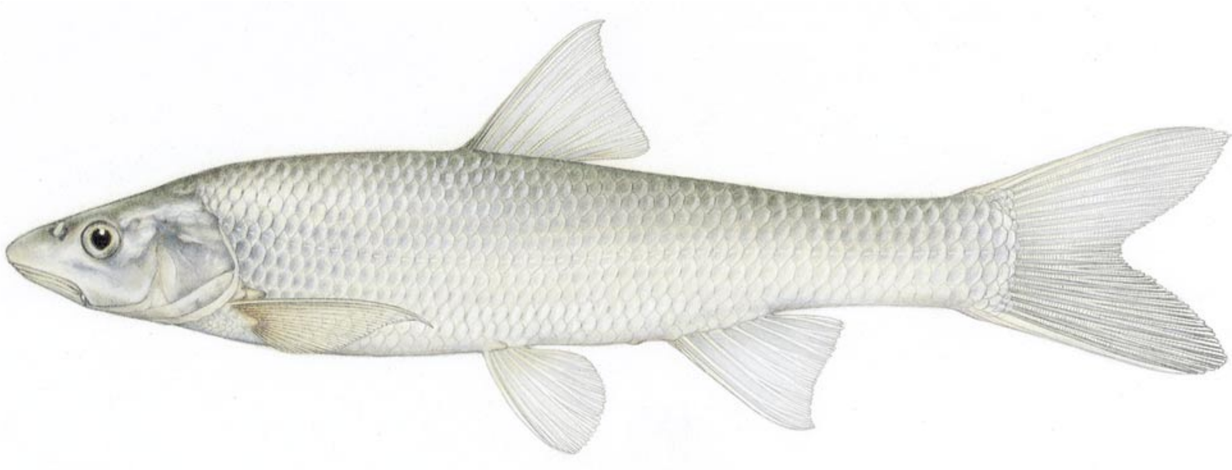
# Flathead Chub (*Platygobio gracilis*):
# A Technical Conservation Assessment



**Prepared for the USDA Forest Service,**
**Rocky Mountain Region,**
**Species Conservation Project**

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## ACKNOWLEDGEMENTS

We thank the many biologists from the states of Colorado, Kansas, Nebraska, South Dakota, and Wyoming, and from the national forests and grasslands within USFS Region 2 who provided information about flathead chub within their jurisdictions. We especially thank Gregory D. Hayward and Richard Vacirca of the USFS for their guidance in the writing of this species assessment. David B. McDonald of the University of Wyoming provided the population demographic matrix analysis.

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## COVER PHOTO CREDIT

# SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF FLATHEAD CHUB

## *Status*

The flathead chub (*Platygobio gracilis*) is not considered a federally threatened, endangered, or sensitive species in the United States, nor is it considered a state threatened, endangered, or sensitive species in Nebraska, South Dakota, or Wyoming. However, the flathead chub is listed as a state threatened species in Kansas and as a species of special concern in Colorado. In Region 2 of the USDA Forest Service, the flathead chub is present on the Comanche National Grassland, the Nebraska National Forest, the Oglala National Grassland, the Samuel R. McKelvie National Forest, the Buffalo Gap National Grassland, and the Thunder Basin National Grassland. The flathead chub is not considered a sensitive species by the USDA Forest Service in Region 2. Across its entire geographic distribution, the flathead chub is generally considered secure in the northern and western portion of its range but imperiled in the southern and eastern parts of its range including the states of Arkansas, Illinois, Kansas, Kentucky, Mississippi, Missouri, Oklahoma, and Texas.

## *Primary Threats*

The major threats to the flathead chub involve habitat alterations associated with the development and operation of reservoirs on large rivers. These include conversion of riverine habitat to standing water habitat via dams, reduction of turbidity, and fragmentation of once continuous rivers into small, free-flowing reaches isolated from other such reaches by dams and reservoirs. Dams cause a loss of connectivity in a drainage network that can exacerbate the loss of fish populations caused by drought, channel dewatering due to irrigation, or poor water quality. Reservoirs foster introductions of piscivorous sportfish that prey on flathead chubs. Reduced turbidity makes predators more effective and also favors sight-feeding fish species that compete with flathead chubs for food.

Other threats involve the presence of livestock, the use of groundwater, and the extraction of coalbed methane. Overgrazing by livestock can increase stream width, decrease depth, and increase the likelihood of streams becoming intermittent, and accumulation of animal wastes in pools in late summer can result in low oxygen and high ammonia concentrations that are detrimental to aquatic organisms. Groundwater removal for agriculture or municipal use can lower the water table to the point that formerly flowing streams become dry for much of the year. By contrast, extraction of coalbed methane can have the opposite effect by increasing streamflows or converting intermittent streams to permanent flow. However, conversion of intermittent streams to perennial ones could be detrimental to flathead chub if it allowed the establishment of nonnative fishes. Additionally, groundwater inputs could alter the thermal regime of surface waters, which in turn, could disrupt the breeding patterns of native fishes. Finally, water produced during coalbed methane extraction can be highly saline and may contain high concentrations of metals toxic to fish.

## *Primary Conservation Elements, Management Implications and Considerations*

The major management actions that would benefit native fishes characteristic of turbid prairie streams are preservation of natural streamflows and turbidity levels, maintenance of stream connectivity, and prevention of the establishment of nonnative predators and competitors. The decline in flathead chub populations is largely associated with the loss of habitat due to reservoir construction. Therefore, restoring natural flow regimes and turbidity levels would facilitate the recovery of this species. Given the high costs of large scale restoration efforts and the political difficulties involved in removing dams, maintaining the few remaining unimpounded turbid prairie rivers in a free-flowing state should be a conservation priority. Furthermore, maintaining such rivers in their naturally turbid state would benefit a suite of fish species that have declined following impoundment of prairie streams.

In some cases, reduction of livestock grazing may be necessary to restore habitat in prairie streams. Although fishes of Great Plains streams evolved in what are often severe environments, overgrazing by livestock can exacerbate naturally stressful conditions. This occurs when livestock trampling makes streams wide and shallow, causing increased intermittency and the loss of pools that serve as refuges during low flow periods. Also, manure from livestock can severely degrade water quality, especially during low flow conditions. Another important threat to prairie stream fishes, including flathead chub, is lowering of the water table to the point that streams stop flowing. The obvious management action would be to reduce the rate of groundwater removal so that groundwater aquifers can be recharged to the point that surface stream flows resume. Conversion of tributaries from intermittent to perennial flow regimes from coalbed methane extraction activities may result in the expansion of nonnative piscivores and/or creation of highly saline aquatic conditions. Here, management options may involve storing and treating water in separate facilities or monitoring species composition within those tributaries.

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# INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for the USDA Forest Service (USFS) Rocky Mountain Region (Region 2). The flathead chub (*Platygobio gracilis*) is the focus of an assessment because there was some level of concern for this species' viability within Region 2 (**Figure 1**) during the Regional Forester's Sensitive Species List revision process in 2001 to 2003 (www.fs.fed.us/r2/projects/scp/sensitivespecies/index.shtml). After full examination it was determined that the status of the flathead chub did not justify listing as a regional sensitive species. However, it was determined that viability may still be and issue at more localized levels within Region 2. This assessment addresses the biology and ecology of flathead chub throughout its range in Region 2. This introduction defines the goal of the assessment, outlines its scope, and describes the process used in its production.

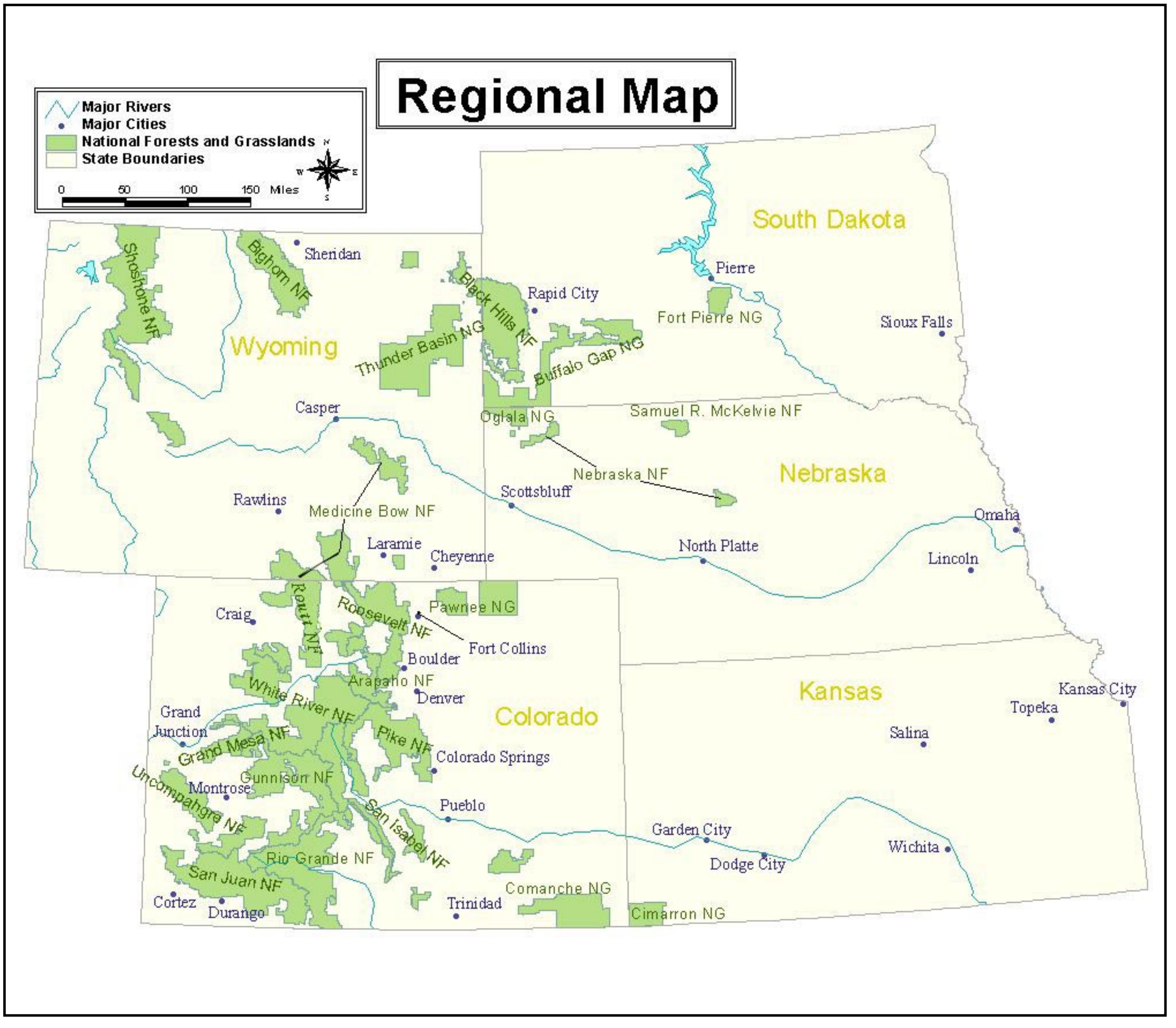


**Figure 1.** National Forests and Grasslands within the Rocky Mountain Region (Region 2) of the USDA Forest Service.

### *Goal of Assessment*

Species conservation assessments produced as part of the Species Conservation Project are designed to provide forest managers, research biologists, and the public with a thorough discussion of the biology, ecology, conservation status, and management of certain species based on available scientific knowledge. The assessment goals limit the scope of the work to critical summaries of scientific knowledge, discussion of broad implications of that knowledge, and outlines of information needs. The assessment does not seek to develop specific management recommendations, but instead it provides the ecological background upon which management must be based. However, it does focus on the consequences of changes in the environment that result from management (i.e. management implications). Furthermore, it cites management recommendations proposed elsewhere and, when management recommendations have been implemented, the assessment examines the success of the implementation.

### *Scope of Assessment*

The flathead chub assessment examines the biology, ecology, conservation status, and management of this species with specific reference to the geographic and ecological characteristics of Region 2 (**Figure 1**). Although some of the literature on the species originates from field investigations outside the region, this document places that literature in the ecological and social context of the central Rockies. Similarly, this assessment is concerned with the reproductive behavior, population dynamics, and other characteristics of flathead chub in the context of the current environment rather than under historical conditions. The evolutionary environment of the species is considered in conducting the synthesis but in a current context.

In producing the assessment, we reviewed refereed literature, non-refereed publications, research reports, and data accumulated by resource management agencies. Not all publications on flathead chub are referenced in the assessment, nor were all published materials considered equally reliable. The assessment emphasizes refereed literature because this is the accepted standard in science. We did use some non-refereed literature in the assessments, however, when information was unavailable elsewhere. Unpublished data (e.g., Natural Heritage Program records) were important in estimating the geographic distribution. These data required special attention because of the diversity of persons and methods used in their collection.

### *Treatment of Uncertainty*

Science represents a rigorous, systematic approach to obtaining knowledge. Competing ideas regarding how the world works are measured against observations. However, our descriptions of the world are always incomplete and our observations are limited, science focuses on approaches for dealing with uncertainty. A commonly accepted approach to science is based on a progression of critical experiments to develop strong inference (Platt 1964). However, it is difficult to conduct experiments that produce clean results in the ecological sciences. Often, we must rely on observations, inference, good thinking, and models to guide our understanding of ecological relations. In this assessment, we note the strength of evidence for particular ideas, and we describe alternative explanations where appropriate.

Information about the biology of flathead chub was collected and summarized from throughout its geographic range, which extends from the Mackenzie River in northwestern Canada southward into the lower Mississippi River drainage. In general, life history and ecological information collected in a portion of this range should apply broadly throughout the range. However, certain life history parameters such as growth, rate, longevity, and spawning activity could differ along environmental gradients, especially those related to length of growing season. Information about the species' conservation status was limited to USFS Region 2 and should not be taken to imply conservation status in other portions of its range.

### *Publication of the Assessment on the World Wide Web*

To facilitate use of species assessments in the Species Conservation Project, they are being published on the Region 2 World Wide Web site (www.fs.fed.us/r2/projects/scp/assessments/index.shtml). Placing the documents on the Web makes them available to agency biologists and the public more rapidly than publishing them as reports. More important, it facilitates their revision, which will be accomplished based on guidelines established by Region 2.

### *Peer Review*

Assessments developed for the Species Conservation Process have been peer reviewed prior to release on the Web. Peer review for this assessment was administered by the American Fisheries Society, employing at least two recognized experts for this or related taxa. Peer review was designed to improve the quality of communication and to increase the rigor of the assessment.

## Management Status and Natural History

### *Management Status*

The flathead chub is not considered a federally threatened, endangered, or sensitive species in the United States according to the U.S. Fish and Wildlife Service (http://endangered.fws.gov/), and it has a Global Heritage Status Rank of G5 (secure status) from the Nature Conservancy (http://natureserve.org/explorer). Within USFS Region 2, the flathead chub has received various conservation designations by federal and state management agencies, and non-governmental conservation organizations. The definitions of these conservation designations can be found on the various Web sites cited below and in **Table 1**. At the state level, the flathead chub is not considered a state threatened, endangered, or sensitive species in Nebraska, South Dakota, or Wyoming. However, the flathead chub is listed as a state threatened species in Kansas. In Colorado, the flathead chub is not listed as a state endangered or threatened species, but it is listed as a species of special concern. However, this is not considered a statutory category in Colorado. The flathead chub is considered a "restricted use species" according to Colorado state fishing regulations which means it is illegal to possess or harvest this species for private or commercial use. The Natural Heritage Rank for this species is S5 (secure) in four states, with a S1 (critically imperiled) ranking in only one state, Kansas.

In USFS Region 2, the flathead chub is present on the Comanche National Grassland, the Nebraska National Forest, the Oglala National Grassland, the Samuel R. McKelvie National Forest, the Buffalo Gap National Grassland, and the Thunder Basin National Grassland. In all of these locations, the flathead chub is not considered a sensitive species by the USFS (**Table 2**). The flathead chub was reported as present on several management units of the Bureau of Land Management in Colorado where it is on the state sensitive species list (**Table 3**). In Wyoming, the flathead chub is not on the sensitive species list of the Bureau of Land Management's State Director's office. We were unable to obtain information on the conservation status of flathead chub for Bureau of Land Management lands in Nebraska or South Dakota. In Kansas, the Bureau of Land Management manages only subsurface waters.

**Table 1.** Occurrence and management status of flathead chub in the five states comprising Region 2 of the USDA Forest Service.

| State | Occurrence | State Status | References | State Heritage Status Rank* |
|---|---|---|---|---|
| Colorado | present | SC = Special Concern | Colorado Division of Wildlife, wildlife.state.co.us | S5 = Secure |
| Kansas | present | Threatened | Kansas Department of Wildlife and Parks, www.kbs.ukans.edu | S1 = Critically Imperiled |
| Nebraska | present | Not listed as Threatened or Endangered | Nebraska Game and Parks Commission, www.ngpc.state.ne.us | S5 = Secure |
| South Dakota | present | S5 = Secure | South Dakota Department of Game, Fish and Parks, www.state.sd.us/gfp/Diversity/index.htm | S5 = Secure |
| Wyoming | present | NSS3 = populations widely distributed and stable, but habitat declining or vulnerable | Wyoming Game and Fish Department, gf.state.wy.us | S5 = Secure |

* State Heritage Status Rank is the status of flathead chub populations within states based on the conservation status ranking system developed by NatureServe, The Nature Conservancy and the Natural Heritage Network, www.natureserve.org.

**Table 2.** Occurrence and status of flathead chub in national forests and grasslands within Region 2 of the USDA Forest Service.

| Management Unit (State) | Occurrence | Information Source | ESA/USFS Status | Basis of Status |
|---|---|---|---|---|
| Arapaho National Forest (CO) | Absent | Arapaho-Roosevelt National Forests and Pawnee National Grassland Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 |
| Comanche National Grassland (CO) | Present | Nesler et al. 1999. Inventory and Status of Arkansas River Native Fishes in Colorado. Aquatic Wildlife Section, Colorado Division of Wildlife, Colorado Springs, CO. | Not T, E, or S | Threatened, Endangered and Sensitive Species of the Pike and San Isabel National Forests and Comanche and Cimarron National Grasslands, May 25 1994. * |
| Grand Mesa National Forest (CO) | Absent | Grand Mesa, Uncompahgre, and Gunnison National Forests Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 |
| Gunnison National Forest (CO) | Absent | Grand Mesa, Uncompahgre, and Gunnison National Forests Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 |
| Pawnee National Grassland (CO) | Absent | Arapaho-Roosevelt National Forests and Pawnee National Grassland Supervisor's Office | Not T, E, or S | Matrix of "Listed" Species in the Great Plains of North America and their Occurrence on National Grasslands** |
| Pike National Forest (CO) | Absent | Pike and San Isabel National Forest and Comanche and Cimarron National Grassland Supervisor's Office | Not T, E, or S | Threatened, Endangered and Sensitive Species of the Pike and San Isabel National Forests and Comanche and Cimarron National Grasslands, May 25 1994. |
| Rio Grande National Forest (CO) | Absent | Rio Grande National Forest Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 |
| Roosevelt National Forest (CO) | Absent | Arapaho-Roosevelt National Forests and Pawnee National Grassland Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 |
| Routt National Forest (CO) | Absent | Medicine Bow-Routt National Forest and Thunder Basin National Grassland Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 |
| San Isabel National Forest (CO) | Absent | Pike and San Isabel National Forest and Comanche and Cimarron National Grassland Supervisor's Office | Not T, E, or S | Threatened, Endangered and Sensitive Species of the Pike and San Isabel National Forests and Comanche and Cimarron National Grasslands, May 25 1994. |
| San Juan National Forest (CO) | Absent | San Juan National Forest Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 |
| Uncompahgre National Forest (CO) | Absent | Grand Mesa, Uncompahgre, and Gunnison National Forests Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 |
| White River National Forest (CO) | Absent | White River National Forest Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 |
| Cimarron National Grassland (KS) | Absent | Pike and San Isabel National Forest and Comanche and Cimarron National Grassland Supervisor's Office. Most recent surveys did not find flathead chubs: 1998 Cimarron River Fishes Survey (www.fs.fed.us/r2/nebraska/gpng/tes_projects/fishreport.html). No record of species collection since 1964 | Not T, E, or S | Threatened, Endangered and Sensitive Species of the Pike and San Isabel National Forests and Comanche and Cimarron National Grasslands, May 25 1994. |
| Nebraska National Forest (NE) | Present | 1998 and 1996 Nebraska Department of Environmental Quality, Fisheries surveys. Copies of fisheries surveys on USFS land acquired from Nebraska National Forest Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 |

**Table 2 (concluded).**

| Management Unit (State) | Occurrence | Information Source | ESA/USFS Status | Basis of Status |
|---|---|---|---|---|
| Ogalala National Grassland (NE) | Present | Nebraska National Forest Supervisor's Office | Not T, E, or S | Matrix of "Listed" Species in the Great Plains of North America and their Occurrence on National Grasslands |
| Samuel R. McKelvie National Forest (NE) | Present | 1998, 1996, 1995 and 1994 Nebraska Department of Environmental Quality, Fisheries surveys. Copies of fisheries surveys on USFS land acquired from Nebraska National Forest Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 |
| Black Hills National Forest (SD) | Unknown but likely present | Black Hills National Forest Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 |
| Buffalo Gap National Grassland (SD) | Present | Buffalo Gap National Grassland, Wall and Fall River Ranger Districts and Nebraska National Forests Supervisor's Office | Not T, E, or S | Matrix of "Listed" Species in the Great Plains of North America and their Occurrence on National Grasslands |
| Fort Pierre National Grassland (SD) | Absent | Fort Pierre National Grassland, District Office and Nebraska National Forests Supervisor's Office | Not T, E, or S | Matrix of "Listed" Species in the Great Plains of North America and their Occurrence on National Grasslands |
| Bighorn National Forest (WY) | Absent | Bighorn National Forest Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 and U.S. Fish and Wildlife Service County Lists |
| Medicine Bow National Forest (WY) | Absent | Medicine Bow-Routt National Forest and Thunder Basin National Grassland Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 and U.S. Fish and Wildlife Service County Lists |
| Shoshone National Forest (WY) | Absent | Shoshone National Forest Supervisor's Office | Not T, E, or S | Regional Forester's Sensitive Species List, USDA Forest Service, Rocky Mountain Region, 2003 |
| Thunder Basin National Grassland (WY) | Present | Medicine Bow-Routt National Forest and Thunder Basin National Grassland Supervisor's Office | Not T, E, or S | Matrix of "Listed" Species in the Great Plains of North America and their Occurrence on National Grasslands |

*Threatened, Endangered and Sensitive Species of the Pike & San Isabel National Forests and Comanche & Cimarron National Grasslands, May 25 1994. Compiled by Nancy Ryke, Forest Wildlife Biologist; David Winters, Fish and Wildlife Program Manager; Louanne McMartin, Biological Technician; Steve Vest, Forest Botanist; Barb Masinton Forest Botanist, Version 12.19.01

**Matrix of "Listed" Species in the Great Plains of North America and their Occurrence on National Grasslands, www.fs.fed.us/r2/nebraska/gpng/matrix/fish.html

**Table 3.** Occurrence and status of flathead chub on Bureau of Land Management (BLM) lands within Region 2 of the USDA Forest Service.

| State | BLM Status | Management Unit Field Office | Occurrence | Basis of Status and Occurrence |
|---|---|---|---|---|
| Colorado | Sensitive | Glenwood Springs | Absent | BLM Colorado State Director's Sensitive Species List |
| | | Grand Junction | Absent | BLM Colorado State Director's Sensitive Species List |
| | | Gunnison | Absent | BLM Colorado State Director's Sensitive Species List |
| | | Kremmling | Absent | BLM Colorado State Director's Sensitive Species List |
| | | La Jara | Present | BLM Colorado State Director's Sensitive Species List |
| | | Little Snake | Absent | BLM Colorado State Director's Sensitive Species List |
| | | Royal Gorge | Present | BLM Colorado State Director's Sensitive Species List |
| | | Saguache | Present | BLM Colorado State Director's Sensitive Species List |
| | | San Juan | Absent | BLM Colorado State Director's Sensitive Species List |
| | | Uncompahgre | Absent | BLM Colorado State Director's Sensitive Species List |
| | | White River | Present | BLM Colorado State Director's Sensitive Species List |

In Wyoming the flathead chub is not listed a sensitive species by the BLM Wyoming State Director's Office. Information for flathead chub on BLM lands in Nebraska and South Dakota was unavailable. The BLM manages only subsurface waters in Kansas.

Across its entire geographic distribution, the flathead chub is generally considered secure (U.S. and Canada Heritage Rank of the Nature Conservancy of S5) in the northern and western portions of its range (http://natureserve.org/explorer). However, the species is considered imperiled or critically imperiled (Natural Heritage Rank of S2 or S1, respectively) in the southern and eastern parts of its range including the states of Arkansas, Illinois, Kansas, Kentucky, Mississippi, Missouri, Oklahoma, and Texas.

## *Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies*

Regulatory mechanisms regarding the harvest or possession of flathead chub vary among the five states within USFS Region 2. The species is not exploited as a gamefish but may be occasionally collected by anglers for use as bait. In Colorado, the flathead chub is classified as a "restricted use species", which means that it is illegal to possess or harvest this species for private or commercial use (Colorado Division of Wildlife; http://wildlife.state.co.us). In Kansas, the flathead chub is considered to be a state threatened species, and thus it is illegal to collect this species for bait (Kansas Department of Wildlife and Parks; www.kdwp.state.ks.us). Additionally, Kansas Administrative Regulation 115-15-3 provides protection for critical habitats of state threatened and endangered species that will be impacted by projects such as highway construction, flood control structures, or pipelines (www.kdwp.state.ks.us/PDF/EnvSrvs/docs/permitpckt.pdf). Developers are required to incorporate mitigating or compensating measures to ensure protection of critical habitats or listed species in the development plans before they can obtain a construction permit from the Kansas Department of Wildlife and Parks.

In the remaining three states of Region 2, harvest of flathead chub is regulated by the general regulations for baitfish harvest in each state. In Nebraska, a general fishing license is required to collect baitfish for personal use with the bag and possession limits both set at 100 fish (Nebraska Game and Parks Commission; http://www.ngpc.state.ne.us). Additionally, baitfish cannot be collected from lakes or reservoirs, and a separate license is required for commercial baitfish collection. In Wyoming, a separate license (other than a general fishing license) is required to collect baitfish and certain drainages are closed to baitfish collecting, but there is no limit to the number of baitfish that can be collected (Wyoming Game and Fish Department; http://gf.state.wy.us). In South Dakota a general fishing license is required to harvest baitfish, the catch limit is twelve dozen, and there are few restrictions regarding where baitfish may be collected (South Dakota Department of Game, Fish and Parks; http://www.state.sd.us/gfp).

We found no state or federal management plans or conservation strategies targeting the flathead chub within Region 2 of the USFS.

## *Biology and Ecology*

### Systematics and species description

The flathead chub (*Platygobio gracilis*) is in the class Osteichthyes, superorder Teleostei, order Cypriniformes, and family Cyprinidae. The Cyprinidae is the largest family of freshwater fishes in the world with at least 286 species in North America (Moyle and Cech 2000). Commonly referred to as minnows, most cyprinids are small fish, but the family includes a number of large species that can reach over 2 m (6.6 ft) in length.

The flathead chub was first described in 1836 from the Saskatchewan River by Richardson as *Cyprinus* (*Leuciscus*) *gracilis* (McPhail and Lindsey 1970). In 1856, Girard described the flathead chub as *Pogonichthys communis*, from a Missouri River collection (Bailey and Allum 1962). In 1896 Jordan and Evermann distinguished the genus *Platygobio* from *Hybopsis* on the basis of pharyngeal tooth counts (McPhail and Lindsey 1970). *Platygobio gracilis* was used as the scientific name for the next several decades until 1951 when Bailey merged several genera, including *Platygobio* into the genus *Hybopsis* (Dimmick 1993). In 1989 the genus *Platygobio* was restored (Mayden 1989). The redesignation of flathead chub as *Platygobio gracilis* has since been supported by several researchers (e.g., Coburn and Cavender 1992, Dimmick 1993).

A number of workers have recognized two subspecies of flathead chub. Simon (1946) recognized *Platygobio gracilis* communis found in northern Wyoming and *P. gracilis gulonellus* found in the North Platte drainage of Wyoming (discussed in Baxter and Stone 1995). Olund and Cross (1961) determined that there were two subspecies based on different morphological and anatomical characteristics, including body size and shape, fin shape and ray number, number of scales, and vertebral counts. They designated *Hybopsis gracilis gracilis* in the Missouri River drainages as the northern subspecies typically inhabiting large rivers and *H. gracilis gulonella* in the Arkansas and Rio Grande river drainages as the southern subspecies characteristically associated with small streams. They also suggested that an intergrade of the two forms occupied the large region in the middle of the species' range from eastern Kansas to northern Montana. Bailey and Allum (1962) disagreed with the suggestion that the morphological variation among flathead chub populations was due to genetic differentiation and did not recognize the subspecies designation. They instead proposed that environmental variation throughout the range of flathead chubs, particularly temperature regime during development, caused geographic differences in morphological characteristics.

Flathead chubs are elongate, streamlined minnows with broad, flattened heads that appear wedge-shaped in profile (Cross and Collins 1975, Woodling 1985, Baxter and Stone 1995, Pflieger 1997). They have large, sub-terminal mouths with well-developed barbels (Scott and Crossman 1973, Cross and Collins 1975, Woodling 1985, Baxter and Stone 1995, Pflieger 1997). The snout is relatively pointed and flattened and extends beyond the upper jaw. Flathead chubs have small eyes with the eye diameter much less than snout length (Scott and Crossman 1973, Pflieger 1997). The pectoral fins are long and sickle-shaped. The dorsal fin is falcate with eight, rarely seven fin rays (Scott and Crossman 1973, Baxter and Stone 1995), and its origin is slightly anterior to the origin of the pelvic fins. The caudal fin is deeply forked with pointed lobes. The anal fin also has eight rays and a falcate trailing edge. The anal and pelvic fins have compound taste buds in the inter-radial spaces (Baxter and Stone 1995). A distinct, slightly decurved lateral line is evident externally. The scales are cycloid and large, and the number of scales in the lateral line ranges from 44 to 56 for populations in the United States (Woodling 1985, Baxter and Stone 1995, Pflieger 1997) and from 50 to 58 for Canadian populations (Scott and Crossman 1973).

The color of adult fish can be light brown, dusky olive, or black above with silvery sides and stomachs. Flathead chubs have no distinctive markings (Cross and Collins 1975, Woodling 1985, Baxter and Stone 1995, Pflieger 1997). All fins are clear although the lower lobe of the caudal fin is slightly darker than the upper lobe (Scott and Crossman 1973, Pflieger 1997). Adult flathead chubs can reach 26 cm (10 inches) in length (Fisher et al. 2002), but they generally range from 9 to 18 cm (3.5 to 7 inches) (Cross and Collins 1975, Woodling 1985, Neumann and Willis 1994, Baxter and Stone 1995, Pflieger 1997).

There appears to be little or no sexual dimorphism in flathead chubs. Breeding males exhibit no special colors. McPhail and Lindsey (1970) suggested that the pectoral fins of males were longer than those of females of a similar size; however, they also noted that the relative lengths of pectoral fins varied considerably with fish size. Small breeding tubercles on the upper surfaces of the head and body and all fins, except the caudal fin, have been reported for breeding males (McPhail and Lindsey 1970, Scott and Crossman 1973, Pflieger 1997); however, their utility as an indictor of sex is questionable. McPhail and Lindsey (1970) noted the presence of tubercles on females, but indicated that they were restricted to the head region or only weakly developed elsewhere. However, Gould (1985) reported finding small tubercles on males, females, and immature fish of both sexes as early as March and as late as November in Montana, indicating that the presence of tubercles is not restricted to the breeding season, mature fish, or males.

## Distribution and abundance

Flathead chubs have a wide native distribution in the central region of North America, occurring in the four major river systems that flow eastward from the continental divide; the Mackenzie, Saskatchewan, Missouri-Mississippi, and Rio Grande (**Figure 2** adapted from Lee et al. 1980). The extensive range of flathead chubs includes the Northwest Territory of Canada south to New Mexico, Texas, and Louisiana (Mayden 1989). In the United States, flathead chubs occur in the western drainages of the Mississippi River bounded by the Rocky Mountains to the west. Flathead chubs are not frequently found in the mainstem of the Mississippi River north of the confluence of the Missouri River; however, flathead chub populations south of Illinois are restricted mainly to the mainstem of the Mississippi River (Pflieger 1997).

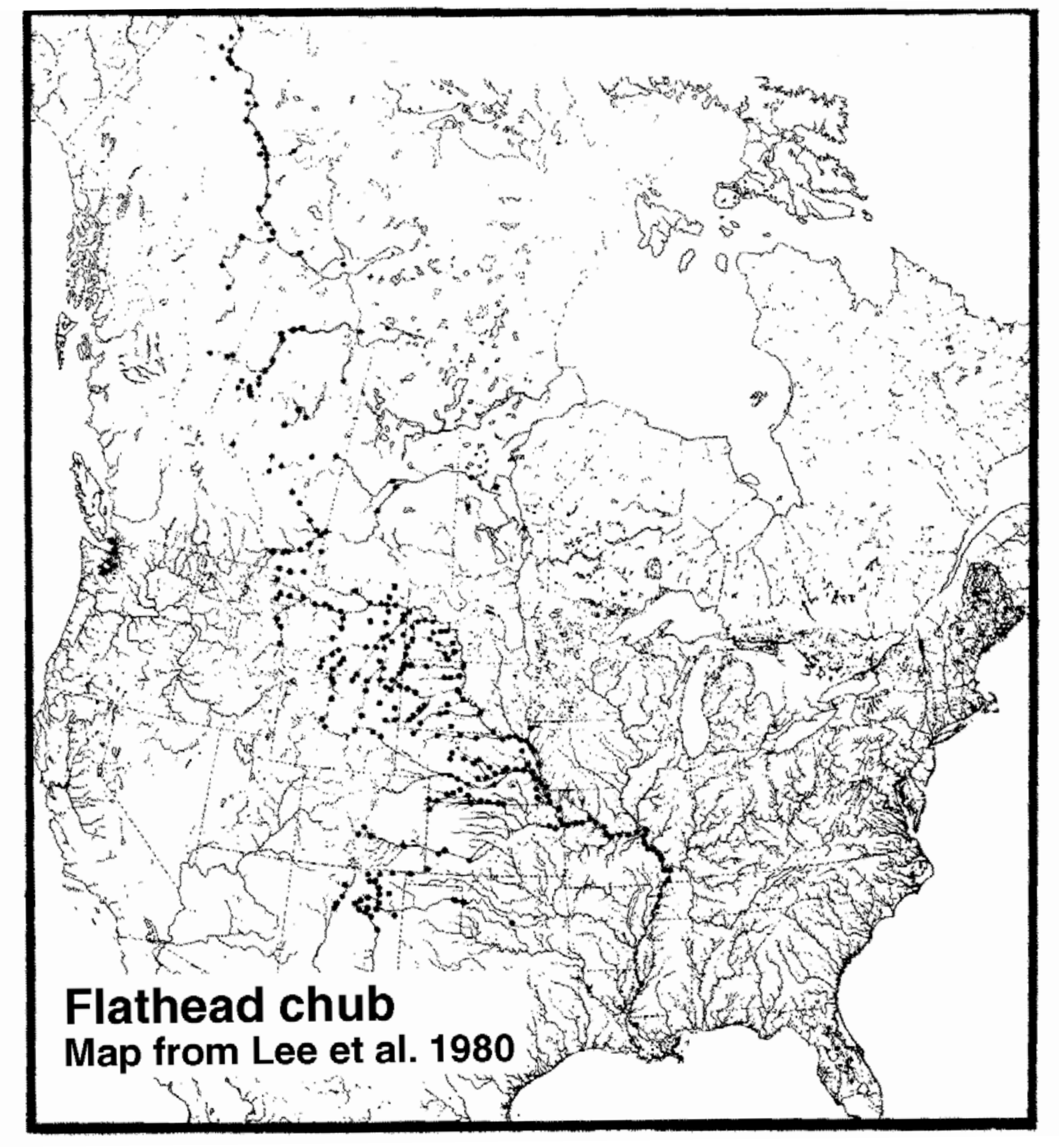


**Figure 2.** Distribution of flathead chubs in North America. They occur in the four major river systems that flow eastward from the continental divide: the Mackenzie, Saskatchewan, Missouri-Mississippi, and Rio Grande rivers. Their geographic range includes the Northwest Territory of Canada, south to New Mexico Texas, and Louisiana. Details of their distribution within Region 2 of the USDA Forest Service are given in **Figure 3**.

Flathead chubs were introduced, via bait bucket release, into the Gila River drainage of New Mexico, but they did not become established (Sublette et al. 1990). Simon (1946) reported the collection of three specimens from the Snake River, also likely transferred by fisherman, but there have been no recent collections to indicate that they became established. No other reports were found indicating the establishment of flathead chub populations outside of their historic range.

In Colorado, flathead chubs occur in the Arkansas and the Rio Grande rivers in the southern part of the state (**Figure 3**). Flathead chubs historically occurred in the Arkansas River up to Salida, Colorado, but specimens have not been collected recently upstream of a large diversion on the Arkansas River near Florence, Colorado (Woodling 1985). Woodling (1985) did not list this species as occurring in the Rio Grande River, but recent surveys have documented the occurrence of flathead chub in this river (Alves 1997). It is unclear if this species was simply missed in earlier surveys or has recently expanded its range into this portion of the Rio Grande River.

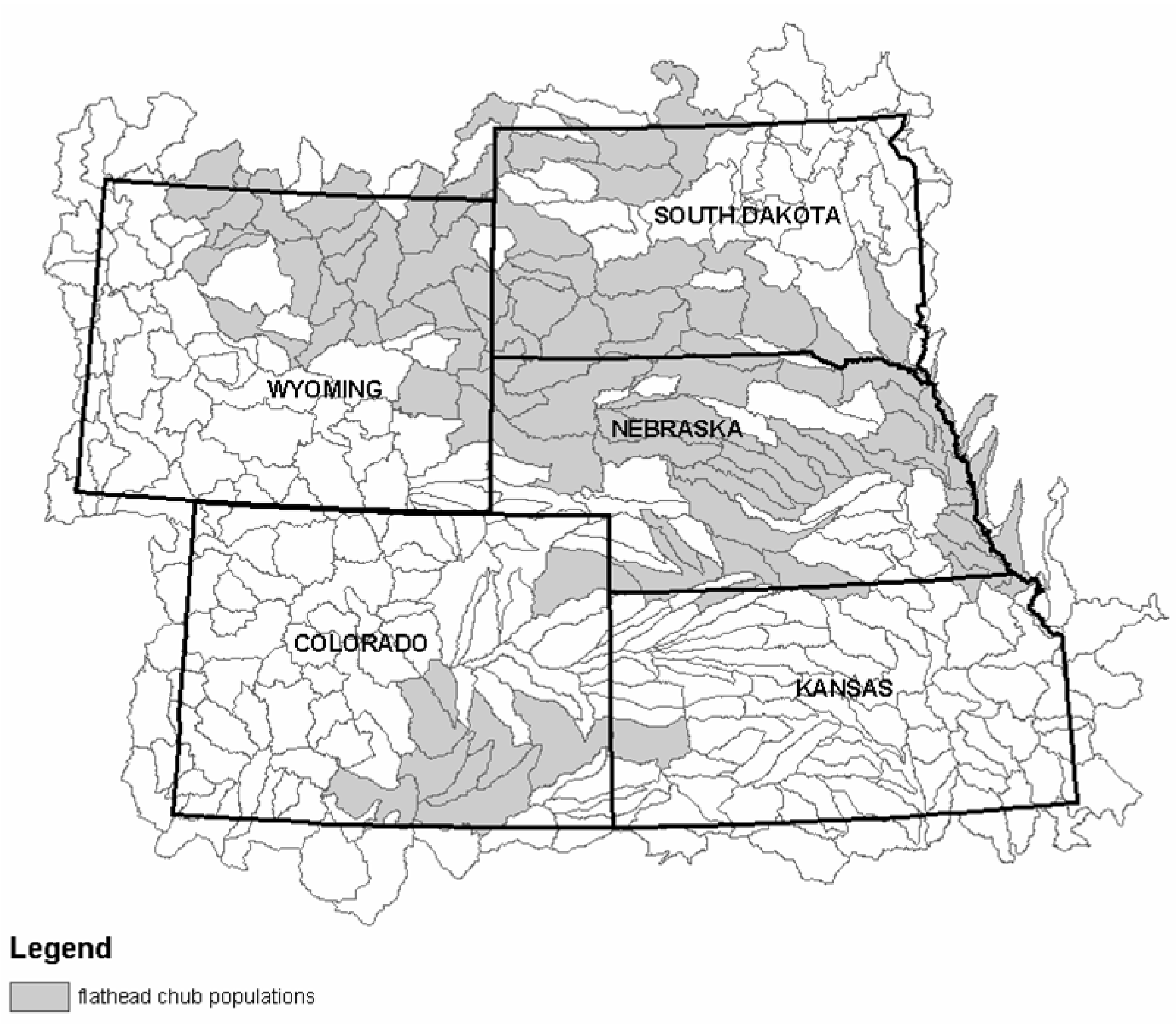


**Figure 3.** Distribution of flathead chub by hydrologic units (HUB 4 level) within the Rocky Mountain Region (Region 2) of the USDA Forest Service. Data sources are given in **Appendix B**.

In Kansas, flathead chubs historically occurred in parts of the Arkansas, Cimarron, Nemaha, and Republican rivers in the west and in the mainstems of the Missouri and Kansas rivers in the eastern part of the state (Cross and Collins 1995). Flathead chub populations have declined throughout the major rivers of Kansas and are listed as a threatened species in Kansas (Cross and Collins 1995). Flathead chubs have not been collected during the Kansas Stream Monitoring Program that began in 1994. However, the lone exception involved the collection of two flathead chubs in the Arkansas River at the Colorado/Kansas border in August of 2002 (**Figure 3**; Hase personal communication 2002).

In Nebraska, flathead chubs most commonly occurred in large rivers such as the Missouri, Platte, Republican, Elkhorn, and Niobrara (Morris et al. 1974, Bouc 1987). Since the late 1930's flathead chub abundance has declined in Nebraska (Hesse 1994) although it still occurs throughout the state (**Figure 3**). In the 1930's flathead chubs were ranked as the 9$^{th}$ most common species, however in the 1990's this rank had fallen to 22$^{nd}$ (Schainost personal communication 2002).

In South Dakota, flathead chubs were common and characterized as the dominant minnow species in the western tributary rivers and larger streams of the Missouri River (Bailey and Allum 1962, Neumann and Willis 1994). To the north and east of the Missouri River, flathead chubs occurred only in the lower portions of larger tributaries (Bailey and Allum 1962). Currently flathead chubs continue to be considered common in the rivers and larger streams of western South Dakota (**Figure 3**; Backlund personal communication 2002). Recent surveys found flathead chubs to be common in the Moreau River (Loomis 1997), the Cheyenne River (Hampton 1998), and the Belle Fourche River (Doorenbos 1998).

In Wyoming, flathead chubs are widely distributed in the rivers of the northeast part of the state, including the Big Horn, Tongue, Powder, Little Powder, Belle Fourche, and Cheyenne river systems (**Figure 3**; Weitzel 2002). Historically, flathead chubs were present in the North Platte and Little Missouri rivers in Wyoming. There has been concern that this species may have been extirpated from these systems because they were not collected in a survey of nongame fishes by Patton (1997). However, in 1996, seven adult specimens were captured in the North Platte River near Douglas by the Wyoming Game and Fish Department indicating that this species remains present in low numbers in this drainage (Wyoming Game and Fish Department 1997).

### Population trends (local, regional, and range wide)

At the local level, there have been no intensive monitoring studies tracking the population trends of flathead chub. The assessments of the population status of this species have been based on synoptic surveys usually taken at widely separated points in time. At the regional level, three such assessments have commented on trends in the occurrence of flathead chub. In Wyoming, Patton (1997) sampled fish populations at 42 stream sites that had been previously surveyed in the 1960's. The number of sites with flathead chub decreased from 22 to 17, suggesting that this species was declining within the Missouri River drainage of Wyoming. It should be noted, however, that comparisons of recent and historical survey data can be complicated by changes in sampling methodology. For example, the 1960's survey in Wyoming involved the use of seines to collect fish. The 1990's survey used seines but also included electrofishing, which is known to be a more effective sampling method for stream fishes. Even when Patton et al. (1998) adjusted their data to account for the increased efficiency of the 1990's sampling, the information still reflected that flathead chub had a decrease in distribution within Wyoming.

In Colorado, flathead chub is considered to be either common or abundant and at a relatively low risk of imperilment in the Arkansas River drainage based on a survey done from 1992 to 1994 (Nesler et al. 1999). In part, this assessment was based on comparison with flathead chub distributions from earlier surveys between 1875 and 1981. The only area of concern was in the lower main stem Arkansas River below John Martin Reservoir, where flathead chubs were uncommon. Nesler et al. (1999) recommended that the causes for the scarcity of flathead chub in this section of the river be investigated. Although past accounts of Colorado's fish fauna did not consider the flathead chub to be present in the Rio Grande drainage within the state (Woodling 1985), it has been collected in the mainstem of the Rio Grande River recently near the New Mexico border (Alves 1997). Whether the species has expanded its range upstream in the Rio Grande River or whether the species was present but not collected in earlier surveys is not known.

In Nebraska, flathead chubs are considered to be declining. Johnson (1942) found flathead chub to be present in 23 percent of all samples in a statewide survey and the 9th most common species. In the 1990's, it was present in 10 percent of all samples and had fallen to the 22nd most common species (Schainost personal communication 2002).

The Platte River Basin Native Fishes Work Group (1999) compared fish species distributions pre-1980 to post-1980 and concluded that the flathead chub was a "species of concern" for the Platte River basin in Wyoming, Colorado, and Nebraska. This groups finding has not changed these states current heritage status designations. Population trend data were not found for Kansas or South Dakota.

Outside of USFS Region 2, flathead chub are generally considered to be secure in the northern portion of their range where Natural Heritage Rank status of the Nature Conservancy is S4 or S5 (Montana, Alberta, British Columbia, Manitoba, Saskatchewan). However, flathead chub are declining and considered imperiled in the southern portion of their range where this species has a Natural Heritage Rank of S1 or S2 (Arkansas, Illinois, Kentucky, Mississippi, Missouri, Oklahoma, Texas). This decline has been especially well documented in the lower Missouri River (Gelwicks et al. 1996, Grady and Milligan 1998). An exception to this trend in the south is New Mexico where flathead chub has a Natural Heritage Rank of S4 (http://www.natureserve.org/explorer).

### Activity patterns

Flathead chubs are thought to be an active species, but there have been no quantitative studies of movement patterns. Pflieger (1997) describes flathead chubs as "active, moving about constantly, often in mixed schools with other big-river minnows." Olund and Cross (1961) noted that flathead chubs in the Purgatoire River in Colorado congregated in loose groups near the bottom of pools in association with cover such as tree roots, aquatic plants, or woody debris. Individuals in the groups moved around independently, no schooling behavior was observed, with fish rising occasionally, possibly for food (Olund and Cross 1961).

The daily activity patterns of flathead chubs could be elucidated by their feeding habits; however, the feeding behavior of flathead chubs is poorly understood. Flathead chubs have several chemosensory organs, barbels, and external taste buds that are thought to enhance their feeding ability in turbid waters (Baxter and Stone 1995, Pflieger 1997). Bonner (2000) found that the feeding efficacy of flathead chubs decreased slightly, but not significantly with increased turbidity. Davis and Miller (1967) indicated that flathead chubs could sight feed effectively on surface-drifting insects even in turbid conditions if light was sufficient to penetrate the first few centimeters of water. Therefore it is probable that flathead chubs are more active during daylight hours. There is not enough information about the species to suggest specific diel activity cycles, such as a crepuscular feeding habit.

Smith and Hubert (1989) studied fish movements and spawning in the Powder River and one of its tributaries, Crazy Woman Creek, in Wyoming and Montana. Unfortunately the researchers were unable to describe temporal trends in movement patterns of flathead chubs because insufficient numbers were collected for the mark-recapture portion of the study. However, they did find large enough numbers of adult flathead chubs and juveniles to conclude that flathead chubs were residents of both the river and the tributary stream. In fact, flathead chubs were the predominant species captured in minnow traps at all sampled sites on Crazy Woman Creek from late June through early August. Flathead chubs were the most abundant fish larvae in drift samples collected at the mouth of the tributary, but there was no diel pattern in drift abundance (i.e., drift did not increase through the evening for flathead chubs as it did for some other species).

Spawning has not been described for this species, and it is unknown if flathead chubs make spawning migrations. Olund and Cross (1961) suggested that flathead chubs migrate into smaller streams to spawn and reference several instances where flathead chubs were only caught in tributaries of large rivers during the breeding season. Flathead chub use of refugia in high or low flows or during winter is unknown

### Habitat

Flathead chubs are associated with turbid rivers and their larger tributaries. In rivers, flathead chubs are most commonly found in fast water habitats having predominately small substrates such as sand and gravel (Woodling 1985, Baxter and Stone 1995, Pflieger 1997). Koster (1957) reported that flathead chubs primarily occupied areas of moderate to strong current in the channel, except during periods of rest. In plains rivers, flathead chubs were found in all habitat types including the main channel, side channels, and backwaters, although adult fish were mainly found in the main channel (Haddix and Estes 1976, Rehwinkel and Gorges 1977, Gardner and Berg 1982, Fisher 1999). Bonner (2000) reported flathead chubs occupied all habitats in the Canadian River in the same proportion as their availability in the channel throughout the year, primarily in the main channel areas with sand substrates. Similarly, Bich and Scalet (1977) found no discernable habitat preferences by flathead chubs in the Little Missouri River in South Dakota.

Baxter and Stone (1995) surmised flathead chubs were well adapted to swift currents in turbid rivers with their streamlined shape and large fins. Peters et al. (1989) identified habitat suitability criteria for flathead chub in the lower Platte River as encompassing water depths from 10 to 30 cm (3.9 to 11.8 inches) in areas of gravel or sandy substrates with current velocities between 20 and 60 cm/s (0.7 and 2 ft/s). Werdon (1992) reported that flathead chubs used sand and gravel substrate habitats similar to those used by sturgeon chubs (*Macrhybobsis gelida*), but also noted that flathead chubs were typically collected in the higher velocity regions of a site. Sites with flathead chubs in the Missouri River Basin had higher mean water velocities, 0.32 to 0.90 m/s (1.1 to 3 ft/s), compared to sites without this species, 0.23 to 0.82 m/s (0.8 to 2.7 ft/s). Similarly, Bonner (2000) described flathead chub habitats in the Canadian River as deeper water depths of 22 to 26 cm (8.7 to 10.2 inches) with swift currents 0.34 to 0.53 m/s (1.1 to 1.7 ft/s). In contrast, Welker (2000) found flathead chubs occupied lower velocity, shallower habitats than sturgeon chubs in the Missouri and Yellowstone rivers. He suggested the difference between his findings and those of others was due to differences in depth and velocity ranges between streams and large rivers.

Flathead chubs often are collected from the lower reaches of tributaries to plains rivers (Personius and Eddy 1955, Elser et al. 1978, Barfoot 1999). In streams, flathead chubs have been found to occupy fast water habitats and pools with a range of substrates, including sand, gravel, and bedrock (Cross and Collins 1975, Pflieger 1997). Flathead chubs were collected from the lower reaches of tributaries of the Yellowstone River in Montana that Clancey (1978) described as being deep, turbid, with substrate ranging from cobble to silt, and having undercut banks and large wood debris in the channel. Olund and Cross (1961) reported flathead chubs in small rivers and creeks displaying a preference for pools with moderate currents. For a stream in Iowa, Martyn (1977) reported flathead chubs were usually found in pools "in the vicinity of brush and logs which had fallen into the creek."

Smith and Hubert (1989) found flathead chubs to be the most abundant species captured by seines from both the mainstem Powder River and one of its tributaries. The Powder River habitat was described as meandering and braided with high turbidity, high salinity, and unstable sand and silt substrates (Smith and Hubert 1989). In contrast, the tributary had a more confined channel with stable, vegetated banks; lower turbidity; gravel substrates; and riffles, pools, undercut banks, and woody debris along its length (Smith and Hubert 1989).

Flathead chubs are rarely found in the clear quiet waters of ponds or lakes (Scott and Crossman 1973). Likewise, Fisher et al. (2002) found limited use of backwater habitats near the confluence of the Missouri and Yellowstone rivers in North Dakota. However, these authors noted that flathead chubs fed extensively on backwater-produced organisms during times of high water flows, suggesting that backwaters might provide indirect benefits to species such as the flathead chub that are normally associated with flowing water habitats. In Canada, there are several reports of flathead chubs congregating and being easily caught in shallow, near shore, eddy areas of rivers (McPhail and Lindsey 1970, Bishop 1975).

Flathead chubs appear to be adapted to the turbidity and high variation in discharge associated with plains streams and rivers. Peak annual discharge in these systems is usually associated with snowmelt in early summer and followed by fluctuations in flow resulting from summer thunderstorms (Olund and Cross 1961, Bishop 1975, Gould 1985). In these systems, dry summers frequently result in intermittent flows in the streams, and extreme drought has similar effects on the rivers (Bailey and Allum 1962, Clancey 1978, Smith and Hubert 1989, Bonner 2000). In a Montana stream where flathead chubs were collected, the reported range of discharge was 4 to 31 $m^3/s$ (141.3 to 1094.8 $ft^3/s$), with the highest flows occurring in May or June and the lowest flows in August and September (Gould 1985). Similarly, at a site in the Powder River in Wyoming where flathead chubs were collected, mean monthly discharge ranged from 6.4 to 33.6 $m^3/s$ (225.4 to 1186.6 $ft^3/s$), with peak annual discharge occurring in early summer (Rehwinkel and Gorges 1977).

The chemosensory barbels and buds of flathead chubs are considered adaptations to the characteristically turbid prairie rivers they inhabit. Smith and Hubert (1989) reported that turbidity often exceeded 500 JTU (Jackson Turbidity Units) in the Powder River where flathead chubs were abundant. Gould (1985) reported average monthly values of suspended solids ranging from 100 to 1,700 mg/l for a prairie stream in Montana. Bonner (2000) reported that flathead chubs were collected from habitats that ranged in turbidity from 9.5 to 19,150 NTU (Nephelometric Turbidity Unit).

Flathead chubs inhabit a range of water temperatures across their extensive geographic range. Gould (1985) reported a temperature range of 0 to 23 °C (32 to 73.4 °F) in a Montana stream having a flathead chub population. Bonner (2000) studied flathead chubs in the southern part of their range, in New Mexico and Texas, and reported that flathead chubs were collected from habitats that ranged in water temperature from 1.9 to 33.5 °C (35.4 to 92.3 °F).

Flathead chubs are frequently associated with alkaline environments characteristic of many streams and rivers in the Great Plains (Olund and Cross 1961). Woodling (1985) noted that flathead chubs tolerate organic enrichment since specimens collected downstream of a wastewater treatment plant on Fountain Creek, Colorado, appeared to be in excellent condition despite the extensive organic enrichment and high ammonia concentrations. Scarnecchia (2002) collected flathead chubs from some intermittent pools that contained extensive amounts of cattle manure in streams of the Little Missouri National Grassland in North Dakota. Nevertheless, Scarnecchia believed that deposition of livestock manure could ultimately render the pools unsuitable for fish, especially when water temperatures are high in summer.

Ontogenetic shifts in habitat use by flathead chub have not been well studied. Martyn and Schmulbach (1978) reported finding mostly age 2 and age 3 flathead chubs in deeper pools and concluded that younger fish were distributed elsewhere in the stream. The authors were unable to locate the younger age classes of flathead chubs when they sampled riffles and other habitats in the stream. However, their inability to capture small fish may have been due to the size-selective gear used in sampling. In the Peace River, Alberta, Bishop (1975) collected all age classes of fish including age 0 fish using a combination of seines, gill nets, and rotenone. Unfortunately, he did not report on distribution patterns or habitat use of different age classes of flathead chubs. Gardner and Berg (1982) reported finding age 0 flathead chubs in side channels of the middle Missouri River in Montana from July to late September. They observed that forage fishes emigrated from the side channels to the main channel in autumn but did not refer to flathead chubs specifically. Welker (2000) reported that 99 percent of flathead chubs captured in the Yellowstone and Missouri rivers were collected from channel border habitat that was less than 1.5 m (4.9 ft) deep. Also, 94 percent of the fish were in current velocities of 0.25 m/s (0.8 ft/s) or less. The majority of flathead chubs captured by Welker (2000) were less than 50 mm (2.0 inches) in length, indicating younger flathead chubs utilize shallower border habitats in large rivers.

Spawning has not been observed for flathead chubs, although several authors have suggested that flathead chubs from large rivers move into smaller streams to spawn (Olund and Cross 1961, Scott and Crossman 1973). Smith (1988) reported that flathead chubs likely spawn over riffle areas in summer at water temps > 21 ºC (69.8 ºF). Gardner and Berg (1992) referenced (Pflieger 1975) when they that stated flathead chubs "spawn near the head of side channels in protected areas on firm substrate." Martyn (1977) noted that because flathead chubs were collected only in stream pools during the peak spawning period, spawning may occur in pools. Olund and Cross (1961) report collecting "dense concentrations" of flathead chubs from small pools with brush or woody debris in streams and small rivers in the fall. Olund and Cross (1961) also found flathead chubs congregating in turbid pools without brush or woody debris in other streams, suggesting that pools may simply be a preferred habitat in smaller rivers and streams. Although the spawning habitat of flathead chubs remains unknown, the timing of the spawning season appears to coincide with lower flows, reduced turbidity levels, and warmer water temperatures in summer (Olund and Cross 1961).

Other potential seasonal variations in flathead chub habitat requirements, such as the use of refugia during winter or high flow conditions have not been investigated.

### Food habits

Koster (1957) described flathead chubs as "more or less omnivorous." McPhail and Lindsey (1970) reported a remarkable array of food items in the stomach contents of northern Canadian specimens including Plecoptera and "other aquatic insect larvae, terrestrial insects, sand, berries, seeds, feathers, young suckers, small spiny-rayed fish and even a young rodent".

Some researchers have suggested that terrestrial insects that have fallen into the water are the primary component of flathead chub diets (Neumann and Willis 1994, Pflieger 1997). Bishop (1975) found primarily terrestrial insects, especially Hymenoptera, Hemiptera, and Trichoptera in stomach samples of flathead chubs from the Peace River, Alberta. He did not report the number or the size of the fish collected for stomach content analysis or in which month they were collected.

Olund and Cross (1961) provided a detailed account of the stomach contents from 21 flathead chubs collected from rivers throughout their range. Terrestrial insects comprised most of the flathead chub diet followed by aquatic larval insects and plant material. Most of the animal food items identified by Olund and Cross (1961) were from the following Insecta orders: Ephemeroptera, Hemiptera, Hymenoptera, Coleoptera, Diptera, and Orthoptera. Miscellaneous material including insect eggs and sand also was found. Roundworms (Nematoda: Aphasmidia) found in stomachs were thought to be parasites, not food items (Olund and Cross 1961).

Scarnecchia et al. (2000) examined the stomach contents of 178 flathead chubs. Unfortunately, only three specimens contained food items that could be identified. For most specimens, stomach contents were too masticated to identify, and 67 stomach specimens were empty. Insects from the orders Coleoptera, Hymenoptera, Orthoptera and Trichoptera were found in the three stomachs. Scarnecchia et al. (2000) reported stomach contents comprised an average of 0.26 percent of total fish weight and that larger fish of both sexes tended to have greater stomach content weights. There were no seasonal patterns in stomach fullness.

Fisher et al. (2002) found that diets of flathead chubs in the Missouri River varied between normal- and high-flow years. In a normal-flow year, flathead chub diets were consistent with previous reports and were comprised primarily of Coleoptera, Diptera, Trichoptera, Ephemeroptera, Hymenoptera, and in lesser amounts Ostracoda, Hemiptera, and Copepoda. During the normal-flow year terrestrial insects, primarily a shore beetle (Coleoptera; Cicindelidae, "tiger beetles"), dominated flathead chub diets in spring and early summer and Hymenoptera and macrophyte plant seeds dominated in late summer and early fall. In contrast, in a high-flow year during early and mid summer, flathead chub diets were composed chiefly of Ostracoda, Copepoda, Hemiptera (predominately Corixidae), and Diptera, with larger flathead chubs also consuming Orthoptera. During late summer and early fall of the high-flow year, flathead diets continued to contain significant amounts of Ostracoda, Hemiptera, and Copepoda, while Ephemeroptera and Tricoptera became more prevalent. Fisher et al. (2002) noted that the taxa dominating flathead chub diets during the high-flow year, especially Copepoda and Corixidae, are obligate calm water taxa during most of their life histories and probably originated from the flushing of backwater and floodplain habitats during high stream flows.

Both Bishop (1975) and McPhail and Lindsey (1970) reported that flathead chubs are easily caught with bait. Bishop (1975) recounts the ease of catching flathead chub with hooks baited with meat, and McPhail and Lindsey (1970) describe flathead chubs being lured into the shallows by a mixture of dog food and soap flakes.

Although there are relatively few studies, the array of food items represented in the diets of flathead chubs suggests that they are opportunistic feeders. Whether flathead chubs are able to digest the plant material they consume has not been established. In general, there appears to be agreement that flathead chubs are primarily insectivorous and that terrestrial insects in the drift are important components of their diet. The importance of terrestrial insects to the diets of flathead chubs is consistent with the fact that the species occurs in turbid waters where low light penetration results in low primary production and hence, a low abundance of aquatic invertebrates (Rehwinkel and Gorges 1977, Fisher 1999, Fisher et al. 2002).

### Breeding biology

Little is known about the breeding biology of flathead chubs. Based on indirect evidence such as gonadal condition and larval densities, several researchers have concluded that flathead chubs spawn in the summer, sometime between May and August (McPhail and Lindsey 1970, Martyn and Schmulbach 1978, Gould 1985, Smith and Hubert 1989). Because abiotic variables such as photoperiod, water temperature, and discharge are important determinants of gonadal development and access to appropriate spawning habitats (Smith 1988), it is likely that the peak spawning period for flathead chubs varies across their range from early to late summer. There have been no published observations of flathead chub spawning behavior, and little is known about the habitat used by spawning fish. Fisher et al. (2002) failed to find flathead chub larvae in backwater habitats of the Missouri River, which indicated that spawning probably occurred in main channel habitats. Based on the absence of large adults on sandbars during the spawning season, Fisher et al. (2002) also concluded that adults did not use shallow, sandbar habitats for spawning, but they did not know which other main channel habitats were the primary breeding sites. Bonner and Wilde (2000) reported that flathead chub belonged to a guild of prairie stream fishes that produce non-adhesive, semi-buoyant eggs. These fishes spawn in response to floods that increase stream flows and keep the semi-buoyant eggs afloat until hatching occurs. Newly-hatched fry are weak swimmers, so strong currents are required to keep fry suspended so that they do not settle to the bottom and become buried.

Martyn and Schmulbach (1978) determined that spawning occurred from mid-July to mid-August based on gonadal weight data. During the spawning period, they reported that the average temperature in the morning was 18.5 ºC (65.3 ºF) and 25 ºC (77 ºF) in the afternoon.

Gould (1985) also reported a July-August spawning season for a population in Montana based on gonadal weights and the presence of mature eggs. Average daily minimum and maximum water temperatures during the spawning period were 18 ºC (64.4 ºF) and 23 ºC (73.4 ºF) in July and 21 ºC (69.8 ºF) and 25 ºC during the first two weeks of August. Gould (1985) noted that these water temperatures were consistent with those reported by Martyn and Schmulbach (1978).

McPhail and Lindsey (1970) inferred spawning was already in progress for a flathead chub population in the Mackenzie River in late June from female ovary condition. For a Peace River population, McPhail and Lindsey (1970) concluded flathead chubs had finished spawning by early August after collecting spent females.

Smith and Hubert (1989) sampled larval fish at the mouth of a tributary of the Powder River in Wyoming/Montana and found that flathead chub larvae were the most abundant species, comprising 41 percent of the total catch in drift samples conducted from May 8 through August 11 in 1986. Flathead chub larvae abundance peaked during the period of June 29 through July 12, further supporting the conclusion that flathead chubs are summer spawners.

It is unclear if flathead chubs are able to spawn multiple times during a season or if there is a single spawning period. Scarnecchia et al. (2000) reported non-synchronous egg development in flathead chubs, with two or more size classes of eggs present in most female fish. They found no evidence of egg reabsorption and suggested that the non-synchronous development of eggs was evidence of fractional and multiple spawning. They proposed that fractional spawning may be an adaptation to the variable river environments that flathead chubs occupy in which peak discharge may vary by a month or more from year to year. Fractional spawning would allow fish to spawn during optimal conditions whenever they occur.

There have been no studies of flathead chub embryonic development despite the unresolved debate of whether the geographic patterns in flathead chub morphological variation are determined by temperature regimes during development or genetic variation that would support sub-species designations. Bailey and Allum (1962) reported that vertebral counts of 476 specimens indicated that flathead chubs from small shallow streams of western South Dakota consistently had lower numbers of vertebrae than specimens collected from the larger Missouri River. The difference was attributed to the large diurnal temperature fluctuations of small, shallow streams compared to the cool and less variable temperatures of the Missouri River during the summer breeding season. Bailey and Allum (1962) also noted that since the small rivers and larger streams of the Great Plains are prone to becoming intermittent during droughts, populations of flathead chubs from larger river sources likely recolonized these streams regularly, suggesting the observed geographic patterns in morphological differences are more reasonably explained by variation in thermal regimes than genetic differentiation.

## Demography

### *Genetic characteristics and concerns*

There has been little research done on population demographics and genetic characteristics of flathead chub. Information on genetic characteristics of flathead chub populations throughout their extensive range could be useful in determining whether there is a single species or if there is a genetic basis for the observed morphological differences that can be explained as two subspecies and their intergrade forms. Olund and Cross (1961) concluded that differences in average counts of morphometric and meristic characters were the results of genetic variation between populations of flathead chubs. They acknowledged the effect of temperature during development and other potential environmental influences on many of the traits they used to distinguish the subspecies, but they still believed that morphological differences were too great to be explained by environmental variation alone. Instead, they suggested that there was a genetic basis for the observed variation between populations found in the southern and western part of the species range and those found in the northern and eastern parts.

A genetic basis for the observed variation was supported by Metcalf (1966) who suggested that populations that occupied a northward-flowing, pre-glacial Missouri River that emptied into the Hudson Bay were the source of the northern subspecies, *Platygobio gracilis gracilis*, whereas the southern subspecies *P. gracilis gulonella* historically occupied the drainages of the "Ancestral Plains Stream" that flowed southward into the Gulf of Mexico. Metcalf (1966) proposed that after glaciation and reorientation of the Missouri River drainage into the Ancestral Plains Stream, co-mingling occurred between the two subspecies which would explain the intergrade form in the central part of the flathead chub range. The northern subspecies survived only in Missouri River headwaters, eventually spreading northward into Canada's Saskatchewan and Mackenzie river drainages.

Genetic research could also elucidate questions regarding flathead chub population dynamics, isolation, and the degree of habitat fragmentation. Currently it is thought that fragmentation of large plains rivers and streams has contributed to the declines in abundance and distribution of this species. There has been little work on flathead chub ecology, and the roles of dispersal, movement, and emigration/immigration in maintaining flathead chub populations are unknown. As a result, the potential effects of population isolation, via habitat fragmentation, on genetic structure of the species are uncertain.

*Life history characteristics*

Life history characteristics, such as length at age, age of sexual maturation, and life span, vary across the extensive range of flathead chubs. A study of flathead chubs in an Iowa tributary of the Missouri River found only five age classes present with most fish maturing by their third year of life (age 2) and reaching a maximum size of 150 mm (5.9 inches) (Martyn and Schmulbach 1978). Another study of a flathead chub population in a Montana stream found only four age classes with most fish reaching sexual maturity at age 2. In contrast, records from larger rivers in Canada and Montana indicate flathead chubs in some populations may live up to 10 years, becoming sexually mature later (age 4), and reaching lengths greater than 300 mm (11.8 inches) (Bishop 1975, Scarnecchia et al. 2000).

Martyn and Schmulbach (1978) used scales to analyze age and growth data for 288 flathead chubs collected from Perry Creek, a tributary of the Missouri River in Iowa. The majority of fish (88.6 percent) were sexually mature. The authors found four age classes of flathead chubs (ages 1-4), but did not collect age 0 fish. Average total length of age 1-4 fish were 78, 110, 132, and 150 mm (3.1, 4.2, 5.2, and 5.9 inches) respectively, with most fish in the age 2 and 3 classes. Martyn (1977) indicated fish length frequency plots were not useful in aging the flathead chubs because age groups were found to have considerable overlap in total length.

In the Peace River of Alberta, (Bishop 1975) found age 1 and age 2 flathead chubs were of comparable lengths to the Iowa population studied by Martyn and Schmulbach (1978). However, age 3 and age 4 fish in the Alberta population were much larger, with mean fork lengths of 168 and 182 mm (6.6 and 7.2 inches). Bishop (1975) found many flathead chubs over 4 years old and some up to 10 years old in the northern part of the species' range. Flathead chubs exceeding 300 mm total length (TL) have been reported in several systems in Canada (Bishop 1975, Kristensen 1980). Although there are records of large flathead chub occurring in the United States, most surveys report smaller mean maximum lengths and fewer age classes (Martyn and Schmulbach 1978, Pflieger 1997, Scarnecchia et al. 2000).

Gould (1985) found that life history traits of flathead chubs in Montana were similar to those reported for populations in the midwestern United States (e.g., Bishop 1975, Martyn and Schmulbach 1978). Gould (1985) observed three size classes in 305 specimens ranging from 29 to 127 mm (1.1 to 5 inches) TL collected in March. Average total lengths of the three groups were 43, 81, and 116 mm (1.7, 3.2, and 4.6 inches). Gould (1985) was unsuccessful in using scales, opercula, and vertebrae in an age analysis. However, if the length groups represent age groups (beginning with age 0 fish with a mean length of 43 mm), the average lengths are consistent with those found by Martyn and Schmulbach (1978).

In a recent assessment of flathead chub life history characteristics, Scarnecchia et al. (2000) collected 1,327 flathead chubs from the lower Yellowstone River in Montana. The specimens ranged from 32 to 304 mm (1.3 to 11.9 inches) TL. The authors were able to age 281 fish ranging in size from 86 to 206 mm (3.4 to 8.1 inches) using scales. Mean lengths were 108 mm (4.3 inches) TL at age 1, 129 mm (5.1 inches) at age 2, 147 mm (5.8 inches) at age 3, 164 mm (6.5 inches) at age 4, 196 mm (7.7 inches) at age 5, 221 mm (8.7 inches) at age 6, and 246 mm (9.7 inches) at age 7. Scarnecchia et al. (2000), like Martyn and Schmulbach (1978), also found considerable overlap in lengths among age groups.

Martyn and Schmulbach (1978) found that mean annual length increment decreased with fish age: 78 mm (3.1 inches) at age 0 to age 1, 32 mm (1.3 inches) at age 1 to age 2, 22 mm (0.9 inches) at age 2 to age 3, and 18 mm (0.7 inches) at age 3 to age 4. They also reported that flathead chub growth rates varied significantly during the first year of life but were more uniform thereafter. The authors suggested that the uniform growth rates between years were evidence of stable environmental conditions for older flathead chubs during the study period. The researchers estimated that two-thirds of annual growth in length occurred between annulus formation in late May and mid-summer (late July through early August).

Martyn and Schmulbach (1978) did not find differences in growth rates between males and females, but they did note that the majority of age 4 fish were females and that females tended to be heavier than males of the same length. Interestingly, of the 281 fish aged by Scarnecchia et al. (2000), none of 27 males were older than age 5 whereas seven of the 48 females were age 6 or age 7. This apparent trend for females to live longer and attain greater sizes suggests sexual dimorphism in flathead chubs (Scarnecchia et al. 2000).

For the Iowa stream population, Martyn (1977) reported that males and females reached maturity at approximately the same age and length. Most specimens greater than 105 mm (4.1 inches) standard length or 127 mm TL were mature, 73 percent were sexually mature by their third year of life (age 2), and all fish aged 3 to 4 were mature (Martyn and Schmulbach 1978).

The youngest mature males found by Scarnecchia et al. (2000) in the Yellowstone River were age 1, and the youngest mature females collected were age 2. The smallest mature female collected was 107 mm (4.2 inches) TL. Unfortunately, Scarnecchia et al. (2000) were unable to estimate the proportion of mature fish for each age class due to small sample sizes of fish of known age and sex.

The smallest mature male collected by Gould (1985) was 123 mm (4.8 inches) TL. Gould found that of 18 males collected in July and August, four males between 124 and 140 mm (4.9 and 5.5 inches) TL were not ripe in August. A possible explanation is that the males were spent. However the observation could also be consistent with Martyn and Schmulbach's (1978) finding that most, but not all, of an age class became sexually mature during the same period. Gould (1985) also reported an approximately 1:1 female to male ratio among size classes of specimens from Montana. However, sex ratios may depart from 1:1 in populations with age 5 to 7 fish, as the older age classes sometimes show a predominance of large females (Scarnecchia et al. 2000).

Fisher et al. (2002) reported that flathead chub scales were difficult to age. However, after some practice, they were able to age 146 specimens from the Missouri River in North Dakota. Maximum age was five years, and mean total lengths at ages 1-5 were 104, 153, 186, 223, and 267 mm (4.1, 6, 7.3, 8.8, and 10.5 inches). Of male flathead chubs captured in April, 66 percent had developed testes at 75 mm (3 inches) TL and 100 percent were mature at 110 mm (4.3 inches). Only 2 percent of the chubs that appeared to be female and were less than 125 mm (4.9 inches) TL contained mature eggs. By 155 mm (6.1 inches), 80 percent of the females were mature, and by 170 mm (6.7 inches), 100 percent of the females were mature. This suggested that some females may release eggs in only one or two seasons of their lifespan.

Martyn and Schmulbach (1978) reported that ovaries averaged 10.3 percent of body weight and testes 1.3 percent during the spawning period. In comparison, Gould (1985) reported ovary weights ranging from 2.3 to 5.9 percent of total body weight for mature females and 0.5 to 1.8 percent of total body weights for immature flathead chubs. Gould collected specimens before, during, and after the spawning period, which could account for the lower estimated ratio of ovary weight to total body weight.

Martyn and Schmulbach (1978) estimated the mean number of eggs per female was 4,974 (range 2,205 to 13,073) for age 1 and older fish (Martyn and Schmulbach 1978). Gould (1985) reported only estimates of mature eggs per female, which were significantly lower (491 mature eggs/ female). The lower estimates by Gould (1985) may be accounted for in part by the time of collection, the fact that only mature eggs (> 1.0 mm diameter) were counted, and that the population studied by Gould (1985) had fewer age classes and consequently fewer large females than the population studied by Martyn and Schmulbach. Scarnecchia et al. (2000) reported a mean total number of eggs per specimen of 6,981 (the mean TL of specimens was 186 mm), and approximately 58 percent of the eggs were greater than 1.0 mm (0.04 inches) in diameter. The largest number of eggs estimated for an individual flathead chub was 36,150 (Scarnecchia et al. 2000).

Martyn and Schmulbach (1978) found a small increase in the mean number of eggs/10 g body weight with increasing body length up to 130 mm (5.1 inches) in length. However beyond 130 mm length there was a decrease in the mean number of eggs/10 g body weight. They determined that age 3 females had the most efficient egg production with 1,769 eggs/ 10 g body weight (TL of specimens ranged from 116 to 125 mm [4.6 to 4.9 inches]). Notably, Gould (1985) found no trend of larger females having more eggs. Although the size range of mature females studied by Gould was 113 to 160 mm (4.4 to 6.3 inches) TL and overlapped the size range studied by Martyn and Schmulbach (1978), the size range is small relative to the longer-lived larger flathead chubs studied in other systems (Bishop 1975, Scarnecchia et al. 2000). Scarnecchia et al. (2000) suggest the observed sexual dimorphism in the size and life span of flathead chubs allows larger females to have higher fecundity.

The maximum ovary weights as percent of body weights of mature female flathead chubs reported by Gould (1985) were approximately 60 percent of those reported for the Iowa population. Gould suggested that flathead chubs in Montana may have fewer or smaller eggs. However the reports of Scarnecchia et al. (2000) demonstrate that Montana flathead chubs can have much greater fecundity in the larger river systems such as the Lower Yellowstone. One problem in making inferences about flathead chub fecundity using these reports is that each study used a different method for estimating egg number. Martyn and Schmulbach counted all eggs present in sub-samples of ovarian tissue and then multiplied by total ovarian weight. Gould (1985) used the same method but only counted mature eggs. Scarnecchia et al. (2000) separated the eggs from the ovarian tissue and weighed subsamples of 100 eggs to estimate the total number of eggs.

Martyn (1977) described flathead chub eggs as light yellow and ovoid in shape, becoming rounder with increased size. The mean size of 10 eggs taken from a single ripe female was 1.35 mm x 1.499 mm (Martyn 1977). Gould (1985) considered mature eggs only, with designation of egg maturity based on egg size (> 1.0 mm in diameter) and color (orange). Gould (1985) reported an egg size range of 0.2 to 1.4 mm. Gould noted that smaller eggs were present in all collection periods (March, July, August, and November), and the larger eggs (> 1.0 mm in diameter) were present in the specimens collected in July and August. Gould (1985) found average diameter of mature eggs peaked in late July and early August.

Scarnecchia et al. (2000) confirmed non-synchronous egg development by finding two distinct sizes classes of eggs present in many of their specimens (81 percent of 42 specimens). Histological analysis of egg cross sections demonstrated that the different sizes of eggs were at intergrading stages of development (Scarnecchia et al. 2000). The two size classes were designated large eggs greater than 1.0 mm in diameter and small eggs less than 0.8 mm in diameter (Scarnecchia et al. 2000). Scarnecchia et al. (2000) reported a mean diameter of 1.11 mm for the large egg size class and 0.41 mm for the small egg size class. Of 42 female specimens, 29 fish had predominately large eggs, five had mostly small eggs, seven had only small eggs, and one had only large eggs (Scarnecchia et al. 2000).

Martyn and Schmulbach (1978) suggested that the differences in age structure and growth rates between the Iowa population and the Peace River flathead chubs (Bishop 1975) could be a result of better habitat and greater food availability in the larger Peace River system or from genetic differences between the proposed northern subspecies and the intergrade form found in the Iowa stream. Martyn and Schmulbach (1978) concluded from the age and growth data that flathead chubs were fast growing while immature and that growth slowed significantly after sexual maturity was reached. Martyn and Schmulbach (1978) noted that the Peace River fish reached sexual maturity later, at age 4, which could explain their greater lengths at ages 3+ than the Iowa population. A similar conclusion is suggested by the comparison of the two Montana studies. Gould (1985) studied a flathead chub population in a stream and found fewer age classes, smaller sizes, and lower fecundity estimates than the Yellowstone River population studied by Scarnecchia et al. (2000).

### *Life cycle characteristics and analysis of demographic matrix*

A life cycle graph (**Figure 4**) was constructed and used as the basis for an analysis of how population demographics might influence the long-term persistence of flathead chub populations (details of the analysis are given in **Appendix A**). The approach was to use a stage-based variation of a Leslie matrix to project population sizes under various scenarios of environmental and demographic stochasticity. A major reason for doing a matrix demographic analysis is to identify which age-specific vital rates (such as the probability that a fish of a given age survives during the next year or the number of eggs produced by a female of a given age) are likely to be most influential in determining population growth rate (λ). Population growth rate, in turn, is critical in allowing flathead chub populations to recover from low-points in abundance and thus avoid going extinct.

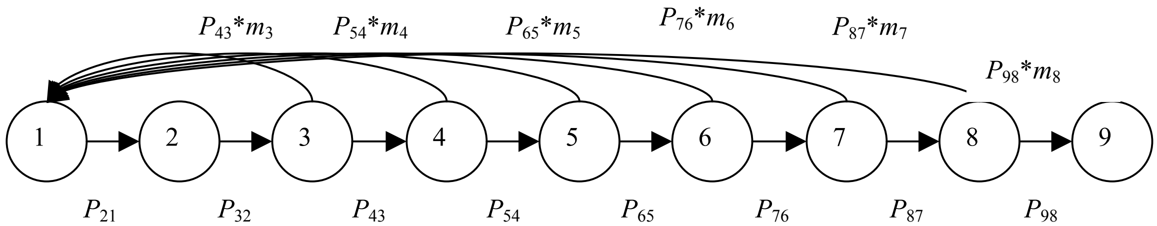


**Figure 4.** Life cycle graph for flathead chub. The numbered circles (nodes) represent the nine age-classes. The arrows (arcs) connecting the nodes represent the vital rates — transitions between age-classes such as survival ($P_{ji}$) or fertility (the six sets of $P_{ji} * m_i$, lying above the respective arcs pointing back toward the first node from Nodes 3 through 8). Note that reproduction begins from Node 3.

Input data needed for a population projection matrix model consist of age-specific survival and fecundity rates. We assembled the sparse data available in the literature on these rates for flathead chub (**Table 4**). The model has two kinds of input terms: $P_i$ describing survival rates, and $m_i$ describing fertilities (**Table 4**). Fertilities are given as female offspring per female. In contrast to fisheries terminology, the convention here is ordinal numbering beginning with 1 (first, second, third, and fourth age-classes). Thus, age 0 in fisheries terminology corresponds to the age class 1 in the matrix model. Each age class describes a one-year census interval period, and the age-class that begins with an egg at the census and proceeds to the first clutch produced by a three-year old female is described by the self-loop $P_{43}m_3$ in **Figure 4**.

**Sensitivity analysis.** Sensitivity is the effect on population growth rate (λ) of an absolute change in the vital rates ($a_{ij}$, the arcs in the life cycle graph, **Figure 4**). Sensitivity analysis can show how important a given vital rate is to l or to fitness. One can use sensitivities to assess the relative importance of survival versus reproductive transitions. Sensitivities also can be used to evaluate the effects of inaccurate estimation of vital rates, to quantify the effects of environmental perturbations, and to identify stage-specific survival or fertility rates that are most critical to increasing λ of an endangered species. The major conclusion from the sensitivity analysis is that first-year survival is overwhelmingly important to population viability (details are given in **Appendix A**). Flathead chub shows large sensitivity to changes in survival, with first-year survival alone accounting for 99.7 percent of the total sensitivity.

**Elasticity analysis.** Interpreting sensitivities can be somewhat misleading because survival rates and reproductive rates are measured on different scales. For instance, a change of 0.5 in survival may be a big

**Table 4.** Parameter values for the component terms ($P_i$ and $m_i$) that make up the vital rates in the projection matrix for flathead chub.

| Parameter | Numeric value | Interpretation |
|---|---|---|
| $m_3$ | 2,225.8 | Number of female eggs produced by a third-year female |
| $m_4$ | 2,603.3 | Number of female eggs produced by a fourth-year female |
| $m_5$ | 2,854.9 | Number of female eggs produced by a fifth-year female |
| $m_6$ | 3,567.9 | Number of female eggs produced by a sixth-year female |
| $m_7$ | 4,092.1 | Number of female eggs produced by a seventh-year female |
| $m_8$ | 4,616.3 | Number of female eggs produced by a eighth-year female |
| $P_{21}$ | 0.000496 | First-year survival rate |
| $P_{32}$ | 0.348 | Second-year survival rate (half that of “adults”) |
| $P_a$ | 0.696 | Annual survival rate of adults |

alteration, e.g., a change from a survival rate of 0.9 to 0.4 corresponds to a reduction in survival from 90 percent to 40 percent. On the other hand, a change of 0.5 in fertility may be a small proportional alteration, e.g., a change from an average clutch size of 100 eggs to 99.5 eggs. Elasticities are the sensitivities of the population growth rate (λ) to proportional changes in the vital rates ($a_{ij}$) and thus largely avoid the problem of differences in units of measurement. Details of the elasticity analysis for flathead chub are given in **Appendix A**. The population growth rate is most elastic to changes in first-year and second-year survival ($P_{21}$, the self-loop on the first node in **Figure 4**, and $P_{23}$), both with an equivalent 20.4 percent of the total, followed by third-year survival ($P_{43}$). The sensitivities and elasticities for flathead chub correspond in rank magnitude, although first-year survival is far more important in the sensitivity analysis (99.7 percent) than in the elasticity analysis (20.4 percent). The summed survival elasticities account for 80 percent of the total (compared to 20 percent for the summed reproductive elasticities). Thus, survival through the first two non-reproductive years, and to a lesser extent "adult" survival, are the data elements that warrant careful monitoring in order to refine the matrix demographic analysis.

**Other demographic parameters.** The stable age distribution describes the proportion of each age-class in a population at demographic equilibrium. For flathead chub at the time of the post-breeding annual census (just after the end of the breeding season), eggs represent 99.9 percent of the population (**Appendix A**, **Table 2**; this table has an "omitting eggs" column to show the non-egg distribution). Reproductive values describe the "value" of a stage as a seed for population growth relative to that of the first (in this case, egg) stage. The reproductive value of the first stage is always 1.0. For example, a female flathead chub in age-class 2 (age 1 in fisheries terminology) is "worth" 2,017 eggs, (**Appendix A**, **Table 3**). The peak reproductive value (6174) occurs at the fifth age-class (age 4 fish in fisheries terminology), and these females are an important stage in the life cycle even though they represent only 8.2 percent of the non-egg census population.

**Stochastic model.** We conducted a stochastic matrix analysis for flathead chub in order to see how variation in survival and fecundity rates might influence the likelihood of extirpation of local populations. We incorporated stochasticity in several ways, by varying different combinations of vital rates or by varying the amount of stochastic fluctuation (see **Appendix A** for details). The stochastic matrix analysis produced two major results. First, varying reproduction had very little effect on λ, whereas varying the survival rates of all age classes lead to extinctions. Second, the magnitude of stochastic fluctuation had a discernible effect on population dynamics. These results indicate that populations of flathead chub are vulnerable to stochastic fluctuations in early survival (due, for example, to annual climatic change or to human disturbance) and, to a lesser degree, to variations in "adult" survival.

Summary of major conclusions from matrix projection models:

- ❖ First-year survival accounts for > 99.9 percent of the total "possible" sensitivity. Any absolute change in this rate will have a major impact on population dynamics.
- ❖ First- and second-year survival account for 40.8 percent of the total elasticity, compared to the 20 percent accounted for by the entire set of fertilities. Proportional changes in first- and second-year survival will have major impacts on population dynamics.
- ❖ The reproductive value of fifth-year females is high. Even though older, larger females may be rare, their high survival rates and high reproductive values make them important buffers against the detrimental effects of variable conditions.
- ❖ Stochastic simulations echoed the elasticity analyses in emphasizing the importance of variation in first- and second-year survival to population dynamics. In comparison to life histories of other fishes with shorter lifespans, flathead chub appear somewhat less vulnerable to environmental stochasticity (because of the buffering effect of a reservoir of large females).

### *Ecological influences on survival and reproduction*

There is little information that would allow mortality of flathead chub to be partitioned among different causes (e.g., predation, competition, parasitism, abiotic stressors) for the various life history stages. As with most fish species that produce many eggs but provide little parental care, the mortality rate of early life history stages is extremely high. Survival from egg through the first year of life was estimated to be only about 0.05 percent based on the matrix population analysis (see **Table 4** under Life cycle characteristics and analysis of demographic matrix section). This suggests that stranding of eggs and larvae in unsuitable habitat and/or predation on eggs and larvae as they drift downstream are likely to be major sources of mortality. Flathead chubs have a broad diet of terrestrial and aquatic insects that overlaps with many other stream fishes, but the extent to which competition for food limits population size is unknown. Flathead chubs have been found in the stomachs of various piscivorous fish, but whether predation is high enough to limit population size has not been determined. There is no evidence to suggest that disease or parasites are major factors impacting survival or reproduction.

The moderate to large-sized streams that are the main habitat of flathead chubs are not likely to experience the same degree of extreme abiotic conditions that often kill fish in smaller, more intermittent water bodies within the Great Plains region. These lethal conditions include drying up, anoxia or high temperatures in summer, or complete freezing and anoxia in winter. Instead, larger streams in the Great Plains region are subject to major high-flow events, but flathead chub evolved in these systems and presumably are adapted to surviving floods.

*Social pattern for spacing*

Flathead chub are often found in groups, and individuals do not defend home ranges. Because spawning behavior has not been observed, we do not know if fish defend spawning sites. However, given that newly-hatched larvae are commonly observed to drift downstream, it is unlikely that the species spawns in a nest, and therefore territoriality during spawning is not likely to be an important component of reproductive success. It does not appear that territoriality plays a role in population regulation for this species.

*Patterns of dispersal of young and adults*

Larvae of flathead chub are commonly found drifting downstream in rivers. As noted by Fausch and Bestgen (1997), fishes whose eggs and larvae are transported downstream must have a mechanism for repopulating upstream reaches. Presumably this involves upstream migration by adults prior to spawning. Such spawning migrations are common in many fish species (Lucas and Baras 2001) but have not been investigated for flathead chub. Olund and Cross (1961) suggested that flathead chubs migrate into smaller streams to spawn and referenced several instances where flathead chubs were only caught in tributaries of large rivers during the breeding season.

Because the species is not territorial, dispersal of young to new areas at the time of sexual maturity is not a life history characteristic. Dispersal is more likely related to population crowding and the existence of corridors that allow movement among suitable habitat patches.

*Spatial characteristics of populations*

Spatial characteristics of populations such as sources and sinks, or metapopulation dynamics, have not been studied in flathead chub. Across their geographic range, flathead chubs show morphological differentiation and were considered to represent two subspecies at one point (see section Biology and Ecology - Systematics and species description). However, the genetic basis for subspecies designation has not been investigated, and most researchers do not recognize subspecies currently.

*Limiting factors*

The main factors limiting population growth for specific populations or the species in general have not been identified but likely involve habitat availability. The species is generally limited to turbid, fast-flowing, warm water rivers. Such rivers have been extensively modified through impoundments built to control floods, store water, and facilitate boat traffic (Berry and Galat 1993). Berry and Erickson (1995) reported that reservoirs cover 1,216 km (755.6 mi) of the 3,768 km (2341.3 mi) of the Missouri River as it flows from the Rocky Mountains in Montana to its confluence with the Mississippi River in Missouri. This represents a loss of nearly one-third of the flowing water habitat in this major river that is in the core range of the flathead chub. Similar replacement of large sections of flowing water with reservoir habitat has impacted nearly all the large rivers of the Mississippi River system (Berry and Galat 1993). Thus, loss of habitat is almost certainly a major cause of decline in flathead chub populations.

In addition to causing an outright loss of habitat as flowing water is converted to standing water habitat, impoundments alter the remaining riverine habitat. Impoundments cause suspended solids to settle out and thus reduce water turbidity in downstream reaches (Pflieger and Grace 1987). It is widely considered that reduced turbidity has had a negative impact on flathead chub populations although the exact mechanism has not been identified. For example, flathead chubs are absent in the clear waters downstream of the Garrison Dam on the Missouri River in North Dakota (Welker 2000). It is likely that reduced turbidity might favor other drift-feeding fish species as suggested by Pflieger and Grace (1987). Also, reduced turbidity might increase predation rates on flathead chub by piscivorous fish or terrestrial predators. Furthermore, impoundments often serve as source environments for piscivores such as walleye (*Stizostedion vitreum*), striped bass (*Morone saxatilis*), and largemouth bass (*Micropterus salmoides*) that would otherwise be absent or rare in the river systems historically inhabited by flathead chubs.

Bonner and Wilde (2000) proposed that in some larger river systems, remaining fragments of free-flowing water between impoundments may be too short to allow successful reproduction by a guild of prairie stream fishes that spawn non-adhesive, semi-buoyant eggs. They note that these fishes spawn in response to floods that increase stream flows and keep the semi-buoyant eggs afloat until hatching occurs. Newly-hatched fry are weak swimmers, so strong currents also are required to keep fry suspended so that they do not settle to the bottom and become buried. Depending on channel morphology, current velocity and water temperature, eggs in large river systems could be transported 72 to 144 km (44 to 89.5 mi) downstream and fry an additional 216 km (134.2 mi) downstream before the fry can swim well enough to find refuge in slower current areas. Bonner and Wilde (2000) placed the flathead chub in this spawning guild and suggested that in larger river systems, free-flowing reaches between impoundments may need to approach 200 to 300 km (124.3 to 186.4 mi) in length in order to provide sufficient habitat for successful spawning by such species. However, flathead chubs remain abundant in some rivers less than 200 to 300 km in length, possibly because slower currents in these smaller systems do not transport fry and larvae as far as in larger rivers.

## Community ecology

### *Predators*

Predators that often occur with flathead chubs include walleye, sauger (*Zander canadense*), northern pike (*Esox lucius*), and channel catfish (*Ictalurus punctatus*) (Rehwinkel and Gorges 1977, Elser et al. 1978, Doorenbos 1998, Fisher 1999). Flathead chubs were found to be a principal food item for sauger in the middle Missouri River (Gardner and Berg 1982) and the Yellowstone River (Elser et al 1977, cited in Gardner and Berg 1982). We found no reports describing predation by mammalian or avian predators.

In the historically turbid, variable flow environments of plains river systems, flathead chubs probably had few sight-oriented aquatic predators (Pflieger and Grace 1987). In plains rivers that have been modified by water management, decreases in flows and turbidities have been suggested to be detrimental to flathead chubs by allowing increases in sight feeding predators (Pflieger and Grace 1987). However, the magnitude of predator effects on flathead chub populations has not been quantified. Flathead chubs have been used as a baitfish due to their size and ability to stay alive for long time on trotline hooks (Martyn1977).

### *Competitors*

Studies of competition between flathead chub and other fish species have not been done, and consequently we do not know what role competition may play in limiting flathead chub populations. Pflieger and Grace (1987) suggested that the flathead chub's habit of sight feeding on terrestrial insects at the water surface would bring them into competition with more effective sight feeders, such as emerald shiner (*Notropis atherinoides*), river shiner (*N. blennies*), and red shiner (*N. lutrensis*), which have become more abundant in the Missouri River with the reduction in turbidity caused by impoundments. Whether this is the primary mechanism causing declines in flathead chub populations in the Missouri River remains to be determined.

Several researchers have reported on fish species often associated with flathead chub and which, therefore, might be potential competitors. Olund and Cross (1961) described fish species associated with what was then considered two subspecies of flathead chub. For the southern subspecies (*Platygobio gracilis gullonella*), the common associates were white sucker (*Catostomus commersonni*), plains minnow (*Hybognathus platica*), red shiner (*Cyprinella lutrensis*), sand shiner (*Notropis stramineus*), fathead minnow (*Pimephales promelas*), central stoneroller (*Campostoma anomalum*), and more rarely, green sunfish (*Lepomis cyanellus*) and orange-spotted sunfish (*L. humilis*). For the northern subspecies form (*Platygobio gracilis gracilis*) associates included the species listed above along with *Carpoides* spp., *Ictiobus* spp. and silt-adapted species of *Hybopsis* and *Notropis* (Olund and Cross 1961).

Olund and Cross (1961) noted that no flathead chubs were collected from the South Platte drainage and that the fish fauna of this drainage included species rarely found with flathead chubs such as longnose sucker (*Catostomus catostomus*), creek chub (*Semotilus atromaculatus*), hornyhead chub (*Hybopsis biguttata*), brassy minnow (*Hybognathus hankinsoni*), common shiner (*Notropis cornutus*), Johnny darter (*Etheostoma *nigrum*), and Iowa darter (*Etheostoma exile*). Olund and Cross (1961) suggested that flathead chubs are the ecological equivalent of creek chubs.

Species associated with flathead chub in Montana's Musselshell River included lake chub (*Couesius plumbeus*), common carp (*Cyprinus carpio*), western silvery minnow (*Hybognathus argyritis*), plains minnow, river carpsucker (*Capriodes carpio*), white sucker, mountain sucker (*Catostomus platyrhynchus*), shorthead redhorse (*Moxostoma macroolepidotum*), smallmouth bass (*Micropterus dolomieui*), and stonecat (*Noturus flavus*) (Gould 1985).

In Colorado's Arkansas River basin, flathead chubs were associated with three habitat zones: coldwater transition, mainstem river, and small rivers (Nesler et al. 1999). In the coldwater transition zone, flathead chub was considered a secondary species and the predominant species were white sucker, longnose dace (*Rhinichthys cataractae*), and fathead minnow. In the mainstem river zone, flathead chub again was considered a secondary species and the primary fish species were suckermouth minnow (*Phenacobius mirabilis*), channel catfish, sand shiner, red shiner, and plains killifish. In small river habitats, flathead chub were among the primary fish species along with longnose dace and fathead minnow. Secondary fish species in the small river habitat included plains killifish (*Fundulus zebrinus*), white sucker, red shiner, sand shiner, and central stoneroller.

### *Parasites and disease*

The role of parasites or disease in regulating flathead chub populations is unknown. An account of extreme parasitism in flathead chubs was described by Hubbs in 1927 (discussed in Olund and Cross 1961). Hubbs described a population of flathead chubs with developmental abnormalities resulting from high degrees of infestation with tapeworms in the genus *Proteocephalus*. The abnormalities appeared to result from retention of larval characteristics, and no teratological adults were found indicating that tapeworm infestation affected survival to maturity. Abnormalities mentioned by Olund and Cross (1961) included unusually high numbers of lateral-line scales, large eyes, short snouts, small fins, small mouths lacking barbels and coalescent nares.

Another case of parasitism was reported by Martyn (1977) for an Iowa population where all flathead chubs exhibited moderate to heavy parasitism by neascus type metacercaria of digenetic trematodes (family Diplostomatidae) or "black grub". No detrimental effects on the health of the infested fish were reported.

### *Symbiotic and mutualistic interactions*

No symbiotic or mutualistic interactions have been documented.

### *Envirogram of ecological relationships*

An envirogram is a useful way of depicting the ecological relationships that influence the survival and reproductive success of a species (Andrewartha and Birch 1984). The envirogram is built around a centrum of four components that together encompass all the major ecological relationships important to the species. These four components are termed resources, malentities, predators, and mates. Environmental (including biotic) factors that modify the four components form a web extending to several levels of indirect causation. For example, aquatic invertebrates may be important as food for a fish species and thus constitute one of the major categories for the resource component of the centrum. The abundance of aquatic invertebrates, in turn, is determined by a hierarchy of environmental factors that constitute the web. For example, invertebrate abundance is influenced by algal production which, in turn, is determined by water fertility, which, in turn, is determined by watershed geology and land-use.

An envirogram depicting the centrum and web for flathead chub is presented in **Figure 5**. The major resource needed by flathead chub is food, which consists largely of invertebrates of both aquatic and terrestrial origin. The abundance of aquatic invertebrates depends on their food sources (e.g., algae and detritus), and these, in turn, depend upon a series of abiotic factors and human modifications of the watershed. The abundance of terrestrial invertebrates depends on the condition and productivity of the riparian vegetation.

Among the major malentities are flow alteration, reduced turbidity, and habitat fragmentation. All of these factors are primarily a consequence of building large, flood control and water storage reservoirs on the large rivers throughout the range of the flathead chub. These reservoirs alter streamflows by converting large sections of rivers into standing water habitats that are suboptimal for riverine species such as the flathead chub. Reservoirs also act as sediment traps and thus reduce the turbidity of outflow waters. The flathead chub is adapted for life in highly turbid rivers

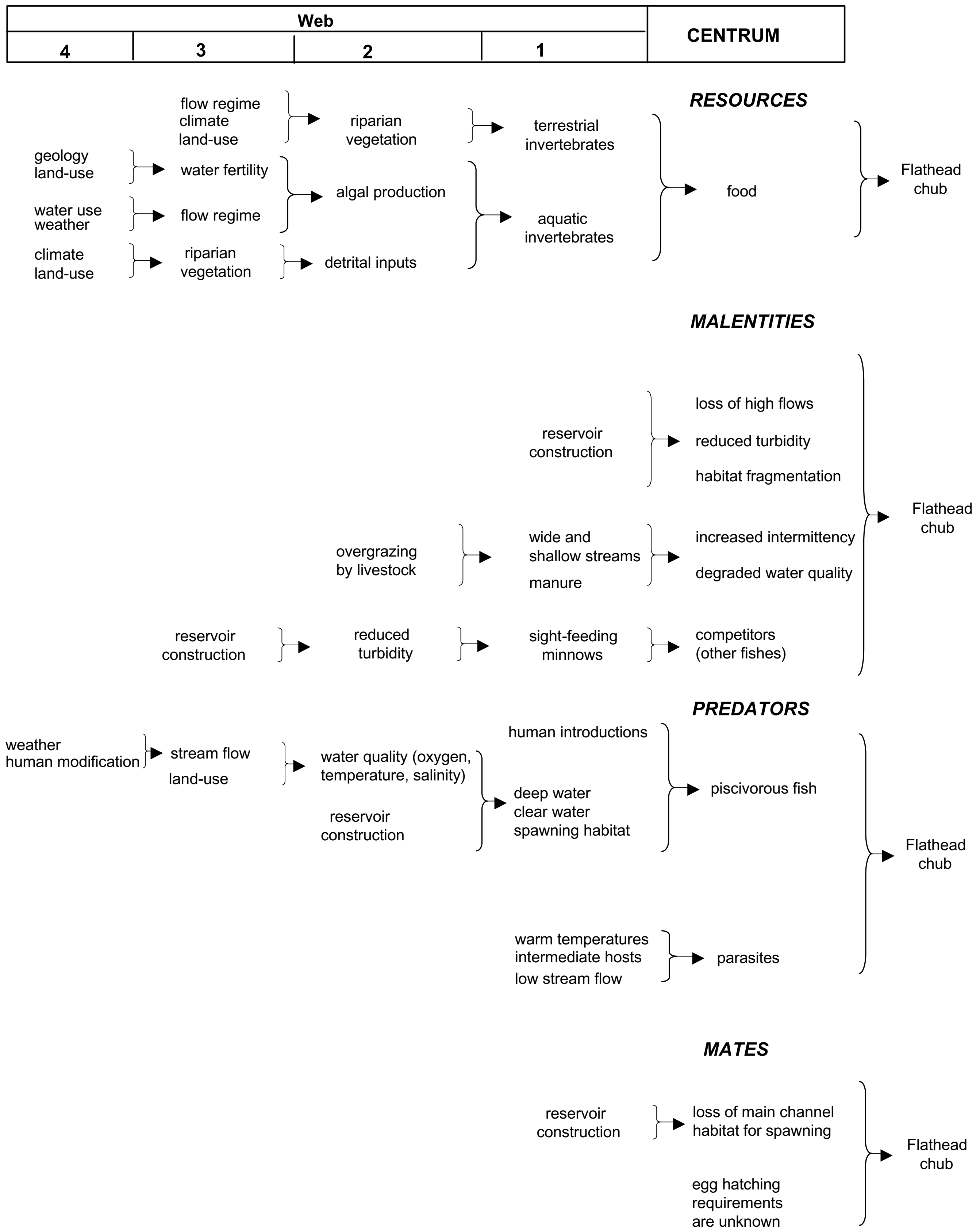


**Figure 5.** Envirogram for flathead chub.

and often suffers population declines when water clarity is increased. Although the mechanism for such declines is not known, increasing competition for food by sight-feeding minnows such as emerald shiner might play a role (Pflieger 1997). Another malentity is overgrazing by livestock, especially in watersheds in semi-arid regions that can increase stream width, decrease depth, and increase the likelihood of streams becoming intermittent (Platts 1991). In intermittent streams the accumulation of animal wastes in pools in late summer can result in low oxygen concentrations and high ammonia concentrations that are detrimental to aquatic organisms (Scarnecchia 2002). Piscivorous fish are likely the major predators although no studies quantifying their impact on flathead chub populations have been done. Under mates, suitable spawning habitat and egg hatching success are major determinants of reproductive success in most fish species but little is known about these factors for the flathead chub.

## CONSERVATION

### *Potential Threats*

The major threats to the flathead chub involve habitat alterations associated with the development and operation of reservoirs on large rivers. These include conversion of riverine habitat to standing water habitat via dams, reduction of turbidity, and fragmentation of once continuous rivers into small, free-flowing reaches isolated from other such reaches by dams and reservoirs.

Water development activities are a dominant feature of Great Plains watersheds. For example, in the Kansas River system of northeastern Colorado, northern Kansas, and southern Nebraska, 18 large reservoirs and 13,000 small impoundments now control discharge from more than 80 percent of the drainage area (Sanders et al. 1993). A major consequence of reservoir construction is the loss of flowing water habitat required by riverine species such as the flathead chub. Berry and Erickson (1995) reported that reservoirs cover 1,216 km of the 3,768 km of the Missouri River as it flows from the Rocky Mountains in Montana to its confluence with the Mississippi River in Missouri. This represents a loss of nearly one-third of the flowing water habitat in this major river that is in the core range of the flathead chub.

Reservoirs also reduce sediment load, making Great Plains rivers less turbid and more confined in narrower, deeper channels. Consider that in the lower Kansas River, average sediment yield declined from $23.48 \times 10^9$ kg/yr during 1958-1961 (before completion of an extensive reservoir system) to $7.71 \times 10^9$ kg/yr during 1978-1980 (after reservoir completion). Thus, sediment loads in the Kansas River have declined to only 33 percent of pre-impoundment levels (Sanders et al. 1993). A similar phenomenon occurred in the Missouri River where water turbidity declined to only 25 percent of historic levels after construction of many large, mainstem impoundments during the middle of the $20^{th}$ century (Pflieger and Grace 1987). The reduced turbidity in Great Plains rivers has resulted in replacement of native fishes tolerant of turbid waters, including the flathead chub, plains killifish, and sturgeon chub, with native or introduced species characteristic of clearer waters such as gizzard shad (*Dorosoma cepedianum*), and several species of minnows and centrarchids (Cross and Moss 1987). Pflieger (1997) noted that during the 50-year period following completion of six large reservoirs on the Missouri River, the flathead chub declined from 31.0 to 1.1 percent of the small fishes in collections from the Missouri River while the sight-feeding emerald shiner increased from 0.1 to 28.5 percent of small fishes.

Dams cause a loss of connectivity in a drainage network that can exacerbate the loss of fish populations caused by drought, channel dewatering due to irrigation, or poor water quality. In some cases, populations of fishes have been extirpated after stream reaches became isolated from the rest of the watershed by construction of a dam. Winston et al. (1991) reported that four minnow species were lost due to the damming of a prairie stream in Oklahoma. The species were cut off from downstream populations by the reservoir that formed behind the dam, and when the upstream populations were lost to due natural disturbances, repopulation from downstream sources was no longer possible. Woodling (1985) speculated that a large diversion constructed upstream of Florence, Colorado, prevented the flathead chub from re-establishing a population in the upper Arkansas River after water quality problems associated with mining were eliminated.

It is difficult to separate threats from nonnative species and threats posed by construction of reservoirs because these two factors interact. Piscivores such as walleye, black crappie (*Pomoxis nigromaculatus*), and largemouth bass, along with potential competitors such as gizzard shad, emerald shiner, and red shiner have been widely introduced into reservoir habitats throughout the native range of the flathead chub. These nonnative species are well adapted to the relatively clear, standing water habitat that is produced when dams impound turbid prairie rivers with naturally high flow fluctuations. The negative effects of nonnative species are often enhanced by reduced turbidity. Piscivores become more effective, and sight-feeding competitors gain a feeding advantage in clearer water (Pflieger and Grace 1987). Thus, construction of reservoirs and introductions of nonnative species have a synergistic negative effect on small native fish species such as flathead chub. In prairie streams that have not been impounded, nonnative fishes have remained uncommon and have not had detrimental effects on native fishes (Quist et al. 2004).

Overgrazing by livestock, especially in the semi-arid regions that are common throughout the range of flathead chubs is another potential threat. Overgrazing can increase stream width, decrease depth, and increase the likelihood of streams becoming intermittent (Platts 1991). In intermittent streams the accumulation of animal wastes in pools in late summer can result in low oxygen concentrations and high ammonia concentrations that are detrimental to aquatic organisms (Scarnecchia 2002).

Historically most streams in the Great Plains experienced large flow fluctuations, and native fishes are generally adapted to these conditions (Dodds et al. 2004). However, two anthropogenic activities often result in streamflow conditions outside the normal range of variability: groundwater pumping and production of wastewater from coalbed methane recovery. Groundwater removal for agriculture or municipal use can lower the water table to the point that formerly flowing streams become dry for most of the year. The Arkansas River in Kansas is a good example; since the 1970's, the pumping of groundwater has led to a mostly dry channel as the river passes through watersheds underlain by the Ogallala-High Plains aquifer (Dodds et al. 2004). The loss of streamflow has resulted in the extirpation of flathead chub from this region of the Arkansas River (Cross and Moss 1987). Extraction of coalbed methane can have the opposite effect by increasing streamflows or converting intermittent streams to permanent flow (Freilich 2004). This flow enhancement results from the discharge of deep groundwater into surface waters during the extraction of methane from coalbeds. Conversion of intermittent streams to perennial ones could be detrimental to flathead chub if it allowed the establishment of nonnative piscivorous fishes. Additionally, groundwater inputs could alter the thermal regime of surface waters which, in turn, could disrupt the breeding patterns of native fishes and favor the establishment of nonnative fishes. Finally, water produced during coalbed methane extraction can be highly saline and may contain high concentrations of metals toxic to fish.

## *Conservation Status of Flathead Chub in Region 2*

The flathead chub has declined in distribution and/or population abundance throughout portions of the Great Plains region, and there is concern about the long-term conservation status of this species in four of the five states within Region 2 of the USFS. The species is most imperiled in Kansas where it is considered a state threatened species and has suffered declines due to loss of streamflow (Cross and Moss 1987). In Colorado, the flathead chub is considered a species of special concern, and it is illegal to possess or harvest this species for private or commercial use. In Nebraska, the flathead chub is not listed as state threatened or endangered, but has declined to the extent that it is considered a species in need of conservation attention. In Wyoming, the flathead chub has declined precipitously in the North Platte River drainage where reservoir construction has lead to habitat loss and the introduction of nonnative piscivores and competitors (Quist et al. 2004). However, flathead chub remains abundant in other drainages within Wyoming. The only state without conservation concerns for flathead chub is South Dakota.

In terms of its status with the USFS, the flathead chub is not considered a sensitive species on those grasslands and forests where it occurs (**Table 2**). Most of the declines in flathead chub populations occurred during the later half of the 20$^{th}$ century and were associated with the construction of large impoundments on large rivers in the region. Continued loss of both turbid conditions and adequate in-channel flow are anticipated to further impact populations. Although the species remains widespread throughout much of its historical range, it is currently unknown if remaining populations are stable or if the species is continuing to decline. Thus, further monitoring of remaining populations is warranted.

## *Potential Management of the Species in Region 2*

### Implications and potential conservation elements

The major management actions that would benefit native fishes characteristic of turbid prairie streams are preservation of natural streamflows and turbidity levels, maintenance of stream connectivity, preventing the establishment of nonnative piscivores, and avoiding introductions of nonnative small-bodied fishes from other Plains watersheds (Fausch and Bestgen 1997). The decline in flathead chub populations is largely associated with the loss of their habitat in fluctuating, turbid, prairie rivers. The primary reason for the loss of habitat is reservoir construction, and thus restoring natural flow regimes and turbidity levels would facilitate the recovery of flathead chub populations. Short of removing dams, one way to restore more natural flow regimes is to create "flushing flows" by releasing water during the normal spring runoff period. Although such flows are of shorter duration than normal spring runoff, they help restore channel complexity, reconnect the stream with its floodplain, and remove accumulated fine sediments (Poff et al. 1997). Efforts are being made to return more natural conditions to large river systems such as the Missouri River by restoring natural channel and floodplain morphology and floodplain vegetation (Hesse et al. 1989). These efforts include recovery of oxbows, sandbars, and vegetated backwater areas and creation of ladders or bypass channels to allow fish to navigate past dams. Such efforts will benefit numerous aquatic and terrestrial wildlife species, especially those that rely on the river-floodplain linkage. Furthermore, such restoration efforts often can be done without removing dams or their associated reservoirs.

Given the high costs of largescale restoration efforts and the political difficulties involved in removing existing dams for strictly ecological reasons (Hart et al. 2002), maintaining the few remaining unimpounded turbid prairie rivers in a free-flowing state would be an obvious conservation priority. Furthermore, maintaining such rivers in their naturally turbid state would benefit a suite of fish species that have declined following impoundment of prairie streams such as flathead chub, Arkansas River shiner (*Notropis girardi*), sturgeon chub, plains minnow, pallid sturgeon (*Scaphirhynchus albus*), Topeka shiner (*N. tristis*), and suckermouth minnow (Cross and Moss 1987, U.S. Fish and Wildlife Service Web site http://www.fs.fed.us/r2/nebraska/gpng/usfwslist.html). An example of such a river is the highly turbid Powder River in Wyoming. Hubert (1993) noted that this relatively pristine river has retained a largely native fish fauna that includes flathead chub and sturgeon chub, and thus it has special value as a remnant of what Great Plains river ecosystems were like prior to anthropogenic alterations. Another example of remnant prairie river habitat is the Missouri River in North Dakota upstream of Lake Sakakawea (Fisher et al. 2002). This river segment retains natural flood-pulse patterns and a functioning relationship with its floodplain and harbors a healthy population of flathead chubs. Areas such as these should be considered important conservation sites for preserving flathead chubs and other fish species characteristic of turbid, fluctuating, prairie rivers.

In some cases, reduction of livestock grazing may be necessary to restore habitat in prairie streams. Although fishes of Great Plains streams evolved in what are often severe environments (Dodd et al. 2004), overgrazing by livestock can exacerbate naturally stressful conditions. This occurs when livestock trampling makes streams wide and shallow, causing increased intermittency and the loss of pools that serve as refuges during low flow periods. Also, manure from livestock can severely degrade water quality, especially during low flow conditions (Scarnecchia 2002).

Another threat to prairie stream fishes, including flathead chub, is the lowering of the water table to the point that streams stop flowing. A prime example is the Arkansas River in Kansas where flathead chub have been extirpated from reaches that have become intermittent due to pumping of groundwater (Cross and Moss 1987, Dodds et al. 2004). The obvious management action would be to reduce the rate of groundwater removal so that groundwater aquifers can be recharged to the point that surface stream flows resume.

## Tools and practices

### *Inventory and monitoring of populations and habitat*

Most inventory efforts to date have involved determining the presence or absence of flathead chub at a range of sites across major drainages. Examples include surveys of the South Platte River and Arkansas River drainages in Colorado (Nesler et al. 1997, 1999) and the Missouri River drainage in Wyoming (Patton 1997). These inventories typically involve collecting all species at a site using seining or electrofishing techniques. Often, the results are compared with earlier inventories to determine which species have decreased and which species have increased their geographic range. For example, the distributions of native fishes in the Arkansas River drainage collected in the 1992 survey were compared with distributions reported in earlier surveys starting in 1900 (Nesler et al. 1999). Likewise, Patton et al. (1998) compared species distributions in the 1990's with distributions from a fish survey done in the 1960's. Unfortunately, except for Patton et al. (1998), recent fish surveys rarely involved the same set of sites from earlier surveys, making it difficult to quantify changes in the occurrence of fishes such as the flathead chub. Although one can determine if a species is still present within a drainage, it is difficult to determine if the species is increasing or decreasing. This makes it difficult to identify species in the early stages of decline because we often can not recognize declines until a species is lost from a drainage basin.

The occurrence of flathead chubs in larger streams with turbid water and shifting sand bottoms poses a challenge for quantifying fish abundance. Such streams can be too shallow for setting gill nets or using boat-mounted electrofishing gear but too deep to seine effectively, especially given the shifting sand substrates. High turbidity and high salinity limit the effectiveness of electrofishing methods. Gerhardt and Hubert (1990) found that hoop nets were the most effective method of sampling fishes in their work on the Powder River in Wyoming. Given that the entire assemblage of small, plains stream fishes can be sampled simultaneously, monitoring programs that revisited the same set of sites at regular intervals could be a cost-effective way to determine trends for a number of species within a national forest or grassland. When there is a large number of possible survey sites and one wishes to make inferences involving a spatially-extensive area, a probability-based sampling design such as used in the U.S. Environmental Protection Agency's EMAP program could be employed (Olsen et al. 1999).

We are aware of only one national grassland within Region 2 where a regular inventory program involving nongame plains fishes is on-going. The Pawnee National Grassland in northern Colorado began a systematic sampling program in 1998. However, the Pawnee National Grassland is within the South Platte River drainage and flathead chub were not historically present in this region.

The little monitoring that has been done for flathead chub has involved determining occurrence (i.e., presence or absence) across relatively large areas. We are not aware of any on-going monitoring being done that would detect population changes for this species. It is likely that individual populations would show fluctuations in population size given that the species occurs in systems with high naturally hydrological variability.

There has been virtually no systematic inventorying or monitoring of instream habitats of plains streams except for occasional studies involving single streams and time periods seldom exceeding a decade. These studies consistently point to the importance of deep pools as refuge habitat and the importance of recolonization in maintaining fish populations in streams prone to intermittency (Bramblett and Fausch 1991, Scheurer et al. 2003). There have been some synoptic papers describing broadscale changes in plains streams during the past century, especially for larger rivers (e.g. Cross and Moss 1987, Pflieger and Grace 1987, Hesse et al. 1989, Berry and Galat 1993, Limbird 1993, Sanders et al. 1993). However, there is little information available to make quantitative estimates of habitat change on mid-size and small streams. Such information would allow managers to track habitat availability for flathead chub and would provide insights into why populations have declined.

A promising approach for identifying watersheds that have the appropriate habitat conditions to support flathead chub populations is the coupling of habitat modeling with a Geographic Information System (GIS). The idea is to identify features such as thermal regime, stream gradient, stream size, and watershed geology that are associated with the presence of flathead chub and then use modeling approaches such as logistic regression to predict which watersheds across a large region have similar features (Scott et al. 2002). This approach has been used to identify watersheds in South Dakota where the flathead chub is predicted to occur (http://wfs.sdstate.edu/sdgap/sdgap.htm). With this information, biologists can focus fish surveys on watersheds that have a high probability of supporting flathead chub in an effort to identify new populations. This information also can be used to identify watersheds that lack flathead chub but which have the habitat conditions to support this species; such watersheds would be prime areas for reintroduction efforts.

### *Population or habitat management practices*

We did not find any ongoing population or management practices directed specifically at flathead chub. The establishment of preserves for native plains fishes has lagged behind efforts to preserve native coldwater fish species in the region, especially cutthroat trout (*Oncorhynchus clarki*) (Young 1995). However, management agencies are increasing their interest in the conservation of native nongame fish species (Nesler et al.1997, 1999; Weitzel 2002). Also, private conservation organizations could play a role in preserving native, plains streams fishes. For example, The Nature Conservancy has purchased the Fox Ranch on the Arikaree River near Wray, Colorado and is helping to preserve the site as an example of a free-flowing, plains stream (Web site: http://nature.org/wherewework/northamerica/states/colorado/preserves/). This preserve will afford conservation protection for an entire assemblage of native fishes. However, such preserves cannot reverse changes in flow regimes or water clarity that are due to impoundments located upstream of the preserve. Conservation efforts at the scale of the entire drainage-basin will be needed to restore natural flow regimes and water quality conditions that will benefit fishes requiring hydrologically-variable, turbid stream ecosystems.

Even though flathead chubs are found downstream of most National Forest System lands in Region 2, activities on the forests and grasslands can potentially impact the species. For instance mining activities that alter water quality and stream flows may negatively impact aquatic organisms far downstream. Metal contamination from mining activities in headwater streams was thought to be the reason for the loss of flathead chubs in the Arkansas River between Salida and Florence, Colorado. Even though water quality has been restored, a large diversion near Florence may be preventing the upstream recolonization of flathead chubs (Woodling 1985).

## *Information Needs*

There is little information available concerning population trends for flathead chub on individual national grasslands and forests within the USFS Rocky Mountain Region. As discussed earlier (see Tools and practices), monitoring flathead chub populations on national grasslands could be done within the framework of monitoring the entire fish assemblage. Such an approach would provide information on a set of prairie stream fishes that are of conservation concern in USFS Region 2. In addition to flathead chub, these include sturgeon chub and Arkansas River shiner. Measures of catch-per-unit-effort provide a cost-effective index of fish abundance and are useful for trend monitoring if the same set of sites is sampled in successive time periods (Hubert 1996, Ney 1999). Estimates of actual population size can be obtained through mark-recapture or depletion-removal approaches, but these approaches require more effort and would reduce the number of sites that could be sampled.

Little is known about the main factors limiting population size for flathead chubs. Little is known about spawning habitat requirements although the species appears to spawn in deep, main channel habitats (Fisher et al. 2002). Much of this habitat has been lost due to the construction of reservoirs. Information on spawning ecology would help to determine if reduced recruitment is a major factor in the decline of flathead chubs in impounded river systems. It is hypothesized that flathead chubs belong to a spawning guild of fishes whose semibouyant eggs and newly-hatched larvae float downstream during development. Also, it has been speculated that a minimum length of free-flowing river on the order of 200 to 300 km may be necessary to maintain populations of fish species that reproduce in this manner (Bonner and Wilde 2000). If this is true, then conservation efforts would entail either preserving or restoring long reaches of free-flowing streams for these species.

For adult flathead chubs, little is known about the role of competitors or predators in limiting population size or how these factors interact with turbidity. Reduction in turbidity is cited by many authors as a reason for the decline of flathead chubs. The mechanisms by which reduced turbidity reduces flathead chub populations have been postulated to include increased competition from other site-feeding fish species and increased predation by visually-oriented piscivorous fishes. Further information on the interaction of competition, predation, and reduced turbidity in limiting flathead chub populations would provide insights as to whether restoration of high turbidity levels is a necessary condition for recovery of flathead chub populations in systems where competing species and predators are currently abundant.

There is a major gap in our knowledge of vital rates important in understanding and modeling population demographics. Age-specific survival rates have not been determined directly and have to be inferred from the few studies that presented size or age-class frequency histograms. There is no information on egg hatching rates in the wild, and this parameter could be determined only by estimating survival rates for other age classes and then back-solving the demographic matrix assuming a stable population size. Information on the spatial and temporal variability of vital rates is important for modeling population fluctuations and extinction probabilities.

Finally, there is an important issue regarding management of information on flathead chub as well as other native Great Plains stream fishes. In our phone conversations and e-mail exchanges with biologists from the various national forests and grasslands within Region 2, it became apparent that much of the data on these species is not in a readily accessible or retrievable form. The biologists with whom we spoke were extremely cooperative in providing information, but this often involved sifting through old field data sheets or sparsely documented reports whose authors were no longer working in that region. In some cases, there was little information about the exact locations sampled, the level of sampling effort, or the meaning of shorthand notations (e.g., for species abbreviations) used in field notes. Better documentation of sampling locations, sampling effort, and fish catches in formalized reports and electronic data bases would ensure that the data remain useful and accessible to future generations of managers and researchers. Such archived data are critical if we are going to detect trends in species abundances or distributions that would signal the need for conservation efforts.

There is a need to develop and implement aquatic habitat inventories in order to identify the role that habitat loss has played in the decline of flathead chub populations. This is especially true for the smaller stream systems where land-use and water development activities such as irrigation and groundwater pumping appear to have increased intermittency (Dodds et al. 2004). On the ground, surveys would be costly to implement, but it should be possible to document the extent of intermittency by use of satellite imagery or aerial photography.

# DEFINITIONS

**Connectivity** refers to the pathways that allow fish to move about a drainage and to recolonize areas after local extinctions have occurred. Dams and road culverts often interrupt the connectivity of a drainage.

**Environmental fluctuations** are changes in habitat conditions such as temperature, salinity, oxygen concentration, or the amount of water flowing in a stream.

**Fecundity** is the number of eggs produced by a female fish.

**Habitat capability** refers to the ability of a habitat to support a species.

**Habitat connectivity** refers to the degree to which organisms can move throughout the area or system of interest.

**Intermittent tributary** is a stream that flows into a larger stream and that ceases to flow during certain periods of the year. The stream may dry up completely or exist as a series of pools.

**Meristic character** is an anatomical feature that can be counted, such as the number of spines on the dorsal fin or the number of scales along the lateral line of a fish. Meristic characters are frequently used to identify fish species using a taxonomic key.

**Metapopulations** are spatially isolated populations that function as independent populations but that can exchange occasional individuals. This exchange allows extirpated populations to become reestablished.

**Microhabitats** are the localized habitat conditions used by organisms.

**Morphometric character** is an anatomical feature that can be measured, such as the length of various body parts or ratios of body parts (e.g. diameter of the eye divided by the length of the head). Morphometric characters are used to identify fish species using a taxonomic key.

**National Heritage Rank of the Nature Conservancy** is a system of rating the conservation status of species based on the following categories: S1 = critically imperiled ($\leq$5 occurrences, very small range); S2 = imperiled (6-20 occurrences, small range); S3 = vulnerable (21-100 occurrences, restricted range); S4 = apparently secure (> 100 occurrences, uncommon not rare), S5 = secure (widespread and abundant)

**Piscivorous** means “fish-eating”.

**Sensitive species** as defined by the USDA Forest Service are plants and animals whose population viability is identified as a concern by a Regional Forester because of significant current or predicted downward trends in abundance or significant current or predicted downward trends in habitat capability that would reduce a species distribution.

**Sink populations** are populations where the death rate exceeds the birth rate. Sink populations require continual immigration from nearby populations if they are to avoid going extinct.

**Source populations** are populations where the birth rate exceeds the death rate, and thus these populations are a source of emigrants to nearby areas, including sink populations.

**Species of concern** is a species that has declined in abundance or distribution to the point that management agencies are concerned that further loss of populations or habitat will jeopardize the persistence of the species within that region.

**Species viability** refers to the likelihood that a species will continue to persist.

**Vital rates** refers to demographic characteristics such as birth rate, fecundity, and survival rate that determine the growth rate of a population.

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# Appendix A

## *Matrix Population Analysis of Population Demographics for Flathead Chub*

The study of Scarnecchia et al. (2000) provided the basis for formulating a life cycle graph for flathead chub that comprised nine age-classes and assigned first reproduction to the third age-class (**Figure A1**). The age-specific egg production rates described by Martyn and Schmulbach (1978) and Scarnecchia et al. (2000) provided the basis for calculating fecundities. Linear regression provided data for those size/age-classes for which data were not available. Survival rates for "adults" were based on a catch curve analysis from data in Bishop (1975). Because the only estimate for first-year survival was from the larval stage to yearling (Bishop 1975), first-year survival ($P_{21}$) was assigned a value that yielded a population growth rate (λ) of 1.0. This "missing element" method (McDonald and Caswell 1993) is justified by the fact that, over the long term, λ must be near 1 or the species will go extinct or the population will grow unreasonably large. From the life cycle graph (**Figure A1**), we produced a matrix population analysis with a post-breeding census (McDonald and Caswell 1993, Caswell 2000). The model has two kinds of input terms: $P_i$ describing survival rates, and $m_i$ describing fertilities (**Table A1**). **Figure A2** shows the symbolic terms and corresponding numeric values for the projection matrix developed from the life cycle graph. The model assumes female demographic dominance so that, for example, fertilities are given as female offspring per female. Thus, the egg number used was half the total, assuming the 1:1 sex ratio noted by Gould (1985). The population growth rate (λ) is 1.000 based on the estimated vital rates used for the matrix. Although this suggests a stationary population, the value was used as an assumption for deriving a vital rate, and therefore it should not be interpreted as an indication of the general well-being of the population. Other parts of the analysis provide a better guide for assessment. In contrast to some fisheries terminology, the convention here is ordinal numbering beginning with 1 (first, second, third, and fourth age-classes). Thus, age-class 0 in fisheries terminology corresponds to age-class 1 in the matrix model. Each age class describes a one-year census interval period, such as the age class that begins with an egg at the census and proceeds to the first clutch produced by a yearling that is described by the self-loop $F_{11}$ in **Figure A1**.

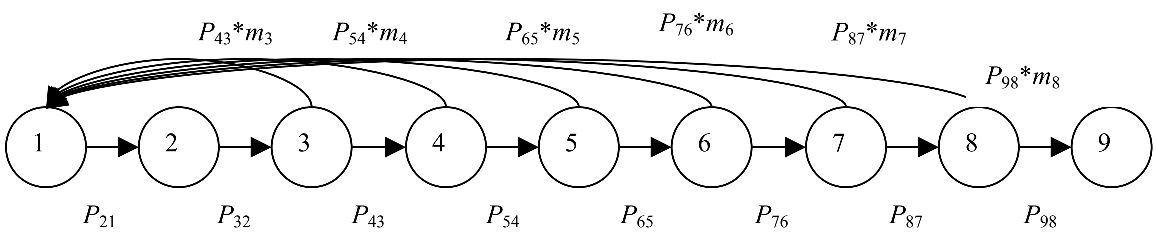


**Figure A1.** Life cycle graph for flathead chub. The numbered circles (nodes) represent the nine age-classes. The arrows (arcs) connecting the nodes represent the vital rates — transitions between age-classes such as survival ($P_{ji}$) or fertility (the six sets of $P_{ji} * m_i$, lying above the respective arcs pointing back toward the first node from Nodes 3 through 8). Note that reproduction begins from Node 3.

**Table A1.** Parameter values for the component terms ($P_i$ and $m_i$) that make up the vital rates in the projection matrix for flathead chub.

| Parameter | Numeric value | Interpretation |
|---|---|---|
| $m_3$ | 2,225.8 | Number of female eggs produced by a third-year female |
| $m_4$ | 2,603.3 | Number of female eggs produced by a fourth-year female |
| $m_5$ | 2,854.9 | Number of female eggs produced by a fifth-year female |
| $m_6$ | 3,567.9 | Number of female eggs produced by a sixth-year female |
| $m_7$ | 4,092.1 | Number of female eggs produced by a seventh-year female |
| $m_8$ | 4,616.3 | Number of female eggs produced by a eighth-year female |
| $P_{21}$ | 0.000496 | First-year survival rate |
| $P_{32}$ | 0.348 | Second-year survival rate (half that of "adults") |
| $P_a$ | 0.696 | Annual survival rate of adults |

## Sensitivity analysis

A useful indication of the state of the population comes from the sensitivity and elasticity analyses. Sensitivity is the effect on λ of an absolute change in the vital rates ($a_{ij}$, the arcs in the life cycle graph, **Figure A1** and the cells in the matrix, A, **Figure A2**). Sensitivity analysis provides several kinds of useful information. First, sensitivities show "how important" a given vital rate is to λ or fitness. For example, one can use sensitivities to assess the relative importance of survival ($P_i$) and reproductive ($F_i$) transitions. Second, sensitivities can be used to evaluate the effects of inaccurate estimation of vital rates from field studies. Inaccuracy will usually be due to paucity of data but could also result from use of inappropriate estimation techniques or other errors of analysis. In order to improve the accuracy of the models, researchers should concentrate additional effort on transitions with large sensitivities. Third, sensitivities can quantify the effects of environmental perturbations, wherever those can be linked to effects on stage-specific survival or fertility rates. Fourth, managers can concentrate on the most important transitions. For example, they can assess which stages or vital rates are most critical to increasing λ of endangered species or the "weak links" in the life cycle of a pest. **Figure A3** shows the "possible sensitivities only" matrix for this analysis (one can calculate sensitivities for non-existent transitions, but these are usually either meaningless or biologically impossible — for example, the sensitivity of λ to moving from age-class 3 to age-class 2).

In general, changes that affect one type of age class or stage will also affect all similar age classes or stages. For example, any factor that changes the annual survival rate of age-class 3 females is very likely to cause similar changes in the survival rates of other "adult" reproductive females (those in age-classes 4 through 8). Therefore, it is usually appropriate to assess the summed sensitivities for similar sets of transitions (vital rates). For this model, the result is that the summed sensitivity of λ to changes in survival is of overriding importance. Flathead chub show sensitivity (100 percent of total) only to changes in survival, with first-year survival alone accounting for 99.7 percent of the total. The major conclusion from the sensitivity analysis is that first-year survival is overwhelmingly important to population viability.

| Age | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | $P_a m_6$ | $P_a m_6$ | $P_a m_6$ | $P_a m_6$ | $P_a m_6$ | $P_a m_6$ | |
| 2 | $P_{21}$ | | | | | | | | |
| 3 | | $P_{32}$ | | | | | | | |
| 4 | | | $P_a$ | | | | | | |
| 5 | | | | $P_a$ | | | | | |
| 6 | | | | | $P_a$ | | | | |
| 7 | | | | | | $P_a$ | | | |
| 8 | | | | | | | $P_a$ | | |
| 9 | | | | | | | | $P_a$ | |

| Age | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 1549.2 | 1811.9 | 1987.0 | 2483.2 | 2848.1 | 3213.0 | 0 |
| 2 | 0.0005 | | | | | | | | |
| 3 | | 0.348 | | | | | | | |
| 4 | | | 0.696 | | | | | | |
| 5 | | | | 0.696 | | | | | |
| 6 | | | | | 0.696 | | | | |
| 7 | | | | | | 0.696 | | | |
| 8 | | | | | | | 0.696 | | |
| 9 | | | | | | | | 0.696 | |

**Figure A2.** The top matrix shows symbolic values for the projection matrix of vital rates, **A** (with cells $a_{ij}$) corresponding to the flathead chub life cycle graph of **Figure A1**. Meanings of the component terms are given in **Table A1**. The bottom matrix presents the actual values used for the matrix analysis.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2 | **412.1** | | | | | | | | |
| 3 | | **0.587** | | | | | | | |
| 4 | | | **0.215** | | | | | | |
| 5 | | | | 0.151 | | | | | |
| 6 | | | | | 0.103 | | | | |
| 7 | | | | | | 0.060 | | | |
| 8 | | | | | | | 0.027 | | |
| 9 | | | | | | | | 0.000 | |

**Figure A3.** Possible sensitivities only matrix, $\mathbf{S_p}$ (blank cells correspond to zeros in the original matrix, A). The three transitions to which the population growth rate (λ) of flathead chub is most sensitive are highlighted: first-year survival (Cell $s_{21}$ = 412.1), second-year survival ($s_{32}$ = 0.587), and third-year survival ($s_{43}$ = 0.215).

## Elasticity analysis

Elasticities are useful in resolving a problem of scale that can affect conclusions drawn from the sensitivities. Interpreting sensitivities can be somewhat misleading because survival rates and reproductive rates are measured on different scales. For instance, a change of 0.5 in survival may be a large alteration e.g., a change in survival rate from 0.9 to 0.4 corresponds to a reduction in survival from 90 percent to 40 percent. On the other hand, a change of 0.5 in fertility may be a very small proportional alteration, e.g., a change from a clutch of 3,000 eggs to 2,999.5 eggs. Elasticities are the sensitivities of λ to proportional changes in the vital rates ($a_{ij}$) and thus largely avoid the problem of differences in units of measurement. The elasticities have the useful property of summing to 1.0. The difference between sensitivity and elasticity conclusions results from the weighting of the elasticities by the value of the original arc coefficients (the $a_{ij}$ cells of the projection matrix). Management conclusions will depend on whether changes in vital rates are likely to be absolute (guided by sensitivities) or proportional (guided by elasticities). By using elasticities, one can further assess key life history transitions and stages as well as the relative importance of reproduction ($F_i$) and survival ($P_i$) for a given species.

Elasticities for flathead chub are shown in **Figure A4**. The population growth rate (λ) is most elastic to changes in first-year and second-year survival ($P_{21}$, the self-loop on the first node in **Figure A1**, and $P_{23}$), both with an equivalent 20.4 percent of the total, followed by third-year survival ($P_{43}$). The sensitivities and elasticities for flathead chub correspond in rank magnitude, although first-year survival is far more important in the sensitivity analysis (99.7 percent) than in the elasticity analysis (20.4 percent). The summed survival elasticities account for fully 80 percent of the total (compared to 20 percent for the summed reproductive elasticities). Thus, survival through the first two non-reproductive years, and to a lesser extent "adult" survival, are the data elements that warrant careful monitoring in order to refine the matrix demographic analysis.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 0.055 | 0.044 | 0.034 | 0.030 | 0.024 | 0.019 | |
| 2 | **0.204** | | | | | | | | |
| 3 | | **0.204** | | | | | | | |
| 4 | | | **0.150** | | | | | | |
| 5 | | | | 0.105 | | | | | |
| 6 | | | | | 0.071 | | | | |
| 7 | | | | | | 0.042 | | | |
| 8 | | | | | | | 0.019 | | |
| 9 | | | | | | | | 0.000 | |

**Figure A4.** Elasticity matrix, **E** (remainder of matrix consists of zeros). The population growth rate (λ) of flathead chub is most elastic to changes in first- and second-year survival ($e_{21}$ = $e_{32}$ = 0.204), followed by third-year survival ($e_{43}$ = 0.150). Note the considerably lesser relative importance of first-year survival in the elasticity analysis relative to the sensitivity analysis.

## Other demographic parameters

The stable age distribution (**Table A2**) describes the proportion of each age-class in a population at demographic equilibrium. Under a deterministic model, any unchanging matrix will converge on a population structure that follows the stable age distribution, regardless of whether the population is declining, stationary or increasing. Under most conditions, populations not at equilibrium will converge to the stable age distribution within 20 to 100 census intervals. For flathead chub at the time of the post-breeding annual census (just after the end of the breeding season), eggs represent 99.9 percent of the population. **Table A2** has a second column, omitting the egg portion, in order to show the non-egg distribution. Reproductive values (**Table A3**) can be thought of as describing the "value" of a stage as a seed for population growth relative to that of the first (newborn or, in this case, egg) stage. The reproductive value of the first stage is always 1.0. A female individual in age-class 2 is "worth" 2,017 eggs, and so on (Caswell 2000). The reproductive value is calculated as a weighted sum of the present and future reproductive output of a stage discounted by the probability of surviving (Williams 1966). The peak reproductive value (6174) occurs at the fifth age-class, and these females are an important stage in the life cycle (although they represent only 8.2 percent of the non-egg census population). The cohort generation time for this fish is 4.9 years (SD = 1.6 years).

**Table A2.** Stable age distribution (right eigenvector). At the census, > 99.9 percent of the individuals in the population should be eggs. The third column is the stable age distribution after omitting eggs. Nearly fifty percent of the non-egg population will be second-year females (censused as yearlings) and the rest will be older, "adult" females.

| Age Class | Description | Proportion | Omitting eggs |
|---|---|---|---|
| 1 | Eggs (to yearling) | > 0.999 | n.a. |
| 2 | Second-year females | 0 | 0.487 |
| 3 | Third-year females | 0 | 0.169 |
| 4 | Fourth-year females | 0 | 0.118 |
| 5 | Fifth-year females | 0 | 0.082 |
| 6 | Sixth-year females | 0 | 0.057 |
| 7 | Seventh-year females | 0 | 0.04 |
| 8 | Eighth-year females | 0 | 0.028 |
| 9 | Maximum-age females | 0 | 0.019 |

**Table A3.** Reproductive values (left eigenvector). Reproductive values can be thought of as describing the "value" of an age class as a seed for population growth relative to that of the first (newborn or, in this case, egg) age class. The reproductive value of the first age class is always 1.0. The peak reproductive value (fifth-year females) is highlighted.

| Age Class | Description | Reproductive values |
|---|---|---|
| 1 | Eggs/first-year females | 1 |
| 2 | Second-year females | 2,016.8 |
| 3 | Third-year females | 5,797.4 |
| 4 | Fourth-year females | 6,106.6 |
| 5 | Fifth-year females | **6,173.5** |
| 6 | Sixth-year females | 6,018.1 |
| 7 | Seventh-year females | 5,081.8 |
| 8 | Eighth-year females | 3,211.8 |
| 9 | Maximum-age females | 0 |

## Stochastic model

We conducted a stochastic matrix analysis for flathead chub. We incorporated stochasticity in several ways, by varying different combinations of vital rates or by varying the amount of stochastic fluctuation (**Table A4**). Under Variant 1 we subjected first-year reproduction ($F_{11}$) to stochastic fluctuations. Under Variant 2 we varied the survival of first-year fish ($P_{21}$). Under Variant 3 we varied the survival of all age classes, $P_i$. Each run consisted of 2,000 census intervals (years) beginning with a population size of 10,000 distributed according to the stable age distribution under the deterministic model. Beginning at the stable age distribution helps avoid the effects of transient, non-equilibrium dynamics. The overall simulation consisted of 100 runs (each with 2,000 years). We varied the amount of fluctuation by changing the standard deviation of the truncated random normal distribution from which the stochastic vital rates were selected. The default value was a standard deviation of one quarter of the "mean" (with this "mean" set at the value of the original matrix entry [vital rate], $a_{ij}$ under the deterministic analysis). Variant 4 affected the same transitions as Variant 3 ($P_i$) but was subjected to half the variation (SD was 1/8 of the mean). We calculated the stochastic growth rate, $log\lambda_S$ (see equation 14.61 of Caswell 2000) after discarding the first 1,000 cycles in order to further avoid transient dynamics.

The stochastic model (**Table A4**) produced two major results. First, varying reproduction had very little effect on λ. For example, none of 100 runs led to extinctions with variable reproduction under Variant 1, from the starting size of 10,000. In contrast, varying the survival rates of all age classes under Variant 3 lead to 39 extinctions. This difference in the effects of stochastic variation is predictable largely from the elasticities. λ was more elastic ($e_{21}$ = $e_{32}$ = 0.204) to changes in first- and second-year survival than it was to the sum of all the changes in the fertility rates (summed fertility elasticities = 0.20). This negative effect of variability occurs despite the fact that the average vital rates remain the same as under the deterministic model — the random selections are from a symmetrical distribution. This apparent paradox is due to the lognormal distribution of stochastic ending population sizes (Caswell 2000). The lognormal distribution has the property that the mean exceeds the median, which exceeds the mode. Any particular realization will therefore be most likely to end at a population size considerably lower than the initial population size. Second, the magnitude of stochastic fluctuation has a discernible effect on population dynamics (compare Variants 3 and 4 in **Table A4**). For flathead chub under the $P_i$ Variant 4 with reduced (1/8 vs. 1/4) variability, none of 100 trials of stochastic projection went to extinction (vs. 39 with SD = 1/4 under Variant 3). These results indicate that populations of flathead chub are vulnerable to stochastic fluctuations in early survival (due, for example, to annual climatic change or to human disturbance) and, to a lesser degree, to variations in "adult" survival. Pfister (1998) showed that for a wide range of empirical life histories, high sensitivity or elasticity was negatively correlated with high rates of temporal variation. That is, most species appear to have responded to strong selection by

**Table A4.** Summary of four variants of stochastic projections for flathead chub.

| | Variant 1 | Variant 2 | Variant 3 | Variant 4 |
|---|---|---|---|---|
| **Input factors**: | | | | |
| Affected cells | $F_i$ | $P_{21}$ | $P_i$ | $P_i$ |
| S.D. of random normal distribution | ¼ | ¼ | ¼ | ⅛ |
| **Output values**: | | | | |
| Deterministic λ | 1 | 1 | 1 | 1 |
| # Extinctions / 100 trials | 0 | 0 | 39 | 0 |
| Mean extinction time | n.a. | n.a. | 1,426 | n.a. |
| # Declines / # survived pop | 45/100 | 84/100 | 57/61 | 73/100 |
| Mean ending population size | 22,615 | 10,352 | 1,715 | 17,252 |
| Standard deviation | 38,826 | 26,340 | 3,954 | 45,750 |
| Median ending population size | 10,954 | 1,608 | 50 | 2,042 |
| Log λs | 0.0001 | -0.0009 | -0.0041 | -0.0008 |
| λs | 1 | 0.9991 | 0.9959 | 0.9992 |
| % reduction in λ | 0 | 0.13 | 0.45 | 0.11 |

having low variability for sensitive transitions in their life cycles. A possible concern is that anthropogenic impacts may induce variation in previously invariant vital rates (such as early survival), with consequent detrimental effects on population dynamics. For the fish, with stochasticity having the greatest impact on early survival, the life history may not allow the kind of adjustment of risk load that may be possible in other species. Variable early survival is likely to be the rule rather than the exception.

### Potential refinements of the models

Clearly, the better the data on survival rates are, the more accurate the resulting analysis. Data from natural populations on the range of variability in the vital rates would allow more realistic functions to model stochastic fluctuations. For example, time series based on actual temporal or spatial variability, would allow construction of a series of "stochastic" matrices that mirrored actual variation. One advantage of such a series would be the incorporation of observed correlations between variation in vital rates. Using observed correlations would improve on this assumption by incorporating forces that we did not consider. Those forces may drive greater positive or negative correlation among life history traits. Other potential refinements include incorporating density-dependent effects. At present, the data appear insufficient to assess reasonable functions governing density dependence.

Summary of major conclusions from matrix projection models:

- First-year survival accounts for > 99.9 percent of the total "possible" sensitivity. Any absolute changes in this rate will have major impacts on population dynamics.
- First- and second-year survival ($P_{21}$ and $P_{32}$) account for 40.8 percent of the total elasticity, compared to the 20 percent accounted for by the entire set of fertilities. Proportional changes in first- and second-year survival will have a major impact on population dynamics.
- The reproductive value of fifth-year females is high. Even though older, larger females may be rare, their high survival rates and high reproductive values make them important buffers against the detrimental effects of variable conditions.
- Stochastic simulations echoed the elasticity analyses in emphasizing the importance of variation in first- and second-year survival to population dynamics. In comparison to life histories of other vertebrates, flathead chub appear somewhat less vulnerable to environmental stochasticity (because of the buffering effect of a reservoir of large females).
- Management should occur at a scale that encompasses a broad range of habitat sites and ecological conditions.

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# APPENDIX B

Sources of information used to produce Figure 3 showing the occurrence of flathead chub within HUB 4 drainages in the five states comprising Region 2 of the USDA Forest Service.


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