Hornyhead Chub (*Nocomis biguttatus*): A Technical Conservation Assessment

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

December 15, 2005

William J. Miller, Ph.D., David E. Rees, Ryan J. Carr, and David S. Berube
Miller Ecological Consultants, Inc.
1113 Stoney Hill Drive, Suite A
Fort Collins, CO 80525-1275

Peer Review Administered by
American Fisheries Society

Miller, W.J., D.E. Rees, R.J. Carr, and D.S. Berube (2005, December 15). Hornyhead Chub (*Nocomis biguttatus*): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/hornyheadchub.pdf [date of access].

Acknowledgments

We would like to thank those people who promoted, assisted, and supported this species assessment for the Region 2, USDA Forest Service. Several individuals from state agencies provided information on species distribution. Thanks go to Steve Schainost (Nebraska Game and Parks) and Deb Simon (Kansas Department of Wildlife and Parks). Laura Hillger provided assistance with report preparation and dissemination.

Authors' Biographies

Dr. William J. Miller has over 25 years experience in fisheries, instream flow, and aquatic ecology studies. He has worked extensively throughout the western United States and is a recognized expert in the areas of Colorado River basin endangered fish species, instream flow, water temperature modeling, and habitat assessments. Dr. Miller's experience includes research and evaluations for several threatened, endangered, and candidate aquatic species in the Colorado River and Platte River basins. He has extensive experience in designing and conducting studies using the Instream Flow Incremental Methodology (IFIM), instream water temperature modeling and developing and implementing ecological models for aquatic systems. He has developed habitat suitability criteria for both anadromous and resident salmonids as well as warm-water game and forage species. Dr. Miller is a Certified Fisheries Scientist (No. 2008).

David E. Rees studied fishery biology, aquatic ecology and ecotoxicology at Colorado State University where he received his B.S and finally his M.S. in 1994. His specific areas of specialization include aquatic insect identification and ecology, and native fish movement and habitat use. He has been involved with and supervised extensive projects involving electrofishing and population studies on the native and nonnative fish in tributaries of the Colorado River drainage, and other various locations. He has supervised habitat use studies using radio telemetry to monitor Colorado pikeminnow and other native and nonnative fish in the Yampa River, San Juan River and Colorado River. He has worked on projects in Colorado, Utah, New Mexico, Nevada, Arizona, Wyoming, Montana, and Puerto Rico. David is currently conducting research on the relationship between physical and ecological processes in the Colorado River, and the implications of these interactions on native fish species.

Ryan J. Carr received a Bachelor of Science degree in Zoology with a concentration in Entomology in 2001. He is currently a candidate for a Master of Science degree in Entomology with a concentration in Systematics. The focus of his studies has been Genetics, Evolutionary Biology and Systematics of Invertebrates. He also has experience working with Native and Non-native fish populations in Arizona and Colorado. Current research focus includes the evolution, systematics, and biogeography of Diptera. Much of his work has focused on using invertebrates to monitor and model aquatic ecosystems.

David S. Berube studied environmental science at Oregon State University where he received his B.S. in 1999. Since then he has performed contract research assistance for the Environmental Protection Agency and assisted as a field hydrologic technician in the Fraser Experimental Research Forest. His specific areas of specialization are riparian zones and the interaction between the flora and fauna, specifically macroinvertebrates. David is currently assisting in a fish escapement study on Elkhead Reservoir near Craig, Colorado in addition to a macroinvertebrate survey in a section of the Colorado River.

Cover Photo Credit

Hornyhead Chub (*Nocomis biguttatus*). © Joseph Tomelleri.

Summary of Key Components for Conservation of the Hornyhead Chub

Status

The USDA Forest Service Rocky Mountain Region (Region 2) has designated the hornyhead chub (*Nocomis biguttatus*) as a sensitive species. This species has evolved and adapted to the specific environmental conditions of Great Plains streams that include the eastern portions of Region 2. Specifically, populations of hornyhead chub can currently be found in the Laramie River (Wyoming), the Big Sioux River basin (South Dakota), and the Kansas River basin (Kansas). Within Region 2, the species' range has declined when compared to its historic distribution. Populations in the Midwest (e.g., Iowa, Illinois, Wisconsin, Indiana, Arkansas) are stable.

Primary Threats

The primary threats to the hornyhead chub in Region 2 generally result from anthropogenic activities. Much of the historic change to the aquatic environment and the majority of future threats are related to water management and flow modifications. Diversion of water has resulted in changes to flow regimes in mainstem rivers and tributary streams. Dams and reservoirs have degraded habitats and caused habitat fragmentation. Other threats to hornyhead chub include the modification of stream channels through channelization, landscape scale changes resulting from land use, and local destruction of riparian zones that reduce the natural function of the stream ecosystem. Also, introduced non-native species have become both predators and competitors with hornyhead chub.

Primary Conservation Elements, Management Implications and Considerations

Detailed information concerning the distribution, life history, population trends, and community ecology of the hornyhead chub in Region 2 is relatively limited. The needs of the hornyhead chub are specific to the conditions in which they evolved. The overall objective should be to manage the system, to the extent possible, to emulate historic conditions. These conditions include a native fish assemblage and a natural hydrograph with ample magnitude to maintain suitable habitat for spawning and rearing. Initial research needs of this species should include accurate surveys of each basin in its historic range. Such detailed population information along with comprehensive physical and chemical characterization of each stream will allow management plans to be tailored to each drainage and the development of rangewide conservation plans.

TABLE OF CONTENTS

EDITOR: Richard Vacirca, USDA Forest Service, Rocky Mountain Region

LIST OF TABLES AND FIGURES

Table:

Figures:

INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for USDA Forest Service (USFS) Rocky Mountain Region (Region 2). The hornyhead chub is the focus of an assessment because Region 2 considers it a sensitive species. Within the National Forest System, a sensitive species is a plant or animal whose population viability is identified as a concern by a Regional Forester because of significant current or predicted downward trends in abundance and/or habitat capability that would reduce its distribution (FSM 2670.5 (19)). Due to concerns with population viability and abundance, a sensitive species requires special management, so knowledge of its biology and ecology is critical. This assessment addresses the biology, ecology, conservation, and management of the hornyhead 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.

Goal

Species conservation assessments are produced as part of the Species Conservation Project to provide forest managers, research biologists, and the public with a thorough discussion of the current understanding of the biology, ecology, conservation status, and management of the hornyhead chub based on available scientific knowledge. The scope of this work is limited 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. Rather, it provides the ecological background upon which management must be based and focuses on the consequences of changes in the environment that result from management (i.e., management implications). Furthermore, it cites management recommendations proposed elsewhere and examines the success of those recommendations that have been implemented.

Scope

This assessment examines the biology, ecology, conservation status, and management of the hornyhead chub with specific reference to the geographic and ecological characteristics of the USFS Rocky Mountain Region. Although a majority of the available literature on this species originates from field investigations outside Region 2, this document places that literature in the ecological and social context of the Great Plains portion of Region 2. Similarly, this assessment discusses the reproductive behavior, population dynamics, and other characteristics of the hornyhead chub in the context of the current environment rather than under historical conditions. The historical environment of the species is considered, but it is placed in a current context.

In producing this assessment, we reviewed refereed literature, non-refereed publications, research reports, and data accumulated by resource management agencies. Not all publications on the hornyhead 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. Non-refereed publications and reports were regarded with greater skepticism. However, we chose to use non-refereed literature in the assessments when information was unavailable elsewhere. Unpublished data (e.g., Natural Heritage Program records) were important in determining the species' status and estimating its geographic distribution. These data required special attention because of the diversity of persons and methods used in 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, because 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, strong inference, as described by Platt, suggests that experiments will produce clean results (Hillborn and Mangel 1997), as may be observed in certain physical sciences. The geologist T. C. Chamberlain (1897) suggested an alternative approach to science where multiple competing hypotheses are confronted with observation and data. Sorting among alternatives may be accomplished using a variety of scientific tools (e.g., experiments, modeling, logical inference). Ecology is, in some ways, similar to geology because of the difficulty in conducting critical experiments and the reliance on observation, inference, good thinking, and models to guide understanding of the world (Hillborn and Mangel 1997). A problem with using the approach outlined in both Chamberlain (1897) and Platt (1964) is that there is a tendency among scientists to resist change from a common paradigm. Treatment of uncertainty

necessitates that a wide variety of hypotheses or experiments by undertaken to test both the true or false nature of the uncertainties at hand (Vadas 1994). Confronting uncertainty, then, is not prescriptive. While well-executed experiments represent a strong approach to developing knowledge, alternative approaches such as modeling, critical assessment of observations, and inference are accepted as sound approaches to understanding and used in synthesis for this assessment. In this assessment, we note the strength of evidence for particular ideas and describe alternative explanations when appropriate.

The synthesis of material for hornyhead chub included the use of the limited data sets that are available for distribution, abundance, movements, habitat requirements, and life history requisites of the species. This species, like many non-game native fish, has not been extensively studied within Region 2; further, it has not been extensively studied rangewide for all the parameters needed for the species assessment. The limited amount of information on key characteristics for the species and our lack of understanding concerning its needs create a great deal of uncertainty pertaining to the assessment for conservation of hornyhead chub in Region 2. This species assessment has synthesized a wide range of available data in Region 2 and other portions of this species' range. The assessment includes historical and current distribution, habitat needs, and management requirements. The general lack of precise information regarding its distribution on National Forest System land or near forest boundaries limits the actual data that can be used for this assessment. We have inferred from available data, using a sound scientific approach, to present an understanding of the current needs of the species for the purpose of this assessment.

Application and Interpretation Limits of this Assessment

Information used in this assessment was collected from studies that occurred throughout this species' range. The greatest emphasis for information regarding life histories and ecology was placed on studies and reports that were specific to Region 2. Although most information should apply broadly throughout the range of the species, it is likely that certain life history parameters (e.g., growth rate, longevity, spawning time) will differ along environmental gradients. Information regarding conservation strategies of the species pertains specifically to Region 2 and does not apply to other portions of the species' range.

Publication of Assessment on the World Wide Web

To facilitate the 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, Web publication will facilitate revision of the assessments, which will be accomplished based on guidelines established by Region 2.

Peer Review

Assessments developed for the Species Conservation Project have been peer reviewed prior to their release on the Web. This report was reviewed through a process administered by the American Fisheries Society, which chose two recognized experts (on this or related taxa) to provide critical input on the manuscript. 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 USDA Forest Service Region 2 considers the hornyhead chub a sensitive species. Within Region 2 states, the hornyhead chub is considered a species of concern in South Dakota (North Dakota Game and Fish Department 1994), threatened in Kansas (Kansas Department of Wildlife and Parks 2000), and a Native Species Status 1 (NSS1) in Wyoming (Meyer et al. 2005). The species has been extirpated from Colorado (Propst and Carlson 1986) and probably Nebraska (Schainost personal communication 2003).

In Kansas, the hornyhead chub is limited to the following counties in the eastern portion of the state: Anderson County (in Pottawatomie Creek basin), Bourbon County (in the main stem of the Marmaton River and several tributaries), Franklin County (in the Marais des Cygnes River basin), Lyon and Miami counties (larger tributaries to the Marais des Cygnes River), and Wabaunsee County (known to occur, and likely still does in Mill Creek) (Kansas Department of Wildlife and Parks 2000). All of these counties have state-designated critical habitat for the species. None of the populations in Kansas are near USFS lands.

The Wyoming Game and Fish Department assigned the hornyhead chub the state ranking of NSS1 suggesting that populations are isolated and habitats are declining or vulnerable. This is due to the isolated nature of the existing known populations in the Laramie and North Laramie rivers (Weitzel 2002).

Currently, the National Heritage Program has assigned the hornyhead chub a global ranking of G5 suggesting that the species' existence is globally secure (NatureServe 2005). State heritage program rankings within Region 2 are as follows: Wyoming (S2, imperiled), Colorado (SX, presumed extirpated), South Dakota (S3, vulnerable), Nebraska (SH, possibly extirpated), and Kansas (S1, critically imperiled). Outside of Region 2, this species has the following rankings: North Dakota (S3, vulnerable), Minnesota (unranked), Iowa (S5, secure), Missouri (unranked), Arkansas (S4, apparently secure), Wisconsin (S4, apparently secure), Michigan (S5, secure), Illinois (S5, secure), Indiana (S4, apparently secure), Ohio (unranked), Pennsylvania (S2 imperiled), New York (S3, vulnerable), Manitoba, Canada (S2, imperiled), and Ontario, Canada (S4, apparently secure).

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

The hornyhead chub has not been assigned a federal status by U.S. Fish and Wildlife Service in the United States. However, some protection does exist in Canada within fish habitat sections of the Fisheries Act (Dalton 1989). The protection in Canada is not species specific but protects destruction of habitat in general.

Currently, there are no management plans or conservation strategies in place specifically for hornyhead chub. Meronek et al. (1997) found that the hornyhead chub was one of several species sold as bait under the generic classification of "chub" in Illinois, Michigan, Minnesota, Ohio, South Dakota, and Wisconsin. Litvak and Mandrak (1993) found that hornyhead chub were often transported outside their range for sale as a baitfish in Canada. This practice was cited as a potential threat to the ecosystems from which these fish are removed and the ecosystems to which they are introduced. Wyoming regulations prevent the seining or trapping of baitfish in reaches where hornyhead chub occur (Weitzel 2002). Other regulations in Wyoming are designed to prevent any net loss of habitat for hornyhead chub.

Biology and Ecology

Systematics and general species description

The hornyhead chub is a member of the family Cyprinidae. This family is defined by one to three rows of pharyngeal teeth, thin lips, large eyes, abdominal pelvic fins, and usually soft fin rays. The hornyhead chub was first described by Kirtland (1840) in Yellow Creek, a tributary of the Mahoning River in the upper Ohio River basin, Ohio. Kirtland named the species *Semotilus biguttatus*; the species name, *biguttatus*, means two-spotted in Latin in reference to the red spot on each side of the head (Pflieger 1997). There have been several taxonomic changes for the species since it was first described. The *biguttatus* species group currently includes *Nocomis biguttatus*, *N. effuses* (redtail chub), and *N. asper* (redspot chub) (Lachner and Jenkins 1967, 1971). The nomenclature in Nelson et al. (2004) has been used since the mid 1920s.

The following description of the hornyhead chub was given by Weitzel (2002):

> "A robust body, large head, and blunt snout characterize the hornyhead chub. The mouth is large with conspicuous barbels and the eyes are moderate. The scales are large with 42-44 scales in the lateral line; dorsal rays number 8; anal rays number 7; pharyngeal teeth are arranged 1,4-4,1. Breeding males have conspicuous nuptial tubercles on the head and forward part of the body. The color is olive above, dark in the younger specimens; the belly is white, a lateral dusky stripe condenses into a black spot at the base of the caudal fin. A round red spot is present behind eye of adult males (Baxter and Stone 1995). The intestine is short, with a single S-shaped loop; the lining of the body cavity is black, young have a bright orange tail. Adults are commonly 5 to 7 inches in total length and may grow as large as 10 inches."

The hornyhead chub is a short-lived species that usually only lives until age 4 (Lachner 1952). The fastest growing hornyhead chub are sexually mature at two years old, but most reach sexual maturity at age 3 (Lachner 1952). The average male captured at Sandy Creek, Lake Ontario, New York measured 106.5 mm (4.2 inches) in standard length (SL) with the largest

captured measuring 125 mm (4.9 inches) SL. Females from the same location were smaller and ranged in size from 88 to 89 mm (3.5 inches) SL (Lachner 1952). Maximum lengths reported from Canada are around 161 mm (6.3 inches) SL for males and 112 mm (4.4 inches) SL for females (Scott and Crossman 1998). Scott and Crossman (1998) report the following ranges for SL have been given for each age class: age 0 (young of year [YOY]) (24 to 36 mm [0.9 to 1.4 inches]), age 1 (44 to 58 mm [1.7 to 2.3 inches]), age 2 (64 to 83 mm [2.5 to 3.3 inches]), age 3 (86 to 100 mm [3.4 to 3.9 inches]), age 4 (131 mm+ [5.2+ inches]).

Hornyhead chub can be difficult to distinguish from other similar cyprinids except possibly for males that are in spawning condition. Spawning males have tubercules on the dorsal surface of their head. Species within the genera *Hybopsis* and *Semotilus* are also easily confused with *Nocomis biguttatus*. The divergent nature of the phylogeny of these similar genera shows the need for molecular tools in identification of and research on this group. Ferguson et al. (1981) developed a method for using eloctrophoresis to distinguish the hornyhead chub from the river chub (*N. micropogon*). This method could be expanded using the loci isolated from muscle tissue (by non-lethal muscle plugs) to allow field sampling of many similar taxa for positive laboratory identification. The laboratory identifications could be used to distinguish separate populations.

Distribution and abundance

It has been speculated that historically hornyhead chub existed throughout plains streams of North America at the beginning of the Pleistocene glaciation period (Cross et al. 1986). They were relocated with the advance and retreat of glaciers that destroyed paths of warm-water fish invasion (Propst and Carlson 1986) and became distributed from New York State, south to the Ozarks and as far north as Canada (Weitzel 2002). The retreat of the glaciers and the removal of waterways for dispersal are responsible for isolated populations in the Rocky Mountain Region (Propst and Carlson 1986).

In the 1970s, hornyhead chub distribution in the United States extended from New York and Ohio west to the Red River drainage of Minnesota and the Dakotas, south to the Mississippi River basin and north to the upper part of the Ohio basin with separate populations in the Platte and Cheyenne drainages of Colorado, Nebraska, and Wyoming (Jenkins and Lachner 1980). The disjunct populations in Wyoming and Kansas are considered to be glacial relics resulting from stranded populations existing in Pleistocene refugia (Weitzel 2002). Distribution was limited in Wyoming, but hornyhead chub were locally common in the North Laramie River and the tributaries of the Laramie River in Platte County (Weitzel 2002).

Propst and Carlson (1986) conducted a survey of the Platte River Basin, Colorado from 1978 to 1980 and determined that hornyhead chub, once a native to Colorado, had now been extirpated. Recent surveys by the Wyoming Game and Fish Department in 1996 and 1997 found that the species probably occurs in 103 miles of the Laramie and North Laramie rivers in Albany and Platte counties, Wyoming. Collection locations in the Laramie and North Laramie rivers were reported within several kilometers of the Medicine Bow National Forest boundary (Weitzel 2002). Due to an absence of survey data, it is unknown if hornyhead chub occurs within the boundaries of the Medicine Bow National Forest, which is within the species' possible historic distribution. The Medicine Bow National Forest is the only National Forest System land in Region 2 that is in close proximity to known hornyhead chub populations (**Figure 1** and **Figure 2**). Currently, populations within Region 2 can be found in the Laramie River (Wyoming), the Big Sioux River basin (South Dakota and Nebraska) and the Kansas River basin (Kansas). Hornyhead chub once occurred in the Lodgepole Creek Drainage (Nebraska and Wyoming), but are currently thought to be extirpated from this drainage (**Figure 2**; Weitzel 2002).

Population trend

Populations of hornyhead chub in Region 2 and throughout the westernmost extent of its range are declining (Baxter and Stone 1995, Patton 1997). However, due to incomplete survey records for hornyhead chub in its historical and current ranges, it is impossible to determine the extent to which populations have been reduced. Hornyhead chub populations in Colorado and western Nebraska are now thought to be extirpated, likely due to changes in land use and stream flows. Distribution in the Platte River basin, Wyoming, consists of isolated populations that appear to be declining when compared with historical data (Patton 1997). In Kansas, hornyhead chub exist only in several counties in the eastern portion of the state.

Populations of hornyhead chub occur outside of Region 2, in North Dakota, Minnesota, Wisconsin, Iowa, Illinois, Michigan, Missouri, Arkansas, Indiana, Ohio, Pennsylvania, and New York. The populations in Iowa, Illinois, Indiana, Wisconsin, Michigan, and Arkansas are mostly stable, but the populations in the

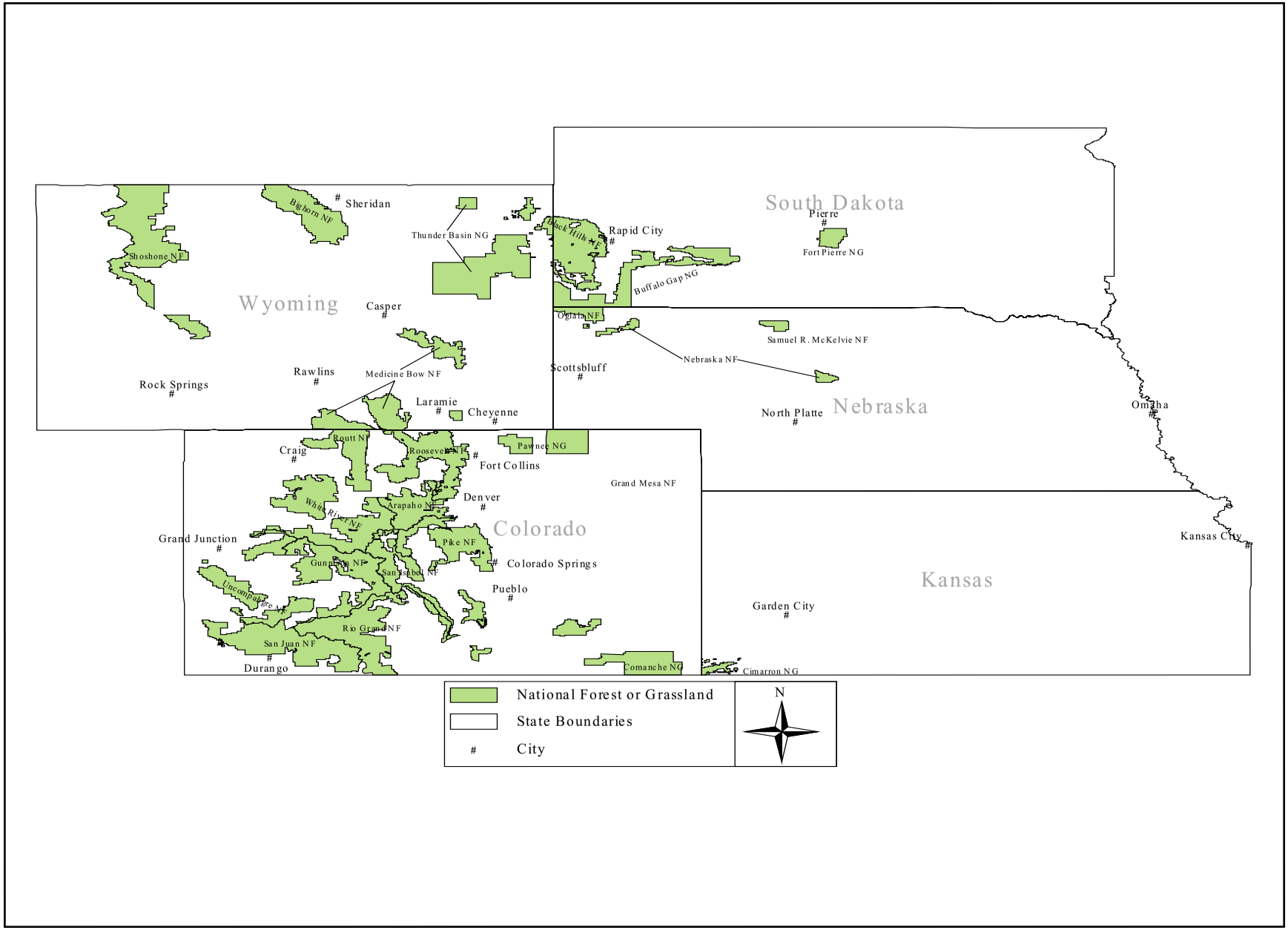

Figure 1. USDA Forest Service Region 2 national forests and grasslands.

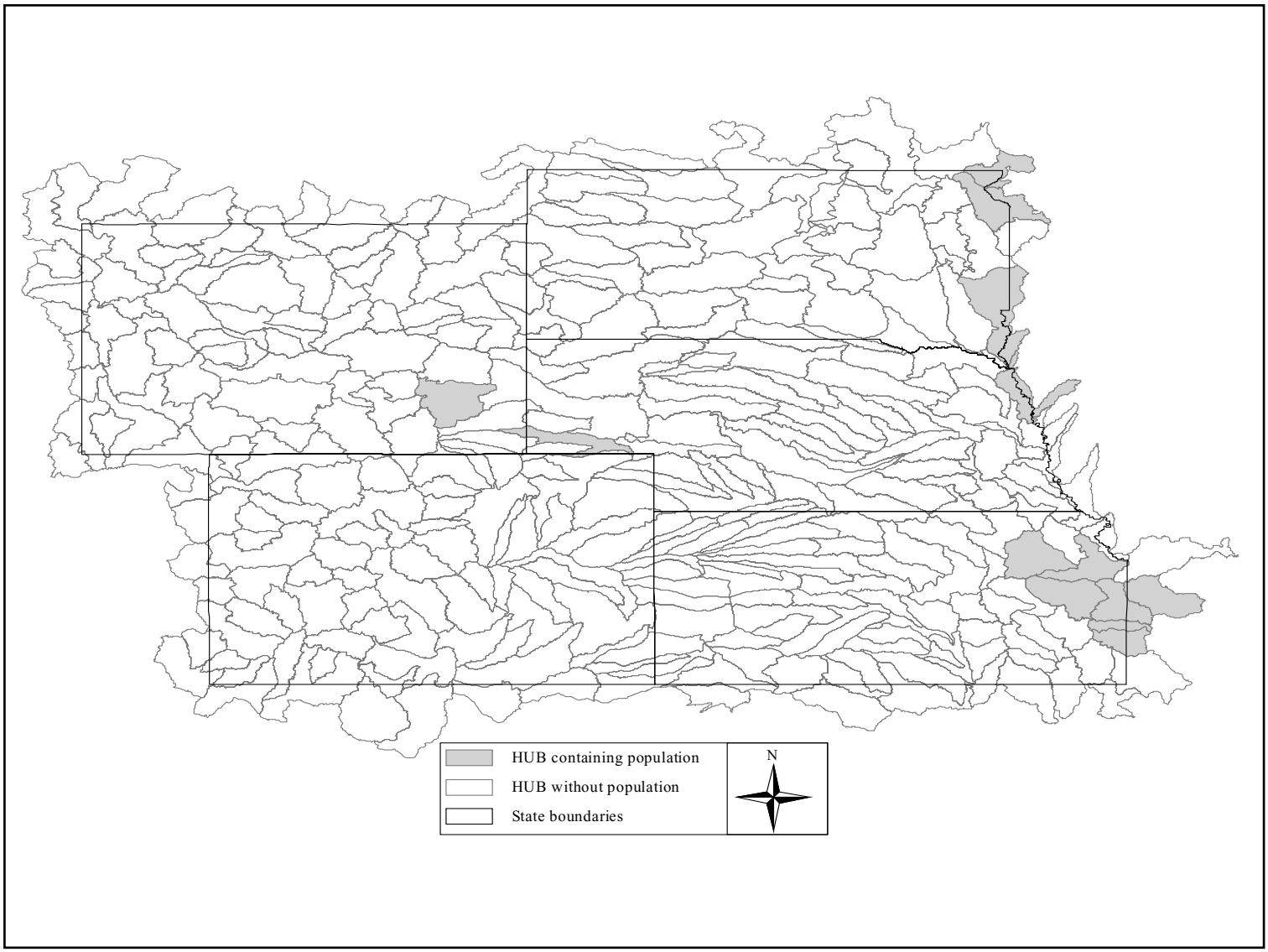

Figure 2. USDA Forest Service Region 2 hydrological units containing hornyhead chub populations. **Note:** the population previously reported in southeastern Wyoming/southwestern Nebraska is thought to be extirpated.

northeastern portion of the hornyhead chub's range (e.g., New York, Pennsylvania) are in decline. Populations in Canada are limited to tributaries to Lake Erie and Lake Ontario and two locations in Manitoba.

Activity pattern

Few research studies have been conducted on the activity pattern of the hornyhead chub, but it is likely that movement is infrequent due to the specific habitat required by the species. Schlosser (1988) reported that age 0 hornyhead chub were found in pools but moved into riffles in the presence of predators (i.e., smallmouth bass [*Microperus dolomieui*]). Larval hornyhead chub were found in the headwaters of Locust Creek (Wabaunsee County, Kansas). This area is not generally used by adults. This indicates that sexually mature adults migrate to and subsequently use this area for spawning (Mammoliti 2002). Information still needs to be collected regarding migration, movement between populations, larval dispersal, nocturnal vs. diurnal patterns, seasonal movement patterns, and regional differences in movement patterns.

Habitat

Hornyhead chubs are usually found in small to medium-sized streams, rarely in lakes or large rivers (Jenkins and Lachner 1980). Stream depths in Allequash Creek, Wisconsin where hornyhead chubs were observed averaged 25.6 cm (10.1 inches) (Vives 1988). While they do not require clear water, their numbers decrease as turbidity increases. Gravel and rock-size substrate are preferred for feeding and also provide the materials necessary for nest construction during spawning; they generally avoid areas of fine sediment deposition (Lachner and Jenkins 1967, Weitzel 2002). This species prefers warm-water rivers and streams that sustain aquatic vegetation (Weitzel 2002). Cross and Moss (1987) observed hornyhead chub in the Kansas River system in cool, spring-fed streams that are stable enough to sustain the growth of beds of macrophytes. Dalton (1989) found that the factors limiting the distribution of hornyhead chub include gravel substrate, small to medium-sized streams and rivers, constant steam flow, and the absence of mud, silt, and turbidity.

Gorman (1988) found that adult hornyhead chubs prefer middle to lower pelagic zones. Age 0 hornyhead chub are often found in near-shore habitats in the same pools and runs where adults were found occupying deeper habitats (Gorman 1987). Juvenile hornyhead chub are often found in algal and vascular plant beds in areas of low velocity (Lachner 1952). Larger hornyhead chubs are found in pools and slower portions of small streams and rivers with large rocks and boulder substrate (Scott and Crossman 1973). In the absence of predatory fish, both large and small hornyhead chub prefer structurally complex pool habitat, but small fish move to shallow riffle areas when predators are present (Schlosser 1988). Angermeier and Karr (1984) determined that adult hornyhead chub were more likely to occur in the areas with natural and added woody debris, which provides cover and may serve to increase the food base.

Heithaus and Grame (1997) found hornyhead chub to be part of a guild of fish species that was intolerant of pollution in the Vermillion River basin, Ohio. When exposed to pollution, members of this guild are extirpated from tributary streams and are subsequently confined to mainstem habitats. Cross and Moss (1987) found that this species was one of the first to disappear from many streams in the Kansas River drainage due to intolerance of turbidity and variable flow and temperature regimes.

Food habits

The hornyhead chub has been classified as an insectivore (Schlosser 1987). However, Schlosser (1982) found that in addition to terrestrial and aquatic insects, the diet of the hornyhead chub also includes small fish, detritus, algae, and other plant material. Juveniles and adults feed mostly on a wide variety of benthic insects, with smaller amounts of crustaceans, mollusks, annelids, and fishes (Jenkins and Lachner 1980). The age 0 fish feed mostly on aquatic vegetation, but diatoms, cladocerans, and aquatic macroinvertebrate larvae (e.g., chironomids) are also eaten (Scott and Crossman 1973). Mature fish (age 2 to 4) often consume insect larvae, annelids, crayfish, fish, and especially snails (Scott and Crossman 1973). Angermeier (1982) found that in Jordan Creek (Vermillion County, Illinois) hornyhead chub took a wide array of sizes of invertebrates and indicated that hornyhead chub have a strong preference for aquatic prey items over terrestrial prey items. It is unknown how feeding preferences of hornyhead chub vary in accordance with discharge or reproductive cycles.

Angermeier (1982) found the diet of hornyhead chub to vary with seasons, having a higher proportion of the population with full guts in the spring compared to the autumn. During March and April, their diet consisted primarily of chironomids (58 percent) and simuliids (15 percent). During May and June, diets were observed to

consist of simuliids (57 percent) and helicopsychids (11 percent). During the period of August through October, their diet consisted of elmids (37 percent) and chironomids (25 percent). During the period of October through January, their diet had shifted to chironomids (56 percent) and clams (15 percent). Shifts in diet due to competition, migration, development, and habitat degradation have not been characterized.

Breeding biology

All species in the genus *Nocomis* are nest builders (Lachner 1952). Male hornyhead chubs build large, dome-shaped nests of gravel and pebbles with sand as the most common underlying substrate (Maurakis et al. 1991). Nests provide protection and a clean substrate for spawning as well as allow oxygenated water to pass over the eggs (Cross 1967, Vives 1988). Nests usually occur within close proximity to new or previously constructed nests, and old nest sites may be reused in subsequent years (Vives 1990). Hornyhead chub nest construction has been observed and documented in Allequash Creek, Wisconsin (Vives 1988, 1990), Michigan (Hankinson 1920), and Missouri (Pflieger 1975). Males begin construction by digging a pit 5 to 10 cm (2 to 3.9 inches) deep. Stones are then carried by males and placed into the pit to obtain a flat surface. The middle stones are then removed to create a 'spawning cup'. Stones are gathered from around the nests and placed in the cup after each consecutive spawning occurrence. Nest sizes were found to range from 305 to 914 mm (12 to 36 inches) wide, 610 to 914 mm (24 to 36 inches) long, and 51 to 152 mm (2 to 6 inches) deep (Vives 1990, Maurakis et al. 1991, Johnston 1994).

Breeding activity occurs from late April to early July (Jenkins and Lachner 1980). Activity was the highest in late May and early June and when water temperatures ranged from 16 to 26 °C (60.8 to 78.8 °F) in Allequash Creek, Wisconsin (Vives 1988, 1990). Females ready to spawn were found to contain 460 to 725 eggs (Scott and Crossman 1973), but only a portion of a female's eggs are laid during each breeding event. Spawning interactions are initiated by the female swimming underneath the male as he constructs the nest (Vives 1990). Eggs are then deposited in the spawning cup, and the male covers the eggs with stones. This is repeated several times, and the result is a mound composed of egg deposits and layers of stone (Vives 1990). The process of covering eggs with rocks protects the eggs from being swept away or being eaten by predators (Johnston 1994). Males will mate with multiple females. Information on hatching times and growth rates of larvae is not available at this time. Information on survival rate and fecundity is also lacking.

Intraspecific competition was observed in Allequash Creek, Wisconsin, when males intruded on a spawning couple (Vives 1990). In one instance, an intruding male ate eggs from the nest. Females also exhibited egg eating behavior patterns. The importance of egg eating to this species, as well as the circumstances leading to this behavior, is unknown. Fighting males butted each other, and on several occasions, an opponent was struck directly with the sharp head tubercles, wounding the fish (Vives 1990). Tubercles develop in males and aid in nest-guarding activities and protection of eggs from predators (Lachner 1952). Male hornyhead chubs are known to defend the nest against predation by suckers and crayfish, and they will group together to ward off predators of larger size (Vives 1990). Hornyhead chub in Allequash Creek, Wisconsin have been observed defending their nests from larger fish including a combined attack by four male hornyhead chub on white sucker (*Catostomus commersoni*) (Vives 1990). A similar attack on a northern hog sucker (*Hypentelium nigricans*) was documented by Hankinson (1931). Observations of defense behaviors indicated that they were effective in some cases, but the rate of success was not quantified.

Demography

Hornyhead chub have been documented hybridizing with the common shiner (*Luxilus cornutus*), the striped shiner (*Notropis chrysochloris chrysocephalus*), and the stoneroller (*Campostoma anomalum*) (Trautman 1981). Ross and Cavender (1981) experimentally hybridized a hornyhead chub with a creek chub (*Semotilus atromaculatus*), and the hybrids were morphologically intermediate between the two species. The extent and effect of hybridization in wild populations of hornyhead chub are unknown at this time.

Mammoliti (2002) observed several affects of impoundments on hornyhead chub populations. The mediation of flows eliminates peaks in flow that signal hornyhead chub to spawn. The elimination of scouring flows leads to sediment accumulation destroying spawning habitats. The increase in turbidity associated with reaches downstream of an impoundment impedes feeding of visual predators. The modification of channels downstream from impoundments leads to deeper, narrower channels in areas that were formerly stable enough to support macrophytic growth. This process destroys habitat used by hornyhead chub. There

is some evidence that hornyhead chub migrate into headwater streams in order to spawn. These historic migration routes become blocked by impoundments, as well as make genetic exchange impossible between once connected populations.

The development of a meaningful life cycle diagram for hornyhead chub would require life stage specific data regarding age structure, age-specific survival rates, age-specific fecundity, and sex ratio. These characteristics often depend on location (e.g., stream size, temperature, habitat) and could vary considerably in Region 2. Such data are sparse or inadequate at this time, and the information that is available is highly variable and typically restricted to specific locations. Carter (1940) and Lachner (1952) provided information on eggs per female. Lachner (1952) reported a mean fecundity of 572 mature ova produced by four mature females that were 81 to 89 mm (3.1 to 3.5 inches) SL; fecundity values ranged from 469 to 725. The hornyhead chub lives three to four years, with a high mortality rate from egg through age 1 and a high mortality rate following the first year of spawning. Age-specific survival rates for the life cycle diagram were estimated for portions of the age structure that were inconclusive or incomplete. Using the average fecundity of 572 ova for age 3 and age 4 fish and assuming a 1:1 sex ratio, we constructed a life cycle diagram (**Figure 3**, **Table 1**). This model is presented as a tool to recognize existing data and to identify data still needed to refine it.

Community ecology

Vives (1990) described the hornyhead chub as a keystone species. While this term is generally used to denote trophic position, Vives (1990) used it in his description of hornyhead chub because of the effect

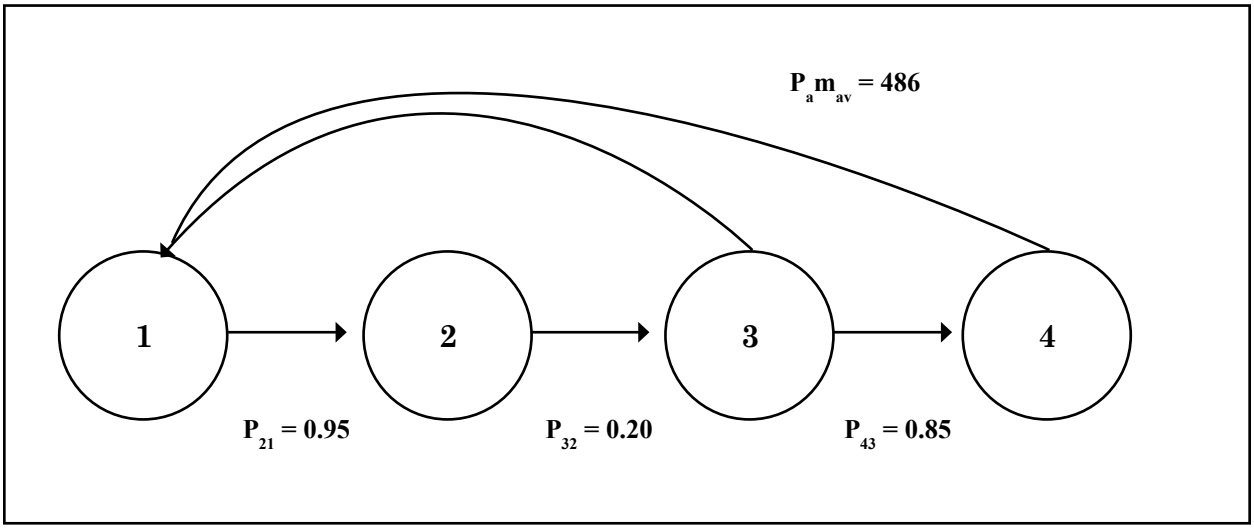

Figure 3. Life cycle graph for the hornyhead chub. The number of circles (nodes) represent the four age-classes. The arrows connecting the nodes represent survival rates. Fertility is represented by the arrows that point back to the first node. Fertilities involve offspring production, mi, number of female eggs per female as well as survival of the female spawners. Note that reproduction begins after two years of growth.

Table 1. Parameter values for the component terms (P_i and m_i) that make up the vital rates in the projection matrix for hornyhead chub. Fecundity and survival rates were estimated from age structure data estimated from Lachner (1952). The model assumes a 1:1 sex ratio.

Parameter	Numeric value	Interpretation
P_{21}	0.05	First year survival rate
P_{32}	0.2	Survival from 2nd to 3rd year
P_A	0.85	Survival for adults
M_{av}	572	Average fecundity for mature females

of the species' nest building on aquatic community structure. When hornyhead chubs build their nests, they concentrate the gravel that is required for spawning habitat for other minnow species. Both the common shiner and the rosyface shiner (*Notropis rubellus*) have been observed spawning in the nests of hornyhead chub (Vives 1990). Common shiners have been observed defending the nest against other shiners and female hornyhead chub (Vives 1988, 1990). Lachner (1952) has speculated that a commensal relationship may exist between the hornyhead chub and the common shiner. These species are often found in the same streams (Lachner 1952), and the hornyhead chub is thought to provide the common shiner with a place to spawn. In return, the common shiner is thought to protect host nests from predators. It has been suggested that *Nocomis* males guarding their nests are the cue used by some "nest mutualists" to stimulate use of a nest for spawning (citations within Johnston 1994). Vives (1988) documented the interactions between the hornyhead chub, the common shiner, and the rosyface shiner in Allequash Creek, Wisconsin and concluded that the common shiner and hornyhead chub association is mutualistic while the rosyface shiner relationship is parasitic with both the common shiner and the hornyhead chub. All associations were previously suggested by Odum (1971).

Hankinson (1931) found common shiner, southern redbelly dace (*Phoxinuss erythrogaster*), and rosyface shiner using the nests of hornyhead chub as breeding sites in the Saline River, Michigan. The temperature required for spawning of these "nest mutualists" was at least 18 °C (64.4 °F). The following species were also found in association with nests of *Nocomis* species including the hornyhead chub: stone roller, blunt-nosed minnow (*Hyborhynchus notatus*), hammerhead sucker (*Hypentelium nigricans*), rainbow darter (*Poecilichthys caeruleus*), green-sided darter (*Etheostoma blennoided*), and Johnny darter (*Boleosoma nigrum nigrum*). It was not reported whether these species were spawning or feeding on eggs.

Little information was found on predators of the hornyhead chub. Mink (*Mustela vison*) and blue herons (*Ardea herodias*) as well as introduced smallmouth bass are considered common predators (Weitzel 2002). The extent of effects of predation and competition on hornyhead populations has not yet been characterized.

The tapeworm *Bialovarium nocomis* (Cestoda: Caryophyllaeidae) was described from a hornyhead chub specimen taken collected in Meadow Creek, Barron County, Wisconsin (Ferguson et al. 1981). The round worm *Rhabdochona rotundicaudatum* (Nematoda: Thelazioidea) was described from specimens of hornyhead chub collected in the Eramosa River (Ontario, Canada) (Bryne 1992). This nematode was also found in several sympatric fish species and in the mayfly *Ephemera simulans* (Ephemeroptera). A complete listing of parasites and diseases that affect hornyhead chub is not available.

An envirogram for hornyhead chub was developed to help elucidate the relationships between existing ecological influences and hornyhead chub population characteristics (**Figure 4**). Those elements that directly affect the hornyhead chub are depicted in the envirogram by the centrum, which is further separated into resources, predators, and malentities. Resources elicit positive response in hornyhead chub populations whereas predators and malentities produce either negative or neutral responses. Web levels illustrate factors that modify elements within the centrum or within the next lower web level. Andrewartha and Birch (1984) provide further detail into the specific description of all envirogram components. Relative importance of some linkages is poorly understood and warrants further study to validate.

CONSERVATION

Threats

The majority of threats to the current and future survival of the hornyhead chub can be organized into two general categories: 1) habitat degradation that includes loss, modification, and/or fragmentation, and 2) interactions with non-native species. These may work independently or in conjunction with the other to create an environment where hornyhead chub populations may be reduced or eliminated. The relative importance of each and the specific cause-effect relationship can depend on a number of biotic and abiotic factors. Also, the effects of habitat degradation may not be limited to local areas but may cascade through the system. Therefore, activities or events occurring on National Forest System lands may have detrimental impacts on populations of hornyhead chubs existing in rivers many kilometers downstream.

Habitat degradation includes three extensive areas of concern: habitat loss, habitat fragmentation, and habitat modification. Habitat loss typically occurs when streams are dewatered due to water use practices. Habitat fragmentation is often another result of dewatering, but it can also be caused by the creation of barriers to fish passage such as dams and diversions. Large and small

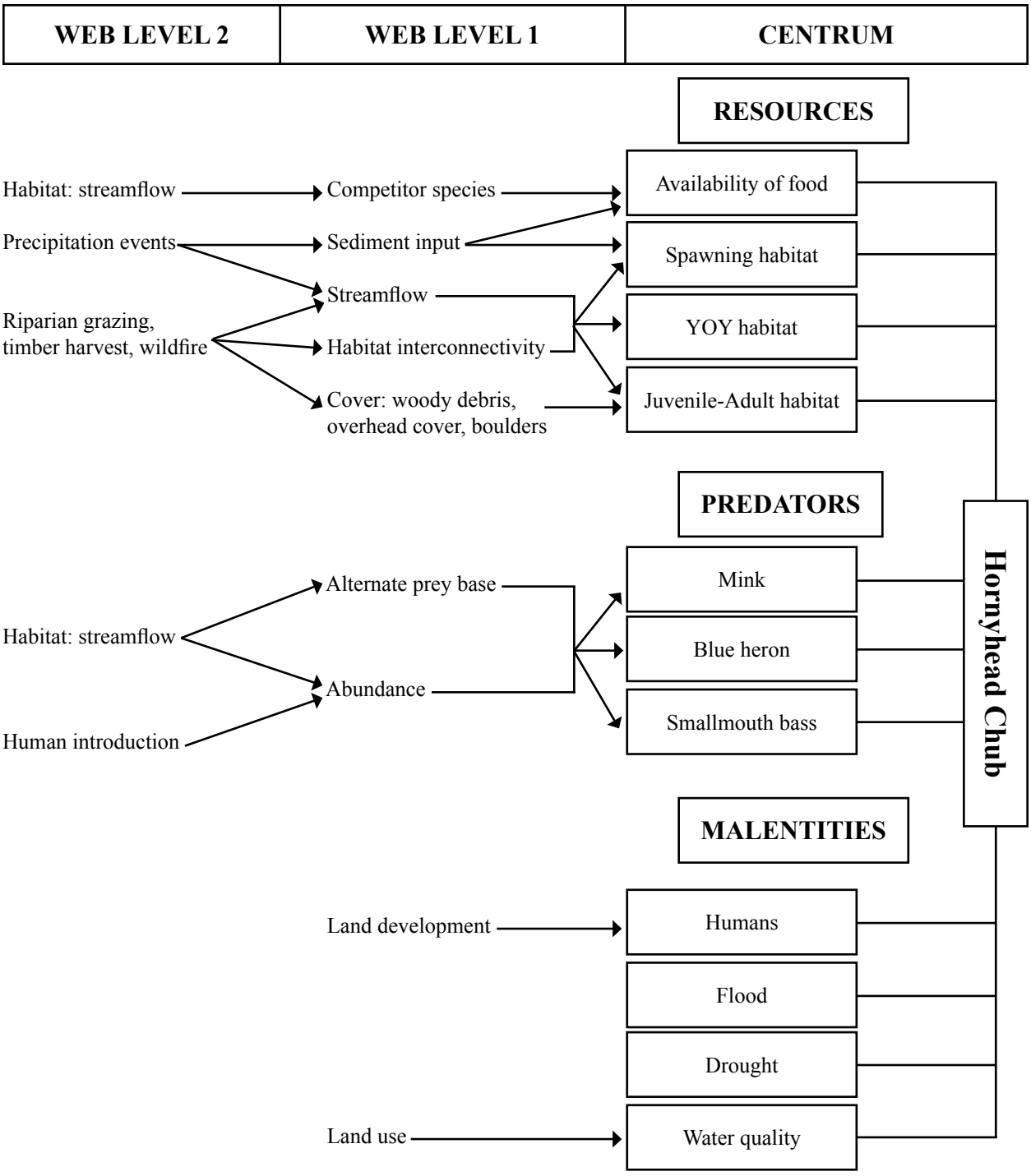

Figure 4. Envirogram for the hornyhead chub.

scale water development projects can have impacts on the persistence of hornyhead chub. Even undersized (or improperly designed) culverts at road or trail crossings can act as barriers, especially at low flows. Irrigation diversions and small capacity irrigation reservoirs reduce streamflow, alter the natural hydrograph, and provide barriers to migration and normal population exchange. Barriers that preclude fish passage can cause population fragmentation and completely prevent or significantly reduce genetic exchange between populations. The fragmented populations in some areas remain viable and maintain population levels at the same density as they were before fragmentation occurred. This currently occurs in small streams that have become isolated

from the mainstem rivers due to water diversions. In instances where habitat is fragmented and populations are isolated, the probability that genetic "bottlenecks" will occur becomes more pronounced and single catastrophic events may extirpate populations from entire drainages.

Habitat modification also occurs when the natural flow regime is altered, and when stream channels are modified due to channelization, scouring, or sedimentation. Land use practices that can impact stream channels include construction of roads through highly erodible soils, improper timber harvest practices, irrigation diversion and return flows, and overgrazing in riparian areas. These can all lead to an increase in fine sediment loads in the system and a subsequent change in stream channel geometry (e.g., widening, incision). These modifications alter width-depth ratios, pool-riffle ratios, and other aspects (e.g., pool depth) that affect the quality of habitat occupied by hornyhead chubs. In plains streams, the smaller single channel streams may become braided resulting in less habitat diversity than the original single channel streams. In the case of the hornyhead chub, sedimentation and the channelization of rivers should be considered major threats. Fine sediment covers the gravel substrate and inhibits the ability of the hornyhead chub to utilize the substrate for nest building and feeding purposes. The increase in turbidity associated with reaches downstream from impoundments interferes with the ability of this species to feed due its dependence on visual predation. Habitat modification also includes changes in temperature and flow regime, as well as alterations to water chemistry related to pollution. Stream bank degradation can result in increased sedimentation. Additional sediment loads can fill pool and run habitats, cover benthic substrate, and smother benthic organisms. The change in sediment load also can result in streams becoming wider and shallower and result in higher than normal water temperatures. Severely reduced stream flows may lead to increased water temperatures, changes in the algal community, and reduced dissolved oxygen levels especially in smaller tributary systems. Although specific tolerances to water quality parameters (i.e., temperature, dissolved oxygen, toxicants) are undefined for this species, it is likely that as water quality is reduced, hornyhead chub fitness will also decline. This species reacts poorly to the presence of pollution and is considered pollution intolerant (Heithaus and Grame 1997).

Competition with and predation by non-native species is another potential threat to hornyhead chub population health and viability. A fusiform shape and lack of protecting spines makes the hornyhead chub a desirable prey item. While competition with other minnows and predation by smallmouth bass has been documented, the effects of competition and predation have not been quantified for this species.

Fire has little direct impact on quality of habitat; however, post-fire conditions can effect downstream populations of hornyhead chub. Inputs of large quantities of sediment into streams frequently occur during storm events on recently burned areas. Once in the watershed, the increased sediment load can cover large substrate, decrease pool depth, diminish suitable spawning habitat, and reduce fitness by decreasing the nutritional value of the food base.

Hybridization is probably only a minor threat to the hornyhead chub due to its unique breeding biology. Further treatment of hybridization can be found in the Demography section.

Conservation Status of the Hornyhead Chub in Region 2

The hornyhead chub evolved in a system with a high natural disturbance regime. Life history attributes and population dynamics allowed this species to persist during (or recolonize after) a disturbance event (e.g., flood flows, drought, increased turbidity after natural fire events). However, modifications to the physical and biological environment have reduced the species' ability to recover after such events. At present, there is concern regarding the status of the hornyhead chub in Region 2. Although the specific mechanisms of most threats to this species are poorly understood, hornyhead chub populations have declined in Region 2. Existing research suggests that the decline in range and abundance of this species is mostly due to habitat alterations in the form of channelization, increased turbidity, and sedimentation. Disturbance of natural flow regimes is particularly detrimental to the hornyhead chub. Habitat fragmentation through streamflow reduction, passage barriers, and habitat degradation can disconnect populations of hornyhead chub. Competition and/or predation associated with altered species assemblages can depress hornyhead chub populations to precarious levels.

Locations that maintain current populations are usually defined by adequate habitat (as specified in the Habitat section of this report), and natural temperature and flow regimes. These areas often maintain healthy populations of other native fish species. The Wyoming Game and Fish Commission's objective is to realize no

loss of habitat function within the range of the hornyhead chub. No seining or trapping of baitfish is allowed in the 103 miles (165.8 km) of the Laramie and North Laramie rivers where the hornyhead chub is known to exist, and the area is currently managed for native fish and is no longer being stocked with game fish (Weitzel 2002). In Kansas, the hornyhead chub has a state designation of threatened, and critical habitat has been designated in the counties in which this species still exists.

While no hornyhead chub populations have been found on National Forest System lands (Barrineau personal communication 2005), the current distribution of hornyhead chub near Medicine Bow National Forest (Laramie Peak Unit) lands creates a unique situation where forest management strategies may cause substantial negative impacts on populations occurring many kilometers downstream of forest boundaries.

Based on impacts to hornyhead chub populations and distribution that have occurred in the last century, the potential for future declines in distribution and abundance is high. Unless alleviated, habitat alterations and interspecies interactions will intensify and jeopardize the existence of hornyhead chub.

Potential Management of the Hornyhead Chub in Region 2

Implications and potential conservation elements

Management for the hornyhead chub should be based on an understanding of specific threats to the species. Considerations for conservation elements should include minimization of sediment input due to anthropogenic causes (e.g., road building, petroleum and mineral exploration and extraction, grazing, agriculture), maintenance of natural flow regimes, and protection of riparian areas.

The addition of fine sediment is particularly harmful to the existence of this species. In fact, Lachner and Jenkins (1967) hypothesized that turbidity may be the most important limiting factor. Construction associated with road improvements or development, grazing, and fire activity can result in increased sediment loads to adjacent streams. While increased sediment loads or deposition at unnatural times (based on historic conditions) probably have a negative impact on hornyhead chub populations, specific thresholds and mechanisms associated with this impact have not been studied well enough to make precise predictions.

Protecting instream flows could also assist in the conservation of the hornyhead chub, as well as the entire native fish assemblage of plains streams. This assemblage of species evolved in a system with a high differential between peak spring runoff and fall base flows. While many of the plains streams have small, easily moved substrates, reduction of stream flows can lead to channel changes and less sediment transport. The lack of sediment transport can cause the loss of habitat features such as pool or run habitat that provide cover and refuge in winter and periods of drought. Thus, altered flow regimes and consequential changes in sediment transport can degrade habitat to the extent where hornyhead chub populations are extirpated from the area. Changes in stream flows can also cause habitat fragmentation and create barriers to fish passage that can isolate populations. Creating isolated populations disrupts the natural exchange of genetic material between populations, and isolated populations are subject to extinction due to catastrophic events because recolonization from nearby populations is impeded. Loss of genetic diversity can also lead the depression of fecundity and survival rates. The preservation of stream flows that are adequate to maintain complex habitat, interconnectivity of habitats, and instream cover should be a focal point of management policy or strategy.

The function of the riparian zone in relation to hornyhead chub population dynamics is poorly understood. Available data show that this species is more abundant in streams with instream cover provided by vegetation and woody debris (Trautman 1981). From a management perspective, policies (e.g. grazing, timber harvest, mineral exploration) and strategies designed to protect riparian zone function may benefit hornyhead chub populations. Conservation elements should address the function of the entire aquatic and riparian ecosystem, with particular attention to downstream populations.

While there has been little research specifically describing interactions between hornyhead chub and non-native fish species, the introduction of non-native fish could threaten hornyhead chub populations. Management of non-native fish species requires strict adherence to existing regulations regarding live release of fish. Implementation of management strategies should be designed to restrain further expansion of non-native fish distribution on National Forest System lands. In addition, management strategies on National Forest System lands, especially the grasslands in the Great Plains, should include evaluation of potential reintroduction of hornyhead chub. These strategies

could include evaluation of land use, riparian habitat, and streamflows.

Tools and practices

We are unaware of any management approaches implemented specifically for hornyhead chub in Region 2. The following review describes specific tools and techniques that could be employed to collect hornyhead chub data that is identified in the next section as Information Needs.

The absence of distribution and abundance data for hornyhead chub in Region 2 (with emphasis toward National Forest System land) is a concern. The initial priority should be a complete survey of all streams that possibly contain hornyhead chub and are within USFS boundaries, with an emphasis on the Laramie Peak Unit of the Medicine Bow National Forest. Because adult hornyhead chub frequent areas with complex instream cover, the use of electrofishing as a means to determine distribution and abundance is warranted. Several electrofishing techniques exist that would provide population estimates. The small size of the hornyhead chub suggests that multiple pass removal estimates would be the most practical method to produce high quality data. Riley and Fausch (1992) recommend a minimum of three passes be conducted when using the removal method. Use of a single pass method to develop a catch per unit of effort is cost effective on a time basis. However, precision may be sacrificed, and the introduction of bias is more likely, especially over long term monitoring with significant researcher/technician turnover. With removal estimates, researchers are able to calculate confidence intervals, allowing insight into sampling quality. Once basic distribution information has been gathered, intensive population estimates would provide baseline information with which the effectiveness of future management strategies could be evaluated. Focus should be on areas where future management strategies may include activities that could possibly impact hornyhead chub populations.

General stream reach habitat surveys should be conducted concurrently with distribution surveys. Winters and Gallagher (1997) developed a basinwide habitat inventory protocol that would be a cost effective (provides quantitative data at relatively low cost) tool to collect general habitat data.

A large data gap also exists in the knowledge of hornyhead chub movement and use of streams on National Forest System lands. The implementation of a survey methodology to determine hornyhead chub distribution and abundance can also provide insight into movement and habitat needs. Habitat selection and preference can be determined through the use a variety of techniques. The simplest technique involves correlating capture locations (during distribution surveys) to specific habitat types. Construction of habitat suitability curves is time intensive but could be used in conjunction with hydraulic modeling methodologies to estimate how habitat changes in relation to stream flow. This would allow land use managers to effectively compare the impacts of different altered flow regimes (due to water development projects) on hornyhead chub habitat. Data obtained could also be used to justify the acquisition of adequate instream flows for the hornyhead chub and other native fishes.

Defining the relationship between habitat alteration and hornyhead chub population characteristics is a relatively difficult task. This process may require significant amounts of data, including quantitative analysis of differences in species assemblage over time, changes in habitat quality/function, and some form of abundance estimates. These data could be obtained through a monitoring program with specific protocols for each data need. Repeated sampling over time would be required to develop the evaluation data set.

To effectively gather data valuable to the conservation of this species, managers need to coordinate with agencies managing portions of streams outside of National Forest System lands and determine or verify the extent of hornyhead chub populations that outside of USFS boundaries but are still affected by USFS management policies and strategies. These data may also be useful for determining habitat requirements and identifying potential reintroduction sites on National Forest System land.

Information Needs

General information needs for hornyhead chub include a wide range of information consisting of distribution and abundance, habitat requirements and associations, general attributes of life history and ecology, movement patterns, the influence of non-native fish, and the effects of human-induced habitat modification. Additional data on temporal and spatial changes in abundance, distribution, and age structure are also needed.

The initial research priority should be to survey all streams with potential habitat for the presence of hornyhead chub, with and emphasis on the Laramie Peak Unit of the Medicine Bow National Forest in

Wyoming, which is the only population in Region 2 that exists in close proximity to (and potentially on) National Forest System land.

To attain the level of understanding that is necessary to properly manage this species at a localized level, specific studies must be conducted in areas of potential habitat. Therefore, during abundance and distribution surveys, information regarding the physical and chemical characteristics of the habitat should be obtained. Data collected should include elevation, water temperature, dissolved oxygen, dissolved solids (pollutants), discharge, depth, turbidity, substrate, and habitat type. This information will provide baseline data regarding habitat requirements and preferences for each physical parameter. Habitat requirements at each life stage should also be addressed.

Data gaps also exist regarding disease, movement and basic life history of the hornyhead chub Sex ratio, survival rate, and fecundity data should be collected to provide missing components for the life cycle diagram.

In order to better understand the community ecology of hornyhead chub, future studies should include inventory and monitoring of all fish (adult, juvenile and larvae), macroinvertebrates, and periphyton taxa in the streams where hornyhead chubs occur. Stomach content analysis at various life stages will allow a better understanding of hornyhead chub feeding habits. Feeding studies on sympatric fish populations need to be conducted to determine potential competition and understand the impact of introduced and native predators on hornyhead chub populations.

In order to ensure the long-term conservation of this species, research must examine techniques to minimize the impacts of sedimentation and altered flow regimes. Research should also focus on providing guidelines for construction of future impoundments, and on exploring the use of off-channel impoundments.

DEFINITIONS

Centrum – any component that directly affects the central organism

Habitat quality – the physical characteristics of the environment (e.g., soil characteristics for plans or channel morphology for fish) that influence the fitness of individuals. This is distinguished from habitat quantity, which refers to spatial extent.

Hybridization – the production of offspring by crossing two individuals of unlike genetic constitution.

Malentities – all components other than predators that directly affect the central organism and cause a negative response.

Scale – the physical or temporal dimension of an object or process (e.g., size, duration, frequency). In this context, extent defines the overall area covered by a study or analysis and grain defines the size of individual units of observation (sample units).

Viability – a focus of the Species Conservation Project. Viability and persistence are used to represent the probability of continued existence rather than a binary variable (viable vs. not viable). We note this because of the difficulty in referring to 'probability of persistence' throughout the manuscript.

References

Andrewartha, H.G. and L.C. Birch. 1984. The ecological web: more on the distribution and abundance of animals. University of Chicago Press, Chicago, IL.

Angermeier, P.L. 1982. Resource seasonality and fish diets in an Illinois stream. Environmental Biology of Fishes. 7: 251-264.

Angermeier, P.L. and J.R. Karr. 1984. Relationships between woody debris and fish habitat in a small warmwater stream. Transactions of the American Fisheries Society 113:716-726.

Barrineau, J. 2005. Fishery Biologist, Wyoming Game and Fish Department, Laramie, WY. Personal communication.

Baxter, G.T. and M.D. Stone. 1995. Fishes of Wyoming. Wyoming Game and Fish Department, Cheyenne, WY.

Bryne, P.J. 1992. *Rhabdochona rotundicaudatum* n. sp. and a redescription of *R. cascadilla* Wigdor, 1918. (Nematoda: Thelaziodea) from minnows in southern Ontario, Canada. Canadian Journal of Zoology 70:476-484.

Carter, A.H. 1940. Life history and ecology of the minnow, *Nocomis biguttatus* (Kirtland). M.A. Thesis. University of Toronto, Toronto, Ontario.

Chamberlain, T.C. 1897. The method of multiple working hypotheses. Journal of Geology 5:837-848 (reprinted in Science 148:754-759).

Cross, F.B. 1967. Hornyhead. Pages 86-88 *in* E.R. Hall, editor. Handbook of Fishes of Kansas. R. R. Sanders, State Printer, Topeka, KS.

Cross, F.B. and R.E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. Pages 155-165 *in* W.J. Matthews and D.C. Heins, editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman and London.

Cross, F.B., R.C. Mayden, and J.D. Stewart. 1986. Fishes in the Western Mississippi Basin (Missouri, Arkansas and Red Rivers). C.H. Hocutt and E.O. Wiley, editors. The zoogeography of the North American Freshwater Fishes. John Wiley and Sons, New York, NY.

Dalton, K.W. 1989. Status of the Hornyhead Chub, *Nocomis biguttatus*, in Canada. Canadian Field Naturalist 103(2): 180-185.

Ferguson, M.M., D.L.G. Noakes, and R.G. Danzmann. 1981. Morphological and biochemical systematics of chubs, *Nocomis biguttatus* and *N. micropogon* (Pisces: Cyprinidae), in southern Ontario. Canadian Journal of Zoology 59:771-775.

Gorman, O.T. 1987. Habitat segregation in an assemblage of minnows in an Ozark stream. Pages 33-41 *in* W.J. Matthews and D.C. Heins, editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman and London.

Gorman, O.T. 1988. An experimental study of habitat use in an assemblage of Ozark minnows. Ecology 69(4):1239-1250.

Hankinson, T.L. 1920. Report on investigations of the fish of the Galien River, Berrien County, Michigan. Occasional Papers from the Museum of Zoology University of Michigan, 89:1-14.

Hankinson, T.L. 1931. Observations on the breeding behavior and habitats of fishes in southern Michigan. Pages 411-425 *in* E.S. McCartney and P. Okkelberg, editors. Papers of the Michigan Academy of Science Arts and Letters. University of Michigan Press, Ann Arbor, MI.

Heithaus, M.R. and C. Grame. 1997. Fish communities of the Vermilion River watershed: comparison of the main channel of tributaries. The Ohio Journal of Science 97(5):98-102.

Hillborn, R. and M. Mangel. 1997. The ecological detective: confronting models with data. Princeton University Press, Princeton, NJ.

Jenkins, R.E. and E.A. Lachner. 1980. Page 221 *in* D.S Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr., editors. Atlas of North American freshwater fishes. North Carolina Biological History Survey, Publication Number 1980-12.

Johnston, C.E. 1994. The benefit to some minnows of spawning in the nests of other species. Environmental Biology of Fishes 40:213-218.

Kansas Department of Wildlife and Parks. 2000. Hornyhead Chub *Nocomis biguttatus*, species description and designated critical habitats.

Kirtland, J.P. 1840. Descriptions of Four New Species of Fishes. Boston Journal of Natural History. 3:273-277.

Lachner, E.A. 1952. Studies of the biology of the cyprinid fishes of the chub Genus *Nocomis* of northeastern United States. American Midland Naturalist 48(2):433-466.

Lachner, E.A. and R.E. Jenkins. 1967. Systematics, distribution, and evolution of the chub Genus *Nocomis* (cyprinidaae) in the Southwestern Ohio River Basin, with the description of a new species. Copeia 3:557-580.

Lachner, E.A. and R.E. Jenkins. 1971. Systematics, distribution, and evolution of the *Nocomis biguttatus* species group (Family Cyprinidae: Pisces) with a description of a new species from the Ozark Upland. Smithsonian Contributions to Zoology, Number 91. Smithsonian Institution Press, Washington, D.C.

Litvak, M.K. and N.E. Mandrak. 1993. Ecology of freshwater baitfish use in Canada and the United States. Fisheries 18(12):6-13.

Mammoliti, C.S. 2002. The Effects of Small Watershed Impoundments on Native Stream Fishes: A Focus on the Topeka Shiner and Hornyhead Chub. Transactions of the Kansas Academy of Science 105(3-4):219-231.

Maurakis, E.G., W.S. Woolcott, and M.H. Sabaj. 1991. Reproductive-behavioral phylogenetics of *Nocomis* species-groups. American Midland Naturalist 126:103-110.

Meronek, T.G., F.A. Copes, and D.W. Coble. 1997. A survey of the bait industry in the North-Central Region of the United States. North American Journal of Fisheries Management 17:703-711.

Meyer, C., D. Zaft, and D. Miller. 2005. Lower Laramie River and North Laramie River Watershed, Strategic Habitat Implementation Plan. Wyoming Department of Game and Fish, Laramie Wyoming.

NatureServe. 2005. NatureServe Explorer: An online encyclopedia of life [web application]. Version 4.6. NatureServe, Arlington, Virginia. Available at http://www.natureserve.org/explorer. (Accessed: November 18, 2005).

Nelson, J.S., E.J. Crossman, H. Espinosa-Perez, L.T. Findley, C.R. Gilbert, R.N. Lea, and J.D. Williams. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. American Fisheries Society, Special Publication 29, Bethesda, MD.

North Dakota Game and Fish Department. 1994. Fishes of the Dakotas. North Dakota Game and Fish Department, Bismarck, ND. Jamestown, ND: Northern Prairie Wildlife Research Center Online:http://www.npwrc.usgs.gov/resource/fish/dakfish/dakfish.htm (Version16JUL97).

Odum, E.P. 1971. Fundamentals of ecology. Third edition. W. B. Saunders Company, Philadelphia, PA.

Patton, T.M. 1997. Distribution and status of fishes in the Missouri River drainage in Wyoming: implications for identifying conservation areas. Doctoral dissertation. University of Wyoming, Laramie, WY.

Pflieger, W.L. 1997. The fishes of Missouri. Missouri Department of Conservation. Jefferson City, MO.

Platt, J.R. 1964. Strong inference. Science 146:347-353.

Propst, D.L. and C.A. Carlson. 1986. The distribution and status of warmwater fishes in the Platte River drainage, Colorado. The Southwestern Naturalist 31(2):149-167.

Riley, S.C. and K.D. Fausch. 1992. Underestimation of trout population size by maximum-likelihood removal estimates in small streams. North American Journal of Fisheries Management 12:768-776.

Ross, M.R. and T.M Cavender. 1981. Morphological analyses of four experimental intergeneric cyprinid hybrid crosses. Copeia 2:377-387.

Schainost, S. 2003. Rivers and Streams Manager, Nebraska Game and Parks. Personal communication.

Schlosser, I.J. 1982. Trophic structure, reproductive success, and growth rate of fishes in a natural and modified headwater stream. Canadian Journal of Fisheries and Aquatic Sciences 39:968-978.

Schlosser, I.J. 1987. A conceptual framework for fish communities in small warmwater streams. Pages 17-24 *in* W.J. Matthews and D.C. Heins, editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman, OK.

Schlosser, I.J. 1988. Predation risk and habitat selection by two size classes of a stream cyprinid: experimental test of a hypothesis. Oikos 52:36-40.

Scott, W.B. and E. J. Crossman. 1998. Freshwater Fishes of Canada. Galt House Publications. Ontario, Canada.

Trautman, M.B. 1981. Hornyhead chub. Pages 268-271 *in* The Fishes of Ohio. Ohio State University Press, Columbus, OH.

Vadas, R.L., Jr. 1994. The anatomy of an ecological controversy: honey bee searching behavior. Oikos 69:158-166 (http://www.beesource.com/pov/wenner/oikos94.htm).

Vives, S.P. 1988. The reproductive behavior of minnows (Pisces: Cyprinidae) in two reproductive guilds. Doctoral dissertation. University of Wisconsin-Madison, Madison, WI.

Vives, S.P. 1990. Nesting ecology and behavior of hornyhead chub *Nocomis biguttatus*, a keystone species in Allequash Creek, Wisconsin. American Midland Naturalist 124:46-56.

Weitzel, D.L. 2002. Conservation and status assessments for the Hornyhead Chub (*Nocomis biguttatus*), Suckermouth Minnow (*Phenacobius mirabilis*), and Orangethroat Darter (*Etheostoma spectabile*): rare stream fish species of Platte River drainages, Wyoming. Wyoming Fish and Game Department, Cheyenne, WI.

Winters, D.S. and J.P. Gallagher. 1997. Basin-wide stream habitat inventory, a protocol for the Pike and San Isabel National Forests and Cimarron and Comanche National Grasslands. USDA Forest Service.