Finescale Dace (*Phoxinus neogaeus*): A Technical Conservation Assessment

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

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We would like to offer thanks to David B. McDonald at the University of Wyoming for providing the demographic matrix analysis that appears in the Appendix for this species. Without this help, we would still be crunching these numbers. We would also like to acknowledge Gary Patton and Richard Vacirca of the USDA Forest Service for all their help in bringing this report to completion. The suggestions and comments provided by anonymous reviewers are much appreciated.

Authors' Biographies

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George R. Cunningham received his Master of Arts Degree from the University of Nebraska at Omaha in 1995. He teaches courses in Conservation Biology at UNO and acts as a private environmental consultant. He is a member of the Topeka Shiner Recovery Team. His research focuses on the ecology of rare fishes of the Great Plains; like Dr. Stasiak, he has a special interest in the biology of those little minnows called dace.

Cover Photo Credit

Illustration of the finescale dace (*Phoxinus neogaeus*) by © Joseph Tomelleri.

Summary of Key Components for Conservation of the Finescale Dace

Status

Although the finescale dace (*Phoxinus neogaeus*) is not considered federally endangered or threatened throughout its entire range in the United States (G5, global secure), this species is uncommon in the Great Plains. It is only found in three of the five states comprising USDA Forest Service (USFS) Region 2. Populations in South Dakota, Wyoming, and Nebraska occur as small, isolated demes that have been declining steadily since European settlement of this region over 100 years ago. Finescale dace are currently listed as state endangered in South Dakota and state threatened in Wyoming and Nebraska.

USFS Region 2 has designated finescale dace as a sensitive species. Administrative units of Region 2 that are in the range of the finescale dace include the Black Hills National Forest in Wyoming and South Dakota, the Buffalo Gap National Grassland in South Dakota, and the Oglala National Grassland and Samuel R. McKelvie National Forest in Nebraska.

Primary Threats

The two major threats to finescale dace in Region 2 include habitat alteration and introduction of non-native fishes. Finescale dace occur in small, confined habitat in places of permanent spring seeps, usually at the extreme headwaters of small streams. The members of the natural fish community in these habitats are highly adapted to the special conditions presented by this environment. Water development activities (e.g., reservoir construction, groundwater pumping, stream diversion, channelization) that alter natural spring flow result in habitat degradation and stream fragmentation, which can negatively affect finescale dace populations. These minnows are also are strongly correlated to beaver (*Castor canadensis*) pond occurrence, so restrictions on beaver activity will result in dace population reductions. As sight-feeding predators, dace depend on relatively clear water, and any activities that cause long-term increases in turbidity will be deleterious. Therefore, construction projects, forestry practices, and cattle activities need to be managed so they do not produce excessive erosion and siltation.

The introduction of non-native species can negatively affect finescale dace and other native fishes through the combined pressures of predation, competition, potential for addition of new parasites and disease, and altering the behavioral components. Introductions of large sunfish, bass, pike, or trout could have an especially significant negative impact on dace populations.

Another threat, which may be of more local concern, would be the overharvest of finescale dace for private or commercial use. In some regions finescale dace are used as bait minnows; in northern Minnesota they have a reputation with fishermen as excellent (perhaps the best) bait to use for walleye fishing.

Primary Conservation Elements, Management Implications and Considerations

The finescale dace is one of the keystone species of small fishes forming a distinctive community in the Great Plains. This assemblage is restricted to small headwater streams, beaver ponds, and small spring-fed lakes. Major management goals should be to maintain and restore these aquatic habitats to pristine or historic conditions. Considerations would be to protect groundwater sources, streamflows, and beaver activity. To maintain the integrity of the natural fish community, the practice of introducing non-native fishes in finescale dace habitat should be eliminated. Existing populations of exotic fishes should be controlled and reduced where they have already become established within finescale dace habitat. Rules pertaining to the use of dace as bait require strict enforcement to be effective. Data gaps identified for this species concern basic life history components such as dispersal patterns and activity cycles. Inventories and monitoring programs should be implemented to update data on distribution and abundance. Studies on the genetics of the isolated populations should also become a key component in protecting finescale dace.

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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) (**Figure 1**). The finescale dace (*Phoxinus neogaeus* Cope) is the focus of this assessment because there was concern for the viability of this species in the states comprising Region 2 during the Regional Forester's Sensitive Species List revision process that took place 2001-2003. 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 downwards trend in abundance and/or habitat capability that would reduce its distribution [FSM 2670.5 (19)]. Finescale dace occur as widely scattered populations in three of the five states comprising Region 2: Nebraska, South Dakota, and Wyoming. They have been collected in streams in the Black Hills National Forest in Wyoming (**Figure 2**). Some finescale dace populations are also found in stream systems that flow adjacent to other USFS units.

This report addresses the biology, ecology, conservation, and management of finescale dace throughout its range in Region 2. The broad nature of this assessment leads to some constraints on the specificity of information for particular locales. Much of the data comes from research conducted on populations that lie outside Region 2, which make up the major portion of the species' distributional range (**Figure 3**).

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 upon available scientific knowledge. The assessment goals limit the

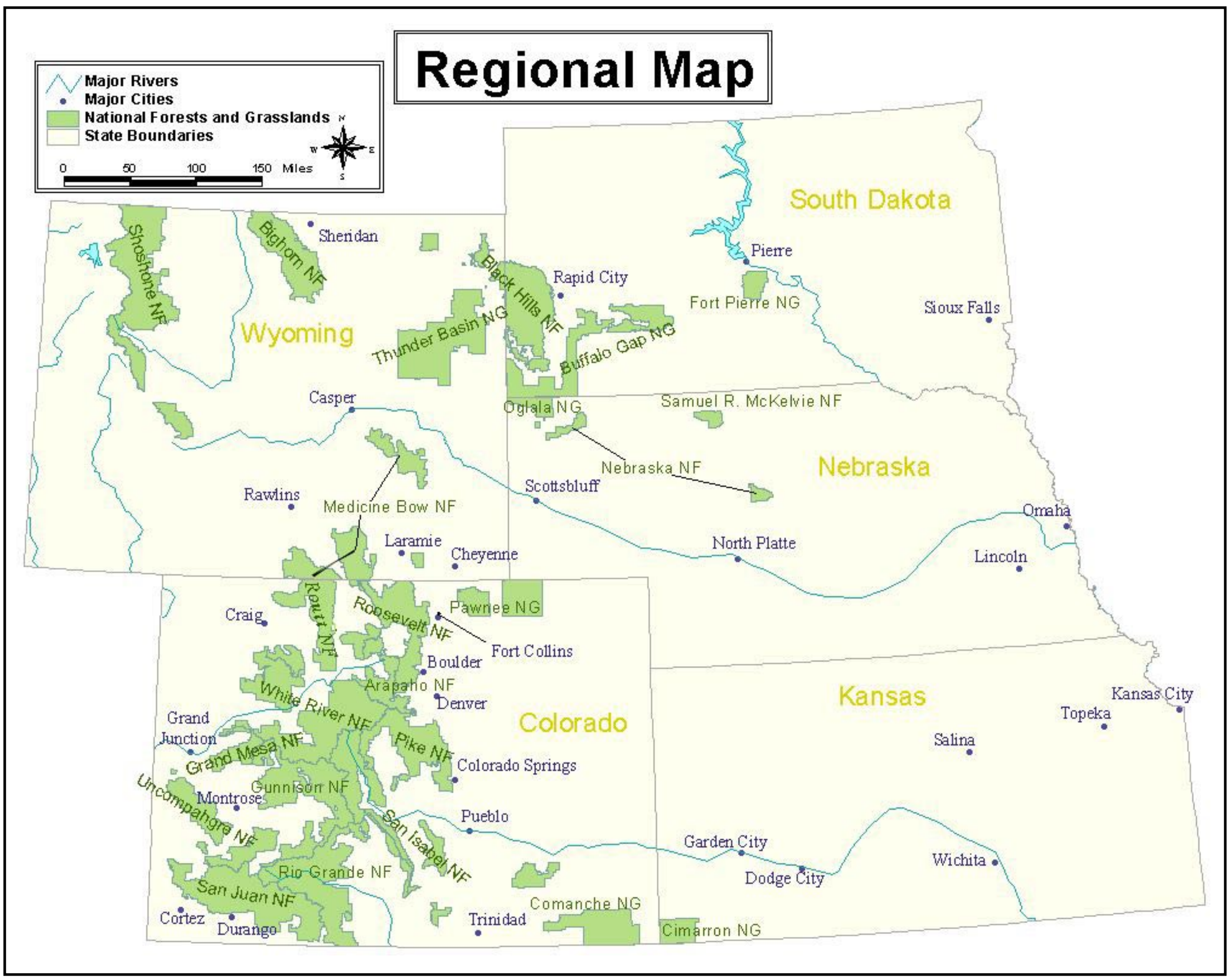

Figure 1. Map of national forests and national grasslands within USDA Forest Service Region 2.

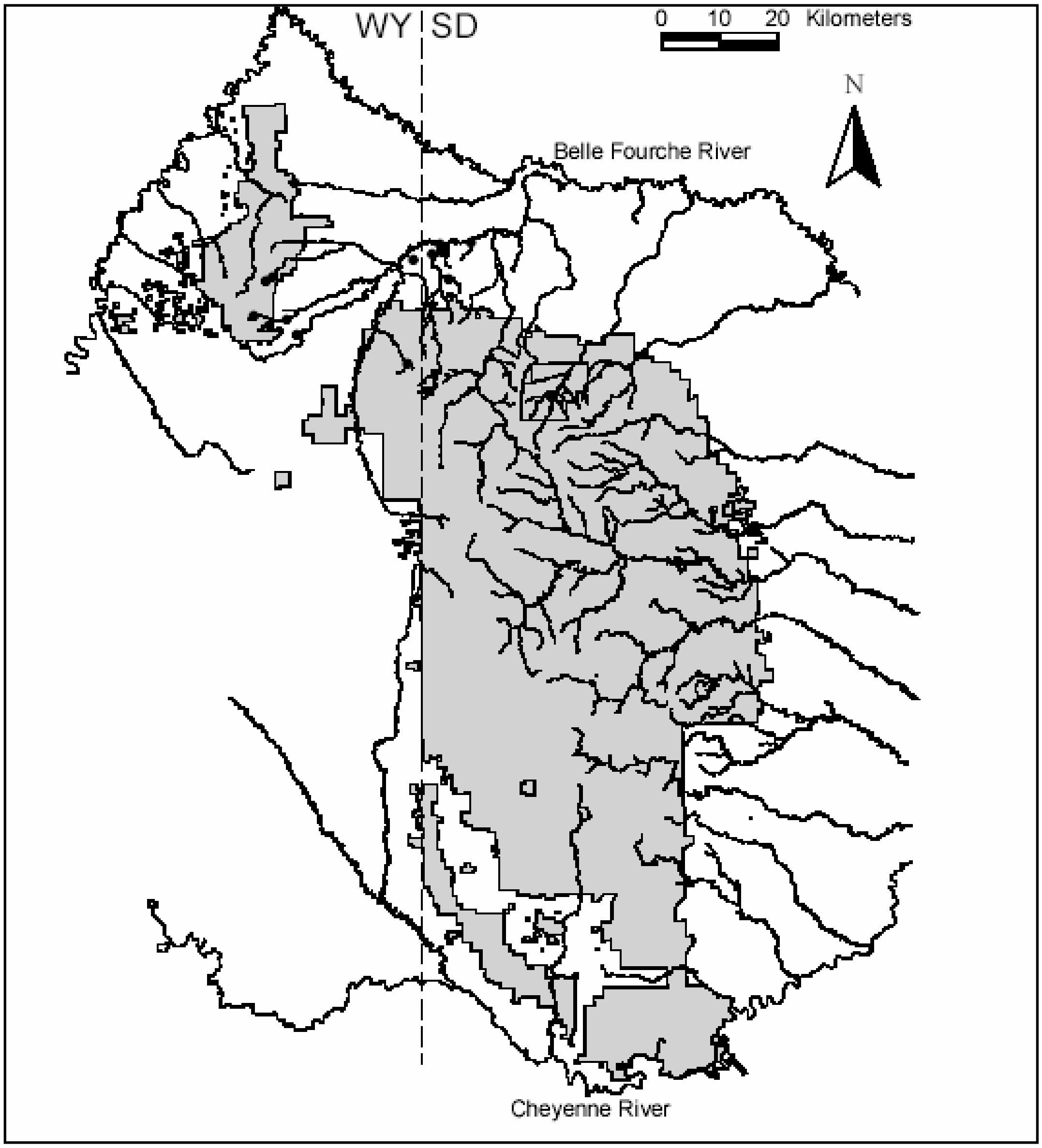

Figure 2. Finescale dace locations in the northern Black Hills region.

scope of the work to critical summaries of scientific knowledge, discussion of the broad implications of that knowledge, and outlines of information needs. This 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 actions (i.e., management implications).

Scope of Assessment

This finescale dace assessment examines the biology, ecology, conservation status, and management of the species with specific reference to the geographic and ecological characteristics of Region 2. While most 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 Rocky Mountains and the Great Plains. Similarly, this assessment is concerned with reproductive behavior, population dynamics, and other characteristics of the finescale dace in the context of the current environmental rather than historical conditions. The evolutionary environment of the species is considered in conducting the synthesis, but it is placed in a current context.

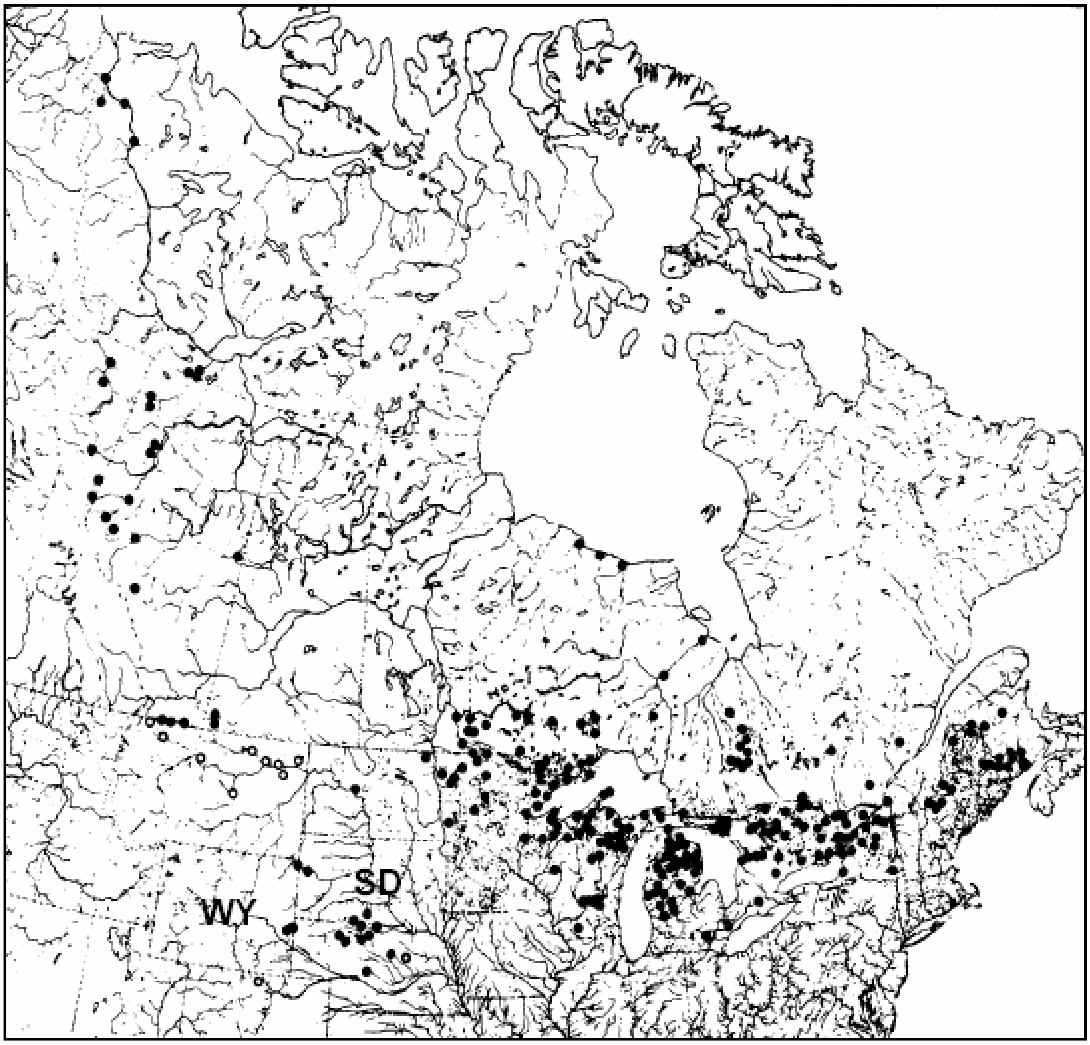

Figure 3. North American distribution of finescale dace. (From Stasiak 1980).

In producing the assessment, the refereed literature was reviewed, as were non-refereed publications, research reports, and data accumulated by resource management agencies. Not all publications on finescale dace are referenced in this assessment, nor were all materials considered equally reliable. This assessment emphasizes refereed literature because this is the accepted standard in science. Some non-refereed literature was used in the report, however, when information was not available in the primary literature. Unpublished data (e.g. Natural Heritage Program Records) were important in estimating the geographic distribution of the species.

Treatment of Uncertainty

Science represents a rigorous, systematic approach to obtaining knowledge. A commonly accepted approach to science is based on a progression of critical experiments to develop strong inference. However, it is difficult to conduct critical experiments in the ecological sciences, and often observations, inference, good thinking, and models must be relied on to guide the understanding of ecological relations. In this assessment, the strength of evidence for particular ideas is noted, and alternative explanations are described when appropriate.

Application and Interpretation Limits of this Assessment

Information about the biology and ecology of finescale dace was collected and summarized from throughout its geographic range, which extends from Canada south to Colorado and Nebraska, and from British Columbia east to the Atlantic Ocean (**Figure**

2). In general, life history and ecological information collected from a portion of this range should apply broadly throughout the entire distribution of the species. However, certain life history parameters (e.g., time of spawning, growth rates, longevity) could differ along environmental gradients, especially in such a wide-ranging species. Information about the conservation status of this species was limited to Regions 2 and should not be taken to imply conservation status in other portions of the species' overall range. Scientific and common names of fishes used in this report follow the latest recommendations from the American Fisheries Society (Nelson et al. 2004).

Publication of 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 revision of the assessment, which will be accomplished based on the guidelines established by Region 2.

Peer Review

Assessments developed for the Species Conservation Project 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 the 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 finescale dace is not considered a federally threatened, endangered, or sensitive species in the United States (U.S. Fish and Wildlife Services; http://endangered.fws.gov/). It is, however, found on the Regional Forester's sensitive species list in USFS Region 2 (Species Conservation Project: Region 2 Regional Forester's Sensitive Species: (http://www.fs.fed.us/r2/projects/scp/sensitivespecies/index.shtml). It has a Global Heritage Rank of G5 (secure) from the Nature Conservancy.

Within Region 2, the finescale dace is listed as state endangered in South Dakota and state threatened in Nebraska and Wyoming. According to the system used by The Nature Conservancy, NatureServe, and the National Heritage Network, this species is ranked S1 (critically imperiled) in South Dakota and S2 (threatened) in Nebraska and Wyoming. The only Region 2 location to document populations of finescale dace is the Black Hills National Forest in Wyoming, where they occur in the Redwater Creek drainage (**Figure 2**; Isaak et al. 2003). Finescale dace populations occur near USFS administered lands in Nebraska and South Dakota (**Figure 4** and **Figure 5**). The species is not present in the state of Kansas, but it may be included in Colorado on the basis of reports of hybrids of finescale dace and northern redbelly dace (*Phoxinus eos*) (Page and Burr 1991).

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

Finescale dace are considered endangered or threatened in all three of the states in which they occur in USFS Region 2 and are given all the legal protection encompassed by that status. This generally prohibits direct collecting, use, or killing of protected minnow species. These states also regulate the taking of bait minnows; this usually involves restricting the number, locations, and gear used by licensed anglers. Commercial dealers need to obtain special permits. It is also usually illegal to collect bait minnows from designated trout waters; this would have the effect of protecting many rare species that occur in streams of high water quality, including finescale dace. In virtually all states, it is illegal to transfer live fishes into bodies of water where they did not originate. These general regulations may impart some measure of protection to finescale dace, but this depends to a large measure on how strictly the laws and regulations are enforced.

All states are currently developing Comprehensive Wildlife Conservation Strategy (CWCS) plans that list the measures they are taking to protect rare species. The finescale dace appears on CWCS plans for both Nebraska (http://www.teaming.com/state_cwcs/nebraska) and Wyoming (http://gf.state.wy.us/wildlife/comConvStrategy/Species/fish). Both of these plans consider finescale dace a Tier I species due to small disjunct populations, and they make note of the threats and research inventory needs. The plan for South Dakota was unavailable at this time.

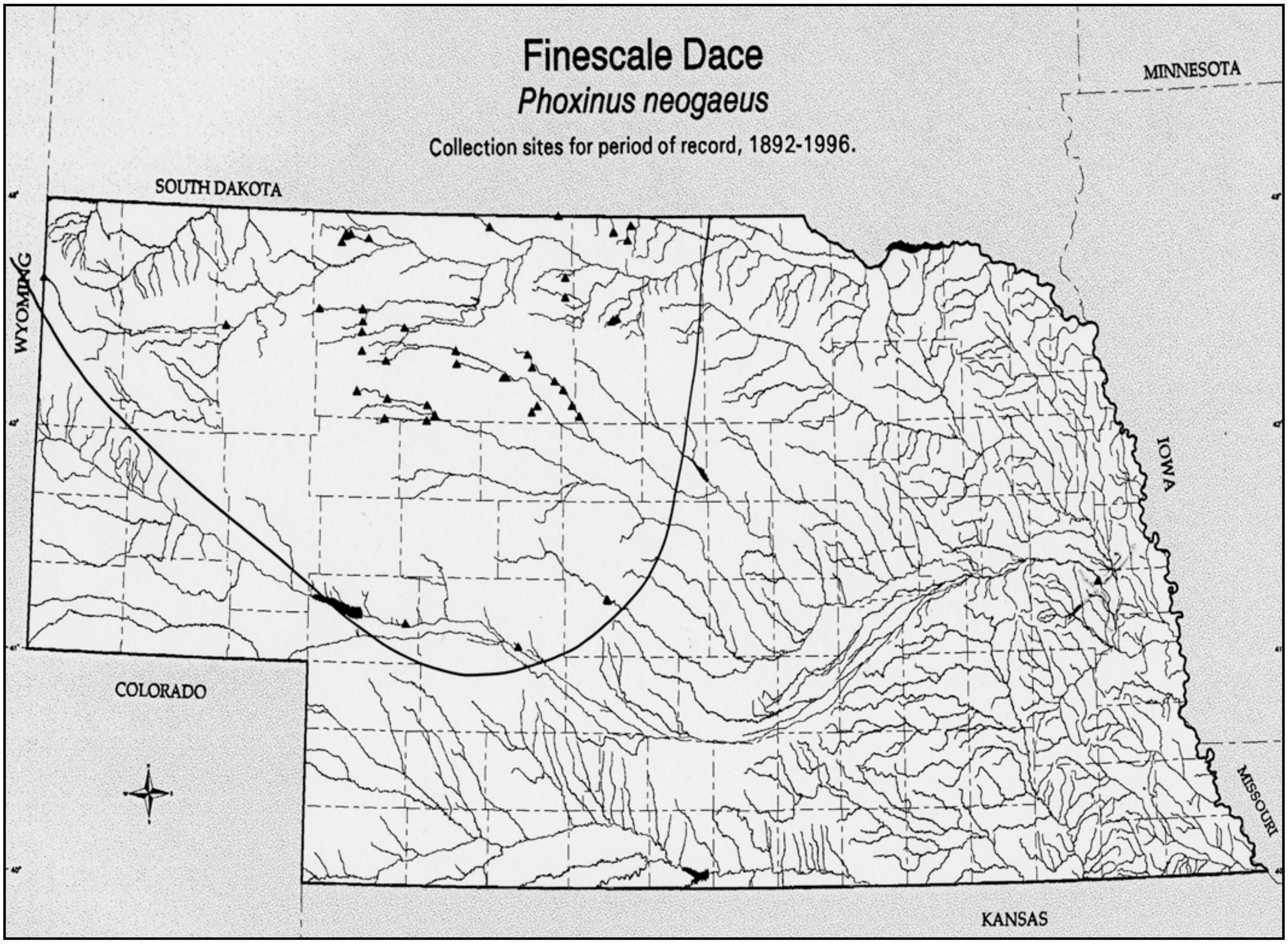

Figure 4. Distribution of finescale dace in Nebraska.

Biology and Ecology

Systematics

The finescale dace (**Figure 6**) is in the bony fish superclass Osteichthyes, Class Actinopterygii, Order Cypriniformes, and family Cyprinidae (Nelson 1994.) It has been placed in several different genera over the past 140 years. The history of this taxonomic shuffling is intriguing. The finescale dace was first described as *Phoxinus neogaeus* in 1869, and most researchers have again used that same name since about 1972. Between those dates, the literature was filled with several different generic designations.

Samuel Rafinesque first used the name *Chrosomus* when he described *C. erythrogaster*, or what he called the Kentucky RedBelly, from a specimen taken from the Kentucky River (Rafinesque 1820). Edward Drinker Cope (1862) described *C. eos* on the basis of specimens from the Meshoppen Creek, Sesquehanna County, Pennsylvania. He included four distinguishing "peculiarities" that separated his *C. eos* from Rafinesque's *C. erythrogaster*. In 1865, Cope again listed a comparison of *C. eos* and *C. erythrogaster*, this time from specimens taken in 1864 from streams flowing into Lake Erie at New Hudson, Livingston County, Michigan. Cope subsequently decided that those 1864 specimens actually represented a new species, not the C. eos he had described in 1862. He named this new species *Phoxinus neogaeus* (finescale dace) in 1867. This name was based upon the resemblance he noted between these fish and *P. laevis*, the common European minnow. Note that the genus *Phoxinus* was also originated by Rafinesque in 1820, on the same page he used to describe the genus *Chrosomus*.

Albert Gunther (1880) listed *Leuciscus neogaeus* (finescale dace) as one of the North American examples of the genus meaning "whitefish" that was originated by Cuvier in 1817. According to Gunther, the small fish of the genus *Leuciscus* were called "minnows", the

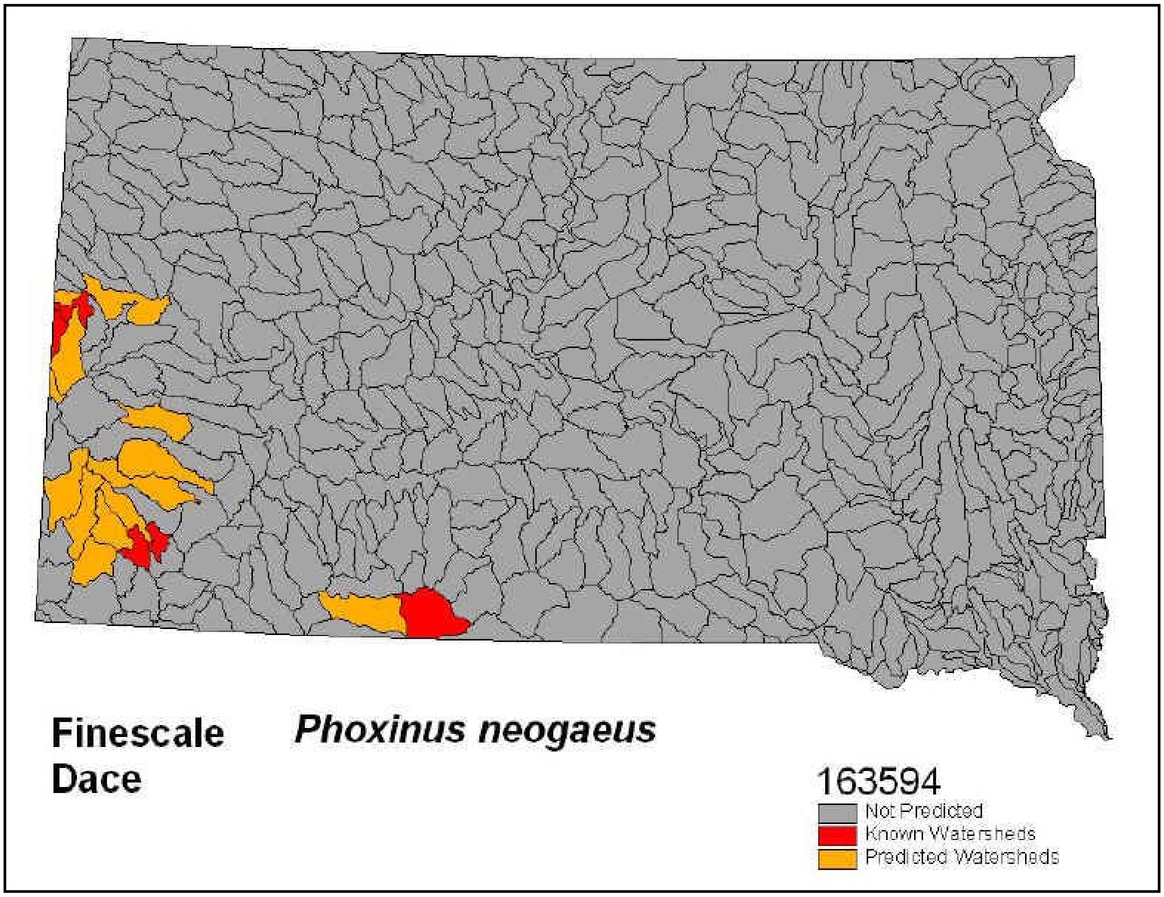

Figure 5. Predicted finescale dace distribution in South Dakota. (From South Dakota GAP analysis).

larger ones were called "shiners" or "dace". *Leuciscus neogaeus* was said to resemble the European species *L. phoxinus*, but differed in having an incomplete lateral line. Barton Evermann (1893) and Evermann and Cox (1896) used the designation *L. neogaeus* in their reports of the Missouri River fauna; other authors, such as Jordan and Gilbert (1882) and William Kendall (1908), continued to use Cope's original *Phoxinus neogaeus*.

David S. Jordan (1924) created the new genus *Pfrille*, the type of which was *Phoxinus neogaeus* Cope. Jordan had this to say about his new genus:

> "This group, based on a single American species, is very close to the European *Phoxinus* Rafinesque (*Cyprinus phoxinus* L.), differing in the larger mouth, the maxillary reaching to opposite the front of the orbit, and in the very short lateral line which does not reach the ventrals. *Pfrille* is the German name of *Phoxinus phoxinus*."

This change by Jordan was generally accepted, and the genus of finescale dace was published as *Pfrille* by many workers (Hubbs 1926, Hubbs and Brown 1929, Greeley and Greene 1931, Greeley and Bishop 1932,1933, Greeley 1934, Greene 1935, Hubbs and Cooper 1936, Churchill and Over 1938, Bailey and Oliver 1939, Dymond and Scott 1941, Lindeborg 1941, Johnson 1942, Hinks 1943, Brett 1944, Radforth 1944, Bangham and Venard 1946, Wynne-Edwards 1952, Scott 1954, Dobie and Meehan 1956, Scott 1957, Carl et al. 1959, Scott and Crossman 1959, McPhail and Lindsey 1970, Stasiak 1972.)

Hubbs and Brown (1929) were first to report the occurrence of hybrids between *Chrosomus* and *Pfrille* (finescale dace); these were found in Ontario, Michigan, and New York. They also noticed the great similarity of the two genera. Special mention was given to the similar triangular areas of breeding tubercles anterior to the pectoral fins in both species, a feature attributed only to those two genera. They stated that *Chrosomus* appeared to be a herbivorous modification of *Pfrille*, just as *Hybognathus* appeared to be a herbivorous modification of *Notropis*. (This is a clarification of a statement appearing in Hubbs [1926]). Only the authors' uncertainty about the fertility of the hybrids

Figure 6. Red (top) and yellow (bottom)-phase male finescale dace taken during the height of the breeding season (27 April 1967). Location was French Creek Bog beaver ponds in Minnesota's Itasca State Park. Photograph by Richard H. Stasiak.

apparently prevented them from combining *Pfrille* and *Chrosomus* at that date.

According to McPhail and Lindsey (1970), it was Reeve Bailey who proposed merging the two genera in 1951; data supporting this suggestion have never been published. Legendre (1954) appears to have been the first published account of this change. On page 7, he listed *Pfrille* with *Chrosomus*, and on page 17 he listed the finescale dace as *C. neogaeus* (Cope). From that date, most authors placed the finescale dace in the genus *Chrosomus* in their works (e.g., Taylor 1954, Hubbs 1955, Underhill 1957, Nordlie et al. 1961, Bailey and Allum 1962, New 1962, Eddy et al. 1963, McPhail 1963, Sherrod 1963, Moore and Roberty 1965, Underhill and Dobie 1965, Tyler 1966, Phillips 1968, Underhill and Moyle 1968, Willock 1969, Legendre 1969, Scott and Crossman 1969, Eastman 1970, Becker and Johnson 1970). Thus, without any published account detailing evidence for such a revision, *P. neogaea* (Cope) became *C. neogaeus* (Cope), and this name came into general use from 1955 to 1970.

In his work on the fishes of Russia, Berg (1949) listed *Pfrille* Jordan as a questionable species under *Phoxinus*. Banarescu (1964), writing on the fishes of Rumania, went one step further and listed *Chrosomus* Rafinesque together with *Pfrille* Jordan as American species of *Phoxinus*. Excepting that addition, Banarescu (1964) translates as an almost verbatim duplicate of Berg's listing of the merger of the genera *Phoxinus, Pfrille,* and *Chrosomus*; again, no documentation was given for this action. In a letter to Gary Phillips at the University of Minnesota in 1968, Reeve Bailey called attention to Banarescu's book (Phillips 1968). Smith-Vaniz (1968) apparently was the first American to publish an acceptance of this opinion. The effect of this revision was to merge all of the American *Chrosomus* species into the European genus *Phoxinus*. Based upon opinions listed with little or no comparative data, *Phoxinus* became the only minnow genus with species in Europe, Asia, and North America. Thus, the finescale dace is presently listed as *P. neogaeus*, just as it was originally described by Cope in 1869 (Mayden et al. 1992).

Species description

The North American dace in the subgenus *Chrosomus* include the finescale dace, southern redbelly dace (*Phoxinus erythrogaster*), northern redbelly dace, mountain redbelly dace (*P. oreas*), blackside dace (*P. cumberlandensis*), Tennessee dace (*P. tennesseensis*), and laurel dace (*P. saylori*) (Page and Burr 1991). These seven species are small to medium-sized (70 to 120 mm [2.8 to 4.7 inches] total length) minnows with very small scales (barely visible without magnification). The number of scales in the lateral line is usually greater than 80 (Stasiak 1977). The pores of the lateral line organ only extend along the side horizontally from the head to about half-way toward the tail. These dace have horizontal black bands along their sides with iridescent silvery areas above the main lateral band. Males of these species have bright red and often yellow below the black side band; these color patterns are especially vivid during the spawning seasons. These bold and distinctive markings are very striking, making the daces obvious and easy to recognize.

Males of the finescale dace can be found with three different color patterns on the lower sides: red, yellow, or red and yellow combined (Stasiak 1972, Scott and Crossman 1973). Finescale dace are the largest of the North American *Phoxinus*, with total lengths reaching about 5 inches (approximately 120 mm). They have thick, fusiform bodies with a large head and mouth. The jaws are large and strong (Mahy 1972, Coad 1976). Internal structures, such as the intestine length and pharyngeal tooth pattern, will also be distinctive (Stasiak 1972, 1977, 1978). Pharyngeal arches have a 2, 4-5, 2 formula, the only North American *Phoxinus* with this dentition (Eastman 1970). The intestine of the finescale dace is much shorter than the other American *Phoxinus*, with a simple S-shape and an overall length of less than the standard length of the fish (Stasiak 1972, 1978). The combination of large mouth and jaws, strong pharyngeal teeth, and a short intestine are typical for a highly predatory minnow. Breeding tubercles are well developed on the males during the spring. Finescale dace develop a unique and distinctive pattern of these structures on their fins, on their sides, in front of the pectoral fins, and above the anal fin (Maas 1994).

In many regions throughout their range, finescale dace are snytopic with northern redbelly dace. Usually it is rather easy to identify the two species; the finescale dace is larger and usually has only one prominent black lateral band. During the breeding season, the males have the unique tubercle pattern and marking described previously. In many situations where finescale dace and northern redbelly dace are found together, hybrids of the species have been reported (Hubbs and Brown 1929, Hubbs 1955, Bailey and Allum 1962, New 1962, Brown 1971, Stasiak 1972, Magnin et al. 1976, Stasiak 1978, Joswiak et al. 1982, Stasiak 1987, Goddard et al. 1989, Gauthier and Boisclair 1996, Schlosser et al. 1998). These fish apparently represent lineages of clonally reproducing gynogens; they are intermediate in most of the body proportions and other characteristics normally used to identify the two parental species (New 1962, Joswiak et al.1982, 1985).

Distribution and abundance

The finescale dace is widely distributed across Canada and the northern portions of the St. Lawrence (Great Lakes), Mississippi, and Missouri River drainages in the United States (Stasiak 1980, Page and Burr 1991). This species has been reported from as far as 67° N latitude, and from as far south as 41° North latitude in Nebraska (**Figure 4**). In Canada, it has been taken from the Northwest Territories, British Columbia, and Alberta (Wynne-Edwards 1952, Lindsey 1956, Carl et al. 1959, Paetz and Nelson 1970, McPhail and Lindsey 1970, Roberts 1973); Saskatchewan (Willock 1969, Smith 1976 and Manitoba (Hinks 1943, Fedoruk 1971, Smith 1976); Ontario (Hubbs and Brown 1929, Dymond and Scott 1941, Lindeborg 1941, Brett 1944, Ryder et al. 1944, Tyler 1966); Quebec (V. Legendre 1953, P. Legendre 1970); and New Brunswick (Scott and Crossman 1959, 1973).

In the United States, finescale dace have been found in Maine and New Hampshire (Kendall 1908); New York (Greeley and Bishop 1932, 1933, Smith 1985); Michigan (Cope 1865, Taylor 1954, Hubbs and Lagler 1949, Wisconsin (Greene 1935, Moore and Roberty 1965, Becker and Johnson 1970, Becker 1983); Minnesota (Smith and Moyle 1944, Stasiak 1972, Underhill 1989, Hatch et al. 2003); North Dakota (Tubb et al. 1965, Copes and Tubb 1966, Evenhuis 1969); South Dakota (Evermann 1893, Evermann and Cox 1896, Churchill and Over 1938, Bailey and Allum 1962, Ashton and Dowd 1991, Isaak et al. 2003); Nebraska (Johnson 1942, Jones 1963, Stasiak 1976, 1980 Madsen 1985, Sasiak 1987, 1988, Cunningham 1995); and Wyoming (Cope 1872, Bailey and Allum 1962). Only hybrids (*Phoxinus neogaeus* x *P. eos*) have been reported from Colorado (Cope and Yarrow 1875, Bailey and Allum 1962, Woodling 1985) and Montana (Brown 1971, Elser et al. 1980).

In the five states comprising USFS Region 2, the finescale dace is found in Nebraska, South Dakota, and Wyoming. The species is not present in Kansas, and only the hybrid *Phoxinus neogaeus* x *P. eos* has been reported from Colorado (Woodling 1985, Page and Burr 1991). In Wyoming, the finescale dace is found in the headwaters of the Niobrara River and some streams in the Redwater Creek drainage in the Black Hills National Forest (**Figure 2**). It is also found in South Dakota Black Hills streams, but not directly on federal lands (**Figure 5**; Isaak et al. 2003). Although populations of finescale dace are scattered throughout the Sandhills region of Nebraska, none of these occur directly on USFS property (**Figure 4**). All of the finescale dace populations in South Dakota, Nebraska, and Wyoming can be considered "glacial relict" populations that have been isolated from the main portion of the species' range to the north (Cross et al. 1986).

Although actual numbers are rarely reported, it is our observation that finescale dace can often be listed as abundant in the localities where suitable habitat still exists.

Population trends

Finescale dace populations are considered stable throughout the main portion of their range in Canada, Minnesota, Wisconsin, Michigan, and New England (Underhill 1957, Becker and Johnson 1970, Smith 1985, Das and Nelson 1990, Hatch et al. 2003). Where they occur as relict populations following the retreat of the Wisconsin Ice Sheet, finescale dace populations are scattered and localized. Here they are found in the headwaters of first-order streams and in areas of groundwater seepage. The cold water provided by this source enables the dace to persist under conditions much more similar to the cooler, wetter conditions that prevailed thousands of years ago when the southern edge of the glacier was much closer to this region (McPhail 1963, Sherrod 1963, Cross et al.1986). The warming and drying of this Great Plains region following the end of the most recent ice age has led to the natural contraction and fragmentation of suitable habitat for this northern species. Human activity that leads to reduction in cold spring seeps will tend to accelerate this process.

Activity patterns

Little is known of the activity patterns of finescale dace in this region. Stasiak (1972) studied a population of finescale in a series of beaver ponds near the headwaters of the Mississippi River in northern Minnesota. The fish were active throughout the pond during daylight hours, but they were not observed at night. Large schools of dace comprising all sizes and year-classes could be observed in open water areas of the ponds in the spring and summer months. Collections made through the ice from December to March indicated that the dace were actively feeding even during the winter months. This species is apparently well-adapted to cold water (Brett 1944, Tyler 1966). Breeding dace were attracted to deep depressions under fallen logs and brushy debris in late April and early May (Stasiak 1987). In a larger lake situation, Gauthier and Boisclair (1996) observed that hybrid dace (*Phoxinus neogaeus* x *P. eos*) made daily movements offshore to inshore at night, probably in relation to feeding forays.

Activity patterns for a 24-hour cycle have not been reported for the Great Plains populations of finescale dace.

Habitat

Finescale dace have a strong habitat affinity for sluggish, spring-fed streams with abundant vegetation and woody debris (Eddy and Surber 1974, Stasiak 1987). They can also be found in small spring-fed lakes and bogs (Greeley and Bishop 1933, Hubbs and Cooper 1936, Das and Nelson 1990). Perhaps the optimal habitat for finescale dace can be described as a series of beaver ponds filled with a constant supply of cool groundwater (Stasiak 1972, Schlosser et al. 1995, 1998). This particular habitat is a key to the presence of finescale dace, particularly in the Great Plains region. The water does not need to be deep; the constant supply of cool spring water provides them with sufficient oxygen, even during the hot and dry summer conditions. The vegetation and cover provided by logs and brush supply shady areas for the dace to stay out of the sun, ambush prey, and avoid predators.

A critical component of their habitat is the exclusion of large predatory fishes. Brightly colored finescale dace simply do not fare well in the presence of large piscivorous species (Stasiak 1972). Active, shallow beaver ponds with their ever-changing dimensions and dams tend to naturally exclude these larger species of fish (Stasiak 1972, Naiman et al. 1988, Olson and Hubert 1994, Schlosser and Kallemeyn 2000). Beaver ponds also usually provide a high amount of organic material that supports a robust community of food organisms for all the life history stages of the dace (Tonn and Magnuson 1982, Angermeier and Karr 1984). Clear water is necessary for the sight-feeding dace to find their prey and their mates. Water can often be stained a reddish or tea color from dissolved organic material (Becker 1983), but this tinted water is still transparent.

In some first-order streams, particularly in the Nebraska Sandhills, finescale dace can be found where the banks are severely undercut, providing deep holes with reduced current and concentrations of cover (snorkeling observations by the authors). The conditions of these small streams include:

- ❖ clear, cool spring seeps
- ❖ lack of a strong current
- ❖ cover in form of undercut banks, heavy vegetation, or brushy debris
- ❖ absence of large piscivorous fish populations.

This species may also be present in small lakes that can be characterized as small, shallow, spring-fed, clear, with heavy vegetation (at least along the shoreline) and few, if any, species of large predatory fishes.

Finescale dace are usually associated with a fairly small but distinctive assemblage of other fish species that are also adapted to similar habitat requirements. In the Minnesota beaver ponds, Stasiak (1972) found northern redbelly dace, fathead minnow (*Pimephales promelas*), brook stickleback (*Culaea incontans*), and central mudminnow (*Umbra limi*) together with finescale dace. Scott and Crossman (1973) found this same fish assemblage across much of the species' range in Canada. In Michigan and Wisconsin, finescale dace have been also found together with brassy minnow (*Hybognathus hankinsoni*), pearl dace (*Margariscus margarita*), common shiner (*Luxilis cornutus*), blacknose shiner (*Notropis heterolepis*), johnny darter (*Etheostoma nigrum*), white sucker (*Catostomus commersoni*), and mottled sculpin (*Cottus bairdii*). In some eastern streams, brook trout (*Salvelinus fontinalis*) are occasionally found with finescale dace; in these cases, the brook trout are native and apparently quite small (usually less than 9 inches maximum size) (Hubbs and Cooper 1936, Stasiak 1972, Becker 1983).

In the Great Plains populations of Region 2, finescale dace are usually associated with northern redbelly dace, pearl dace, brassy minnow, blacknose shiner, fathead minnow, creek chub (*Semotilus atromaculatus*), and Iowa darter (*Etheostoma exile*) (Bailey and Allum 1962, Stasiak 1976, Baxter and Stone 1995).

Food habits

Finescale dace are carnivores, feeding on animals taken from the entire water column, surface to bottom. As adults, they are primarily sight-feeding predators, selecting relatively large individual target prey (Stasiak 1972). Hubbs and Cooper (1936) included finescale dace as one of four examples of distinctly carnivorous minnow species. They characterized these fish as follows: "large terminal mouths for seizing animals; pointed and hooked pharyngeal teeth, for holding their prey and tearing the flesh, and a very short intestinal tract, which suffices for the rapid digestion and assimilation of animal matter". Keast and Webb (1966) also described predator minnows as having larger heads, larger mouth gapes, and stronger jaws.

McPhail and Lindsy (1970) reported that finescale dace from three localities in northwestern Canada fed primarily on insects. Litvak and Hansell (1990) examined the intestines of 111 finescale dace from a small Ontario lake and found a combination of crustaceans, insects, and plant debris. Cochran et al. (1988) compared the diet of finescale dace and northern redbelly dace in a small northern Michigan bog lake. They reported that both species consumed plant material and invertebrates from the algal mat, but that finescale dace ate a higher proportion of animal material and less vegetative material than northern redbelly dace. In Minnesota beaver ponds, Stasiak (1972) examined intestinal tracts from 348 dace of different sizes. Adult fish consumed a wide variety of invertebrates, especially aquatic insects and mollusks. Insects included midges (Diptera), beetles (Coleoptera), caddisflies (Trichoptera), mayflies (Ephemeroptera), and bugs (Hemiptera). Fingernail clams and snails were found in 30 percent of the specimens examined. This indicates that benthic macroinvertebrates constitute a significant portion of the diet. Planktonic crustaceans (cladocerans and copepods) were more common in their diet during the winter months when the pond was covered with ice. Miscellaneous invertebrates in the diet included mites, spiders, ants, and dragonflies. The intestinal tract of one large male in late June was completely filled with fish eggs (presumed to be that of the northern redbelly dace). The large terminal mouth and strong pharyngeal teeth enable finescale dace to take prey that is large for their body size. In captive feeding experiences (personal observations), finescale dace readily consumed the large last instar larvae of tenebrio beetles (mealworms). Becker (1983) stated that dace in aquaria easily ate guppies. Dace under 35 mm depended more on small crustaceans and midge larvae (Stasiak 1972). Some vegetation has been found in their intestines as well as sand, and it is assumed that this material is taken incidentally when feeding on benthic invertebrates.

The diet of an adult finescale dace would be very similar to that of a large, sight-feeding predator fish, such as a trout or a sunfish. In the ponds and small streams where finescale dace are found (and other larger predatory fishes are absent or rare), they fill the feeding niche of the large, sight-feeding insectivore. One of the most obvious differences between finescale dace and the closely related but smaller northern redbelly dace (and their hybrids) is the highly predatory behavior of the finescale dace (Naud and Magnan 1988, Trudel and Boisclair 1994, Gauthier and Boisclair 1996).

Breeding biology

The finescale dace is one of the first minnow species to spawn in the early spring, soon after ice cover is eliminated. Spawning appears to be triggered by a combination of water temperature and photoperiod (Stasiak 1972). Depending on the latitude, spawning occurs from April to early June (McPhail and Lindsey 1970, Stasiak 1972, 1978, Das and Nelson 1990). Stasiak (1978) reported that breeding behavior is initiated when water temperature reaches 13 to 15 °C (about 55 °F). Finescale dace in the Great Plains states of Region 2 usually spawn in mid-April to mid-May (Clausen and Stasiak 1994). Since water temperatures can rise and fall rapidly during this time of year, breeding behavior may commence and then be suspended for periods of time. In locations with substantial groundwater flow, the temperature rise is more gradual and it fluctuates less, providing a more stable breeding situation. In these cases, most of the spawning activity may be concentrated in a short period of time, perhaps one or two weeks (Stasiak 1972).

Reproductive behavior for North American *Phoxinus* species generally includes the broadcasting of non-adhesive eggs into a substrate, usually done by a group of fish, not an individual spawning pair. Breeding biology of *P. eos* has been described by Cooper (1936) and Slateneko (1958). Smith (1908) and Phillips (1968) described the reproductive biology for *P. erythrogaster*. Bullough (1939) studied the European minnow *P. phoxinus*. As expected, the breeding biology of finescale dace is generally similar.

The only comprehensive study of the reproductive biology of finescale dace was carried out by Stasiak (1972, 1978) in beaver ponds at French Creek Bog in Minnesota's Itasca State Park. This seepage complex is within 800 m (½ mile) of where the Mississippi River flows out of Lake Itasca. Finescale dace have also spawned in aquaria and have been artificially propagated (Stasiak 1972, 1978, Joswiak et al. 1982, 1985, Goddard et al. 1989).

Sexual dimorphism is apparent in finescale dace. Females are usually larger than males and do not display the red and yellow sides and bellies of breeding males (**Figure 7**). Males attain very bright red or yellow pigmentation on the lateral and ventral portions of the body during the spring (**Figure 6**); this pattern is obvious even before spawning and is retained to some extent throughout the entire year. Some males carry only red color; some have only yellow; and some show both red and yellow (Stasiak 1972). Males also have fins that are proportionally larger than the same fins of females; this is especially obvious for the large, scoop-shaped pectoral fins. Finescale dace males have a unique compliment of breeding tubercles. These nuptial tubercles (often called pearl organs) develop on males of most species of cyprinids, and they are usually species-specific in number, size, structure, and location (Reighard 1903). The males have rows of tubercles in front of the pectoral fins, above the anal fin, and on the rays of the paired fins and anal fin (Stasiak 1972, Maas 1994). The male's colors, large fins, and breeding tubercles are all used to stimulate the release of eggs by the female. Spawning occurs in groups of males with single or multiple females; the large pectoral fin of males is used to hold and guide the females into substrates such as brush, logs, rocks, or aquatic plants. The spawning dace seek out structure in deep pools or undercut banks in streams. Based on observations in large aquaria, dace may spend up to 1 minute actually releasing eggs in these situations. Each female releases 20 to 30 eggs during this time, and they are fertilized by the multiple males accompanying her (Stasiak 1972, 1978). The dace may perform this spawning act many times per hour for several days during the reproductive period. Newly fertilized finescale dace eggs average 1.4 mm in diameter. Embryos hatch in about 6 days at 20 °C, at about 4.2 mm in total length (Stasiak 1978). At 24 °C, eggs hatched in 4 days (Stasiak et al. 1988).

Demography

Genetic characteristics and concerns

Genetic studies of finescale dace populations have concentrated on ways of separating them from the closely related and syntopic northern redbelly dace (*Phoxinus eos*) (Joswiak et al. 1982, 1989). Most of this research has centered on characterizing the genetics of the populations of gynogens (presumably of hybrid origin between these two species that often outnumber the parental species in the Great Plains region; Joswiak et al. 1982, 1985, Goddard et al. 1989, Elder and Schlosser 1995). Finescale dace differ from redbelly dace at three allozyme loci: PGM (phosphoglucomutase), SOD (superoxide dimutase), and MDH (malate dehydrogenase) (Joswiak et al. 1982). These markers can be used to identify finescale dace from northern redbelly dace or their hybrids. Little or no genetic research has been done on the different populations considered to be pure finescale dace.

Figure 7. Dorsal view showing sexual dimorphism of pectoral fins. Top specimen is a male and bottom specimen is a female. Photograph by Richard H. Stasiak.

Because these dace have a wide range (from Alberta to Prince Edward Island in Canada, and Wyoming to Maine in the United States), it would be interesting to compare the genetics of dace from different regions.

Dace populations were forced south into several different refuges during the last Ice Age advance. Finescale dace followed the melting ice as they dispersed back to the north via several different routes. Long after the last glacial retreat, we now have isolated populations of finescale dace that exist in spring seeps in Nebraska, Wyoming, and South Dakota. In many cases, these populations have been separated and isolated from other dace populations for many generations. The dace have had sufficient time in isolation for selection processes to allow genetic changes, and many of these regional populations may be uniquely adapted to their own ecological conditions. Research into the genetic characterization of these demes is a key to understanding the evolutionary implications for these Region 2 populations. Toline and Baker (1994) presented some genetic data for northern redbelly dace in Ontario, but apparently this type of data is lacking for all the Great Plains species of *Phoxinus* at this time. Perhaps this is one type of research that should be a priority funding measure.

In the vast majority of cases in Region 2, northern redbelly dace are found with finescale dace. This association between two closely related species often has resulted in hybridization (Hubbs and Brown 1929, Hubbs 1955, New 1962, Brown 1971, Stasiak 1978, Joswiak et al. 1982, 1985, Goddard et al. 1989, Schlosser et al. 1998). Populations of hybrid origin usually exist as all-female gynogens reproducing clonally. Fish of hybrid origin can outnumber the parental species. In many Nebraska streams, it is common to find populations of hybrid dace and a small population of parental northern redbelly dace, but no parental finescale dace. Most of these hybrids are diploid (2n = 50) with one set of chromosomes from redbelly dace and the other from finescale dace, but some are triploid (3n = 75) and some are even mosaics (with some diploid and some triploid cells and tissue in the same fish) (Joswiak et al. 1986, Goddard et al. 1989, Schlosser et al. 1998). Each of these hybrid populations may represent a different self-perpetuating lineage. A few of these hybrid specimens have been collected from Montana (Brown 1971) and Colorado (Woodling 1985); to date, no specimens thought to be pure finescale dace have been taken in those states. The hybrid populations appear to be most prevalent in habitats that are less than ideal for finescale dace. This may include rapid temperature rises in the spring, which could allow syntopic northern redbelly dace to overlap finescale dace spawning activity (Stasiak 1972). Hybrids are rare throughout most of the main portion of the range of these species; for example, Stasiak (1972) found no hybrids present in the Minnesota beaver ponds despite abundant populations of both dace species. In this situation, finescale dace spawned shortly after ice-melt when the water temperature reached about 16 °C (60 °F); northern redbelly dace began spawning perhaps two weeks later, when the water warmed up to about 19 °C (67 °F). Timing of spawning appears to be critical to prevent hybridization in these species.

Life history characteristics

Most of the information concerning life history characteristics of finescale dace is taken from the data provided by Stasiak (1972, 1978) for a population in a series of beaver ponds in Minnesota. Das and Nelson (1990) studied a population of dace in a lake in Alberta. Becker (1983) reported on age and growth of finescale dace in a small stream in Wisconsin. These reports can be summarized with the following general age and growth information:

- ❖ finescale dace live to a maximum age of 4 to 6 years
- ❖ they reach a maximum total length of about 120 mm (about 85 mm standard length)
- ❖ females tend to live longer than males
- ❖ females tend to reach a greater size than males.

The following data were based upon the studies of Stasiak (1972, 1978) in the Minnesota beaver ponds. These data were also used to construct the Matrix Population Analysis of Population Demographics for finescale dace (**Appendix A**). At one year, fish had a mean standard length of 38 to 40 mm (1.5 to 1.6 inches); age 2 fish averaged 50 mm (2 inches); age 3 fish averaged 55 mm (2.2 inches); age 4 fish were 60 to 70 mm (2.4 to 2.6 inches); age 5 fish were 64 to 80 mm (2.5-3.2 inches); and age 6 fish were about 85 mm (3.4 inches). Although a few individuals matured at the end of Age Class I (1 ½ years old), most fish reached sexual maturity at Age Class II. Most of the spawning effort was contributed by fish of Age Classes II and III. Most females spawned for the first time when 2 years old (age class II). Counting the maximum eggs present in the ovaries just prior to spawning, the following mean numbers of eggs were obtained: Age Class II, 800; Age

Class III, 1500; Age Class IV, 2600; Age Class V, 2800. The greatest number of eggs was from a female of Age Class VI that had 3060 eggs. Only two individuals of this age were collected, so very large numbers of eggs such as this would be an extremely rare circumstance. Females of Age Classes II and III comprised over 60 percent of the spawning females in the beaver ponds while Age Classes IV and V (the largest fish with the greatest numbers of eggs per individual) only comprised 10 percent of the breeding population.

Based on this information, an important conclusion is that a finescale dace population could withstand a year or two of poor reproductive effort and still recover due to the number of fish in Age Classes II and III. Likewise, three poor years of recruitment in a row would be detrimental to maintaining the size of the population. This can also be seen from the life cycle diagram and analysis of the demographic matrix performed by David McDonald (**Appendix A**) and the envirogram (**Figure 8**).

Ecological influences on survival and reproduction

Mortality of finescale dace is due to many conditions including predators, parasites, disease, food abundance, and competition; in some situations, human harvest may take a toll. Abiotic stressors such as drought, temperatures, and habitat availability are also important factors influencing reproductive success. Some of these factors are more likely to impact different ages and sizes and even sexes of dace differently. Finescale dace in the Great Plains are restricted to relatively small regions where the entire suite of ecological conditions remains similar to the cooler and wetter conditions prevailing several thousand years ago (Bleed and Flowerday 1989). Suitable habitat for this species has been undergoing a natural contraction as the climate has changed and become warmer and more arid (McPhail 1963, Cross 1970, Cross et al. 1986, Cross and Moss 1987). In this region, the most critical ecological factors are probably a constant flow of cool groundwater and an unaltered fish community (Stasiak 1972, Clausen and Stasiak 1994). The quality of the water supply (i.e., temperature, oxygen, clarity) is important to maintain the proper ranges for spawning and feeding. A suitable fish community allows the finescale dace to survive in its niche without undue competition and predation.

Social pattern for spacing

Finescale dace do not display territorial behavior; they do not defend nests or feeding areas. Adult fish are usually in loose schools comprised of individuals of mixed sizes and ages.

Patterns of dispersal of young and adults

Few studies have been published dealing directly with the dispersal of either young or adult finescale dace. We have studied finescale dace populations for many years using snorkeling and fish tagged with dyes. We have also used marked fish in capture-recapture studies in streams and beaver ponds in Minnesota, South Dakota, and Nebraska. The following data are based on these observations.

Newly hatched fish are usually restricted to areas of heavy cover and reduced current. This is probably important to reduce predation and to provide the habitat and substrate used by small crustaceans, one of the main food sources of dace at that age. As the fish mature and reach about one year of age, they become much stronger swimmers and gradually move into more open water. Schools of adult fish are generally mixed with respect to age and size (Stasiak 1972). Adult fish (large enough to be marked) demonstrate high site fidelity; most of the fish have been recaptured in the same pool from which they were originally captured or observed. Finescale dace can probably spend their entire life in one beaver pond or a single large pool in a small stream. In beaver ponds, dispersal occurs when breaks periodically appear in the dam structure; this allows the water and fish from one isolated pool to connect to others in the system. In streams, flooding would most likely be the prime dispersal agent, carrying the young fish to downstream areas. Adult fish in streams probably gravitate upstream as they seek cool, spring seeps with reduced current flow, clear water, heavy cover and a lack of piscivorous fishes. These conditions are usually found near the headwaters of small streams rather than in downstream sites. Since most of these data are unpublished, it is important for the USFS to conduct studies of this nature to verify the patterns of dispersal in this region.

Spatial characteristics of populations

Because the populations of finescale dace are usually restricted to spring seeps, beaver ponds, and small first-order streams, they tend to be isolated from other populations. They can be dispersed at times of flooding and high water conditions, but these events probably have become reduced in the centuries since the last glacial retreat from the Great Plains. Populations have become contracted, fragmented, and isolated from each other and from the populations comprising the main range of this species to the north.

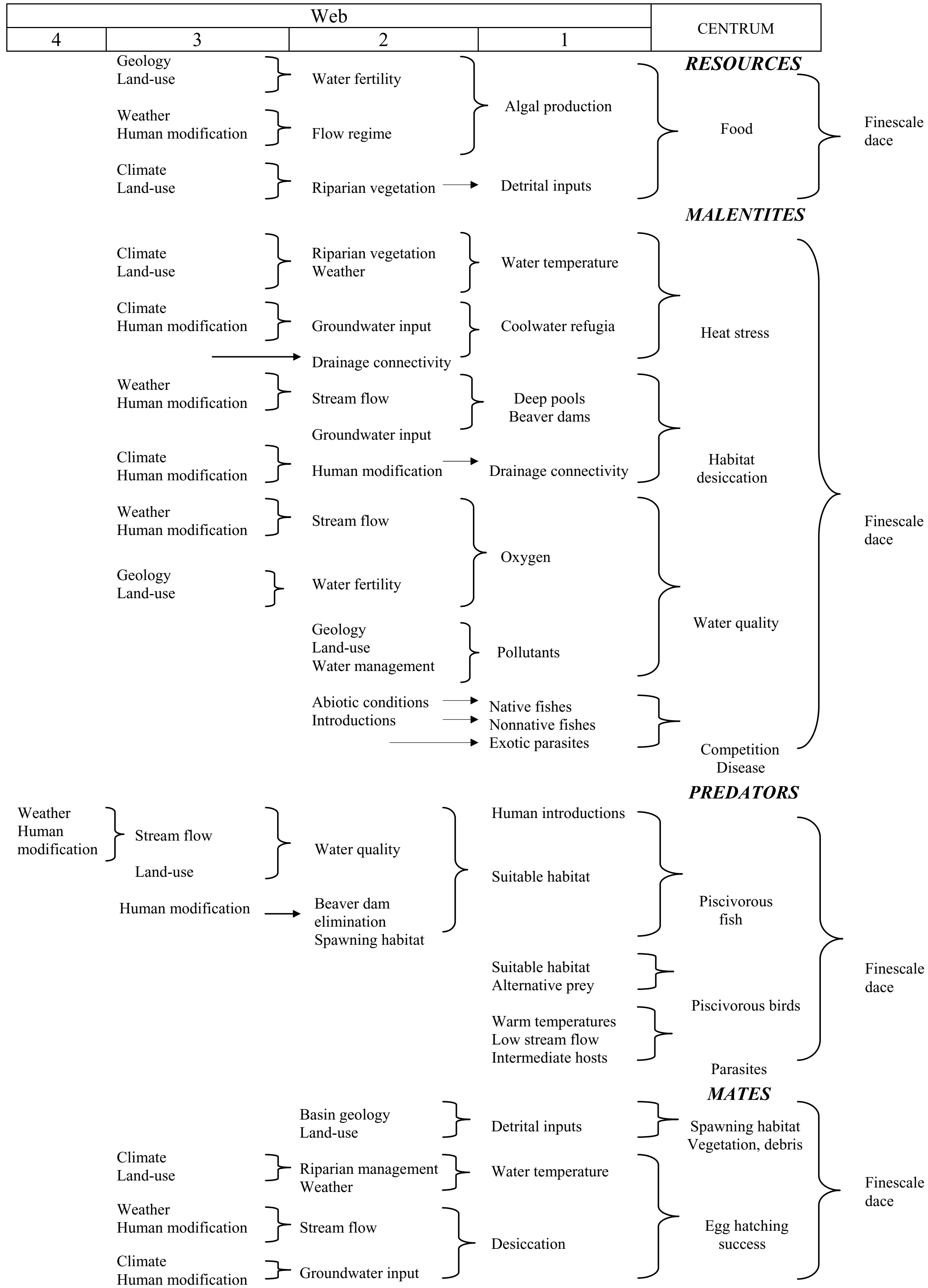

Figure 8. Envirogram for finescale dace describing the complex relationships of food (Resources), threats (Malentities), ecological (Predators) and demographic (Mates) factors influencing populations.

The result is little genetic exchange between demes in this region. Some of these dace populations have existed as separate populations long enough to possibly represent unique evolutionary units. The study of the population genetics of these isolated populations is hereby identified as perhaps one of the most critical of the information needs.

Limiting factors

Availability of suitable habitat is probably one of the most significant factors involved in limiting finescale dace populations in this region. Prime habitat for finescale dace includes swampy areas fed by clear groundwater. Heavy vegetation and brush would be present, and large predatory fish species would be absent. Beaver ponds fed by constant spring seepage near the head of small forested creeks often fulfill this set of constraints. Dace populations Region 2 have been naturally reduced to habitat of this type as the Great Plains have gradually become warmer and drier. Human activity related to water usage in the Great Plains has likely altered suitable habitat as well.

The Sandhills region of Nebraska and South Dakota still contains many permanent groundwater sources (Bleed and Flowerday 1989). Many of these form the headwaters of small first-order streams, or small seepage lakes. Since the European settlement of this region beginning perhaps 150 years ago, permanent sources of cool, clear groundwater have become highly desired resources for human uses. Underground and surface water are pumped for irrigation or used for domestic or municipal water supplies. Many streams have been dammed up to form relatively large reservoirs. This tends to dewater streams and fragment habitat. Rivers and streams are often polluted with toxic materials ranging from agricultural chemicals to synthetic hormones. Frequently the remaining relatively natural streams have been stocked with sport species of sight-feeding predatory fishes (e.g., trout, pike, bass, sunfish) that can reduce native minnow populations. Colorful species of minnows such as finescale dace appear to be especially sensitive to these introductions (Clausen and Stasiak 1994, Whittier et al. 1997). These practices that alter the aquatic environment and hydrology have most likely contributed to the further isolation of finescale dace into diminishing pockets of relatively pristine habitat.

Community ecology

Predators

Under natural conditions, the chief vertebrate predators of finescale dace are probably piscivorous birds (Steinmetz et al. 2003). Belted kingfisher (*Megaceryle alcyon*) and great blue heron (*Ardea herodias*) have been observed actively feeding on schools of these minnows (Stasiak 1972). Kingfishers are especially attracted to habitat of the type favored by the dace; the clear, shallow water and brightly colored minnows provide easy prey for this bird (Hamas 1994). Kingfishers have been observed to use a perch on dead trees in beaver ponds as a feeding platform from which they dive into schools of minnows (Fry and Fry 1992). One bird consumed six dace in a 10-minute period (Stasiak 1972). Finescale dace are about the ideal size for a kingfisher, but herons of several species will also take these minnows. In deeper ponds, fish-eating birds such as loons, ducks, grebes, and cormorants can also quickly reduce dace populations (Steinmetz et al. 2003). Fish-eating snakes, turtles, and frogs are common predators in dace ponds and streams. Mink (*Mustella vison*) and raccoons (*Procyon lotor*) have been observed eating finescale dace.

Carnivorous aquatic invertebrates can also feed heavily on finescale dace (Borror and White 1970). Predacious diving beetles of the family Dyticidae (larvae are commonly called water tigers) and giant water bugs of the family Belostomatidae were constantly found eating dace of all sizes in Minnesota beaver ponds (Stasiak 1972). These voracious insects can reach 70 mm (2.7 inches) in total length; they commonly eat aquatic vertebrates such as frogs and tadpoles, snakes, and fishes (Hungerford 1920, Bobb 1974, McCafferty 1998). When fish traps are used to collect minnows in beaver ponds, they must be checked frequently to avoid having these efficient predators decimate the confined fish. Other insects such as dragonfly larvae (Odonata) and smaller bugs (Hemipetra) like water scorpions and backswimmers will also include dace, especially young individuals, in their diet.

In most situations, the one type of predator that native dace do not have to deal with is a large fish species. The small and shallow nature of the ponds and streams containing dace generally are not suited for large predatory fish species. The temperature ranges and potential low oxygen levels common to dace habitat also tend to eliminate large fish species.

Dace ponds are often subject to heavy ice and snow cover in the winter. The ice may reduce the volume of water substantially, and little oxygen is present in the remaining fluid water.

Non-native species can affect native species through a number of mechanisms including predation, competition, habitat alteration, pathogen transfer, and behavioral displacement (Ault and White 1994). Some of the smaller fish species that are often associated with finescale dace, especially central mudminnows and less frequently creek chubs, can occasionally eat dace. Stasiak (1972) found the bony pharyngeal arches of finescale dace in two mudminnow stomachs in the Minnesota beaver ponds. When they occur together, large creek chubs are very capable of eating small dace. These fish species are naturally occurring predators that will play a role in eating very young dace, but their overall effect is probably very small compared to the collective effect of the predatory insects.

Introduced species of large predatory fishes (sport fishes) will have a serious effect on the dace because they eat even the largest adult dace. There is no doubt that dace are readily eaten by game fish. In some regions, finescale dace are used as bait minnows; in northern Minnesota they have reputation with fishermen as excellent (perhaps the best) bait to use for walleye fishing (Dobie and Meehan 1956). The commercial bait dealers often sell them under the trade name of "rainbow chub", and these dace command premium prices.

Competitors

Finescale dace are hardy fish that can survive environmental extremes of oxygen, pH, annual temperatures, and ice cover conditions that few other species can handle (Brett 1944, Tyler 1966). They are usually associated with a small number of other fish species that are adapted to similar conditions. In the Great Plains, finescale dace typically occur with northern redbelly dace, brook stickleback, pearl dace, and brassy minnow (Baxter and Stone 1995, Isaak et al. 2003). Combinations of these fishes usually represent a well balanced fish community of small species that can successfully partition the resources available in a relatively confined habitat.

Finescale dace do not appear to thrive in large streams, lakes, or any other habitat that harbors a large diverse fish community. In their preferred habitat of small ponds and creeks, finescale dace take on the niche as the top sight-feeding predatory fish species. The other fishes that are commonly found with finescale dace usually feed at lower trophic levels on the food chain (detritus and plants) or take animals of smaller size. To the extent that other sight-feeding predatory fish species would be present or introduced, they would be in direct competition with finescale dace. Species of this type that occasionally occur with dace in Nebraska include creek chubs, pearl dace, and green sunfish (*Lepomis cyanellus*). These small predatory fish likely reduce the finescale dace populations, but they do not necessarily eliminate them.

Finescale dace do not appear to be able to adapt to the added competition and predation when confronting species of larger predatory fishes (Findley et al. 2000). When larger predatory fishes (e.g., trout, pike, bass) are introduced into these relatively small and confined habitats, they serve not only as competitors, but also as direct predators even on the adults (He and Kitchell 1990, Whittier et al. 1997). MacRae and Jackson (2001) and Shields (2004) discussed ways that introduced species can alter the behavior and add additional stress factors to native species, above and beyond the negative effects of competition, predation, and disease introduction. This would certainly be true for finescale dace, which appear to be very sensitive to interactions with fish species outside of the small group of normal associates.

In Region 2, another competitive situation needs to be examined. Gynogen fish of hybrid origin (*Phoxinus neogaeus* x *P. eos*) can be considered a separate species for matters of competition. While the feeding niches of finescale and northern redbelly dace generally do not overlap (Stasiak 1972, Litvak and Hansell 1990, Gauthier and Boisclair 1996), the hybrid fish are intermediate (i.e., they can feed on a diverse diet, which includes much of the diet of the parental species). Since these fish reproduce clonally, they may also have a reproductive advantage. The result is that "pure" finescale dace populations are usually absent or much reduced in locations where the hybrid fish exist (Stasiak 1987).

Parasites and disease

Parasites and disease appear to have a minimal impact on finescale dace. The only studies of parasites of finescale dace appear to be Bangham and Venard (1946), Hoffman (1970), Stasiak (1972), and Mayes (1976). Hoffman listed three species of protozoans and two species of larval trematodes (*Uvulifer ambloplites* and *Echinochamus donaldsoni*). The former of these worms is often referred to as “black grub” or “neascus”. The adult black grub is very common as a parasite in the throat of fish-eating birds, and the larvae are very common as tiny black cysts in the skin and muscles of virtually all species of freshwater fishes that are found in shallow water with vegetation. It is common throughout the Midwest to see sport fishes such as pike, bass, perch, and sunfish practically covered with these small black spots. Stasiak (1972) found that fathead minnows, sticklebacks, and central mudminnows in the French Creek beaver ponds in Minnesota were frequently and heavily infected with this parasite; meanwhile, only 1 percent of the finescale and northern redbelly dace populations were affected. In general, *Phoxinus* species appear to be only rarely afflicted with external parasites. Phillips (1968) attributed this to the habit of dace swimming actively in mid-water, thus escaping the swimming cercaria released by snails. The very small scales of *Phoxinus* may also provide good protection from this parasite that actively penetrates through the skin. Personal observations of dace in Nebraska reveal that *Phoxinus* are also free of other common ectoparasites such as the copepod *Lernaea* (anchor worm), which is frequently found on syntopic fishes.

Stasiak (1972) reported that the most common parasite of finescale dace in Minnesota was another larval trematode in the genus *Petasiger*. Metacercaria of these worms (family Echinostomatidae) were found in the majority of dace specimens in the Minnesota beaver ponds. They were usually found as cysts in the liver, but they also were common in the walls of the gonads. The life cycle of this worm includes adults in piscivorous birds, and the fish get infected by ingesting infected snails (Schell 1970). Since finescale dace include snails as one of the main diet items, it is easy to see why this is a common parasite in this species. Despite heavy levels of infestation (over 50 cysts in a single fish liver), these internal parasites did not appear to have any negative impact on the fish. Indeed, these fish were very active and robust and externally showed no signs of impairment.

Mayes (1976) described new species of monogene flukes from the gills of dace collected in Nebraska; upon subsequent examination of the fish host specimens, we concluded that the hosts represented the hybrid dace (*Phoxinus neogaeus* x *P. eos*). These small worms could possibly infect parental finescale dace, but pure finescale dace were not sampled in this study. These tiny gill parasites probably do not harm the dace significantly at current low levels of density (number of parasites per fish) normally encountered (Hoffman 1970).

Conservation

Potential Threats

Paralleling decreases in terrestrial biodiversity, the principal reasons for fish species decline in general are the loss, modification, and fragmentation of habitat and the introduction of non-native species (Moyle 1976, Andrewartha and Birch 1984, Cross and Moss 1987, Warren and Burr 1994, Masters et al. 1998). These factors appear especially important in the case of finescale dace conservation in Region 2. Presently there are ever-increasing human demands for water resources and continued landscape modification, and streams and ponds fed by cool, clear groundwater are often stocked with sport fish that are not compatible with finescale dace. Populations of finescale dace throughout USFS Region 2 appear to be declining (Clausen and Stasiak 1994), and given the isolated position of these populations and the unique habitat types required by this relict species, long-term viability is questionable.

Unlike most Great Plains stream systems, the headwater streams occupied by finescale dace demonstrate less stochasticity in drying and intermittency (perannum) due to inflows from abundant groundwater sources. In fact, these streams have been remarkable in the constancy of their flow (Bleed and Flowerday 1989). However, over the last 50 years, groundwater pumping and water diversions have occurred extensively across the Great Plains, and such activities may have deleterious consequences for finescale dace viability within Region 2. Fortunately, the ecoregion with multiple extant populations of northern redbelly dace is the Sandhills of Nebraska and South Dakota where groundwater depletion is currently not a threat to stream systems because the edaphic conditions are not suitable for row crop agriculture. However, along the margins of the Sandhills ecoregion, particularly the Upper Niobrara River valley, center pivot irrigation of alfalfa and pasture has increased substantially (Bleed and Flowerday 1989). In addition, groundwater use for agricultural production exists in the sub-watersheds occupied by finescale dace in South Dakota and Wyoming. In the future, if groundwater withdrawals exceed annual recharge rates, then aquifer-dependent headwater streams and natural lakes will be adversely affected. Maintenance of this hydrologic pathway is critical because the persistence of finescale dace at specific sites during extended dry periods requires groundwater inflows.

Besides direct groundwater pumping, instream diversion units appropriate water for agricultural products or municipal supplies both in the Upper Niobrara River and North Platte River drainages in Nebraska and Wyoming. These activities modify flow regimes within these drainages and dewater sections of streams; they might also modify stream temperatures and trap sediment (Bunn and Arthington 2002). In these drainage systems, decreased flows have reduced channel scour and affected the spatio-temporal heterogeneity of floodplain habitats. Future water diversions in the northern Black Hills will probably fragment remaining populations of this species and most likely cause extirpation of extant finescale dace populations.

Hydrologic alteration has occurred in the Sandhills ecoregion, albeit in a different form. In this ecoregion, channel ditching and water control structure placement and operation have modified sub-irrigated meadow hydrology and created homogeneous instream habitat and incised channel morphology. These activities have modified nearly every Sandhills stream (Bleed and Flowerday 1989) and have contributed to habitat fragmentation and the disruption of stream ecosystem processes. Most likely, species viability has been maintained despite these alterations because of the combination of habitat created by culvert-type drop structures, long periods between instream excavation episodes, and late winter-early spring precipitation that occurs every 5 to 7 years, producing overbank flooding.

An essential component linked to the abiotic hydrologic process of the headwater systems and spring-fed lakes that finescale dace inhabit is the presence of beaver activity (Olson and Hubert 1994). As has been observed further north in Minnesota, Wisconsin, and Canada (Stasiak 1972; Tonn and Magnuson 1982, Schlosser 1995), finescale dace have a strong correlation with beaver pond environments. Their interaction of beavers with other biotic (predation) and abiotic (physiographic, vicarance) components has a great impact on the assemblage and structure of fish communities (Jackson et al. 2001). These "ecosystem engineers" have strong effects on physical, chemical, and biological attributes within the aquatic ecosystem (Naiman et al. 1988, Schlosser and Kallemeyn 2000). Work in north-temperate beaver bog streams and lakes systems inhabited by finescale dace and other cyprinid dace species conclude that beaver activity is a major factor in fish dispersal (Schlosser 1995), recolonization dynamics (Schlosser and Kallemeyn 2000), and fish community assemblage (Tonn and Magnuson 1982, Angermeier and Karr 1984) in small streams. The mosaic of aquatic patches created by beaver activity is temporally and spatially dynamic, a series of shifting successional habitats of flooded, deep-water, semi-permeable collapsed ponds, and debris-laden streams.

This phenomenon is observed both in the Sandhills and the northern Black Hills ecoregions, but with some interesting adjustments and surrogates. Beaver have only recently returned in significant numbers to both these ecoregions. In the Sandhills ecoregion, the L-shaped culvert drop structures placed in headwater streams appear to be surrogates for beaver dams. Both on the upstream and downstream ends of these water control structures, pools form, and they are dominated by dace species, particularly the large pools downstream of the structure. Additionally, the small, shallow impoundments or spring-fed lakes fitted with headgates found in the northern Black Hills mimic beaver ponds. Although these anthropogenic structures appear to violate the condition of temporal heterogeneity, at least for the Sandhills streams, the water control structures are designed and used to manipulate water levels, thus varying flows during certain times of the year. Moreover, because of the fine sandy soils of the sub-irrigated meadows, control structures do erode out of place and are occasionally blown-out by high flows. In this way, they can mimic the natural changes over time that resulted from beaver activity in these stream systems. While some resource managers may find these anthropogenic structures appealing substitutes for beaver activity, they should not be considered to be a satisfactory replacement.

Water improvement projects such as channelization and placement of water control structures are very common in the Sandhills ecoregion, and these negatively affect stream hydrology. Conversely, impoundment and reservoir development are scarce. This is in contrast to the northern Black Hills ecoregion, which has many stock dams, small impoundments, and larger reservoirs. Unfortunately, these larger bodies of water tend to dewater downstream reaches, degrading habitat and further fragmenting fish populations. While they appear to mimic beaver pond areas, these larger bodies of water simply retain too much water and may disrupt groundwater flow and recharge patterns. Perhaps even worse, they provide habitat for non-native fishes, particularly introduced piscivorous sport fishes.

Studies in the north-temperate region clearly demonstrated the profound effect that non-native predator fish have on native cyprinid (such as *Phoxinus*) communities in small lakes (He and Kitchell 1990, Findley et al. 2000, MacRae and Jackson 2001). Indeed, Jackson (2002) listed a group of fishes (including *Phoxinus*) as being highly vulnerable to centrarchid (sunfish family) predation. Lakes dominated by salmonids (trout) contained significantly more cyprinid species than centrarchid-dominated lakes. This phenomenon is best explained by overlapping habitat between centrarchids and cyprinids, particularly in the littoral zone. Trout have limited overlap in summer habitat with cyprinids, at least in lake environments (Jackson 2002). Thus, impoundments or reservoir development on streams with finescale dace that experience non-native centrarchid introductions can lead to extirpation of native cyprinid species. Although impounding a stream is a modification of natural stream structure and function, finescale dace can reside in some small impoundments and spring-fed lakes in Region 2. The presence and presumed persistence of this species in these artificial environments is due to the absence of centrarchids. The harsh winter conditions (extremely low dissolved oxygen concentrations) found in very small lakes usually prevent centrarchids (particularly bass) from becoming established (Schlosser 1995, Jackson 2002).

Both finescale dace and trout can exist together in a few lakes with the correct structural heterogeneity. For example, Cox Lake in the northern Black Hills of South Dakota is a deep lake with large, shallow shelves in the littoral zone. The shallow areas are heavily vegetated and provide good food and cover for the finescale dace. Introduced trout spend most of their time in the open pelagic zone, effectively partitioning the habitat. In similar lakes nearby, sunfish occupy the littoral zones, and native dace are absent (Olson 1998).

Stream-dwelling populations of finescale dace are equally vulnerable to both centrarchid and salmonid introductions. Whether stream systems with native *Phoxinus* species have been altered by impoundment structures and stocked with centrarchids or whether they have been managed as trout fisheries by resource agencies, native headwater cyprinids are either absent or extremely low in number (Cunningham and Hickey 1995).

Studies indicate that non-native species can also disrupt the connection between headwater minnow populations by acting as barriers to fish migration. This effects recolonization and exchange of genetic material (Fausch and Bestgen 1997). For example, finescale dace have been collected in the headwaters of the Niobrara River at the Wyoming border (Baxter and Simon 1970, Patton 1997), but they are absent just a few miles downstream at Agate Fossil Beds National Monument (Stasiak 1976, 1989). This is likely due to the presence of stocked brown trout (*Salmo trutta*), northern pike (*Esox lucius*), largemouth bass (*Micropterus salmoides*), and bluegill (*Lepomis macrochirus*). A similar circumstance applies to the finescale dace in first-order streams (one is called Sand Draw) feeding into Bone Creek just southwest of Ainsworth, Nebraska. Here an established population of brown trout just downstream from the city apparently restricts dace to the immediate headwaters springs. In these examples, introduced sport fishes appear to act as a barrier to successful downstream dispersal by finescale dace. Unlike in lentic systems, trout in lotic environments have an overlapping habitat association with the headwater cyprinid community (Jackson 2002). Direct trout predation has been observed in some Sandhills streams (Cunningham and Hickey 1995) where trout occupy pool and undercut bank habitats.

Indirect effects on finescale dace would include territorial displacement and competition (altering foraging behavior and diet) for food resources (Shields 2004). The negative impacts of introduced predators to small native fishes include resource compaction, increased intra- and interspecific competition, and stress (Jackson 2002). Clearly, most introductions and modifications of lotic habitat to deeper lentic habitat that allow non-native piscivorous fish to persist are detrimental to finescale dace populations. Studies with other cyprinid species in lotic systems link the disappearance of certain cyprinid species and an alteration in small stream fish community assemblage to the presence of introduced piscivorous sport fishes (Winston et al. 1991, Schrank et al. 2001, Mammoliti 2002).

Another potential consequence of fish introductions is the effect of pathogen transfer from non-native fish species to the native fish community or other biota within the watershed (i.e., amphibians) (Kiesecker et al. 2001). Shields (2004) documented several cases of parasite (nematodes, trematodes, and cestodes) transfer from introduced fishes in Oregon, resulting in severe population reductions in native fishes. Although relatively understudied, pathogen transfer among different aquatic taxa may represent an undiagnosed perturbation within aquatic ecosystems that induces stress to a set or sets of aquatic organisms, which ultimately affects survivorship, recruitment, and persistence of these species. Moreover, the introduction of non-native species could alter native aquatic community assemblage patterns, possibly affecting native host-pathogen dynamics (Kiesecker et al. 2001).

A poorly understood element in the long-term viability of headwater fish species is the synergistic effects of multiple stressors (Dodds et al. 2004). By itself, extended severe drought may have only modest effects on the long-term viability of fish assemblages (Matthews and Marsh-Matthews 2003). Combined with groundwater pumping, irrigation, and water diversion, however, it may severely deplete (by affecting hydrology and recharge) a population or extirpate a species on a regional basis. Couple these phenomena with climate change predictions, and the prospective for long-term viability is difficult to assess (Jackson and Mandrak 2002). However, given the already highly fragmented distribution of finescale dace within Region 2, this species would be adversely affected by the combined influences of future increased groundwater extraction, water diversion, and climate change-induced extended dry cycles. Thus, developing conservation strategies to abate such multiple stressors to species viability will need to incorporate the elements of connectivity, spatio-temporal habitat dynamics, and life history processes, as well as their associated linkages. How multiple stressors affect these ecological variables must be evaluated.

Two other human-related activities generally cited as common causes of species declines include pollution and overharvest. Pollution does not currently appear to be major problem for finescale dace populations in Region 2, but this is always something that needs to be monitored. It is possible that future mining and/or agricultural operations could release harmful substances into the streams, watersheds, or groundwater. Dace need relatively clear water; anything that would cause sustained turbidity (e.g., erosion, siltation, prolonged use of a water source by cattle) affects their visual ability to find food and to reproduce (Belsky et al. 1999). In terms of direct harvest by humans, anglers often collect wild minnows for use as bait. Finescale dace are known to be an excellent bait species. We have seen them used this way in the Ainsworth, Nebraska area, despite their "protected" status. It is possible that commercial activity of this type could have a significant impact on small, isolated dace populations. Strict enforcement of the laws and regulations concerning minnow harvest could reduce this threat.

Conservation Status of Finescale Dace in Region 2

The area occupied by finescale dace within USFS Region administration units is extremely small, and existing populations appear to be declining. While streams in the Sandhills ecoregion account for the vast majority of the populations in Region 2, this species is not present within the Bessey Unit of the Nebraska National Forest or the Samuel R. McKelvie National Forest, which are located in this ecoregion (Cunningham and Hickey 1995). The only extant population(s) of this species known to occupy USFS administered lands is in the northern Black Hills, which encompasses one watershed, the Redwater Creek drainage basin (**Figure 2**). Some current locations occupied by finescale dace are the results of transplants conducted by the USFS in the late 1970's and early 1980's. However, these transplanted locations were reported by Isaak et al. (2002) as having records of finescale dace from the 1960's, yet Baxter and Simon (1970) did not mention these sites. Moreover, Patton (1997) stated that he was not able to sample some 1960's sites because of a lack of location descriptions. Clearly, the first attempt at developing a conservation strategy for this species on USFS lands is to determine exactly what sites were sampled and what species have been collected in the Redwater and Belle Fourche drainage basins since the 1930's.

All three of the Region 2 states that have finescale dace populations currently designate finescale dace at the level of highest conservation concern and list them in their CWCS plans. While this does confer limited conservation protection, the species is still vulnerable to extirpation by hydrologic modification of stream systems and presence of non-native species.

Potential Management of Finescale Dace in Region 2

Implications and potential conservation elements

Conservation of this dace species will require resource managers to consider the unique habitat features utilized by this species across a mosaic of heterogeneous shifting habitats that are highly dynamic in space and time. In addition, the presence of non-native species, particularly piscivores, has a major impact on the persistence of finescale dace populations. Thus, the management of finescale dace in Region 2 should focus on conserving natural system processes in streams and the prevention and control of non-native species introductions. Specific management strategies for this species include:

❖ Prohibit the stocking of non-native species within aquatic ecosystems

- ❖ Renovate natural spring-fed lakes containing non-native fish species and restock with finescale dace from the nearest native source population
- ❖ Protect spring sources flowing into naturally meandering streams, particularly if beaver activity is present
- ❖ Manage for the restoration of beaver activity within watersheds
- ❖ Develop watershed-based management strategies with partnering organizations and private landowners for connectivity and natural stream ecosystem processes
- ❖ Restrict harvest of finescale dace by enforcing laws and regulations pertaining to bait and aquarium trade.

While finescale dace are present in three states within Region 2, successful conservation on USFS lands is limited to the Belle Fourche River basin, Redwater Creek watershed in the northern Black Hills. Since much of this watershed is outside the national forest boundaries, efforts are needed to work in conjunction with its partners (i.e., other federal agencies, state resource agencies, non-profit conservation organizations, and private landowners) to develop and manage stream systems within Region 2 on a watershed basis, and these efforts should focus on native stream fishes. Currently, a vast majority of Black Hills streams are managed for non-native salmonids (i.e., trout) at the expense of native fishes, particularly finescale dace, lake chub, and mountain sucker (Erickson et al. 1993). The presence of non-native species (e.g., trout, bass) has probably been a significant factor for finescale dace decline in aquatic systems not only in the northern Black Hills but the Sandhills ecoregion as well. Resource managers need to be cognizant of the effects of non-native species introductions and their management on aquatic ecosystems (Minckley and Deacon 1991).

Concurrently, hydrological modifications (i.e., water development projects, subirrigated meadow alterations, groundwater pumping) have altered aquatic systems throughout the Rocky Mountain Region. Future human water demands and continued drought conditions coupled with the effects of predicted climate change could jeopardize remaining finescale dace populations. Resource managers may be tempted to build habitat for this species by impounding water on sections of streams inhabited by this species. Conceptually, this may be appealing. However, these created ponds would need to be designed to mimic beaver pond morphology, hydrologic retention and flow, and provide unsuitable habitat for piscivorous fishes. Moreover, simply creating a pond or hole on the landscape is not ecologically sufficient to ensure viability of finescale dace; connectivity to other habitats and resources is essential for various life history demands such as ontogenetic feeding shifts, spawning habitat, dispersal and segregation of larvae, juveniles, and adults (Bunn and Arthington 2002). Resource managers must understand and recognize the spatial arrangement and temporal dynamics of interacting processes at hierarchical scales (Frissell et al. 1986). For example, beaver pond placement, morphology, and successional shift within the landscape mosaic will influence finescale dace population establishment and persistence greatly (Schlosser and Kallemeyn 2000). Moreover, terrestrial characteristics across the land-water template within a drainage unit will affect the hydrology, sediments, nutrient inputs, and litter and detritus composition. Several conceptual models of stream fish population ecology and life history linking key ecosystem processes across multiple scales have been developed (Schlosser and Angermeier 1995, Labbe and Fausch 2000). These would serve as guides for resource managers to use in understanding and assessing the necessary and sufficient elements for finescale dace conservation.

Every attempt should be made to maintain the natural flow regime in the streams where this species resides and to manage for the expansion of beaver activity within these watersheds. Future water diversion, groundwater pumping, and reservoir construction would only further fragment the distribution of finescale dace, disrupting connectivity patterns and possibly leading to additional non-native species establishment. The expansion of beaver activity is a difficult one for private landowners since the result of such activity can back water up into unwanted locations or saturate soils. However, on USFS administered lands, expanded beaver activity should not affect other uses such as grazing and timber harvest. Beaver sites, particularly those areas exhibiting year round spring discharge that flow into a defined meandering stream channel, should be actively managed. For example, absolute unrestricted use of beaver ponds by cattle (particularly during the warm season) would lead to excessive sedimentation, increased turbidity, algal grow, and nutrient concentrations. Managing for only limited temporary access by cattle would be more ecologically sound, but resource managers must focus their conservation efforts beyond individual pools.

Finescale dace populations will require restoring the ecological processes that create and maintain beaver pond habitats across the landscape plus their associated colonization pathways. Ultimately, management actions that recognize and promote natural ecosystem process (i.e., flow regimes, biota and abiotic interactions) within a landscape context that integrates preservation, maintenance, and restoration will be successful in meeting finescale dace conservation goals.

If attempts are made to re-establish extirpated populations with brood stockings of finescale dace, care must be taken to use parental stock from the nearest possible population.

Tools and practices

Inventory and monitoring

Efforts are needed to inventory and monitor known finescale dace populations and areas of potential occupancy within Region 2. Inventory efforts to date have focused on the presence or absence of this species as part of statewide stream fish surveys or ecoregional sampling efforts (Ellis 1914). Surveys in the three states with extant finescale dace populations have been "spotty" and limited. Eiserman (1996) and Patton (1997) compared species distribution in the 1990's with distributions from Baxter's 1960's state-wide fisheries survey data in Wyoming (1970). The finescale dace was recorded from the headwaters of the Niobrara River during both inventories, but Patton (1997) did not record this species from the Redwater Creek drainage. No systematic statewide fish survey has been conducted in South Dakota in over fifty years, but smaller projects or inventories have recorded finescale dace in recent years.

Johnson's (1942) survey of Nebraska fishes serves as the baseline for information in this state. Finescale dace have apparently become extirpated in several of his sites in eastern Nebraska (Clausen and Stasiak 1994). Bliss and Schainost (1972) conducted fish surveys for all the major stream systems in Nebraska, but specimens were not saved and much confusion still remains concerning the identities for some of the sampled fishes. The Sandhills ecoregion was extensively sampled as part of a Nebraska Natural Heritage Program inventory in the 1990's (Cunningham and Hickey 1995, Cunningham et al. 1995, Cunningham and Hickey 1995). The authors of this report have conducted periodic sampling throughout Region 2 for the past three decades.

Data from a report pertaining to aquatic management indicator species done by the Black Hills National Forest (website: http://www.fs.fed.us/r2/blackhills/projects/planning/amend_2001/03_01_25_AquaMIS.pdf) list several efforts to transplant finescale dace to sites within the Redwater Creek watershed during the late 1970's and early 1980's. The source population for the initial transplants is unknown since Olson (1998) stated that the Montana Lake population had not been sampled before 1964. We assume the Hemler Reservoir site is the source because it was found to have finescale dace in 1976 (see Black Hills AquaMIS report). Additional references to surveys were found in the ecoregional conservation plan for the Black Hills (Hall et al. 2002). A map within this document depicts stream survey sites for the 1980's and 1990's, but no finescale dace were found except at Cox Lakes in the northern foothills.

Many studies can act as a framework for inventory and monitoring protocols (Loeffler, 1982, Hankin and Reeves 1988, Green and Young 1983, Simonson et al. 1994, Angermeier and Smogor 1995, Sclosser and Angermeier 1995, Hubert 1996, Hays et al. 1996, Overton et al. 1997, Mullner et al. 1998, Bryant 2000, USEPA 2001, Quist et al. 2006a). However, it is also important to have a mechanism in place (i.e. interagency database) to share the information gathered from these inventories in a timely fashion.

Population or habitat management practices

We are not aware of any ongoing population or habitat management practice specifically targeted toward finescale dace. Attempts at stream or hydrologic restoration are being made in some areas of Region 2. In the Sandhills ecoregion, several sub-irrigated meadow hydrologic restoration projects have been undertaken that involve modifying stream and channel hydrology. (website: http://www.sandhillstaskforce.org). However, the efficacy of these projects to restore and enhance the native headwater fish assemblage is unknown; post-construction research and monitoring have not been conducted at these sites. Additional opportunities for restoration exist in the northern Black Hills of South Dakota in the Cox, Mud, and Mirror lakes complex, specifically the removal of non-native species from Mud and Mirror Lakes. However, we are not aware of any discussion within the South Dakota Department of Game, Fish and Parks to conduct such restoration.

Although we are unaware of any state plans or initiative specifically targeted for finescale dace, the aquatic conservation assessment portion of the Black Hills ecoregional plan (Hall et al. 2002) has identified areas of biological significance based partly on finescale dace presence within the watershed. Given that much of the watershed (Redwater Creek) is private property, management at the watershed level will require a partnership of federal and state resources agencies, non-profits, and private landowners working across state boundaries to develop and implement a conservation strategy for finescale dace there.

Managing habitats to enhance finescale dace populations is basically a matter of restoring the stream system to its natural function. This dace is an excellent "Management Indicator Species" (MIS) of pristine conditions at the headwaters of spring-fed streams. They are known to be very sensitive to most biotic or abiotic alterations. Several guides to the methodology of evaluating and monitoring stream habitat have become available. These are some recent reports: Platts et al. (1983), Frissell et al. (1986), McMahon et al. 1996, Richter et al. 1996, Overton et al. (1997), Mullner et al. 1998, Bain and Stevenson (1999), Pedroli et al. (2003), Labbe and Fausch 2000, and Quist et al. (2006b). Mueller (2005) presented information that controlling non-native predators is much more successful in the low-order streams (where dace would be found) than on large rivers.

Information Needs

The distribution of finescale dace is well known in Region 2, particularly the Sandhills ecoregion. Because of the unique position and habitat requirements that this species has within a stream system, further inventory targeting finescale dace is relatively straight forward. Additional inventory efforts are suggested within Redwater Creek and its associated tributaries. Furthermore, interagency cooperative attempts should be made to inventory stream sections on private property, given the landownership pattern in the Redwater Creek watershed. Although sampling has been conducted on USFS units in the Nebraska Sandhills (Cunningham and Hickey 1995, and research by the authors), a systematic inventory at spring pool discharge areas in the rivers bordering the Halsey and McKelvie Units would close a data gap for this species in the Sandhills ecoregion.

Little data are available regarding the population dynamics of finescale dace in Region 2. Within the small area that this species is known to occupy on USFS administered lands (Redwater Creek watershed), information concerning age class distribution, population size, and recruitment success is needed to develop a conservation management plan for this species. Moreover, the question of persistence of the transplanted populations in Wyoming remains unanswered. Additional information needs for this species are the barriers to fish movement (e.g., impoundments, culverts, non-native species) among habitat types and recolonization areas. Effective conservation planning requires this type of information to ensure the viability of the species.

Finescale dace populations occur in rather discrete isolated demes on the Great Plains. Research on the genetic makeup of these populations and how they are related to each other and the fish found in the main portion of the species' range should be a priority of any conservation effort.

We are not aware of any monitoring activities associated with finescale dace in Region 2. Various resources and studies are available to serve as templates for designing a monitoring strategy for this species. Fish censusing techniques are well described in Hays et al. (1996) and Hubert (1996), and protocols and methods for assessing streams and fish communities are available in Hankin and Reeves (1988), Simonson et al. (1994), Angermeier and Smogor (1995), (Bain and Stevenson 1999) and various environmental monitoring and assessment program protocols of the U.S. Environmental Protection Agency (2001). Full adoption of these methods is probably unnecessary; rather a modification of one or a combination of the methods listed above would serve resource managers well.

Information management and document archiving are important in managing rare species. Although much of the location and ancillary data recorded at the time of finescale dace collections are recorded in areas such as natural heritage database systems of individual states comprising Region 2, location information found in Isaak et al. (2003) and the status information in the Black Hills National Forest Aquatic MIS report are not found in complete heritage database records or in the literature. Moreover, the transplant activities in Wyoming in the Redwater Creek watershed are described in the Aquatic MIS as personal communications. Every attempt should be made to obtain any records detailing these transplant activities (e.g., source of transplants, how many individuals, what dates) and to verify with the original biologists involved in these efforts the actions taken at the time. All pertinent information should be placed in the natural heritage databases of Wyoming, South Dakota, and Nebraska given the proximity of state borders and a shared watershed. All notes, field forms, communications, and notations from any state or federal sampling effort undertaken in the past and all future inventories and monitoring should be shared with natural heritage programs for database archival.

The Nebraska CWCS plan lists the following under research/inventory needs: determine age structure, recruitment, population dynamics, seasonal movements, and habitat use. The Wyoming plan lists the need for the following information: distribution, habitat, population status, and continual monitoring efforts.

Definitions

Deme – a local population of a species that is more or less reproductively isolated from other populations of the same species.

Edaphic – due to soil or geologic conditions.

Extant – still in existence.

Extirpated – no longer existing in a particular location.

Fecundity – the total number of ova produced by female.

Gynogen – a female fish that reproduces asexually by releasing mitotic (usually diploid) eggs that may develop with or without fertilization. In the case of finescale dace, the gynogens are often more abundant than the meiotic females.

Keystone species – a species whose presence exerts a great effect on the other species in its community.

Lateral line – a fish organ that detects pressure waves. It runs horizontally under the skin along the side of the fish and can often be seen due to surface pores.

Lentic – standing water habitats, such as ponds, bogs, or lakes.

Lotic – running water habitats, such as streams, creeks, brooks, or rivers.

Management Indicator Species (MIS) – a species under management planning because its population changes indicate the effects of management activities.

Pharyngeal teeth – teeth found on the pharyngeal arches (behind the gills) in the throat of minnows. Their anatomy is species-specific (related to their diet), so these are of considerable taxonomic interest to ichthyologists.

Piscivorous – fish eating.

Planktivorous – eating tiny plants and animals.

"r-selected Species" – a species whose life history attributes indicate selection for high fecundity, rapid growth, early age of maturation and reproduction, good colonization ability, and a relatively short life span. These species are good at finding and living in new or disturbed habitats where there are few competing species.

School – aggregation of individual fish in close proximity that form a single shoal, almost acting as a single large organism.

"Species of Concern" – 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 its persistence within that region.

Syntopic species – those that occur together in the exact same habitat.

Sexual dimorphism – male and female fish of the same species show differences in anatomy or color.

Viability – the likelihood that a species will continue to persist.

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. and J.R. Karr. 1984. Relationship between woody debris and fish habitat in a small warmwater stream. Transactions of the American Fisheries Society 113:716-725.

Angermeier, P.L. and R.A. Smogor. 1995. Estimating number of species and relative abundances in stream-fish communities: effects of sampling effort and discontinuous spatial distributions. Canadian Journal of Fisheries and Aquatic Sciences 52:935-949.

Ashton, D.E. and E.M. Dowd. 1991. Fragile legacy. Endangered, threatened and rare animals of South Dakota. South Dakota Department of Game, Fish and Parks, Report No. 91-04. 56pp.

Ault, T.R. and R.W. White. 1994. Effects of habitat structure and the presence of brown trout on the population density of *Galaxias truttaceus* in Tasmania, Australia. Transaction of the American Fisheries Society 123:939-949.

Bailey, J.R. and J.A. Oliver. 1939. The fishes of the Connecticut watershed. Pages 150-189 *in* Biological Survey of the Connecticut Watershed. New Hampshire Fish and Game Department Survey No. 4.

Bailey, R.M. and M.O. Allum. 1962. Fishes of South Dakota. University of Michigan Museum Zoology, Miscellaneous Publication No. 119. Ann Arbor, MI. 113 pp.

Bain, M.B. and N.J. Stevenson. 1999. Aquatic habitat assessment: common methods. American Fisheries Society, Bethesda, MD.

Balinsky, B.I. 1948. On the development of specific characters in cyprinid fishes. Proc. Zool. Soc. London, 118(2): 335-345.

Bain, M.B. and N.J. Stevenson. 1999. Aquatic habitat assessment: common methods. American Fisheries Society, Bethesda, MD.

Banarescu, P. 1964. Fauna Republicicii Populare Romine. Pisces-Osteichthyes, Vol. xiii. Academ. Rep. Romine Bucuresti. 989pp.

Bangham, R.V. and C.E. Venard. 1946. Parasites of fish of Algonquin Park lakes. Publications of the Ontario Fisheries Research Laboratory No. 65, University of Toronto Studies in Biology Series No. 53.

Baxter, G.T. and J.R. Simon. 1970. Wyoming fishes. Wyoming Game and Fish Department, Cheyenne, WY.

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

Becker, G.C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison, WI.

Becker, G.C. and T.R. Johnson. 1970. Illustrated key to the minnows of Wisconsin. Department of Biology, Wisconsin State University, Stevens Point, WI.

Belsky, A.J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54:419-431.

Berg, L.S. 1949. Freshwater fishes of the U.S.S.R. and adjacent countries. Akad. Nauk. SSSR. English Translation by Israel Prog. Sci. Trans., Jerusalem.

Berkman, H.E. and C.F. Rabeni. 1987. Effect of siltation on stream fish communities. Environmental Biology of Fishes 18(4):285-294.

Black Hills National Forest. 1996. Final environment impact statement, 1996 revised land resource management plan. Black Hills National Forest, Custer, SD.

Bleed, A. and C. Flowerday. 1989. An Atlas of the Sand Hills. Resource Atlas No. 5a. Conservation Survey Division. University of Nebraska, Lincoln, NE.

Bliss, Q. and S. Schainost. 1972. Fish surveys in Nebraska streams. Nebraska Game and Parks Commission, Lincoln, NE.

Bobb, M.L. 1974. The insects of Virginia: No.7. The aquatic and semi-aquatic Hemiptera of Virginia. Research Division, Bulletin 87. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Borror, D. and R. White. 1970. A field guide to insects: North America to Mexico. Houghton Mifflin, Boston, MA.

Brett, J.R. 1944. Some lethal temperature relations of Algonquin Park fishes. Pub. Fish Res. Lab. No. 63, University of Toronto Biological Studies Series No. 52.

Briggs, J.D. 1986. Introduction to the zoogeography of North American fishes. Pages 1-16 *in* C.H. Hocutt and E.O. Wiley, editors. The Zoogeography of North American Freshwater Fishes. John Wiley and Sons, New York, NY.

Brown, C.D. 1971. Fishes of Montana. Big Sky Books, Montana State University, Missoula, MT.

Bryant, M.D. 2000. Estimating fish populations by removal methods with minnow traps in southeast Alaska streams. North American Journal of Fisheries Management 20:923-930.

Bullough, W.L. 1939. A study of the reproductive cycle of the minnow in relation to the environment. Proceedings of the Zoological Society of London Series A 109:79-102.

Bunn, S.E. and A.H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30(4):492-507.

Carl, G.C., W.A. Clemens, and C. Lindsey. 1959. The freshwater fishes of British Columbia. British Columbia Provincial Museum Handbook No. 5. 192pp.

Churchill, E.P. and W.H. Over. 1938. Fishes of South Dakota. South Dakota Department of Game and Fish, Pierre, SD. 87pp.

Clausen, M. and R. Stasiak. 1994. Nebraska's threatened and endangered species: pearl, northern redbelly, and finescale dace. Nebraska Game and Parks Commission, NebraskaLand April 1994. Lincoln, NE.

Coad, B.W. 1976. On the intergeneric relationships of North American and certain Eurasian cyprinid fishes (Cypriniformes, Cyprinidae). Ph.D. Thesis, University of Ottawa, Ottawa, Ontario.

Cochran, P.A., D.M. Lodge, J.R. Hodgson, and P.G. Knapik. 1988. Diets of syntopic finescale dace, *Phoxinus neogaeus*, and northern redbelly dace, *Phoxinus eos*: a reflection of trophic morphology. Environmental Biology of Fishes 22(3):235-240.

Cooper, G.P. 1936. Some results of the forage fish investigations in Michigan. Transaction of the American Fisheries Society 65:132-142.

Cope, E.D. 1862. Observations upon certain cyprinid fish in Pennsylvania. Proceedings of the Academy of Natural Science Philadelphia 13(1861):522-524.

Cope, E.D. 1865. Partial catalogue of the cold-blooded vertebrata of Michigan. Pt. 1. (1864) 16:276-285.

Cope, E.D. 1869. Synopsis of the Cyprinidae of Pennsylvania. Trans. Amer. Philos. Soc. 8 (new series) 351-399.

Cope, E.D. 1872. Recent reptiles and fishes: report on the reptiles and fishes obtained by the naturalists of the expedition. Pages 432-443 *in* F.V. Hayden, editor. Preliminary Report of the U.S. Geological Survey of Wyoming and Portions of Contiguous Territories, Part IV: Special Reports.

Cope, E.D. and H.C. Yarrow. 1875. Report on the collections of fishes made in portions of Nevada, Utah, California, Colorado, New Mexico, and Arizona, during the years 1871, 1872, 1873, and 1874. Report on Geography and Geological Exploration and Surveying West of the 100th Meridian 5:635-703.

Copes, F.A. and R.A. Tubb. 1966. Fishes of the Red River tributaries in North Dakota. Cont. Instit. Ecolog. Stud., University of North Dakota. No. 1.

Cross, F. B. 1973. Rare, endangered, and extirpated species in Kansas. I. Fishes. Transaction of the Kansas Academy of Science 76:97-106.

Cross, F.B., R.L. Mayden, and J.D. Stewart. 1986. Fishes in the western Mississippi Basin (Missouri, Arkansas, and Red rivers). Pages 363-412 *in* C.H. Hocutt and E.O Wiley, editors. The Zoogeography of North American freshwater fishes. John Wiley and Sons, New York, NY.

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, OK.

Cunningham, G.R. 1995. Life history traits and reproductive ecology of the pearl dace, *Margariscus margarita*, (Pices: Cyprinidae), in the Sandhills of Nebraska. M.A. Thesis, University of Nebraska at Omaha, Omaha, NE.

Cunningham, G.R. and S.M. Hickey. 1995. Habitat parameter determination and threatened fish inventory of Sandhills streams. Report to the Nebraska Natural Heritage Program. Nebraska Game and Parks Commission, Lincoln, NE.

Cunningham, G.R., R.D. Olson, and S.M. Hickey. 1995. Fish surveys of the streams and rivers in south central South Dakota west of the Missouri River. Proceedings South Dakota Academy of Sciences 74:55-64.

Das, M.K. and J.S. Nelson. 1990. Spawning time and fecundity of northern redbelly dace, *Phoxinus eos*, and finescale dace, *Phoxinus neogaeus*, and their hybrids in Upper Pierre Grey Lake, Alberta. Canadian Field-Naturalist 104 (3):409-413.

Dobie, J. and O.L. Meehan. 1956. Raising bait fishes. U.S. Fish and Wildlife Service Circ. No. 35. U.S. Government Printing Office, Washington, D.C. 124pp.

Dodds, M.E., K.B. Gido, M.R. Whiles, K.M. Fritz, and W.J. Matthews. 2004. Life on the edge: ecology of prairie streams. Bioscience 54:205-216.

Dymond, J.R. and W.B. Scott. 1941. Fishes of the Patricia portion of the Kenora District, Ontario. Copeia 1941:243-245.

Eastman, J.T. 1970. The pharyngeal bones and teeth of Minnesota cyprinid and catostomid fishes: functional morphology, variation, and taxonomic significance. Ph.D. Thesis, University of Minnesota. Minneapolis, MN.

Eddy, S., J.B. Moyle, and J.C. Underhill. 1963. The fish fauna of the Mississippi River above St. Anthony Falls as related tot he effectiveness of this falls as a migration barrier. Proceedings of the Minnesota Academy of Science 32(2):111-115.

Eddy, S. and T. Surber. 1974. Northern fishes. Third edition. University of Minnesota Press, Minneapolis, MN. 414pp.

Eiserman, F.M. 1996. A fisheries survey of streams and reservoirs in the Belle Fourche, Cheyenne, Little Missouri, Little Powder and Niobrara River Drainages. Wyoming Game and Fish Commission, Fisheries Technical Report Number 15, Cheyenne.

Elder, J.F. and I.J. Schlosser. 1995. Extreme clonal uniformity of *Phoxinus eos/neogaeus* (Pisces: Cyrinidae) among variable habitats in northern Minnesota beaver ponds. Proceedings of the National Academy Science 92: 5001-5005.

Ellis, M.M. 1914. Fishes of Colorado. Univeristy of Colorado Studies 11:1-136.

Elser, A.A., M.W. Gorges, and L.M. Morris. 1980. Distribution of fishes in southeastern Montana. Montana Department of Fish, Wildlife, and Parks and U.S. Department of the Interior, Bureau of Land Management, Miles City, Montana.

Erickson, J., R. Koth, and L. Vanderbush. 1993. Black Hills Stream Management Plan. Report No. 93-8. Department of Game, Fish, and Parks. Pierre, SD.

Evenhuis, B.L. 1969. A list of fish collected in North Dakota 1964-1968. Report No. A-1011, North Dakota State Game and Fish Dept., Bismarck, ND.

Evermann, B.W. 1893. The ichthyological features of the Black Hills region. Proceedings of the Indiana Academy of Science (1892):73-78.

Evermann, B.W. and U.O. Cox. 1896. A report upon the fishes of the Missouri River basin. Rept. U.S. Comm. Fish. 20:325-429.

Fausch, K.D. and K.R. Bestgen. 1997. Ecology of fishes indigenous to the central and southwestern Great Plains. Pages 131-166 *in* F.L. Knopf and F.B. Samson, editors. Ecology and Conservation of Great Plains Vertebrates. Springer-Verlag, New York, NY.

Fedoruk, A.N. 1971. Freshwater fishes of Manitoba: checklist and keys. Province of Manitoba Department Mines, Resources, and Environmental Management, Winnipeg, Manitoba.

Findlay, C.S., D.G. Bert, and L. Zheng. 2000. Effect of introduced piscivores on native minnow communities in Adirondack lakes. Canadian Journal of Fisheries and Aquatic Sciences 57:570-580.

Frissell,, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10:199-214.

Fry, C.H. and K. Fry. 1992. Kingfishers, bee-eaters, and rollers. Princeton University Press, Princeton, NJ.

Gauthier, S. and D. Boisclair. 1996. The energetic implications of diel onshore-offshore migration by dace (*Phoximus eos* x *P. Neogaeus*) in a small oligotrophic lake. Canadian Journal of Fisheries and Aquatic Sciences 54: 1996-2006.

Goddard, K.A., R.M. Dawley, and T.E. Dowling. 1989. Origin and genetic relationships of diploid – triploid mosaic biotypes in the *Phoxinus eos – neogaeus* unisexual complex. Pages 268-280 *in* R.M. Dawley and J.P. Bogart, editors. Evolution and ecology of unisexual vertebrates. New York State Museum Bulletin 466, Albany, NY.

Greeley, J.R. 1934. Fishes of the Raquette watershed. Pages 53-103 *in* A biological survey of the Raquette watershed. Supplement to 23rd Annual Report, New York State Conservation Department.

Greeley, J.R. and S.C. Bishop. 1932. A biological survey of the Oswegatchie and Black River systems, with annotated list. Supplement to 21st Annual Report, New York State Conservation Department.

Greeley, J.R. and S.C. Bishop. 1933. Fishes of the upper Hudson watershed with annotated list. Pages 61-101 *in* A biological survey of the upper Hudson watershed. Supplement to 22nd Annual Report, New York State Conservation Department.

Greeley, J.R. and C.W. Greene. 1931. Fishes of the area with annotated list. Pages 44-94 *in* A biological survey of the St. Lawrence watershed. Supplement to 20th Annual Report, New York State Conservation Department.

Green, R.H. and R.C. Young. 1993. Sampling to detect rare species. Ecological Applications 3:351-356.

Greene, C.W. 1935. The distribution of Wisconsin fishes. Wisconsin Conservation Commission, Madison, WI. 235pp.

Gunther, A.C. 1880. An introduction to the study of fishes. R. and R. Clark, Edinburgh. 720pp.

Hall, R.O,.Jr., J.B. Wallace, and L.S. Eggert. 2000. Organic matter flow in stream food webs with reduced detrital resource base. Ecology 81:3445-3463.

Hall, J.S., H.J. Marriott, and J.K. Perot. 2002. Ecoregional conservation in the Black Hills. The Nature Conservancy. Arlington, VA http://www.conserveonline.org.

Hamas, M.J. 1994. Belted kingfisher (*Ceryle alcyon*). *In*: A. Poole and F. Gills, editors. The birds of North America No. 84. Philadelphia. Academy of Natural Sciences, Washington, D.C. The American Ornithologists Union.

Hankin, D.G. and G.H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834-844.

Hatch, J.T., K.P. Schmidt, D.P. Siems, J.C. Underhill, R.A. Bellig, and R.A. Baker. 2003. A new distributional checklist of Minnesota fishes, with comments on historical occurrence. Journal of the Minnesota Academy of Science 67:1-17.

Hays, D.B., C.P. Ferreri, and W.W. Taylor. 1996. Active fish capture methods. Pages 193-220 *in* B.R. Murphy and D.W. Willis, editors. Fisheries Techniques. Second edition. American Fisheries Society, Bethesda, MD.

He, X. and J.F. Kitchell. 1990. Direct and indirect effects of predation on a fish community: a whole-lake experiment. Transactions of the American Fisheries Society 119:825-835.

Hinks, D. 1943. The fishes of Manitoba. Department of Mines and Natural Resources, Winnipeg, Manitoba.

Hoffman, G.L. 1970. Parasites of North American freshwater fishes. Second edition. University of California Press, Berkley, CA. 350pp.

Hubbs, C.L. 1926. A checklist of the fishes of the Great Lakes and tributary waters. University of Michigan Miscellaneous Publication 15:1-77.

Hubbs, C.L. 1955. Hybridization between fish species in nature. Systematic Zoology 4(1):1-20.

Hubbs, C.L. 1964. Fishes of the Great Lakes region. Third edition. Cranbrook Institute of Science Bulletin 26.

Hubbs, C.L. and D.E. Brown. 1929. Materials for a distributional study of Ontario fishes. Transaction of Royal Canadian Institute 17:1-56.

Hubbs, C.L. and G.P. Cooper. 1936. Minnows of Michigan. Cranbrook Institute of Science Bulletin 8. 84pp.

Hubbs, C.L. and K.F. Lagler. 1949. Fishes of Isle Royale, Lake superior, Michigan. Pennsylvania Michigan Academy of Science, Arts, and Letters 33:73-133.

Hubbs, C.L. and K.F. Lagler. 1964. Fishes of the Great Lakes region. Third edition. Cranbrook Institute of Science Bulletin 26.

Hubert, W.A. 1996. Passive capture techniques. Pages 157-192 *in* B.R. Murphy and D.W. Willis, editors. Fisheries Techniques. Second edition. American Fisheries Society, Bethesda, MD.

Hungerford, H.B. 1920. The biology and ecology of aquatic and semi-aquatic Hemiptera. Kansas University Science Bulletin XI:1-256.

Isaak, D.J., W.A. Hubert, and C.R. Berry. 2003. Conservation assessment for lake chub, mountain sucker, and finescale dace in the black hills national forest, South Dakota and Wyoming. Report to U.S. Forest Service, Rocky Mountain Region, Black Hills National Forest, Custer, SD.

Jackson, D.A. 2002. Ecological impacts of *Micropterus* introductions: the dark side of black bass. *In*: D. Phillip and M. Ridway, editors. Black Bass: Ecology, Conservation and Management. American Fisheries Society, Bethesda, MD.

Jackson, D.A. and N.E Mandrak. 2002. Changing fish biodiversity: predicting the loss of cyprinid biodiversity due to global climate change. *In*: N.A. McGinn, editor. Fisheries in a Changing Climate. American Fisheries Society Symposium 32. American Fisheries Society, Bethesda MD.

Jackson, D.A., P.R. Peres-Neto, and J.D. Olden. 2001. What controls who is where in freshwater fish communities – the role of biotic, abiotic, and spatial factors. Canadian Journal of Fisheries and Aquatic Sciences 58:157-170.

Johnson, R.E. 1942. The distribution of Nebraska fishes. Ph.D. Thesis, University of Michigan. Ann Arbor, MI.

Jones, D.J. 1963. A history of Nebraska's fishery resources. Dingell-Johnson Federal Aid in Fish Research., Project F-4-R. Nebraska Game, Forest, and Parks Commission, Lincoln, NE.

Jordan, D.S. 1924. Concerning the American dace allied to the genus *Leuciscus*. Copeia 132:70-72.

Jordan, D. S. and C.H. Gilbert. 1882. Fishes of North America. Bulletin 16, U. S. National Museum, Washington, D.C.

Joswiak, G.R., A.B. Eisenbrey, M. Baeton, E.M. Rasch, R.H. Stasiak, N. Billington, C. Noble, P. Hebert, and J. Hudson. 1989. Genome size determination in the cyprinid genus *Phoxinus* by fuelgen staining and flow cytophotometry. Page 105 *in* Program of the 69th Annual Meeting of the American Society of Ichthyologists and Herpetologists. California Academy of Sciences, San Francisco, CA.

Joswiak, G.R., R.H. Stasiak, and B.F. Koop. 1985. Diploidy and triploidy in the hybrid minnow, *Phoxinus eos* x *Phoxinus neogaeus* (Pisces: Cyprinidae). Experientia 41 (1985):505-507.

Joswiak, G.R., R.H. Stasiak, and W.S. Moore. 1982. Allozyme analysis of the hybrid *Phoxinus eos* x *Phoxinus neogaeus* (Pisces: Cyprinidae) in Nebraska. Canadian Journal of Zoology 60(5):968-973.

Keast, A. and D. Webb. 1966. Mouth and body form relative to feeding ecology in the fish fauna of a small lake, Lake Opinicon, Ontario. Journal of Fisheries Research Board Canada 23(12):1845-1875.

Keast, A. and L. Welsh. 1968. Daily feeding periodicities, food uptake rates, and some dietary changes with hour of day in some lake fishes. Ibid. 25(6):1133-1144.

Keleher, J.J. 1956. The northern limits of distribution in Manitoba for cyprinid fishes. Canadian Journal of Zoology 34:263-266.

Kendall, W.C. 1908. Fauna of New England. Part 8., List of the Pisces. Occasional Papers of Boston Society of Natural History, No. 7. 152pp.

Kiesecker, J.M., A.R. Blaustein, and C.L. Miller. 2001. Transfer of a pathogen from fish to amphibian. Conservation Biology 15:1064-1070.

Labbe, T.R. and K.D. Fausch. 2000. Dynamics of intermittent stream habitat regulate persistence of threatened fish at multiple scales. Ecological Applications 10:1774-1791.

Legendre, P. 1969. Two natural hybrids of the cyprinid fish *Chrosomus eos*. M.S. Thesis McGill University.

Legendre, P. 1970. The bearing of *Phoxinus* hybridity on the classification of its North American species. Canadian Journal of Zoology 48(6):1167-1179.

Legendre, V. 1953. The freshwater fishes of the Province of Quebec: list of the species, ecological groups, history, nomenclature, annotations. Ninth Report. Biology Bureau, Game and Fish Department, Province of Quebec. 294pp.

Legendre, V. 1954. Key to game and commercial fishes of the Province of Quebec. First English edition. Volume 1. Society of Canadian Ecology, Montreal, Quebec. 180pp.

Lindeborg, R.G. 1941. Records of fishes from the Quetico Provincial Park of Ontario, with comments on the growth of the yellow pike-perch. Copeia 1941:159-161.

Lindsey, C.C. 1956. Distribution and taxonomy of fishes in the Mackenzie drainage of British Columbia. Journal of the Fisheries Research Board of Canada 13:759- 886.

Litvak, M. K. and R.I.C. Hansell. 1990. Investigations of food habit and niche relationships in a cyprinid community. Canadian Journal of Zoology 68:1873-1879.

Loeffler, C. 1982. Arkansas River threatened fishes survey. Colorado Division of Wildlife, performance report SE-8-1, Colorado Springs.

Maas, M.R.L. 1994. Scanning electron microscopy comparative study of the breeding tubercles in *Phoxinus* (Pisces: Cyprinidae): *P. neogaeus*, *P. eos*, and *P. erythrogaster*. M.A. Thesis, University of Nebraska at Omaha, Omaha, NE.

MacRae, P.S. and D.A. Jackson. 2001. The influence of smallmouth bass (*Micropterus dolomieu*) predation and habitat complexity on the structure of littoral-zone fish assemblages. Canadian Journal of Fisheries and Aquatic Sciences 58:342-351.

Madsen, T.I. 1985. The status and distribution of the uncommon fishes of Nebraska. M.A. Thesis, University of Nebraska at Omaha. Omaha, NE.

Magnin, E., C. Fradette, and R. Burdin. 1976. Bio-ecologie des *Phoxinus eos* x *Phoxinus neogaeus* du lac Trition Dans Les Laurentides, Quebec. Naturaliste Can. 103:11-19.

Mahy, G.J.D. 1972. Osteology of the North American species of the *Chrosomus* and their Eurasian relative *Phoxinus phoxinus* (Pisces, Cyprinidae). American Zoologist 12:728-729.

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 Sciences 105(3-4):219-231.

Masters, L.L., S.R. Flack, and B.A. Stein. 1998. Rivers of Life: Critical Watersheds for Protecting Freshwater Biodiversity. The Nature Conservancy, Arlington, VA.

Matthews, W.J. and E. Marsh-Matthews. 2000. Geographic, terrestrial, and aquatic factors: which most influence the structure of stream fish assemblages in the Midwestern United States? Ecology of Freshwater Fish 2000: 9-21.

Matthews, W.J and E. Marsh-Matthews. 2003. Effects of drought on fish across axes of space, time, and ecological complexity. Freshwater Biology 48:1232-1253.

Mayden, R.L., B.M. Burr, L.W. Page, and R.R. Miller. 1992. The native freshwater fishes of North America. Pages 827-863 *in* Systematics, historical ecology, and North American freshwater fishes. Stanford University Press, Stanford, CA.

Mayes, M. 1976. The adult platyhelminth parasites of Nebraska fishes. Ph.D. Thesis. University of Nebraska, Lincoln, NE.

McCafferty, A. 1998. Aquatic Entomology. Jones and Bartlett, Boston, MA.

McMahon, T.E., A.V. Zale, and D.J. Orth. 1996. Aquatic habitat measurements. Pages 83-120 *in* B.R. Murphy and D.W. Willis, eds. Fisheries Techniques, Second edition. American Fisheries Society, Bethesda, MD.

McPhail, J.D. 1963. The postglacial dispersal of freshwater fishes in northern North America. Ph. D. Thesis. McGill University.

McPhail, J.D. and C.C. Lindsey. 1970. Freshwater fishes of Northwestern Canada and Alaska. Bulletin 173., Fisheries Research Board Canada Ottawa.

Meester, R.J. 1998. Statewide Fisheries Surveys, 1997, part 2 streams region 1. Annual Report Number 98-15, South Dakota Department of Game, Fish, and Parks. Pierre, SD.

Minckley, W.L. and J.E. Deacon, editors. 1991. Battle against extinction: Native fish management in the American West. University of Arizona Press, Tucson, AZ.

Moore, H.H. and B.A. Roberty. 1965. Distribution of fishes in U.S. streams tributary to Lake Superior. U.S. Fish and Wildlife Service, Special Scientific Report No. 516. Washington, D.C.

Morrice, J.A., H.M. Valett, C.N. Dahn, and M.E. Capana. 1997. Alluvial characteristics, groundwater-surface water exchange, and hydrological retention in streams. Hydrological Processes 11:253-267.

Moyle, P.B. 1976. Inland Fishes of California. University of California Press, Berkeley, CA.

Moyle, P.B. and B. Vondracek. 1985. Persistence and structure of the fish assemblage in a small California stream. Ecology 66:1-13.

Mueller, G.A. 2005. Predatory fish removal and native fish recovery in the Colorado River mainstream: what have we learned? Fisheries 30(9):10-19.

Mullner, S.A., W.A.Hubert, and T.A.Wesche.1998. Snorkeling as an alternative to depletion electrofishing for estimating abundance and length-class frequencies of trout in small streams. North American Journal of Fisheries Management 18:947-953.

Naiman, R.J., C.A. Johnston, and J.C. Kelly. 1988. Alteration of North American streams by beaver. Bioscience 38: 753-762.

Naud, M. and P. Magnan. 1988. Diel onshore-offshore migrations in the northern redbelly dace, *Phoxinus eos* (Cope), in relation to prey distribution in a small oligotrophic lake. Canadian Journal of Zoology 66:1249-1253.

Nelson, K. and M. Soule. 1987. Genetical conservation of exploited fishes. Pages 345-368 *in* N. Ryman and F. Utter, editors. Population Genetics and Fishery Management. University of Washington Press. Seattle,WA

Nelson, J.S. 1994. Fishes of the World. Third edition. John Wiley & Sons, New York, NY.

Nelson, J.S., E.J. Crossman, H. Espinosa-Rosa, L.T. Findley, C. Gilbert, R. Lea, and J.D. Williams. 2004. Common and Scientific names of fishes from the United States and Canada. Sixth edition. American Fisheries Society Special Publication No. 29. Bethesda, MD.

New, J.G. 1962. Hybridization between two cyprinids, *Chrosomus eos* and *Chrosomus neogaeus*. Ibid 147-152.

Nordlie, F., J. Underhill, and S. Eddy. 1961. New distributional records of some Minnesota fishes. Minnesota Academy of Sciences 29:255-258.

Olson, M.D. 1988. Upstream changes in native fish abundances after reservoir impoundments in California streams of the Lahontan Basin. M.S. Thesis, University of California, Berkley.

Olson, R. and W.A. Hubert. 1994. Beaver: water resources and riparian habitat manager. University of Wyoming, Laramie, WY.

Olson, R.D. 1998. Finescale dace and lake chub survey, South Dakota Wildlife Diversity Small Grants results and reports. Report Number 99-12, South Dakota Department of Game, Fish, and Parks. Pierre, SD.

Overton,C.K., S.P.Wollrab, B.C. Roberts, and M.A. Radko. 1997. R1/R4 (northern/intermountain regions) fish and fish habitat standard inventory procedures handbook. U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, Utah, INT-GTR-346.

Page, L.M. and B.M. Burr. 1991. A field guide to the freshwater fishes: North America north of Mexico. Houghton Mifflin, Boston, MA.

Paetz, M.J. and J.S. Nelson. 1970. The fishes of Alberta. Queen's Printer, Edmonton.

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

Pedroli, B., G.D. Blust, K.V. Looy, and S.V. Rooij. 2002. Setting Targets for River Restoration. Landscape Ecology 17(Suppl.1):5-18.

Quist, M.C., W.A. Hubert, and F.J. Rahel. 2006a. Concurrent assessment of fish and habitat in warmwater streams in Wyoming. Fisheries Management and Ecology 13:9-20.

Quist, M.C., W.A. Hubert, M. Fowden, S.W. Wollf, and M.R. Bower. 2006b. The Wyoming habitat assessment methodology (WHAM): a systematic approach to evaluating watershed conditions and stream habitat. Fisheries 31(2):75-81.

Phillips, G.L. 1968. *Chrosomus erythrogaster* and *C. eos* (Ostreichthyes: Cyprinidae): taxonomy, distribution and ecology. Ph.D. Thesis, University of Minnesota, Minneapolis, MN.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. U.S.Departments of Agriculture, Forest Service, Intermountain Research Station, Ogden, Utah, GTR-INT-138.

Poff, N.L. and J.D. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. Ecology 76(2):606-627.

Radforth, I. 1944. Some considerations on the distribution of fishes in Ontario. Contributions of the Royal Ontario Museum of Zoology No. 25. Toronto, Ontario. 116p.

Rafinesque, C.S. 1820. Ichthyologia Ohiensis, or natural history of the fishes inhabiting the River Ohio and its tributary streams. *In*: R.E. Call. 1899. Ichthyologia Ohiensis. The Burrows Bros., Cleveland, OH. 175pp.

Rahel, F.J. 2002. Homogenization of Freshwater Fuanas. Annual Reviews of Ecological Systems 33:291-315.

Reighard, J. 1903. The function of the pearl organs of the Cyprinidae. Science 17(431):531.

Reighard, J. 1904. Further observations on the breeding habits and the function of the pearl organs in several species of Eventognathi. Science 19(457):211-212.

Resh, V.H., A.V. Brown, and A.P. Covich. 1988. The role of disturbance in stream ecology. Journal of the North American Benthogical Society 16:425-433.

Roberts, W.E. 1973. *Percina caprodes semifasciata*, the logperch, newly recorded in Alberta, and new distribution records for *Chrosomus neogaeus* and *Semotilus margarita*. Canadian Field Naturalist 87:467-468.

Ryder, R.A., W.B. Scott, and E.J. Crossman. 1944. Fishes of northern Ontario, north of the Albany River. Roy. Ont. Mus. Life Sci. Cont. 60., University of Toronto, Toronto, Ontario.

Schell, S.C. 1970. How to know the trematodes. William Brown Co., Dubuque, IA.

Schlosser, I.J. 1995. Dispersal, boundary processes, and trophic-level interactions in streams adjacent to beaver ponds. Ecology 76(3):908-925.

Schlosser, I.J. and P.L. Angermeier 1995. Spatial variation in demographic processes in lotic fishes: conceptual models, empirical evidence, and implications for conservation. American Fisheries Society Symposium 17: 360-370.

Schlosser, I.J., M.R. Doeringsfeld, J.F. Elder, and L.F. Arzayus. 1998. Niche relationships of clonal and sexual fish in heterogenous landscape. Ecology 79(3):953-968.

Schlosser, I.J. and L.W. Kallemeyn. May 2000. Spatial variation in fish assemblages across a beaver-influenced successional landscape. Ecology 81(5):1371-1382.

Schrank, S.J., C.S. Guy, M.R. Whiles, and B.L. Brock. 2001. Influence of instream and landscape level factors on the distribution of Topeka shiners, *Notropis topeka*, in Kansas streams. Copeia 2:413-421.

Scott, W.B. 1954. Freshwater fishes of Eastern Canada. University of Toronto Press, Toronto, Ontario. 128 pp.

Scott, W.B. 1957. Distributional records of fishes in western Canada. Copeia 2:160-161.

Scott, W.B. and E.J. Crossman. 1959. The freshwater fishes of New Brunswick: a checklist with distributional notes. Contributions to Royal Ontario Museum No. 51.

Scott, W.B. and E.J. Crossman. 1969. Checklist of Canadian freshwater fishes, with keys for identification. Royal Ontario Museum Life Science Publication.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Bulletin 184, Fisheries Research Board of Canada, Ottawa.

Seaburg, K.G. and J.B. Moyle. 1964. Feeding habits, digestive rates, and growth of Minnesota warmwater fishes. Trans. Amer. Fish. Soc. 93(3):269-285.

Sherrod, N. 1963. Late Pleistocene fish from lake sediments in Sheridan County, North Dakota. Miscellaneous Series North Dakota Geological Survey 21:32-36.

Shields, B.A. 2004. Effects of introduced exotic species: Behavioral changes induced upon a native bull trout (*Salvelinus confluentus*) population by introduced brook trout (*Salvelinus fontinalis*) in Oregon. Annual meeting of the Oregon Chapter of the American Fisheries Society.

Simonson, T.D., J. Lyons, and P.D. Kanehl. 1994. Quantifying fish habitat in streams: transect spacing, sample size, and a proposed framework. North American Journal of Fisheries Management 14:607-615.

Smith, B.G. 1908. The spawning habits of *Chrosomus erythrogaster* Rafinesque. Biological Bulletin 15(1):9-18.

Smith, C.L. 1985. The inland fishes of New York. New York State Department of Environmental Conservation, Albany, NY.

Smith, J. 1976. Finescale dace in Saskatchewan. Blue Jay Journal of the Saskatchewan Natural History Society 2:86-87. Saskatoon, Saskatchewan.

Smith, L.L., Jr. and J.B. Moyle. 1944. A biological survey and fishery management plan for the streams of the Lake Superior North Shore Watershed. Minnesota Department of Conservation, Fish and Game Technical Bulletin No.1. Minneapolis, MN.

Smith-Vaniz, W.F. 1968. Freshwater fishes of Alabama. Auburn University Agriculture Research Station, Paragon Press, Montgomery, AL. 211 pp.

Snodgrass, J.W. and G.K. Meffe. 1998. Influence of beavers on stream fish assemblages: effects of pond age and watershed position. Ecology 70(3):928-942.

Stasiak, R.H. 1972. The morphology and life history of the finescale dace, *Pfrille neogaea*. *In*: Itasca State Park, Minnesota. Ph.D. Thesis, University of Minnesota, Minneapolis, MN.

Stasiak, R.H. 1976. Updated distributional records for Nebraska Fishes. Page 27 *in* Proceedings of the Nebraska Academy of Sciences and Affiliated Societies, Lincoln, NE.

Stasiak, R.H. 1977. Morphology and variation in the finescale dace, *Chrosomus neogaeus*. Copeia 1977:771-774.

Stasiak, R.H. 1978. Reproduction, age, and growth of the finescale dace, *Chrosomus neogaeus*, in Minnesota. Transactions of the American Fisheries Society 107(5):720-723.

Stasiak, R.H. 1980. *Phoxinus neogaeus* Cope. Page 336 *in* D.S. Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, editors. Atlas of North American Freshwater Fishes. North Carolina State Museum Natural History, Raleigh, NC.

Stasiak, R.H. 1987. The minnows and killifish. Pages 56-64 *in* The Fish Book. Nebraskaland Special Publication for January-February 1987. Lincoln, NE.

Stasiak, R.H. 1989. The fishes of Agate Fossil Beds National Monument, 1979-1989. Report to United States National Park Service. Scotts Bluff, NE.

Stasiak, R.H., G.R. Joswiak, and K.A. Berven. 1988. Laboratory development of the hybrid *Phoxinus eos* x *Phoxinus neogaeus* (Pisces: Cyprinidae). Experientia 44 (1988) 262-263.

Steinmetz, J., S.L. Kohler, and D.A. Soluk. 2003. Birds are overlooked predators in aquatic food webs. Ecology 84: 1324-1328.

Taylor, W.R. 1954. Records of fishes in the John N. Lowe collection from the Upper Peninsula of Michigan. Miscellaneous Publication University Michigan Museum of Zoology 87:1-50.

Toline, C.A. and A.J. Baker. 1994. Genetic differentiation among populations of the northern redbelly dace (*Phoxinus eos*) in Ontario. Canadian Journal of Fisheries and Aquatic Science 51:1218-1228.

Tonn, W.C. and J.J. Magnuson. 1982. Patterns in the species composition and richness of fish assemblages in northern Wisconsin lakes. Ecology 73:1149-1166.

Trudel, M. and D. Boisclair. 1994. Seasonal consumption by dace (*Phoxinus eos* x *P. neogaeus*): a comparison between field and bioenergetic model estimates. Canadian Journal of Fisheries and Aquatic Sciences 51:2558-2567.

Tubb, R., F.A. Copes, and C. Johnston. 1965. Fishes of the Sheyenne River of North Dakota. Proc. No. Dak. Acad. Sci. 19:120-128.

Tyler, A.V. 1966. Some lethal temperature relations of two minnows of the genus *Chrosomus*. Canadian Journal of Zoology 44:349-364.

Underhill, J.C. 1957. The distribution of Minnesota minnows and darters in relation to the Pleistocene Glaciation. Minnesota Museum of Natural History Occasional Paper No. 7.

Underhill, J.C. 1989. The distribution of Minnesota fishes and late Pleistocene glaciation. Journal of the Minnesota Academy of Science 55:6-13.

Underhill, J.C. and J. Dobie. 1965. The fishes of Itasca. Minnesota Conservation Volunteer May-June, 1965.

Underhill, J.C. and J.B. Moyle. 1968. The fishes of Minnesota's Lake Superior region. Minnesota Conservation Volunteer. January-February, 1968.

U.S. Environmental Protection Agency. 2001. Revised protocols for sampling algal, invertebrate, and fish communities as part of the National Water-Quality Assessment Program. S.R. Moulton, J.G. Kennen, R.M. Goldstein, and J.A. Hambrook. Available online at http://www.epa.gov/emap/html/pubs/docs/groupdocs/surfwatr/field/fomws.html.

Vanderbush, L. 1999. Five year fisheries management plan: Deerfield Reservoir. Pages 23-27 *in* D.R. Jost, editor. Statewide fisheries surveys, 1998, management plan. Annual Report Number 99-22, South Dakota Department of Game, Fish and Parks, Pierre, SD.

Warren, M.L. and B.M. Burr. 1994. Status of freshwater fishes of the United States: overview of an imperiled fauna. Fisheries 19:6-18.

Weitzel, D.L. 2002. Conservation and status assessments for the finescale (*Phoxinus neogaeus*), pearl dace (*Margariscus margarita*), and plains topminnow (*Fundulus sciadicus*): rare native fish species of the Niobrara and Platte River Basins, WY.

Whittier, T.R., D.B. Halliwell, and S.G. Paulson. 1997. Cyprinid distributions in Northeast USA lakes: evidence of region-scale minnow biodiversity losses. Canadian Journal of Fisheries and Aquatic Sciences 54:1593-1607.

Willock, T.A. 1969. Distributional list of fishes in the Missouri drainage of Canada. Journal of Fisheries Research in Canada 26:1439-1449.

Winston, M.R., C.M. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. American Fisheries Society Transactions 120(1):98-105.

Woodling, J. 1985. Colorado's Little Fish. A guide to the minnows and other lesser known fishes in the state of Colorado. Colorado Division of Wildlife, Denver, CO.

Wynne-Edwards, V.C. 1952. Freshwater vertebrates of the Arctic and subarctic. Fisheries Research Board Canadian Bulletin 94. 28pp.

Appendix A

Life Cycle Graph and Model Development

The life history described by Stasiak (1972, 1978) provided the basis for an age-classified life cycle graph with seven age-classes (**Figure A1**) and matrix population analysis, for a birth-pulse population with a one-year census interval and a post-breeding census (Cochran and Ellner 1992, McDonald and Caswell 1993, Caswell 2001) for finescale dace. The model has two kinds of input terms: P_i, describing survival rates, and m_i, describing fertilities (**Table A1**). **Figure A2a** shows the symbolic terms in the projection matrix corresponding to the life cycle graph. **Figure A2b** gives the corresponding numeric values. The model assumes female demographic dominance so that, for example, fertilities are given as female offspring per female; thus, the offspring number used was half the clutch size, assuming a 1:1 sex ratio. Note also that the fertility terms (F_i) in the top row of the matrix include a term for offspring production (m_i) as well as a term for the survival of the mother (P_i) from the census (just **after** the breeding season) to the next birth pulse almost a year later. The population growth rate, λ, was 1.003 based on the estimated vital rates used for the matrix. Although this suggests a stationary population,

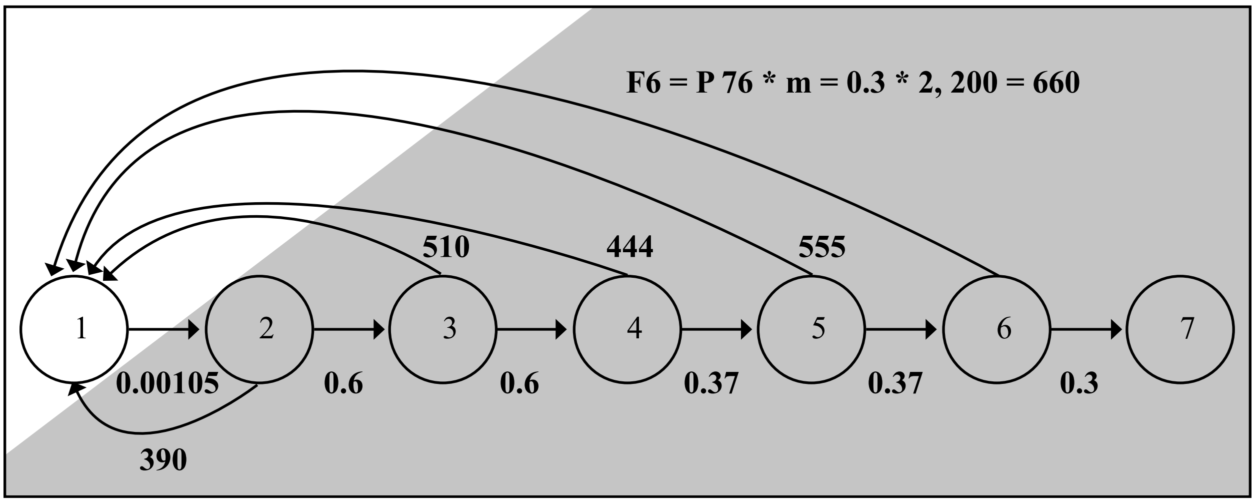

Figure A1. Life cycle graph for finescale dace, consisting of circular *nodes*, describing age-classes in the life cycle and *arcs*, describing the *vital rates* (transitions between stages). The horizontal arcs are survival transitions (e.g., first-year survival, P_{21}= 0.00105). The remaining arcs, pointing back to Node 1, describe fertility (e.g., $F_6 = P_{76} * m_6$). For symbolic values see the cells in the corresponding matrix (**Figure A2**).

Table A1. Parameter values for the component terms (P_i and m_i) that comprise the vital rates in the projection matrix for finescale dace.

Parameter	Numeric value	Interpretation
m2	650	Number of female offspring produced by a second-year female
m3	850	Number of female offspring produced by a third-year female
m4	1,200	Number of female offspring produced by a "young adult" female
m5	1,500	Number of female offspring produced by an "older adult" female
m6	2,200	Number of female offspring produced by oldest females
P_{21}	0.00105	Probability of surviving first year (egg to yearling)
P_{32}	0.6	Probability of surviving the second year
P_{42}	0.6	Probability of surviving the third year
P_{52}	0.37	Probability of surviving the fourth year
P_{62}	0.37	Probability of surviving the fifth year
P_{72}	0.3	Probability of surviving the sixth year

the value is subject to the many assumptions used to derive the transitions and should not be interpreted as an indication of the general well-being and stability of the population. Other parts of the analysis provide a better guide for assessment.

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 (see Caswell 2001, pp. 206-225). First, sensitivities show how important a given vital rate is to λ, which Caswell (2001, pp. 280-298) has shown to be a useful integrative measure of overall fitness. One can use sensitivities to assess the relative importance of the survival (P_i) and fertility (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 accurate estimation of 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

Stage	1	2	3	4	5	6	7
1		$P_{32}*m_2$	$P_{43}*m_3$	$P_{54}*m_4$	$P_{65}*m_5$	$P_{76}*m_8$	
2	P_{21}						
3		P_{32}					
4			P_{43}				
5				P_{54}			
6					P_{65}		
7						P_{76}	

Figure A2a. Symbolic values for the matrix cells. The top row is fertility with compound terms describing survival of the mother (P_i) and offspring production (m_i). Note that the last column of the matrix consists of zeros in order to allow tabulation of the (small) proportion of seventh-year individuals that just completed their final breeding pulse.

Stage	1	2	3	4	5	6	7
1		390	510	444	555	666	
2	0.00105						
3		0.6					
4			0.6				
5				0.37			
6					0.37		
7						0.3	

Figure A2b. Numeric values for the projection matrix.

Figure A2. The input matrix of vital rates, **A** (with cells a_{ij}) corresponding to the finescale dace life cycle graph (**Figure A1**). a) Symbolic values. b) Numeric values.

Stage	1	2	3	4	5	6	7
1		0	0	0	0	0	
2	**317.3**						
3		**0.33**					
4			**0.15**				
5				0.10			
6					0.03		
7						0	

Figure A3. Possible sensitivities only matrix, $\mathbf{S_p}$ (remainder of matrix is zeros). The three transitions to which λ of finescale dace is most sensitive are highlighted. Note the overwhelming dominance of the value for first-year survival (Cell s_{21}) and the negligible contribution of the fertilities (rounds to zero to the fourth decimal place).

"adult" reproductive females (those in Stages 4 through 9). 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 sensitivity of λ to changes in first-year survival (317.3; 99.8 percent of total) is overwhelmingly important. Virtually all the remaining 0.2 percent of the sensitivity was connected with survival, with fertility accounting for less than 0.01 percent of the total sensitivity of λ to changes in vital rates. The major conclusion from the sensitivity analysis is that first-year recruitment is the key to population viability.

Elasticity analysis

Elasticities are the sensitivities of λ to **proportional** changes in the vital rates (a_{ij}). 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 vital rates (the a_{ij} arc coefficients on the graph or 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. It is important to note that elasticity as well as sensitivity analysis assumes that the magnitude of changes (perturbations) to the vital rates is small. Large changes require a reformulated matrix and reanalysis.

Elasticities for finescale dace are shown in **Figure A4**. The λ of finescale dace was most elastic to changes in first-year survival, followed successively by second-year survival and then second-year fertility. Overall, survival transitions accounted for approximately 67 percent of the total elasticity of λ to changes in the vital rates. The survival rates through the first two years are the data elements that warrant careful monitoring in order to refine the matrix demographic analysis.

Other demographic parameters

The **stable age distribution** (SAD; **Table A2**) describes the proportion of each a-class in a population at

Stage	1	2	3	4	5	6	7
1		**0.135**	0.106	0.055	0.025	0.011	
2	**0.332**						
3		**0.197**					
4			0.091				
5				0.036			
6					0.011		
7						0	

Figure A4. Elasticity matrix, **E** (remainder of matrix is zeros). The λ of finescale dace is most elastic to changes in survival through the first two years and reproduction in the second year (Cells e_{21}, e_{32} and e_{12}).

Table A2. Stable age distribution (SAD, right eigenvector). At the census, 99.8 % of the population should be eggs. Excluding the first-year individuals, almost half the census total will be yearlings, with very few fish in their seventh year (0.7%).

Stage	Description	Proportion	Proportion excluding eggs
1	First-year females (eggs)	0.998	—
2	Second-year females	0.001	0.465
3	Third-year females	0.001	0.278
4	Fourth-year females	0	0.166
5	Fifth-year females	0	0.061
6	Sixth-year females	0	0.023
7	Seventh-year females	0	0.007

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 SAD within 20 to 100 census intervals. For finescale dace at the time of the post-breeding annual census (just after the end of the breeding season), eggs represent 99.8 percent of the population. Excluding that hugely dominant age-class, 46.5 percent of the "adult" fish are beginning their second year, 28 percent beginning their third year, with sharply declining proportions such that the oldest age-class represents fewer than 1 percent of the "adult" fish. **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 (Caswell 2001). 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 reproductive value of the first stage is, by definition, always 1.0. A yearling female (age of first breeding) is "worth" approximately 956 female eggs. The cohort generation time for finescale dace is 3.0 years (SD = 1.1 years).

Stochastic model

We conducted a stochastic matrix analysis for finescale dace. 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 altered the offspring production terms (m_i). Under Variants 2 and 3 we varied the survival of the first two age-classes (P_{21} and P_{32}). Each run consisted of 2,000 census intervals (years) beginning with a population size of 10,000 distributed according to the SAD under the deterministic model. Beginning at the SAD helps to avoid the effects of transient, non-equilibrium dynamics. The overall simulation consisted of running each of 100 replicate populations for 2,000 annual cycles, from a starting size of 10,000. We varied the amount of fluctuation by varying the standard deviation of the beta distribution from which the stochastic vital rates were selected. The beta distribution has the useful property of existing in the interval zero to one, thereby avoiding problems

Table A3. Reproductive values for females. Reproductive values can be thought of as describing the "value" of a stage as a seed for population growth, relative to that of the first (egg) stage, which is always defined to have the value 1. Seventh-year females have no reproductive value because they have just reproduced for the last time and will not survive to breed again.

Age-class	Description	Proportion
1	First-year females (egg)	1
2	Second-year females	955.7
3	Third-year females	948.2
4	Fourth-year females	735.8
5	Fifth-year females	795.6
6	Sixth-year females	657.6
7	Seventh-year females	0

Table A4. Summary of three variants of stochastic projections for finescale dace. Each variant consisted of 100 runs, each of which ran for 2,000 annual census intervals. Stochastic vital rates were selected from a beta distribution with mean at the deterministic value and SD of 1/4 or 1/8 of that deterministic mean.

	Variant 1	Variant 2	Variant 3
Input factors:			
Affected cells	Fi	P21 and P32	P21 and P32
S.D. of random normal distribution	1/4	1/4	1/8
Output values:			
Deterministic λ	1.003	1.003	1.003
# Extinctions / 100 trials	38	100	32
Mean extinction time	1,261	435	1,392
# Declines / # survived populations	53/62	—	56/68
Mean ending population size	5,633	—	52,352
Standard deviation	15,250	—	212,224
Median ending population size	1,636	—	651
Log λ_s	-0.0028	-0.021	-0.0026
λ_s	0.997	0.979	0.997
% reduction in λ	0.62	2.42	0.6

of impossible parameter values (<0 or >1) or altered mean and variance (as when using a truncated normal distribution). 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 3 affected the same transitions as Variant 2 (P_{21} and P_{32}) but was subjected to lower variability (SD was 1/8 rather than 1/4 [= 0.125 compared to 0.25] of the mean). We calculated the stochastic growth rate, $log\lambda_S$, according to Eqn. 14.61 of Caswell (2001), after discarding the first 1,000 cycles in order to further avoid transient dynamics. A population was considered "pseudoextinct" (Morris and Doak 2002) if it dipped below 10 individuals.

The stochastic model (**Table A4**) produced two major results. First, altering the survival rates had a much more dramatic effect on λ than did altering the fertilities. For example, under the varied fertilities of Variant 1, the median ending size was 1,636 with 38 pseudoextinctions and 53 populations declining from their initial size. In contrast, the same degree of variation acting on survival under Variant 2 resulted in all 100 replicate populations going pseudoextinct. Second, large-effect stochasticity has a negative effect on population dynamics, at least when it impacts transitions to which λ is highly sensitive. The negative effect of stochasticity occurs despite the fact that the average vital rates remain the same as under the deterministic model. This apparent paradox is due to the lognormal distribution of stochastic ending population sizes (Caswell 2001). 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. For finescale dace under the survival Variant 3 with a low degree of stochasticity (SD = 1/8 of the mean), 32 out of 100 trials of stochastic projection went to pseudoextinction, with a further 56 of the surviving populations declining in size, and a median size for the surviving populations of just 651. Variant 3 shows that the magnitude of fluctuation has a potentially large impact on the detrimental effects of stochasticity. Increasing the magnitude of fluctuation increased the severity of the negative impacts – the number of pseudoextinctions went from 32 to 100. These differences in the effects of stochastic variation are predictable from the sensitivities and elasticities. λ was much more sensitive to changes in first- and second-year survival, P_{21} and P_{32}, than it was to changes in the entire set of fertilities, F_i. These results suggest that populations of finescale dace are relatively tolerant of stochastic fluctuations in offspring production (due, for example, to annual climatic change or to human disturbance) but extremely vulnerable to variations in the survival of young individuals. 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 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 annual survival), with consequent detrimental effects on population dynamics. Further, in the case of high sensitivity of λ to changes in first-year survival, selection may be relatively ineffective in reducing variability that surely results from a host of biotic and abiotic factors.

Potential refinements of the models

Clearly, the better the data on early survival rates, 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 variations in vital rates. Using observed correlations would incorporate 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 account for 99.8 percent of total "possible" sensitivity. Any absolute changes in this rate will have major impacts on population dynamics.

- First-year and second-year survival account for 53 percent of the total elasticity, more than one and a half times the total of the elasticities for all the fertility transitions. Proportional changes in early survival will have major impacts on population dynamics.

- The similarity between the conclusions from the sensitivity and elasticity analyses suggests that survival in the first years of life is critical to the population dynamics of finescale dace.

- Stochastic simulations echoed the elasticity analyses in emphasizing the importance of variation in early survival to population dynamics. Management should consider that periodic opportunity for recruitment of young may be critical to finescale dace population viability.

References

Caswell, H. 2001. Matrix Population Models: Construction, Analysis, and Interpretation, Second Edition. Sinauer Associates, Sunderland, MA.

Cochran, M.E. and Ellner, S. 1992. Simple methods for calculating age-based life history parameters for stage-structured populations. Ecological Monographs 62:345-364.

McDonald, D.B. and H. Caswell. 1993. Matrix methods for avian demography. Pages 139-185 *in* D. Power, editor. Current Ornithology. Vol. 10. Plenum Press, New York, NY.

Morris, W.F. and D.F. Doak. 2002. Quantitative Conservation Biology. Sinauer Associates, Sunderland, MA.

Pfister, C.A. 1998. Patterns of variance in stage-structured populations: Evolutionary predictions and ecological implications. PNAS USA 95:213-218.

Stasiak, R.H. 1972. The morphology and life history of the finescale dace, *Pfrille neogaea*. *In*: Itasca State Park, Minnesota. Ph.D. Thesis, University of Minnesota, Minneapolis, MN.

Stasiak, R.H. 1978. Reproduction, age, and growth of the finescale dace, *Chrosomus neogaeus*, in Minnesota. Transactions of the American Fisheries Society 107(5):720-723.

Williams, G.C. 1966. Natural selection, the costs of reproduction, and a refinement of Lack's principle. American Naturalist 100:687-690.

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