

**Environmental Factors Limiting Suckermouth Minnow  
*Phenacobius mirabilis* Populations in Colorado**

**Final Report**

Submitted to:

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## Executive Summary

We conducted research to determine historic and present distribution and abundance patterns, habitat use, and reproductive ecology of suckermouth minnow *Phenacobius mirabilis* in eastern plains streams of Colorado. In the South Platte River Basin, suckermouth minnow was historically widespread in foothills and plains stream reaches, but is now present only in the lower South Platte River and Lodgepole Creek. Historical distribution and abundance of suckermouth minnow in the Republican and Arkansas River basins was difficult to infer from the few collections available. Suckermouth minnow may be extirpated from the Republican River Basin but remains relatively widespread in the Arkansas River downstream of John Martin Dam; it is also present in tributaries including the Purgatoire River, and Big Sandy and Cheyenne creeks. Logistic regression models showed that abundance and habitat use of suckermouth minnow varied by river basin and seasonally in response to drought. This was particularly true for the South Platte River, where the few suckermouth minnows found occupied mostly deep pools and runs below diversion dams in summer. Suckermouth minnows were more common in the Arkansas River and occupied deeper riffles, runs, and pools. Sand dominated the substrate at most plains sample sites but suckermouth minnows were typically captured over gravel. We successfully spawned suckermouth minnows twice in a laboratory setting, once with hormone injections and once without. Reproduction and culture was successful at temperatures ranging from 17 to 23°C and a developmental series of eggs and larvae were preserved. Impassable diversion dams and low flows may be limiting distribution and abundance of suckermouth minnows in the South Platte River system. Maintaining connected mainstem and tributary habitat and providing stream flow of sufficient quality and quantity to promote survival of suckermouth minnows even in drought seems critical to long-term persistence of the species in Colorado. We make research and management recommendations to better understand factors limiting distribution and abundance of suckermouth minnows in Colorado, which may enhance its conservation status.

## Introduction

Fish assemblages in streams of the arid Great Plains region of mid-western North America are well adapted to variable environmental conditions including floods, drought, and extremes in physico-chemical conditions (Matthews 1988, Fausch and Bestgen 1997). Most species are tolerant of high water temperatures and low dissolved oxygen, and several have evolved reproductive strategies specialized for life in shifting sand-bedded streams (Fausch and Bestgen 1997). Despite the highly adaptable life history traits of plains fishes, effects of water development for irrigation and municipal use, habitat alteration, and introduction of non-native fishes have been so severe that many are now reduced in distribution and abundance (Rabeni 1996, Fausch and Bestgen 1997) and listed as imperiled by state or federal regulatory agencies. For example, six of 38 plains stream fishes from Colorado have been extirpated and an additional 13 are now listed as endangered, threatened, or of special concern (Nesler et al. 1997, Fausch and Bestgen 1997, Scheurer et al. 2003). Conservation efforts to improve the status of many of these species are underway but are often hindered by limited information about their historical distribution and ecology.

One of those species, suckermouth minnow *Phenacobius mirabilis*, was listed as an endangered species in Colorado in 1998. Listing status was downgraded from "Species of Special Concern" after inventories conducted by Colorado Division of Wildlife (CDOW) in the South Platte and Arkansas River drainages found the species "bordering on extirpation" (Nesler et al. 1997) and highly imperiled (Nesler et al. 1999). Nesler et al. (1997, 1999) also recommended more intensive surveys to further document factors limiting distribution and abundance of suckermouth minnow, as well as studies to determine life history, habitat, and reproductive requirements.

The primary goal of this investigation is to identify factors limiting suckermouth minnow populations in Colorado and recommend management activities that will increase distribution and abundance of the species within the State. Specific objectives set out to accomplish that goal are as follows:

**Objective 1.** Describe the historical distribution of suckermouth minnow in Colorado.

**Objective 2.** Describe current distribution of suckermouth minnow in Colorado, with emphasis on populations in the Arkansas River below John Martin Reservoir and the lower South Platte River, by sampling locations where suckermouth minnow are, or were, abundant. Information from Objectives 1 and 2 will define present status of suckermouth minnow in Colorado and assist in identifying areas for additional conservation activities.

**Objective 3.** Identify potential causes for species' decline (limiting factors) by surveying and describing habitat characteristics where suckermouth minnow still occur in Colorado and in the region.

**Objective 4.** Describe reproductive and life history characteristics of suckermouth minnow. Habitat use and life history information gathered in objectives 3 and 4 will help define the spatial and temporal scale of habitat and river reaches needed for conservation of the species and will also help identify additional areas where conservation activities may occur.

**Objective 5.** Integrate the data generated by all aspects of this investigation in order to recommend management activities that will increase distribution and abundance of suckermouth minnow populations.

#### **Suckermouth minnow life history overview**

***Distribution and habitat*** - Suckermouth minnow inhabit plains ecoregions of the United States, ranging west to Colorado, east to Ohio, north to Minnesota and south to Texas (Rohde 1980). The type locality for the species is Arkansas River, Fort Smith, Arkansas (Girard 1856). Suckermouth minnow is reported abundant in small to large streams that have permanent flow, low to high gradient, sand and gravel substrate, and

rifle habitat (Larimore et al. 1952, Pflieger 1975, Miller and Robison 1980, Cross and Collins 1975). A key requirement seems to be sufficient gradient and flow to keep the gravel substrate clean (Pflieger 1975, Trautman 1981). Haas (1977) suggested the most productive suckermouth minnow riffles in his study were more than 75 m long and had at least 100 mm depth and coarse gravel substrate. He found that young-of-the-year (YOY) inhabited the same gravel riffles as adults, but also found YOY in sand riffles.

Suckermouth minnows appear tolerant of fluctuating water levels, high turbidity, and varying water chemistry, factors which may have promoted their relatively recent eastward expansion. Prior to 1800, suckermouth minnow occurred only as far east as the Mississippi River. Conversion of forests and prairie to crop land changed clear, gravel and sand substrate streams to turbid and silty ones, and coincided with an eastern expansion of suckermouth minnow through Ohio (Trautman 1981). Expansion of suckermouth minnow into Indiana, Ohio, and Texas has also been associated with environmental degradation caused by water diversion, groundwater withdrawal, and other stream modifications related to agriculture (Hubbs and Lagler 1958, Wilde and Bonner 2000).

In Colorado, suckermouth minnow is native to eastern plains streams, including the South Platte, Arkansas, Arikaree and Republican rivers (Cancalosi 1980, Loeffler et al. 1982, Propst 1982, Woodling 1985). Propst (1982) suggested that lack of permanent tributaries in the South Platte River may restrict suckermouth minnow to the mainstem.

***Spawning and reproduction*** - Little is known about the reproductive habits or requirements of suckermouth minnow. Sexual maturity has been reported in yearlings (Haas 1977) and at age-2 (Etnier and Starnes 1993). Adult males exhibit tubercles on the head, back, pectoral fins, and pelvic fins (Trautman 1981) and individuals may remain reproductively active throughout the spawning season (Cross 1967). Smaller females spawn earlier than larger females (Haas 1977), and all females may spawn two to three times per season (Cross 1967). Spawning has been documented at an array of temperatures, from 14 to 25°C (Cross 1950). Timing of reproduction is dependent on geographical location, ranging from April to August. In Kansas, Cross (1967) found suckermouth minnow to have a longer reproductive period than other riffle fishes. Haas (1977) never observed spawning behavior, although he found congregations of 20 to 25

individuals. Spawning is believed to take place in gravel riffles, the year-round habitat of the species in Missouri (Pflieger 1975).

Haas (1977) classified fecundity of suckermouth minnow in three periods: before, during, and after spawning. For all three periods, fecundity related directly to fish size, but egg size did not strongly relate to fecundity or fish size. The most fecund female captured by Haas measured 88 mm total length (TL) and held 1080 eggs. Becker (1983) reports a 90 mm TL female with approximately 1640 eggs.

**Length and growth** - Maximum length of adult suckermouth minnow differs by study, ranging from 65-120 mm (Cross 1967, Pflieger 1975, Haas 1977, Smith 1979, Etnier and Starnes 1993), with the largest adult documented by Trautman (1981) at 122 mm. Standard or total lengths were not specified in most studies. Young-of-the-year sizes vary greatly by study and geography. Haas (1977) found that suckermouth minnows attained 72% of their maximum length during the first growing season. Age-3 fish nearly disappeared by the time age-0 fish were detected. In all his sampling periods, the greatest percentage of the population consisted of the youngest age group present. Haas suggested that scales were a better indicator of age than length.

**Diet** - The genus name *Phenacobius* is Greek for "deceptive life" (Tomelleri and Eberle 1990). The ventral position of the mouth, general appearance, and habits are similar to those of benthic-feeding suckers. Jordan and Evermann (1896) point out "the appearance of the fish suggest an herbivorous species with long intestines, which it really is not." Most studies have noted that suckermouth minnow is a benthic insectivore (Forbes and Richardson 1920, Starrett 1950b). In a comprehensive study, Haas (1977) found that of the 827 suckermouth minnow examined, dipterans made up >96% of stomach contents, followed by Trichoptera, Ephemeroptera, and unidentified insects (Haas 1977). Absence of terrestrial insects in the diet implies that suckermouth minnow is not a drift or surface feeder. Haas (1977) postulated that the fleshy lips and many sensory organs of suckermouth minnow make this species a sensitive and selective feeder, searching by touch and taste rather than sight. Lack of extraneous debris in the analyzed stomachs demonstrated that ability. Such a strategy may enable suckermouth minnow to easily inhabit turbid water (Haas 1977).

**Species associations** - Species often associated with suckermouth minnow tend to be relatively small, headwater and riffle fish including other minnows, darters, and larger YOY suckermouth minnow (Haas 1977). Nesler et al. (1997 and 1999) used cluster analysis techniques to form species associations. In both the South Platte River and Arkansas River inventories, suckermouth minnow fell into the “Big river habitat/silt tolerant species” category, along with *Cyprinella lutrensis*, *Notropis stramineus*, *Pimephales promelas*, *Hybognathus placitus*, *Dorosoma cepedianum*, *Ictalurus punctatus*, *Cyprinus carpio*, and *Pomoxis nigromaculatus*.

## Study Area

Both the South Platte (SP) River Basin and the Arkansas River (AR) Basin in Colorado originate just east of the Continental Divide and extend to the state’s eastern border. The South Platte River Basin encompasses nearly 60,000 km<sup>2</sup> and ranges in elevation from 4,350 m to 1,035 m. The Arkansas River Basin drains approximately 65,870 km<sup>2</sup> and ranges from about 3,960 m to 1,005 m. Agriculture and livestock production constitute most of the land use in the eastern plains of both basins (USGS 2002). In 1985, agricultural use accounted for 80.2% of total water use in the South Platte Basin (Litke and Appel 1989). Morgan, Logan, and Sedgwick counties in the eastern plains alone supported approximately 122,600 ha of irrigated land (U.S. Bureau of the Census 1999). Irrigation water there was 51% surface water and 49% groundwater (Bash and Young 1994). Most surface water in both basins comes from the main stems, as permanently flowing tributaries, particularly in the South Platte system, are rare (Propst 1982, Nesler et al. 1997). In the Arkansas River Basin, approximately 95,900 ha of land were under irrigation in Otero, Bent, and Prowers counties (U.S. Bureau of the Census 1999).

Human-induced impacts to plains streams began as early as 1889, when Jordan (1891) noted that streams of Colorado were often left dry due to irrigation as western settlement increased. He observed that the South Platte River “becomes a shallow, muddy stream, with sandy bottom” (Jordan 1891). Ellis (1914) also noted human impacts on the fish fauna of Colorado, including “deflecting water for irrigation, leaving

the streams low or even dry in some seasons” and “allowing the fishes to run into unscreened ditches”. Li (1968) remarked that diversions changed the streambed of the South Platte River “from a wide, shallow river, braided with sandbars” to “narrow, deep and steeply banked” with heavy siltation, and that irrigation return water was the greatest source of nitrates in the basin. Agriculture, livestock production, and municipal effluent have contributed to elevated levels of dissolved solids, suspended sediment, and nutrient contamination in the Arkansas River (Smith et al. 1996).

The main study areas were the lower reaches of the South Platte and Arkansas rivers and their tributaries in Colorado. Most sampling localities in the lower South Platte River were from Fort Morgan to Julesburg and in Lodgepole Creek; however, a few sample sites were in lower St. Vrain Creek and Cache la Poudre River basins. In the Arkansas River, our study area extended from upstream near Rocky Ford, Colorado, downstream to Cheyenne Creek, near the Kansas border, and included the mainstem and several tributaries. Other aspects of the physical habitat characteristics of these systems will be discussed in Results.

Hydrology of the South Platte and Arkansas rivers is highly variable, but historically was dominated by snowmelt runoff from high elevation headwater areas. Flows typically peak in May or June and recede to base flow level in late summer or autumn (Fig. 1). In drought years such as 2001 and 2002, peak flows were low or not evident and base flows were very low. Summer thunderstorms sometimes cause short-term flow fluctuations or flooding. Flow of the South Platte River is affected by storage reservoirs, but most are upstream or in off-channel areas. Numerous diversion dams exist throughout the main stem South Platte River in the study area; water is diverted for irrigation or storage. In the Arkansas River, historical peak flows in May, June, and August were common. At present, hydrology of the lower main stem Arkansas River is controlled almost completely by John Martin Reservoir, which began storing water in 1943. Flows downstream are predicated mostly on irrigation water delivery, which is highest from April through October. Flows during the remainder of the year are very low, particularly in the drought years of 2001-2002.

## Methods

### Historical & current distribution

To compile historical species accounts and distribution data, we searched literature and museum databases (Appendix I). Museums with fish holdings were located via internet searches, literature references, and personal communications. We queried on-line museum databases or contacted curators to locate Colorado holdings. Records were downloaded or sent from museums electronically or, occasionally, we obtained copies of original field datasheets and museum catalog records. We compiled all records into a single spreadsheet and followed the standardized list of acronyms for museum names compiled by Leviton et al. (1985). Suckermouth minnow collection records were extracted using a search with several scientific names including *Exoglossum mirabile*, *Phenacobius mirabilis*, *Phenacobius scopifer*, *Phenacobius teretulus liosternus*, *Sarcidium scopiferum*.

To describe current distribution of suckermouth minnow, we sampled historical and new sites from June 2001 to October 2002. Historical and more recent sample sites where suckermouth minnow were thought to occur were sampled as close to the original locations as possible. New sites were chosen to fill spatial gaps in sample site coverage but often depended on flow levels and landowner access. Charlie Bennett (CDOW Aquatic Biologist in Lamar) and Jay Stafford (CDOW Aquatic Biologist in Sterling) assisted with sample site selection and timing of sampling. Sites included mainstem rivers, water diversion canals, and tributaries. We also sampled several locations multiple times to gain an understanding of shifts in species abundance and habitat use through time.

Sampling localities for suckermouth minnow in the lower South Platte River from upstream of Sterling, Colorado downstream to the Colorado border were mapped in four time periods, 1967-1968, 1978-1980, 1993-1998, and 2001-2002, to show shifts in distribution. Those time periods were chosen because they represented discrete studies conducted over relatively short time periods (Li 1968, Propst 1982, Nesler et al. 1997, this study, 2001-2002) and several sites were sampled within the reach during each time so distribution patterns were illuminated. It should be noted that sampling localities for

all but our own 2001-2002 records were digitized from maps and are shown only for effect; exact sample site localities are mostly poorly known.

### **Fish sampling procedure**

Most sampling at sites followed a standard one-pass sampling procedure conducted with 4.5 m x 1.8 m seines (4.76 mm-mesh size). Numbers of seine hauls varied among sites, and was positively related to site length and habitat complexity. Habitat heterogeneity and presence of physical barriers also played a role in determining site length. We attempted to sample all meso-scale habitat types at a location including riffles, pools, runs, and backwaters. Seine hauls were generally up- to downstream, except where riffles were kick-seined. When habitat data were collected, survey flags marked the margins of each seine haul. Fish processing occurred after each seine haul. We counted and measured suckermouth minnows, plains minnows, brassy minnows, and any other species of special interest, and noted presence of and estimated abundance of other fishes captured. A few voucher specimens were retained to ensure identity of potentially problematic species. Fin clips of suckermouth minnows were taken for genetic analysis at several sites, and live specimens were captured at two sites and transported back to the Larval Fish Laboratory for reproductive experiments (see **“Reproduction & culture”** below). Otherwise, all fish were released downstream of the seine haul location.

### **Efficiency tests**

We conducted tests of sampling efficiency to assess if our standard one-pass seine sampling technique was adequate to detect presence of suckermouth minnows and other species at sample sites. We sampled each of eight sites with the single standard sampling pass using eight to 15 seine hauls, and followed that effort with two more passes of seining, and on all but the main stem Arkansas River site, one pass with a backpack electrofisher. Sample sites were chosen to represent the range of stream sizes and habitat complexity in which we expected suckermouth minnows to occur. Seine haul number and intensity was equal across all sampling passes and similar on the first pass to that employed during standard sampling.

We sampled all habitat types thoroughly with as many hauls as necessary. We included hard-to-seine areas such as submerged vegetation, riprap, and in-stream obstructions in our sampling regimen. We sampled around larger substrate by agitating the surrounding water or disturbing structure as we seined. Deeper, fast-moving riffles were sampled by stretching the seine across the downstream end and thoroughly kicking through the substrate (kick-seining) as we walked toward the seine. After one sampling pass, fish were identified, counted, weighed en masse, and held in live baskets. When number of fish captured was very large, we weighed the entire sample and identified the fishes in a weighed subsample (about  $\frac{1}{2}$  or more of the total sample), so that we could estimate total number of fish captured. For passes 2 and 3, all species were listed, total weight of each sample was recorded, and fish were held in live baskets. Suckermouth minnows were counted, measured, and weighed for all seine haul sets. The fourth electrofishing pass was then conducted and used primarily to sample areas not easily accessible to the seine, such as submerged brush piles and large riprap. The electrofishing sample was scanned for species composition and individuals of new taxa were counted.

### **Habitat sampling procedure**

We collected habitat information at most sites so that we could compare habitat attributes of sites with suckermouth minnows present and absent. Some sites where suckermouth minnows regularly occurred were sampled more than once to obtain seasonal habitat use information, or to simply obtain more capture localities where the species was rare and we had few data (e.g. South Platte River). We did not discriminate between sites sampled multiple times and those sampled only once because flow changes and habitat availability likely shift among occasions. For site-level measurements, five to seven transects were evenly spaced along and perpendicular to the length of the site. We measured wetted and bank-full widths of the river at each transect. At five equidistant points along each transect we measured depth and noted the ratio of the three dominant substrate types. We used a modified Wentworth scale to estimate proportions of substrate in categories: silt (0.0-0.1 mm), sand (0.2-1.9 mm), gravel 1 (G1, 2-10 mm),

gravel 2 (G2, 11-20 mm), gravel 3 (G3, 21-30 mm), gravel 4 (G4, 31-40 mm), gravel 5 (G5, 41-50 mm), gravel 6 (G6, 51-64 mm), and cobble or larger (CB, >64 mm).

Additional data collected at each site included: water chemistry (pH, DO, temperature, conductivity, salinity) measured with a YSI 85 instrument, adjacent land use (crops, natural, quarry, range/pasture, state trust land, water treatment plant, state wildlife area), and presence and type of in-stream structures (algae, woody debris, logs, overhanging vegetation, undercut banks, bridge abutments, diversion structures, other cover).

We also measured meso-scale habitat information for seine hauls at designated stream sites. Seine hauls were typically short and restricted to a single meso-habitat type, so that we could better describe habitat used by suckermouth minnow. Data collected for each seine haul included: meso-habitat type (riffle, run, pool, backwater, eddy); distance from the center point of the seine haul to closest bank, presence of vegetation or other structure; depth; velocity; and substrate types. Area swept by each seine haul was divided by transects perpendicular to each other, forming cross hairs. At points (N = 5 or 9, depending on seine haul length and number of transects) along these lines, we measured depth, velocity (using a Marsh-McBirney flowmeter), and estimated proportions of the three dominant substrate types. These data allowed us to characterize habitat used by suckermouth minnows at a relatively fine scale and compare that to attributes of areas seined that did not contain suckermouth minnow.

### **Reproduction & culture**

Suckermouth minnows were collected for laboratory reproduction experiments on two separate occasions, 21 June 2001 and 24 May 2002. We transported suckermouth minnows in a cooler filled with aerated river water (15-17°C) to the Colorado State University Aquatic Research Laboratory. In order to understand more about the reproductive ecology of suckermouth minnow, we attempted to induce spawning in the laboratory in three separate trials. On 22 June 2001, suckermouth minnows (N=31) collected from the mainstem Arkansas River were separated by sex based on degree of tuberculation, plumpness, and pectoral and pelvic fin size and shape (Becker 1983). Both sexes were allowed to acclimate for a few days to several experimental temperatures in

aquaria with a variety of substrates. We then injected some fish of each sex with a regimen of chorionic gonadotropin (HCG) (pers. comm., R. Hamman, Dexter National Fish Hatchery and Technology Center). Males received one injection of 0.661 IU/g in the abdominal cavity on day 1. Females received three injections in their dorsal musculature: one dose of 0.220 IU/g on three successive days. Fish were returned to their respective tanks after injections and observed over a period of several days.

We collected a second group of suckermouth minnows (N=28) in reproductive condition from the Purgatoire River on 23 May 2002. Males (N=16) exhibited strong tuberculation on their heads and pectoral fin rays, and gametes were easily expressed. Females (N=12) were plump, less tuberculate, and expressed ovipositors with slight pressure but did not release eggs. On 24 May 2002, males were injected with HCG as described above, and females were injected once with 0.0044 mg/g of carp pituitary. We held each sex in separate aquaria overnight. Groups of males (N = 3 to 4 per group) and females (N = 2 to 3 per group) were then placed together in three separate tanks, after acclimation for one hour, that had water temperatures of 17, 19, and 23°C. Each tank had a water current generated by an underwater pump, a variety of substrate ranging from sand to cobble, a spawning mop and frame, and a vertical bubble stream created by a large air stone placed at one end of the aquarium. Observations of activity were recorded and presumptive spawning behavior was captured with a video camera.

We also attempted to artificially propagate embryos from those injected adults. Four females and five males not placed in spawning tanks were stripped of gametes to produce embryos for incubation. Eggs were dry-stripped into a petri dish and fertilized with sperm from one or more males. A few milliliters of water were added, and the eggs were gently stirred. After water hardening (about 1 hour), embryos were acclimated over a period of about two hours to each of three test temperatures (17, 19, and 23°C) and placed in fine-mesh chambers in the three adult holding tanks. From observations and inspections of embryos and larvae, we noted development, growth, and behavior, and also preserved a developmental series. The most complete series resulted from eggs hatched at 17°C and reared between 17 and 19°C. For the first 24 days, five specimens were preserved daily. We preserved larvae every third day for the next two months. Finally, we preserved specimens each week for the next three weeks. Due to lower hatch

success and fewer specimens, fish from the 23°C tank were preserved less frequently: three to four specimens every three days to begin, then once per week for the next three months. Embryos incubated at 19°C had low hatch success and most larvae died one day post-hatch, so the few remaining fish were preserved by day 11. We measured lengths (mm SL or TL) of all preserved specimens. Larvae were initially fed a combination of soaked, crushed flake and reconstituted freeze-dried micro-crustaceans and later switched to a dry flake and live *Artemia sp.* diet.

From 31 May to 1 June 2002, we conducted a third spawning trial with the same group of suckermouth minnow adults. Four small groups of two to three females and three to four males were injected with the same regimen of hormones as in the second trial and placed in 21°C and 23°C aquaria. None of the fish appeared as ripe as in the previous trial, and very few exhibited any spawning behavior. We videotaped and observed each group for 20 minutes.

After all spawning trials were complete and preservation of the developmental series ceased in autumn 2002, we combined adult and larval suckermouth minnows into one large aquarium. Photoperiod was maintained at a 14.5:9.5 hr light/dark cycle and temperature averaged 17°C. All fish were fed a prepared flake-food diet.

### **Factors affecting suckermouth minnow presence**

We were interested in understanding if suckermouth minnow presence was affected by physical habitat variables at the stream-site and seine-haul spatial scales. To accomplish the stream site analysis, presence/absence of suckermouth minnows was treated as a binary response in a logistic regression model that predicted the probability of presence of suckermouth minnow as a function of a suite of explanatory variables (Table 1). This analysis assumed that we could sample suckermouth minnows effectively enough to detect their presence when they existed at a site, an assumption borne out in seine sampling efficiency tests. Akaike's Information Criterion (AIC) was used to arrive at a reduced model with a useful subset of explanatory variables (Burnham and Anderson 1998). Those model results were useful to understand a broad view of factors that influenced suckermouth minnow presence at sites across the South Platte and Arkansas River basins, Colorado. The logistic regression models used are based on maximum

likelihood estimation procedures (MLE), which are iteratively fitted by the computer software until a best approximating model is found (model convergence is the result). If the MLE model fit is not achieved for some reason, such as not having data observations in all cells of the model that was specified for fitting, estimating models do not converge and no parameter estimates are produced. Then, one or more explanatory variables must be deleted and the analysis attempted again.

We were also interested in understanding what suite of physical habitat variables influenced presence of suckermouth minnows at the spatial scale of a seine haul. Main stem or tributary sites chosen for seine-haul scale data collection were required to be within the present known geographic range of suckermouth minnows in Colorado (e.g., lower South Platte River, lower Arkansas River, and selected tributaries). Although suckermouth minnows were not always found at some South Platte River Basin sites during habitat sampling efforts, only data from sites known to support the species at least once during this study were retained for this analysis.

At the seine haul spatial scale, a logistic regression model was built that predicted presence of suckermouth minnows as a function of explanatory variables (Table 1). Those variables described characteristics of the habitat within the seine haul area swept (e.g., meso-habitat type, depth, velocity, substrate type or percent composition), or aspects of the habitat surrounding the seine haul (e.g., distance to or type of adjacent cover). We thought presence and abundance might also be affected by time of year or geographic location. Therefore, we included season and river basin (South Platte or Arkansas) as explanatory variables. We defined seasons mostly based on our observations of shifts in water temperatures: spring was mid-March through May, summer was June through August, autumn was September through November, and winter was December through mid-March. These model results would be useful to understand if small-scale habitat variables affected presence of suckermouth minnows, which when combined with the site-scale analysis results, might be useful to identify sites where suckermouth minnow conservation activities might be most successful.

## Results

### **Historical distribution and abundance**

Our literature search and the 53 museum contacts made revealed a total of 1897 Colorado fish museum records, only eight of which were suckermouth minnow (Appendix I). One record came from a collection by Hendricks (1950), housed at the California Academy of Science (CAS), two records were collected by Ellis (1914) and housed at University of Colorado Museum, and the remainder was housed at University of Michigan Museum of Zoology (UMMZ). Additional collection records reported here were found in literature sources, but have no museum associations.

***South Platte River Basin*** - Most early accounts of fish sampling in Colorado originate in the South Platte River Basin, but records of suckermouth minnows were relatively uncommon (Fig. 2). Juday and Spangler conducted their work in the Boulder County area and reported three suckermouth minnows captured in St. Vrain Creek near Longmont in 1903 (Ellis 1914). Smith collected suckermouth minnows from the South Platte River at Julesburg (Cockerell 1911). In 1912, Ellis found 16 suckermouth minnows in Lodgepole Creek, near Ovid, and eight in Boulder Creek, just east of Boulder (Ellis 1914, UCM 348 and 349, respectively). Lots with no named collector included: South Platte River at Julesburg, 1912, and Rock Creek at Erie, 1913 (UMMZ 66135 and 66160, respectively). Little additional ichthyological sampling occurred in the state until 1950 when Hendricks surveyed fishes of Boulder County (Hendricks 1950). He collected one suckermouth minnow specimen (CAS 68232) from St. Vrain Creek in Longmont. Following Hendricks (1950), Li (1968) sampled many localities throughout foothills and plains reaches of the South Platte River Basin and found only four suckermouth minnows at two South Platte River sites, one near Julesburg and one south of Ovid (Fig. 3). Li declared suckermouth minnow rare in 1968. Propst (1982) conducted a more thorough survey of warmwater fishes of the River Basin. He recorded suckermouth minnows at every one of the 13 sites he sampled between Merino and Julesburg (all in 1980, Fig. 3). Average number of specimens collected in his sampling was 43 with as many as 331 at a site near Julesburg. However, he classified the species

as uncommon due to the relatively low number of fish captured and their restricted distribution in the basin. A South Platte River inventory conducted by the CDOW from 1992 to 1994, which included many sites in the area that Propst (1982) sampled, plus additional sampling after completion of that study, detected only five suckermouth minnows in two samples from Lodgepole Creek (Nesler et al. 1997) and none in the South Platte River proper (Fig. 3).

***Republican and Arkansas River Basins*** - Few historical sources refer to fish sampling in the Republican or Arkansas River basins. In 1915, Cockerell found four suckermouth minnows in Black Wolf Creek, a tributary of the Arikaree River (UMMZ 66117). Cancalosi (1980) captured only two suckermouth minnows in the Arikaree River near Black Wolf Creek during his relatively comprehensive inventory of the basin. None were found in the Arikaree River from 2000-2001 during intensive sampling, which included reaches up and downstream from Black Wolf Creek (Scheurer 2002).

In the Arkansas River Basin, Hubbs and Schultz found 36 suckermouth minnows in an unnamed Arkansas River tributary and one in Clay Creek (UMMZ 94924 and 94935) in 1926, both near Lamar, Colorado and downstream of present-day John Martin Reservoir. Little other sampling occurred there until a basinwide survey of the Arkansas River, Colorado, by Loeffler et al. (1982), who found 680 suckermouth minnows, all in the mainstem Arkansas River downstream of John Martin Reservoir and tributary Clay Creek (Fig. 4). An Arkansas River Basin fish inventory conducted by the CDOW from 1993-1996 found 80 suckermouth minnows, all downstream of John Martin Reservoir (Nesler et al. 1999). They also had additional suckermouth minnow capture sites in Big Sandy Creek (N = 2) and at two sites upstream of John Martin Reservoir (one west of Rocky Ford Diversion dam and one below the Fort Lyon Irrigation Company diversion dam), all in 1998. Suckermouth minnow (N = 34) were also collected from six unidentified sample sites (11 total sites sampled) between John Martin Reservoir and the Kansas state line in 1999. No suckermouth minnows have been found in Clay Creek in recent years (pers. comm., C. Bennett, CDOW).

### **Current distribution and abundance**

***South Platte River Basin*** – In the South Platte River Basin, we sampled 23 unique sites between Fort Collins and Julesburg; 20 sites were downstream of Fort Morgan. Streams sampled included the mainstem South Platte River (16 sites), Lodgepole Creek (3 sites), diversion canals (2 sites), Spring Creek, and lower St. Vrain Creek (Table 2, Fig. 3). Most sites (N=17) were sampled two to five times during summer and autumn of 2001 and 2002. Site lengths ranged from 60 to 462 m (average = 182 m). Numbers of seine hauls per site ranged from six to 17. Lengths of seine hauls ranged from 2.0 to 23.2 m (average = 8.5 m).

A total of 444 suckermouth minnows (N = 1 to 148 per sample) was captured at nine of the 23 sample sites. Number per seine haul ranged from one to 73. Distribution of suckermouth minnows in the South Platte River was from upstream of Sterling at Dune Ridge State Wildlife Area downstream to the Colorado-Nebraska border near Julesburg. We found suckermouth minnows at two sites in Lodgepole Creek (only a single site is shown on the map, and one for the South Platte River just downstream). Suckermouth minnows were generally uncommon at sites except at Liddle Ditch diversion.

Presence and abundance of suckermouth minnow at individual South Platte River sites shifted through time. Of the nine sites where suckermouth minnows were found, we sampled seven of those two to five times. At six of those seven sites that were sampled multiple times, we recorded no suckermouth minnows on one or more occasion. Only at the South Platte River site below Liddle Ditch were suckermouth minnows captured on all sampling occasions (N = 5). Middle Lodgepole Creek and South Platte River sites below Liddle and Peterson ditch diversions seemed to support the most reliable and abundant suckermouth minnow populations. Abundance at those varied widely and over a short time frame. The large population at Liddle Ditch diversion in August 2001 was much reduced in October of the same year after the diversion gate was opened. A site visit to middle Lodgepole Creek showed it dry in June 2002. During August 2002 sampling after flow was restored, we detected 19 suckermouth minnows in middle Lodgepole Creek, including YOY as small as 22 mm TL.

**Arkansas River Basin** - In the Arkansas River Basin, we sampled 20 unique sites between Rocky Ford and the state line. Streams sampled include the mainstem Arkansas River (13 sites), Big Sandy Creek (2 sites), Purgatoire River (2 sites), Cheyenne Creek, Timpas Creek, and an irrigation return (Fig. 4, Table 3). Of the 20 sites, nine were sampled from two to five times from summer 2001 through autumn 2002. Site lengths ranged from 109 to 375 m (average = 201 m). Number of seine hauls per site ranged from six to 25. Lengths of seine hauls ranged from 1.6 to 22.4 m (average = 8.6 m).

A total of 613 suckermouth minnows ( $N = 1$  to 132) was captured at 11 of the 20 sample sites; number per seine haul ranged from one to 86. Those sites included eight on the main stem Arkansas River, one site each on Big Sandy and Cheyenne creeks, and one in the lower Purgatoire River. Suckermouth minnows were not detected at the first two sites downstream of John Martin Dam, but were found at every other main stem site downstream of there except one (AR-23).

Presence and abundance of suckermouth minnow at individual Arkansas River Basin sites shifted through time, but not as much as in the South Platte River. Of the eleven sites where suckermouth minnows were found, we sampled nine of those two to five times. At two of those nine sites that were sampled multiple times, we recorded no suckermouth minnows on one occasion each. Abundance at most sites varied through time, particularly at the Arkansas River east of Granada (AR-02), and lower Big Sandy Creek. In that tributary, 49 suckermouth minnows were captured in November 2001 and none were captured in May 2002.

### **Efficiency sampling**

Seine sampling efficiency tests were conducted at eight sites ranging from the relatively small tributaries Spring Creek, Lodgepole Creek, and Cheyenne Creek (one site each), intermediate-sized St. Vrain Creek ( $N = 1$  site), up to larger sites on the main stem South Platte ( $N = 3$  sites) and Arkansas ( $N = 1$  site) rivers. Total number of species captured at sites ranged from 10 to 21. Sub-sampling occurred at four of eight sights due to the large number of fish captured; an average of 47.3% (39.1 to 53%) of the total sample was identified at those sites. An estimated total of 28,374 fish were captured on the first sampling passes of those eight efficiency tests (mean = 3,547, range 304 to

7,502). Fish were examined on subsequent passes to note the occurrence and number of species not detected on previous passes, but were not weighed or counted.

At the four sites where suckermouth minnows were detected, they were captured on all seine-sampling passes including the first. On average, only one species (0 to 3, median = 1) was added to the first pass total with two subsequent seine-sampling passes of equal effort (Fig. 5). Comparison of first pass data to that collected with two additional seine passes and one electrofishing pass (four total except only three at the main stem Arkansas River site) suggested that on average, two species were not detected on the first pass that were eventually detected on all passes (range one to three species, median 1). Species missed included centrarchids (six occasions, five species, average of one individual), cyprinids (three occasions, three species, average of one individual), channel catfish (one occasion, one individual), yellow perch (one occasion, two individuals), white sucker (one occasion, one individual), brook stickleback (one occasion, one individual), and freshwater drum (one occasion, one individual). On average, only a single specimen of each rare species missed during first-pass sampling was captured in subsequent passes.

#### **Habitat associations: site level differences**

The lower main stems of the South Platte and Arkansas rivers exhibited differences in stream geomorphology that may have influenced presence of suckermouth minnows. At sites with and without suckermouth minnows, the South Platte was wider, and had a much more braided, shifting channel, which was reflected in the wider bank-full and wetted channel widths than the Arkansas River (Table 4). The channel of the Arkansas River was generally single-thread and more confined, perhaps because of dense riparian tamarisk. Narrower Arkansas River channel widths were also due, in part, to inclusion of more tributaries in width calculations ( $N = 3$ ) than in the South Platte River ( $N = 1$ ). The South Platte River generally had more silt, sand, and G1 gravel substrate, both in terms of presence of individual particles sizes and their percent composition, than the Arkansas River, and less larger gravel. Presence of diversions near sampling sites, was much higher in the South Platte River due to intentional placement of a few such sampling sites. Presence of bridges at sampling sites was higher in the Arkansas River.

This was due more to accessibility at those sites; habitat was likely unaffected by presence of bridges because we usually sampled upstream from them. Conductivity and salinity were higher in the Arkansas River than in the South Platte River. Mean and maximum depths were not different between the two rivers.

Most (88%) sites where suckermouth minnows were captured in the South Platte River Basin had adjacent land use that was largely undisturbed (State Wildlife Area [SWA] land or other relatively undisturbed areas). Land use at one other site was a combination of crops on one bank and a water treatment plant on the other. Adjacent land use at the 14 sites where suckermouth minnows were absent also included SWA land (50% of sites). The preponderance of sites on SWA's (11 of 23 total sites) in the basin was due to accessibility issues. Other land uses at sites without suckermouth minnows included: State Trust land or other natural land (29%) and crops, range/pasture, or city (21%).

Land use at a majority of sites (55%) in the Arkansas River Basin with suckermouth minnow present was classified as largely undisturbed. Other uses included: crops or range/pasture (36% of sites) and quarry (9%). Adjacent land uses at sites without suckermouth minnows included: SWA or other natural land (78% of sites) and range/pasture (22%).

Within the South Platte and Arkansas River basins, differences existed between sites occupied by suckermouth minnows and those that were not, but differences varied by basin (Table 5). In the South Platte River, sites occupied by suckermouth minnows tended to be those that were not close to bridges and had a slightly higher proportion of gravel substrate and less silt. Occupied sites had deeper mean and maximum water depths, which was likely a result of presence of diversion dams at many sites.

In the Arkansas River Basin, sites occupied by suckermouth minnows tended to be closer to bridges than those that were not, but that was likely due to site access characteristics. Occupied sites were never adjacent to diversions and mean and maximum depths were similar among occupied sites and those that were not. Bank-full width was wider and undercut banks more prevalent at occupied sites, attributes that may indicate presence of higher lateral stream movement and erosion and more channel

complexity. Occupied sites also tended to have less silt and sand, more gravel size-classes, and a higher proportion of gravel.

Water chemistry at South Platte River sampling sites was widely variable depending on stream size, season, and time of day but varied little between sites where suckermouth minnows were present or absent. Water at sites where suckermouth minnows were present and absent had an average pH of 8.6. Dissolved oxygen levels at sites with suckermouth minnows ranged from 6.15 to 10.70 mg/l over all sampling seasons. Levels at sites without suckermouth minnow captures ranged from 6.36 to 15.77 mg/l. We captured suckermouth minnows over several seasons at temperatures ranging from 9.8 to 32.4°C. Conductivity at sites with suckermouth minnows ranged from 1,399 to 2,352  $\mu$ S. Other variables also varied little between sites occupied by suckermouth minnows and those where they were not found.

Water chemistry differences of Arkansas River sites with and without suckermouth minnows were minimal. Average pH was 8.5 at sites with and without suckermouth minnows. Dissolved oxygen levels at sites with suckermouth minnows ranged from 5.25 to 12.10 mg/l over all sampling seasons, and 6.54 to 9.40 mg/l at sites without suckermouth minnow. We captured suckermouth minnows over several seasons when water temperature ranged from 8.4 to 29.0°C. Conductivity at sites with suckermouth minnows ranged from 2,703 to 5,220  $\mu$ S. Sometimes large differences in water chemistry attributes among South Platte and Arkansas River basin sites were not included in logistic regression analysis because widely varying values (e.g., conductivity, salinity) acted like basin descriptors rather than factors that might affect presence of suckermouth minnows.

Comparison of sites occupied by suckermouth minnows in the South Platte and Arkansas River basins (Table 5) suggested that South Platte sites were wider, were adjacent to diversion dams, and had lower presence and percent gravel, particularly the larger sizes classes. In contrast, Arkansas River Basin occupied sites had a narrower channel, were never associated with a diversion dam, and had presence and percent of gravel, particularly for larger sizes classes.

Descriptive differences in physical attributes of sites among basins were mostly directly or indirectly borne out by logistic regression analysis. Model results suggested

the most important factor associated with presence of suckermouth minnows was the basin in which the site was located (Table 6). The large coefficient for the Arkansas River Basin was the result of suckermouth minnow presence in 73% of sampling occasions (29 of 40), compared to only 38% (17 of 45 occasions) in the South Platte River Basin. Maximum depth at sites was also positively related to presence of suckermouth minnow. Inspection of the data suggested that the significance of this variable was due mostly to the influence of South Platte River sites, where suckermouth minnows were commonly found in deep water downstream of diversion dams. Finally, percent of G1 gravel (up to 10 mm width) was also positively related to presence of suckermouth minnows at all sites. Higher presence of gravel likely suggested that a lower proportion of sand, the predominant substrate type at all sites, existed at those sites.

#### **Habitat associations: seine sample level comparisons**

We compared physical habitat use at the seine haul level across each basin to understand if areas that supported suckermouth minnows had different attributes than those that did not. Suckermouth minnows occupied a variety of meso-scale habitat types including riffles, runs, pools, eddies, and backwaters, and use of such varied by river basin and season (Table 7). In the South Platte River Basin, we captured suckermouth minnows at 18 unique capture points (seine hauls). Suckermouth minnows were found predominantly in runs and pools, less often in eddies, and never in riffles or backwaters during sampling conducted when habitat measurements were collected. All the pools and eddies and eight of eleven runs were located immediately downstream of diversion dams. Comparison of the percentage of times suckermouth minnows occurred in those habitat types with the total percent occurrence of those habitat types in samples suggested avoidance of riffles, and slight selection for runs and pools, and no difference in use and availability of eddies and backwaters given the small sample of those available.

In the Arkansas River Basin, we captured suckermouth minnows at 63 capture points (unique seine hauls). Suckermouth minnows were captured mostly in runs, riffles, and pools about an equal percentage of the time (25 to 36%), and less often in eddies and backwaters. Comparison of the percentage of times suckermouth minnows occurred in those habitat types with the total percent occurrence of those habitat types in samples

suggested slight selection for riffles and pools, slight avoidance of runs, and no difference in use and availability of eddies and backwaters given the small sample of those available.

Habitat characteristics of seine hauls with and without suckermouth minnows differed in several ways and those characteristics differed between South Platte and Arkansas River basins (Table 8). South Platte River seine samples with suckermouth minnows present had deeper maximum depths, lower mean and maximum velocity, and less percent silt and more sand than sites where suckermouth minnows were absent. High occurrence of silt at South Platte River sites where suckermouth minnows were present was likely because of the pools they occupied were depositional environments. Arkansas River seine samples with suckermouth minnows had less sand, more gravel in all size classes except G1, both for percent occurrence and percent composition.

Habitat use was little different among seasons, although comparisons were limited by the few data available in spring and winter in the Arkansas River and absence of data for those seasons in the South Platte River (Table 9). Mean depth increased and velocity declined in South Platte River habitat from summer to autumn, likely because of declining stream flow and restriction of available habitat to pools and deep runs. Patterns were opposite that in the Arkansas River, where water velocities increased in the same time periods. The only dramatic shift in habitat use noted was in winter in the Arkansas River. Samples collected in the usual productive riffles and runs produced no suckermouth minnows. The two seine hauls where suckermouth minnows were captured were from backwaters that had near zero current velocity and silt substrate.

We captured few early life stages of suckermouth minnows < 30 mm TL and thus, have limited observational data regarding their habitat use. Most were from relatively deep, low-velocity pools or backwaters with silt or sand substrate. A few captured from Lodgepole Creek in summer 2002 were from a slow-moving channelized pool with sand substrate.

The descriptive differences in physical attributes of seine sample localities among basins were partially borne out by the logistic regression analysis. Model results suggested the most important factors associated with presence of suckermouth minnows in seine hauls were percent of sand, basin where sampling occurred, and season of

collection (Table 10). Those variables reflected differences in basin-scale attributes, the higher abundance of suckermouth minnows in the Arkansas River, and their generally higher presence in summer samples relative to other seasons, especially winter. The Basin main effect was also present nested with other variables (e.g., percent sand, maximum velocity at sites). Nesting Basin with other explanatory variables exposed differences between the Arkansas and South Platte River basins for a particular attribute, which otherwise would have been obscured within a single estimate.

After accounting for basin and season covariates, logistic regression analysis showed that percent sand and maximum velocity at the seine haul location varied among basins. The positive coefficient for sand and the negative one for maximum velocity in the South Platte River suggested that seine hauls with suckermouth minnows tended to be over mostly sand substrate, the dominant type in the Platte, and in low velocity areas. This is congruent with finding suckermouth minnows in a higher percentage of pools (not riffles), and downstream of diversions, areas where one would expect lower velocities. In the Arkansas River, seine hauls with suckermouth minnows tended to be in areas with less sand (more gravel) and where water velocity was faster. That finding was congruent with occurrence of more suckermouth minnows in riffles and runs in the Arkansas River.

Mean length of seine haul, maximum depth within the seine haul area, and percent of G2-sized gravel were positively associated with presence of suckermouth minnows in seine hauls in both the South Platte and Arkansas River basins. Seine haul length simply reflected a higher occurrence of suckermouth minnow captures if a greater area was swept. The positive coefficient for maximum depth reflected greater occurrence in slightly deeper areas, whether they were pools or runs in the South Platte River or runs and riffles in the Arkansas River. The small positive effect for higher percent of gravel (G2) at occupied sites suggested that, even though sand may be a dominant substrate size class in these plains streams, small amounts of gravel were generally found at seine haul sites occupied by suckermouth minnows. Such substrate was common in the Arkansas River but was rare in the South Platte, occurring only below diversion dams in the scour pool or as isolated small patches in other areas. The importance of even small isolated gravel patches was illustrated in the South Platte River near Julesburg, CO. The eight

suckermouth minnows captured there were all found over a single 1 x 2 m patch of algae-covered gravel, at a site that had an otherwise completely sand substrate.

Other explanatory variables did not enhance model fit or caused non-convergence in the logistic regression model. One example was the class variable for meso-scale habitat type. Despite the large differences in meso-habitats occupied by suckermouth minnows in the South Platte and Arkansas rivers (described above), habitat type was not included in the model because the limited South Platte River presence data (N = 18) did not contain at least one observation for each habitat type. When habitat type was fit using only the Arkansas River data, the model converged statistically but it was not a significant effect.

## **Reproduction & culture**

**Laboratory observations** - The first attempt to spawn suckermouth minnows collected from the mainstem Arkansas River in June 2001 was unsuccessful. We did not detect spawning behavior or other tangible signs of spawning activity.

The second spawning trial, using fish collected from the Purgatoire River on May 2002, was more successful. Spawning activity was detected in the 17°C tank within 15 minutes of combining males and females. In the 19 and 23°C tanks, spawning behavior was documented within two hours. Observed spawning activity consisted of fish chasing each other and swimming rapidly in circles within 5 cm from the substrate, males nudging females near the vent, and fish positioning themselves side-by-side over substrate before releasing gametes.

To verify spawning, we searched the substrate in each tank shortly after observing presumptive spawning behavior. One viable embryo was found attached to a gravel particle in the 17°C tank. In the 19 and 23°C tanks, a very few groups of one to three embryos per stone were found. In the 19°C tank, stones with eggs attached measured 0.5 x 0.5 cm, 1.0 x 1.0 cm, and 1.0 x 1.5 cm. Stones with eggs in the 23°C tank measured 1.0 x 2.0 cm, 3.0 x 3.5 cm, and 3.5 x 5.0 cm. Individuals were observed burrowing vertically into the substrate immediately after presumptive spawning acts, remaining that way for several seconds while actively probing interstitial spaces. Although not observed, we assumed that those fish were consuming newly deposited embryos attached

to stones. We searched the substrate again in all tanks 24 hours after observed spawning. No embryos were found in the 17°C tank. In the 19°C tank, eight pieces of 1.0 x 1.0 cm gravel had embryos attached. Seven had one embryo each, and one had four embryos. All pieces with attached embryos came from underneath the spawning mop frame. Out of all the gravel chips and more than 100 stones searched in the 23°C tank, four stones had embryos attached. Three had one embryo each, and one had five. The group of five embryos was left exposed and was missing 24 hours later. We did not observe spawning behavior or embryos over sand substrate, which suggested selection of gravel or larger particles for spawning sites.

The third spawning trial occurred about one week after the second. Fish were combined in the tanks after injections, but only limited spawning activity was observed. Most fish interactions were observed within the first 15 minutes after combining the sexes. Three fish in the 23°C hovered around and above a fourth, but it was not clear if gametes were ever released. The fish separated and began feeding in all substrate types soon after. We searched the substrate 20 minutes after combining the sexes, but no embryos were found. Fish in the 21°C tank did not exhibit any spawning behavior. The group of five fish were stacked up in one corner, and reacted only to the current. We searched the substrate after 5 minutes and after 10 minutes, but found no embryos.

Development of embryos and larvae was described from those produced by stripping fish. At 1 hour post-fertilization, embryo diameter averaged 1.63 mm (1.55 to 1.70 mm). Embryos were adhesive to most surfaces, confirming observations in aquaria. A 4-cell blastodisc was evident at 4 hours post-fertilization. Only about 50% of embryos incubated at both 17 and 19°C remained viable after 24 hours. Approximately 75% of eggs incubated at 23°C were dead after 24 hours. That group was the most developed, having pigmented eyes and obvious notochords. At 48 to 52 hours post-fertilization, the 23°C embryos had beating hearts, visible myomeres and otoliths, and tails detached from yolks. The 23°C embryos began hatching approximately 3 days post-fertilization, the 17 and 19°C embryos a full day later at 4 days post-fertilization. After hatching, most of the 19°C larvae died within 2 days. The 23°C fish first ate crushed flake and reconstituted freeze-dried microcrustaceans 5 days post-hatch and *Artemia sp.* at 13 days post-hatch. Larvae reared at 17°C started first feeding at 8 days post-hatch.

Growth and development of larvae in the two temperature treatments diverged at about 10 d post-hatch (Fig. 6). Mean increase in length per day between measurement intervals was 2.7% for the 17°C larvae and 3.4% for the 23°C larvae for the 64 days post-hatch period (Appendix II). Expressed as growth/day after fish lengths diverged at 10 days post-hatch, fish in the 23°C treatment grew 0.54 mm/d, faster than fish in the 17°C treatment, which grew at 0.39 mm/d. Average length at day 64 post-hatch was 27.5 mm TL and 35.8 mm TL, for 17°C and 23°C treatments, respectively.

***Field observations on reproduction*** – We detected suckermouth minnows in reproductive condition (tuberculation, expression of milt or eggs, plumpness, visibility of ovipositor) in both drainages. In the South Platte River Basin, fish that were tuberculate or expressing gametes were found at two sites in early June 2002, downstream of Liddle Ditch and Peterson Ditch diversions. In the mainstem Arkansas River, tuberculation was noted in May, June, and late August, and in the Purgatoire River, in May 2002.

### **Size structure**

Size structure of suckermouth minnow populations appears dominated by one or two age-classes. Modes in length-frequency histograms (Fig. 7) show that age-0 fish in late summer or autumn are between 41-50 or 61-70 mm TL. Those same fish in the following spring are likely 61-80 mm TL. Larger age-1 fish in late summer or autumn appear to be 81-100 mm TL. Few adult suckermouth minnows exceeded 100 mm TL.

### **Fish community composition**

We detected a total of 31 and 22 fishes in samples collected in the South Platte and Arkansas River basins, respectively (Tables 11 and 12, appendices III and IV). In the South Platte River, we detected a total of nine species at more than 50% of sites, and on average, we detected 10 species per site sampled (3 to 21). The most common taxa found were sand shiner, fathead minnow, red and bigmouth shiners, and plains killifish, all occurring at 40 (89%) or more of 45 sites. In general, we found fish in the South Platte River extremely abundant, especially during low flows in summer and autumn, 2002.

In the Arkansas River, we detected a total of six species at more than 50% of sites and, on average we detected 8 species per site sampled (3 to 14). The most common taxa found were sand and red shiners, which occurred at 36 (90%) of 40 sites.

Other state-listed species captured in our South Platte River sampling included plains minnow (12 of 23 sites, 18 of 45 occasions) and brassy minnow (7 of 23 sites, 11 of 45 occasions). Plains minnow were widely distributed in the lower South Platte River study area, occurring at sites from upstream of Sterling at Dune Ridge State Wildlife Area downstream to the border. Plains minnow were extremely abundant at several sites, particularly just below the Liddle Ditch Diversion Dam in August 2002. During seine efficiency sampling conducted there, first pass efforts resulted in 304 plains minnow captured. We estimated that another 500-700 plains minnow were captured on the two subsequent seine-sampling passes. Abundance at other sites was much less, ranging from about one to 82 specimens, although 361 plains minnows were captured just downstream of the Sterling # 1 canal diversion dam at Dune Ridge State Wildlife Area in November 2001 (pers. comm., J. Stafford, Colorado Division of Wildlife).

Brassy minnow were less widespread and less common in samples than plains minnow in the South Platte River. We found brassy minnow from a few kilometers upstream of Sterling downstream to Liddle Ditch Diversion. Although we did not enumerate species at sites regularly, we generally caught five or fewer individuals at each site where they were found.

We also captured fish in the genus *Carpiodes* at several South Platte River localities. During initial sampling efforts, we assumed they were all river carpsucker *Carpiodes carpio*. We then analyzed the few voucher specimens collected and realized that most carpsuckers captured may be quillback *Carpiodes cyprinus*. Because most specimens were small (<150 mm TL) and did not have the elongate first dorsal ray present in typical eastern quillback, we are having carpsucker specimens verified.

Other South Platte River fishes sampled that were of particular interest were plains topminnow and western mosquitofish. We found plains topminnow near Liddle Ditch Diversion once, the only time in 45 sampling occasions. Western mosquitofish were much more widespread, occurring from St. Vrain Creek downstream to Julesburg at the Nebraska border on 18 of 45 sampling occasions, and at times were very abundant.

At one site just downstream of the Highway 6 crossing of the South Platte River in Sterling in July 2001, we found thousands of adult western mosquitofish in a warm water seep.

Notable finds in the Arkansas River Basin were flathead chubs at several sites downstream of John Martin Reservoir. We also found non-native longnose sucker at a single site and freshwater drum at 4 sites in that same area. No Arkansas darters *Etheostoma cragini* were detected.

### **Suckermouth minnow species associations**

At the site level, suckermouth minnow co-occurred with a total of 23 fishes in the South Platte River and 20 in the Arkansas River (Tables 11 and 12). In the South Platte River, eight species occurred at 50% or more of those sites. In the Arkansas River, seven species occurred at 50% or more of sites where suckermouth minnows occurred.

At the seine haul level, suckermouth minnow co-occurred with sixteen other fishes in each of the South Platte and Arkansas rivers (Table 13). In the South Platte River, fathead minnow, sand shiner, red shiner, plains killifish, bigmouth shiner, creek chub, and plains minnow occurred at more than 50% of sites where suckermouth minnow occurred. In the Arkansas River, only sand and red shiners and plains killifish occurred in more than 50% sites occupied by suckermouth minnows.

## **Discussion**

### **Historical distribution patterns**

Documented historical distribution of suckermouth minnow in the South Platte River Basin was from two main locations: one a relatively higher elevation area in foothills streams in or near Boulder County and another lower elevation one downstream in the lower South Platte River from near Ovid, Colorado, downstream to the state line near Julesburg. While little early sampling occurred in other foothills stream systems (e.g., Poudre River, Big Thompson River, foothills sections of the South Platte River), or

in the South Platte River downstream of Denver to near Ovid, it is not unreasonable to assume that suckermouth minnows occurred throughout warm water reaches of the South Platte River Basin, Colorado, including places where specimens have never been documented. A relatively wide historical distribution is also supported by more recent widespread occurrences in the lower South Platte River (e.g., Propst 1982). Preference of suckermouth minnow for sand-gravel riffles (Haas 1977, Propst 1982, observations in this study), which are common in foothills streams and throughout the main stem, also supports the notion that suckermouth minnows were likely widespread in the basin.

Although suckermouth minnow was relatively widespread in the Boulder County area until 1914 (Ellis 1914) and still present in low numbers until 1950 (Hendricks 1950), neither Li (1968), Propst (1982), nor Nesler et al. (1997) found the species in foothills streams of the South Platte River Basin. Early degradation of fish communities in foothills streams was documented as early as 1914, when Ellis described fish kills in Boulder Creek (Ellis 1914). Continued degradation of fish communities in foothills streams has been documented (Li 1968, Propst and Carlson 1986, Bestgen 1989, Bestgen and Fausch 1993a, Bestgen and Fausch 1993b, Nesler et al. 1997), particularly for species whose historical distribution was limited to that area. Although reasons for the decline of foothills fish communities vary, most reasons are related to increased human development along the Front Range.

Sampling localities mapped for suckermouth minnow in the lower South Platte River from upstream of Sterling, Colorado downstream to the Colorado border from 1968 to 2001 showed shifts in distribution over four discrete time periods. The first sampling period from 1967-1968 (Li 1968) showed a restricted distribution pattern, with the two suckermouth minnow records documented near or downstream of Lodgepole Creek. The next relatively comprehensive South Platte River sampling documented a much broader distribution of suckermouth minnows (Propst 1982), and significantly, the species was captured at every site sampled in the lower South Platte River. Distribution of suckermouth minnow had declined by the mid-1990's, as Colorado Division of Wildlife sampling found suckermouth minnow in only a single locality (two occurrences), lower Lodgepole Creek (Nesler et al. 1997). By 2001-2002, distribution of suckermouth

minnow had expanded again, and included most of the range occupied in 1978-1980. Suckermouth minnow was not detected at several sampling sites from 2001-2002.

Historical distribution of suckermouth minnow in the Republican River Basin, Colorado, is difficult to infer from the few historical samples. We presume it was relatively widespread there based on its preference for gravel riffles, which were once common in the basin (Cancalosi 1980), even though historical sampling detected it only in the Arikaree River Basin. Recent sampling (Scheurer 2002) has not detected presence of suckermouth minnow and it may be extirpated there. Additional sampling should be conducted to verify status of suckermouth minnow in the Republican River Basin, Colorado.

Historical distribution of suckermouth minnows in the Arkansas River, Colorado, is also difficult to infer based on the scant sampling conducted in the basin. The earliest suckermouth minnow records in 1926 indicated their presence only in tributaries in the downstream portion of the basin. Unpublished museum records for other fishes (University of Kansas, University of Michigan) showed periodic sampling occurred in the main stem Arkansas River from near Pueblo downstream to the Kansas border from 1926 into the 1960's, some of which were prior to first water storage in John Martin Reservoir in 1943 (in part, Scheurer 2002, Scheurer et al. 2003). We surmise that if suckermouth minnow in the main stem had been as abundant as it is now, it surely would have been detected. Thus, the reasonably widespread and abundant population in the lower Arkansas River, Colorado, may be a relatively recent phenomenon. Below, we speculate on likely reasons for expanded distribution and abundance of suckermouth minnows in that river reach.

Prior to construction of John Martin Reservoir and establishment of tamarisk, the main stem Arkansas River in the plains reach of Colorado was much broader, composed of shifting channels and a mostly sand bottom (Nadler and Schumm 1981). Thus, the historical main stem below present-day John Martin Reservoir may not have been as suitable for suckermouth minnows as it is now. The stronghold of suckermouth minnow in the Arkansas River Basin, Colorado, may have been in the tributaries. The main stem may have supported suckermouth minnows only where scour points or alluvial fans near tributary mouths supplied gravel to the system.

We speculate that construction of John Martin Reservoir created more favorable downstream conditions for suckermouth minnow in the lower Arkansas River perhaps, in part, because of more reliable flows. Another likely major factor was release of sediment-free flows, which scoured sand from the channel bed and revealed more gravel substrate than historically occurred. Those conditions allowed suckermouth minnows to expand from a mostly tributary existence in the Arkansas River Basin, Colorado, into the main stem.

This scenario is supported by several pieces of information, including present-day distribution patterns of suckermouth minnows in tributaries and main stem river reaches in Colorado and Kansas. Suckermouth minnow has not been documented from the main stem upstream of John Martin Reservoir, except near Rocky Ford below a diversion dam, a site that had gravel substrate present (pers. comm., J. Melby, CDOW). The present-day channel upstream of John Martin Reservoir, which is in large part unaffected by the scouring flows released from main stem dams, is shifting and sandy-bottomed. Most of that reach, which is likely geomorphically more similar to the pre-dam condition of the lower Arkansas River, Colorado, does not presently support suckermouth minnow. The hypothesis that the stronghold for suckermouth minnows was tributaries is supported by recent sampling (Loeffler et al. 1982, Nesler et al. 1999, this study), which documented the species in Big Sandy, Clay, and Cheyenne creeks, and the Purgatoire River. A similar scenario seems to occur in Kansas, where few samples of suckermouth minnow were detected in the sand-bedded main stem Arkansas River, but tributary records are more common (Rohde 1980, Cross and Collins 1975).

Historical status of suckermouth minnow in the Purgatoire River is confusing. Intensive sampling in the upstream canyon-bound reach of the Purgatoire River did not detect suckermouth minnows (Bramblett and Fausch 1991, Fausch and Bramblett 1991), nor were they found in historical sampling downstream near the confluence with the Arkansas River near Las Animas (Loeffler et al. 1982, Univ of Kansas, unpublished collection records). More recent sampling by CDOW and us at that same site revealed presence of a relatively strong population of suckermouth minnows there. Why suckermouth minnows are not more widespread in that system, which is dominated by

native fishes (Bramblett and Fausch 1991), and why they were only recently found there, is an enigma.

### **Tests of seine sampling efficiency**

Tests of sampling efficiency showed that suckermouth minnows were captured on the first pass of every efficiency test where they were eventually found (three sites). We did not specifically target sites where suckermouth minnows were known to occur for all efficiency tests because we were interested in obtaining more general capture efficiency information for streams that varied in size, complexity, and fish assemblage composition.

Tests showed that community composition estimated by our one-pass seine sampling was representative for the entire fish community at that site, even when three additional passes were conducted with seining and electrofishing. Species missed the most were typical of those missed in other studies (centrarchids or ictalurids, Schuerer 2002), likely because they prefer cover-filled or benthic areas where seining efficiency is somewhat reduced. More often, species were missed simply because they were extremely rare at study sites. On average, only single individuals of species that were missed on the first pass were captured on subsequent passes. An extremely rare species was freshwater drum; only two were noted during this entire study in the South Platte River and one was collected during the second seine sample pass in an efficiency test.

Results of seine sampling efficiency tests suggested that assertions made about presence or absence of suckermouth minnows at a site in the South Platte or Arkansas River basins could be made with confidence. This was important when discussing the importance of explanatory variables used in binomial response regression models that may be used to predict presence or absence of suckermouth minnows at sites or in seine hauls. This data should also provide a foundation for estimating sampling effort and intensity needed at sites in plains streams for long-term monitoring purposes.

### **Habitat associations, site level**

Geomorphology of the lower main stems of the South Platte and Arkansas rivers exhibited differences that may have influenced presence of suckermouth minnows. The channel of the South Platte River is mostly shifting, braided, and relatively wide,

compared to the Arkansas River, which is mostly a single channel, does not shift as much, and is relatively narrow. Although each is dominated by sand substrate, the South Platte River has less gravel, and most is in the G1 size-class.

The drought had a large effect on the characteristics of sites occupied by suckermouth minnows in the South Platte River. That was because most occupied sites and sampling occasions were sampled when water was low and suckermouth minnows were in refuges. Several of those South Platte River sites were ones we returned to more than once, simply because it increased the likelihood of capturing any suckermouth minnows to use for habitat measurements, which increased the proportion of sampling occasions where they were found. Occupied sites were close to diversions or had deeper mean and maximum water depths, and had a slightly higher proportion of gravel substrate and less silt. Thus, sites without a diversion dam or deep water present typically held few or no suckermouth minnows.

Occupied sites in the Arkansas River were never adjacent to diversions, because few existed there and mean and maximum depths were similar among occupied sites and those that were not. Bank-full width was wider and undercut banks more prevalent at occupied sites, attributes that may have indicated more lateral stream erosion, and more channel complexity. Occupied Arkansas River sites also tended to have less silt and sand, more gravel size-classes present, and a higher proportion of gravel.

Logistic regression analysis showed that sites with the highest probability of occurrence were from the Arkansas River. This was a reflection of the much larger proportion of occupied sites in that basin. Although it was a smaller effect, presence of deep water was also important to predict presence of suckermouth minnows at sites in each basin. For many South Platte River sites, this meant that a diversion dam was likely present. Thus, diversion dam presence and deep water were likely highly correlated. In the Arkansas River, deeper pools were natural features. Occupied sites in each basin also had a higher proportion of gravel substrate.

#### **Habitat associations, seine haul level**

Suckermouth minnow use of meso-habitats at the level of seine hauls was also affected by drought conditions, particularly in the South Platte River. Suckermouth

minnows there were found predominantly in runs and pools, less often in eddies, and never in riffles or backwaters. All the pools and eddies and eight of eleven runs were located immediately downstream of diversion dams, locations more likely to be occupied in low water. In the Arkansas River, suckermouth minnows occurred mostly in riffles, runs, and pools at about the same percentage of time.

Qualitative comparison of characteristics of seine hauls with and without suckermouth minnows showed differences between South Platte and Arkansas River basins. South Platte River seine samples with suckermouth minnows present had deeper maximum depths, lower mean and maximum velocity, and lower percent silt and higher percent sand than sites where suckermouth minnows were absent. Arkansas River seine samples with suckermouth minnows had less sand, more gravel in all size classes except G1, both for percent occurrence and percent composition.

Comparisons of seasonal habitat use were hindered because of low sample size in spring and winter. In winter in the Arkansas River, absence of suckermouth minnows from their usual riffle-run habitat was the strongest evidence that a shift had occurred. However, the two data points collected do not offer strong evidence that backwaters are their primary winter habitat. Absence from other habitat types could also reflect that suckermouth minnows are more difficult to capture in winter. A slight habitat use shift from summer to autumn to deeper pools in the South Platte River may have reflected reduced autumn streamflow and further restriction of fish to the few pools that were available. Although water flow had not ceased, riffles and runs were very shallow and few fish other than early life stages were observed in those places.

The few early life stages of suckermouth minnows < 30 mm TL captured offered little insight into their habitat needs. Most were captured in backwaters or pools, likely owing to their small size and relatively poor swimming ability. Low velocity habitat in a reach may be important to support all life stages of suckermouth minnows.

Descriptive physical attributes of seine sample localities were mostly verified by the logistic regression analysis. Similar to the site level analysis, there was a strong drainage basin effect that suggested suckermouth minnows were much more likely to occur in seine hauls in the Arkansas River Basin than in the South Platte River Basin. The basin main effect would have been much larger had it not been nested with other

variables (e.g., percent sand, maximum velocity at sites). Nesting Basin effects with explanatory variables is functionally similar to using interaction terms, which allow examination of effects by basin for a particular variable.

We also detected a large effect of season, which suggested that suckermouth minnows were either easier to capture in summer or that they were more abundant then, or both. The smallest effect was for winter, when suckermouth minnows were very difficult to capture.

Mean seine haul length and presence of suckermouth minnows was positively correlated. Longer seine hauls might be expected to detect more suckermouth minnows; we took care to restrict seine hauls to a single meso-habitat type, if possible, so that we could restrict habitat measurements to the area where we thought the species actually occurred.

We detected a large effect for the percent of sand at seine hauls where suckermouth minnows occurred, but the effect was positive in the South Platte River and negative in the Arkansas River. In the South Platte River, seine hauls were mostly over sand, which may account for the positive association with sand. Sand may also be a dominant substrate type in depositional, low-velocity diversion pools where most suckermouth minnows in the South Platte River were found. Conversely, percent sand and presence of suckermouth minnows was negatively correlated in the Arkansas River. That effect likely translates into a higher proportion of gravel being important at a seine haul location. This was supported by the presence of a weak positive effect for percent of G2 gravel. That suggested that presence of some sort of substrate larger than sand, even in the South Platte River, was important to occurrence of suckermouth minnows. The positive effect for maximum depth was likely the result of finding suckermouth minnows in relatively deeper habitat, whether in deep diversion pools of the South Platte River or deeper runs, riffles, and pools in the Arkansas River. Similar to the opposite basin effects for percent of sand substrate, suckermouth minnows were more likely to occur in slower habitat in the South Platte River and faster habitat in the Arkansas River. This is again the likely outcome of finding the preponderance of suckermouth minnows in slow deep diversion pools in the South Platte River during drought times compared to their higher occurrence in faster riffles and runs in the Arkansas River.

### **Spatial and temporal abundance shifts**

Suckermouth minnow exhibited dramatic shifts in distribution and abundance in the South Platte River, where distribution patterns since 1967-1968 changed with each of the four major fish sampling efforts conducted. It is unlikely that poor sampling technique or misidentification resulted in those variable patterns, because suckermouth minnow is not a difficult species to capture or identify. Instead, patterns suggested that suckermouth minnow changed in abundance, or shifted habitat use with flow conditions, habitat availability, or other changes in environmental conditions.

Propst (1982) sampled the lower South Platte River in 1980 (no samples collected there in 1978 or 1979) and captured suckermouth minnows at every sample site visited. His sample sites were restricted to the length of the electrofishing cable available (about 100 m), and his sites were limited to those that were readily accessible by vehicle. Suckermouth minnow must have been quite common in that year. When CDOW sampled in the 1990's, sampling proceeded at regular intervals along the river, likely including some of the same sites sampled by Propst (1982), but few specimens were captured. Suckermouth minnows were clearly not as abundant, did not occupy the same habitat, or both.

By 2001-2002, the species was much more widespread again, but quite rare in samples until we began to focus on locations where we were most likely to encounter the species in drought conditions. Most sample sites where we encountered suckermouth minnows in 2001-2002 were below diversion dams, places that held large numbers of other fishes as well. These were ideal places to find suckermouth minnows because they concentrated fishes in relatively deep water, which acted as a refuge from low and shallow or non-existent flows elsewhere. Fish were likely concentrated there because they moved in search of more suitable habitat and eventually encountered diversion dam barriers and deep pools. These places were also suitable because scour pools provided gravel substrate over which suckermouth minnows were often found. In the absence of samples collected downstream of diversion dams, we likely would have concluded that suckermouth minnows were very rare in the South Platte River.

Rapidly shifting abundance of suckermouth minnows at multiply sampled sites during 2001-2002 also offered evidence that the species responded quickly to changing environmental conditions. When flow levels were not severely depleted, suckermouth minnows were likely dispersed and occupied the limited riffle-run gravel-bottomed habitat present in the South Platte River. At those times, the few suckermouth minnows present were widely dispersed and difficult to detect. As flows became depleted, fish moved to avoid very shallow or drying environments and encountered diversion pools, became concentrated, and were more easily detected by us. Changes in flow conditions, such as happened below Liddle Ditch diversion when the gate was opened in October 2001, or a flow increase above some threshold, may have caused fish to disperse again.

Another piece of information that adds to the evidence of rapidly shifting distribution and abundance patterns was results of sampling conducted in May 2003. As part of a different effort, sampling was duplicated at most sites where suckermouth minnow was found in 2001-2002. Sampling at 11 sites captured 8,133 fish but not a single suckermouth minnow was detected, including at sites such as Liddle Ditch where the species was most abundant.

Dynamic abundance shifts were not restricted to the main stem South Platte River. Abundance shifts were noted at least once in tributary populations in Big Sandy Creek in the Arkansas River and Lodgepole Creek in the South Platte River. Highly variable flows in those systems may be responsible for abundance shifts. We also noted a quick response to re-wetting in Lodgepole Creek, where over a less than two-month interval, suckermouth minnows re-colonized and perhaps reproduced in a formerly dry reach.

We did not detect distribution and abundance shifts for suckermouth minnow in the main stem Arkansas River. The Arkansas was not subject to desiccation as severe as that in the South Platte River, and deeper refuges were more widespread. Lack of perceived abundance shifts may be because of the larger resident population or because suitable gravel-bottomed riffles and runs were more widespread and flow was sufficient to keep them wetted and useful to fish.

It is plain that habitat use characteristics for suckermouth minnows in the South Platte River were dominated by observations taken during drought. It follows that habitat

use and needs during other hydrological conditions may be different. Notwithstanding, observations during drought, which must be one of the most limiting times for plains stream fishes (Fausch and Bestgen 1997), are useful. In order for suckermouth minnows and many other species to survive in stream reaches that are severely dewatered, they must have access to deep pools that do not exceed their thermal or other tolerances. Deep pools were rare in the South Platte River because the shifting sand bed, and most were found downstream of diversion dams. A balance between the benefits of diversion dam pools, as drought protection for fish, and the overall negative effects of stream dewatering seems needed.

### **Reproduction & culture**

We were able to successfully spawn suckermouth minnows in the laboratory using hormone injections. We successfully reared larvae from eggs stripped from females. We also observed a few naturally deposited embryos that hatched and survived in larger tanks. The first unsuccessful attempt to spawn suckermouth minnows may have been caused by an overly long acclimation period prior to injections and subsequent loss of spawning condition. Several injected fish died, but all others remained healthy in captivity until we returned them to the capture site in May 2002. The main differences during our second and successful attempt were we injected suckermouth minnows immediately and fish were more reproductively ready initially.

Suckermouth minnow embryos were adhesive, and in the laboratory were found attached to a variety of different-sized gravel particles ranging from the G1 to G6 size-classes, but not to sand. Further, we observed spawning behavior only over gravel. This finding suggested that presence of gravel was very important for appropriate spawning sites for suckermouth minnows, but the gravel size used for reproduction was not specific. In the South Platte River, gravel substrate is less common than in the Arkansas River, which may necessitate fish moving to find appropriate spawning areas. Finding early life stages of suckermouth minnows in the once-dry Lodgepole Creek supports this notion.

We may have observed cannibalism of freshly deposited embryos by adult suckermouth minnows in spawning tanks but we do not know if this occurs in the wild.

Extensive cannibalism in the wild may limit reproductive success of suckermouth minnows if gravel substrate is limited.

Development of embryos and growth of larvae was substantially faster at warmer water temperatures. This suggested that if size-dependent processes were important for survival of early life stages of suckermouth minnows, warmer water might promote faster growth and higher survival.

We observed the same fish that we injected in spring 2002 spawning in tanks without injections in June 2003. Fish held at ambient room temperature conditions became plump and eventually spawned on their own volition over gravel substrate in a 380 l aquarium. We did not observe spawning, but first detected larvae in aquarium gravel in late June. They appeared to be several days post-hatch.

Laboratory studies and observations of wild fish suggested suckermouth minnows spawned beginning in late spring and, based on presence of tuberculate fish in the Arkansas River in August, continued through summer. Haas (1977) also observed extended spawning in Missouri populations of suckermouth minnows. Water temperatures in the South Platte and Arkansas rivers when reproductive fish were observed were at least 15-17°C. That is similar to the 17°C water temperature in aquaria where captive suckermouth minnows ripened on their own volition over winter in the laboratory.

### **Environmental factors limiting suckermouth minnows in Colorado**

A number of factors limit distribution and abundance of suckermouth minnows in Colorado at this time. Numerous impassable diversion dams may limit upstream movement of suckermouth minnows in the lower South Platte River. Presently inaccessible and unoccupied reaches would provide additional habitat for fish and provide safeguards for the South Platte River population when drought conditions prevail. Upstream movement of suckermouth minnows is not necessarily a major issue in the lower Arkansas River main stem, although the reach below John Martin Dam downstream to near Lamar may not support the species.

Upstream foothills tributaries in the South Platte River Basin provided habitat for suckermouth minnow until about 1950. Because those reaches may have more reliable

flow than downstream reaches, re-establishing populations of suckermouth minnows in areas of suitable habitat may be an effective conservation strategy if other limiting factors were resolved.

Tributary populations may serve an important role in maintaining suckermouth minnows in main stem reaches, but the extent of occupied habitat is limited and water flow is sometimes unreliable. Enhancing stream flow and dispersal routes for existing tributary populations would stabilize those areas as refuges in case main stem habitat is unavailable. Expanding available tributary habitat would provide additional refuges for suckermouth minnows.

Arkansas River main stem populations appear relatively widespread and stable. Maintenance of flow patterns and levels that create gravel riffles and complex habitat, and maintenance of some base flow, may ensure continued stability of those populations.

Suckermouth minnow populations in the lower South Platte River main stem have fluctuated dramatically over time. Flow patterns that create gravel riffles and maintain deep pools seem important to maintenance of those populations. Because the South Platte River is susceptible to very low flows, providing unhindered river reaches for long distance movements and deep refuge pools is critical to maintaining those populations. More stable and reliable base flows will permit those populations to expand throughout the reach.

The fish communities of the South Platte and Arkansas rivers are composed of mostly native species, a condition that will enhance persistence of suckermouth minnows there. Establishment of other species that prey upon or compete with suckermouth minnows should be avoided.

## Recommendations

We offer the following research recommendations with a goal of increasing understanding of factors limiting populations of suckermouth minnows in Colorado. Increasing understanding of limiting factors may illuminate additional management activities that may enhance the conservation status of suckermouth minnow.

- 1). Better understand movement dynamics of suckermouth minnow.

This seems key to understanding the type of habitat complexes needed to sustain populations of suckermouth minnows. Particularly important may be the role of declining water levels in motivating movement of these fish within the main stem and in tributaries.

- 2). Better understand the role of tributaries in sustaining populations.

The interplay of suckermouth minnows between main stem and tributaries such as Lodgepole Creek may be important to sustain populations. Seasonal dynamics particularly related to declining water levels and barriers seems important.

- 3). Define effects of stream geomorphology and fluvial processes on habitat availability.

Geomorphology of the South Platte and Arkansas rivers plays a role in defining sites and habitat suitable for suckermouth minnow. However, processes may be different in each river and changing over time due to altered flow levels and effects of reservoir releases.

- 4). Define habitat use and stream reaches of importance to suckermouth minnows in non-drought times.

Most habitat use data gathered for South Platte River were gathered during drought periods and are not representative of that needed by suckermouth minnows at other times.

5). Understand better effects of changing water management practices on hydrology of the system.

System hydrology appears to be changing as a result of groundwater recharge, diversion dam modifications, increased use of wells and pumping, and other practices associated with irrigated agriculture. Understanding effects of these practices on the long-term water budget and flow dynamics, especially in drought years, should give managers the ability to forecast when main stem populations will be most affected.

6). Investigate reasons for occurrence and abundance of other state-listed species discovered in 2001-2002.

We discovered relatively large and widespread populations of plains minnow in the South Platte River during this study, when few have been documented historically. Understanding more about this species when they are relatively common may yield insights into their distribution and abundance dynamics.

The following management recommendations are offered that may assist with conservation of existing populations of suckermouth minnows.

1). Secure populations of South Platte and Arkansas River suckermouth minnows while they are relatively common, if brood stock are deemed needed.

2). Identify localities where additional conservation activities may occur.

Identification of sites with appropriate habitat would give managers the option to expand populations that may presently be dispersal-limited by diversion dams or other instream structures. Such may occur in plains or foothills stream reaches. If experimental introductions occur, their distribution and survival should be closely followed.

- 3). Investigate opportunities for stabilizing flows and habitat in key main stem reaches and tributaries.

Certain main stem reaches are particularly valuable for suckermouth minnows in the South Platte River. Ensuring some water flow would secure those populations in time of drought. Suckermouth minnows have used tributaries such as Lodgepole Creek since the first collections made in the basin. The Arkansas River Basin also contains several viable tributary populations of suckermouth minnow. Enhancing habitat in small streams may provide a source population for the main stem and a refuge population outside of the larger and harder to manage main stem.

- 4). Monitor existing populations.

Occasional surveys of the South Platte River since 1967 have provided insights into distributional dynamics of suckermouth minnows. Appropriately designed monitoring schemes may yield information into seasonal and flow-related population dynamics and movements. This will offer managers data to remediate negative effects of drought or other large-scale factors that may threaten existing populations.

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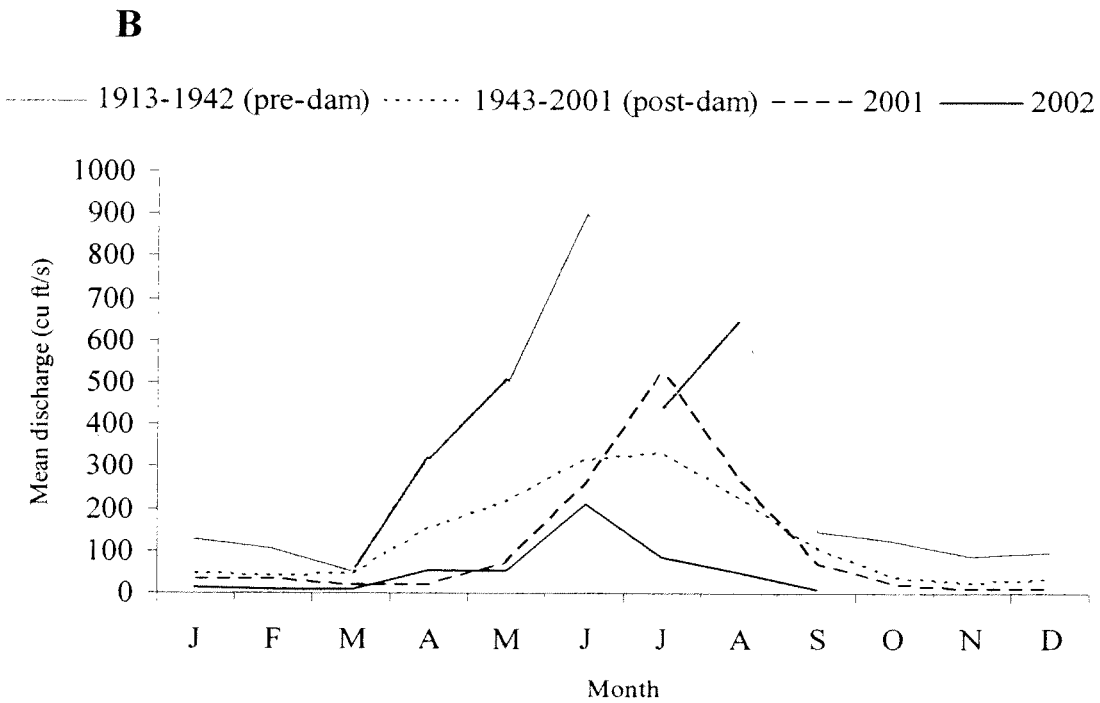


Figure 1.—Historical and recent mean monthly discharge in the South Platte River at Julesburg, Colorado, U.S. Geological Survey gage #06764000 (A) and Arkansas River at Lamar, Colorado, gage #07133000 (B).



Figure 2.—Distribution of suckermouth minnow in eastern Colorado, 1903 to 1981. Triangles represent samples collected prior to 1967, circles represent samples collected 1967 to 1981.

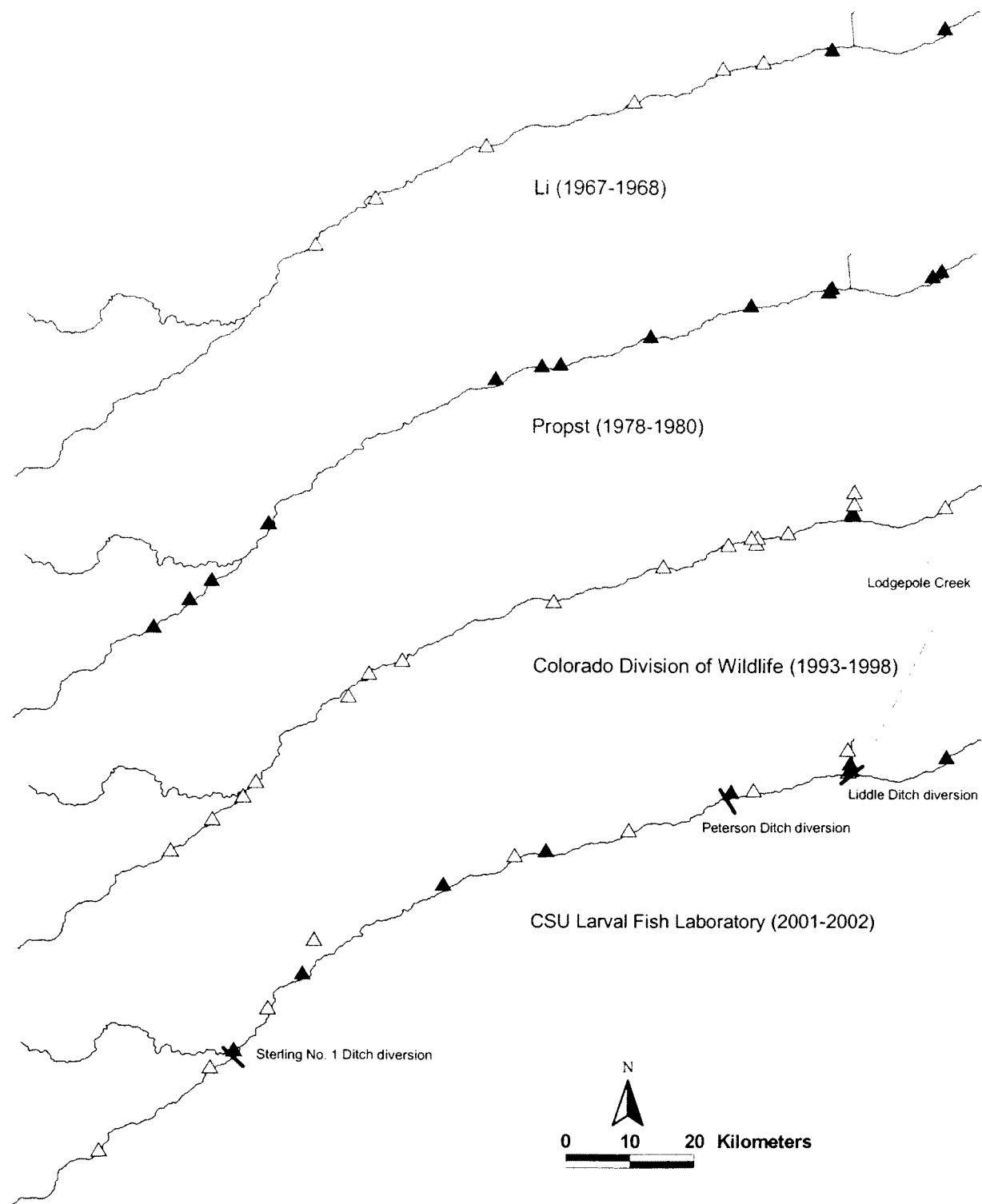


Figure 3.—Distribution of suckermouth minnow (filled triangles) and sampling sites without suckermouth minnow (open triangles) in four time periods in the lower South Platte River Basin, Colorado, 1967-2002. Samples site localities for all but the 2001-2002 sampling are approximations digitized from maps.

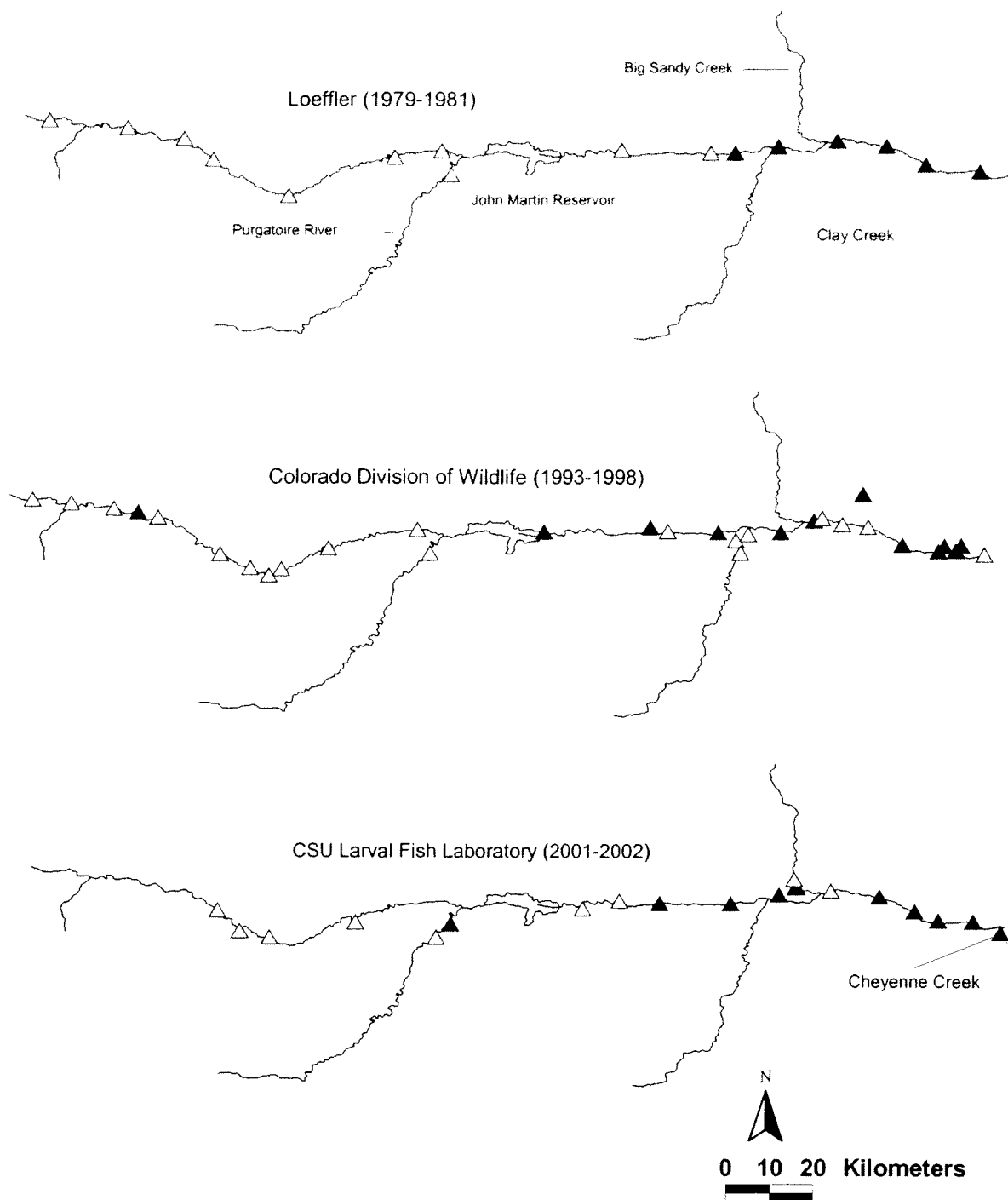


Figure 4.—Distribution of suckermouth minnow (filled triangles) and sampling sites without suckermouth minnow (open triangles) in three time periods in the lower Arkansas River Basin, Colorado, 1979-2002. Samples site localities for all but the 2001-2002 sampling are approximations digitized from maps.

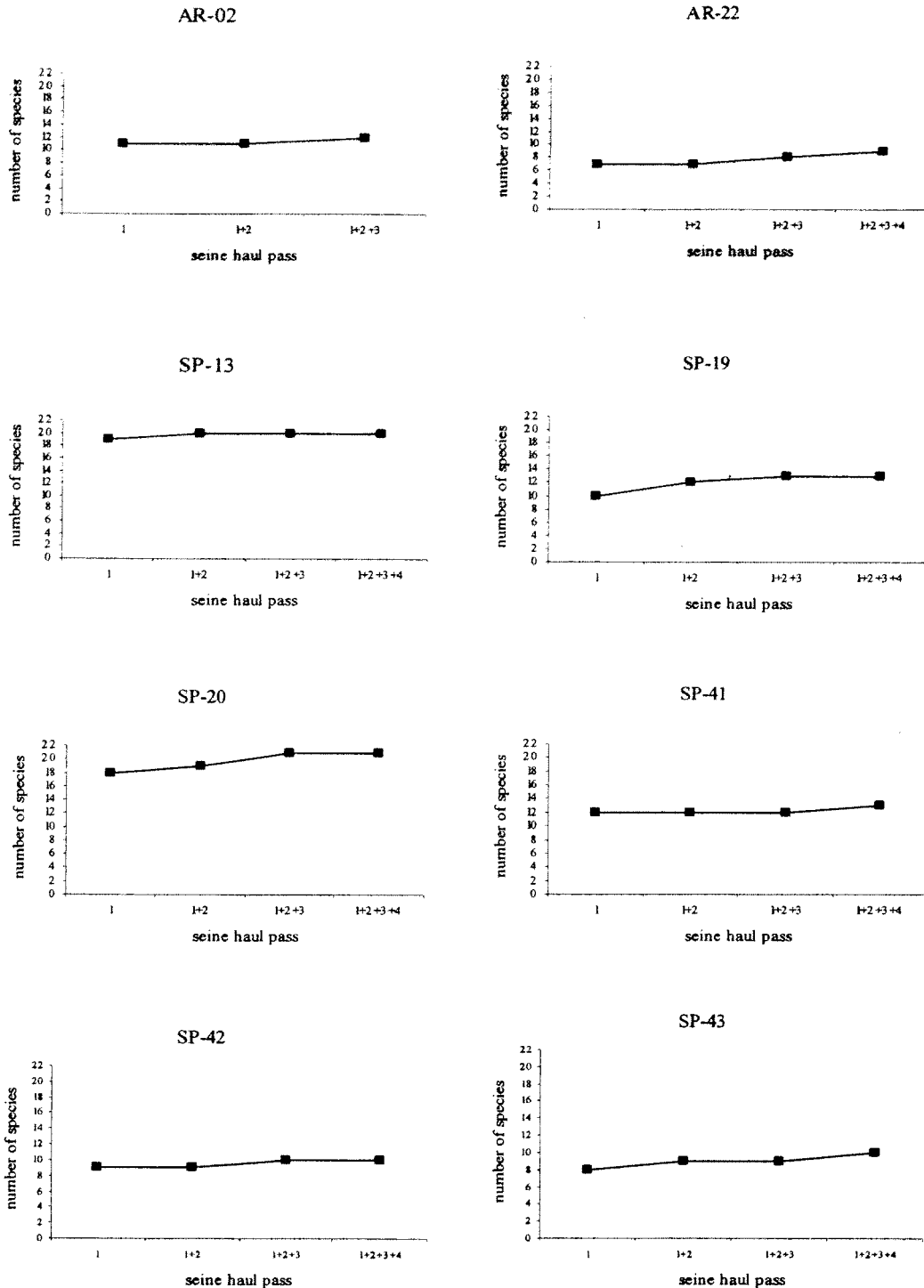


Figure 5.--Cumulative fish species richness in consecutive sampling passes at seine efficiency sample sites, Arkansas (AR) and South Platte (SP) River basins, Colorado, 2002. AR-02 = Arkansas River at Highway 50; AR-22 = Cheyenne Creek at Highway 50; SP-13 = South Platte River below Liddle Ditch diversion; SP-19 = Lodgepole Creek ¼ mi upstream of Highway 138; SP-20 = South Platte River below Peterson Ditch diversion; SP-41 = South Platte River at Highway 85, Evans; SP-42 = Spring Creek at Prospect Street, Fort Collins; SP-43 = St. Vrain Creek at CR 34, Gowanda.

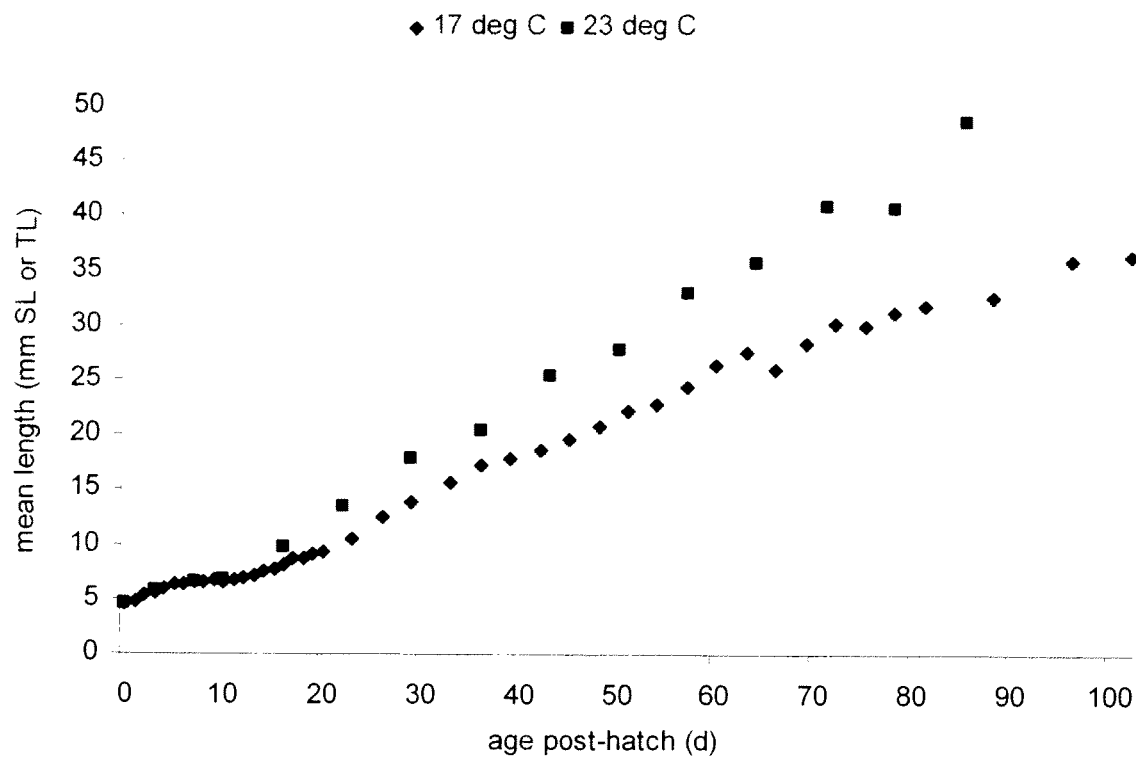


Figure 6.—Mean length of laboratory cultured suckermouth minnow as a function of days post-hatch. The developmental series was preserved in 10% formalin. Larvae up to 10mm standard length (SL, anterior margin of snout to posterior margin of notochord) were measured to 0.01mm using a microscope and micrometer. Larger larvae were measured to 0.01mm total length (TL, anterior margin of snout to posterior margin of finfold or caudal fin) using digital calipers.

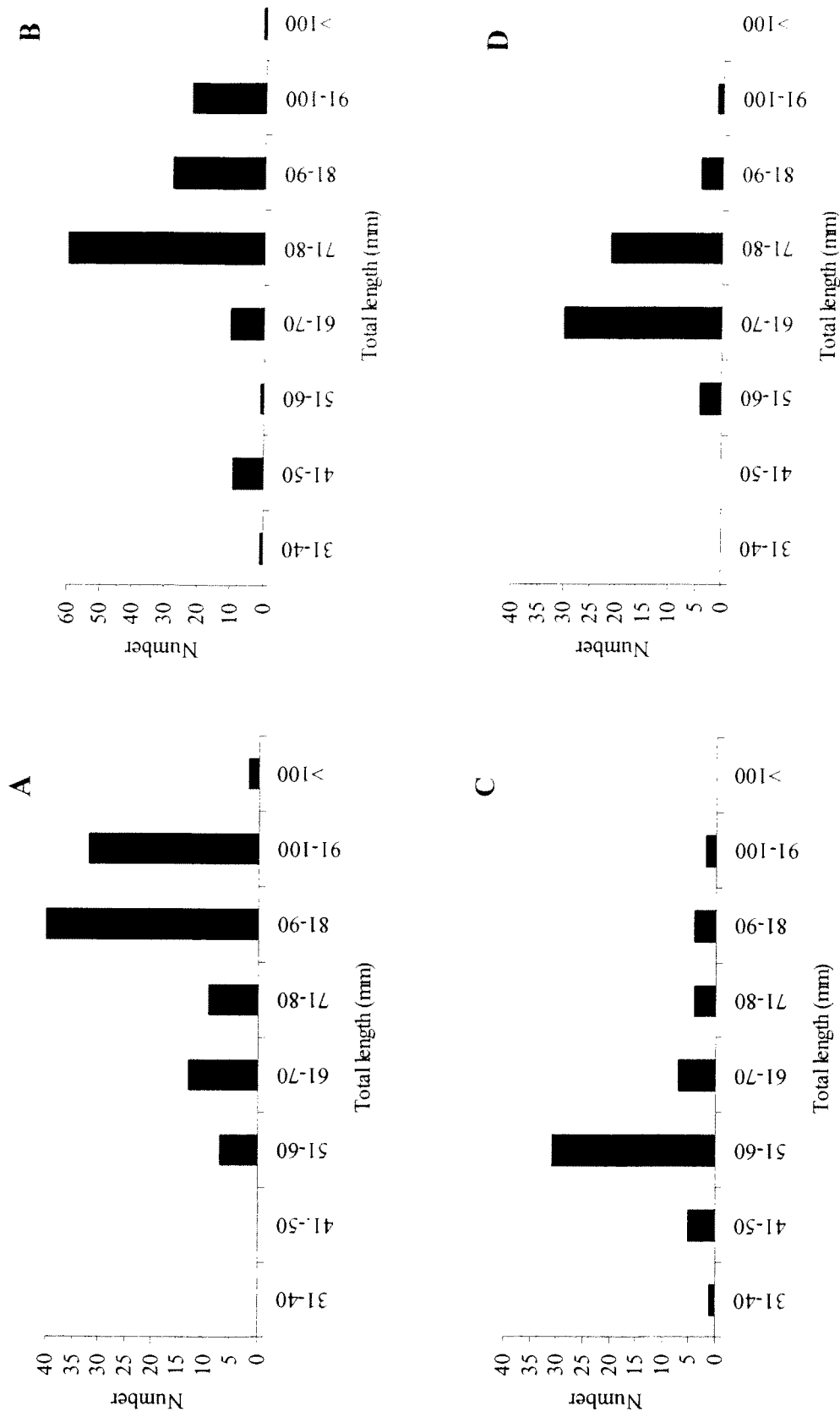


Figure 7.—Length-frequency histograms of suckermouth minnows from South Platte River below Liddle Ditch diversion, September 2002 (A), Arkansas River at Highway 50, October 2002 (B), Arkansas River east of Lamar, August 2002 (C), Purgatoire River at Highway 101, May 2002 (D).

Table 1.—Habitat variables measured at Larval Fish Laboratory sample sites and seine haul locations in the South Platte and Arkansas River basins, Colorado, 2001 – 2002.

Variable	Site	Seine
Elevation	X	
seine hauls per site	X	
ph	X	
DO (mg/l)	X	
temperature (°C)	X	
conductivity (µs)	X	
salinity (ppt)	X	
length (m)	X	X
bank-full width (m)	X	
wetted width (m)	X	
area (m <sup>2</sup> )		X
depth (cm)	X	X
maximum depth (cm)	X	X
velocity (cm/s)		X
maximum velocity (cm/s)		X
distance to structure (m)		X
IN-STREAM STRUCTURE, PRESENCE		
algae	X	X
woody debris	X	
logs	X	
overhanging vegetation	X	
undercut bank	X	
bridge abutment	X	
diversion structure	X	
other cover	X	
SUBSTRATE, PRESENCE		
silt	X	X
sand	X	X
G1 gravel	X	X
G2 gravel	X	X
G3 gravel	X	X
G4 gravel	X	X
G5 gravel	X	X
G6 gravel	X	X
cobble or larger	X	X
SUBSTRATE, PERCENT		
silt	X	X
sand	X	X
G1 gravel	X	X
G2 gravel	X	X
G3 gravel	X	X
G4 gravel	X	X
G5 gravel	X	X
G6 gravel	X	X
cobble or larger	X	X

Table 2.—Suckermouth minnow sampling localities, size, and abundance, South Platte River Basin, 2001-2002 . LFL = Larval Fish Laboratory.

LFL Site #	Location	Date	# SMM	# measured	Size range (mm TL)
SP-07	South Platte River, Tamarack SWA near Proctor	20 July 2001	0	n/a	n/a
"	"	16 Aug 2002	5	5	51-58
SP-08	South Platte River, Tamarack SWA	20 July 2001	1	1	49
SP-11	South Platte River, Julesburg	14 Aug 2001	8	4	56-65
"	"	23 Oct 2001	0	n/a	n/a
"	"	11 Jun 2002	0	n/a	n/a
SP-13	South Platte River, Ovid, below Liddle Ditch diversion	14 Aug 2001	104+	3	60-100
"	"	24 Oct 2001	4	4	68-87
"	"	11 Jun 2002	15	15	75-103
"	"	14 Aug 2002	148	27	38-102
"	"	24 Sep 2002	105	103	52-102
SP-16	South Platte River, Bravo SWA	15 Aug 2001	1	1	95
"	"	19 Oct 2001	0	n/a	n/a
"	"	13 Jun 2002	0	n/a	n/a
SP-18	Lodgepole Creek, lower	22 Aug 2001	2	1	89
"	"	26 Oct 2001	0	n/a	n/a
SP-19	Lodgepole Creek, middle	22 Aug 2001	1	1	81
"	"	23 Oct 2001	2	2	85-88
"	"	14 Aug 2002	19	10	22-60
"	"	25 Sep 2002	0	n/a	n/a
SP-20	South Platte River, Sedgwick, Peterson Ditch diversion	23 Aug 2001	7	0	n/a
"	"	25 Oct 2001	5	5	72-79
"	"	12 Jun 2002	16	16	73-97
"	"	13 Aug 2002	0	n/a	n/a
SP-36	South Platte River, Dune Ridge SWA	13 Jun 2002	1	1	80

Table 3.— Suckermouth minnow sampling localities, size, and abundance, Arkansas River Basin, 2001-2002 . LFL = Larval Fish Laboratory.

LFL Site #	Location	Date	# SMM	# measured	Size range (mmTL)
AR-01	Arkansas River, Lamar	19 Jun 2001	7	7	25-88
"	"	04 Nov 2001	8	8	45-95
"	"	07 Aug 2002	23	23	40-75
AR-02	Arkansas River, East of Granada	20 Jun 2001	36	2	27-84
"	"	01 Nov 2001	9	9	59-92
"	"	21 May 2002	8	8	68-91
"	"	08 Aug 2002	22	22	40-103
"	"	01 Oct 2002	132	132	38-101
AR-03	Arkansas River, North of Granada	20 Jun 2001	13	1	22
"	"	02 Nov 2001	10	10	37-92
"	"	14 Mar 2002	1	1	89
AR-04	Arkansas River, Holly	20 Jun 2001	5	0	n/a
"	"	02 Nov 2001	0	n/a	n/a
AR-22	Cheyenne Creek	28 Aug 2001	4	1	62
"	"	31 Oct 2001	3	3	73-81
"	"	02 Oct 2002	18	17	53-96
AR-24	Arkansas River, East of Lamar	28 Aug 2001	7	2	39-46
"	"	03 Nov 2001	17	17	58-93
"	"	14 Mar 2002	6	6	71-96
"	"	09 Aug 2002	54	54	33-97
AR-25	lower Big Sandy Creek	29 Aug 2001	4	1	68
"	"	01 Nov 2001	49	49	44-106
"	"	21 May 2002	0	n/a	n/a
AR-26	Arkansas River, Prowers	29 Aug 2001	3	1	32
"	"	04 Nov 2001	11	11	60-100
AR-27	Purgatoire River, Las Animas	29 Aug 2001	36	1	87
"	"	05 Nov 2001	44	44	58-84
"	"	23 May 2002	60	60	57-93
"	"	09 Aug 2002	8	8	38-48
AR-28	Arkansas River, Amity	30 Aug 2001	11	1	82
AR-29	Arkansas River, confluence with Big Sandy Creek	30 Aug 2001	4	0	n/a

Table 4.—Habitat characteristics (mean, standard error parenthetically) of sample sites in the South Platte and Arkansas River basins, Colorado, 2001-2002. Values for presence variables are the percent of sites at which the particular variable occurred.

Variable	South Platte River Basin	Arkansas River Basin	Variable	South Platte River Basin	Arkansas River Basin
Elevation	3701.5	3641.2			
Seine hauls per site	(29.4) 11.0	(45.7) 11.5	SUBSTRATE, PRESENCE		
pH	(1.0) 8.6	(1.0) 8.5	Silt	87.0 (7.2)	77.8 (10.1)
Dissolved oxygen (mg/l)	(0.1) 8.7	(0.0) 8.2	Sand	95.7 (4.3)	100 (0.0)
Temperature (°C)	(0.5) 18.6	(0.4) 20.1	G1 Gravel	95.7 (4.3)	100 (0.0)
Conductivity (µs)	(1.0) 1672.8	(1.0) 3204.0	G2 Gravel	91.3 (6.0)	88.9 (7.6)
Salinity (ppt)	(47.8) 1.0	(195.0) 2.0	G3 Gravel	47.8 (10.6)	66.7 (11.4)
Site length (m)	(0.0) 182.1	(0.1) 201.2	G4 Gravel	26.1 (9.4)	66.7 (11.4)
Bank-full width (m)	(20.8) 46.1	(17.7) 30.7	G5 Gravel	8.7 (6.0)	44.4 (12.1)
Wetted width (m)	(6.2) 36.2	(3.3) 15.3	G6 Gravel	13.0 (7.2)	27.8 (10.9)
Depth (cm)	(4.8) 20.5	(2.0) 19.3	Cobble or larger	17.4 (8.1)	33.3 (11.4)
Maximum depth (cm)	(3.4) 72.6	(1.3) 66.5			
	(8.8)	(6.6)			
IN-STREAM STRUCTURE, PRESENCE			SUBSTRATE, PERCENT		
Algae	97.1 (2.9)	88.0 (6.6)	Silt	16.1 (5.2)	14.9 (4.1)
Woody debris	93.3 (4.6)	96.0 (4.0)	Sand	50.9 (4.2)	47.1 (4.6)
Logs	87.2 (5.4)	73.1 (8.9)	G1 Gravel	21.0 (2.1)	18.2 (3.1)
Overhanging vegetation	94.1 (4.1)	81.8 (8.4)	G2 Gravel	7.7 (1.3)	4.8 (1.2)
Undercut bank	67.9 (9.0)	33.3 (10.5)	G3 Gravel	1.3 (0.4)	3.7 (1.0)
Bridge abutment	30.8 (9.2)	47.6 (11.2)	G4 Gravel	1.0 (0.5)	3.4 (1.2)
Diversion structure	35.5 (8.7)	5.0 (5.0)	G5 Gravel	0.1 (0.1)	2.1 (0.8)
Other cover	77.5 (6.7)	69.2 (9.2)	G6 Gravel	0.2 (0.1)	1.8 (1.3)
			Cobble or larger	1.8 (1.1)	4.0 (2.0)

Table 5.—Habitat characteristics (mean, standard error parenthetically) of sample sites where suckermouth minnow (SMM) were present and absent in the South Platte and Arkansas River basins, Colorado, 2001-2002. Values for presence variables are the percent of sites at which the particular variable occurred.

Variable	South Platte River Basin		Arkansas River Basin		Variable	South Platte River Basin		Arkansas River Basin	
	SMM present	SMM absent	SMM present	SMM absent		SMM present	SMM absent	SMM present	SMM absent
Elevation	3613.6	3749.4	3611.8	3741.0	SUBSTRATE, PRESENCE				
Seine hauls per site	(36.4)	(38.8)	(46.9)	(122.7)	Silt	100	78.6	75.0	100
	12.5	10.1	12.5	8.9		(0.0)	(11.4)	(11.2)	(0.0)
pH	(2.3)	(0.9)	(1.2)	(1.0)	Sand	100	92.9	100	100
	8.6	8.6	8.5	8.5		(0.0)	(7.1)	(0.0)	(0.0)
Dissolved oxygen (mg/l)	(0.1)	(0.1)	(0.0)	(0.0)	G1 Gravel	100	92.9	100	100
	8.4	8.9	8.3	7.7		(0.0)	(7.1)	(0.0)	(0.0)
Temperature (°C)	(0.5)	(0.8)	(0.5)	(0.6)	G2 Gravel	88.9	92.9	93.8	(0.0)
	19.7	17.9	20.1	20.1		(11.1)	(7.1)	(6.3)	(50.0)
Conductivity (µs)	(1.7)	(1.30)	(1.1)	(2.9)	G3 Gravel	33.3	57.1	75.0	0.0
	1793.9	1601.1	3256.4	2903.0		(11.1)	(13.7)	(11.2)	(0.0)
Salinity (ppt)	(64.7)	(62.6)	(206.1)	(631.7)	G4 Gravel	33.3	21.4	68.8	50.0
	1.0	0.9	2.0	2.0		(16.7)	(11.4)	(12.0)	(50.0)
Site length (m)	(0.0)	(0.0)	(0.1)	(0.3)	G5 Gravel	11.1	7.1	50.0	0.0
	155.9	195.3	207.3	152.0		(12.9)	(7.1)	(12.9)	(0.0)
Bank-full width (m)	(34.9)	(26.0)	(19.3)	(12.0)	G6 Gravel	11.1	14.3	31.3	0.0
	43.9	47.3	32.0	20.5		(11.1)	(9.7)	(12.0)	(0.0)
Wetted width (m)	(11.4)	(7.6)	(3.5)	(10.2)	Cobble or larger	11.1	21.4	37.5	0.0
	37.7	35.4	15.1	16.6		(11.1)	(11.4)	(12.5)	(0.0)
Depth (cm)	(8.6)	(5.9)	(1.9)	(12.9)	SUBSTRATE, PERCENT				
	25.1	18.1	19.4	18.5	Silt	12.9	17.7	13.1	29.4
Maximum depth (cm)	(6.1)	(4.1)	(1.5)	(2.5)		(4.9)	(7.4)	(4.3)	(13.0)
	98.1	54.1	66.2	67.7	Sand	48.8	51.9	46.1	55.2
	(16.9)	(6.3)	(7.3)	(16.5)		(4.4)	(5.9)	(5.0)	(14.4)
IN-STREAM STRUCTURE, PRESENCE					G1 Gravel	25.0	19.0	18.8	13.9
Algae	100	95.5	94.4	71.4		(3.2)	(2.5)	(3.4)	(0.1)
	(0.0)	(4.5)	(5.6)	(18.4)	G2 Gravel	9.4	6.9	5.3	1.1
Woody debris	92.3	94.1	100	83.3		(2.7)	(1.5)	(1.3)	(0.9)
	(7.7)	(5.9)	(0.0)	(16.7)	G3 Gravel	1.1	1.4	4.1	0.0
Logs	87.5	87.0	81.0	40.0		(0.8)	(0.5)	(1.1)	(0.0)
	(8.5)	(7.2)	(8.8)	(24.5)	G4 Gravel	1.1	0.9	3.8	0.4
Overhanging vegetation	100	90.5	77.8	100		(1.0)	(0.6)	(1.3)	(0.4)
	(0.0)	(6.60)	(10.1)	(0.0)	G5 Gravel	0.0	0.1	2.3	0.0
Undercut bank	66.7	68.4	41.2	0.0		(0.0)	(0.1)	(0.9)	(0.0)
	(16.7)	(11.0)	(12.3)	(0.0)	G6 Gravel	0.4	0.1	2.1	0.0
Bridge abutment	11.1	41.2	52.9	25.0		(0.4)	(0.1)	(1.5)	(0.0)
	(11.1)	(12.3)	(12.5)	(25.0)	Cobble or larger	1.4	2.0	4.5	0.0
Diversion structure	69.2	11.1	0.0	25.0		(1.4)	(1.5)	(2.2)	(0.0)
	(13.3)	(7.6)	(0.0)	(25.0)		(1.4)	(1.5)	(2.2)	(0.0)
Other cover	63.3	68.0	57.9	100		(1.4)	(1.5)	(2.2)	(0.0)
	(6.7)	(9.5)	(11.6)	(0.0)		(1.4)	(1.5)	(2.2)	(0.0)

Table 6.—Parameter coefficients, confidence limits, and significance levels for binomial response regression models to predict presence of suckermouth minnow at sites in the South Platte (SP) and Arkansas (AR) River basins, 2001-2002, as a function of explanatory variables. Negative parameter estimates suggested the explanatory variable and suckermouth minnow presence were negatively associated.

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence		Chi-Square	Pr > ChiSq
				Limits			
Intercept	1	-5.2776	2.0375	-9.2709	-1.2842	6.71	0.0096
AR basin	1	3.9391	1.1103	1.7628	6.1153	12.59	0.0004
SP basin	0	0	0	0	0	.	.
maximum depth	1	0.0408	0.0200	0.0017	0.0800	4.18	0.0409
Percent G1 gravel	1	0.0982	0.0557	-0.0109	0.2074	3.11	0.0777

Table 7.—Percent of meso-habitat types occupied by suckermouth minnows compared to percent of all types sampled in the South Platte and Arkansas River basins, Colorado, 2001-2002. N = total sample size.

Basin	Riffle	Run	Pool	Eddy	Backwater
South Platte River					
SMM present (N = 18)	0	50	39	11	0
Total (N = 153)	20	41	25	11	3
Arkansas River					
SMM present (N = 63)	29	36	25	8	2
Total (N = 187)	22	49	21	5	3

Table 8.—Habitat characteristics (mean, standard error parenthetically) of seine hauls where suckermouth minnow (SMM) were present and absent in the South Platte and Arkansas River basins, Colorado, 2001-2002. Values for presence variables are the percent of seine hauls at which the particular variable occurred.

Variable	South Platte River Basin		Arkansas River Basin	
	SMM present	SMM absent	SMM present	SMM absent
Length (m)	6.1 (0.6)	5.0 (0.2)	5.8 (0.3)	5.1 (0.3)
Distance to structure (m)	3.3 (0.5)	2.2 (0.1)	2.3 (0.1)	2.1 (0.1)
Area (m <sup>2</sup> )	98.8 (23.4)	72.5 (8.2)	86.2 (8.7)	61.6 (7.2)
Depth (cm)	36.3 (2.9)	35.8 (2.4)	30.0 (1.7)	30.3 (1.8)
Maximum depth (cm)	58.1 (4.7)	49.7 (3.2)	43.5 (2.6)	41.7 (2.4)
Velocity (cm/s)	11.9 (3.8)	24.3 (2.6)	25.0 (2.3)	25.0 (1.6)
Maximum velocity (cm/s)	18.8 (5.2)	35.6 (3.3)	39.1 (3.2)	37.4 (2.1)
SUBSTRATE, PRESENCE				
Silt	81.3 (10.1)	51.3 (5.8)	49.2 (6.3)	57.0 (4.8)
Sand	100 (0.0)	86.2 (3.7)	85.7 (4.4)	93.5 (2.4)
G1 Gravel	88.2 (8.1)	81.6 (4.5)	84.1 (4.6)	84.1 (3.6)
G2 Gravel	64.7 (11.9)	67.1 (5.4)	87.3 (14.2)	61.7 (4.7)
G3 Gravel	18.8 (10.1)	44.7 (5.7)	69.8 (5.8)	45.8 (4.8)
G4 Gravel	6.3 (6.3)	21.1 (4.7)	63.5 (10.7)	38.3 (4.7)
G5 Gravel	0.0 (0.0)	15.8 (4.2)	36.5 (6.1)	18.7 (3.8)
G6 Gravel	0.0 (0.0)	6.6 (2.9)	22.2 (5.3)	8.4 (2.7)
Cobble or larger	0.0 (0.0)	25.9 (4.9)	30.2 (5.8)	25.2 (4.2)
Algae	27.3 (14.1)	35.9 (6.0)	61.0 (7.7)	35.4 (4.9)
SUBSTRATE, PERCENT				
Silt	15.9 (3.4)	22.5 (4.1)	14.7 (2.9)	15.1 (2.4)
Sand	56.3 (4.8)	35.3 (2.9)	27.7 (2.9)	48.2 (2.9)
G1 Gravel	21.0 (4.4)	21.3 (1.9)	22.2 (2.5)	16.8 (1.6)
G2 Gravel	5.1 (1.6)	8.6 (1.0)	9.2 (1.2)	4.9 (0.7)
G3 Gravel	0.8 (0.5)	3.5 (0.7)	8.1 (1.1)	4.4 (0.7)
G4 Gravel	0.9 (0.9)	1.5 (0.5)	6.5 (1.1)	3.4 (0.6)
G5 Gravel	0.0 (0.0)	1.2 (0.4)	3.4 (0.7)	2.4 (0.6)
G6 Gravel	0.0 (0.0)	0.3 (0.1)	1.2 (0.4)	0.6 (0.2)
Cobble or larger	0.0 (0.0)	4.5 (1.4)	7.1 (2.1)	4.3 (1.2)

Table 9.—Seasonal habitat characteristics (mean, standard error parenthetically) of seine hauls where suckermouth minnows were present in the South Platte and Arkansas River basins, Colorado, 2001-2002. Values for presence variables are the percent of seine hauls at which the particular variable occurred.

Variable	Spring	Summer		Autumn		Winter
	Arkansas River Basin (N = 6)	South Platte River Basin (N = 7)	Arkansas River Basin (N = 22)	South Platte River Basin (N = 9)	Arkansas River Basin (N = 33)	Arkansas River Basin (N = 2)
Length (m)	4.8 (1.1)	5.6 (0.9)	5.3 (0.6)	6.6 (0.9)	6.5 (0.5)	3.5 (0.5)
Distance to structure (m)	2.7 (0.2)	4.7 (0.9)	2.3 (0.1)	2.2 (0.3)	2.1 (0.2)	2.7 (0.2)
Area (m <sup>2</sup> )	92.1 (17.1)	95.5 (23.8)	144.2 (12.7)	161.3 (38.6)	45.7 (7.9)	99.0 (84.6)
Depth (cm)	29.8 (4.2)	39.6 (4.1)	27.4 (3.7)	33.3 (4.0)	31.7 (2.0)	29.0 (5.0)
Maximum depth (cm)	45.7 (9.7)	55.1 (4.2)	44.9 (5.8)	60.3 (7.9)	42.3 (2.6)	41.5 (7.5)
Velocity (cm/s)	20.5 (7.8)	17.3 (6.1)	20.0 (3.7)	7.8 (4.7)	30.7 (3.1)	1.0 (0.0)
Maximum velocity (cm/s)	33.3 (11.7)	27.3 (8.1)	35.3 (5.7)	12.2 (6.2)	44.8 (3.9)	5.0 (1.0)
SUBSTRATE, PRESENCE						
Silt	83.3 (0.2)	85.7 (0.1)	27.3 (0.1)	77.8 (0.1)	54.5 (0.1)	100 (0.0)
Sand	100 (0.0)	100 (0.0)	95.5 (0.0)	100 (0.0)	81.8 (0.1)	0.0 (0.0)
G1 Gravel	83.3 (0.2)	100 (0.0)	100 (0.0)	77.8 (0.1)	78.8 (0.1)	0.0 (0.0)
G2 Gravel	83.3 (0.2)	50.0 (0.2)	81.8 (0.1)	77.8 (0.1)	72.7 (0.1)	0.0 (0.0)
G3 Gravel	100 (0.0)	0.3 (0.2)	0.7 (0.1)	11.1 (0.1)	69.7 (0.1)	0.0 (0.0)
G4 Gravel	83.3 (0.2)	0.1 (0.1)	0.5 (0.1)	0.0 (0.0)	57.6 (0.1)	0.0 (0.0)
G5 Gravel	50.0 (0.2)	0.0 (0.0)	0.3 (0.1)	0.0 (0.0)	42.4 (0.1)	0.0 (0.0)
G6 Gravel	16.7 (0.2)	0.0 (0.0)	0.2 (0.1)	0.0 (0.0)	24.4 (0.1)	0.0 (0.0)
Cobble or larger	33.3 (0.2)	0.0 (0.0)	0.2 (0.1)	0.0 (0.0)	39.4 (0.1)	0.0 (0.0)
Algae	83.3 (0.2)	0.4 (0.2)	0.0 (0.0)	0.0 (0.0)	60.6 (0.1)	0.0 (0.0)
SUBSTRATE, PERCENT						
Silt	17.3 (7.2)	18.6 (5.5)	5.5 (2.4)	13.8 (4.4)	15.3 (3.5)	100 (0.0)
Sand	28.2 (6.3)	55.4 (6.1)	38.6 (5.8)	56.9 (7.4)	21.9 (3.0)	0.0 (0.0)
G1 Gravel	11.5 (4.4)	16.6 (5.5)	25.9 (3.7)	24.4 (6.6)	23.0 (3.9)	0.0 (0.0)
G2 Gravel	11.5 (3.1)	5.6 (3.2)	9.6 (1.6)	4.7 (1.6)	9.0 (1.9)	0.0 (0.0)
G3 Gravel	13.0 (3.4)	1.6 (1.0)	6.9 (1.5)	0.1 (0.1)	8.5 (1.7)	0.0 (0.0)
G4 Gravel	13.3 (5.1)	2.1 (2.1)	4.2 (1.3)	0.0 (0.0)	7.2 (1.6)	0.0 (0.0)
G5 Gravel	2.2 (1.0)	0.0 (0.0)	2.5 (1.1)	0.0 (0.0)	4.4 (1.1)	0.0 (0.0)
G6 Gravel	1.0 (1.0)	0.0 (0.0)	2.4 (1.1)	0.0 (0.0)	0.5 (0.3)	0.0 (0.0)
Cobble or larger	2.5 (2.1)	0.0 (0.0)	4.7 (2.5)	0.0 (0.0)	10.1 (3.7)	0.0 (0.0)

Table 10.—Parameter coefficients, confidence limits, and significance levels for binomial response regression models to predict presence of suckermouth minnow in seine hauls at sites in the South Platte (SP) and Arkansas (AR) River basins, 2001-2002, as a function of explanatory variables. Negative parameter estimates suggested the explanatory variable and suckermouth minnow presence were negatively associated.

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence		Chi-Square	Pr > ChiSq
				Limits			
Intercept	1	-6.0665	1.4389	-8.8866	-3.2464	17.78	<0.0001
AR basin	1	3.1019	0.9639	1.2128	4.9911	10.36	0.0013
SP basin	0	0	0	0	0		
Spring	1	1.3303	0.9691	-0.5691	3.2297		
Summer	1	3.6521	0.9477	1.7946	5.5095	1.88	0.1698
Autumn	1	1.6670	0.8769	-0.0516	3.3856	14.85	0.0001
Winter	0	0	0	0	0	3.61	0.0573
Seine haul length	1	0.0838	0.0415	0.0026	0.1651		
Percent sand, AR	1	-0.0410	0.0084	-0.0575	-0.0245	4.09	0.0432
Percent sand, SP	1	0.0398	0.0139	0.0127	0.0670	23.72	<0.0001
Maximum depth	1	0.0111	0.0070	-0.0027	0.0248	8.26	0.0041
Maximum velocity, AR	1	0.0154	0.0091	-0.0024	0.0332	2.49	0.1144
Maximum velocity, SP	1	-0.0263	0.0140	-0.0539	0.0012	2.89	0.0893
Percent G2 gravel	1	0.0242	0.0209	-0.0168	0.0651	3.51	0.0608
						1.34	0.2475

Table 11.—Fish community composition of samples on 45 sampling occasions in the South Platte River Basin, Colorado, 2001-2002. I = introduced, N = native. SMM = suckermouth minnow.

Species	Common name	Status	Frequency in samples	Percent Frequency in samples (N = 45)	Percent Frequency in samples with SMM (N = 17)
<i>Campostoma anomalum</i>	central stoneroller	N	23	51.1	82.4
<i>Cyprinella lutrensis</i>	red shiner	N	40	88.9	100
<i>Cyprinus carpio</i>	common carp	I	27	60.0	64.7
<i>Hybognathus hankinsoni</i>	brassy minnow	N	11	24.4	47.1
<i>Hybognathus placitus</i>	plains minnow	N	18	40.0	47.1
<i>Notropis dorsalis</i>	bigmouth shiner	N	40	88.9	100
<i>Notropis stramineus</i>	sand shiner	N	43	95.6	100
<i>Phenacobius mirabilis</i>	suckermouth minnow	N	17	37.8	.
<i>Pimephales promelas</i>	fathead minnow	N	41	91.1	94.1
<i>Rhinichthys cataractae</i>	longnose dace	N	7	15.6	5.9
<i>Semotilus atromaculatus</i>	creek chub	N	32	71.1	88.2
<i>Carpionodes</i> sp.	river carpsucker or quillback	N	13	28.9	41.2
<i>Catostomus catostomus</i>	longnose sucker	N	4	8.9	0.0
<i>Catostomus commersoni</i>	white sucker	N	33	73.3	88.2
<i>Ameiurus melas</i>	black bullhead	N	2	4.4	5.9
<i>Ictalurus punctatus</i>	channel catfish	N	3	6.7	5.9
<i>Fundulus sciadicus</i>	plains topminnow	N	1	2.2	5.9
<i>Fundulus zebrinus</i>	plains killifish	N	40	88.9	100
<i>Gambusia affinis</i>	western mosquitofish	I	18	40.0	41.2
<i>Culaea inconstans</i>	brook stickleback	I	3	6.7	0.0
<i>Lepomis cyanellus</i>	green sunfish	N	7	15.6	17.6
<i>Lepomis humilis</i>	orangespotted sunfish	N	8	17.8	35.3
<i>Lepomis macrochirus</i>	bluegill	I	1	2.2	0.0
<i>Micropterus salmoides</i>	largemouth bass	I	4	8.9	0.0
<i>Poxomis nigromaculatus</i>	black crappie	I	1	2.2	0.0
<i>Etheostoma nigrum</i>	johnny darter	N	2	4.4	0.0
<i>Perca flavescens</i>	yellow perch	I	2	4.4	5.9
<i>Stizostedion vitreum</i>	walleye	I	2	4.4	5.9
<i>Aplodinotus grunniens</i>	freshwater drum	I	2	4.4	5.9
<i>Dorosoma cepedianum</i>	gizzard shad	I	11	24.4	17.6

Table 12.—Fish community composition of samples on 40 sampling occasions in the Arkansas River Basin, Colorado, 2001-2002. I = introduced, N = native. SMM = suckermouth minnow.

Species	Common name	Status	Frequency	Percent	Percent
			in samples	Frequency in samples (N = 40)	Frequency in samples with SMM (N = 29)
<i>Campostoma anomalum</i>	central stoneroller	N	18	45.0	55.2
<i>Cyprinella lutrensis</i>	red shiner	N	36	90.0	89.7
<i>Cyprinus carpio</i>	common carp	I	17	42.5	44.8
<i>Notropis stramineus</i>	sand shiner	N	37	92.5	96.6
<i>Phenacobius mirabilis</i>	suckermouth minnow	N	29	72.5	.
<i>Pimephales promelas</i>	fathead minnow	N	32	80.0	79.3
<i>Platygobio gracilis</i>	flathead chub	N	11	27.5	24.1
<i>Rhinichthys cataractae</i>	longnose dace	N	2	5.0	6.9
<i>Catostomus catostomus</i>	longnose sucker	N	3	7.5	10.3
<i>Catostomus commersoni</i>	white sucker	N	22	55.0	51.7
<i>Ameiurus melas</i>	black bullhead	N	2	5.0	3.4
<i>Ameiurus natalis</i>	yellow bullhead	I	1	2.5	0.0
<i>Ictalurus punctatus</i>	channel catfish	N	17	42.5	41.4
<i>Fundulus zebrinus</i>	plains killifish	N	26	65.0	72.4
<i>Gambusia affinis</i>	western mosquitofish	I	17	42.5	51.7
<i>Lepomis cyanellus</i>	green sunfish	N	9	22.5	31.0
<i>Lepomis humilis</i>	orangespotted sunfish	N	11	27.5	34.5
<i>Lepomis macrochirus</i>	bluegill	I	1	2.5	3.4
<i>Poxomis annularis</i>	white crappie	I	1	2.5	3.4
<i>Poxomis nigromaculatus</i>	black crappie	I	5	12.5	10.3
<i>Aplodinotus grunniens</i>	freshwater drum	I	4	10.0	10.3
<i>Dorosoma cepedianum</i>	gizzard shad	I	13	32.5	37.9

Table 13.—Fish species frequency in seine hauls where suckermouth minnow were present, South Platte and Arkansas River basins, Colorado, 2001-2002.

Species	South Platte River Drainage (N = 18)		Arkansas River Drainage (N = 63)	
	Frequency	Percent	Frequency	Percent
fathead minnow	16	89	28	44
sand shiner	16	89	60	95
red shiner	15	83	56	89
plains killifish	14	78	32	51
bigmouth shiner	13	72	not present in drainage	
creek chub	11	61	not present in drainage	
plains minnow	10	56	not present in drainage	
brassy minnow	6	33	not present in drainage	
white sucker	6	33	7	11
central stoneroller	5	28	16	25
western mosquitofish	4	22	15	24
common carp	3	17	7	11
orangespotted sunfish	2	11	3	5
freshwater drum	1	6	0	0
plains topminnow	1	6	not present in drainage	
<i>Carpiodes</i> sp.	1	6	not present in drainage	
black bullhead	0	0	0	0
black crappie	0	0	3	5
bluegill	0	0	0	0
brook stickleback	0	0	not present in drainage	
channel catfish	0	0	7	11
flathead chub	not present in drainage		4	6
gizzard shad	0	0	3	5
green sunfish	0	0	2	3
johnny darter	0	0	not present in drainage	
largemouth bass	0	0	not present in drainage	
longnose dace	0	0	3	5
longnose sucker	0	0	1	2
walleye	0	0	not present in drainage	
yellow perch	0	0	not present in drainage	

## APPENDIX I. List of museum contacts

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<http://chameleon.tnhc.utexas.edu/fish/search.asp>

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Yale University, Peabody Museum

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**NO RESULTS (no collections or no fish)**

Mesa SW Museum, AZ  
Oakland Museum of CA  
Orange Cty NHM  
San Diego NHM  
Connecticut State MNH  
Utah MNH, Salt Lake  
MNH and Science, Cincinnati  
University of Oregon MNH  
MNH Providence  
Virginia Tech MNH  
Burke MNH and Culture, UW, Seattle  
Museum of Vertebrate Zoology, UC Berkeley  
Las Cruces MNH  
Carnegie MNH, Pittsburgh  
James R. Slater MNH, University of Puget Sound  
Delaware MNH  
University of Iowa Research Collections  
Houston Museum of Natural Science

# Appendix II.--Suckermouth minnow developmental series measurements.

Temp °C	day (post-hatch)	date	time	N <sup>a</sup>	mm SL:TL* per specimen								avg	% inc	% inc/day
					1	2	3	4	5	6	7	8			
room	eggs	25-May		5	1.50	1.60	1.70	1.80	1.80				1.68		
17	eggs	27-May	1230	5	1.75	1.75	1.75	1.75	1.80				1.76		
17	eggs	29-May	0945	5	1.70	1.75	1.75	1.80	1.80				1.76		
17	1	30-May	1120	5	4.55	4.55	4.60	4.70	4.75				4.63		
17	2	31-May	1000	5	4.50	4.70	4.85	4.90	5.00				4.79	3.46%	3.46%
17	3	1-Jun	1000	5	4.90	5.10	5.40	5.60	5.60				5.32	11.06%	11.06%
17	4	2-Jun	0945	5	5.30	5.40	5.70	5.70	5.90				5.60	5.26%	5.26%
17	5.5	3-Jun	2100	6	5.60	5.80	6.10	6.10	6.10	6.20			5.98	6.85%	6.85%
17-19	6	4-Jun	1000	5	6.20	6.20	6.30	6.30	6.40				6.28	4.96%	4.96%
17-19	7	5-Jun	1000	4	6.30	6.30	6.40	6.50					6.38	1.51%	1.51%
17-19	8	6-Jun		5	6.50	6.50	6.60	6.70	6.70				6.60	3.53%	3.53%
17-19	9	7-Jun	1005	6	5.90	6.30	6.50	6.60	6.80	6.90			6.50	-1.52%	-1.52%
17-19	10	8-Jun	1145	5	6.50	6.60	6.70	6.70	6.80				6.66	2.46%	2.46%
17-19	11.25	9-Jun	1640	5	6.20	6.60	6.60	6.70	6.90				6.60	-0.90%	-0.90%
17-19	12	10-Jun		5	6.60	6.70	6.80	6.90	6.90				6.78	2.73%	2.73%
17-19	13	11-Jun		5	6.90	6.90	6.90	7.00	7.20				6.98	2.95%	2.95%
17-19	14	12-Jun		6	6.80	7.10	7.20	7.20	7.30	7.70			7.22	3.39%	3.39%
17-19	15	13-Jun	0952	5	7.30	7.50	7.50	7.60	7.60				7.50	3.93%	3.93%
17-19	16	14-Jun		5	7.30	7.40	7.70	7.70	8.30				7.68	2.40%	2.40%
17-19	17	15-Jun	1107	5	7.60	8.10	8.10	8.20	8.70				8.14	5.99%	5.99%
17-19	18	16-Jun	1455	5	7.90	8.60	8.90	8.90	9.10				8.68	6.63%	6.63%
17-19	19	17-Jun	0835	5	8.50	8.60	8.80	9.00	9.10				8.80	1.38%	1.38%
17-19	20	18-Jun		5	8.70	8.90	9.00	9.10	9.50				9.04	2.73%	2.73%
17-19	21	19-Jun		5	9.20	9.30	9.40	9.50	9.60				9.40	3.98%	3.98%
17-19	24	22-Jun		3	9.90	10.93	11.01						10.61	12.91%	4.30%
17-19	27	25-Jun		3	12.11	12.28	13.30						12.56	18.37%	6.12%
17-19	30	28-Jun		3	13.57	13.84	14.26						13.89	10.56%	3.52%
17-19	34	2-Jul		3	15.07	15.73	16.41						15.74	13.29%	3.32%
17-19	37	5-Jul		3	15.96	17.00	18.67						17.21	9.36%	3.12%
17-19	40	8-Jul		3	17.71	17.95	18.09						17.92	4.11%	1.37%
17-19	43	11-Jul		3	17.47	18.87	19.89						18.74	4.61%	1.54%
17-19	46	14-Jul		3	19.13	19.21	20.40						19.58	4.46%	1.49%
17-19	49	17-Jul		3	19.61	21.25	21.90						20.92	6.84%	2.28%
17-19	52	20-Jul		3	21.59	21.82	23.49						22.30	6.60%	2.20%
17-19	55	23-Jul		3	22.14	22.61	23.70						22.82	2.32%	0.77%
17-19	58	26-Jul		3	23.99	24.47	25.03						24.50	7.36%	2.45%
17-19	61	29-Jul		3	25.10	25.84	28.18						26.37	7.66%	2.55%
17-19	64	1-Aug		3	25.27	27.36	29.90						27.51	4.31%	1.44%
17-19	67	4-Aug		3	24.01	26.11	27.89						26.00	-5.48%	-1.83%
17-19	70	7-Aug		3	27.71	28.43	29.23						28.46	9.43%	3.14%
17-19	73	10-Aug		3	30.00	30.06	30.15						30.07	5.67%	1.89%
17-19	76	13-Aug		3	29.53	30.06	30.10						29.90	-0.58%	-0.19%
17-19	79	16-Aug		3	30.30	31.19	32.09						31.19	4.34%	1.45%
17-19	82	19-Aug		3	30.39	32.06	32.81						31.75	1.80%	0.60%
17-19	89	26-Aug		3	30.87	32.92	33.92						32.57	2.57%	0.37%
17-19	97	3-Sep		3	34.04	36.35	37.17						35.85	10.08%	1.26%
17-19	103	9-Sep		3	35.44	36.71	37.00						36.38	1.48%	0.25%
mean : 2.70%															
19	eggs	27-May	1300	7	1.50	1.50	1.60	1.60	1.70	1.70	1.80		1.63		
19	1	30-May	1700	55(\$ mean)	4.30	4.40	4.70	4.80	5.30				4.70		
19	11	10-Jun	1020	8	6.50	6.80	6.90	6.90	7.00	7.00	7.20	7.20	6.94		
23	eggs	27-May	1130	5	1.50	1.70	1.70	1.70	1.80				1.68		
23	0	28-May	1230	3	4.20	4.50	4.80						4.50		
23	3	31-May	1030	3	5.50	5.90	6.00						5.80	28.89%	9.63%
23	7	4-Jun	0900	3	6.30	6.60	6.70						6.53	12.64%	3.16%
23	10	7-Jun	1015	3	6.60	6.70	6.90						6.73	3.06%	1.02%
23	16	13-Jun		3	9.28	9.81	10.28						9.79	45.40%	7.57%
23	22	19-Jun	0920	4	12.92	13.30	13.89	14.22					13.58	38.74%	6.46%
23	29	26-Jun	1018	4	17.13	17.21	18.20	18.76					17.83	31.24%	4.46%
23	36	3-Jul		4	19.48	19.94	20.47	22.18					20.52	15.11%	2.16%
23	43	10-Jul		4	23.91	25.62	25.91	26.03					25.37	23.64%	3.38%
23	50	17-Jul		4	26.39	26.67	28.12	29.95					27.78	9.52%	1.36%
23	57	24-Jul		4	32.23	32.28	32.57	34.32					32.85	18.24%	2.61%
23	64	31-Jul		4	34.16	35.35	36.30	37.25					35.77	8.87%	1.27%
23	71	7-Aug		4	39.29	39.83	40.87	43.50					40.87	14.28%	2.04%
23	78	14-Aug		4	36.44	40.83	42.12	43.08					40.62	-0.62%	-0.09%
23	85	21-Aug		3	44.49	50.03	51.47						48.66	19.81%	2.83%
mean : 3.42%															

\* larvae up to 10 mm SL (anterior margin of snout to posterior margin of notochord) measured to 0.01 mm with microscope & micrometer  
larvae over that size measured to 0.01 mm TL (anterior margin of snout to posterior margin of finfold or caudal fin) with digital calipers

# Appendix III.—Fish community composition on 45 sampling occasions in the South Platte River Basin, Colorado, 2001-2002.

Drainage	Site	River	Specific locality	Date	bigmouth stoner	black bullhead	black crappie	bluegill	brassy minnow	brook stickleback	central stonefly	common carp	creel club	fathead minnow	freshwater drum	gizzard shad	green sunfish	johnny darter	largemouth bass	longnose dace	longnose sucker	orange-spotted sunfish	plains killifish	plains minnow	plains topminnow	red stoner	Carpiodes sp.	sand stoner	suckermouth minnow	valley	western mosquitofish	white sucker	yellow perch
SP	05	South Platte River	S of Atwood, N channel upstream of Hwy 63 zone: 13 X: 646777 Y: 4488962	19 Jul 2001	X				X		X	X	X	X	X	X					X		X	X	X	X					X		
SP	05	South Platte River	"	16 Aug 2002	X					X		X	X	X	X				X					X		X	X	X	X		X	X	
SP	06	South Platte River	Sterling, downstream of Hwy 61 zone: 13 X: 653226 Y: 4498228	19 Jul 2001	X				X		X	X	X	X	X	X	X			X			X	X		X							
SP	06	South Platte River	"	13 Jun 2002	X										X					X			X	X	X	X	X						
SP	07	South Platte River	Tamarack SWA downstream of CR67 zone: 13 X: 673253 Y: 4517930	20 Jul 2001	X				X		X	X	X	X	X				X				X	X	X	X	X	X	X		X	X	
SP	07	South Platte River	"	16 Aug 2002	X				X		X	X	X	X	X								X	X	X	X	X	X	X		X	X	
SP	08	South Platte River	Tamarack SWA upstream of Hwy 55 zone: 13 X: 685069 Y: 4523488	20 Jul 2001	X				X		X	X	X	X	X								X	X	X	X	X	X	X		X	X	
SP	09	South Platte River	Tamarack SWA, from Area 8 parking one: 13 X: 681403 Y: 4522620	20 Jul 2001	X				X		X	X	X	X	X								X	X	X	X	X	X	X		X	X	
SP	09	South Platte River	"	13 Jun 2002	X				X		X				X								X	X	X	X	X	X					
SP	10	South Platte River	Sedgwick Bar SWA, downstream of Hwy 59 zone: 13 X: 709018 Y: 4533492	13 Aug 2001	X						X	X	X	X	X								X										
SP	11	South Platte River	SE of Julesburg, upstream of Hwy 385 zone: 13 X: 731273 Y: 4539541	14 Aug 2001	X					X			X	X	X								X			X	X	X	X				
SP	11	South Platte River	"	23 Oct 2001	X								X	X	X								X	X	X	X	X	X	X				
SP	11	South Platte River	"	11 Jun 2002	X								X	X	X								X	X	X	X	X	X	X				
SP	12	South Platte River	Julesburg SWA, 2* channel downstream of CR29 zone: 13 X: 731280 Y: 4539536	14 Aug 2001	X								X		X								X										
SP	13	South Platte River	Julesburg SWA, below Little Ditch diversion zone: 13 X: 720244 Y: 4537015	14 Aug 2001	X					X		X	X	X	X								X	X	X	X	X	X	X				
SP	13	South Platte River	"	24 Oct 2001	X					X		X	X	X	X								X	X	X	X	X	X	X				
SP	13	South Platte River	"	11 Jun 2002	X				X		X	X	X	X	X		X						X	X	X	X	X	X	X				
SP	13	South Platte River	"	14 Aug 2002	X				X		X	X	X	X	X								X	X	X	X	X	X	X				
SP	13	South Platte River	"	24 Sep 2002	X				X		X	X	X	X	X								X	X	X	X	X	X	X				
SP	14	South Platte River	Tamarack SWA, upstream of CR53 zone: 13 X: 694629 Y: 4526892	14 Aug 2001	X					X		X	X	X	X								X	X	X	X	X	X	X				
SP	14	South Platte River	"	12 Jun 2002	X							X	X	X	X								X			X	X	X	X				
SP	15	South Platte River	Meeker SWA, upstream of CR59 zone: 13 X: 634045 Y: 4475773	15 Aug 2001	X							X	X	X	X								X	X	X	X	X	X	X				
SP	16	South Platte River	Bravo SWA, east of CR34 zone: 13 X: 657139 Y: 4503760	15 Aug 2001	X							X	X	X	X								X	X	X	X	X	X	X				
SP	16	South Platte River	"	19 Oct 2001	X																		X			X	X	X	X				
SP	16	South Platte River	"	13 Jun 2002	X										X								X	X	X	X	X	X	X				
SP	17	Lodgepole Creek	N of Ovid, downstream of CR34 zone: 13 X: 719751 Y: 4540054	22 Aug 2001	X							X	X	X	X								X	X	X	X	X	X	X				
SP	18	Lodgepole Creek	S of Ovid, confluence with South Platte River zone: 13 X: 720103 Y: 4537078	22 Aug 2001	X				X			X	X	X	X								X	X	X	X	X	X	X				
SP	18	Lodgepole Creek	"	26 Oct 2001								X	X	X	X								X	X	X	X	X	X	X				
SP	18	Lodgepole Creek	"	12 Jun 2002										X									X			X	X	X	X				

# Appendix III.—continued

Drainage	Site	River	Specific locality	Date	bigmouth shiner	black bullhead	black crappie	bluegill	brassy minnow	brook stickleback	central stoneroller	channel catfish	common carp	creek chub	fathead minnow	freshwater drum	gizzard shad	green sunfish	johnny darter	largemouth bass	longnose dace	longnose sucker	orange-spotted sunfish	plains killifish	plains minnow	plains topminnow	red shiner	spottail shiner	sand shiner	suckermouth minnow	walleye	western mosquitofish	white sucker	yellow perch
SP	19	Lodgepole Creek	1/4 mi upstream of Hwy 138 zone 13 X: 720114 Y: 4538012	22 Aug 2001	X								X	X	X																			
SP	19	Lodgepole Creek	"	23 Oct 2001	X										X																		X	
SP	19	Lodgepole Creek	"	14 Aug 2002	X								X	X	X		X																X	
SP	19	Lodgepole Creek	"	25 Sep 2002									X				X																	
SP	20	South Plate River	Peterson Ditch diversion 1/4 mi W of Sedgewick zone 13 X: 706405 Y: 4533175	23 Aug 2001	X				X				X	X	X																			
SP	20	South Plate River	"	25 Oct 2001	X								X	X	X																			
SP	20	South Plate River	"	12 Jun 2002	X								X	X	X																			
SP	20	South Plate River	"	13 Aug 2002	X								X	X	X																			
SP	21	South Plate River	Ford Main SWA upstream of CR40 zone 13 X: 658350 Y: 4508991	23 Aug 2001	X								X	X	X																			
SP	21	South Plate River	"	13 Jun 2002	X										X																			
SP	36	South Plate River	Dune Ridge SWA, below Sterling No 1 diversion zone 13 X: 649453 Y: 4491685	14 Jun 2002	X								X	X	X																			
SP	37	Sterling No 1 ditch	Dune Ridge SWA, at diversion zone 13 X: 649453 Y: 4491685	14 Jun 2002	X								X	X	X																			
SP	38	South Plate River	Below Upper Plate and Beaver Canal zone 13 X: 599199 Y: 4458696	26 Sep 2002	X								X	X	X																			
SP	41	South Plate River	S of Evans, downstream of Hwy 85 zone 13 X: 525871 Y: 4468104	08 Aug 2002	X								X	X	X																			
SP	42	Spring Creek	Ft Collins downstream of Prospect St zone 13 X: 496956 Y: 4490552	09 Aug 2002				X							X																			
SP	43	St. Vrain Creek	N of Gowanda, upstream of RD 34 zone 13 X: 508660 Y: 4453197	12 Aug 2002									X	X	X																			

Appendix IV.—Fish community composition on 40 sampling occasions in the Arkansas River Basin, Colorado, 2001-2002.

Drainage	Site	River	Specific locality	Date	black bullhead	black crappie	bluegill	central stoneroller	channel catfish	common carp	fathead minnow	flathead chub	freshwater drum	gizzard shad	green sunfish	longnose dace	longnose sucker	orange-spotted sunfish	plains killifish	red shiner	sand shiner	suckermouth minnow	western mosquitofish	white crappie	white sucker	yellow bullhead
AR	01	Arkansas River	Lamar, upstream of Hwy 287 zone 13 X 708782 Y 4220931	19 Jun 2001			X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	
AR	01	Arkansas River	"	04 Nov 2002			X			X	X		X	X	X	X			X	X	X	X				
AR	01	Arkansas River	"	07 Aug 2002						X	X				X	X			X	X	X	X	X			
AR	02	Arkansas River	E of Granada, ~1/2 mi upstream of Hwy 50 zone 13 X 742300 Y 4216309	20 Jun 2001	X		X										X	X	X			X			X	
AR	02	Arkansas River	"	01 Nov 2001			X			X	X		X	X					X	X	X	X				
AR	02	Arkansas River	"	21 May 2002			X			X	X		X	X	X			X	X	X	X	X				
AR	02	Arkansas River	"	08 Aug 2002						X	X		X	X	X			X	X	X	X	X			X	
AR	02	Arkansas River	"	01 Oct 2002			X	X	X	X	X		X	X	X	X		X	X	X	X	X			X	
AR	03	Arkansas River	N of Granada, downstream of Hwy 385 zone 13 X 735797 Y 4219550	20 Jun 2001			X		X	X					X	X					X	X			X	
AR	03	Arkansas River	"	02 Nov 2001			X		X	X			X	X	X	X			X	X	X	X			X	
AR	03	Arkansas River	"	14 Mar 2002						X	X		X	X	X	X			X	X	X	X			X	
AR	04	Arkansas River	S of Holly, up and downstream of Hwy 89 zone 13 X 753008 Y 4214287	20 Jun 2001				X											X	X	X	X				
AR	04	Arkansas River	"	02 Nov 2001					X	X			X	X					X	X	X	X			X	
AR	22	Cheyenne Creek	Downstream of Hwy 50 zone 13 X 758913 Y 4215426	28 Aug 2001				X			X		X	X					X		X	X				
AR	22	Cheyenne Creek	"	31 Oct 2001						X	X								X		X	X				
AR	22	Cheyenne Creek	"	02 Oct 2002			X	X	X	X									X	X	X	X	X		X	
AR	23	Arkansas River	N of Carlton, upstream of CR 19 zone 13 X 726910 Y 4220590	28 Aug 2001	X		X	X	X	X	X		X	X				X	X	X	X	X			X	
AR	24	Arkansas River	E of Lamar, upstream of CR 13 zone 13 X 717490 Y 4219436	28 Aug 2001	X		X	X	X	X			X	X	X					X	X	X	X		X	
AR	24	Arkansas River	"	03 Nov 2001			X			X	X								X	X	X	X			X	
AR	24	Arkansas River	"	14 Mar 2002						X								X		X	X	X				
AR	24	Arkansas River	"	09 Aug 2002	X		X	X	X	X	X							X	X	X	X	X	X	X	X	X

# Appendix IV.—continued

Drainage	Site	River	Specific locality	Date	black bullhead	black crappie	bluegill	central stoneroller	channel catfish	common carp	flathead chub	freshwater drum	gizzard shad	green sunfish	longnose dace	longnose sucker	orange-spotted sunfish	plains killifish	red shiner	sand shiner	suckermouth minnow	western mosquitofish	white crappie	white sucker	yellow bullhead
AR	25	Big Sandy Creek	Downstream of Hwy 196 zone 13 X 720562 Y 4221478	29 Aug 2001				X	X	X	X	X					X	X	X	X	X	X		X	
AR	25	Big Sandy Creek	"	01 Nov 2001				X		X								X	X	X	X	X		X	
AR	25	Big Sandy Creek	"	21 May 2002					X	X								X	X	X	X				
AR	26	Arkansas River	N of Prowers, twin bridges zone 13 X 695721 Y 4218550	29 Aug 2001		X				X	X		X	X			X	X	X	X	X	X		X	
AR	26	Arkansas River	"	04 Nov 2001					X	X	X		X	X			X	X	X	X	X	X		X	
AR	27	Purgatoire River	S of Las Animas, downstream of Hwy 101 zone 13 X 657853 Y 4211168	29 Aug 2001					X	X	X	X	X				X	X	X	X	X	X		X	
AR	27	Purgatoire River	"	05 Nov 2001					X	X	X		X		X			X	X	X	X	X			
AR	27	Purgatoire River	"	23 May 2002					X	X	X	X			X			X	X	X	X	X			
AR	27	Purgatoire River	"	09 Aug 2002			X			X	X	X		X							X	X			
AR	28	Arkansas River	S of Amity mining operation zone 13 X 746635 Y 4214319	30 Aug 2001				X	X	X		X	X					X	X	X	X	X		X	
AR	29	Arkansas River	Confluence with Big Sandy Creek zone 13 X 720600 Y 4221178	30 Aug 2001				X	X	X	X	X	X				X	X	X	X	X	X		X	
AR	30	Big Sandy Creek	At end of CR LL zone 13 X 720139 Y 4223123	30 Aug 2001	X			X		X									X	X	X	X		X	
AR	31	Arkansas River	1st bridge crossing downstream of John Martin Reservoir zone 13 X 681853 Y 4215237	13 Mar 2002		X												X	X	X			X		
AR	32	Arkansas River	CR30 bridge crossing zone 13 X 688523 Y 4217264	13 Mar 2002					X	X									X	X	X		X		
AR	33	Arkansas River	1 or 37 RD crossing, Bent-Otero county line zone 13 X 640583 Y 4211239	22 May 2002						X	X								X	X				X	
AR	34	Arkansas River	Rocky Ford SWA, downstream of Hwy 266 zone 13 X 615437 Y 4213570	22 May 2002					X		X								X	X	X				
AR	35	Timpas Creek	W of Swink, Hwy 50 crossing zone 13 X 619491 Y 4208836	22 May 2002					X	X	X								X					X	
AR	39	Purgatoire River	Purgatoire R SWA, dirt lot from RD DD zone 13 X 655272 Y 4208041	03 Oct 2002						X	X	X							X						
AR	40	Fi Lyon canal return	N of La Junta, Canal St to private dyke road zone 13 X 624868 Y 4207488	04 Oct 2002						X	X	X							X	X	X	X			X