to assess the benefits of habitat improvement activities, such as chute restoration (Harberg et al. 1993).

Velocity and depth. Flow is an important factor of riverine fish habitat because it affects other habitat features like water quality, energy sources on the floodplain, physical habitat structure, and biotic interactions. Flow attributes that are important to benthic fishes are velocity, depth, and patterns in the flow regime.

Many analyses of flow regime before and after impoundment have been made. Unregulated monthly flows were simulated for the period 1898-1990 (reviewed by Latka et al. 1993). Prior to flow regulation, the inter-reservoir and channelized section exhibited a bimodal annual flow regime regardless of temporal climate changes (Figure 4). There was a spring “rise” in April from snow melt in the Great Plains and ice breakup on the main channel and major tributaries (Galat and Lipkin 2000). A second, or June rise, was produced by runoff from snowmelt in the Rocky Mountains and rainfall throughout the basin. Lowest flows were in December. The present hydrograph (1966-1985 in Figure 4) reflects the flood control and navigation operations of the system that reduce spring flows and increase low summer and fall flows (Figure

4).

Reservoir releases are managed to maintain minimum flows (700-1160 m^3 sec^{-1}) in the channelized section for the April-November navigation season. In the non-navigation season releases maintain minimum flows (170-650 m^3 sec^{-1}) for water quality, hydropower production and flood control. Consequently, in the river downstream from dams, flood zone inundation rarely occurs in June because the river does not reach "bankfull" levels (Hesse 1996). Inundation is more likely to occur in August, but sometimes does not occur at all (Latka et al. 1993). Discharges from large tributaries like the Platte River increase Missouri River stages, but waters are somewhat confined by levees in the channelized zone.

Galat and Lipkin (2000) compared flows from the period 1929-1948 to those from the period 1967-1996 for representative river sections. Mean annual discharge for all stations ranged from 8 - 42% higher, inter-annual flow variability was lower, and flow predictability was higher in the post-regulation period. Flow regulation caused reduced flooding, longer periods of low flow with fewer low-flow pulses, earlier seasonal low flows in the spring, an increase in flow reversal frequency, and a reduced rate of change in river flows. These conditions were smallest in the least-altered zone and most frequent and severe in the inter-reservoir and upper-channelized river zones. The depression of the annual flood pulse by reservoir operations was partially offset by tributary inflow in the lower river, but the increase in low-flow discharge was not.

Fish association with velocity and depth. Velocity and depth are two factors thought to be important when describing the habitat suitability for any fish. Habitat descriptions are based on 1) movement studies of individual fish, 2) habitat conditions where fish are captured, and 3) habitat selection in laboratory tests. Fish vary in their ability to swim against current. For example, the most suitable habitat for adult smallmouth buffalo is where average current velocity is

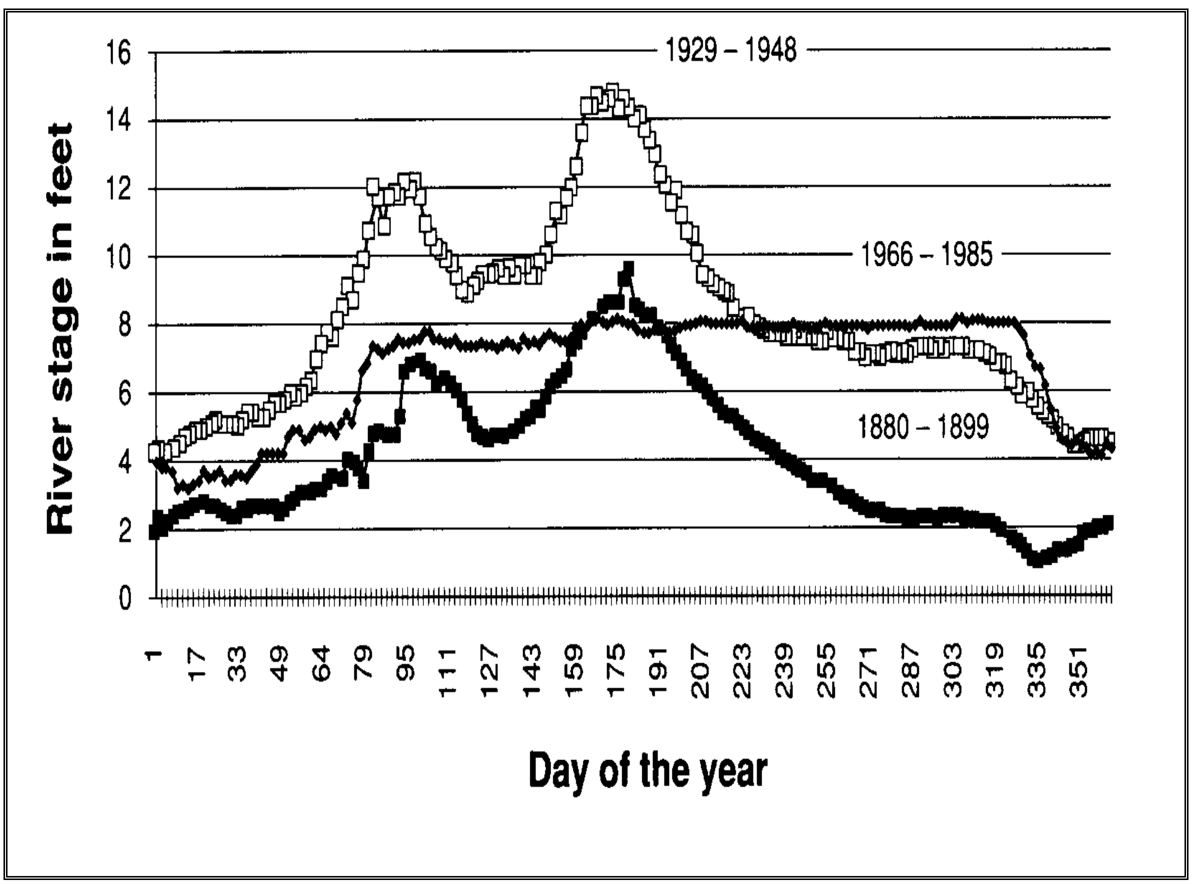


Figure 4. Missouri River hydrograph during two pre-dam periods, and one post-dam period (from Hesse and Mestl, 1993).

from 50-75 cm/s, whereas suitable habitat for juvenile stages is where velocities are less than 20 cm/s (Edwards and Twomey 1982a). Radio-tagged shovelnose sturgeon in the Mississippi River were typically found in areas with a sand bottom, mean water depth of 5.8 m, and mean bottom current velocity of 0.23 m/s (Curtis et al. 1997). Suitable velocities for juvenile shovelnose sturgeon are less than 20 cm/s. The variables that quantify flow regime are more important to fish than single hydraulic components because flow regimes determine potential flow energies and flow patterns.

Flow regime is the permanence and seasonal patterns of stream flow. It is assumed that fish become adapted to seasonal flooding and low flows. Flow regime is thought to be an underpinning to ecological integrity (Poff et al. 1997; Richter et al. 1997). Natural flow regimes have intra- and inter-annual variability that include magnitude, timing, duration, frequency, and rate of change that are critical to sustaining the full native biodiversity and integrity of aquatic systems, including the community function and life-history patterns of riverine fishes (see reviews by Heede and Rinne 1990, Bailey and Li 1992). Consequently, a working hypothesis about flow regime might be: changes in flow regime causes changes in the fish assemblages.

Many studies have monitored the decline of riverine fisheries as river habitat changed, but precise causes have not been identified because of the difficulty of conducting experiments in large rivers. There are hypotheses about how changes in the Missouri River habitat have caused changes in the fish community. For example, where flooding has been controlled, it is hypothesized that suppression of the spring food pulse has caused loss of spawning cues (i.e. warm-water coupled with river stage increases) that triggered spawning activity in native river fishes. Lack of flooding may also reduce nutrient transport and hence fish productivity, because historical flows included detritus and other carbon sources produced on the floodplain and in off-channel wetlands. Also, the loss of half of the historical natural channel and meander belt has reduced aquatic habitat quantity and diversity. Increased velocities in portions of the river may require energetic expenditures that affect fish growth and survival, or exceed limits for some adult fishes or fish life stages, thus lowering recruitment. However, there are a few tests of this hypothesis.

Substrate. Substrate refers to river bottom material, which is usually studied in habitat surveys because 1) substrate composition influences channel hydraulics (water depth, width, current velocity), 2) substrate provides the micro-habitat conditions (velocity refuge, spawning substrate) needed by many fish species and invertebrate fish food organisms, and 3) substrate measurements are an index to local and watershed influences on stream habitat quality. We characterized substrate as 1) the proportion of the substrate in one of three particle size classes (gravel, sand, silt), and 2) by measures of particle size central tendency (McMahon et al. 1996).

The historical condition of the bottom substrates in the Missouri River is not as well known as historical flow conditions. Berner (1951) described lower Missouri River substrates in 1945 after improvement for navigation had taken place. Some idea of the historical substrates can be obtained from 1) routine substrate surveys downstream from dams, and 2) comparison of substrates between channelized and unchannelized reaches. For example, substrate surveys at the Gavins Point dam site in 1955 found that most (90%) of the substrate was <1 mm in diameter (Shen 1989). During the 30 years since dam closure, substrates 24 km (15 miles) downstream had changed from fine (about 0.4 mm) to course (about 10 mm). Such changes were typical of those downstream from any new dam (Shen 1989).

Before regulation, there were probably more substrates dominated by silt and detritus. Silt and detritus (course organic material like leaves and woody debris) accumulate in low-velocity areas. Our preliminary analysis indicated that backwater substrates were 85% silt, 14% sand and 1% gravel whereas main channel substrates were 1% silt, 19% gravel, and 80% sand. Most of the 65% of the benthic habitat that has been lost in the channelized reach was probably habitat where water velocity was low and where silt and debris accumulated (Morris et al. 1968), thus leaving the shifting-sand substrates of the main channel as the dominant habitat in any reach.

Fish association with substrate. Fishes are associated with substrates in two primary ways: 1) fishes select certain substrates as habitat, and 2) benthic substrates support attached periphyton and the benthic invertebrate community that are important in riverine fish food webs. Lower benthic invertebrate production often results in lower fish production. Regarding substrates as habitat for benthic invertebrates, comparisons between channelized and unchannelized reaches have shown that invertebrate production is lower in channelized reaches because substrates are different (Morris et al. 1968). Furthermore, river discharge affects the biomass of benthic and drifting macroinvertebrates, and thus fish feeding success (Modde and Schmulbach 1973, 1977). Secondary production in the Missouri River downstream from Gavins Point Dam might be about half that in the historical unmodified river (Mestl and Hesse 1993).

Most information on bottom substrate suitability for fish is about fish spawning. For example, sand-to-gravel size substrate is optimum for white suckers (Twomey et al. 1984), whereas paddlefish require gravel and larger substrates (Hubert et al. 1984). We assumed that substrate would be an important habitat component for adult benthic fishes, but there is little information on substrate preferences of most benthic species adults.

Water quality. Water temperature, conductivity, and turbidity were measured at locations where benthic fishes were sampled. Each characteristic has a particular value to our study, and allowed comparisons among zones, sections and macrohabitats. We tried to limit temperature influences by sampling only in mid- to late-summer on the upper ascending limb and upper descending limb of the water temperature curve. All samples were collected at water temperatures between 14 and 26 C. Our temperature data will be useful to future scientists who wish to duplicate our study. Other benefits of sampling in mid- to late-summer were: 1) avoided seasonal variation in fish catch rates (Jordan 2000), 2) sampling was more effective after high spring flows declined, 3) young fishes were usually large enough to capture, identify and age, and 4) macrohabitats were well defined.

Conductivity is a commonly recorded water characteristic because the data indicate dissolved material quantities, which tend to be positively related to biological productivity. For the benthic fishes study, conductivity measurements give the conditions while sampling, and allow comparison of chemical conditions and potential biological productivity among river segments. Conductivity varied greatly in tributary habitat because each tributary watershed was unique. However, conductivity in the main-stem varied by segment. Segments in the upper and middle zone had conductivity values of 400 to 600 uS/m, whereas values were about 800 uS/m in the lower channelized zone.

Water turbidity is a measure of the extent that suspended solids reduce light penetration. Suspended sediment is a major contributor to turbidity, so inputs from tributaries probably affect the main-stem. Sediment loads at Hermann, Missouri, were reduced by about 1/3 after the reservoir system became operational. Turbidity measurements (Jackson Turbidity Units, JTU) at St. Louis did not change when Fort Peck Dam closed in 1940. However, between 1930 (1200-2600 JTU) and 1983 (200-400 JTU), there was nearly a fourfold decrease in turbidity, the most abrupt decline occurring in the 1950s as additional reservoirs became operational (reviewed by Pflieger and Grace 1987).

We expected a longitudinal increase in temperature throughout the river because of the decrease in latitude of about 10 degrees, and because the river is a continuum (Sedell et al. 1989). We also expected abrupt temperature reductions in inter-reservoir segments, and modification of main-stem thermal regimes from major tributaries (Schmulbach et al. 1992). For example, inflows from the Niobrara River increase Missouri River main-stem temperatures significantly (Jordan 2000), and hypolimnetic discharges from Fort Peck Dam reduce main-stem temperatures for about 200 km downstream (Schmulbach et al. 1992).

Fish association with turbidity and temperature. Turbidity is an important fish habitat characteristic because it affects feeding behavior (e.g., reduces sight-feeding distances), fish food production (e.g., primary production), spawning (e.g., time, place, and behavior), and physiology (e.g., respiratory patterns). Most information on turbidity is related to coldwater species, and some information is available for warm-water riverine species (Muncy et al. 1979, Bruton 1985). However, the turbidity-fish relationship issue on the Missouri River is "too little turbidity, not too much turbidity."

Increased clarity is not directly harmful to adults and may improve egg survival. Many riverine species do well in impoundments where turbidity is low. Turbidity in impounded rivers usually decreases, which can indirectly change fish assemblages that are adapted to higher turbidity. In general, when turbidity decreases in rivers, some riverine fish species are replaced by sight-feeding planktivores and piscivores adapted to lentic habitats and clear water. Such changes were apparent by 1974 in the lower Missouri River (Funk and Robinson 1974).

Fishes are poikilothermic (cold-blooded) so ambient temperature is one of the most potent factors influencing fish ecology. Clear cold water discharged from dams usually causes a decline in warm-water fishes and an increase in cold-water fishes that support popular tail-water fisheries, such as that described by Wickstrom (1999) downstream from Gavins Point Dam. Cold water releases change fish communities in many ways, including delayed spawning and hence reduced growth of young fishes (e.g. Fort Randall Dam, Jordan 2000; Garrison Dam, Wolf et al. 1996). Downstream from the coldwater habitat, water is warmer but remains clear, and the enhanced clarity continues to have indirect effects on fishes (Cross and

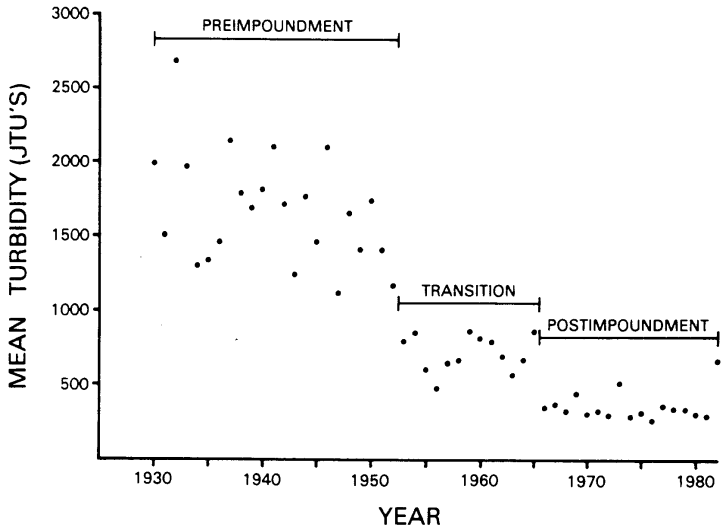


Figure 5. Mean annual turbidities of the Missouri River determined from daily measurements at the St. Louis water-treatment facility (from Pflieger and Grace 1987).

Moss 1987). For example, enhanced clarity promotes primary production that 1) supports planktivorous fish populations, and 2) may alter food webs (Stanford and Ward 1983).

The Missouri River Fish Community

The lower Missouri River was a refuge for fishes during glaciation, so the archaic families Acipenseridae (sturgeons), Polyodontidae (paddlefish), Lepisosteidae (gar), and Hiodontidae (goldeye) exist. Today, there are about 156 fish species recorded in the Missouri River basin, but about 100 species regularly use the main channel or floodplain habitats downstream from Gavins Point Dam (Hesse 1996). About 35 native species are thought to be declining whereas some 23 species (including 9 introduced species) are thought to be increasing (Hesse 1996). Table 2 shows the species captured during the benthic fishes study, other than the 26 selected benthic fishes that were listed in Table 1. The most important warm-water sport fishes are walleye, sauger, yellow perch, channel catfish, paddlefish, shovelnose sturgeon, and northern pike.

There have been no large-scale investigations of Missouri River fish populations, and never a study as large as the benthic fishes study. Our focus is on fishes of the main-stem where we expected to find species assemblages associated with the benthic habitat (our chosen fish assemblage for assessment), floodplain habitats, mid-channel habitats, and longitudinal zones (Schlosser 1991). However, comprehensive localized studies have been done, and synthesized by Hesse et al. (1989) in a review of basin-wide fish fauna. We review here the most comprehensive studies of main-stem fishes, grouped by zone (i.e. channelized, inter-reservoir, least-altered).

Channelized Zone

For the lower Missouri River, Funk and Robinson (1974) were the first to synthesize data on the changes in the fish populations. They reviewed anecdotal information and sketchy reports from 100 years of commercial fishing. The pallid sturgeon was not distinguished from other sturgeon (shovelnose, lake sturgeon) in the early days, and may never have been especially abundant. Over-harvest of walleye, sauger, crappies, sunfishes, and largemouth bass caused population declines in the early 1900s and the commercial fishery for these species was closed. The best data were from 1945-1963 when the total catch of dominant commercial species (e.g., catfishes, buffaloes, carp) declined. Similar trends were seen in the catch of sturgeons, paddlefish, and freshwater drum. They noted the increased number of fishes associated with clear water, such as the skipjack herring, white bass, mimic shiner, and spotfin shiner. Pflieger and Grace (1987) updated information by describing fish faunal changes in the lower Missouri River from 1940 to 1983. They reported 67 species. Pelagic planktivores and sight-feeding carnivores increased in abundance, and more exotics began to appear (e.g., rainbow smelt, grass carp, silver carp, striped bass). Some species specialized for life in the presettlement Missouri River (e.g., pallid sturgeon, flathead chub) declined whereas others (e.g., sicklefin chub, sturgeon chub) had not declined. Commercial fishing for flathead and channel catfish was prohibited in the early 1980s because larger fishes were becoming scarce (reviewed by Galat et al. 1996).

The Nebraska Game and Parks Commission began fish surveys in the channelized Nebraska-Iowa section of the Missouri River in the late 1950s. Through the 1960s, 40 species were documented in the Nebraska section (Schmulbach et al. 1975). Intensive fish surveys were begun when two nuclear power plants were constructed beside the Missouri River in Nebraska in the 1970s (Hesse et al. 1982). Hesse et al. (1982) wrote

"The (study) design was based on the critical

Table 2. List of other fishes collected during the conduct of the benthic fishes study. The common carp is the only exotic species included in the benthic fishes assemblage, so it is not listed here.

Introduced and exotic	
Bighead carp	*Hypopthalmichthys nobilis*
Brown trout	*Salmo trutta*
Bullhead minnow	*Pimephales vigilax*
Chinook salmon	*Oncorhynchus tshawytscha*
Grass carp	*Ctenopharyngodon idella*
Ciscoe (Lake herring)	*Coregonus artedi*
Goldfish	*Carassius auratus*
Lake whitefish	*Coregonus clupeaformis*
Western mosquitofish	*Gambusia affinis*
Muskellunge	*Esox masquinongy*
Rainbow smelt	*Osmerus mordax*
Rainbow trout	*Oncorhynchus mykiss*
Rock bass	*Ambloplites rupestris*
Striped bass	*Morone saxatilis*
Spottail shiner	*Notropis hudsonius*
White bass	*Morone chrysops*
White perch	*Morone americana*
Other species captured	
Banded killifish	*Fundulus diaphanus*
Bigeye shiner	*Notropis boops*
Bigmouth shiner	*Notropis dorsalis*
Black buffalo	*Ictiobus niger*
Black bullhead	*Ameiurus melas*
Black crappie	*Pomoxis nigromaculatus*
Bluegill	*Lepomis macrochirus*
Bluntnose minnow	*Pimephales notatus*
Bowfin	*Amia calva*
Brook silverside	*Labidesthes sicculus*
Brook stickleback	*Culaea inconstans*
Chestnut lamprey	*Ichthyomyzon castaneus*
Common shiner	*Luxilus cornutus*
Creek chub	*Semotilus atromaculatus*
Freckled madtom	*Noturus nocturnus*
Ghost shiner	*Notropis buchanani*
Gizzard shad	*Dorosoma cepedianum*
Golden redhorse	*Moxostoma erythrurum*
Golden shiner	*Notemigonus crysoleucas*
Goldeye	*Hiodon alosoides*
Grass pickerel	*Esox americanus vermiculatus*
Green sunfish	*Lepomis cyanellus*
Highfin carpsucker	*Carpiodes velifer*
Johnny darter	*Etheostoma nigrum*
Lake chub	*Couesius plumbeus*
Lake sturgeon	*Acipenser fulvescens*
Largemouth bass	*Micropterus salmoides*
Largescale stoneroller	*Campostoma oligolepis*
Logperch	*Percina caprodes*
Longear sunfish	*Lepomis megalotis*
Longnose dace	*Rhinichthys cataractae*
Longnose gar	*Lepisosteus osseus*
Longnose sucker	*Catostomus catostomus*
Mimic shiner	*Notropis volucellus*
Mottled sculpin	*Cottus bairdi*
Northern hog sucker	*Hypentelium nigricans*
Northern pike	*Esox lucius*
Northern redbelly dace	*Phoxinus eos*
Orangespotted sunfish	*Lepomis humilis*
Paddlefish	*Polyodon spathula*
Pearl dace	*Margariscus margarita*
Quillback	*Carpiodes cyprinus*
Red shiner	*Cyprinella lutrensis*
River redhorse	*Moxostoma carinatum*
River shiner	*Notropis blennius*
Shortnose gar	*Lepisosteus platostomus*
Silver chub	*Macrhybopsis storeriana*
Silverband shiner	*Notropis shumardi*
Skipjack herring	*Alosa chrysochloris*
Slender madtom	*Noturus exilis*
Smallmouth bass	*Micropterus dolomieu*
Speckled chub	*Macrhybopsis aestivalis*
Spotfin shiner	*Cyprinella spiloptera*
Spotted bass	*Micropterus punctulatus*
Spotted gar	*Lepisosteus oculatus*
Striped shiner	*Luxilus chrysocephalus*
Suckermouth minnow	*Phenacobius mirabilis*
Tadpole madton	*Noturus gyrinus*
Threadfin shad	*Dorosoma petenense*
White crappie	*Pomoxis annularis*
Yellow bass	*Morone mississippiensis*
Yellow bullhead	*Ameiurus natalis*
Yellow perch	*Perca flavescens*

assumption that the channelized Missouri River presented a homogeneous environment, a concept that proved to be erroneous as field work progressed. The variable spatial and temporal nature of the river made statistical analysis difficult."

About 90,000 fishes representing 57 species were collected near the proposed power plants. Hesse et al. (1982) caught all species sought by the benthic fishes study team except pallid sturgeon and brassy minnow. The authors described the fish community and life history traits for channel catfish, carp, gizzard shad, river carpsucker, freshwater drum, goldeye, smallmouth buffalo, bigmouth buffalo, flathead catfish, and sauger. These 10 species represented about 90% of the fishes collected by electrofishing. Species with downward population trends were sauger, blue catfish, burbot, shovelnose sturgeon, longnose gar, and flathead catfish (Hesse et al. 1993). Hesse and coworkers also kept catch per effort (C/E) data on certain species and associated the data with river conditions (reviewed by Hesse 1996). The sauger population declined when spring river flows fluctuated greatly for electrical power peaking, or were low because water was being stored in upstream reservoirs.

The 10 most abundant smaller species representing 90% of the seine catch were gizzard shad, western silvery minnow, plains minnow, silver chub, emerald shiner, red shiner, sand shiner, river shiner, bigmouth shiner, river carpsucker, and channel catfish. The C/E trends were declining for three chub species (flathead, silver, speckled) and two minnows (plains, western silvery). Only one sturgeon chub and one sicklefin chub were among the 26,000 small fishes seined from the Nebraska section of the river between 1970 and 1993 (Hesse 1994).

Inter-reservoir Zone

There are two sections with different characteristics: 1) Segment **15** on the South Dakota-Nebraska border downstream from Gavins Point Dam is distinct because physical habitat is somewhat natural although hydrologic conditions are modified. 2) Other inter-reservoir segments are limited upstream by a dam and downstream by a reservoir (segments **14**, **12**, **10**, **8**, **7**).

The few studies in South Dakota were limited because seining was the primary collection technique used by Bailey and Allum (1962) who documented 45 species including seven introduced species. The Fish and Wildlife Service also surveyed fishes and fish food organisms in the South Dakota, Nebraska, and Iowa portions of the river (Kallemeyn and Novotney 1977). However, research by Dr. Jim Schmulbach was among the first to reveal changes occurring after Gavins Point Dam was closed (Schmulbach et al. 1975). Overall, his research showed that fish and macroinvertebrate numbers decreased in the channelized reach (our segment *17*) compared to the unchannelized reach (our segment **15**), and that dam discharges influenced the macroinvertebrate community and shovelnose sturgeon feeding (Modde and Schmulbach 1977). Schmulbach speculated on future trends stating "Continuing reduction in the size of the aquatic backwater habitats portends deterioration of the Missouri River fishery." He determined that there were 113 fish species in the unchannelized reach (main-stem and tributaries), and he collected 50 of the 65 species reported in the main-stem by sampling tail waters, main channel, chutes, sandbars, backwaters, and tributary confluences (Schmulbach et al. 1975).

Annual surveys have been done by biologists from Nebraska (e.g. Mestl 1999b) and South Dakota (e.g. Wickstrom 1996) in our Segment **14**, which is isolated between Ft. Randall Dam and Lewis and Clark Lake. Monitoring emphasis has been on the river-reservoir transition zone where a delta has formed. A combination of gillnets, hoop nets, electrofishing, seining, and trawling has produced 54 species recently. Population metrics (e.g. relative weight), and C/E data have been calculated for recreational species.

Fish surveys of the inter-reservoir segments in North Dakota were limited prior to 1991, except for work by Steinhaus (1979). Mizzi (1994) listed 70 species that had been recorded in the main-stem, and collected 42 species by using seines and minnow traps in major macrohabitats (except main channel) near Bismarck and Williston, North Dakota. The North Dakota Game and Fish Department has found 57 species in riverine habitat up- and downstream from Lake Sakakawea. Six species were introduced coldwater species. Standardized investigations of the 144-km-long (90 miles) riverine portion between Lake Oahe and Lake Sakakawea were begun in 1991 (Hendrickson et al. 1995). Standardized sampling at five tributary mouths and nine main-stem sites is done with frame nets, gill nets and seining. Water in the main-stem is cool (<17 °C in August) and clear year-round, and flow is highly regulated. Fifty-two species were captured in this reach between 1991 and 1994 (Hendrickson et al. 1995).

Upstream from Lake Sakakawea, standardized surveys of the fish community were begun in 1991. Prior to 1991, surveys focused on paddlefish. Riverine reaches in North Dakota include a 21-km (13 miles) portion of the lower Yellowstone, and a 29-80-km (18-53 mile) reach of the Missouri River main-stem, depending on Lake Sakakawea water levels. Standardized sampling with frame nets, gill nets, and seines has been done in backwaters, side channels, oxbows, and tributaries. Thirty-six species were found in this reach between 1991 and 1994. Western silvery minnows and flathead chubs usually dominated seine catches: a few sturgeon chubs and sicklefin chubs sometimes were found.

Least-altered Zone

In Montana, little historical information is available about Missouri River fishes. However, in the 1970s and 1980s, inventories were done downstream from Fort Peck Lake (Gardner and Stewart 1987) and upstream from the Lake (Berg 1981). Fish data were needed upstream from the lake to manage the recently designated Wild and Scenic river reach, and to assess water development impacts (Berg 1981). Berg found 53 species representing 14 families in the basin (tributaries and Fort Peck Reservoir) and 42 species in the main-stem. The most widely distributed species were sauger, burbot, white sucker, longnose sucker, shorthead redhorse, river carpsucker, carp, goldeye, freshwater drum, emerald shiner, western silvery minnow, flathead chub, and longnose dace. Twenty-four of our benthic assemblage species were present (excluding the blue catfish and sand shiner), and pallid sturgeon were found at four sites, sicklefin chubs at three sites, and sturgeon chubs at two sites. Berg (1981) also provides information on water quality, benthic invertebrates, and life history of common fish species (abundance, spawning periods, growth, larval fish density, length at age).

The fish assemblage in the lower Yellowstone River was intensively studied in the mid-1970s because of potential coal mining in eastern Montana. The studies were done to provide the Bureau of Reclamation with basic data on fish life history and distribution in the lower river (Graham et al. 1979), and to support efforts to secure instream flows for fishes (Peterman 1980). Most sampling was done with electrofishing to develop information on game fishes (Peterman 1979), but a forage fish inventory was also conducted (Schwehr 1977). The fish species list for the lower Yellowstone River (our segment 9) included 46 species by 1980. All fishes that we studied in the benthic fishes project were found except the sand shiner, sicklefin chub, and blue and flathead catfish.

Studies Concurrent with the Benthic Fishes Study

During the benthic fishes study, there were numerous other fish studies underway (Table 3). Most were focused on a specific fish (i.e. seven studies on pallid sturgeon) in a specific river segment, so these had low relevance to our study. Studies having moderate to high relevance to the benthic fishes study were those investigating fish populations, relations between fish and habitat, and sampling methods.

BENTHIC FISHES STUDY

In 1995 our consortium of Coop Units, the Montana FWP, and the Columbia ERC (USGS-BRD) began a fish study in the warm-water portion of the Missouri river system. However, the groundwork for the study was laid over the preceding 6 years during a time when large interjurisdictional rivers moved into the Congressional and Federal agency spotlight. At that time, the Coop Units were in the Research Division of the Fish and Wildlife Service.

Benthic Fishes Study Background

In 1989, the Service received a congressional inquiry about the need for additional refuges on the Missouri River. Several coordination meetings were held between Regions 3 (Minneapolis), 6 (Denver), and 8 (Research) at which time it was determined that the foremost concern of the Service was the continued addition of fishes dependent on the Missouri River habitat to the list of endangered species. From these meetings came a “New Beginnings” document that recognized many Tribal, State, Federal, and private conservation efforts, and proposed that the Service assume a coordination role.

In 1988, the South Dakota Coop Unit and the Montana Coop Fishery Unit submitted the first prospectus for a multi-unit study of the fish and wildlife of the Missouri River. Administrators in both Regions 6 and 8 requested proposals from Service researchers, and other unsolicited proposals were also submitted from the Coop Unit Program. We sought funding from various Service programs, but were not funded. While the Units were unsuccessful in obtaining funds for a multi-Unit study, several units were carrying out smaller projects with Service, State Cooperator, or Corps funding. These studies and an assessment of research needs were reported in 1991 to the Service’s “scoping team” led by Dr. Bill Mauck. Additionally, in 1992 the South Dakota Unit provided information for the Service’s Congressional testimony on HR4169 “The Interjurisdictional River Fisheries Restoration Act.” South Dakota Unit Leader Dr. Charles Berry, briefed all Coop Unit Leaders on interjurisdictional river initiatives at the February 1992 Unit Leader’s meeting in Las Cruces, New Mexico, where the idea of a multi-Unit study was discussed further.

In January 1993, the document titled “Missouri River - Conserving a River Ecosystem” or MORCARE was produced primarily by Dr. Kent Keenlyne of the Service (and Adjunct Professor at SDSU). The

Table 3. Routine monitoring and special studies underway on the riverine reaches of the Missouri River during the field-work portion of the benthic fish study, 1995-1998.

State	Agency	Person to contact	Goal of Study	Relevance to benthic fish study
MT	Montana DFWP and WAPA	J. Liebelt	Monitoring and recovery of pallid sturgeon; systematic sampling	moderate
		B. Gardner	Monitoring pallid sturgeon, paddlefish, and sauger	moderate
	Montana DFWP and USGS-BRD (Midwest Ecology Center)	M. Ruggles and D. Fuller	Relation of fish to habitat, bathometric studies of velocity and habitat gradients	high
		M. Ruggles and K. Bovee	Yellowstone fish habitat, bathometric studies	high
	B. Reclamation and other agencies	S. Hiebert	Intake and fish passage over lowhead dams; Yellowstone fish bibliography	moderate
	U.S. Fish and Wildlife Service	S. Krantz	Pallid sturgeon status in upper Missouri River	low
	Montana State University	R. Bramblett	Habitats of pallid and shovelnose in Yellowstone and Missouri rivers.	moderate
	Montana State University	G. Grisak	Status of sicklefin chub	low
	U. of Idaho	S. Everett	Biology of 3 native benthic fishes	high
ND	U. of Idaho	D. Scarnecchia	Monitoring techniques for paddlefish	low
	U.S. Fish and Wildlife Service and SDSU	D. Willis and S. Fisher	Backwater habitats for fish	low
	SDSU	D. Willis and S. Wilson	Tadpole madtom in backwaters	low
	North Dakota GF	F. Rykman	Annual paddlefish survey	low
		J. Lee and J. Hendrickson	Fish population of main stem	high
		J. Lee and J. Hendrickson	Status of selected species of concern in ND Missouri River system	moderate
		W. King	Sexing pallids and shovelnose with ultra sound	low
	U. of Idaho	S. Evertt and D. Scarnecchia	Life history and ecology of 3 native benthic fish	moderate
SD	U.S. Fish and Wildlife Service and SDSU	D. Willis and G. Jordan	Seasonal variation in fish populations downstream from Ft Randall	high
	South Dakota GFP	J. Riis, C. Stone and J. Wickstrom	Angler creel survey in tailwater fisheries; Ft. Randall reach	moderate
		W. Nelson-Stastny	Bionomics of paddlefish between Ft. Randall and Gavins Point Dam.	low
	South Dakota State University	B. VanZee	Walleye, sauger and black bass in Lewis and Clark Lake	moderate
IA	Iowa DNR	—	Contaminant analysis	low
NB	Nebraska	L. Hesse	Various studies, status of fishes in the Missouri River, 40-yr database	high
		G. Mestl	Hamberg Bend restoration	moderate
		G. Mestl	Routine monitoring, mostly for large fish, but 30+ species collected	high
	Rivers Corporation	L. Hesse	Develop relation between discharge and CPUE for selected species	high

Table 3. continued

MO	Missouri Dept. of Cons.	V. Travlacek	Routine Missouri River monitoring and special studies	moderate
		K. Graham	Status of the paddlefish	low
		J. Robinson	Sampling procedures for flathead and channel catfish in the Missouri river	moderate
	U.S. Fish and Wildlife Service	M. Young	Endocrine disrupting chemicals in channel catfish, and sturgeon	low
	U.S. Fish and Wildlife Service	J. Milligan	Monitoring for Big Muddy NWR	moderate
		J. Milligan	Status of Asian carp invasion	low
		J. Grady and J. Milligan	Status of selected cyprinid species in the lower Missouri	high
	U. of Missouri	G. Gelwicks	Fish movement between wetland and Missouri River	low
		J. Sargent	Wetland as fish nursery habitat	low
		T. Coon	Fish larvae in the lower Missouri River	moderate
		D. Galat and R. Lipkin	Histroical flow regime	moderate
		J. Kubisiak and D. Galat	Flood-scoured basins as fish nursery areas	low
	USGS-Columbia Environmental Research Center	M. Laustrop	Lower Missouri river Ecosystem Initative: bibliography, homepage, mapping and GIS	moderate
	USGS-Columbia Environmental Research Center	E. Little	Pallid sturgeon life history and assessment of habitat use	low
	USGS-Columbia Environmental Research Center	B. Poulton and M. Wildhaber	Critical habitats for benthic invertebrates	low
Other	Conte Anadromous Fish Research Center, Mass.	B. Kynard	Lab experiments on habitat preferences of young sturgeon	low

Service submitted the MOR-CARE package as a fishery budget initiative ($1.5 million) for FY 1994. The Service got $350,000 that was divided among Regions 3, 4, and 6. Regions 3 and 6 agreed to host a Missouri River Conference to begin developing partnerships. In 1994, MOR-CARE was superseded by the Service's ecosystem planning effort. Region 6 coordinator Keenlyne wrote a eulogy to MOR-CARE in his last Missouri River Update (April 1994) in which he said that even though the initiative died, the idea of studying, planning, and restoring the Missouri River ecosystem had taken hold in agencies like the Corps, Bureau of Reclamation, and EPA. The message remained alive in other groups like American Rivers (1997), The Nature Conservancy, and the Environmental Defense Fund.

In 1993, a multi-Unit study of the shovelnose sturgeon feeding habitats was begun because the shovelnose was thought to be a surrogate for the pallid sturgeon, at least for smaller size classes of pallids (Erickson 1992, Megargle 1993). However, the study included only the South Dakota and Montana Units. At a progress report meeting on the sturgeon feeding study at the Corps offices in Omaha on December 15, 1994, what has become the benthic fishes study was first proposed as a pallid sturgeon study. The meeting began with the Montana and South Dakota Units briefing the group on progress, and each Unit (except Idaho) describing their background and interests in the Missouri River. Representatives from the Corps described their research needs, which were being driven by the thought that the preferred alternative to managing the river (i.e. a spring rise to benefit fishes) might be implemented. If so, the Corps would need baseline data to evaluate the fishery benefits of changes in system operation.

It was at this meeting that the benthic fishes study idea was developed. The meeting was concluded with a plan to study the shovelnose sturgeon as a surrogate for the pallid sturgeon. However, later discussions between David Galat (Assistant Unit Leader-Missouri) and Doug Latka (Corps) resulted in a broader study with the rough proposal title of "Patterns of benthic fishes within macrohabitats along the Missouri River." This approach was adopted because 1) the Corps will continue to influence habitat (velocity, relief, substrate, cover, etc.) more than any other river feature, and 2) a multispecies, assemblage approach would be more informative than a single species approach. The benthic fishes assemblage was chosen because it included the pallid and shovelnose sturgeon, other candidate species (e.g., sicklefin chub, flathead chub, blue sucker), and recreational species (e.g., catfishes).

The Coop Units drafted a study plan and met for the first time in June 1995 in Omaha to plan the research with David Galat assuming the coordinator's role. The South Dakota Unit Leader assembled the contracting documents from each University into one package on May 26, 1995, and traveled to Arlington, Virginia in July to oversee the final contracting details. The Research Work Orders were signed on July 26, 1995, and the benthic fishes study was underway. The Units were now in the new National Biological Survey, which helped the study by contributing $10,000 for start-up equipment for a "pilot study" during the summer of 1995.

Administration and Funding

Coop Units were authorized by the Cooperative Units Act (PL86-686). Each Unit is staffed by three scientists. Cooperating agencies are the state fish and game departments, the state university, and the Wildlife Management Institute. During the benthic fishes study, the Coop Units were moved among three Federal agencies, so the Federal cooperator was first the Fish and Wildlife Service, then the National Biological Survey, and finally, the U.S. Geological Survey (USGS).

Work was carried out at each University as Research Work Orders, which were extensions of Cooperative Agreements that established each Unit at each University. The Research Work Order is a simplified research proposal. Federal agencies such as the Corps can fund the University proposal by transferring funds to the USGS (Economy Act, 31 U.S. C. 686). The Universities supported the project by waiving some overhead charges.

Researchers from the Montana FWP and the Columbia ERC were invited to the June meeting to give their input as to the objectives, design, and sampling methods for the benthic fishes study. Their expertise added greatly to the benthic fishes research team. Stastistical design and data analyses were conducted under the leadership of Dr. Mark Wildhaber, Columbia ERC, Linda Sappington, Columbia ERC, edited standard operating procedures, conducted data management and quality assurance/quality control programs. Jeanne Heuser and Chris Henke, Columbia ERC, develped web based data projects using funding from the Corps, U.S. Environmental Protection Agency, and the USGS. An important study component was the work on the lower Yellowstone River and Missouri River downstream from Ft Peck Dam, which was done by the Montana FWP with funding from the Bureau of Reclamation.

Benthic Fishes Study 1995

The project started on July 26, 1995 with approved Research Work Orders for Coop Units at the University of Missouri, Kansas State University, Iowa State University, South Dakota State University, Montana State University, and University of Idaho (which worked in North Dakota). During the summer of 1995, the benthic fishes research team recruited graduate students and conducted preliminary studies. After initially funding the project for $85,730, the Corps provided another $64,000 in August to purchase capital equipment.

Specific objectives for 1995 were 1) to establish the study design including hierarchical classification and delineation of Missouri and Lower Yellowstone rivers into study zones, segments, and macrohabitats, 2) establish a benthic fishes list, and 3) acquire equipment and evaluate fish sampling gears.

The benthic fishes consortium held a meeting in Omaha in May, 1995 to make preliminary plans for conducting the project and visiting each river zone. Each researcher needed a basinwide understanding of the river habitats and fish community, so it was agreed that workshops would be held in each river zone. On September 11-15, personnel from each Coop Unit, the Columbia ERC, and Montana FWP toured the upper river and practiced using sampling gears. On November 7-10, the consortium met in Omaha to review the first field season and make plans for the second field season. The group toured the river and practiced sampling at the Platte River confluence. Data from the first year and other information about activities in 1995 were compiled in an annual report (Braaten and Guy, 1995). We selected 26 species to represent the Missouri River benthic fishes assemblage, 15 species that would be studied for growth and condition, and agreed on a river habitat classes. We drafted a study design with 27 river segments and a study design with 18 river segments. The 18-segment design was adopted for the 1996 field season.

Benthic Fishes Study 1996

The second study year was funded by the Corps ($647,159) to conduct the first full summer of field work.

Overall project objectives were reworded to:

1) Describe and evaluate recruitment, growth, size structure, body condition, and relative abundance of selected benthic fishes within and among study sections and among segments.
2) Describe habitat use of benthic fishes and availability of dominant benthic macrohabitats within and among study sections and segments, and
3) Measure physical habitat features (e.g., velocity, bottom type, turbidity, and temperature) at sampling sites.

Ms. Linda Sappington (Columbia ERC) joined the group to provide data management and quality assurance for standard operating procedures (SOPs). Developing SOPs included developing an information management plan and field data recording forms, adopting standards for data processing and storage, programming to include internal quality assurance and quality control checks, testing the database, populating the database, and the developing a graphical user interface to query and retrieve data. The Corps provided another $70,000 in September to support the study.

The consortium held an April, 1996 meeting in Omaha where Columbia ERC researchers presented a proposed statistical approach for the project and began leading the SOP development process. Each Unit conducted field trials in May in preparation for a June 21-22 workshop in Omaha to finalize sampling and analysis protocols and prepare plans for the first season. At the workshop, the Ph.D. students presented Dissertation concepts.

Objectives for 1996 were to 1) finalize study segments, 2) develop and test SOPs, 3) test alternative fish sampling gears, 4) conduct a formal field season, and 5) communicate preliminary results to interested agencies.

The first formal field season began on July 8, 1996 and was completed in 16 weeks. About 25,690 fishes representing 78 taxa and two hybrids were collected. These included nine introduced species and all target taxa except pallid sturgeon.

The fall of 1996 was a difficult time for the benthic fishes project because 1) the Coop Unit Program and the Columbia ERC were moved to the USGS, which changed contracting processes, and 2) the Corps had funds for only one-third of the proposed budget for the coming year. At our fall workshop in Omaha on November 22-23, 1996, we discussed the uncertain future of the project, reviewed progress, and proposed changes in SOPs based on the 1996 field experiences. We decided to continue the project with hope that the Corps could provide more funding later in the year, and planned to seek other funding.

The 1996 annual report includes activities in 1996 and preliminary findings (Dieterman et al. 1997). For example, for the sturgeon chub, we collected 308 fish, but none from the interreservoir zone. All but one were collected with the benthic trawl from the main channel and secondary channels where depths were 2-3 m, turbidity was 50-100 NTUs, velocity was 0.5-1.2 m/s, and temperature was 22-24 C. Similar findings were reported for each benthic fish. Physical habitat data were also summarized by segment and macrohabitat. For example, we reported that gravel was more abundant (30%) in least-altered segments than in other segments, and more abundant (10%) on outside bends than in other macrohabitats.

Benthic Fishes Study 1997

We met June 20-21 at the Corps office in Yankton for a spring workshop to view the habitat downstream from Gavins Point Dam. A problem arose when the Corps announced that there would be record high flows in the system in 1997. The South Dakota segments would have flows of about 40,000 CFS (cubic feet per second) rather than 20,000 CFS. However, we felt that these conditions might help us evaluate climate-driven variability in the fisheries data. The benthic fishes project was becoming well known. Agencies began asking for data. The Missouri River Natural Resources Committee invited us to help design the Missouri River Environmental Assessment Program. The Environmental Protection Agency (National Geographic Initiative Funds), Fish and Wildlife Service, and four State fish and game agencies (Kansas, Idaho, Missouri, and Iowa) contributed about $150,000, which with the Corps funding was enough to address the basic study objectives.

Objectives for 1997 were 1) implement any necessary improvements to existing methods, 2) continue standardized sampling for a second year, and 3) communicate preliminary results to interested agencies and at professional meetings and conferences. We modified the 1996 SOPs for the 1997 field season to clarify sampling unit identity (e.g., macrohabitats) and sampling protocol to increase uniformity. We deleted three segments from the study design, thus leaving 15 segments to be sampled, but increased sampling effort (e.g., more electrofishing time, gill nets set longer).

The consortium accomplished 100% of the

fieldwork in 1997 (Young et al. 1998). Studies began in July and continued for 13 weeks. We collected 56,185 fishes in 93 taxa, compared to 25,692 fishes in 78 taxa in 1996. All benthic fishes were collected including a pallid sturgeon. Eight introduced species were found: bighead carp, chinook salmon, ciscoes, grass carp, mosquito fish, rainbow smelt, striped bass, and white bass.

Authors of the Annual Report (Young et al. 1998) reported that habitat use data from 1997 was similar to that found in 1996. The first age and growth data were presented for fish collected in 1996. An example of preliminary results of age and growth analysis was as follows for the channel catfish: maximum ages varied from 8 to 11 years among zones; age frequencies were skewed toward older fish in the least-impacted zone, toward younger fish in the channelized zone. Channel catfish grew slower in the inter-reservoir zone compared to other zones.

Consortium participants made 15 scientific presentations, and several were members of steering committees for the first (Columbia, Mo.), second (Nebraska City, Neb.), and third (Pierre, SD) Missouri River Natural Resources Conferences. Most Units were out of funds when the Corps obligated another $200,000 and the USGS obligated $50,000. A continuing resolution delayed Corps funds so Research Work Orders were extended.

Benthic Fishes Study 1998

As in the previous year, the first months were spent finding funding. The Corps obligated half ($350,000) of what was needed and contracts were signed on February 11, 1998. The EPA Region 7 ($25,000), the Coop Unit Program ($80,000), Bureau of Reclamation ($15,000) and Iowa Department of Natural Resources ($17,000) provided additional funding. Again, we had a budget shortfall and "what work to cut?" was on the agenda for the spring training workshop at the Leid Conference Center in Nebraska City following the Second Annual Missouri River Conference. We revised budgets downward through efficiencies, and the Corps obligated another $70,000, which was enough to plan for a full field season in 1998. The study design was the same as that for 1997. This was the first time we talked about the content and authorship of the Final Report. The Corps was projecting normal water conditions for the final field season. Normal flows were welcome because they reduced logistical problems, and provided a contrasting hydrologic pattern to the previous 2 years.

We accomplished 100% of the planned fieldwork for 1998. Sampling times matched those of previous years (early July to mid-September). We collected 51,213 fishes of 80 species, and representatives of all 26 species in the benthic assemblage, including three pallid sturgeons. The most commonly caught species (16% of the catch) was the gizzard shad, followed by emerald shiner (14%). We rushed to submit field data sheets to the data managers so that we could begin writing the final report. Age and growth data development for 1997 samples was completed. The Annual Report for 1997 was printed in October, 1998 after delays caused by data management problems.

Soon after the start of the new Federal Fiscal Year (October 1, 1998), the Corps obligated $200,000 for the final project year that was to expire on September 30, 1999. The Corps sought data for a biological assessment of dike maintenance from Sioux City to the mouth, and for a cumulative impact assessment of activities in the upper river.

Benthic Fishes Study 1999

The Principal investigators met on February 24 in San Diego (after another meeting) to plan the final report. All staff and students met for one last workshop after the Third Missouri River Conference, March 21 in Pierre, SD. Most discussion was on data management and statistical analysis approaches for the three main report sections - physical habitat, fish distribution and abundance, and age and growth. All data sheets were submitted to the data manager by December 15 for key input and quality control. Students had now completed sampling and could work full time on Dissertations, which complimented the benthic fishes study. Work on the final report was delayed because data sets were not clean; however, primary authors of each final report volume began expanding draft outlines and analyzing data, though the data was not fully checked for quality. The last funding increment was obligated by the Corps with an interagency agreement on November 17, 1999 bringing the total funding to about $2.75 million from five Federal agencies and four state agencies (Table 4). University contributions to the project were in the form of overhead waivers of various amounts depending on stipulations in the cooperative agreements that established Cooperative Units at each University (Table 4).

Benthic Fishes Study 2000

Principal Investigators met in Bismarck, ND after the 4th Annual Missouri River Natural Resources Conference in May 2000 to review progress on the final report. The data managers reported that a final data set on CD would be available in July. Rough drafts of Volumes I and II were delivered, and it was reported that two Ph.D. Dissertations were finished

Table 4. Direct funding contributions to the benthic fish study on the Missouri and Lower Yellowstone rivers, 1995-2000 (FY Oct 1-Sept. 30). Universities that contributed by waiving about 35% of normal overhead rates were Univ. of Missouri, Kansas State Univ., Iowa State Univ., South Dakota State Univ., Montana State Univ., and Univ. of Idaho.

Source	**FY95**	**FY96**	**FY97**	**FY98**	**FY99**	**FY00**
Corps of Engineers	262,634	717,000	410,000	424,000	270,000	50,000
Geological Survey	10,000*		130,000	50,000		4,000
Bureau of Reclamation		82,000	63,000	77,000	17,000	
Environmental Protection Agency			22,000	25,000		
State Fish and Game Agencies**			17,000	62,000		
U. S. Fish and Wildlife Service			60,000			

* Contribution from defunct National Biological Service
** North Dakota, Iowa (2 years), Kansas, Missouri

and others would be available in 3-6 months. We realized that we needed to extend the project to July 30, 2001, and a no-cost time extension was arranged. The USGS contributed $4,000 to publish a semitechnical report summarizing the essential findings.

STUDY DESIGN

A spatial hierarchical structure (Frissell et al. 1986) composed of zones, segments, and macrohabitats was developed based on geomorphic, hydrologic, and constructed features (e.g., major tributaries, dams) along the Missouri and Lower Yellowstone rivers (Table 5). Study segments were grouped into least-altered, inter-reservoir, and channelized zones. The basic experimental design was as follows: dependent variables were measures related to physical habitat (e.g. depth, velocity), to fish distribution and abundance (e.g. relative abundance), and to fish population indices (e.g. growth, condition). Independent variables were year, zone, segment, and macrohabitat. The basic statistical method was Analysis of Variance, but other statistical approaches (e.g. Principal Components Analysis) were also applied.

Macrohabitats

Six macrohabitats common to all river segments are channel cross-overs, inside bends, outside bends, tributary mouths, connected secondary channels and non-connected secondary channels. Because some macrohabitats are complex, they were further divided into smaller units termed mesohabitats. These include sand bars, channel borders, deep pools, and steep shorelines of inside bends, large and small tributary mouths, deep and shallow secondary channels. We also allowed a “wild card” macrohabitat for unusual macrohabitats (e.g., dams tailraces) that were unique to some segments. Five macrohabitats and mesohabitats were sampled each year (when present) within a segment. Water conditions each year determined the number of mesohabitats, i.e. when water was low, there were less inside bend pools and more secondary channel-non-connected macrohabitats than during high-water years. For example, we always found five channel cross-overs, so over the course of the study,

Table 5. List of sections and segments of the Missouri and Yellowstone rivers included in the benthic fish study, 1995-2000. rm = river mile; rkm = kilometer; * not sampled in 1997 and 1998.

Section and impact	Seg. No.	Segment description and length (mi)	Segment boundaries rm	rkm
Missouri headwaters least-altered zone	3	Arrow Creek-Birch Creek, 19	1999-1980	3217-3187
	5	Sturgeon Island-Beauchamp Coulee, 70	1952-1882	3141-3029
Yellowstone least-altered zone	9	Intake diversion-confluence, 71	71-0	114-0
Inter-reservoir zone	**6***	Ft. Peck Dam-Milk R., 10	1770-1760	2847-2831
	7	Milk River-Wolf Pt., 59	1760-1701	2831-2737
	8	Wolf Pt. – Yellowstone R., 99	1701-1582	2737-2545
	10	Yellowstone R. -L. Sakakawea.,30	1582-1552	2545-2497
	12	Garrison Dam-Lake Oahe, 85	1398-1304	2235-2098
	14	Ft. Randall – Niobrara R., 45	880-835	1416-1343
Unchannelized reach	**15**	Gavins Pt. Dam-Ponca, Neb., 57	810-753	1303-1212
Channelized zone	*17*	Big Sioux R. - Little Sioux R., 71	740-669	1191-1077
	*18**	L. Sioux R. -Platte R., 74	669-595	1076-958
	19	Platte R. -Nishnabotna River, 54	595-542	958-872
	*21**	Rulo, Neb. - St. Joseph, 58	498-440	801-708
	22	St. Joseph-Kansas River, 72	440-367	708-591
	23	Kansas River - Grand River, 117	367-250	591-402
	25	Glasgow-Osage River, 90	220-130	354-210
	27	Missouri River rm50-Mississippi R., 50	50-0	80-0

225 channel cross-over macrohabitats were sampled (Table 6). However, there were not always five secondary channel-non-connected macrohabitats so only 109 were sampled.

Fishes

We targeted 26 benthic species for evaluation (Table 1) and counted and identified other fish species (Table 2). Criteria for inclusion in the benthic fishes assemblage were 1) primarily benthic habitat use, 2) important as native, commercial, recreational, or prey, and 3) presence in most of the main-stem. The benthic assemblage comprised representatives of six families: Acipenseridae (shovelnose and pallid sturgeon), Cyprinidae or minnows (10 species), Catostomidae or suckers (six species), Ictaluridae or catfishes (four species), Gadidae (burbot), Percidae (walleye and sauger), and Sciaenidae (freshwater drum). The assemblage is not meant to be a guild, which is made up of ecologically similar species. In our benthic

Table 6. List of segments and macrohabitats where fish were collected and physical habitat. Measurements were made during the benthic fishes study of the Missouri River, 1996-1998.

Segment	Macrohabitat			
	River bend	Secondary channel-connected	Secondary channel-non-connected	Tributary mouth
3	15	16	1	0
5	15	24	6	0
7	15	20	12	11
8	15	25	16	12
9	15	24	16	3
10	15	15	10	2
12	15	16	12	8
14	15	20	7	12
15	15	25	8	13
17	15	1	0	17
19	15	6	0	16
22	15	2	4	19
23	15	15	1	17
25	15	25	1	19
27	15	25	15	11
Total	225	259	109	160

fishes assemblage are species with different body shapes, mouth placements, swimming abilities, spawning requirements, and functional designations (e.g., omnivore, detritivore, predator). The assemblage includes all benthic fishes listed "at risk" by Missouri River states and the Service as well as important commercial and recreational taxa.

Fifteen species from the benthic fishes assemblage were selected for age and growth analysis:

blue sucker	flathead catfish
sicklefin chub	channel catfish
flathead chub	sand shiner
brassy minnow	emerald shiner
shovelnose sturgeon	freshwater drum
smallmouth buffalo	river carpsucker
sauger	plains minnow
W. silvery minnow	

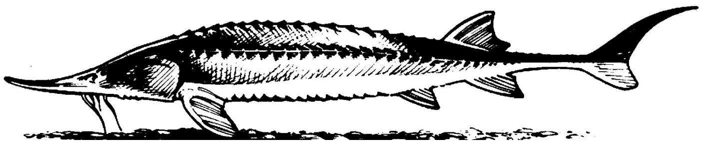
Growth analysis required not only that length and weight measures be taken, but that scales, spines, fin rays or otoliths be removed. So that growth rings could be counted, most spines and rays were sectioned with a low-speed saw whereas otoliths were sanded until translucent. Sections of spines, rays, and otoliths, and all scales were mounted on glass slides for age determination. Procedural details for determining age and growth can be found in the SOP manual (Sappington et al. 1998).

Benthic Fishes

Following is a brief summary (with figure) of the appearance, size, and ecology of each fish in the benthic fishes assemblage as described by Pfleiger (1997), Harlen and Speaker (1987), Bailey and Allum (1963), Morris et al. (1974), Brown (1971), and Baxter and Stone (1995).

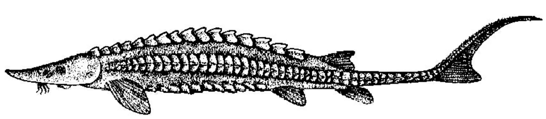
Pallid sturgeon: This large (maximum weight about 22 kg, length about 1.8 m) sturgeon is currently the only Federally-listed endangered fish in the Missouri River. It has characteristics typical of this primitive group: heterocercal caudal fin, cartilaginous skeleton, notocord, and bony plates (skutes) in rows along body. They have a shovel-shaped snout, a sucker-like mouth with thick lips, and a row of sensory barbels in front of the mouth. The mouth and barbels are adapted for bottom feeding. Named for their whitish color, this species is confined to the main-stems of large rivers. Little was known about this species until recently when museum specimens were reexamined, a few wild fish were radio-tagged, and the fish was successfully spawned and reared in captivity (reviewed by Duffy et al. 1996). Fish spawn in the spring on gravel beds. The species is being reared in captivity and is being stocked in the Missouri River.

We collected four pallid sturgeons. Since our study, six adult and 22 juvenile fish were implanted with sonic transmitters and released in the riverine portion of Lewis and Clark Reservoir (our segment **14**), and 758 hatchery-reared yearlings were released upstream



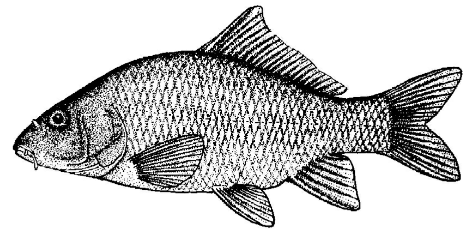
from Ft. Peck reservoir (our segments 3,5). Researchers sampling especially for pallid sturgeon have recently (1998-2000) collected two adults and three larvae in Missouri (our segments *23*,*25*,*27*), one possible adult in the Nebraska reach (our segment **15**), and 14 adults (7 tagged, 7 new) in the Yellowstone River confluence area (our segments **8**, 9, **10**).

Shovelnose sturgeon: The shovelnose sturgeon looks like the pallid sturgeon, except that it is smaller (maximum length about 1 m, weight about 3.6 kg) and browner in color. It is usually distinguished from the pallid by the barbels, which are in a straight line in the shovelnose sturgeon, and by having skutes on the belly. The young of both species have an unusual threadlike extension of the cartilaginous backbone that trails from the upper lobe of the caudal fin. The shovelnose sturgeon is the most common sturgeon in large rivers of the central United States, but may migrate upstream into tributaries to spawn if the flow is strong and if rocky bottoms are available. It reaches maturity at 5 to 7 years and probably spawns in river channels over rocky substrate. It eats benthic invertebrates, and growth of the shovelnose varies by region. For example, a 10-yr-old fish in the Yellowstone River might average 745 mm, whereas those in

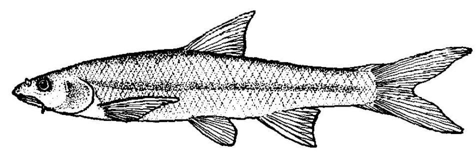


the Bismarck (Everett 1999) and Yankton reaches are smaller (about 500 mm long). We collected 1,446 shovelnose sturgeon. Preliminary data showed that fish got to 34-yrs-old in the least-altered zone, but only to 14-yrs-old in the channelized zone (Young et al. 1998).

Common carp: The common carp is the only exotic species in our benthic fishes assemblage, having been introduced to North America about 100 years ago. It is sometimes considered a nuisance species in lakes and ponds, but is also harvested commercially for many products including meat, chemicals, and fertilizer. It can reach 22 kg but most adults usually weigh 0.5-3.6 kg and are 0.5-1.0 m long. It is an opportunistic omnivore and bottom feeder taking mostly invertebrates and plant matter. It spawns in the spring and casts adhesive eggs onto submersed vegetation in shallow water. A habitat suitability index model has been developed for the common carp (Edwards and Twomey 1982b). This species does well in rivers and reservoirs. About 3,000 were caught during the benthic fishes study.

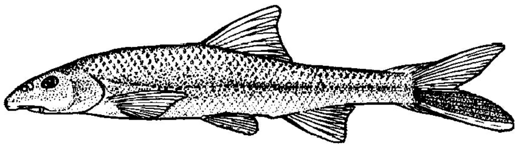


Flathead chub: The flathead chub is the largest (reaching 30 cm in length, 0.25 kg in weight) of the eight chubs in the Missouri River drainage. Chubs are in the minnow family (Cyprinidae), and are characterized by a plump body, and small barbel in the corner of the mouth. The flathead chub is green to brown above and silvery below without spots. Its head is broad and somewhat flat on top, hence the name. It has large eyes and mouth and feeds on terrestrial and aquatic insects. Only a little is



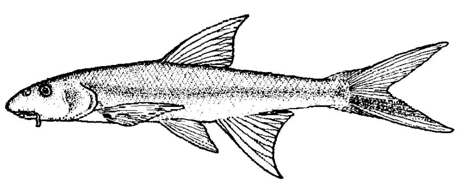
known about the biology of this species in South Dakota (Martyn and Schmulbach 1977) and in the Yellowstone River (Scarnecchia et al. 2000). It inhabits all major streams in the western plains that are usually turbid, alkaline, and have unpredictable flow regimes (e.g. Moreau River, Loomis et al. 1999). The species has declined or disappeared where dams and irrigation diversions have reduced stream flows, especially in the southern part of the Missouri River basin. However, it is common in the main-stem except in the lower river (Grady and Milligian (1998). We caught about 10,000.

Sturgeon chub: The sturgeon chub is important to the benthic fishes study because it is considered rare in the Missouri River basin. The small (maximum length about 8.5 cm, weight about 85 grams) minnow has adaptations that are thought to confer survival advantages in turbulent, turbid rivers. Its depressed head and slender body profile provide minimal resistance to flow. Its small eyes are partly shielded from abrasion by water-born sand. It has papillae on the lower head and fins that are external taste buds, and each dorsal scale has a small keel. The mouth is well beneath the head in a placement somewhat similar to that of the sturgeon. It has no distinguishing coloration. It is thought to prefer shallow areas with strong current and gravel bottom, and is found in such habitat in several large tributaries to the Missouri River in the Dakotas (e.g. Cheyenne River, Hampton and Berry 1997; White River, Fryda 2001). Grady and Milligan (1998) collected 29 sturgeon chubs by trawling in the lower Missouri River. We collected 2,000 sturgeon chubs that were found at 15 of our 19 study segments; most were collected in the upper river. Everett (1999) also noticed the absence of the sturgeon chub from the reach downstream from Garrison Dam. Catch rates in various macrohabitats in the upper Missouri River were part of a Ph.D. Dissertation done by a student with the benthic fishes study (Welker 2000).

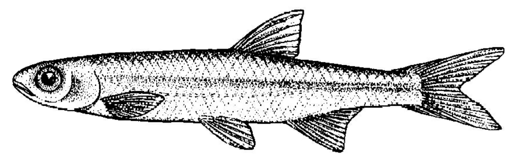


Sicklefin chub: The sicklefin and sturgeon chub look somewhat alike and may have similar habitat needs. The sicklefin chub grows to about 11 cm in length (113 grams). Fins are sharply pointed and sickle-shaped. The pectoral fin is long, extending beyond the insertion of the pelvic fin. It is a plain-colored fish: brown to green above with silvery sides and belly. The mouth is sub-terminal beneath a rounded snout. The eyes are very small, and protected by a flap of skin. The sicklefin chub is listed by several states in the basin as rare. It is thought to inhabit swift-water, channel habitat in the Missouri River main-stem. Grady and Milligan (1998) found 60 fish in the Lower Missouri River, primarily in trawls. Most of the 700 fish we captured were found in the upper river. Like the sturgeon chub, most were collected with the benthic trawl. Little is known about the ecology of this species, but recent studies have made habitat associations. In the Yellowstone River area, the presence of sicklefin chubs increased with increasing depth and velocity, and decreasing clarity (Everett 1999). The biology (Dieterman 2000) and catch rates in upper Missouri River habitats (Welker 2000) were covered in Ph.D. dissertations done concurrently with the benthic fishes study.

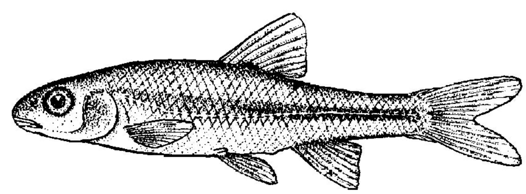
Emerald shiner: This minnow is not associated with the benthic habitat as much as other species in our benthic fishes assemblage However, it is probably important as food for many species because it is widespread and abundant. This shiner is slender and is somewhat transparent with a narrow silver streak on the sides. Adults are about 7 cm long and weigh about 100 grams. The mouth is terminal for feeding on zooplankton and small, drifting invertebrates. It is an annual spawner that lives only 3-4 years.



The fish occupies both rivers and reservoirs, but few details of its ecology are known. Its presence in both riverine and reservoir habitat, and its morphometric and meristic plasticity (Bailey and Allum 1962) presented an opportunity to study how this species was responding to the different selection pressures in each. One Ph.D. Dissertation (Young 2001) presents data on the genetics of this species throughout the basin, and on differences between body shape, meristics, and swimming ability of riverine and reservoir groups. We found emerald shiners in all segments and caught more (about 19,000) than any other species.



Sand shiner: The sand shiner is a small (maximum length about 8 cm, weight about 50 grams) minnow that is widespread and common in the upper basin, but more so in tributaries than in the main-stem. We caught 682 sand shiners, all upstream from the channelized section. However, the species is commonly found in tributaries to the Missouri River in lower basin states. Its stout body is silvery with a prominent lateral line that is pigmented alongside each pore. Dark pigment also outlines each dorsal scale. It spawns from April through August, a long reproductive season that may be important to life in harsh Great Plains rivers. It eats benthic macroinvertebrates. Like the emerald shiner, this species may be polymorphic (various body shapes and scale counts) because several subpopulations have been suggested in Kansas and South Dakota (Bailey and Allum 1962, Cross and Collins 1995). The species name was changed from *stramineus* to *ludibundus* in 1991, so older literature lists the sand shiner as *N. stramineus*.



Western silvery minnow: In the benthic fishes assemblage were three minnow species in the genus *Hybognathus* that presented a challenge when identifying them. The three species were western silvery minnow, *H. argyritis*; plains minnow, *H. placitus*; and brassy minnow, *H. hankinsoni*. The western silvery minnow is considered rare in some basin states. None were found by Grady and Milligan (1998) in the Lower Missouri River, but they are abundant in some tributaries (e.g. Moreau River, Loomis et al. 1999). Little is known about its ecology, but Welker (2000) collected more along shallow channel borders than in the main channel.

The western silvery minnow, like other *Hybognathus* species are silver-colored minnows. The Western silvery minnow can reach 15 cm in length but most adults are 75-100 mm long (weight about 100 grams), whereas other *Hybognathus* species are smaller. This species has a long intestine, black peritoneum, and slightly subterminal mouth. It ingests mud and organic matter. The long intestine helps digest algae, invertebrates and plant material.

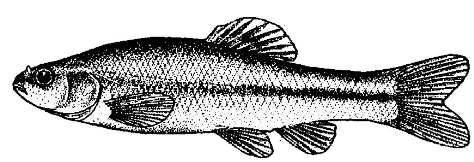
The western silvery and plains minnows are similar but can be identified by examining the pharyngeal process on the basioccipital bone, which we did not do. A useful external character is the number, pattern, and size of belly scales between lateral lines, which can be assessed by inspection or counting. *H. placitus* has 18±4 scales whereas *argyritis* has 14±3 small, irregular scales around the belly just anterior to the pelvic fin. *H. argyritis* has a large eye and pupil usually >1/5 head length, whereas *H. placitus* has a smaller eye. However, external differences are difficult to use for juveniles and may change with latitude.

Because these three species were difficult to identify, our protocol stated that we would report the species name only if the identity was certain based on external characteristics. Consequently, our data shows that we collected 12,906 *Hybognathus* spp. and 374 western silvery minnows. We found Age-0 fish in all zones, indicating that natural reproduction is occurring throughout the river.

Plains minnow: This species of *Hybognathus* looks like the western silvery minnow, but is usually smaller (maximum length about 12 cm, weight about 75-100 grams). It is straw-colored dorsally with silvery sides and belly. The species is partly herbivorous, feeding along the bottom on diatoms and algae growing on course substrates. It also consumes benthic invertebrates in calm, shallow backwaters. The fish is thought to be most numerous in shallow, braided streams, especially where sediment accumulates. Abrupt rises in flows may stimulate spawning, but its reproductive habitats are not fully documented. Grady and Milligan (1998) collected 676 fish by seining in the Lower Missouri River. We collected only 57 plains minnows during the study, but may have collected many more and identified them only as *Hypognathus spp*. The small sample size precluded using them for age and growth analysis as planned.

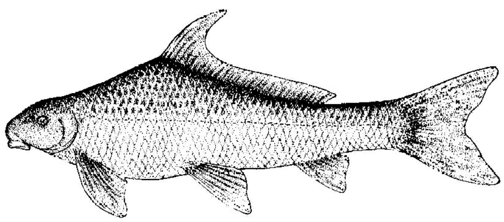
Brassy minnow: The brassy minnow is also a *Hybognathus* species, but is usually distinguishable from the plains and Western silvery minnows. It is distinguishable by its brassy-yellow color (best developed in adults), longitudinal stripes on the sides, and rounded dorsal fin. It is thought to inhabit pools in sluggish, clear creeks over sand and gravel, or among vegetation in clear pools. Like the plains and Western silvery minnows, this species is omnivorous. Some of the diet is plant material that is processed in the long intestine that is typical for herbivorous fishes. Adults are usually 76-100 mm long and weigh about 85 grams. Few specific details are known about its biology. We collected 142 brassy minnows, which were limited to the South Dakota and Iowa segments.

Fathead minnow: The fathead minnow is well known to most anglers because it is widely sold as a bait minnow. It grows to about 5-7 cm in length and weighs about 75-100 grams. It does well in silty pools of intermittent streams and tolerates warm temperatures and low dissolved oxygen levels. Much is known about this species because it is extensively cultured for bait and for use in laboratory bioassays. Females lay adhesive eggs under stones, twigs or other objects and the male guards the nest. The male develops a spongy pad on the head and nape, and spiny tubercles on the snout to use in nest defense and egg cleaning. We collected 739 fathead minnows, which were present in most segments.



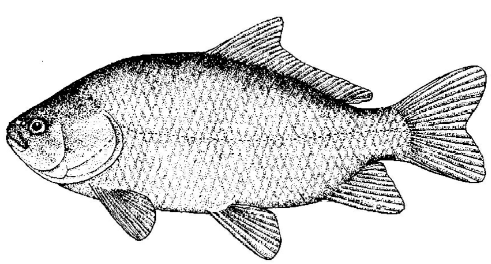
Blue sucker: This large (3-4 kg) sucker is widely distributed in the Upper Mississippi, Missouri and Ohio river drainages. This is the only sucker with a long, sickle-shaped dorsal fin on a slender body. It has no distinguishing markings, but the back is usually blue-gray and the ventral region pale. The head has a small, pointed shape that may provide hydrodynamic advantages in chutes or rapids where the water is deep and the bottom rocky.

The mouth is small, but the sucker lips are full and papillose (bumpy). It eats benthic macroinvertebrates and algae. It survives in reservoirs, but needs flowing water for spring spawning on gravel. Blue sucker larvae have been captured drifting from the James River (SD) into the Missouri River (Muth and Schmulbach 1984) and in a Missouri River backwater (Fisher and Willis 2000). Details of its ecology are fairly well known (Beal 1963, Rupprecht and Jahn 1980, Moss et al. 1983). Blue sucker populations have been declining (FWS 1993). It is prized for its table quality. The fish is still commonly captured in some locations, including Missouri River tributaries. It is protected as a "species of special concern" in some states. We collected 178 fish, including some in each age group up to age 10.



Bigmouth buffalo: The bigmouth buffalo occurs throughout the Mississippi River drainage and in the Lake Erie drainage in both rivers and reservoirs. Adults are commonly 40-90 cm in long and weigh 1.5-7 kg. Older specimens may be 10 - 20 years old. It has no distinguishing markings, but is colored gray to olive-bronze above with green and copper reflections. It is distinguished from the smallmouth buffalo by mouth position: terminal in the bigmouth, subterminal in the smallmouth.

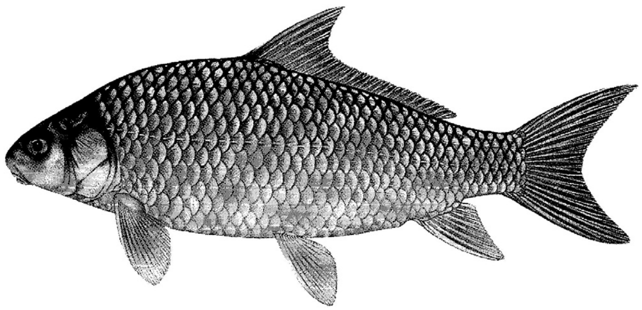
Much is known about bigmouth buffalo biology because it is the largest and most commercially important sucker, and because it occurs in high numbers in many lakes and rivers. Maturity depends on size. Fishes in the south mature in 2 years at about 50 cm in length, whereas fishes in the north mature in 8 years. Juveniles and adults occupy a food niche overlapping as both benthic invertebrate and limnetic plankton feeders. Year class strength is positively correlated with flooding. The species spawns in the spring when water temperatures reach 14 °C in shallow areas. Eggs are broadcast over vegetation. The species tolerates turbid waters but not low oxygen levels. A habitat suitability index model is available (Edwards 1983) for both rivers and reservoirs. The species can be found in many habitats and hydrologic conditions in rivers. We collected about 500 bigmouth buffalo, which were present in most segments.



Smallmouth buffalo: The smallmouth is similar to the bigmouth buffalo (above) except that it has an arched back, small head and subterminal mouth as small as the eye. Individuals can reach 23 kg in weight and 104 cm in length. The species is common throughout the Mississippi River drainage. Size determines maturity, which is attained at about 460 g (2 years in the south and 7 in the north). Like most species, the young eat zooplankton whereas adults are opportunistic bottom feeders. Spawning is initiated at 13 °C by rising water levels and increasing temperatures. Spawning occurs over many bottom types. Eggs are scattered and left unattended.

A habitat suitability model has been developed for the smallmouth buffalo (Edwards and Twomey 1982a). The species typically inhabits large rivers, preferring deep, clear, warmwaters with a current, but is also found in backwater areas. It survives well in reservoirs or lakes where they can be found in shallow water (1 - 2 m) with submersed vegetation and a silt bottom. They can tolerate turbid waters (>100 JTU), but growth is better in clearer waters. We collected about 500 smallmouth buffalo from all zones. Preliminary analyses indicated that growth might be slower in the channelized zone than in other zones. We collected fish up to 11-yr-old.

River carpsucker: This sucker looks somewhat like the common carp and is called the "white carp" by anglers. Individuals are thick bodied and grow to 70 cm in length and about 4 kg. It has no distinguishing markings on the olive to silvery body. The snout is short, firm and rounded. The mouth is small and ventral with thin lips. A distinguishing feature is a small nipple protruding forward on the lower lip. The dorsal fin covers much of the back, and the anterior dorsal rays reach over about 1/2 of the fin. It is widespread

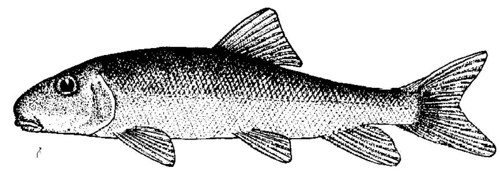


and common in the Mississippi River drainage. It feeds in slack water where small benthic macroinvertebrates, diatoms, and algae accumulate on stable stream substrates. Females mature at 25 cm in length and spawn in the spring when waters warm to about 26 °C. Eggs are deposited on vegetation and roots. Braaten et al. (1999) compared age and growth estimates using scales and dorsal fin ray sections. Fish from our study reached 11-yrs-old and preliminary indications were that they grew faster in the channelized zone.

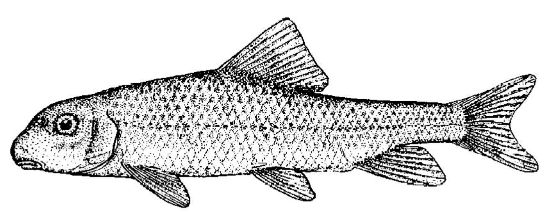
River carpsucker is the most abundant carpsucker (Genus *Carpoides* includes the quillback and highfin carp sucker), and does well in both rivers and reservoirs. It was the fourth most abundant fish in our catch (about 6,000 fish). The biology of the suckers (family Catostomidae) in the Missouri River was the subject of a Ph.D. Dissertation (Welker, 2000) that was supported by the benthic fishes study. Welker compared sucker populations in the reach downstream from the Yellowstone confluence (moderately altered) with those in the reach downstream from Garrison Dam (highly altered). Bigmouth buffalo, smallmouth buffalo, and river carpsuckers represented 94% of the sucker catch in the moderately altered segment, whereas in the highly altered segment, white suckers and longnose suckers constituted 98% of the sucker catch.

White sucker: This species is widespread and common in rivers and lakes from the Rocky Mountains to the Atlantic Ocean. It reaches 3 kg and 45 cm and may live 15 years. The species has no distinguishing markings, except for three distinctive dark spots along the lateral line on young fish. Fry have a terminal mouth and feed on zooplankton. After 30 days, the mouth moves to the subterminal position. Adults are omnivorous, feeding on plants, algae, and macroinvertebrates, but were considered feeding specialists by Welker (2000). White suckers ate mostly midge larvae (by stomach volume) and zooplankton (by number in the stomach) in our segment 12 of the Missouri River (Welker 2000).

In the spring, white suckers make upstream spawning runs when river discharge increases, and water temperatures reach 10 C. Spawning fish congregate near riffles. Males typically reach maturity in 2-6 years (15-23 cm in length) depending on geographic location. Females mature 1 - 2 years later than males. Eggs are adhesive and cling to clean gravel or float downstream where they adhere to substrate. Fry emerge in 9 - 11 days and drift downstream at night. White suckers tolerate broad environmental conditions. Even though white suckers are generalists, optimum habitat conditions have been described for stream and reservoir populations (Twomey et al. 1984). We caught about 2,000 white suckers, all from the upper and middle basin segments.

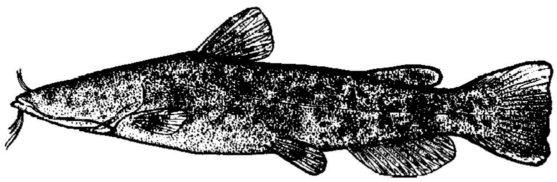


Shorthead redhorse: This species represents a widespread group of redhorse suckers in the Genus *Moxostoma.* The shorthead is olive or tan above, copper or silver on the sides with crescent-shaped dark spots on scales on the back and sides. Its fins are usually red. Maximum adult length is about 75 cm and weigh is about 2.8 kg. Like other suckers, it spawns in the spring over gravel in currents. Shorthead redhorses are generalists that occur in many macrohabitats and flow conditions. The diet is primarily macroinvertebrates, including some mollusks. It was the only sucker to select for large macroinvertebrates in the upper Missouri River (Welker 2000). There are subspecies and intergrades in the lower Missouri River basin and tributaries. We captured 1,200 shorthead redhorse, mostly in the upper and middle basin. They made up <2% of the sucker catch



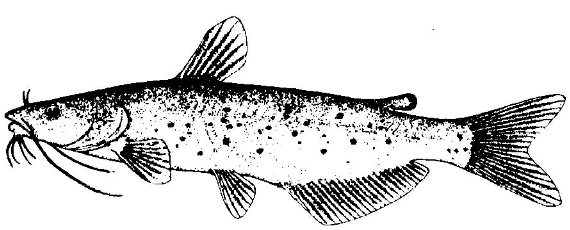
up- and downstream from Lake Sakakawea (Welker 2000).

Flathead catfish: This species is native to the lower Missouri River and many large tributaries in the central and south-central United States (Jackson 1999). It is a predator and important recreational species, reaching over 45 kg in reservoirs and 31 kg (1-m long) in the Missouri River. It is mottled black, olive brown and yellow, and has a very broad head and jutting lower jaw. Flathead catfish are common in pools with



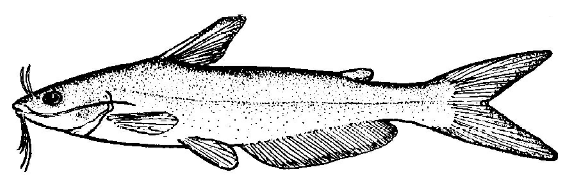
instream structure (e.g., snags, rubble, bridge supports). Many anglers fish for this species at night when it actively searches for food. Adults are carnivores and most are caught by anglers using live baitfish. The species spawns once a year (spring) in cavities in the bank and may live for more than 20 years. We caught about 1,500 flathead catfish, most downstream from Gavins Point dam, and all downstream from Fort Randall Dam (segment **14**). They have been occasionally taken in Lake Sakakawea, but have not been reported in Montana (Reigh and Owen 1979). The abundance, growth, and age structure of the flathead and channel catfish were recently studied in two major tributaries (James River, Big Sioux River) that enter our segment **15** (Arterburn 2001, Kirby 2001).

Channel catfish: Channel catfish are a popular game fish that are common throughout the United States (Hubert 1999). They do well in rivers or lakes, and support a large commercial fishing industry for wild fish, or hatchery fish. We collected about 6,000 channel catfish, which were found at every segment. Maximum age was 11yrs with age frequencies skewed toward older fish in the least-impacted zone and younger fish in the channelized zone (preliminary results). A summary of information about this species was recently published in the Proceedings of the International Ictalurid Symposium (Irwin et al. 1999).

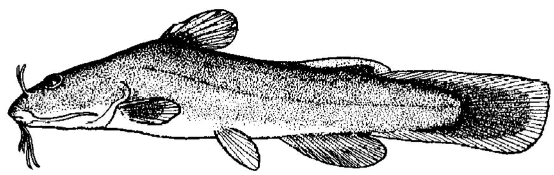


Channel catfish commonly reach 4.5 kg (60 cm long) and can reach 23 kg (120 cm long). They vary in color and shape depending on size, sex, and season, and are sometimes confused with the blue catfish. Young channel catfish may be greenish with dark spots. Mature fish are generally slender and blue-gray, blending into white on the belly, and with a few dark spots. Channel catfish are omnivorous and sometimes are scavengers, being most active at night or after an increase in river discharge. Spawning takes place in holes or crevices along stream banks that are cleaned and guarded by the male. Breeding males are unspotted, dark blue to black with fleshy humps on top of the head and wide, fleshy lips. Eggs hatch in a week and the fry remain schooled near the nest for a few days before dispersing to nearby riffles where they spend their first summer and fall. A habitat suitability index model has been presented for the channel catfish (McMahon and Terrell 1982). The species tolerates high turbidity and unpredictable flows. Their population in the Missouri River declined because of commercial fishing but recovered when a moratorium was in place (Mestl 1999a).

Blue catfish: Adult blue catfish are very pale white or bluish gray without spots on the silvery sides. It differs from the channel catfish in color pattern and by the longer anal fin. This species is the largest recreational catfish, sometimes weighing up to 44 kg (about 140 cm long). It lives in main river channels in the Mississippi River basin, particularly in stretches with bedrock, gravel or sandy bottoms with swift current, but it also does well in reservoirs (Graham 1999). Blue catfish migrate upstream in the spring to spawn in tributaries where they build a nest cavity. The state record fish (61 lbs, 27.7 kg) caught by an Iowa angler was caught in 1993 in the Big Sioux River, just upstream from the Missouri River. Blue catfish move downstream in the fall to winter in deep pools and warmer water. It is a predator, eating crayfish, clams, and other fishes. The species is thought to be uncommon, and has declined in abundance because of commercial fishing. We caught 430 blue catfish in increasing abundance downstream in the channelized section.

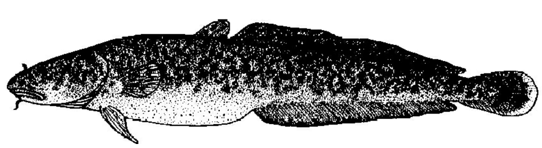


Stonecat: The stonecat is one of the 25 *Noturus* species that are small (<23 cm long) catfishes (Burr and Stoeckel 1999). These catfishes are well known for having a venom gland at the pectoral fin base. The stonecat can reach 23 cm in length (weight about 200 grams) and is widely distributed and common in streams of the Mississippi River basin. It grows large

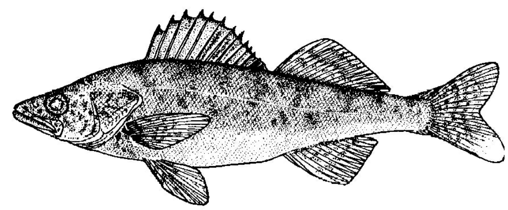


enough to be harvested by anglers (Doorenbos et al. 1996) in Missouri River tributaries. It feeds at night on immature insects and fish. The stonecat is yellowish brown with a dusky streak through the center of the tail. It spawns when water temperatures reach 24 °C beneath large rocks in pools or riffles. The male guards the nest. It lives in relatively clear, perennial streams in shallow riffles where it takes refuge by day in the crevices between stones or beneath litter, and is therefore difficult to capture. We captured about 350 stonecats, a few from each segment.

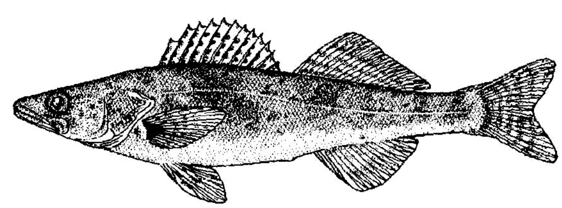
Burbot: The burbot is a freshwater codfish that is principally a northern species, occurring in the upper Missouri and Mississippi rivers, Canada, and Alaska. The burbot has an unusual shape: slender body, long dorsal and anal fins and a small rounded tail. There is one barbel on the lower jaw. The color is mottled greenish brown and the scales are so small that the body appears naked. It can grow to large sizes (20 kg, 100 cm long), but usually reaches only about 1.5 kg (60 cm long) in the Missouri River. Relative weight of burbot populations in lotic (riverine) situations is less than that in lentic habitats (Fisher et al. 1996), suggesting differences in body shape, a plasticity phenomenon that was investigated using emerald shiners during the benthic fishes study (Young 2001). For example, relative weight of burbot from the Missouri River in Montana was 72-76 over four length classes, whereas that for burbot from Lake Sakakawea was 86-109 for the same length classes. This species is also unusual because it spawns in winter, scattering eggs over firm substrates. Small burbot eat insects; large burbot are piscivorous. We caught 220 burbot, all upstream from Fort Randall dam.



Walleye: The walleye is a sport fish, which occasionally reaches 6.8 kg (about 80 cm long). It was included in the benthic fishes assemblage because it is associated with deep-water substrates near steeply sloping banks or bars without much cover. It is recognizable by its glassy eyes that include crystalline matter that allows night feeding. The fish have 6-8 dark bars on the back; the first dorsal fin is spiny and shows a large dark blotch. The lower tip of the caudal fin is white. There are no scales on the cheeks. It is common in rivers and lakes, and is commonly reared in captivity for stocking, but stocking is not normally done in the Missouri River. The species moves upstream in the spring to spawn over rocky substrates (e.g. rip rap, natural rock riffles) when water temperatures reach 7 - 10 C. Eggs adhere to stones during development, which requires about 2 weeks. Walleye fry eat zooplankton but soon become piscivorous. We caught about 600 walleye that were distributed among all study segments.

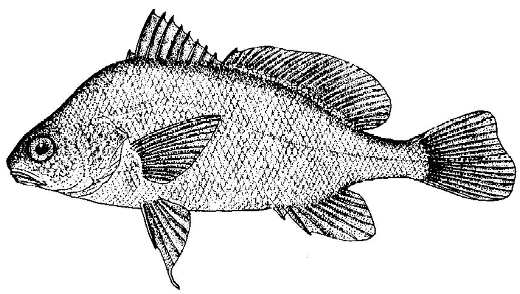


Sauger: The sauger is a piscivorous game species that is similar to the walleye. Both are native to the Missouri River, but sauger were the most abundant before main-stem dams were closed (Bailey and Allum 1962). Sauger are usually shorter and more slender and have dark markings that appear as blotches angling downward onto the sides. The spiny, first dorsal fin has small scattered black spots, cheeks are scaled, and the eye has a glassy appearance. Identification is confounded because sauger x walleye hybrids (saugeye) have been stocked. Sauger are said to prefer more turbid water than walleye, but otherwise inhabit both rivers and lakes throughout the Mississippi River basin. Sauger grow to 2-3 kg (40-70 cm long); the all-tackle record is a 3.8 kg fish taken from Lake Sakakawea in 1971.



Spawning is in early spring after an upstream migration to rocky areas. We caught about 600 sauger distributed among all study segments.

Freshwater drum: This species is abundant and widespread in the Mississippi River basin. It is a large (maximum about 22 kg and 80 cm) silvery fish with an arched back and rounded caudal fin. An important commercial and recreational species, drum are unique due to 1) their use of their air bladder to make sounds, 2) feeding on hard-shelled animals such as mollusks by crushing them (but also eat benthic invertebrates), and 3) the large otoliths in the head that are collected as " lucky stones" and for jewelry. The species spawns in the spring in deep pools. The eggs drift freely near the surface during development. Spawning success of the freshwater drum was a topic of a Ph.D. Dissertation (Braaten, 2000) that was a product of the benthic fishes study. We collected about 2,600 drum, which were found in all study segments. Braaten (2000) investigated the growth, mortality, and sources of freshwater drum larvae in the lower channelized zone. Sources were the main-stem and tributaries as far upstream as South Dakota.



Other Captured Fishes

About 100 fish species have been recorded from the free-flowing Missouri River, so we expected to catch many species other than the 26 species we focused on in the benthic fishes assemblage. We caught 54 other species in 1996 (3,934 fish), 65 species in 1997 (11,414 fish), and 53 species in 1998 (9,880 fish) for a total of 80 other fish species (Table 2). Of this group, 14 species were introduced and three species were exotics (excluding the common carp) that was in the benthic fish assemblage.

Species represented by more than 1,000 specimens were goldeye, longnose sucker, quillback, red shiner, spotfin shiner, and white crappie. Other commonly captured native species were longnose dace, river shiner, shortnose gar, silver chub, and spottail shiner. Also common were introduced centrarchids (bluegill, green sunfish, largemouth bass, smallmouth bass, white bass). We also found three hybrids: 1) striped bass x white bass, 2) walleye x sauger, and 3) green sunfish x *Lepomis* sp. (i.e. bluegill, orangespotted sunfish). Some smaller fishes could not be identified to species. About 9% of the catch was unidentified in 1996 (n = 2,330) when many young of the year fish were collected. Afterward, we could not identify 2% in 1997 (n = 916), and 3% in 1998 (n = 1,631).

Sampling Methods and SOP

Developing standard operating procedures (SOP) is required in any study, but formalizing the process was especially important for the benthic fishes study because of the number of individual teams working at the large spatial scale. Well-defined quality assurance and quality control procedures were used (Sappington et al. 1998). In general, each procedure was written by a team member(s) and checked by the Quality Assurance Officer. Nineteen SOPs were developed in 1996 that described fish sampling protocols, physicochemical measurements, data analyses, and quality assurance and quality control measures. Yearly meetings and field trips were held to review the SOPs. We made a few changes in SOPs, but in general, most remained unchanged throughout the study (Table 7).

Five gears were used to collect fishes. Experimental gill nets were 30.5 m long x 1.8 m deep with four 7.6-m panels of 19, 38, 51, and 76-mm mesh. Trammel nets were 22.9 m long and 1.8 m deep with a 25-mm inner mesh and 203-mm outer mesh (bar measure). Bag seines were 10.7 m long and 1.8 m deep with 5-mm mesh. The benthic trawl was hung on a rigid frame with skis. The trawl net was 2 m wide, 0.5 m deep, and 5.5-m long with 3.2-mm inner mesh. Electrofishing was done with a 5000-watt generator using pulsed DC current and 2 netters with 5-mm mesh dip nets. A minimum of two fish collection gears was used in each mesohabitat (Table 8). The exceptions were shallow habitats (i.e. shallow, connected secondary channels, inside bend bars) where only a seine was used.

Data Management

We recorded, analyzed, and managed data following standard protocols to allow investigators to combine, sort, and analyze in various ways data from the full geographic extent of the study, and so that the information to be ultimately available and useful to the public. We followed a data management plan that began with data acquisition and ended with archiving (Brown and Austen 1996). Data were recorded on three data sheets: habitat data, fish field data, and laboratory fish data. Barcodes on each data sheet linked the three sheets and facilitated data entry and management.

One habitat measurement sheet (Figure 6a) was

Table 7. Brief description of standard operating procedures for fieldwork approved in 1996, with record of changes during the conduct of the study. Full descriptions of standard procedures can be found in Sappington et al. (1998).

Procedure (Coop Unit or CERC)	1996	1997	1998
Fish collection			
Bag seining (IA)	5-mm mesh, half-arc, 2 hauls per macrohabitat	Modified[1]	Same
Benthic Trawl (MT)	2-m wide, 0.5-m deep, trawl distance 150 m	Modified[2]	same
Electrofishing (KS)	Boat with sphere, pulsed DC, 2 10-min samples per habitat	Modified[3]	same
Gill net (SD)	1.8, 3.7, 5.0, 7.5 cm mesh net, 1 3-hr daytime set	Modified[4]	
Trammel net (MT)	1.8 m x 25 m, 2.5-cm inner wall mesh, bottom drift for 300 m	same	same
Fish identification			
Age and Growth (IA)	Weight and length, scale, otolith, and spine removal,	Modified[5]	same
Fish treatment (SD)	Humane practices	same	same
Endangered Species (SD)	Handling pallid sturgeon	same	same
Experimental design and data management			
Experimental design (CERC)	Hypotheses and statistical analyses	same	same
Coding (CERC)	Field data sheets	same	same
Chain of custody (CERC)	Record with samples	same	same
Habitat			
Bed form (MO)	Paper chart of area sampled	same	same
Depth, velocity (MO)	Meter readings at various gear deployment locations	Modified[6]	same
Global position (SD)	GPS receiver coordinates gear deployment sites	same	same
Substrate (SD)	Pipe dredge dragged along bottom; percentage by size class	same	same
Time (ID)	Military	same	same
Turbidity (KS)	Turbidimeter, one sample each gear deployment	same	same
Temp, conductivity (KS)	Meter	same	same
Weather (MT)	Air temperature, wind, cloud cover and precipitation	same	same

1. From 2 to 3 hauls per macrohabitat, deploy to 1.2 m instead of 1.8 meters
2. From 150 m distance to 300 m distance
3. Increase electrofishing time; generally <30 min depending on macrohabitat
4. From 3-hr before noon to overnight from 12 to 18 hr
5. Added section for laboratory analysis of aging spines, otoliths, and scales
6. From one velocity measure at gillnet midpoint to three measures at 25, 50, and 75

completed for each collection. This sheet was used to document gear-specific sampling effort, detailed spatial data, key physical and chemical measurements, comments, and quality assurance data. One or more fish field measurements sheets (Figure 6b) were used to record fish collected in each sample. One or more laboratory fish measurement sheets were used to record fish that were preserved in the field for later identification. A collection was defined as a sampling venture consisting of a unique combination of location, time, and sampling gear. Each time a meso- or macrohabitat habitat was subsampled, two new data sheets were used. The barcode attached to each data sheet for that subsample (field fish, lab fish, habitat) was the same, and linked the data sheets for future data management. All data were recorded according to SOPs so that the data were unambiguous and could withstand legal challenge. An SOP for chain of custody was also followed to insure sample integrity from collection to data reporting.

Quality assurance for data correctness began with each investigator inspecting the raw data on the data sheet for completeness and checking unusual data for reasonableness. Data sheets were sent to the quality control officer who managed data entry into an electronic database. A commercial data entry company entered data from sheets into files, and used a double entry process to certify their work and provide a second quality control layer. Investigators did a third check on data quality by comparing the hand written data with the electronic data. The checking process for correctness was done by the quality control officer by using an error checking SAS program during the first 2 years, and done by individual investigators for year 3. A final step in developing a usable data set was done by statisticians who searched for "outliers" by evaluating each variable in the data set to determine whether the range of values in the set was reasonable. When outliers were found, each investigator was contacted to defend the data entry. If the investigator certified that there was an error in collection or recording, then the information was changed or deleted, otherwise, questionable data were accepted. The resulting data set can be analyzed with confidence knowing that when patterns arise, they are real and not an artifact of incorrect data. Each investigator received a compact disc with all data.

Data are currently available as raw data sheets (8 full file cabinet drawers) stored at the Columbia ERC. Study records will be housed at the Center until 2018 according to USGS archiving guidelines. Date are also available on a CD in Volume 6, and on the worldwide web site of the U.S. Army Corps of Engineers (see Preface). The electronic databases are backed up on compact disks possessed by each principal investigator.

Data Analysis

We posed both research and statistical hypotheses. A research hypothesis is a theoretical generalization or assumption as yet unproved. It is a preconception of a factual relationship. The research hypothesis is sometimes called a "working" hypothesis because from it, researchers work forward. We posed several research hypotheses after reviewing the literature on riverine fish ecology and on the Missouri River situation. For example, one research hypothesis about the fish community was -

> "Recruitment will be more consistent in segments that resemble the natural river structure and hydrology than in perturbed segments."

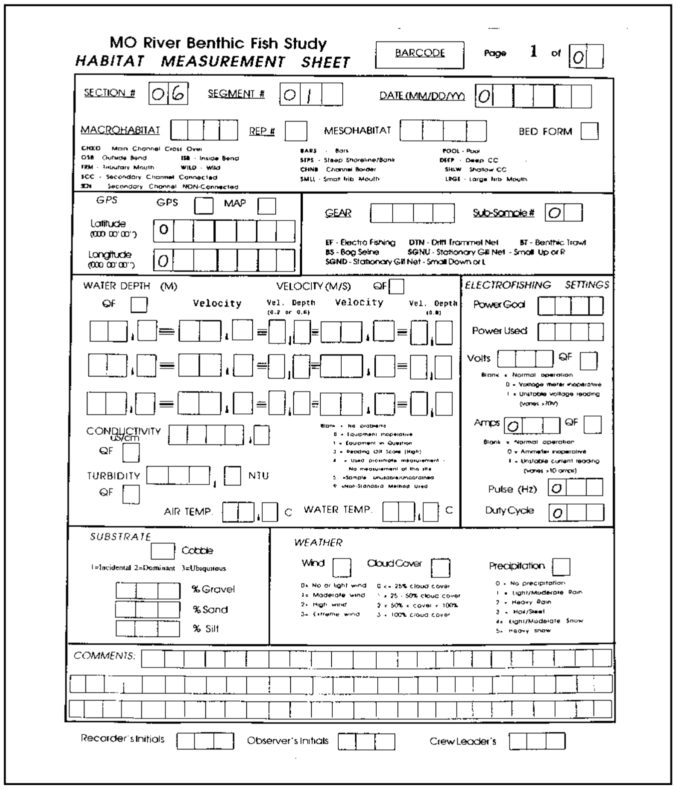
One research hypothesis about the river habitat was -

> "Water velocity will be greater in channel macrohabitats in the channelized segments than in other segments."

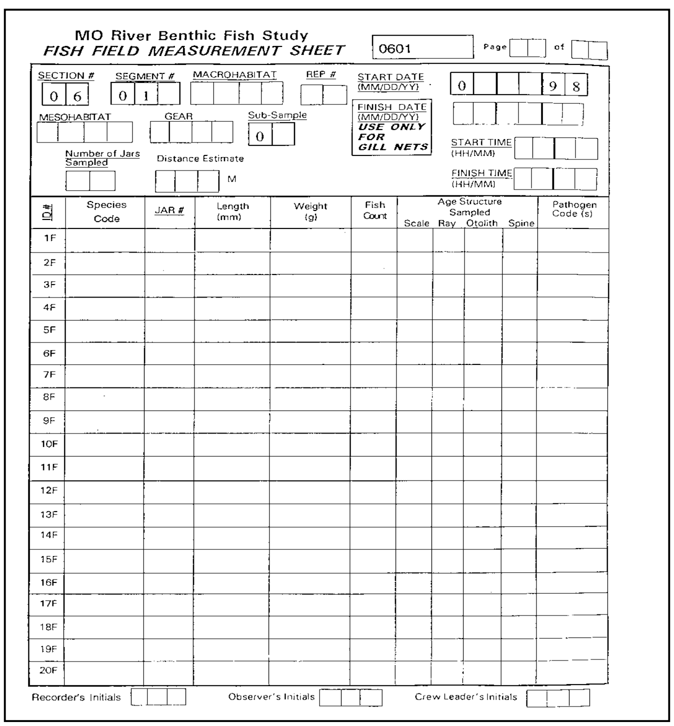
We also posed statistical hypotheses according to standard methods (Brown and Austen 1996). A statistical or null hypothesis is useful in statistics because it clearly states the dependent and independent variables in the relationship. We stated a null hypothesis, an alternative hypothesis, suggested an appropriate statistic, and specified the level of significance (alpha = 0.05). We used power analyses (i.e. 1-beta = 0.8) to support null hypotheses that we did not reject using alpha < 0.05. The SOP manual (Sappington et al. 1998) lists null and alternate hypotheses. For example:

> *Null hypothesis:* There is no difference among segments in the catch of benthic fishes from main channel habitat using the benthic trawl.
> *Alternate hypothesis:* The catch of benthic fishes caught in main channel habitat using the benthic trawl increases downstream.

We used a stratified random sampling design to sample benthic fishes and associated habitat variables. Our strata were the six macrohabitats (Table 8) with segments being the experimental blocking in which we randomly sampled macrohabitats. Stratified random sampling is a commonly used and effective method for evaluating measurement parameters when easily identifiable strata are present. We analyzed several dependent variables relating to fish community structure, population structure and associated habitat variables using the statistical tests (e.g. analysis of


MO River Benthic Fish Study
HABITAT MEASUREMENT SHEET
BARCODE Page 1 of 0
SECTION # 06 SEGMENT # 01 DATE (MM/DD/YY) 0
MACROHABITAT REP # MESOHABITAT BED FORM
GPS: GPS MAP
Latitude (000 00' 00") 0
Longitude (000 00' 00") 0
GEAR Sub-Sample # 0
EF - Electro Fishing DTN - Drift Trammel Net BT - Benthic Trawl
BS - Bag Seine SGNU - Stationary Gill Net - Small Up or R
SGND - Stationary Gill Net - Small Down or L
WATER DEPTH (M) VELOCITY (M/S) QF
QF Velocity Vel. Depth (0.2 or 0.6) Velocity Vel. Depth (0.8)
ELECTROFISHING SETTINGS
Power Goal
Power Used
Volts QF
Amps 0 QF
Pulse (Hz) 0
Duty Cycle 0
CONDUCTIVITY uS/cm QF
TURBIDITY NTU QF
AIR TEMP. C WATER TEMP. C
SUBSTRATE
Cobble
1=Incidental 2=Dominant 3=Ubiquitous
% Gravel
% Sand
% Silt
WEATHER
Wind Cloud Cover Precipitation
COMMENTS:
Recorder's Initials Observer's Initials Crew Leader's

(A) Habitat data sheet


MO River Benthic Fish Study
FISH FIELD MEASUREMENT SHEET
0601 Page of
SECTION # 06 SEGMENT # 01 MACROHABITAT REP #
START DATE (MM/DD/YY) 0 98
FINISH DATE (MM/DD/YY) USE ONLY FOR GILL NETS
MESOHABITAT GEAR Sub-Sample 0
START TIME (HH/MM)
FINISH TIME (HH/MM)
Number of Jars Sampled
Distance Estimate M

ID#	Species Code	JAR #	Length (mm)	Weight (g)	Fish Count	Age Structure Sampled: Scale	Ray	Otolith	Spine	Pathogen Code (s)
1F										
2F										
3F										
4F										
5F										
6F										
7F										
8F										
9F										
10F										
11F										
12F										
13F										
14F										
15F										
16F										
17F										
18F										
19F										
20F										

Recorder's Initials Observer's Initials Crew Leader's Initials

(B) Fish data sheet

Figure 6. Data sheets used to record data in the field during each of the three years of the benthic fishes study. See Sappington et al. 1998 for details on data sheets.

variance) deemed appropriate from the list made during project planning.

Fish community structure refers to the relative species abundance within a fish assemblage. *Relative abundance* is traditionally measured by catch in numbers per unit of sampling effort. For this study, we used multiple (2 or 3) gears to sample mesohabitats within six macrohabitats in each segment (Table 8). The gears, macrohabitats, and replicates were standardized so that we could accurately measure species richness. Species richness is the total number of fish species in a river segment (not including hybrids).

Population structure was defined as the distribution of individuals of a single species among size or age groups. Population structure evaluation was done on each benthic species. *Size distribution* is the number of specimens taken in a collection or in a unit of effort that falls into selected size categories. In our study, the unit of effort is the macrohabitat since the combination of the multiple gears used in each macrohabitat was designed to, as much as possible, sample the entire fish population within a macrohabitat. *Recruitment* was defined as the addition of new members to the aggregate under consideration. In a fishery, recruitment is the supply of fishes that become available at some particular stage in their life history. In our study, we were interested in the age-1 recruitment to gear. Population structure can also be evaluated using growth. In our study, we analyzed *average growth* per year both in length and weight that was back-calculated from aging structures. We also calculated relative weight (Anderson and Gutreuter 1985).

We tested data for normality by plotting the frequency distribution of the data and calculating a Shapiro-Wilk test statistic for normality. We decided whether or not the variable was normally distributed by examining the frequency distribution, and used the test statistic as a further guide. When the frequency distribution appeared close to normal and the value of the test statistic was close to normal, we assumed that the data were normally distributed. We tested for homogeneity of variance on a gear-habitat level by plotting the residuals based on habitat for a gear and testing for a significant correlation between means and variances for the gear-habitat level. If the data were not normal,

Table 8. Fish collection gears and Missouri River macro- and meso-habitats where each gear was deployed.

Macro- and meso-habitats	Bag seine	Experimental gill net	Boat electrofishing	Benthic trawl	Drifting trammel net
Channel cross-overs				X	X
Outside bends			X	X	X
Inside bends					
channel border				X	X
Bars	X				
Pools		X			
steep shorelines			X		
Tributary mouths					
Small		X	X		
Deep			X	X	X
Secondary channels: Non-connected	X	X	X		
Secondary channels: Connected					
Shallow	X				
Deep	X		X	X	X

they were transformed to try to meet the normality assumptions.

CONCLUSION

Conserving fishes, and especially rare species, in large river systems requires studies with large spatial scale (Abrams 1992, Volkman 1992) to evaluate the ecological consequences of land and water use changes on riverine biota. However, such studies are rarely done because of logistical constraints (Turner et al. 1995, Wiens et al. 1986, Lobchenco et al. 1991). Some logistical problems of large spatial scale studies can be solved when Universities cooperate (Temple et al. 1986). University cooperation was suggested as a way of studying the rare species of the Missouri River (Berry and Erickson 1995), and became a reality with the benthic fishes study.

USGS Mission

The successful conduct of the benthic fishes study is an example of the capability of the USGS for conducting broad spatial scale and interdisciplinary studies. The need for a broad scale project on the Missouri River fit the capabilities of the Coop Research Units and the Columbia ERC in several ways. First the project matched well with the overall goal of the Biological Resources Division: "…provide the scientific understanding and technologies needed to support the sound management and conservation of our Nation's biological resources." The benthic fishes project also addressed several Program Elements of the Biological Resources Division (see box below).

The basis for USGS program success is collaboration within the USGS, with Federal and State agencies, and with Universities. This success is exemplified by the benthic fishes study that attracted funding from five Federal agencies, four state agencies, and six Universities. A substantial state cooperator was the Montana FWP, without whose cooperation we would not have had important comparative data on the Yellowstone River and the Missouri River below Ft Peck Dam.

Benthic Fishes Study: Problems of Scale

The benthic fishes study was a success in that we undertook a large spatial scale study in a river that is a hazardous working environment, and accomplished all planned fieldwork. We collected 134,163 fishes (77,196 identifiable specimens in the benthic assemblage). The databases total about one million pieces of data. For example, the habitat database has 7,289 collection points with 65 variables at each, while the fishes database has 45 variables. Each field season we launched 12 boats (6 fish sampling, 6 habitat measurement) with a total field crew of about 36. Tasks related to the pursuit of advanced degrees by Unit students (e.g., class work, independent research) were an integral part of the benthic fishes study, but essentially separate from the study. We found that major tasks of the benthic fishes study could be categorized as 1) Administration, 2) Communication, 3) Sampling, 4) Data management, and 5) Data analysis

USGS-BRD Program Element	Activity addressed by the benthic fishes study
Status and trends	Describe biological diversity, develop methods and protocols for inventory and monitoring
Fisheries and aquatic resources	Determine factors affecting reproduction, determine distribution of species of concern
Ecosystems	Investigate interactions among biotic and abiotic ecosystem components, investigate spatial heterogeneity across landscapes
Endangered and at-risk species	Determine status and trends, identify factors that cause decline
Exotic species	Investigate the spread of invasive organisms
Biological Information Management and Delivery	Advance access to and dissemination of biological data, information

and reporting.

Administration

Research teams function best when there is camaraderie and leadership. Fortunately, our group learned early that there was collegiality among Principal Investigators and Ph.D. students. We anticipated the need for leadership and agreed that Dr. David Galat (Missouri) would be the "Science Officer." The Science Officer promoted the project in Washington, D. C., Reston, and other venues, provided general direction and insights to the team into large river ecology, coordinated communication, coordinated final reporting, and did many other duties. Administrivia that need to be considered during the conduct of a multi-unit study are 1) assign lead responsibility for writing the annual reports, 2) making rules about authorship and data ownership, 3) periodic updates and information sharing, 4) conflict resolution, 5) coordinate site visits, 6) coordinate scientific presentations at Missouri River conferences, 7) lead, prepare agendas, distribute notes and action items from the biannual meetings, 8) prepare project timetables, 9) coordinate final report writing and distribution, and other duties.

Unforeseen developments required other leadership positions. The yearly funding problems, addition of other funding agencies, and contracting details over 5 years required a great amount of time and Dr. Charles Berry (South Dakota) assumed the duties of coordinating the contracting and funding aspects of the study. Additionally, the age and growth analysis became a large sub-project that required coordination. Dr. Chris Guy (Kansas) and Dr. Clay Pierce (Iowa) assumed that role.

In hindsight, we needed two other assignments. Our work generated many, many questions from funding agencies, other user groups, and the general public. We should have appointed one Principal Investigator to coordinate responses to questions and assume some of the work that responses entail. We also needed a Performance Auditor, which is a Principal Investigator who would visit each team to insure standardization of field methods and data recording. We assumed that field trips as a group and one meeting each year would insure standardization, but the addition of a Performance Auditor would have been an extra level of quality assurance.

Communication

Obviously, communication was important for such a large study. We had to communicate among the team and with the public, and provide technical assistance to funding agencies. Semi-annual meetings usually included an information and extension program followed by a closed meeting of team members. The information program was presented to update the general public (usually interested administrators from funding agencies). The closed meetings were opportunities for team members to discuss progress and problems. Field trips to different segments gave each team member an understanding of the river ecosystem, and problems encountered by other team members who worked in that particular segment. Esprit-de-corps may seem trite in a research setting, but it is important in any group. Our team-building efforts were spontaneous and included awards at annual meetings, and periodic communication sharing information about team members and Missouri River issues.

If research is vital, there will be inquiries. We had to develop an information dissemination plan that covered verbal, written, and electronic information from the project. We needed extension materials to 1) attract funding, 2) inform agencies on progress, and 3) inform the public. We used the Internet to some extent, with an early site established at South Dakota State University, and later ones at the Columbia ERC (www.cerc.cr.usgs.gov) and on the USGS home page (biology.usgs.gov/outreach/infocus.htm). An important education effort was the 4-page brochure for the USGS series Biology in Focus. The brochure was titled "Missouri River Hooks its Largest Fish Study." We also delivered project briefings at various meetings (e.g., Missouri River Basin States Association), and delivered scientific papers at conferences and meetings (See Appendix for paper titles and venue).

Technical Assistance included responding to needs of agencies, and advising the multi-state group planning the Missouri River Environmental Assessment Program. Typical examples of technical assistance were 1) to the Fish and Wildlife Service - responding to questions about where candidate species were captured, 2) to the Corps - responding to questions about pallid sturgeon status, and 3) to Bureau of Reclamation - responding to information needs on the proposed developments in the Yellowstone basin.

Year	Papers or posters presented at scientific meetings	Extension activities at general public meetings
1996	9	2
1997	13	2
1998	12	1
1999	5	1
2000	6	1

Sampling

Planning was assisted by a pilot study in each segment in 1996 that allowed us to plan access points, select segments, suggest the best gears, estimate budgets, realistically set timelines, and make other decisions before the first full year of field work. The book of SOPs that was developed by the quality control officer was absolutely critical to the conduct of the study (Sappington et al. 1998).

Fish identification and voucher specimens were an issue. We did not anticipate the need for a central location for storage of the specimens, or for an outside expert to check the voucher collection. We contracted with an ichthyologist, Dr. William Pflieger, to analyze the 461 specimens of benthic fishes that were kept as voucher specimens. His report, dated May 1999, stated that only 10 of the 461 were incorrectly identified (Pfleiger et al. 1999). Taxa incorrectly identified were all juveniles: walleye (2), white sucker (4), stonecat (1), and sicklefin chub (3). The sicklefin chubs were probably hybrids (sturgeon chub x sicklefin chub), which is the first report of hybridization between these species in Montana. Hybrids are possible in the lower Missouri River (Grace 1985). We also submitted 49 specimens of other fishes for verification, of which two were incorrectly identified. All specimens are curated at the University of Missouri.

Equipment needs were great. Sampling in areas of woody debris destroyed many nets. For example, 17 trammel nets were torn up in 1997 because of snags in the South Dakota segments. We were fortunate to have large boats and motors that were purchased by the Corps or donated by USGS. Reliable boats, motors, and trailers helped insure the safety of field workers. A great savings in expense was made when the USGS donated several trucks to the project.

Data Management

This part of the study caused concern and was one reason we needed a time extension to finish the final report. Perhaps if we had had more experience with large studies, we would have known that assembling and checking databases is one of the greatest challenges in broad-scale ecological studies. Database management is time- and cost-intensive, and is an activity that requires a large initial investment that researchers frequently underestimate for both the time and money required (Turner et al. 1995). Our goal of having an online database for use by the principal investigators during the conduct of the study was never really met.

In future studies like ours, we suggest 1) thorough training and communication in how to fill out the data sheets, 2) frequent inspection of raw data sheets for unreasonable entries (although a tedious chore) before the data are entered into the data base, and 3) enough funding for a fulltime database manager. Although data management was a problem area for our study, the problems were not with standardized or inaccurate data, but with the number of inconsistencies that needed to be resolved between data managers, statisticians and field workers, and the large volume of data that we were not prepared to handle.

The key to a successful data management program for a multi-investigator study such as ours is for investigators to understand and accept the study objectives, design, sampling procedures, data collection, and database format before any data are collected. By meeting after the first year of fieldwork, we realized that some data recording procedures were not fully understood. Lapses in standardization occurred because of differing interpretations of the SOPs, ignoring various aspects of the SOPs due to logistics, time constraints, and even disagreement with the methods stated in the SOPs by various field workers. Further, some data were inaccurate due to 1) equipment failure, 2) one set of physical measurements used for several fish subsamples, and 3) incorrect macrohabitat classification. These inconsistencies and occasional human error lead to excessive data verification work before analyses could be done. On-the-other-hand, the vast majority of the data were usable because of the standardization efforts planned before the study. Overall, our preplanned data management program greatly reduced the amount of discarded data and allowed us to discard erroneous data, thus improving the quality of final products.

STRUCTURE AND INTENT OF VOLUMES TO FOLLOW

The final report for the benthic fishes study is divided into 12 volumes. The first six present findings related to the study objectives. The latter six volumes are Ph.D. Dissertations on related subjects. Following is an overview of each volume and how each relates to the objectives of the benthic fishes study which were:

1) Describe and evaluate recruitment, growth, size structure, body condition, and relative abundance of selected benthic fishes,
2) Measure physiochemical features (e.g., velocity, turbidity) in dominant habitats where fishes are collected, and
3) Describe the use of dominant habitats by benthic fishes.

Study Objectives: Final Report Volumes

Volume 1. Introduction and Study Design (Objectives 1, 2, 3)

Here the reader will find a synthesis of the fish literature for the Missouri River; other studies going on during the benthic fishes study years; a summary of how the benthic fishes study consortium managed the project; overall study design and basic approach; and a list of products (publications, presentations, technical assistance activities). The fundamental statistical analysis was analysis of variance of dependent variables (e.g. number of fishes, fish growth) on independent variables year, segment, and macrohabitat.

Volume 2. Spatial Patterns of Physical Habitat (Objective 2)

This volume details efforts to meet project objective two which was - measure physical habitat features in dominant macrohabitats where fishes are collected. The reader will find the most comprehensive and robust synthesis of aquatic physical habitat ever assembled for the Missouri River. The reader will find descriptive statistics, statistical analyses, and other analyses of contrasts of physical conditions (10 physical habitat variables) among 3 zones, 15 segments, and 6 macrohabitats. The data show longitudinal changes throughout the river, and how dams and tributaries affect the physical habitat. Seven conclusions and recommendations are made.

Volume 3. Fish Distribution and Abundance (Objective 1, 3)

This volume describes benthic fish use of zones, segments, macrohabitats and physical habitat. Some of the most useful figures from the annual reports have been those showing (for example) that 90% of a certain species was caught at depths < 2 m, and that catch-per-effort was highest in outside bend macrohabitats. The reader will see changes in the relative abundance of each species by zone and segment, and find distribution maps for all species. Here the reader will also find information on the distribution and abundance of the 80 other species of fishes that were collected. The reader will find specific information on the location and abundance of certain groups (e.g., endangered, exotic, recreational fishes). Readers contemplating biomonitoring will learn positive and negative aspects of the six gears that were used.

Volume 4. Fish Growth, Mortality,Recruitment, Condition, and Size Structure (Objective 1)

This volume focuses on research objective one, which was to describe and evaluate recruitment, growth, size structure, body condition, and relative abundance of selected benthic fishes (shovelnose sturgeon, flathead chub, sicklefin chub, emerald shiner, western silvery minnow, plains minnow, brassy minnow, blue sucker, smallmouth buffalo, river carpsucker, flathead catfish, channel catfish, sauger, freshwater drum). Here the reader will learn about differences in recruitment between altered river segments and more natural ones; whether growth varies with latitude; how populations have responded to habitat changes in major segments of the river; and how hydrologic and physical modifications of the river have influenced benthic fish population structure (growth rates, recruitment, age structure, body condition).

Volume 5. Synthesis of the Benthic Fish Study (Objective 1, 2, 3)

In Volumes 1-4, the reader was presented information about the physical habitat, fish community, and age and growth of selected populations. Volume 5 is intended to synthesize these three data groups. The reader will learn how impoundments affect the benthic fishes, and how habitat modification through bank stabilization and levee construction might affect macrohabitats and fishes. Here the reader will find recommendations on how future operations of the system can be conducted to conserve and enhance native benthic fishes.

Volume 6. Part 1: Physical Habitat and Fishes Databases. Part 2: Standard Operating Procedures, 1996-1998 (Objectives 1,2,3)

This volume includes project SOPs, metadata, and tables of all project data on a compact disk.

Ph.D. Dissertations

Volume 7. Development of an index of biotic integrity for measuring biological condition on the Missouri River; Ph.D.Dissertation, Montana, Lee Bergstadt (Objectives 1,2,3)

Quantification of regional and watershed quality is facilitated by the index of biotic integrity, which uses attributes of the fish community to evaluate anthropogenic effects within a stream reach. Use of the index on great rivers is experimental, so these data (Bergstedt 2001) for the Missouri River might be considered research rather than application, but the analysis applies to the basic search for fish-habitat associations that is a goal of the benthic fishes study.

Volume 8. Growth and mortality of fishes in the Missouri River, with emphasis on freshwater drum; Ph.D. Dissertation, Kansas, Pat Braaten (Objective 1)

Growth and condition of benthic fishes are described in Volume 4, but this volume investigates some of the causative factors that can affect growth and condition of emerald shiner, sicklefin chub, freshwater drum, river carpsucker, and sauger. The reader will also find information on factors influencing recruitment of freshwater drum. Results emphasize the importance of upstream to downstream linkages in the recruitment dynamics of fishes in demographically open aquatic systems (Braaten 2000).

Volume 9. Spatial patterns in phenotypes and habitat use of sicklefin chub, *Macrhybopsis meeki*, in the Missouri and lower Yellowstone rivers; Ph.D. Dissertation, Missouri, Douglas Dieterman (Objective 3)

The sicklefin chub may be the next species listed as endangered. These data will contribute to information needed to make that decision, and be useful in planning management of the river for recovery of this species. The number of sicklefin chubs collected during the benthic fishes study exceeds the sum of all those reported in the scientific literature since 1880. Like the study of emerald shiners (Volume 11), this study reports on the phenotypic variability of the species. Similar information has been used in other situations to identify distinct subspecies requiring legal protection or specific management, and to plan population restoration through propagation and stocking. Distribution of sicklefin chubs among zones, segments, and macrohabitats is new information that will help design physical and hydrological habitat to conserve the species (Dieterman 2000).

Volume 10. Hydrological variation along the Missouri River and its effect on the fish community; Ph.D. Dissertation, Iowa, Mark Pegg (Objective 1, 3)

Water velocity and discharge are fundamental variables that can be managed in the Missouri system. Readers will find detailed analyses of how climate and dam operation affect hydrology at 15 gauging stations. There was strong evidence that the fish communities differed in composition and richness with flow conditions in zones of the river. This volume also reports on latitudinal patterns in growth of five endemic fishes (channel catfish, emerald shiners, freshwater drums, river carpsuckers, and saugers), but results were somewhat unexpected although reasonable given the fragmented nature of the Missouri River (Pegg 2000).

Volume 11. Intraspecific variation among emerald shiners of the Missouri River; Ph.D. Dissertation, South Dakota, Brad Young (Objective 1)

The reader will learn how the genetics (protein gel electrophoresis), physiology (swimming stamina), and morphology (meristics, morphometrics, body shape defined by truss analysis) of a “subpopulation” of a riverine fish species change after 40 years of confinement in a lake. A stamina tunnel was used to compare swimming ability of river and lake fish (Young 2001). Relating swimming stamina of emerald shiners to Missouri River macrohabitat conditions is a direct application of this research. This volume addresses subjects on the frontier of ecological research (Thompson et al. 2001) - the combined roles of phylogeny and ongoing evolution, phylogenetic structure and ecological processes, and rapid evolution and ecological dynamics. In terms of issues on the Missouri River, this research asks - Do dams disrupt gene flow and alter phenotype?

Volume 12. Ecological structure of fish communities in the Missouri and lower Yellowstone River area; Ph.D. Dissertation, Idaho, Tim Welker (Objective 3)

Much of the description of the niche includes habitat. The reader will find detailed descriptions of the status of the sucker family in the upper river, particularly their dietary preferences. Contrasts are made between the segments upstream (least-altered) and downstream (altered, inter-reservoir) from Lake Sakakawea. Included is a chapter on the W. silvery minnow, flathead chub, sturgeon chub, and sicklefin chub. The data relates specifically to objective three - describe the use of dominant macrohabitats by benthic fishes.

Outreach Report (All objectives)

This product is written in a semi-technical style and is intended for non-biologists. The reader will find a synopsis of essential findings and recommendations presented in a colorful booklet.

ACKNOWLEDGEMENTS

Principal Investigators and Doctoral student members of the Missouri River Benthic Fishes Consortium not listed as authors of this volume but equally responsible for design and execution of this research include. Lee Bergstedt, Pat Braaten, Doug Dieterman, David Galat, Chris Guy, Mark Pegg, Clay Pierce, Mike Ruggles, Dennis Scarnecchia, Tim Welker, Mark Wildhaber, and Robert White. David Galat served as the Consortium’s “Science Officer;” Chuck Berry as the “Administrative Officer.” We thank the many field and laboratory technicians who worked over the five years of the Benthic Fishes Project and without whose dedication we would have not succeeded. We thank the U. S Geological Survey’s Cooperative Research Units Program, particularly Dr. Jim Fleming and Dr. Lynn Haines, for fostering an esprit-de-corps among the Units participating in this research and having faith (and funding in emergencies) in our ability to collectively execute such a comprehensive research effort. Linda Sappington administered the database and kept us organized. Robin Lipkin produced the layout of this volume. Jim Liebelt, John Nestler, and Virginia Sutton participated in initial Project design.

Tom Parks believed greatly in this Project, but unfortunately will not see its products. Doug Latka was instrumental in conceiving of the research, project development, and in securing funding for the project. We are particularly indebted to Becky Latka for managing the Project and her tireless encouragement and enthusiasm for the research. We greatly appreciate financial and logistic support to the Project from the following agencies: U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, U.S. Geological Survey, Kansas Department of Wildlife and Parks, Iowa Department of Natural Resources, Missouri Department of Conservation, Montana Department of Fish, Wildlife and Parks, Nebraska Game and Parks Commission, North Dakota Game and Fish Department, and South Dakota Department of Game, Fish and Parks. The Wildlife Management Institute is a cooperator in each Cooperative Unit and promoted the Unit Program during reorganization of the Fish and Wildlife Service and U.S. Geological Survey. Universities that supported the project by waiving part of the usual overhead charge, thus allowing funding to go much farther, were The University of Missouri, Kansas State University, Iowa State University, South Dakota State University, Montana State University, and The University of Idaho.

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Appendix:

Products of the Benthic
Fishes Study

APPENDIX: PRODUCTS OF THE BENTHIC FISHES STUDY

Besides the 12-Volume final report that includes six Ph.D. Dissertations, we expect to produce several publications in peer-reviewed scientific journals. However, to date (January, 2002) most products have peen in the form of Annual Reports and technical presentations offered at scientific meetings.

1996

Oral Reports for 1996

Galat, D. 1996. Missouri River benthic fish study. Presented at the Big Rivers/catfish meeting, Missouri Dept. Conservation, Columbia, Missouri.

Pegg, M. 1996. A new study on the benthic fishes of the Missouri River. Presented at the Joint meeting of the Iowa/Nebraska Chapters of the American fisheries Society, Council bluffs, Iowa.

Pegg, M. 1996. Update on the benthic fishes study. Presented at the rivers and Streams Technical Committee Meeting, North Central Division of the American Fisheries Society, Rock Island, Illinois.

Galat, D. 1996. Update on the Missouri River benthic fishes project. Presented at the planning and evaluation workshop, Contaminants in the Mississippi River Basin, NBS, BEST program. Columbia, Missouri

Scarnecchia, D. 1996. The benthic fishes study. Presented at the Annual meeting of the North Dakota Game, Fish and Parks Department. Bismarck, North Dakota.

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White, R. 1996. Benthic fishes study group searchers for pallids. Presented at the pallid sturgeon work group meeting, Miles City, Montana.

Missouri River Benthic Fish Consortium. Poster presented at the 58th Midwest Fish and Wildlife Conference, Omaha, Nebraska.

Braaten, P., and C. Guy. 1996. Preliminary results from the benthic fishes study. Poster presented at the 58th Midwest Fish and Wildlife Conference, Omaha, Nebraska.

Galat, D. 1996. Goals and objectives of the benthic fishes study. Presented at the Missouri River Natural Resources Committee Meeting, Omaha, Nebraska.

Written Reports for 1996

Sappington, L., D. Dieterman, and D. Galat. Editors. 1996. 1996 Standard operating procedures to evaluate population structure and habitat use of benthic fishes along the Missouri and Lower Yellowstone Rivers. Missouri River Benthic Fish Consortium, USGS-BRD, Columbia Environmental Research Center, 4200 New Haven Rd., Columbia, Missouri 65201.

1997

Oral Reports for 1997

Bergstedt, L. 1997. Population structure and habitat use of benthic fishes along the Missouri River. Poster Presented at the Annual Meeting of the Montana Chapter of the American Fisheries Society, Bozeman,

Welker, T. 1997. Ecology and structure of fish communities in the Missouri and Lower Yellowstone rivers. Presented to the University of Idaho Faculty and Students Seminar. Moscow, Idaho.

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Ruggles, M. 1997. Benthic fish of the Yellowstone and Lower Missouri Rivers in Montana. Presented at the Upper basin pallid sturgeon working group. Miles City, Montana.

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Young, B 1997. Overview of the Benthic Fish Study - Objectives and Preliminary Results. Presented at the South Dakota Missouri River and Reservoir Management Conference, Brookings.

Berry, C. 1997. The Benthic fish study - an example of cooperative information management. Presented at the USGS Information Management Workshop, Sioux Falls, South Dakota.

Berry, C. 1997. The Status of the benthic fish study on the Missouri river. Presented at the Annual Meeting of the Missouri River Coalition, Sioux City, Iowa.

Pegg, M., and C. Pierce. 1997. Longitudinal age and growth comparison of Missouri River shovelnose sturgeon, Presented at the 59th Midwest Fish and Wildlife Conference, Milwaukee, Wisconsin.

Braaten, P., and C. Guy. 1997. Population structure and habitat use of benthic fishes along the Missouri

River and Lower Yellowstone Rivers. Presented at the 59th Midwest Fish and Wildlife Conference, Milwaukee, Wisconsin.

Dieterman, D., and D. Galat. 1997. Population structure and habitat use of benthic fishes along the Missouri River. Presented at the Missouri Forest, Fish and Wildlife Conference, Osage Beach, Missouri.

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Electronic Products for 1997

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1998

Oral Reports for 1998

Berry, C., and D. Galat. 1998. Large-scale studies: the Missouri river benthic fish example. Presented at the 2nd Annual Missouri River Conference, Nebraska City, Nebraska.

Baird, M., D. Dieterman, and D. Galat. 1998. Effects of seasonal variability and hoop net mesh size on fish population indices in the Missouri River, Missouri. Poster Presented at the 2nd Annual Conference on Natural Resources of the Missouri River, Nebraska City, Nebraska.

Bergstedt, L., D. Galat, and W. white. 1998. Development of an index of biotic integrity for measuring biological condition on the Missouri River. Poster at the International Conference on Ecological Integrity of Running Waters, Vienna, Austria.

Braaten, P., and C. Guy. 1998. Growth, mortality, and sources of freshwater drum larvae in the lower channelized Missouri River. 60th Midwest Fish and Wildlife Conference, Cincinnati, Ohio.

Braaten, P., M. Doeringsfeld, and C. Guy. 1998. Physiochemical determinants of fish abundance in tributary confluences of the lower channelized Missouri river. 24th Annual Forum for Student Research, KSU, Manhattan, Kansas.

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Galat, David. 1998. Accomplishments of the benthic fish study. Presented at the annual meeting of the Missouri River Natural Resources Conference.

Pegg, M., L. Coyle, and C. Pierce. 1998. Longitudinal age and growth comparison of Missouri River shovelnose sturgeon. Presented at the annual Meeting of the Iowa Chapter, American Fisheries Society, Ames, Iowa.

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Ruggles, M., and L. Bergstedt. 1998. Yellowstone River fish community, a reference condition for a large river index of biotic integrity. Presented at the 2nd Annual conference on Natural Resources of the Missouri River Basin, Nebraska City, Nebraska.

Schrank, S., P. Braaten, and C. Guy. 1998. Spatial and temporal abundance of bighead carp larvae in the channelized Missouri River, Poster at the 60th Midwest Fish and Wildlife Conference, Cincinnati, Ohio.

Wildhaber, M. L. 1998. Population structure and habitat use of benthic fishes along the Missouri and Lower Yellowstone Rivers. U.S. Geological Survey, Biological Resources Division, National program Review, Fisheries and Aquatic Resources Program, Madison, Wisconsin. (poster)

Young, B., R. Johnson, D. Dateo, and C. Berry. 1998. Integrating terrestrial, riparian, and riverine habitat and species assessments in South Dakota's Missouri River corridor. Presented at the 2nd Missouri River Natural Resources Conference, Nebraska City, Nebraska.

Young, B. 1998. A proposal: The study of the intraspecific variation among emerald shiners of the Missouri River. Presented at the SDSU Sigma Xi Ph.D Proposal Competition, Brookings, SD. (First Place Winner).

Young, B. A. 1998. Physical and ecological effects of dams - the Missouri River from 1940-2000. Presented at the Univ. Marii Curie-Sklodowskiej, Lubin, Poland.

Young, B. A. 1998. Intraspecific variation among vicariant populations of emerald shiners in response to Missouri River channel alterations. Presented to the Akademia Rolnicza, Katedra Hydrobiologii Ichtiobiologii, Lubin, Poland.

Written Reports for 1998

Young, B., T. Welker, M. Wildhaber, C. Berry, and D. Scarnecchia. Editors. 1998. Population structure and habitat use of benthic fishes along the Missouri and Lower Yellowstone Rivers. 1997 Annual Report of Missouri River Benthic Fish Study, Contract PD-95-5832 to the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation.

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1999

Oral Reports for 1999

Berry, C., and B. Young. Status of river fish communities in South Dakota and use of new information. Presented at the 61st Midwest Fish and Wildlife Conference. Chicago, Illinois.

Dieterman D., and D. Galat. 1999. Morphometric and meristic differences among Missouri River sicklefin chubs. Presented at the 3rd Annual Conference Conference on Natural Resources of the Missouri River, Pierre, South Dakota.

Braaten, P., and C. Guy. 1999. Growth, mortality, and sources of larval freshwater drum in the lower Missouri River. Paper presented at the 24th Ann. Meeting of the Kansas Chapter of the American Fisheries Society, Emporia.

Schrank, S., P. Braaten, and C. Guy. 1998. Spatial and temporal abundance of bighead carp larvae in the channelized Missouri River. Paper presented at the 24th Ann. Meeting of the Kansas Chapter of the American Fisheries Society, Emporia.

Young, B. A., T. Welker, and M. Wildhaber. 1999. Habitat use and catch rates of benthic fishes in the Missouri River. Presented at the 3rd Annual Missouri River Natural Resources Conference, Pierre, South Dakota.

Young, B., and C. Berry. 1999. Fishes of the Missouri National Recreational River, South Dakota and Nebraska. Poster presented at the 3rd Annual Missouri River Natural Resources Conference, Pierre, South Dakota.

2000

Oral Reports in 2000

Berry, C. 2000. Warm-water fish surveys in South Dakota, 1989-1999. Annual Meeting of the Dakota Chapter of the American Fisheries Society, Spearfish, South Dakota.

Berry, C. 2000. Wildlife and fisheries resources of the Missouri River. Special Lecture Series, The Missouri river Institute, Univ. of South Dakota, Vermillion.

Berry, C., and D. Galat. 2000. Status of the benthic fish community in the Missouri River. Presented at the 4th Missouri River natural Resources Conference, Bismarck, North Dakota.

Braaten, P., M. Pegg, C. Guy, and C. Pierce. 2000. Population dynamics of benthic fish in the Missouri and Lower Yellowstone Rivers. Presented at the Annual Meeting of the American Fisheries Society, St. Louis, Missouri.

Bergstedt, L., M. Pegg, C. Pierce, and R. White. 2000. Biological assessment for large rivers - examples and lessons from the Missouri and Lower Yellowstone rivers. Presented at the Annual Meeting of the American Fisheries Society, St. Louis, Missouri.

Bergstedt, L. and R. White. 2000. Current status of large river species of concern in the Missouri River and its major tributaries in Montana. Presented at Annual Meeting of the Western Division American Fisheries Society, Telluride, Colorado.

Pegg, M. A., C. Pierce, and A. Roy. 2000. Effects of channelization and impoundment on flow in the Missouri River: a time-series analysis (poster). Annual Meeting of the American Fisheries Society, St. Louis, Missouri.

Pegg, M. A., and C. Pierce. 2000. Latitudinal growth comparisons of selected Missouri River fishes. Annual Meeting of the Iowa Chapter, American Fisheries Society, Council Bluffs.

Galat, D. L., M. Wildhaber, and D. J. Dieterman. 2000. Physical habitat patterns at multiple spatial scales along the Missouri River, USA. International Symposium on Regulated Streams, France.

Wildhaber, M., P. Lamberson and D. Galat. Fish catch data in relation to large river bed form. Presented at the Annual Meeting of the American Fisheries Society, St. Louis, Missouri.

Young, B., and C. Berry. 2000. Intraspecific variation among emerald shiners of the Missouri River. Presented at the Annual meeting of the Society of Ichthyologists and Herpetologists. La Paz, Mexico.